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MINUTES
OF THE ELEVENTH
EXPLOSIVES SAFETY SEMINAR

SHERATON-PEABODY HOTEL
MEMPHIS, TENNESSEE
9-10 SEPTEMBER 1969

VOLUME I

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PREFACE

The "Eleventh Annual Explosives Safety Seminar" was held in Memphis, Tenn., on 9-10 September 1969, with 439 persons in attendance. Administrative support was provided by the Defense Depot, Memphis.

Due to elimination of the customary field trip, the seminar was reduced from three days to two days. There were eight formal presentations which included reports by research institutes performing R&D work for the ASESB under contract. In this manner, attendees were fully informed on new developments undertaken by the Department of Defense in the field of explosives safety.

As was the case during the 1968 seminar, most of the time was devoted to small group discussions on subjects of interest suggested by participants. There were twenty such specialist sessions, all of which were repeated the second day to afford an opportunity for each participant to attend the maximum number of discussions. In addition, an opportunity was afforded attendees to meet with those who presented formal papers in order to ask questions and receive more detailed information on the study projects.

These minutes contain a resume of the presentations and discussions that took place in Memphis during the 1969 Seminar, and represent the opinions and views of the participants. As such, they have no regulatory, or official, status.

B. B. Abrams

B. B. ABRAMS
Colonel, USA
Chairman

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CURRENT ASESB ACTIVITIES & PROJECTS

COL B. B. Abrams, USA
Chairman
Armed Services Explosives Safety Board

The 11th Annual Explosives Safety Seminar is now in session. I am COL Abrams, Chairman of the Armed Services Explosives Safety Board.

We will begin with a review of recent activities of the Explosives Safety Board - followed by a resume of future plans.

It may be beneficial to review the current functions of the ASESB, particularly in view of the new mission recently assigned in the area of "chemical-biological safety."

With regard to ammunition, explosives, and CB safety matters, it is the responsibility of the Board to:

Develop, establish, and maintain uniform DOD safety standards designed to prevent or correct hazardous conditions.

Survey and evaluate DOD activities to determine compliance with established safety standards and to detect conditions hazardous to life and property.

Maintain liaison with industry, allied governments, and other United States departments having a mutual interest in safety matters.

Evaluate, approve, and provide timely, impartial and objective advice on the safety of proposed site plans for construction or modification of ammunition/explosives/CB facilities, and the safety of other operating facilities located in proximity to the proposed construction site.

Review and analyze accident/incident reports, data, and information for recognition of hazardous conditions, and recommend establishment, or revision, of appropriate safety standards.

Direct and conduct investigations, studies and test programs to evaluate the validity of present safety standards and to provide the basis for new or modified standards.

Provide impartial and objective advice on the above matters to the Secretary of Defense and the Secretaries of the Military Departments.

Perform other tasks as assigned by the Secretary of Defense.

With regard to "Organization," the Chairman, ASESB, is assigned to the Office, Secretary of Defense, from which he receives policy direction and program guidance. Administrative support is received from the Secretary of the Army. The Army and Air Force, each, provide an officer in the grade of "Colonel" to serve as members of the Board, while the Navy is represented by a "Captain." In support of the Board in fulfilling the day-to-day activities is a "Secretariat" organized into a "Standards" Division and a "Survey" Division. A recent addition is the "Senior Chemical-Biological Safety Specialist" who reports directly to the Chairman.

The Secretariat is a small organization comprised of three senior military officers, a Grade 15 "CB Safety Specialist," seven Grade 15 "Safety Engineers," a Grade 14 "Safety Engineer," a Grade 8 "Editorial Research Assistant" and three clerical personnel.

During Fiscal Year 1969, a total of 482 "explosives accidents" were reported as compared to 392 in FY 68. Army accidents, accounted for 36. The big blows occurred during the first quarter. The Navy had 12 accidents spread rather evenly throughout the year. The Air Force accounted for the bulk of the accidents - 434. This is greatly misleading, because the Air Force's classification of an "accident" is much broader than that in use by both the Army and Navy. A combined services task group recently developed a standard definition of an "accident" which is now being staffed. When adopted, it will place the three Services on a comparable basis.

Fifty five "injuries" were reported during the past fiscal year. This is a reduction over the 109 reported the previous year. The Army and Navy each had 17 persons injured, and the Air Force 21.

There were 19 "fatalities" during the year, about the same as in Fiscal 68. The Army's resulted from the explosions at Louisiana Army Ammunition Plant, during the first quarter; and the Navy suffered casualties at Naval Ammunition Depot, Crane, also during the first quarter. The Air Force casualties occurred during the second, third and fourth quarters, but locations were not reported.

The accidents in FY 69 cost the Government almost nine million dollars - a sizeable increase over the two million dollar loss in FY 68. The Army accounted for almost all of the dollar cost due to the explosions at Louisiana Army Ammunition Plant and Longhorn Army Ammunition Plant.

"Money" is a subject close to all of our hearts. In the area of "research and development," the Board is attempting to accomplish quite a bit with very little money. About $460,000 was programmed for FY 69. We managed to obtain and obligate $434,000. This was far less than the $726,000 spent in FY 68, but I do believe that the accomplishments in '69 were more beneficial.

We have programmed about $1,100,000 in R&D funds for this fiscal year. Of this amount, about a half-million has been allocated to us as of this date. Whether the balance will be forthcoming, later in the fiscal year, is uncertain. However, we have hopes for at least part of it.

Our request for funds was based upon justifying the following projects:

Further experimentation on sequential detonations.

Pay of our "scientific advisory panel" and other consulting services.

Phase III of the "fragmentation" project, including some experimentation.

Investigation of "high explosive yield of solid propellants."

Additions to the soon-to-be distributed manual on "protective construction." This will cover design criteria for those vital portions of structures other than "walls."

Development of a "weapons sensitivity handbook."

Updating and automation of the explosion/accident files.

A review of "quantity-distance" protection based upon the findings of past and current R&D projects. This should result in new tables.

Development of "chemical/biological downwind hazards criteria."

As you will recall, a function of the Standards Division is to review and evaluate all site plans for the construction and modification of ammunition and explosives facilities. We have no control over the number of plans which are submitted for review. Based upon FY 68 receipts, a total of 218 were programmed for FY 69. Actually, 374 were received. Of this number, 366 were evaluated on a timely basis, with only 8 site plans carried over to this year.

As a matter of interest, of the 366 evaluated, 259 were accepted as submitted; 79 were accepted with exceptions, or after adjustments were made by the originators. It was necessary to return only 28 as "unacceptable." The average cost of reviewing a single plan was $64.00.

In FY 68, 4 safety engineers inspected 284 installations in the United States and overseas. The program of visits in FY 69 was reduced to 234 by designating some facilities to be visited every 2nd, 3rd, or 4th year, instead of annually. This was done in order that plants with hazardous conditions might be revisited until existing deficiencies were corrected. The reduction in the schedule has also made it possible to make safety engineers available for special visits on demand and on short notice. As it turned out, 287 surveys were actually made - this number exceeding the revised schedule and the original program of 270.

One hundred fifty seven places visited had hazards requiring action; 5 revealed serious exposures requiring notification of the Secretary of Defense; there were 9 instances where previously reported serious exposures required follow-up. The average cost to survey an installation in FY 69 was $437.00.

I am extremely proud of the accomplishments over the past 13 months. Among those are:

A successful seminar.

Resolving the matter of "sequential detonations" on which you will receive detailed information later.

Establishment of standards for the conduct of safety surveys.

Resolution of some of the "barricades" problems, a subject which was identified at last year's seminar for clarification at this year's seminar. You will receive detailed information on this project later in the program.

Board meetings have been revitalized with more emphasis placed on "decision-making."

Our Scientific Advisory Panel has rendered yeoman service in the resolution of our problems.

DOD 4145.27M entitled "DOD Ammunition & Explosives Safety Standards" has been published and distributed. This consolidates all standards into one document. Copies may be obtained from the Defense Documentation Center, Cameron Station, Alexandria, Va.

A program of instruction on scientific explosive phenomena was instituted and carried out for edification of the Secretariat Staff.

Phases I and II of a 5-phase study of "fragment and debris hazards from explosives" are under way. Progress thus far will be reported to you later in the seminar.

Beginning in FY 1971, the ASESB will have its own budget program under the Director of Defense Research & Engineering.

The new Navy Member of the Board is a representative of the Chief of Naval Operations.

The Navy has improved its waiver program and has established rigid controls.

Work has been started on the "analysis of blast effects on inhabited structures" and personnel.

For the first time, Board activities have been carried into a combat theater. Two members of the Secretariat are at this moment in Vietnam to render any possible assistance and to gather information which may be of value in the Board's work.

Microfilming of ASESB drawings has been completed. This has greatly reduced storage requirements.

And last, but not least, Dr. Ralph Scott has joined the Secretariat to head up the chemical/biological safety effort.

Although the number of problems was reduced during the past year, several are still with us. Among these are:

The need for a scientific basis in decision-making.

Definition of "fragment hazard."

Proper utilization of data derived from studies on "sequential detonations."

The practical application of research data on "barricades," "blast effects on structures," etc.

The expansion of explosives safety standards.

Development of C/B safety standards.

Lack of sufficient funds for R&D purposes.

Our "future plans" are directly related to our "major problems" and projects now in process.

The manual on "Structures to Resist the Effects of Accidental Explosions" is actually at the printers and distribution, hopefully, will be made by the end of this calendar year.

The DOD standard governing what was once known as "simultaneity" and is now referred to as "sequential explosions" will be changed in accordance with the recent findings.

We hope to provide more adequate guidance on the use of "barricades" at a very early date.

The microfilming of ASESB files should be finished this year.

Completion, at an early date, of the program for reduction of classified material and elimination of safes in the Board's offices.

Expansion of explosives safety standards.

Development and publication of C/B safety standards.

Continuation of the program of instruction for keeping staff members abreast of scientific developments.

The conduct of R&D under an ASESB budget program.

Sponsoring of another seminar next year.

Extension and completion of the 5-phased study on "fragmentation hazards."

Automation of the accident/incident files.

Review and revision of the Q-D tables based upon recent, current and future scientific findings.

A study of "high explosive yield of solid propellants."

Expansion of the forthcoming manual on "Design of Structures to Resist Effects of Accidental Explosions."

Development of a "Weapons Sensitivity Handbook."

It seems appropriate to end my presentation with some statistics concerning the seminar itself.

Registration has steadily increased from 300 in 1966 to near 500 last year and 451 this year. The number of formal presentations has been reduced from 28 seat-blistering papers in 1966 to 8 stimulating ones this year.

Specialist sessions have been increased from none in 1966 to 40 this year.

FAR FIELD OVERPRESSURE FROM CLOSELY SPACED SEQUENTIAL DETONATIONS

T. A. Zaker
IIT Research Institute
Chicago, Illinois 60616

ABSTRACT

This paper describes an investigation of the air blast produced by sequentially detonated high explosive charges. Criteria are established relating the coalescence of successive blast waves to explosion time delay, charge weight, and distance from the explosion site.

A finite-difference technique based on the method of characteristics was used to determine numerically the pressure fields produced by spherical charges with various time delays between successive detonations. Small-scale experiments were conducted with hemispherical explosive charges totaling 2 lb in weight detonated on a rigid surface. Transient pressures were observed at six stations on each of two gage lines.

Comparisons are made between the peak pressures and pulse separations predicted numerically and those obtained experimentally. The results are useful in developing recommendations for siting of structures adjacent to multiple-unit explosive stores.

FAR FIELD OVERPRESSURE FROM CLOSELY SPACED SEQUENTIAL DETONATIONS

INTRODUCTION

Standards governing separation distances between multiple-unit explosive stores and other structures such as inhabited buildings or explosive processing facilities currently permit the designer to base the separation distance on the quantity of explosive in a single bay of the multiple-unit store. This is permitted as long as the storage units (or bays in the case of a multiple-unit processing facility) are separated by dividing walls that are considered substantial within the definition of the regulations.[1*]

This practice does not require that the dividing wall prevent explosion propagation from one storage unit or bay to another. It presumes, however, that propagation is delayed sufficiently long so that the blast and missile hazard from explosion of the contents of a single bay controls the placement of adjacent structures. In other words, sequential explosions, if they occur, are assumed to be spaced sufficiently far apart timewise that adjacent buildings are subjected at worst to the effects of the individual explosions successively, and that these effects do not mutually reinforce.

It is well known that secondary shock waves following an initial shock in air tend to overtake the initial shock. This has been observed experimentally in simple systems such as shock tubes, and the reasons for the overtaking phenomenon are rather well understood in a qualitative sense. Briefly, a shock of finite amplitude will heat the gas through which it passes because the gas is compressed adiabatically, that is, without heat transfer during shock passage. The shock also sets in motion the initially undisturbed gas. The sound speed in gases is an increasing function of the temperature, so that signals following a shock of finite amplitude are propagating in a moving, more dense medium of higher signal speed than the undisturbed gas. Therefore such signals will overtake and reinforce the initial shock. It is only in the case of waves of infinitesimal amplitude (acoustic waves) that this nonlinear effect is absent.

This means that, for some range of delay time between two adjacent sequential explosions, the effect at a distance from the explosions will be substantially the same as that from a single detonation of the total mass of explosive involved.

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*Superscript numerals designate appended references.

This paper describes a program of numerical analysis of sequential explosions designed to determine quantitatively the time separation of blast pulses from successive explosions as a function of distance from the explosion site, time delay between detonations, and charge weights of the explosions. The results of small-scale experiments with sequentially detonated explosive charges were used to verify and extend theoretical predictions of the blast-wave coalescence phenomenon.

ANALYTICAL METHODS

We consider spatially coincident, sequentially detonated spherical explosions. The idealization represented by assuming spatial coincidence of spherical explosions is permissible because the initial separation distance between sequentially detonated charges will generally be quite small compared with distances at which coalescence phenomena are of interest. For example, in recently reported simultaneity tests[3] the 24-ft separation between two 5000-lb charges is less than three percent of the inhabited building distance (40 $W^{1/3}$) for barricaded stores based on W = 10,000 lb. With this idealization, the number of independent spatial variables is reduced to one.

Numerical Technique

The equations of unsteady compressible fluid flow are of hyperbolic type. A distinguishing property of hyperbolic equations is the existence of certain characteristic lines in the plane of independent variables (in this case distance r and time t), usually called simply characteristics.

Physically, the characteristics can be interpreted as lines along which infinitesimal disturbances (wavelets) of pressure and other flow variables can propagate. Characteristics are thus signals which carry information about local flow disturbances to other parts of the fluid at later times.

Along a characteristic, the dependent variables satisfy a certain differential relation known as a compatibility equation. Such relations provide the key to the computational technique known as the method of characteristics. The compatibility equations contain ordinary first-order derivatives rather than partial derivatives. Therefore these relations lend themselves to numerical integration in cases not solvable analytically.

There are two basically different ways in which the properties of characteristics can be used to construct numerical solutions. One of these, referred to as the natural-grid method, is to obtain the solution along particular members of each of two families of characteristic lines determined continuously as the solution is advanced. The other, called the fixed-time method, uses the properties of characteristics to relate the flow at the beginning and end of a prescribed time interval at each step of the calculations. The former method is useful in certain special cases, particularly for isentropic flows. The latter method, due to Hartree[4], provides results in the form of profiles of pressure and velocity at fixed times, and has several advantages over the natural-grid method for problems of the type we consider in the present work.

We devised a version of the fixed-time method in which computations are performed following particle trajectories in the the r, t plane. Shocks are accounted for independently as they propagate through the mesh of particle trajectories. Computational mesh elements at a typical interior (continuous) point of the calculations and at a shock are shown in Figures 2 and 3. Characteristic lines through the solution point to be determined on the new time line meet the previous calculated time line at points a and b in Figure 2, and at point a in Figure 3. The compatibility relations and the shock relations are solved simultaneously as appropriate to determine the solution at points on the new time line.

To advance the solution of the blast field in air exterior to the explosion gas sphere to the times and positions of interest requires the addition of new particle trajectories at the leading shock, thereby expanding the computed field. We devised a point addition routine which results in zones of approximately equal mass between computed trajectories. This point addition method was found to provide relatively uniform resolution of blast pressure gradients.

A simple automatic rezoning scheme was adopted for use in computing the far-field blast pressures. Periodically, alternate particle trajectories are deleted as the computed field expands and the available data storage is filled.

Initial Detonation Product Expansion

In order to determine an appropriate model for the initial formation of the air shock from an explosive charge, we examined some aspects of spherical charge detonation and the early expansion of the explosion gas.

The profiles of pressure and dimensionless particle velocity in a centrally initiated spherical charge of pentolite are shown in Figure 4 at the instant the detonation front emerges at the surface of the charge.

When the detonation front emerges at the surface of a centrally initiated spherical charge, the high-pressure detonation product gas contacts the surrounding air. This drives a strong shock into the air, while the product gas sphere expands through a strong, inward-traveling rarefaction wave (Figure 5).

Using the ideal-gas equation of state for air, we found the initial value of the air shock pressure to be 847 atm, a value consistent with an empirical fit of experimental data on air shock pressures close to spherical pentolite charges.[5] The pressure profile shortly after the detonation wave emerges at the charge boundary is shown in Figure 6.

FAR FIELD AIR BLAST ANALYSIS

Computer programs were written in FORTRAN IV programming language using the fixed-time characteristic scheme to calculate the far-field propagation of air blast from spherical explosions.

Computer Program Test

As a test of the accuracy of the code, we obtained a numerical solution of the single explosion problem using as initial data the pressure, velocity, and energy density profiles which characterize the strong point explosion. The numerical solution developed from these initial data must reproduce the blast field given by the exact similarity solution to this problem at all later times.

We developed the numerical solution in a region of the r,t plane bounded by a constant time line and by the similarity line $r = 0.8\ r_s$, where r_s is the shock radius at any time. The initial data were resolved with 20 equally spaced points on the initial time line. Calculations were continued until the shock pressure decreased by two orders of magnitude from its initial value.

The computed field and the pressure profile are shown in Figures 7 and 8 at the time when the shock pressure has decreased to about 1 percent of its initial value. The relative error in the results along the last line of computation is less than 0.05 percent. The maximum error in the pressure at the shock front, incurred at a relatively early time, is about 0.3 percent. The pressure profile is resolved with 50 points at this time.

Explosion Gas Sphere Model

In order to compute far-field blast pressures from explosions, it is essential to reduce the level of detail retained in calculations of the explosion gas sphere itself. As initial and boundary conditions for computing the far-field propagation, we replace the explosive charge by a sphere of detonation product gas having the same total energy and mass as the original explosive, at uniform but time-varying pressure.

A subsequent explosion is inserted computationally by increasing the current values of total energy and mass in the explosion gas sphere by the energy and mass of the second charge. The energy and density of the gas sphere are increased uniformly over the sphere volume at the time of the subsequent explosion. This neglects the time of propagation of the shock from the subsequent charge through the gases of the prior explosion. The instantaneous pressure increase is uniquely determined from the increase of internal energy and density, and from the requirement that the explosion products continue to satisfy the applicable equation of state. This process immediately initiates a second air shock at the boundary of the gas sphere, and tends to underestimate the separation between successive main shocks in the surrounding air.

Computed Results

We applied the code to sequential spherical explosion problems to predict blast wave coalescence phenomena. Problem conditions were selected so as to duplicate those of several of the ccale-model tests described in the next section. Detonation properties of pentolite, for which the computations were performed, are quite similar to those of plastic explosive C-4, which was used in the experiments. Computations are performed internally with dimensionless variables, but the resulting times and distances are scaled by the TNT equivalent of the total weight of explosive detonated on a rigid ground surface. Therefore the results are applicable to any explosive weight for the conditions of charge weight ratio and scaled time delay considered in these problems.

For conditions equivalent to those of the experiments (2 lb of C-4 detonated on a rigid surface), the time delays and charge weight ratios for which computations were performed are listed in Table 1.

Table 1

Time Delays by Run Number

Time Delay (msec)	Charge Weight Ratio			
	1:1	2:1	1:2	1:1:1
0.8	1	6		9
1.5	2	7	8	10
2.2	5			
2.9	3			
5.7	4			

In each case we continued the calculations beyond coalescence, if it occurred, or until the results were sufficient to provide a basis for understanding the behavior of successive pulses in the experiments. Time separations of the pulses at various distances were obtained by cross-plotting the normally output results, which are in terms of pressures and positions at fixed times.

The computed pulse separation times for two equal charges at various explosion time delays are shown as functions of distance in Figure 9. Peak pressures as functions of distance from two equal charges at an explosion time delay of 1.10 msec/lb$^{1/3}$ are shown in Figure 10; these results are typical of the cases in which coalescence occurs. All times and distances are scaled by the TNT equivalent of the total weight of explosive in the event.

The following features of the computed results are noted:

- The computational model simulates a situation in which each observation point is equidistant from sequentially detonated, spatially separated charges (as on the lateral blast gage line of the experiments described in the next section), and has an unobstructed view of both.

- The distance at which coalescence occurs tends to be underestimated for very short time delays (5.5 ft/lb$^{1/3}$ compared with an experimental value of 7.3 ft/lb$^{1/3}$ for a scaled time delay of 0.6 msec/lb$^{1/3}$). This is because the second explosion is modeled by adding its energy and mass uniformly over the gas bubble of the first explosion at the instant of the second detonation. This effectively assumes an infinite propagation speed of the second shock in the products of the first explosion. The agreement improves rapidly with increasing time delay, however, as this effect becomes relatively less important.

- The peak pressure of a coalesced wave is substantially the same as that from the simultaneous explosion of the total weight of explosive in the event, as confirmed extensively in the experiments.
- For long time delays there is no tendency for the successive blast pulses to coalesce. In fact, for a scaled time delay of 4.2 msec/lb$^{1/3}$ (the largest considered) with equal charge weights, the second shock travels in the negative pressure phase of the blast pulse from the first explosion.

SEQUENTIAL EXPLOSION EXPERIMENTS

A series of 20 small-charge experiments was designed in conjunction with the theoretical investigation to determine the effects of delay time between sequential explosions on the coalescence of successive blast pulses produced by the explosions.

Test Arrangement

Experiments were conducted with two sequential explosions in which the ratio of the weights of successively fired charges was 1/2, 1, and 2. A few experiments were also conducted with three sequential explosions. The total charge weight in each experiment was 2 lb. Blast pressure measurements were made at six locations on each of two gage lines axial and transverse to the line of centers of the charges. The time delays between detonations were obtained electronically. The actual time delays between sequential explosions were monitored by means of ionization probes placed at the charge centers. All pressure gage and ionization probe signals were recorded on magnetic tape.

Hemispherical charges of plastic explosive C-4 were used for all experiments. In the test configuration the charges rested on a 1-in. thick steel base plate, and were separated by a steel dividing wall to prevent sympathetic detonation. The dividing wall was 6 in. high by 1 in. thick. The distance between centers of the charges was 10 in.

The pressure transducers were installed flush with the ground surface in mechanically isolated steel mounting plates on the centerlines of two 75-ft long by 10-ft wide concrete slabs. A general view of the test area is shown in Figure 11. Figure 12 shows a typical gage installation in the 6-in. by 1/2-in. cover plate of the centerline conduit through which the transducer cables of each blast line were carried.

Experimental Results

A reference shot utilizing a single 2-lb sphere of C-4 was fired. The pressure-distance curve is shown in Figure 13. The distance is scaled by the TNT equivalent of the explosive weight.

The experimental setups for two- and three-charge sequential explosion tests are shown in Figures 14 and 15. The experiments were conducted at time delays ranging from 0.8 to 5.7 msec at intervals of 0.7 msec. The actual delay, observed in each experiment on the ionization probes, was always within 0.1 msec of the programmed delay. The nominal delays at which the shots were fired are given in Table 2.

Table 2

Programmed Delays by Shot Number

Nominal Delay (msec)	Charge Weight Ratio			
	1:1	2:1	1:2	1:1:1
0.8	12	17		
1.5	11	16	24	28
2.2	10	18	22	29
2.9	13		23	
3.6	9	19		30
4.3	14		25	31
5.0	15			
5.7	20			

A typical set of pressure-time records from successive gages in the line transverse to the line of centers of the charges is shown in Figure 16. Coalescence of the waves from the two explosions is clearly evident.

Experimentally obtained pulse separation times on the axial and lateral blast lines are shown as functions of distance in Figure 17 for the experiments with two equal charges. The results for the lateral line are shown in another way in Figure 18 as curves of constant pulse separation in coordinates of explosion time delay and distance from the explosion site; we call this a coalescence map.

Typical experimentally obtained peak pressures are given in Figure 19 for two equal charges at a time delay of 1.07 $ms/lb^{1/3}$. The reference pressure-distance curve for the total weight of explosive in the event is shown, as well as that for half the total weight up to the point of coalescence. The results on the lateral line compare favorably with the computed results (Figure 10) for very nearly the same explosion time delay.

Times and distances are scaled by the TNT equivalent of the total weight of explosive present. Therefore the results are applicable to any explosive weight in the types of situations tested. In the following paragraphs we give general conclusions and inferences drawn from the experimental results.

- The firing sequence of the charges, together with the presence of the dividing wall, has a relatively strong effect on coalescence on the line of gages axial to the line of centers of the charges. In all tests we fired the charge farther away from the axial line first. This enhances coalescence on the axial line relative to that on the transverse line. Overlaying the two sets of time separation curves shows that the effect of firing sequence is roughly equivalent to reducing the time delay by about 1.8 msec, or about 1.3 $msec/lb^{1/3}$ based on the TNT equivalent of the total charge present.

- In all cases when coalescence occurs the resultant shock pressure is essentially that from a single explosion of the total quantity of explosive involved.

- In the lateral direction, there is substantially no tendency for the shocks from two equal charges to coalesce for time delays larger than 4.3 msec, or 3.2 msec/lb$^{1/3}$ based on the TNT equivalent of the total charge in the event. The tendency to coalesce was observed on the axial line in all experiments. However, since the effect of firing sequence on the axial line is equivalent to reducing the scaled time delay by 1.3 msec/lb$^{1/3}$, it can be inferred that there will be no tendency for the shocks to coalesce in the axial direction if the scaled time delay exceeds 4.5 ft/lb$^{1/3}$.

- Coalescence occurs more readily when the successive charges are in the ratio of 1:2, and less readily for the ratio 2:1, than with equal charges.

- In the case of three explosions separated by two equal time delays, the third pulse tends to overtake the second before the second overtakes the first.

Comparisons

A large-scale test was conducted in April 1968 at the Naval Weapons Center with two 5000-lb charges detonated 20 msec apart[3]. An analysis of the published data shows that the coalescence of the two shocks occurred at approximately 230 ft from the site of the explosions. The scaled time delay in this test is $20/(10{,}000)^{1/3} = 0.93$ msec/lb$^{1/3}$ based on the total TNT charge weight in the event, and the scaled coalescence distance is $230/(10{,}000)^{1/3} = 11$ ft/lb$^{1/3}$. We found in our experiments with two equal charges that for time delays of 0.6 and 1.1 msec/lb$^{1/3}$ the respective coalescence distances are 7.3 and 13.0 ft/lb$^{1/3}$ along the (lateral) gage line analogous to that in the NWC test (Line A) on which the coalescence data were reported[3]. Thus for a scaled time delay of 0.93 msec/lb$^{1/3}$ our test results predict a coalescence point at about 11 ft/lb$^{1/3}$, in full agreement with the NWC test result. Moreover, our pressure data are in good agreement with the findings of the NWC test.

In a series of small-scale tests with two 1/4-lb charges, Kaplan[2] reported the result of an experiment in which the time delay was 2.73 msec, or 3.2 msec/lb$^{1/3}$ if we assume that the total charge weight in his experiment was 1/2 lb of C-4 or a similar energetic explosive. A pressure record from this test shows two pulses separated by a time interval apparently about equal to the explosion time delay. One of our equal-charge experiments was fired at approximately the same scaled time delay. At this time delay we found no appreciable tendency for the shocks to coalesce; this agrees qualitatively with the reported result. Other tests[2] with two 1/4-lb charges involved time delays well below 1 msec/lb$^{1/3}$; single pulses were observed at gage stations from 16 to 37 ft/lb$^{1/3}$. In our tests with short time delays we found coalesced waves at all but the closest gage stations, in agreement with the reported observations.

CONCLUSIONS

- The results we have obtained agree quite well with data from similar studies with widely different explosive weights (ranging from 1/4 to 5000 times the quantity of explosive in our experiments). Thus blast coalescence phenomena can be investigated quite adequately with scale model experiments.

- When coalescence of successive blasts occurs, the resulting shock pressure is substantially the same as that from simultaneous explosion of the total weight of explosive in the event.

- There is no tendency for the pulse from a second explosion to overtake the first when the scaled time delay is greater than

  3.2 msec/lb$^{1/3}$ for a charge weight ratio of 1:1
  2.6 msec/lb$^{1/3}$ for a charge weight ratio of 2:1
  3.7 msec/lb$^{1/3}$ for a charge weight ratio of 1:2

  where the time delay is referenced to the total weight of explosive in the event.

- There is a considerable directional effect in evidence when the line of observation is axial to the line of centers of the charges. The enhancement of coalescence, relative to positions lateral to the line of centers, is equivalent to a reduction of the scaled explosion time delay by 1.3 msec/lb$^{1/3}$.

- When three successive explosions take place spearated by two equal time intervals, the third shock tends to overtake the second well before the second overtakes the first. Thus this type of event may be treated (conservatively) as a two-explosion event with a charge weight ratio of 1:2.

- Existing explosive storage and facilities design standards are unconservative with regard to the treatment of sequential explosions. In siting adjacent structures, the design basis accident should be taken as the total explosive weight in adjacent bays, unless it can be assured that propagation between the stores will be delayed by scaled time intervals not less than those listed above for the applicable donor configurations and acceptor positions.

ACKNOWLEDGEMENTS

This study was performed under Contract No. DAHC-04-69-C-0020 for the Armed Services Explosives Safety Board, supervised by Col. B. B. Abrams, Chairman, and Mr. R. G. Perkins, Safety Engineer.

Several IIT Research Institute staff members contributed significantly to this work. Special thanks are due to Mrs. H. S. Napadensky, who designed the test series and assisted in interpretation of the experimental data, and to Mr. T. V. Eichler, who performed the computer programming.

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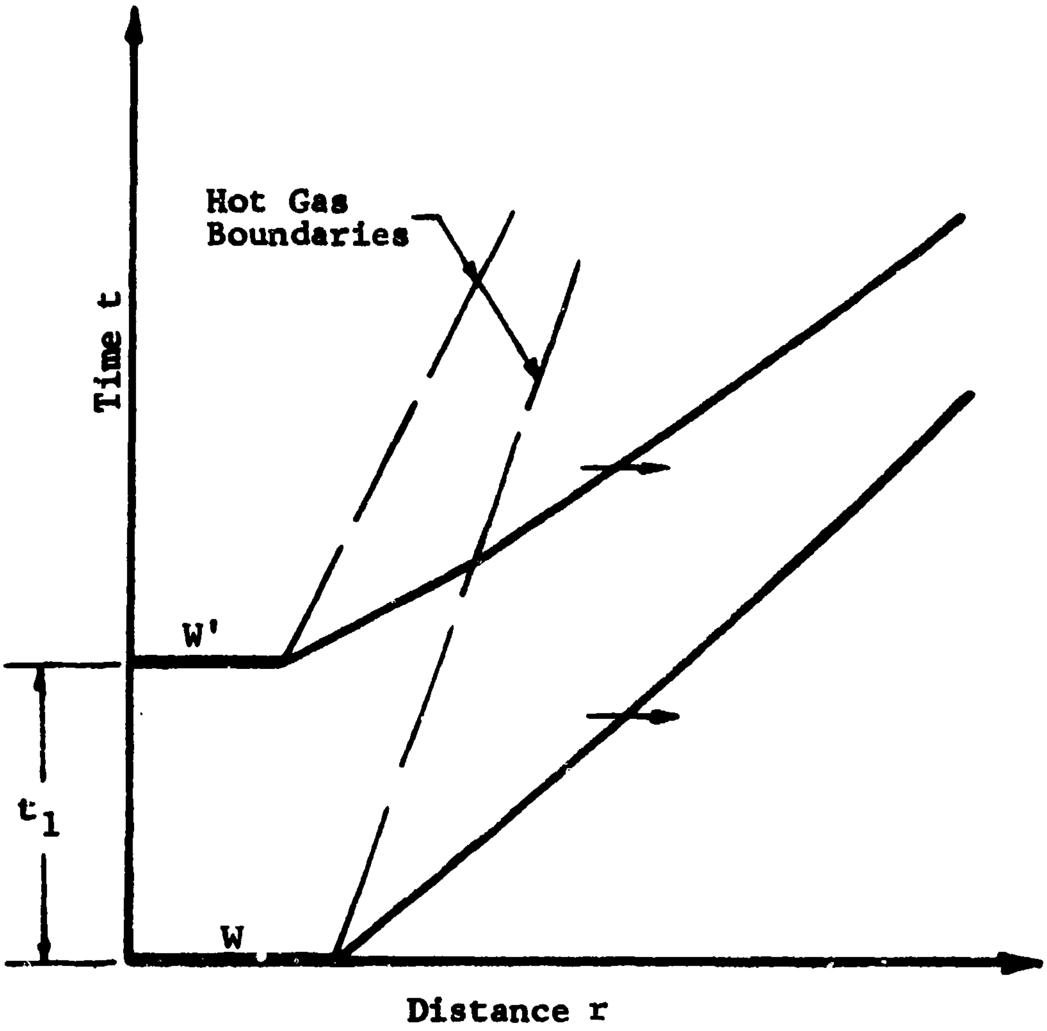


Figure 1 Sequential Spherical Explosions-Schematic

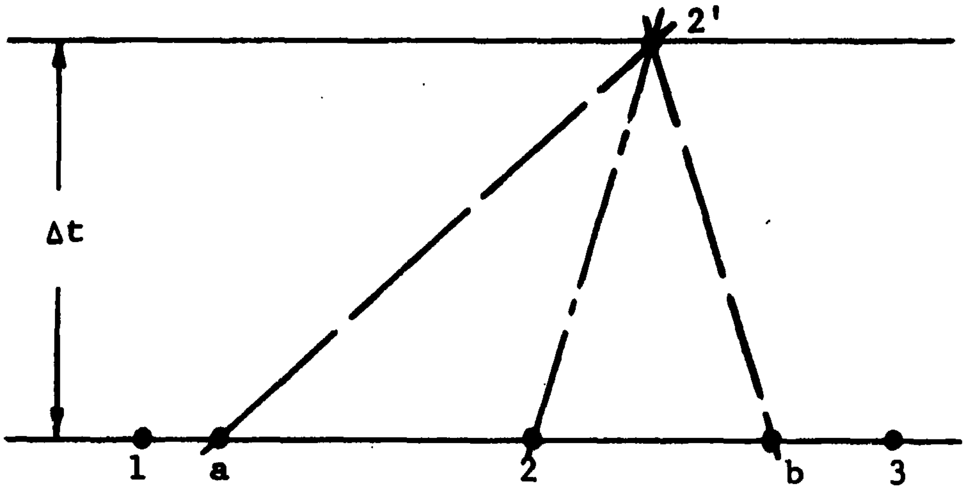


Figure 2 Fixed-Time Calculation at an Interior Point

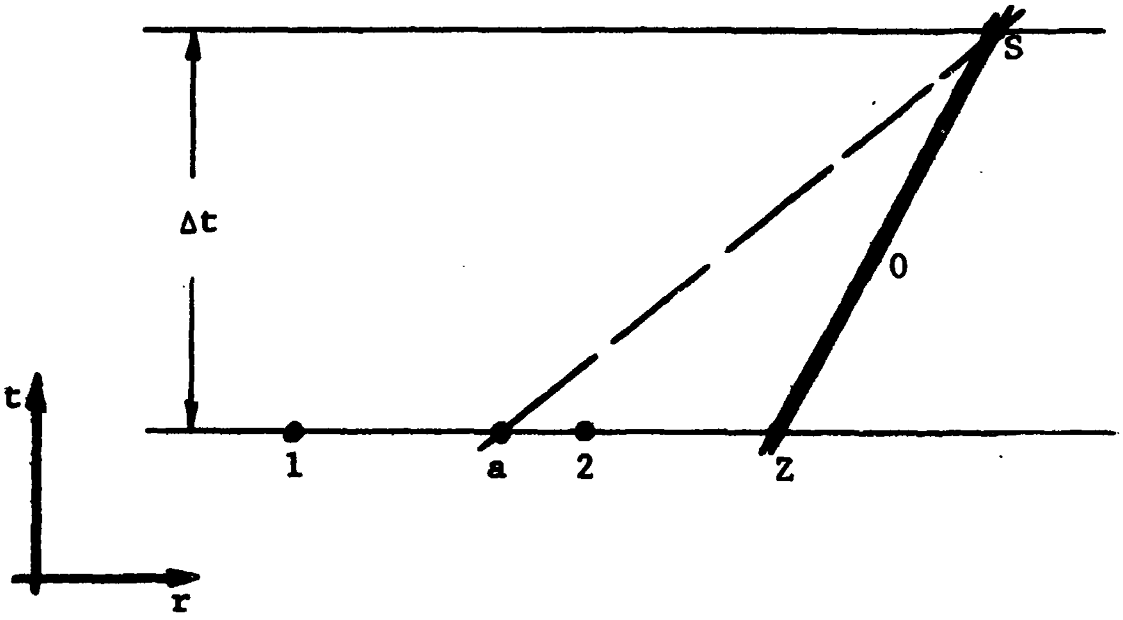


Figure 3 Fixed-Time Calculation at a Shock

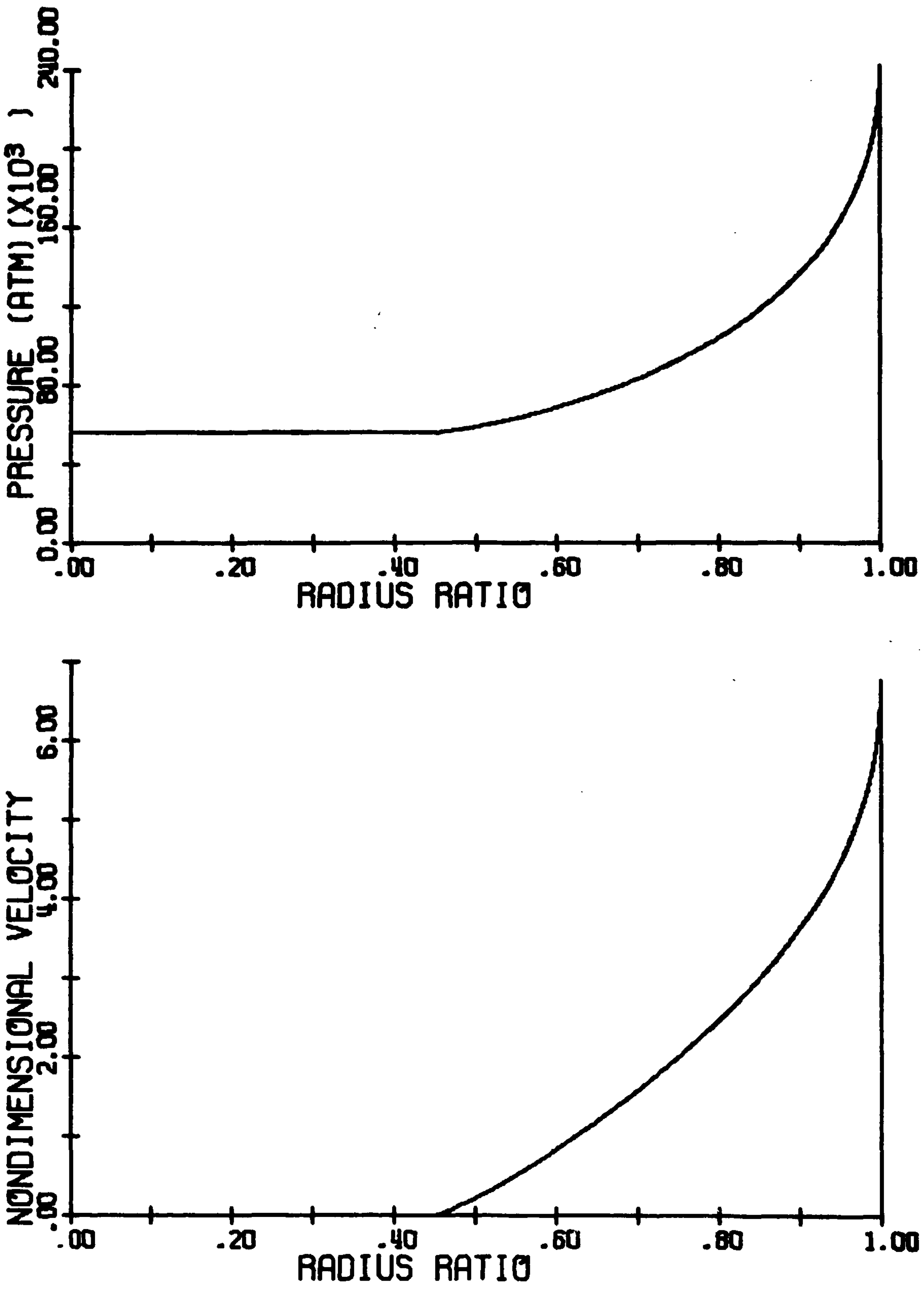


Figure 4 Spherical Charge Detonation Wave Profiles

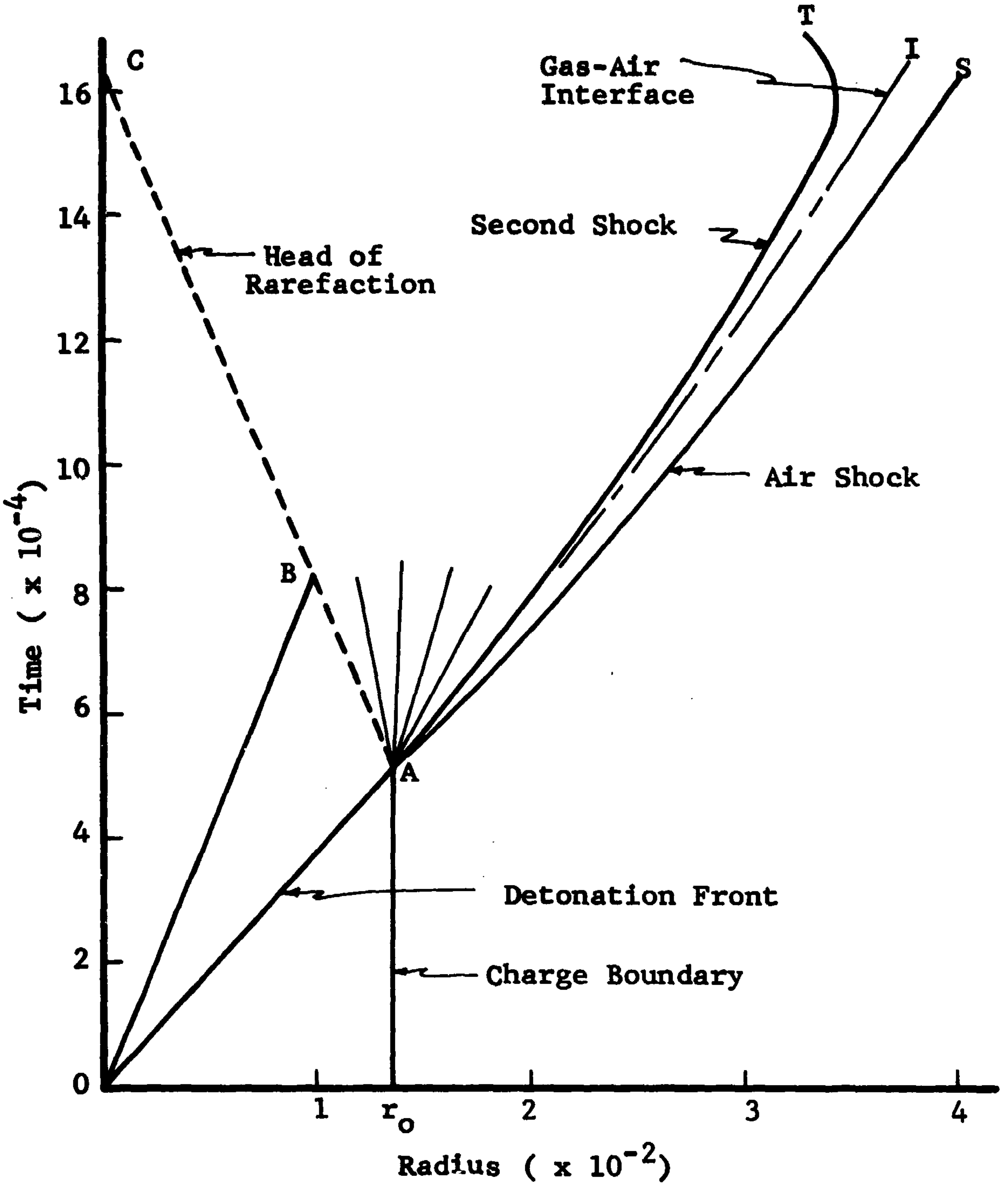


Figure 5 Early Expansion of Explosion Gas

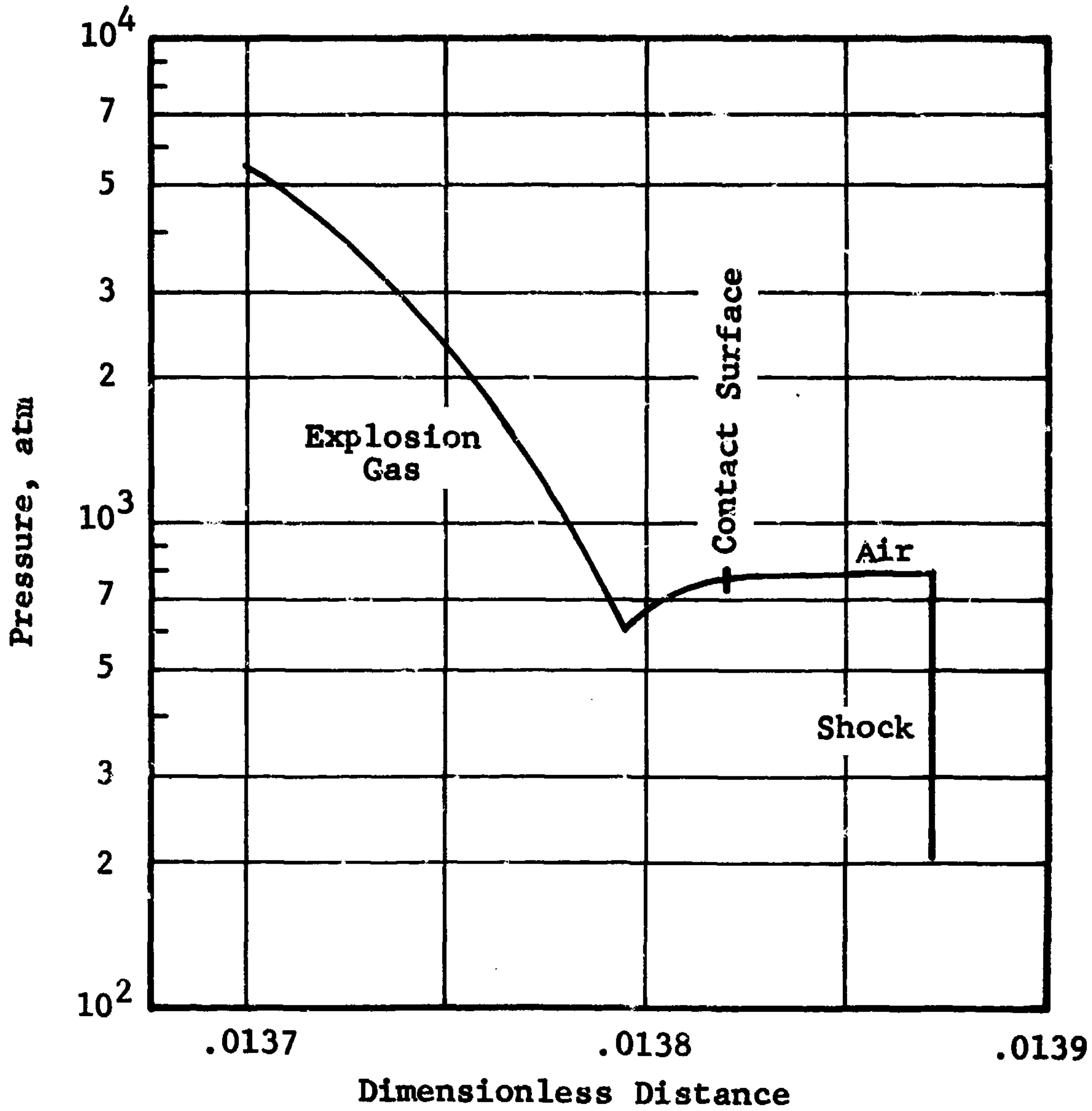


Figure 6 Pressure Profile at Early Time
Charge Radius = 0.01357

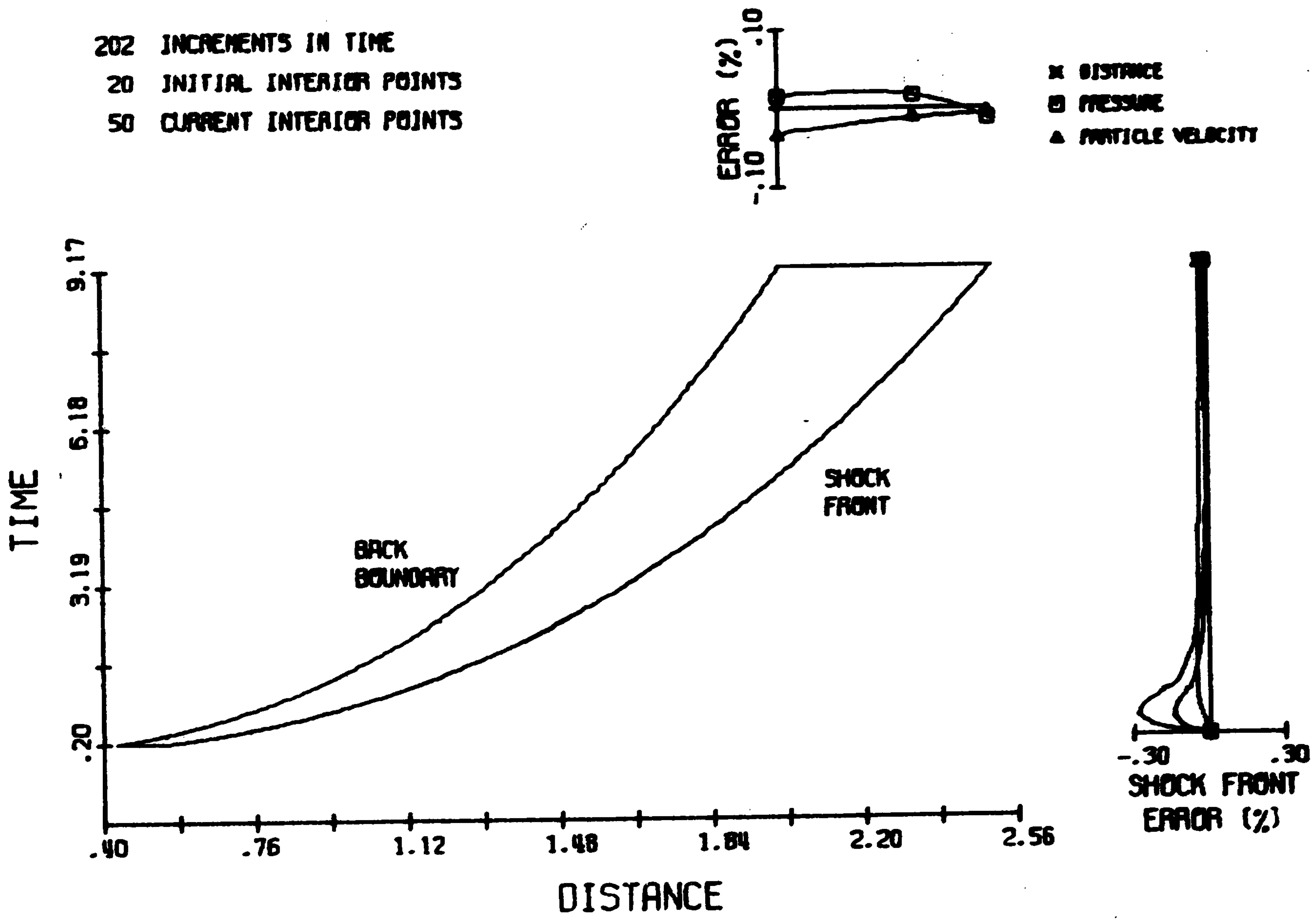


Figure 7 Point Explosion Field at $p_g = 0.01$

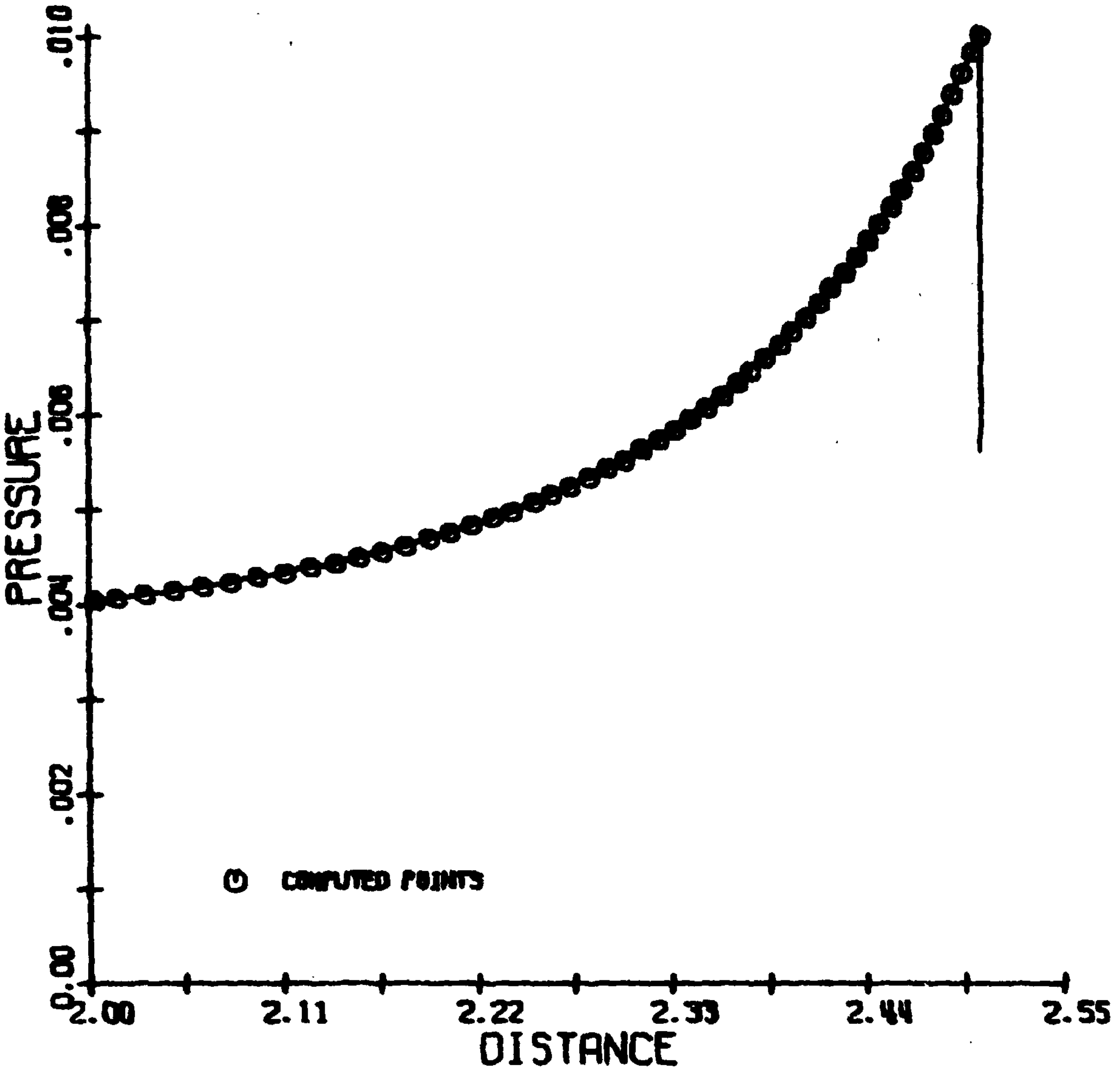


Figure 8 Point Explosion Pressure Profile at $p_s = 0.01$

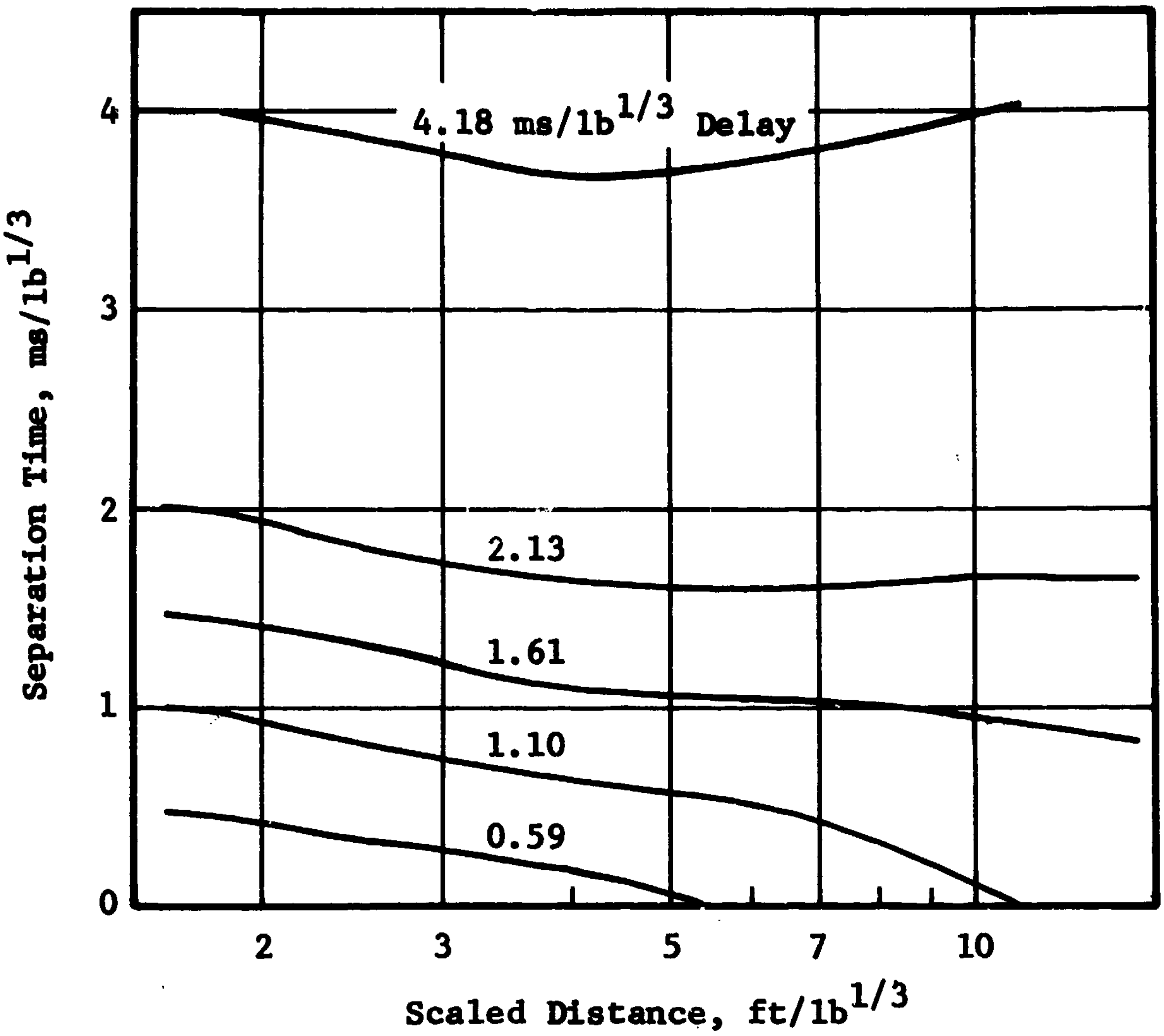


Figure 9 Computed Pulse Separation Times, Charge Weight Ratio 1:1

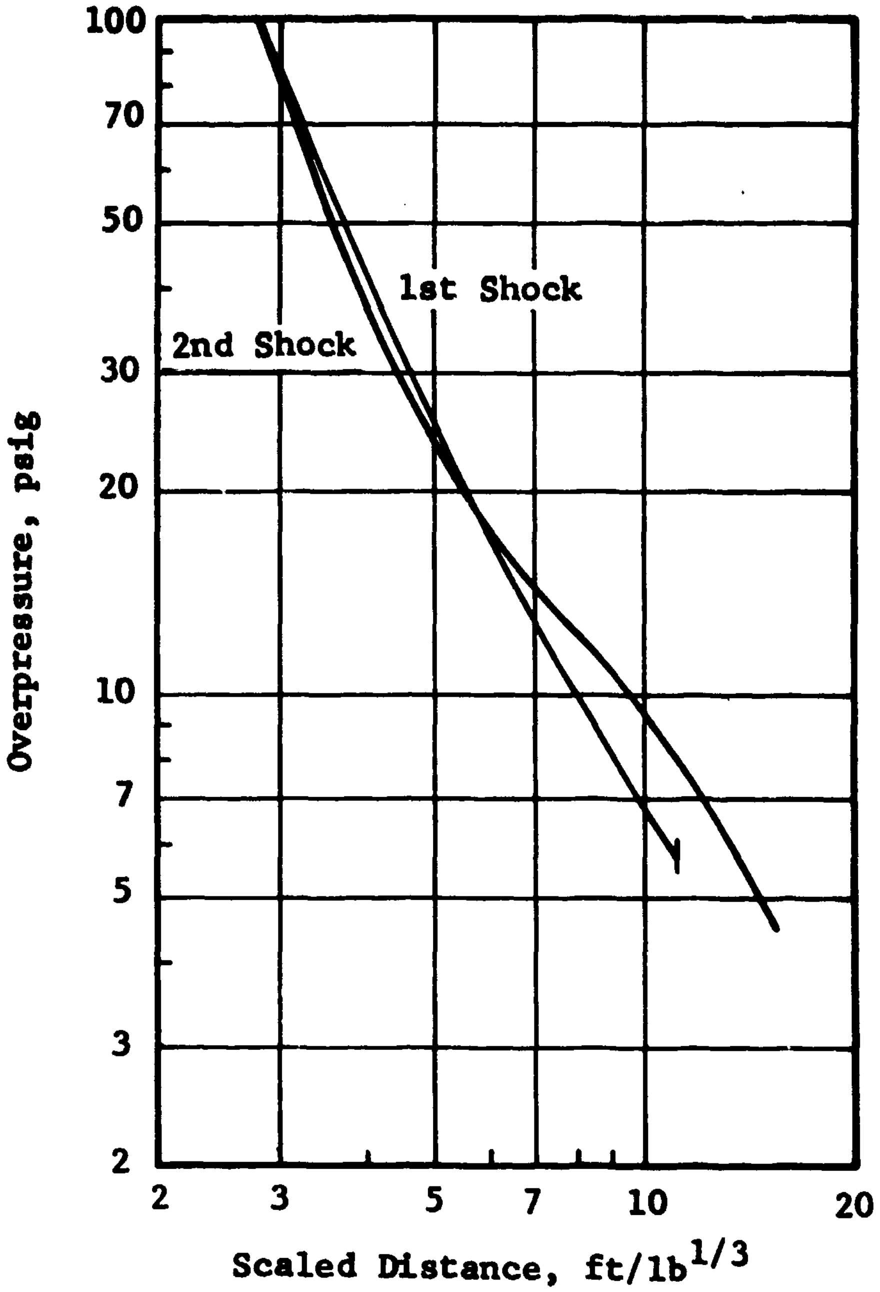


Figure 10 Computed Pressures, Run No. 2, Charge Weight Ratio 1:1, Delay 1.10 ms/lb$^{1/3}$

Figure 11 Air Blast Gage Lines

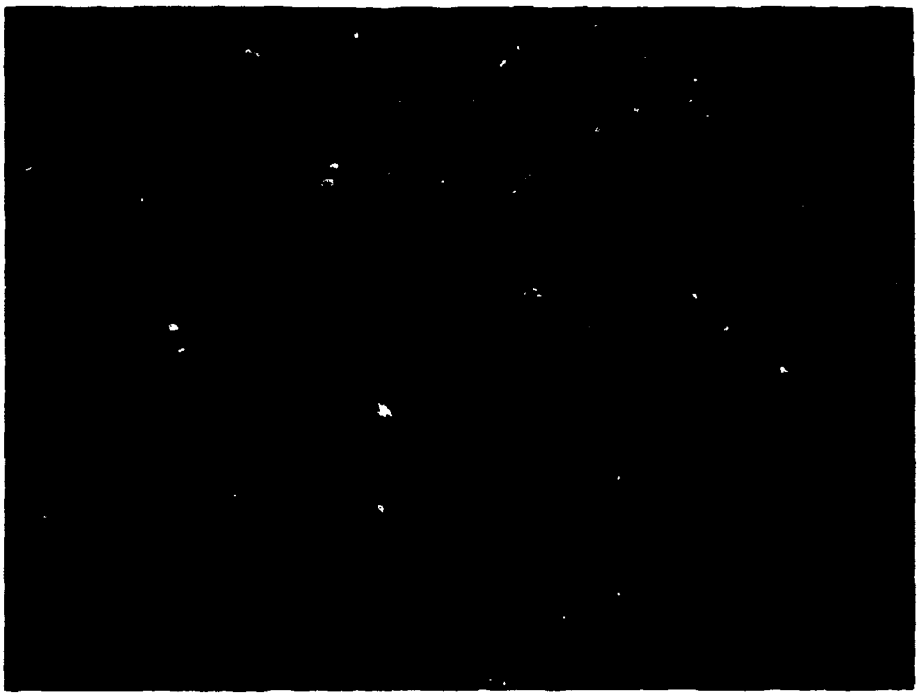


Figure 12 Photocon Gage Installation

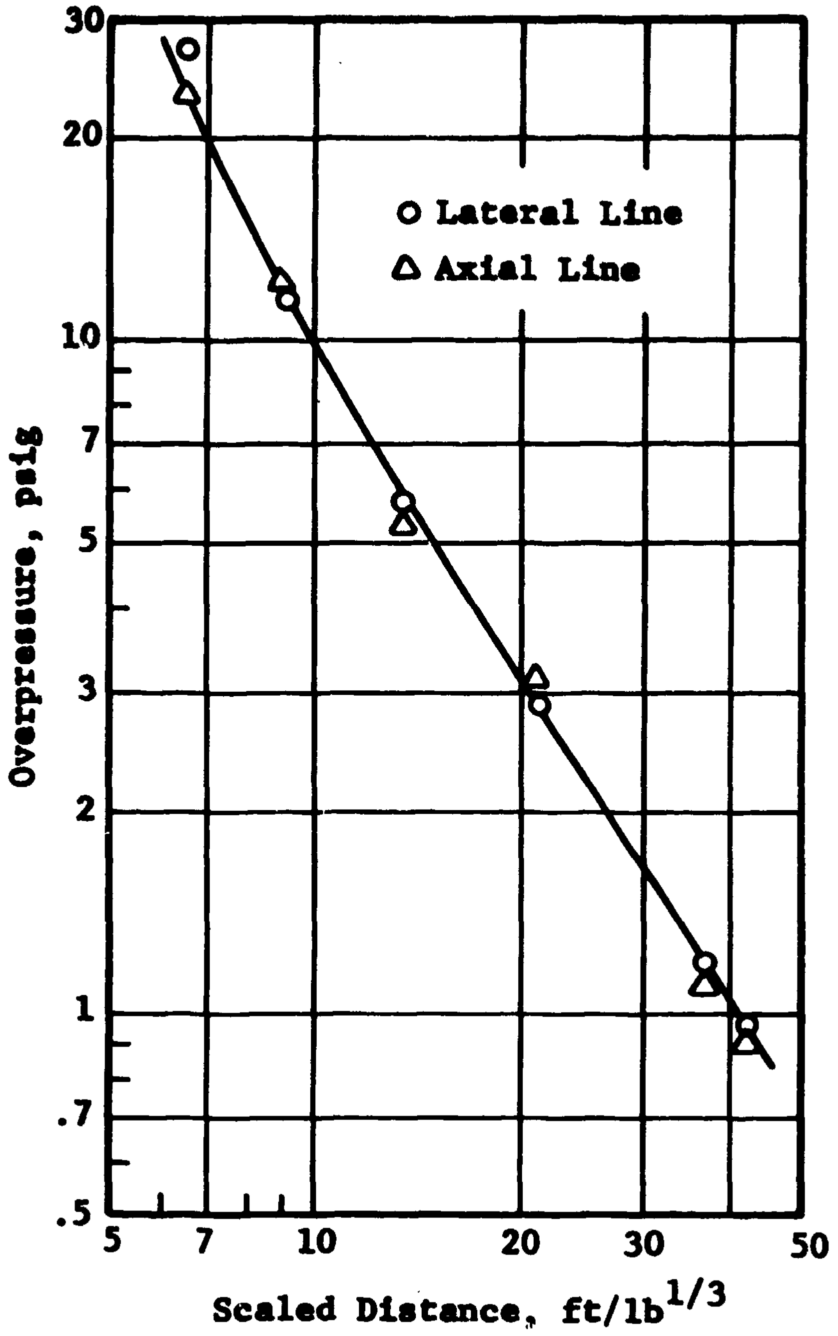


Figure 13 Pressure - Distance Curve for C-4

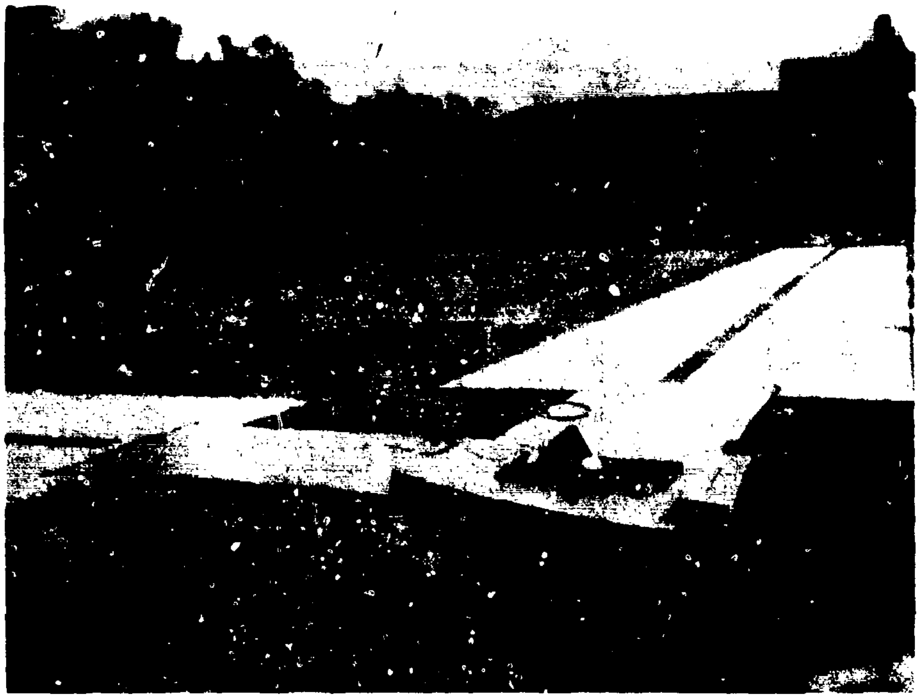


Figure 14 Two-Charge Experimental Setup

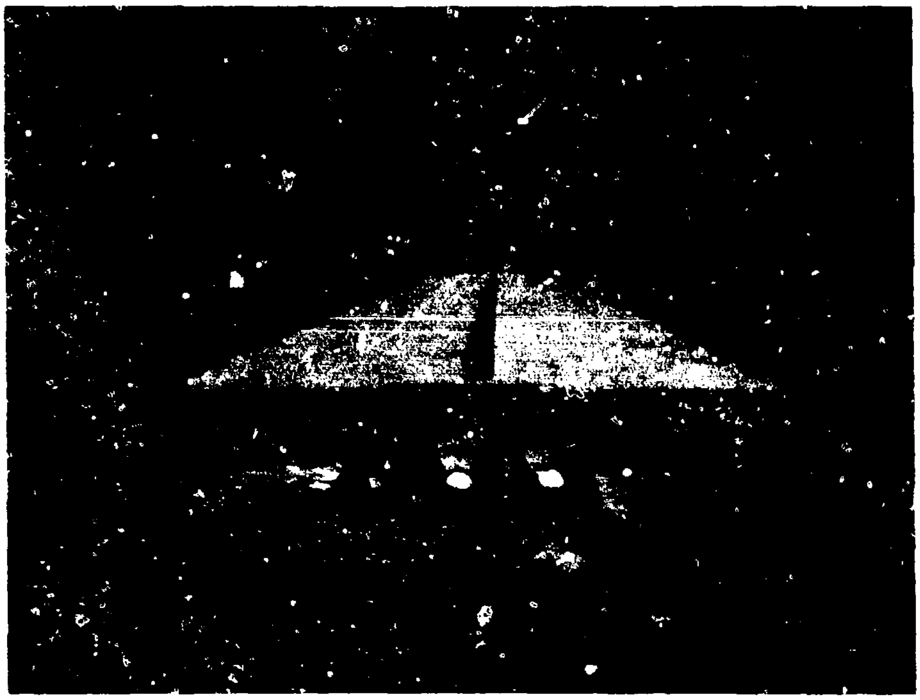
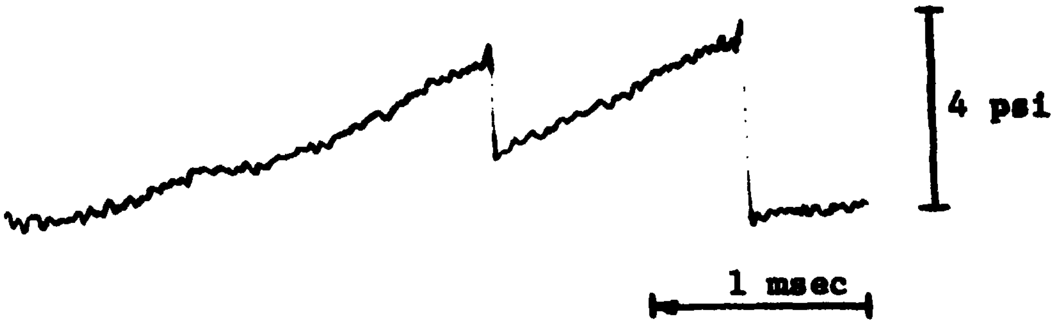
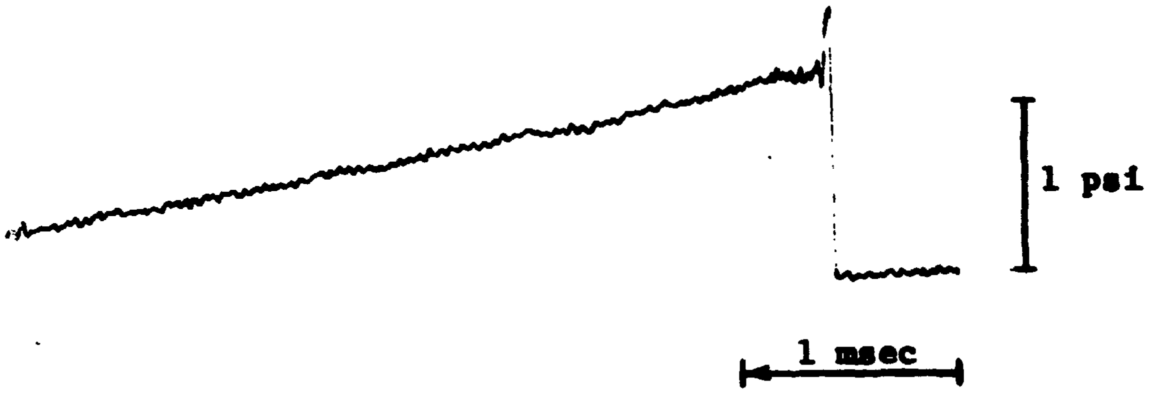


Figure 15 Three-Charge Experimental Setup



Scaled Distance 13.5 ft/lb$^{1/3}$

Scaled Distance 20.9 ft/lb$^{1/3}$



Scaled Distance 37.1 ft/lb$^{1/3}$

Figure 16 Pressure Records, Lateral Line, Shot No. 16, Charge Weight Ratio 2:1, Time Delay 1.16 ms/lb$^{1/3}$

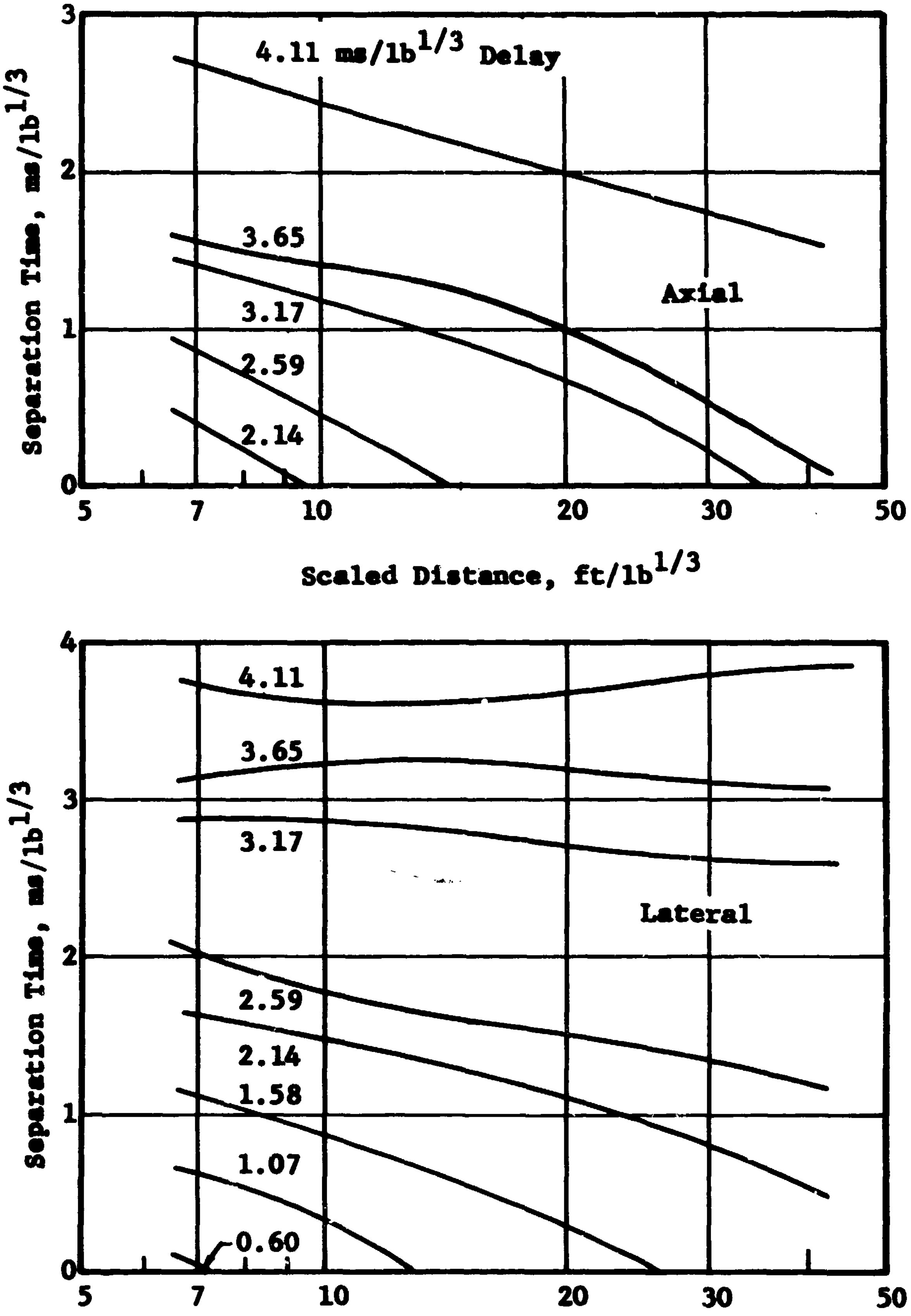


Figure 17 Pulse Separation Times, Charge Weight Ratio 1:1

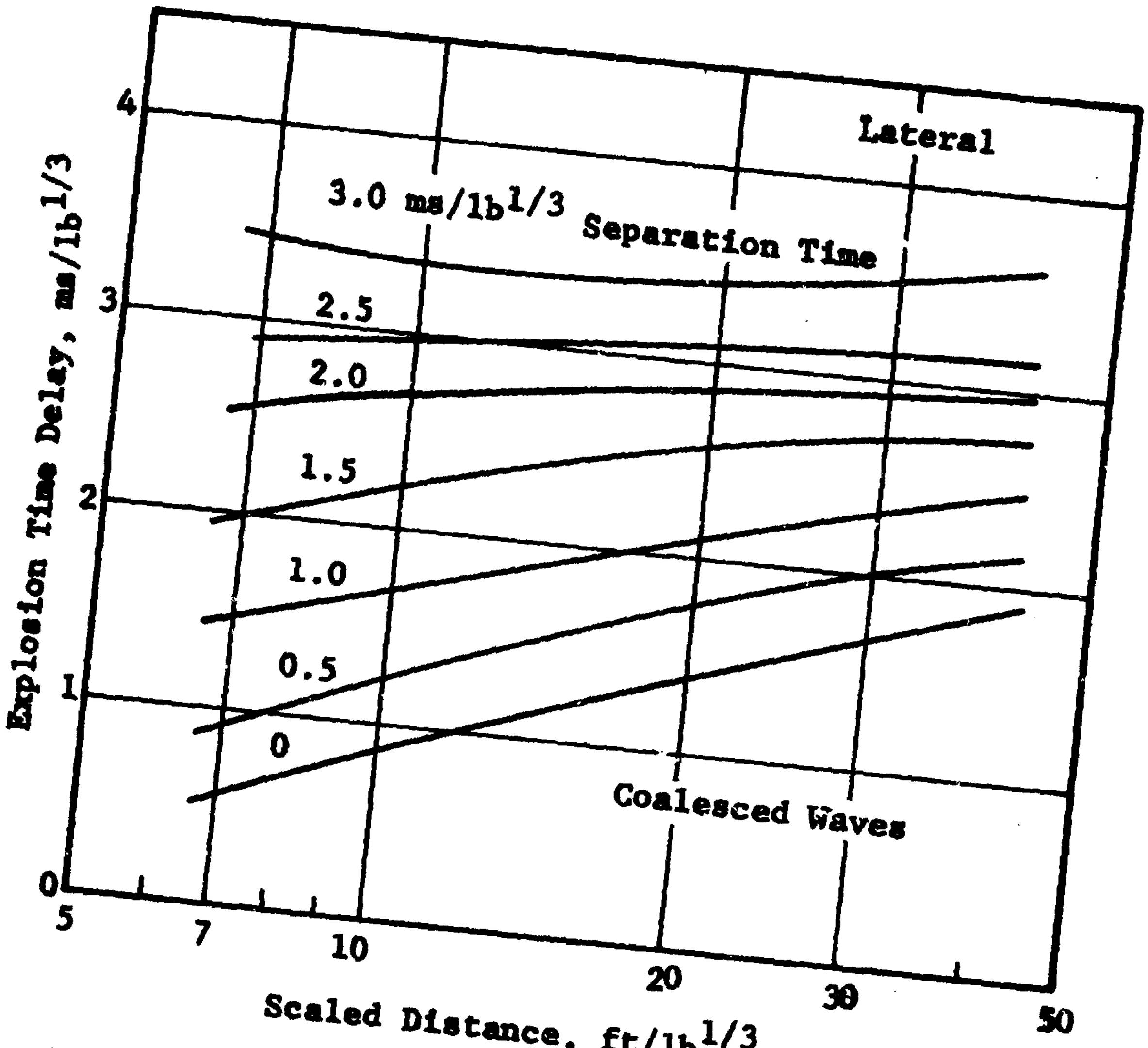


Figure 18 Coalescence Map, Charge Weight Ratio 1:1

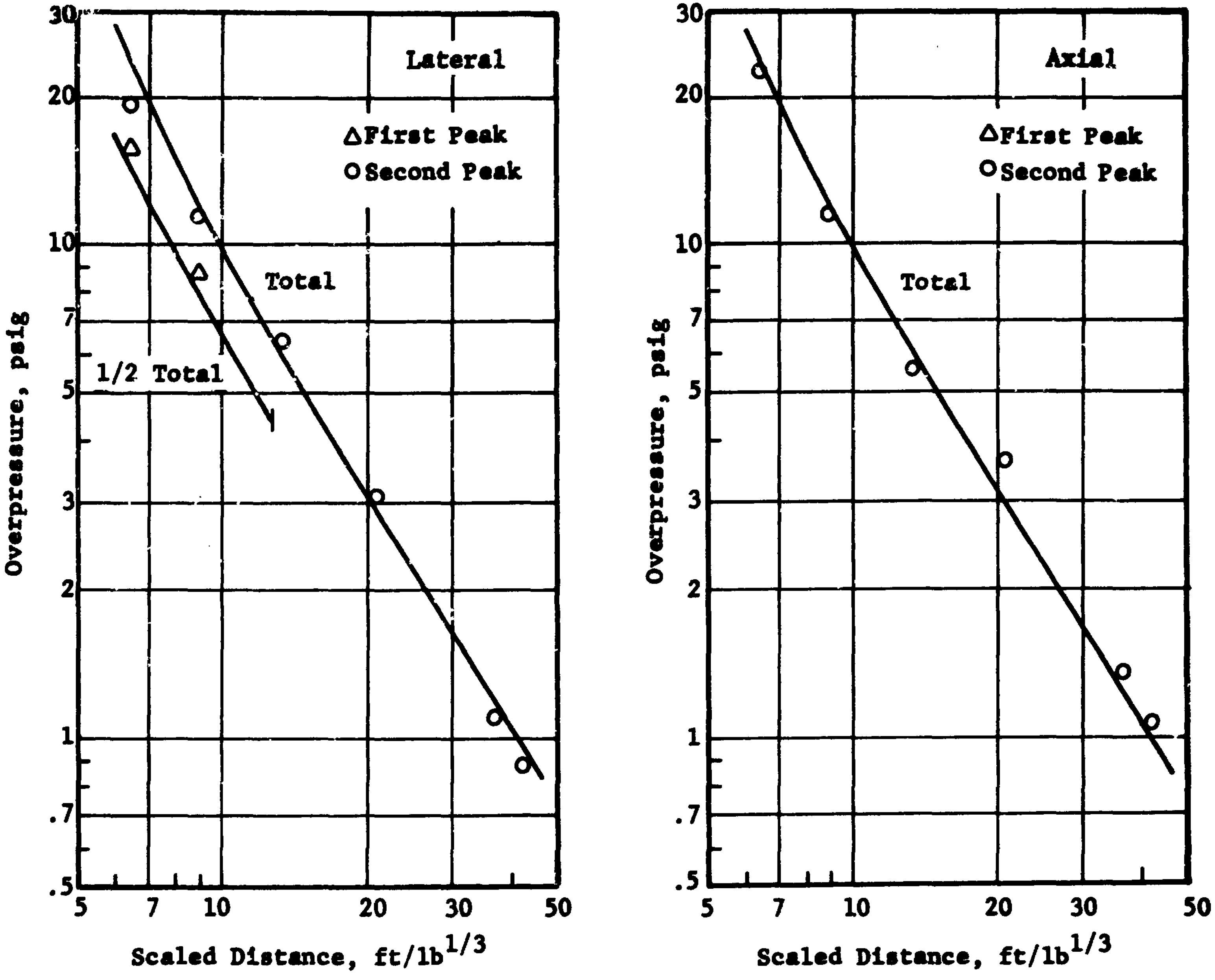


Figure 19 Pressures, Shot No. 11, Charge Weight Ratio 1:1, Time Delay 1.07 ms/lb$^{1/3}$

Discussion of Paper Entitled "Far Field Overpressure from Closely Spaced Sequential Detonations"

Specialist sessions were conducted on September 9 and 10, 1969 to discuss details and implications of the results of the paper on sequential explosions given in the general session. Discussion was divided into three phases: comparisons with data from other sources and with theoretical (numerical) predictions reported in the paper, the significance of directional effects on blast coalescence, and utilization of the results in applications to quantity-distance standards.

GENERAL

Tabular comparisons with data from other sources were presented, and limitations on the computational model were discussed.

Comparisons

In the Naval Weapons Center test[3*] of April 1968 referenced in the main session paper, a line of blast gages (Line A) extended in a direction perpendicular to the line of centers of two 5000-lb charges detonated with a programmed delay of 20 msec between explosions. (In discussion from the floor, it was stated that the actual delay between detonations was 23.8 msec rather than the reported 20 msec.)

Published pressure-time records from gages on Line A of the NWC test were analyzed to determine the distance at which the two shocks coalesced. This distance was estimated at 230 ft. A comparison of the scaled time delay and coalescence distance with those observed in two model experiments with 1-lb charges (IITRI Shots 11 and 12) is shown in the first three lines of Table 1. This favorable comparison is based on the nominal delay of 20 msec in the NWC test, and the times and distances are scaled by the TNT equivalent of the total quantity of explosive in each event.

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*Superscript numerals designate references cited in main session paper.

If the time delay in the NWC test was actually 23.8 msec, the corresponding scaled delay would have been about 1.1 msec/lb$^{1/3}$, a value nearly the same as the actual scaled delay of IITRI Shot 11. On the other hand, within the accuracy to which the coalescence distance can be determined from the records of the NWC test, the shocks may have coalesced as far as 260 ft from the explosion site. This corresponds to a scaled coalescence distance of about 12 ft/lb$^{1/3}$, which yields a still acceptable comparison with the model test data.

A qualitative comparison between a test with two 1-lb charges (IITRI Shot 14) and a test at URS[2] with two 1/4-lb charges is also shown in Table 1.

Finally, Table 1 gives a rough comparison between observations on the line of blast gages transverse to the axis of two 1-lb charges (IITRI Shot 13) and those on the axial line (Line C) in the NWC test[3]. As discussed in a later paragraph of this summary, the effect of firing sequence with respect to charge position was found to be equivalent to an apparent difference of 1.3 msec/lb$^{1/3}$ scaled explosion delay time between the axial and lateral blast lines. For the firing sequence in the NWC test, the effect is an apparent increase of explosion delay. Coalescence in the NWC test took place at some point between gage stations at scaled distances of 40 and 76 ft/lb$^{1/3}$, while the model test predicts by extrapolation a coalescence point at about 60 ft/lb$^{1/3}$.

Computer Code Limitations

It was pointed out in the discussion that the theoretical (numerical) analysis is based on a one-dimensional representation of the spherical blast field, in that the successively detonated charges are assumed to be spatially coincident. Thus the computational model simulates best the effects on the line of blast gages transverse to the axis of the charges, since points on this line have an unobstructed view of both charges.

The uniform gas sphere model used to represent the detonation products eliminates details such as weak aftershocks which characteristically appear in the negative pressure phase of spherical blast pulses. This simplification of the source does not materially affect predictions of the coalescence of main shocks except for very short time delays, at which the coalescence distance tends to be underestimated.

The possibility of using a numerical technique based on the method of characteristics in two-dimensional problems was discussed. It was pointed out, however, that the logical complications associated with this method in two dimensions are probably prohibitive for all but the simplest two-dimensional problem geometries.

DIRECTIONAL EFFECTS

The conclusions of the study regarding the directional effect of firing sequence with respect to charge position were recapitulated. They are

- There is a strong directional effect on the coalescence of successive blast pulses from sequentially detonated charges due to the sequence in which the charges are fired.

- The enhancement of coalescence along an observation line axial to the line of charge centers, relative to a lateral observation line, is equivalent to a reduction of scaled explosion time delay by 1.3 msec/lb$^{1/3}$ for an initial scaled distance between charges of only 0.6 ft/lb$^{1/3}$.

Thus the effects of initial charge separation and explosion time delay are strong functions of the angle that the observation line makes with the axis of the charges. At a scaled time delay of 1.9 msec/lb$^{1/3}$, for example, we would find that the blast pulses from two equal charges coalesce at scaled distances of

8 ft/lb$^{1/3}$ in the axial direction

42 ft/lb$^{1/3}$ in the lateral direction.

In Figure 1 are sketched possible coalescence contours for this case. It is clear that there is a wide possible variation of the locus of coalescence for two equal charges at a given time delay (and hence a wide variation of safe distance as a function of orientation).

It was pointed out that such directional effects cannot be explained on the basis of elementary one-dimensional analytical models, and must be studied experimentally in experiments with small charges.

APPLICATION TO STANDARDS

A suggested change to current quantity-distance standards was discussed which comprises a new simultaneity provision based on the sequential explosion study. The change would require that, where the possibility of explosion propagation exists in a subdivided quantity of explosive, the total quantity be used in distance determinations unless it can be assured that propagation is delayed by time intervals not less than those given in Table 2.

The table is based on scaled time delays which are the least values required to insure that successive blast pulses from sequential explosions do not coalesce. The numerical values are for severe but realistic conditions, inasmuch as the second of two explosions is taken to be twice as large as the first, and the explosions are assumed to occur in a sequence with respect to charge location in such a way as to maximize the tendency for the blast waves to coalesce. The suggested standard implicitly covers cases of more than two equal sequential explosions, since it was found that this situation can be treated conservatively as two sequential explosions in which the second charge is twice the first.

For acceptor positions on radii within 60 degrees of the line of centers of the charges, the table assumes conservatively that coalescence phenomena are the same as on the line of centers. The value of 60 degrees is a conservative estimate of the effect of angular location of the acceptor, based on the data currently available. This provisional value could be refined as more information concerning the angular variation of effects is developed.

Table 1

COMPARISONS

Charge Weight lb	Ref.	Delay ms	Scaled Delay ms/lb$^{1/3}$	Coalescence Distance ft	Scaled Coalescence Distance ft/lb$^{1/3}$
2	IITRI	0.81	0.60	9.9	7.3
10,000	NWC, Line A	20	0.93	230	11
2	IITRI	1.53	1.07	17.7	13.0
2	IITRI	4.30	3.17	No Coalescence	
1/2	URS	2.73	3.19		
2	IITRI	2.91	2.14	~ 80	~60
10,000	NWC, Line C	20	0.9 + 1.3 = 2.2	865 to 1640	40 to 76

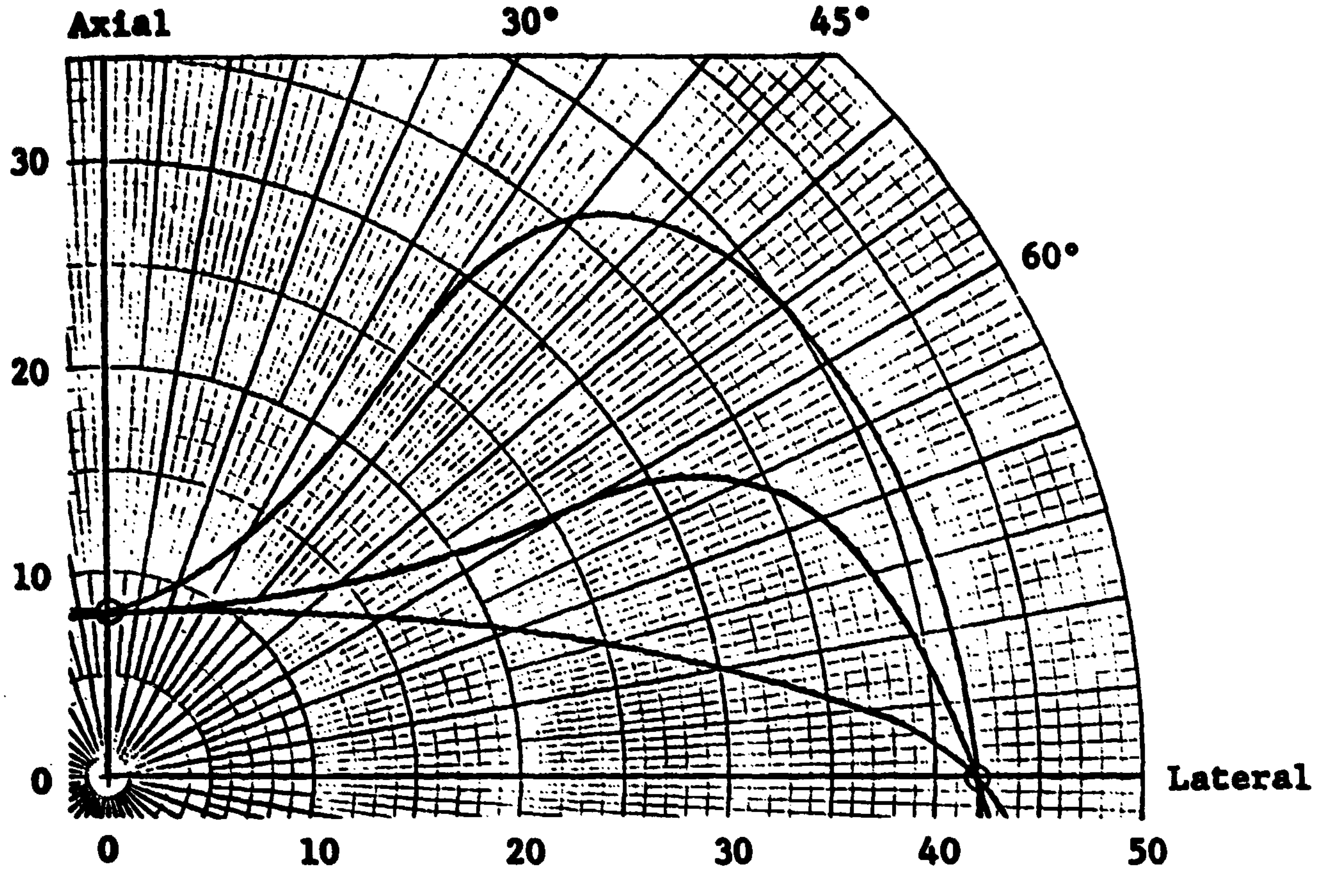

Figure 1

Possible Coalescence Contours as a Function of Angle from Axis of Charges, Scaled Time Delay 1.9 ms/lb$^{1/3}$

Table 2

Minimum Propagation Delay Time Required to Assure Nonsimultaneous Effects of Explosion of a Subdivided Total Quantity of Explosive

Total Pounds of Explosives		Minimum Required Propagation Delay Time in Milliseconds between Any Two Subdivisions of Total Quantity	
Over	Not Over W	Acceptor Positions on Radii within 60 Degrees of Axis of Subdivisions* $5.0\ W^{1/3}$	Other Acceptor Positions $3.7\ W^{1/3}$
(1)	(2)	(3)	(4)
0	1,000	50	40
1,000	5,000	85	65
5,000	10,000	110	80
10,000	20,000	135	100
20,000	30,000	155	115
30,000	40,000	170	130
40,000	60,000	195	145
60,000	80,000	215	160
80,000	100,000	235	175

*Value of 60 degrees is provisional pending development of additional information on angular variation of effects from near-simultaneous explosions.

Influence of a Barricade Upon Blast Wave Parameters

Part I: Background and Analytical Work

by

A. R. Schleicher

with

F. A. Bryan, Jr., Ph.D.
P. N. Hunt
R. H. Thornton
Research Triangle Institute

J. N. Perkins, Ph.D.
Associate Professor
North Carolina State University

Part II: Experimental Work

by

A. B. Wenzel
Southwest Research Institute

Based on work done under
Contract DAHC04-69-C-0028
Sponsored by
Armed Services Explosives Safety Board

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LIST OF FIGURES

Part I

I. BACKGROUND AND ANALYTICAL WORK

A. Introduction

Barricades of earth and other materials have long been used as a protective measure against blast and fragments from accidental explosions. The premise for such use is that obstacles between an object and an explosion provide a "shadow" region protected from blast and fragments. In recent years, the increasing understanding of supersonic wave behavior brought into question the premise concerning a blast "shadow." It is known that supersonic pressure waves (or shocks) tend to reform after passing around obstacles. It is also known that such shock waves involve non-linear phenomena and cannot be directly compared to linear phenomena such as light waves and incompressible fluid flow. In addition to fundamental understanding of shock waves, various empirical data tend to indicate that barricades are not always effective shields against blast effects.

The questions concerning barricade effectiveness have been a matter of concern to the Armed Services Explosives Safety Board. DoD Manual 4145.27M specifies what are considered "safe" distances based on quantities of explosive and the exposure situation, with and without barricades. Questions concerning the effectiveness of barricades led the Board to undertake examination of the problem. As a portion of the Board's examination, a contract was issued to the Research Triangle Institute. The contract program consisted of two parts, an analysis by computer modeling and experimental field tests. The field tests were to serve as a validation test for the computer model. The program is nearing completion; some of preliminary results will be a part of this presentation.

B. Background Discussion on Barricades

DoD 4145.27M provides quantity-distance standards intended for safe separation of explosives and accidental "targets." Situations covered are intermagazine, intraline, inhabited buildings and passenger railroads or public highways exposed to accident effects. In the Manual, credit is given for effective barricades. This credit considers safe distance with a barricade to be approximately one-half of that without a barricade. Of special concern to the Board are situations involving property not controlled by the Federal government. Buildings and transportation facilities near government or contractor sites may fall into this category. It is important to determine if barricades actually reduce blast effects. For intraline situations, for example, safe distances are specified as being approximately $18W^{1/3}$ for unbarricaded situations and $9W^{1/3}$ for those with barricades present. The obvious implication is that the same pressures could be expected under both conditions. For an unbarricaded TNT charge at $18W^{1/3}$ the expected peak overpressure is approximately 3-1/2 psi. At a distance of $9W^{1/3}$ with a totally ineffective barricade, a peak overpressure of about 11-1/2 psi would be experienced. For inhabited buildings the specifications of $80W^{1/3}$ unbarricaded will result in a peak pressure of about 0.45 psi. With an ineffective barricade, a building at the specified distance of $40W^{1/3}$ could experience up to 1.2 psi. The differences in hazards for these examples are quite significant if barricades are ineffective.

The term "effective" as has been used means, of course, that the barricade actually does reduce peak pressures in the region of interest. As used in Manual 4145.27M, "effective" means a barricade having certain structural characteristics and no conditions specified in terms of reduced blast pressures.

If the answer to the basic question of whether barricades offer any protection is "yes," there is the question of where the protection occurs. Although Manual 4145.27M says the barricade shall be as near the source as possible, it still implies credit can be given for specified barricades located anywhere between source and target.

Research on supersonic aircraft and space vehicles has developed much information on supersonic flow and the interactions of aerodynamic shocks with bodies. Shock tube studies have likewise provided information on shock waves passing over obstacles. From results in these areas, it is known that shock waves tend in time to regain their original character after being disturbed by an obstacle. The obvious implication is that blast waves will tend to regain their properties after encountering a barricade. The two questions which arise are what is the extent and what is the magnitude of the region where the blast wave is disrupted to give reduced peak pressures.

RTI PROGRAM OBJECTIVES

OVERALL: DEVELOP A METHODOLOGY FOR DETERMINING THE EFFECTS OF BARRICADES ON BLAST WAVES. PURPOSE IS TO FIND MEANS OF DETERMINING IF BARRICADES ARE BENEFICIAL.

ANALYTICAL PROGRAM: DEVELOP TWO DIMENSIONAL COMPUTER MODELS OF BLAST BEHAVIOR WHICH CAN PREDICT INFLUENCE OF BARRICADES.

EXPERIMENTAL PROGRAM: TO PROVIDE REFERENCE POINTS FOR ANALYTICAL WORK AND A CHECK AGAINST PREDICTIONS OF COMPUTER MODEL.

FIG. I-1

REPRESENTATION OF GENERALIZED
2-DIMENSIONAL COMPUTER MODEL
COMPUTATION FIELD

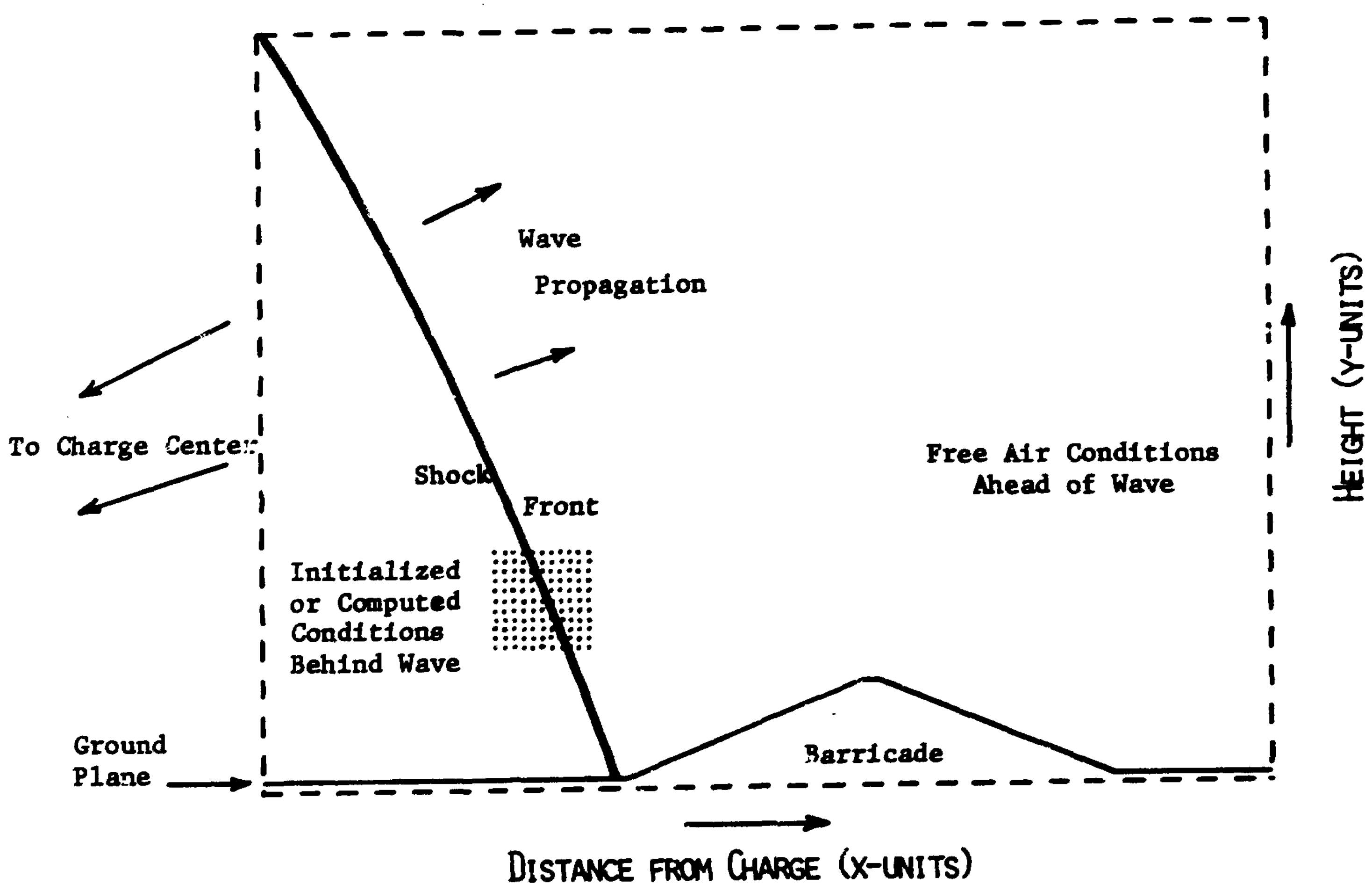


FIG. I-2

In addition to sources just mentioned, evidence has come from direct explosives experiments indicating that barricades do not give blast protection in all regions of line-of-sight shielding. A number of test shots have been made where barricades were present. The results have been variable. Generally the indications have been that barricades offered little protection. In some cases a "crossover" effect was reported with both reduction and enhancement of pressure depending on the distance from the charge or barricade.

C. RTI Program

In order to resolve some of the uncertainties regarding barricade effects, the Research Triangle Institute undertook a two-part program. One effort is the computer modeling of blast-barricade interactions. The other effort is a program of field experiments. The two efforts are to provide checks against each other.

Analytical Program

The objective of the computer modeling work is to provide an analytical description of the effects of a barricade on a blast wave. The computer modeling technique utilizes a two dimensional grid. The model is shown schematically in Fig. I-2. Calculations are done to follow a shock in a vertical plane aligned through the center of the charge and center of the barricade. The vertical plane is considered as an array of coordinate points. This array, or calculational field, is initialized by putting in values of pressure, density and velocity components at the proper points in order to describe a shock wave at an initial time and position. The values of the shock parameters may be computer using the von Neumann strong shock method with charge weight and distance as input. Alternatively, previously determined values of shock parameters may be read-in to start up the program. The method used depends on the case being treated as regards the use of the program and barricade location relative to the charge.

The computations describing the propagation of the shock use the differential equations describing conservation of mass, momentum and energy. The equations are used in finite difference form. The differencing techniques used for time and position coordinates cause the wave to propagate in the computational field as the calculations are done repeatedly. The calculations treat air as an ideal gas.

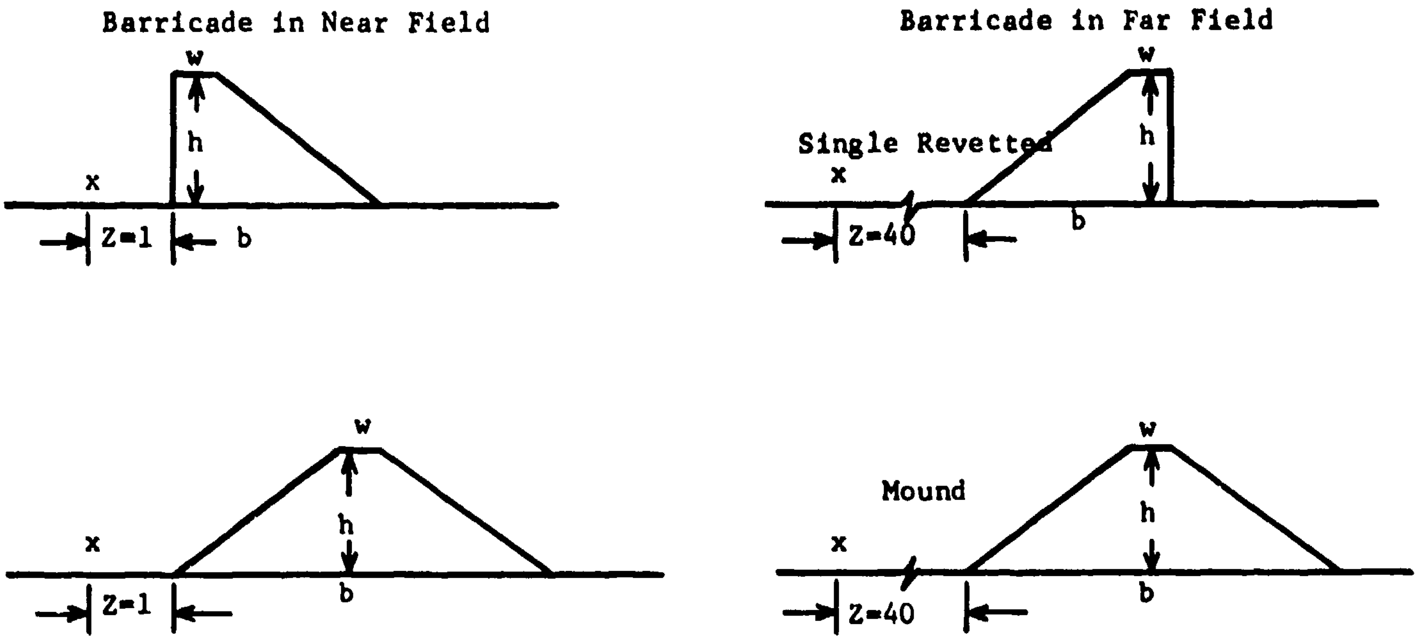
The computer blast wave model is designed to be run on a large computer, such as the IBM 360/75. To economize on large computer time, data processing programs for producing pressure histories at points, pressure versus distance on horizontal lines, and peak pressure and time of occurrance at any point, have been developed for operation on small computers. These data processing programs may be run on small computers against output data tapes of the model calculations on the large computer.

In difference equation calculations such as are employed in the analytical simulation of a supersonic blast wave, the control of boundaries is usually a major problem. In the computer model described, air-solid interfaces, such as at the ground and barricade surfaces, are handled satisfactorily by a reflection technique. The treatment of free air boundaries where the calculation field simply stops is much more difficult. The most straightforward method of treating these boundaries is to place them far enough away so that they have no influence on regions of interest. The difficulty with this method is that it puts many extra computation points into the computer. With large problems such as the blast model, other techniques may be needed. Methods used in the blast model result in reducing the disturbances introduced by the field boundaries. If boundary disturbances are minimized, propagation of the disturbances back to regions of interest is delayed.

It was realized from the outset that the modeling of a barricade very close to an explosion would be very difficult. The very high pressure and velocity gradients near the charge present difficulties in maintaining stability in the repetitive difference equations.

With computer problems as complex as the blast-barricade analysis, the computer programs often must be developed in an evolutionary fashion. This permits location of errors as they may develop in the program. As the complexity and the number of programming shortcuts increase, it becomes more difficult to find errors in the computer program.

Because of the problems just discussed, the analytical work was begun with the case of a barricade and target in the far field where the shock front approximates a plane wave. This situation enables the use of distances between points in the computational field which give reasonable running times and satisfactory stability for the computations.



Barricade in Near Field

Barricade in Far Field

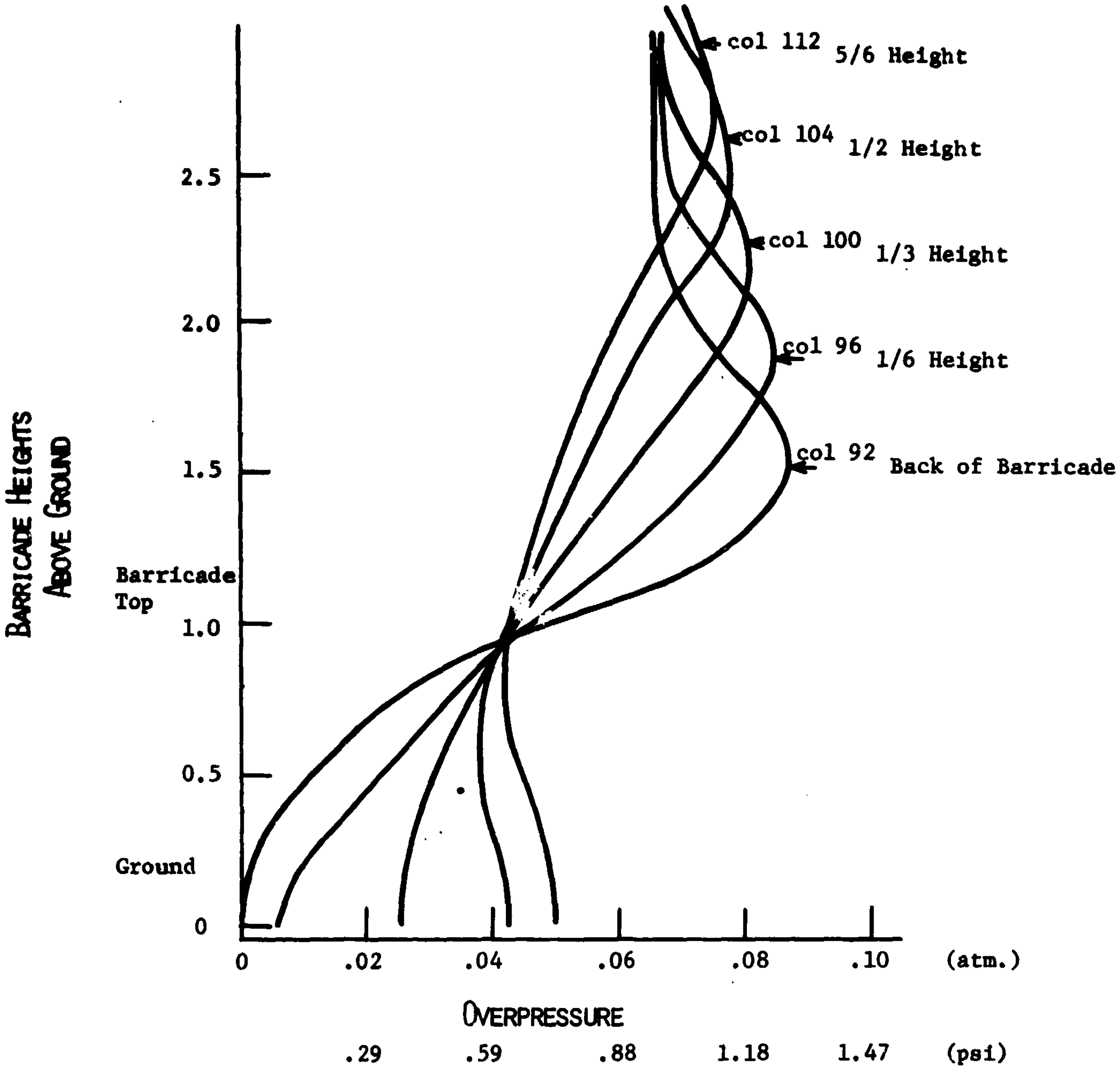
(x = charge center)

BARRICADE CASES STUDIED

FIG. I-3

SINGLE REVETTED BARRICADE
TOE AT Z=40 (REVETTED TOWARD TARGET).

PRESSURE VS. HEIGHT



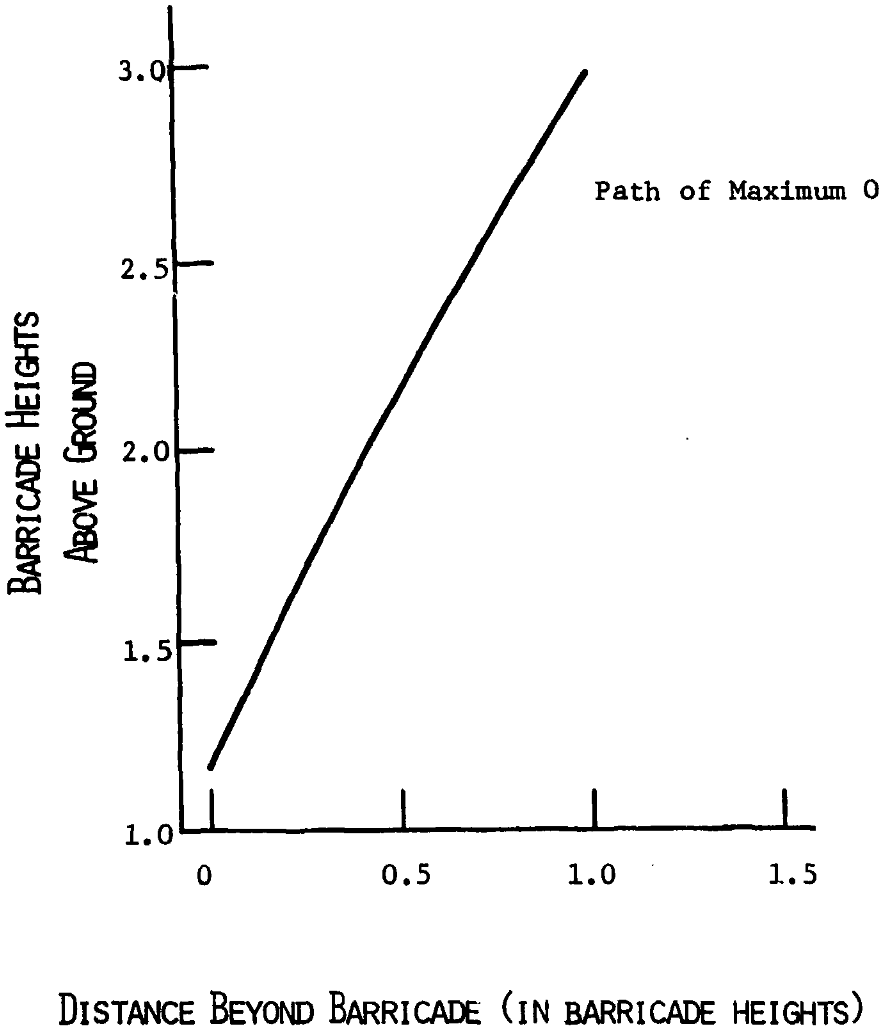
STATIC PRESSURE PROFILES OF TIMES WHEN OVERPRESSURE IS A MAXIMUM (COMPUTED)

FIG. I-4

The distances between points in the computation field are selected to give the best compromise between stability and running time for the program. The size of these distance difference steps may be estimated, but final selection is based on trial runs.

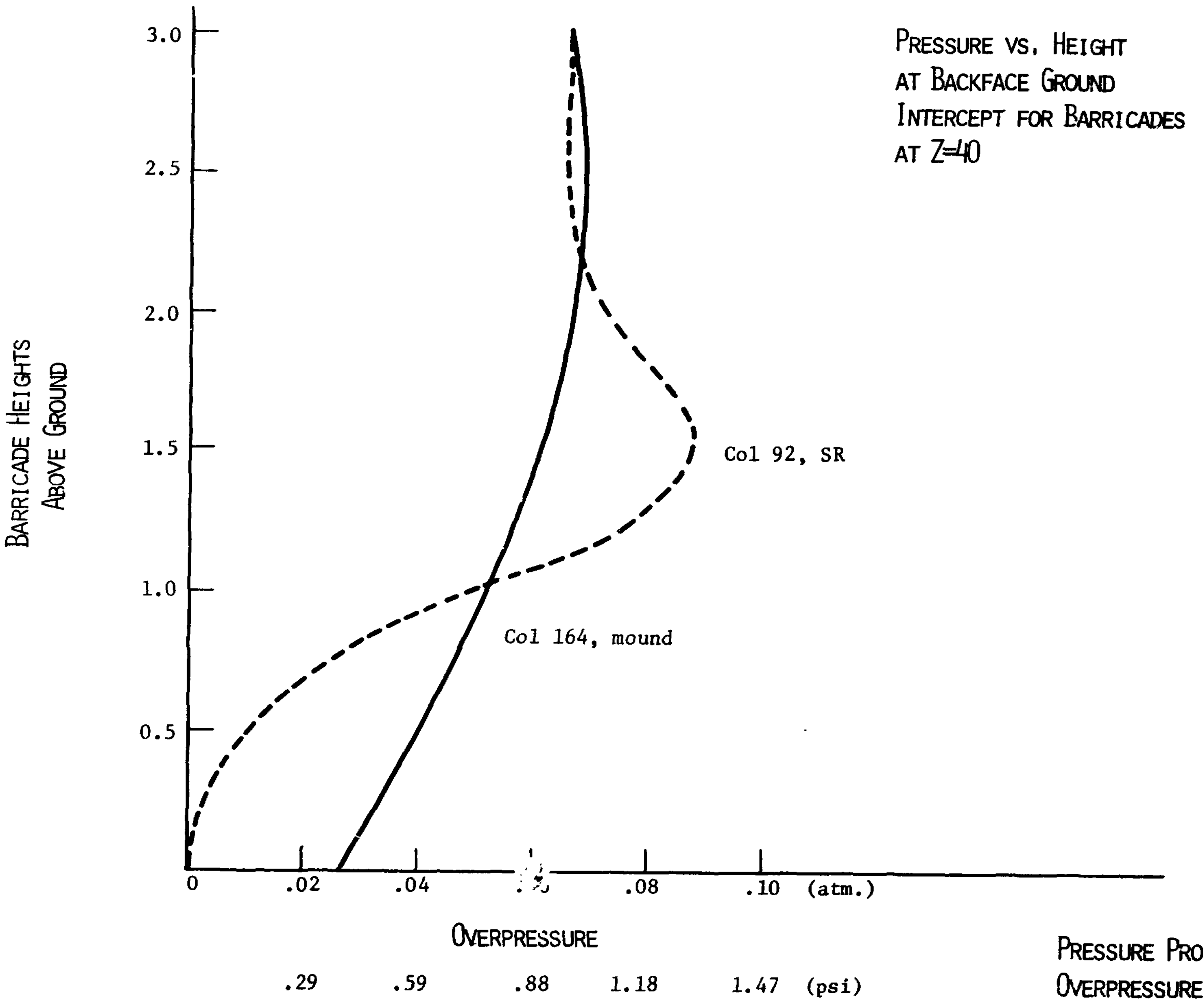
For purposes of both the analytical and experimental program it was decided to examine two limiting cases as shown in Fig. I-3. In one case the barricade is situated with its nearest point at a scaled distance of Z=1 ft/lb$^{1/3}$ from the charge. For the other case the barricade has its nearest point at Z=40 ft/lbs$^{1/3}$. Both single revetted and mound barricades are being considered in each case. The accompanying figure illustrates the placement of the barricades. The sloping faces of the barricades have rises of 1:2.0 to 1:2.5.

The plane wave calculations have given several interesting results. The accompanying Fig. I-4 shows pressure versus height above ground at several distances beyond barricade. The barricade is located at Z=40 ft/lbs$^{1/3}$, singly revetted away from the charge. In this and the other computer results shown here, the shock front is beyond the barricade, but flow of the pulse over the barricade is not completed. Note that this figure does not show shock profiles but rather vertical pressure distribution at the time the highest pressure seen on a vertical line occurs. Maximum pressure on the column 92 at the back of the barricade occurs somewhat higher than the top of the barricade. At this time the pressure at ground level has not yet begun to rise. By the time maximum pressure reaches column 96, the pressure at ground level is also rising at column 96. Notice that as these trends continue, the shock is regaining plane wave character. Another interesting feature here is the "pivot" point where pressures change very slowly along a horizontal line just below the top of the barricade.



Propagation of Maximum Pressure Point on Shock after Passing over Single Revetted Barricade at Z = 40

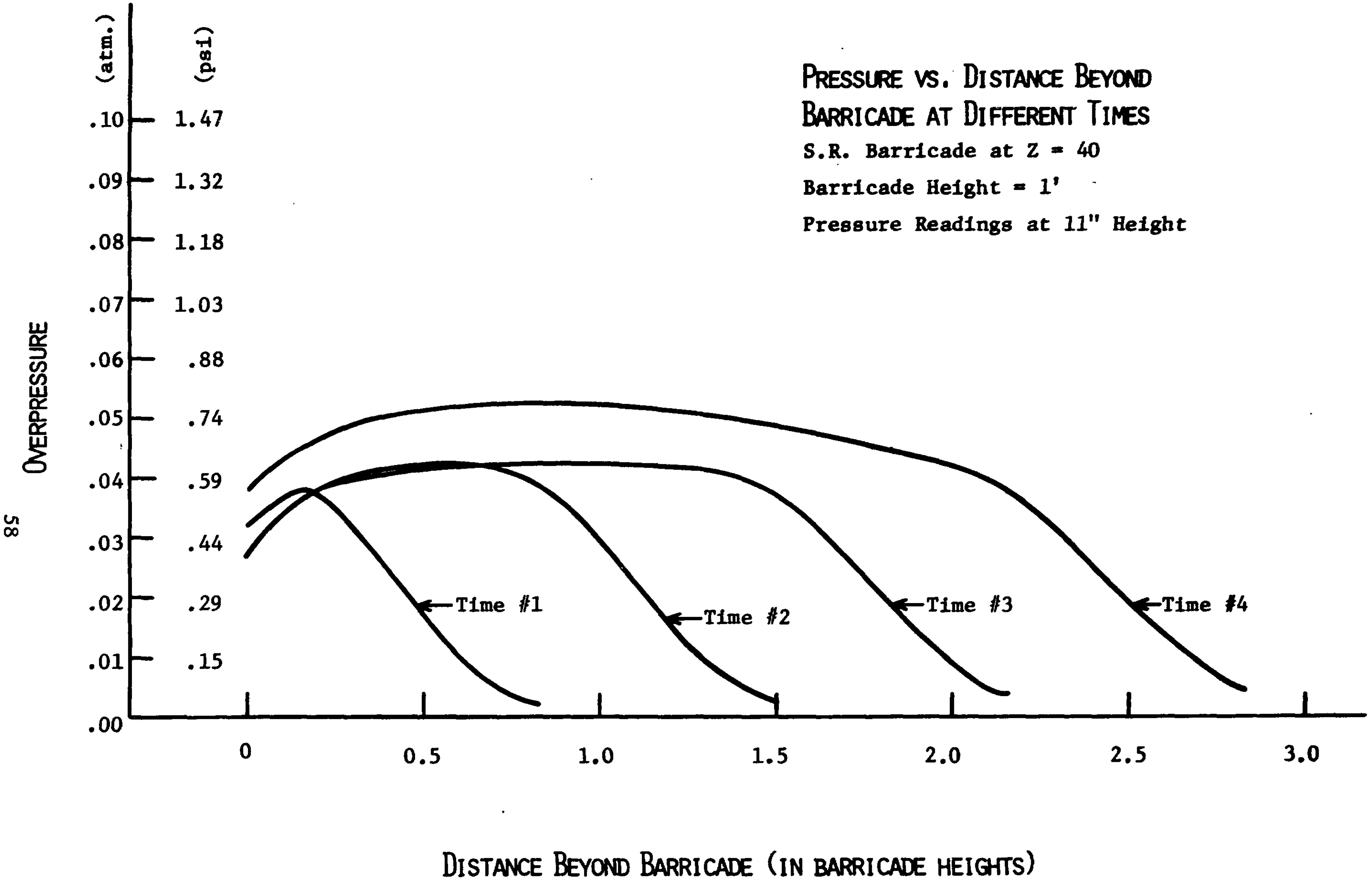
Fig. I-5



Pressure vs. Height
at Backface Ground
Intercept for Barricades
at Z=40

Pressure Profiles when Maximum
Overpressure Occurs at any Point
on Column

Fig. I-6



PRESSURE VS. DISTANCE BEYOND BARRICADE AT DIFFERENT TIMES

S.R. Barricade at Z = 40

Barricade Height = 1'

Pressure Readings at 11" Height

FIG. I-7

PRESSURE VS. CYCLE NO. (TIME) AT A POINT 11" HIGH AND 1" BEYOND THE BACK TOP CORNER OF THE BARRICADE

Far Field, SR, 1 ft. High

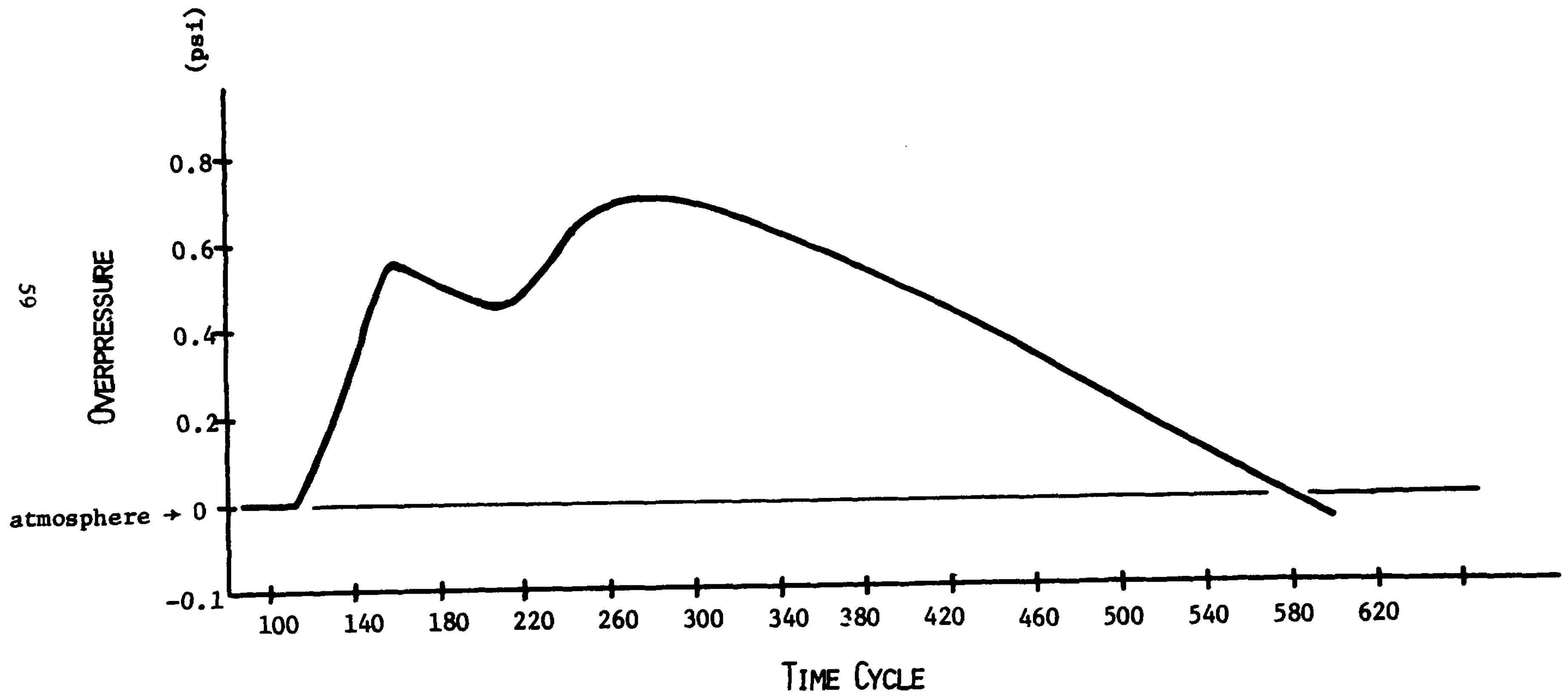


FIG. 1-8

The next illustration, Fig. I-5, shows the path of the points of maximum pressure from the previous graph. This line of maximum pressure points moves upward with distance beyond the barricade.

The next illustration, Fig. I-6, compares vertical pressure distributions at the time maximum pressure occurs on a column at the back face-ground intercept of a mound and a single revetted barricade located at Z=40. Note that the pressure distribution with the mound is already smoothing out. It must be remembered that the back toe of the mound is further downfield than the back corner of the top or the back of the single revetted barricade.

The next illustration, Fig. I-7, shows pressure versus distance beyond the barricade at four different times. The barricade is again singly revetted away from the charge and located at Z=40. The curves are for points eleven inches above the ground behind a one-foot barricade.

It has observed that pressures just behind the barricade drop slightly from those seen as the shock initially passes, as may be noted from the Fig. I-8. They then rise slowly again beyond the pressures produced by the original shock proceeding down the back of the barricade. This indicates a double pressure peak, with the second less sharp than the first, occurring before the first peak has decayed appreciably. A pressure history plot for the same point has been run to combine the observation as shown in the next figure.

Further analysis of the data presented here is required before final conclusions are published. The information presented here and in the experimental section is for discussion purposes at this time.

It was originally hoped that a generalized model could be developed that could handle both near and far field problems. It does not appear practical to begin calculations in the near field and carry them continuously out to the far field because of the amount of computer time required. A more practical approach is to begin at selected condition and calculate only through the regions of most interest. A generalized model has been developed for both near and far field conditions, but to date boundary treatments have required excessively large computation fields for near field computer runs.

Results from the far field computations are still being analyzed and compared with experimental results. Agreement has thus far been found in predicted trends.

LIST OF FIGURES

Part II

II. EXPERIMENTAL WORK

A. Introduction

In order to properly interpret the experimental results which are presented below, the following points are made:

1) The experimental program was completed two weeks prior to this presentation. Therefore, the data reported in this report is preliminary and must be considered subject to correction and interpretation.
2) The main purpose of the experiments was not to attempt to answer the questions of how efficient barricades are in reducing damage, or which barricade geometry is better than another, but to provide data for comparison with the analytical model generated by RTI.
3) Although the results presented here are relationships of peak overpressure versus scaled distance, other blast parameters such as impulse, time of arrival, and overpressure duration have been measured and are available for the discussions at the specialists session meeting.

A total of 105 scaled experiments were conducted with the objective of measuring air blast parameters from barricaded and unbarricaded high explosive charges. The results were compared with the RTI analytical calculations.

The experimental program was designed by applying the conventional cube root scaling laws to the following full-scale conditions:

1) Explosive limits--8,000 and 64,000 lbs. of TNT.
2) Barricade shapes--single revetted and mound.
3) Barricade dimensions--10 ft and 20 ft high; slope 2.5:1.
4) Location of barricade relative to explosive charge--scaled distance ($Z = R/W^{1/3}$) and 1 and 40.

The scale models generated from the above conditions were as follows:

1) Explosive--pentolite spheres.
2) Explosive weights--1 and 64 lbs.

3) Barricade shapes--single revetted and mound.

4) Barricade dimensions--6", 12" and 24" high; slope 2.5:1.

5) Location of barricades relative to explosive charge--scaled distance ($Z = R/W^{1/3}$) = 1 and 40.

6) Height of the explosive charge above the ground--4" to the center of the one lb charge and 16" to the center of the 64-lb charge.

The relationship of scaling equivalents between explosive weights and barricade dimensions is shown in Table I. The barricade shapes are illustrated in Figure II-1.

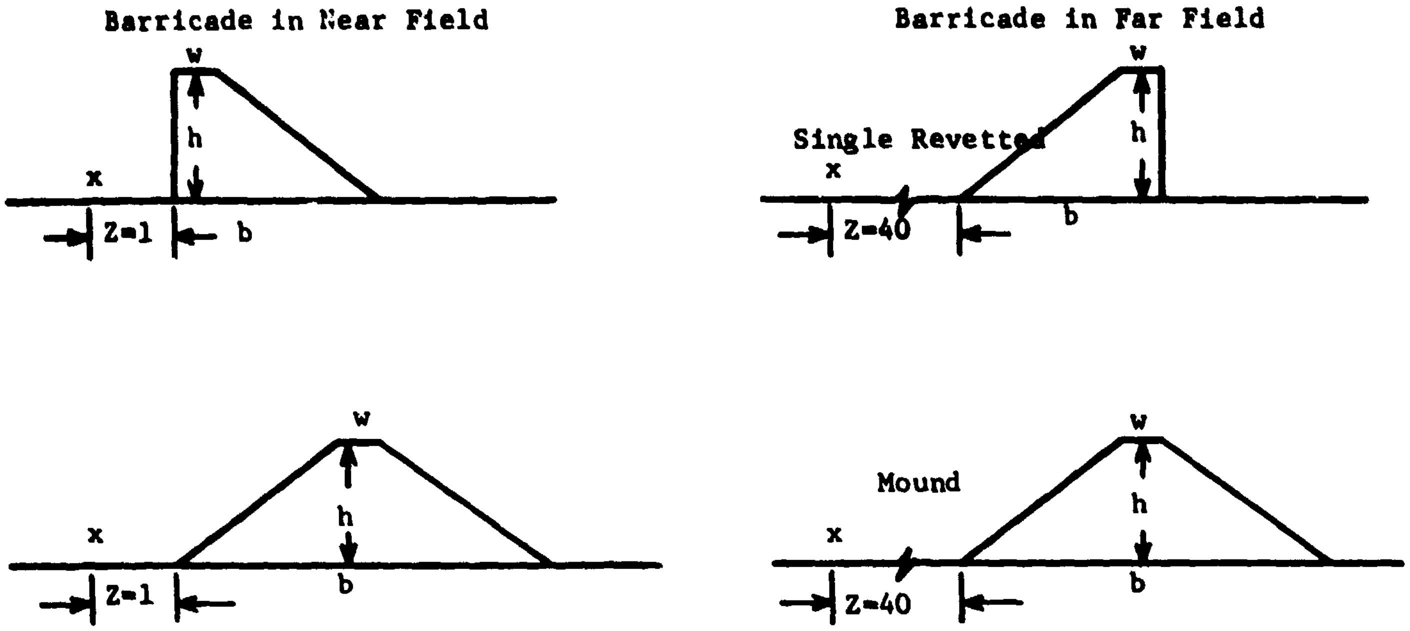
Table I

RELATIONSHIP OF SCALED EQUIVALENCY

Model Scale		Full Scale	
Explosive Weight (lb)	Barricade Height (in.)	Explosive Weight (lb)	Barricade Height (ft)
1	6	64,000	20
64	24	64,000	20
1	12	8,000	20
1	6	8,000	10
64	12	64,000	10

B. Experimental Set-up

Figure II-2 shows a plan view of the field tests illustrating the general geometry employed in the experimental program. The figure shown has the barricade located in the near field at a scaled distance from the charge of unity. Blast parameters reported here were measured with Atlantic Research LC-33 pressure transducers. The transducers were located about the perpendicular to the barricade in such a manner as to minimize flow interference between successive gage stations. Two transducers were used at each location and their outputs were recorded with a channel tape recorder with a maximum frequency response of 20 KHz. In the far field configuration, the barricade



Barricade in Near Field

Barricade in Far Field

Single Revetted

Mound

(x = charge center)

Figure II-1. Barricade Cases Studied.

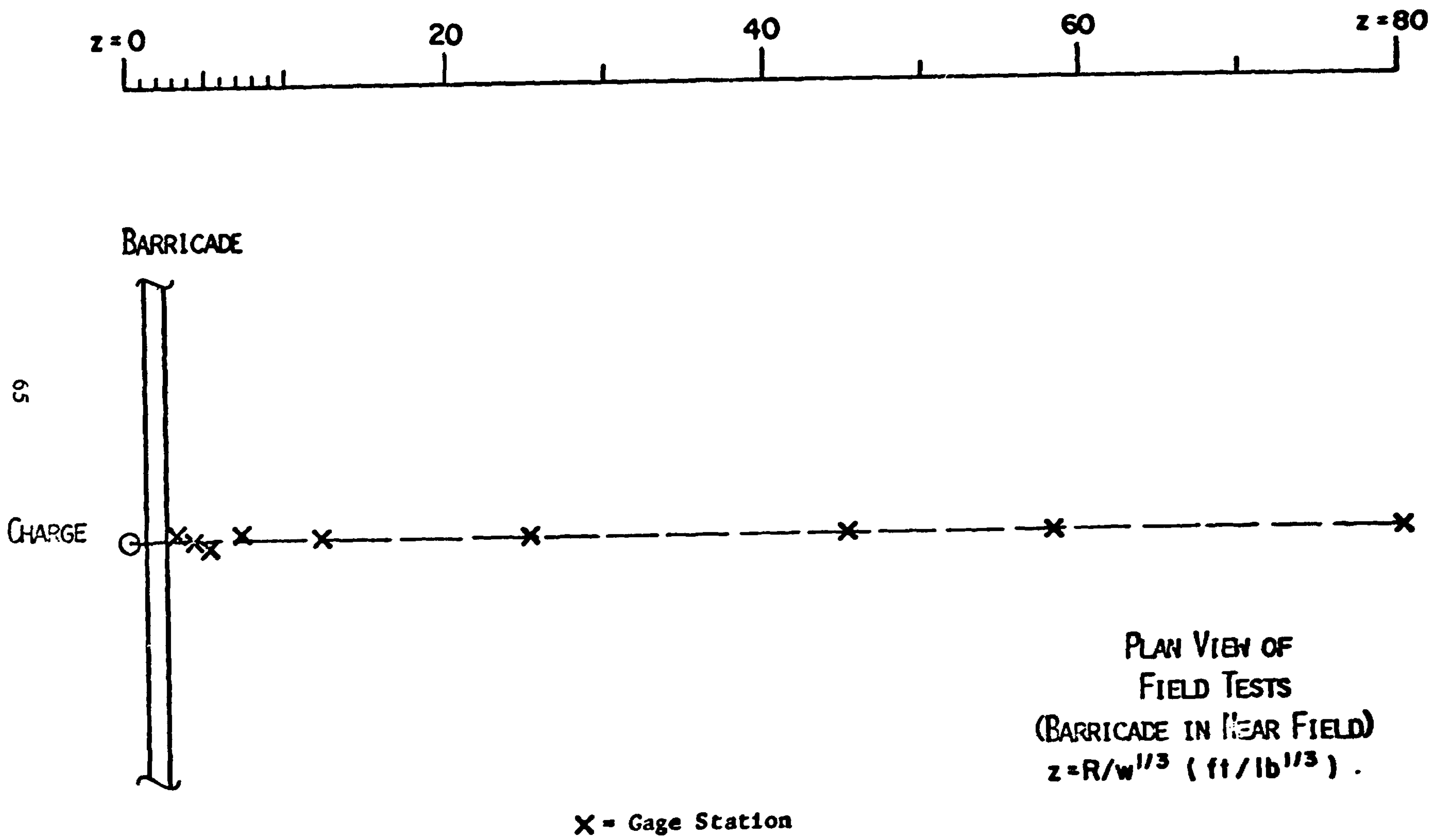


Figure II-2. Plan View of Blast Field.

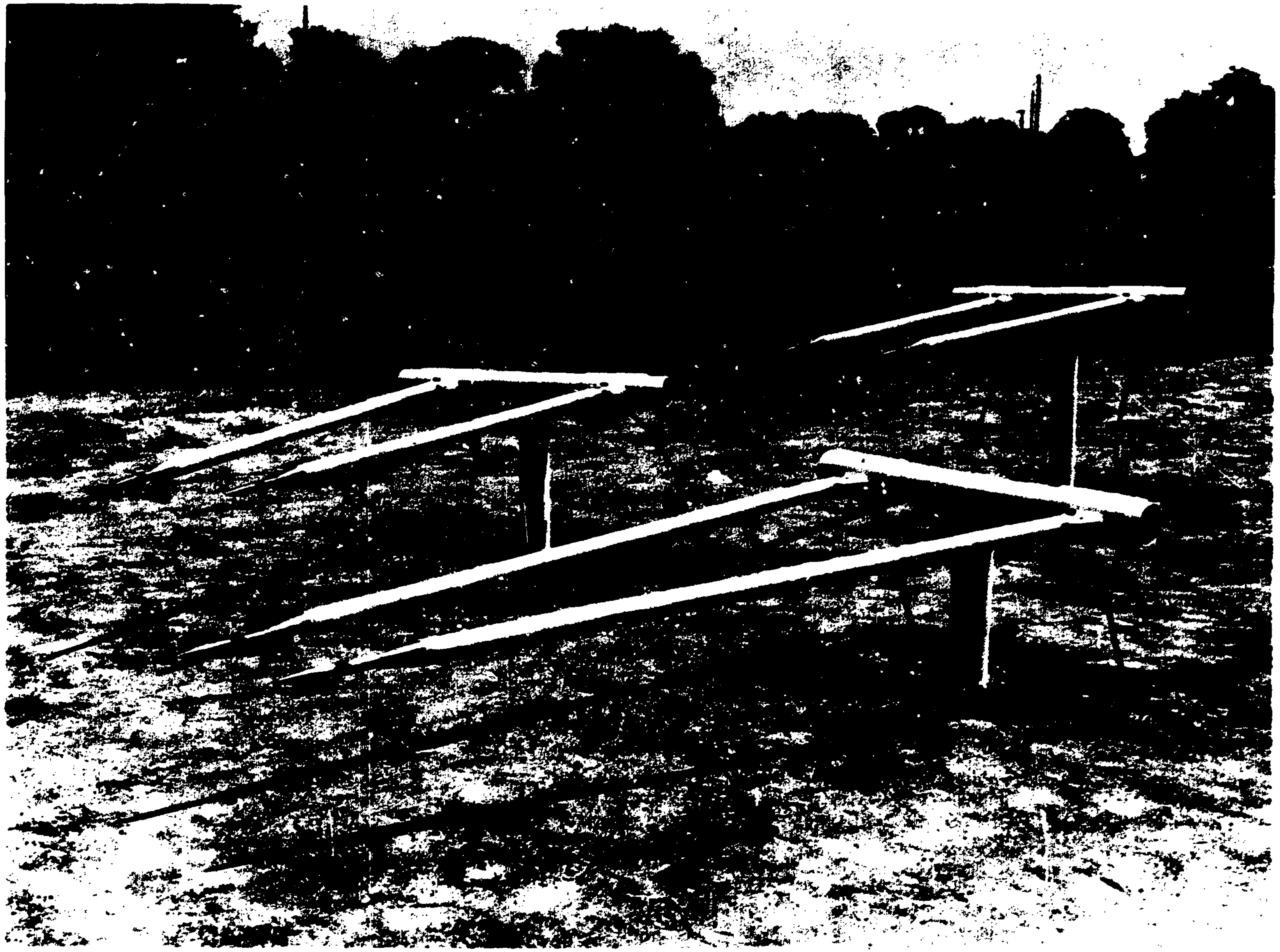


FIGURE II-3. TYPICAL GAGE MOUNTS

FIGURE II-4. SET-UP OF SITE FOR NEAR FIELD SINGLE REVETTED BARRICADE 64 LB CASE

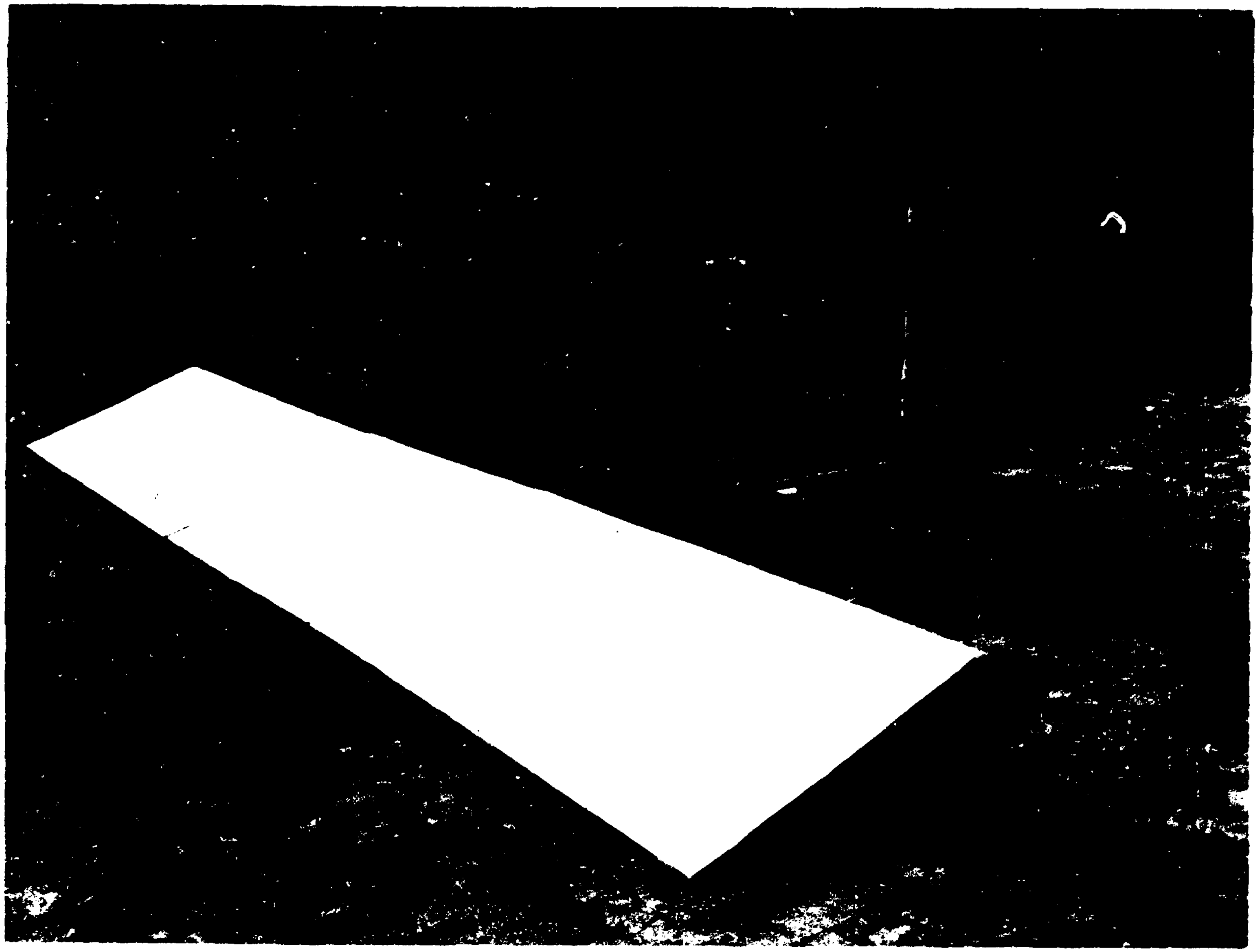
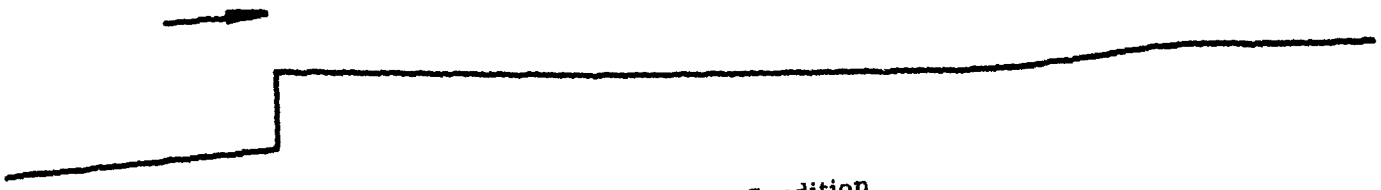
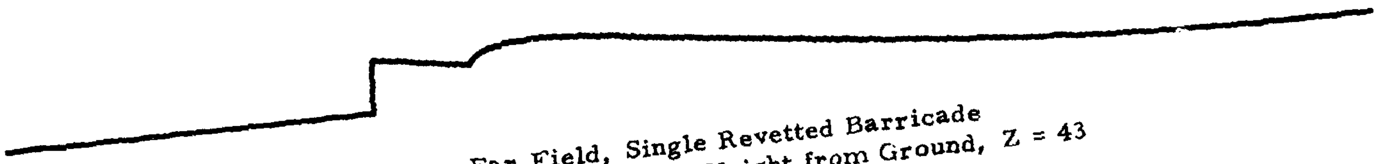


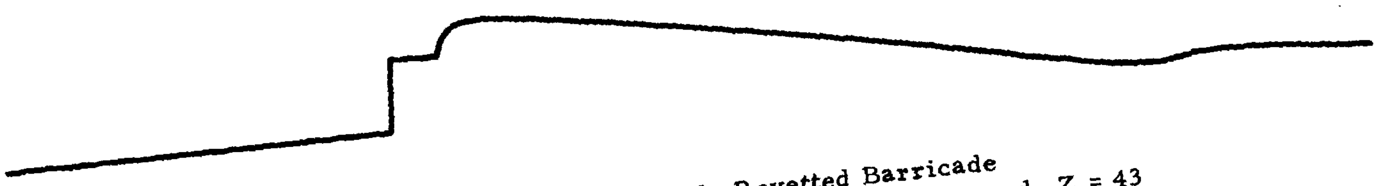
FIGURE II-5. SET-UP OF GAGES WITHIN TWO BARRICADE
HEIGHTS OF SINGLE REVETTED BARRICADE
FAR FIELD CASE



Free Field Condition



Far Field, Single Revetted Barricade
Sensor at One Barricade Height from Ground, Z = 43



Far Field, Single Revetted Barricade
Sensor at One-Sixth Barricade Height from Ground, Z = 43

Figure II-6. Typical Pressure-Time History was located at a scaled distance of Z = 40, and the transducers were distributed behind the barricades in a manner similar to that shown in the near field illustration. The location of the gages relative to the explosive charge and their scaled heights from the ground are given in Table II, and typical illustrations of gage mounts and location of stations relative to the barricades are shown in Figures II-3 through II-5.

For the near gage locations, the heights of the detectors increase with distance from the barricade. In every case the scaled heights ($H = \frac{h}{W^{1/3}}$, ft/lb$^{1/3}$) were preserved for experiments with different charge sizes. The increase in height with scaled distance was designed to minimize any ground interference effects.

Typical pressure-time history traces are shown in Figure II-6. The upper trace shows a typical pressure-time history for an unbarricaded condition, illustrating the well-known sharp rise time and exponential decay of the shock wave. The middle trace illustrates the pressure-time history obtained from a gage located behind a single revetted barricade in the far field condition at a scaled distance of Z = 43 and a one barricade height from the ground. The initial rise represents the arrival of the incident wave. The source of the secondary hump following the initial rise may represent the arrival of the reflected wave generated as the shock wave passed over the barricade. The lower trace represents the typical pressure-time history of a gage located in the same place as the above trace, but at 1/6 barricade height from the ground. In this particular case the pressure associated with the secondary peak was actually greater than that of the initial peak. This effect was also observed by the analytical calculations presented earlier by RTI. The peak pressures reported in subsequent figures were obtained by measuring the maximum pressure output recorded by the individual gages.

C. Experimental Results

To verify the scaling law, unbarricaded (free field) experiments were performed comparing nominal charge weights of 1 and 64 lbs. The

Table II

LOCATION OF GAGES

Location From HE $Z = R/W^{1/3}(ft/lb^{1/3})$	Height of Gage $h/W^{1/3}(ft/lb^{1/3})$
Free Field	
5	0.75
7	1.00
12	1.50
25	2.00
45	3.00
58	3.00
80	3.00
Near Field	
3	0.5*
4	.017*
5	0.75
7	1.00
12	1.50
25	2.00
45	3.00
45	0.75**
58	3.00
80	3.00
Far Field	
12	1.50
25	2.00
43	0.17
43	0.50
43	1.00
43	3.00
45	3.00*
58	2.00***
58	3.00
80	3.00

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* Stations Located Only in the 64 lb Case

** Used in 64 lb Mound Case Only

*** 1 lb Case Only

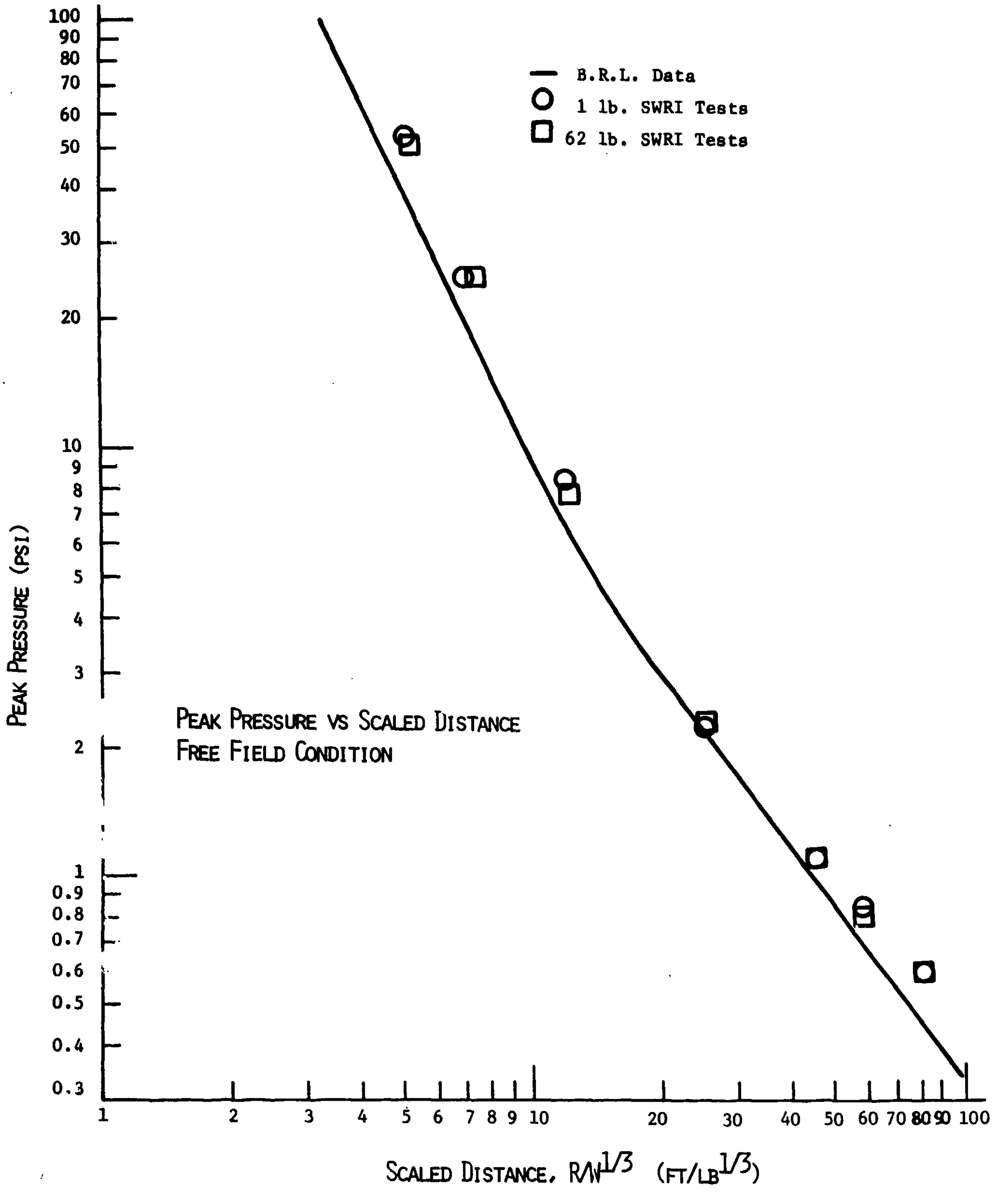

Figure II-7. Peak Pressure vs. Scaled Distance For Free Field Condition.

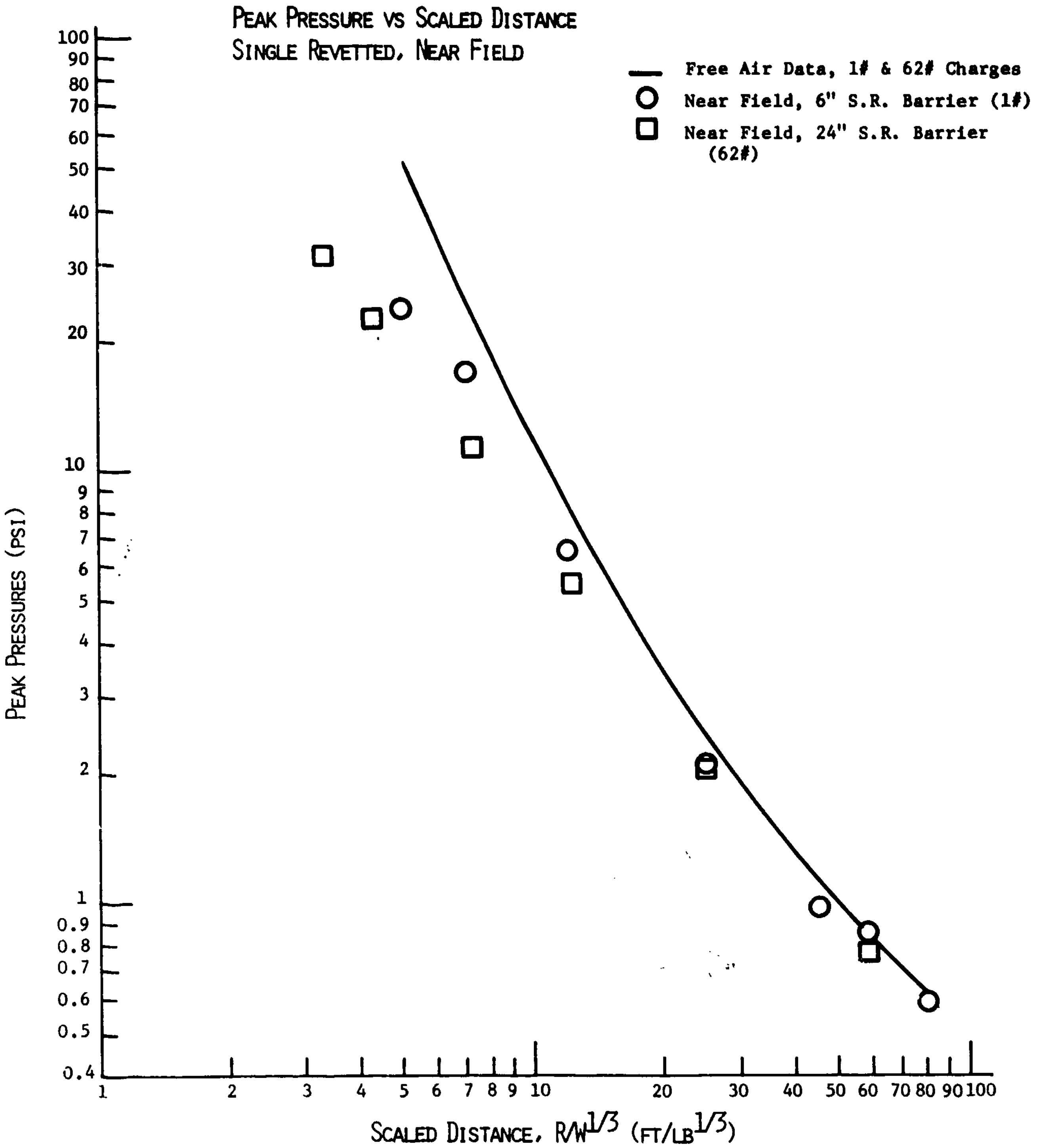

Figure II-8. Peak Pressure vs. Scaled Distance
Single Revetted, Near Field.

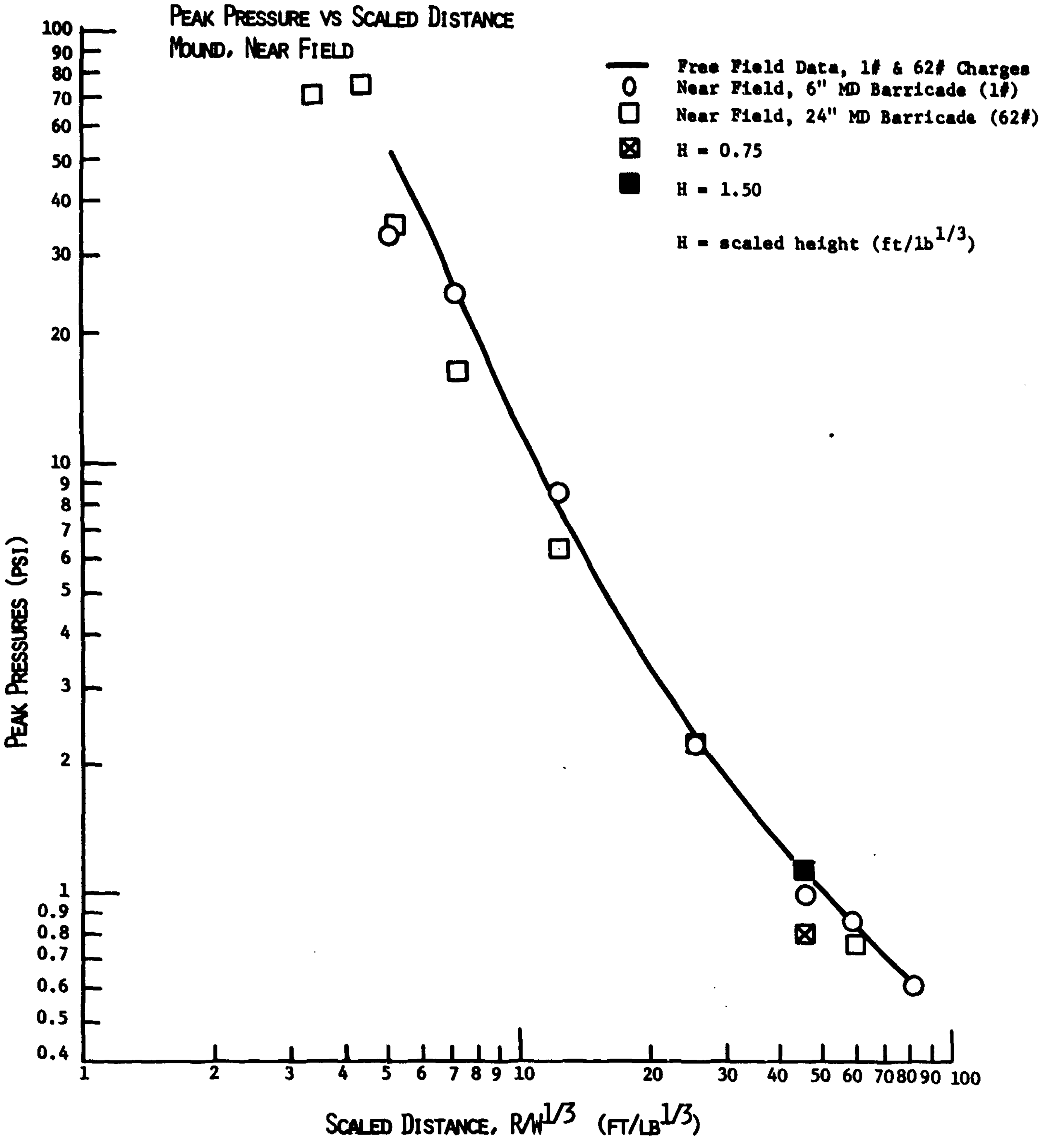

Figure II-9. Peak Pressure vs. Scaled Distance Mound, Near Field.

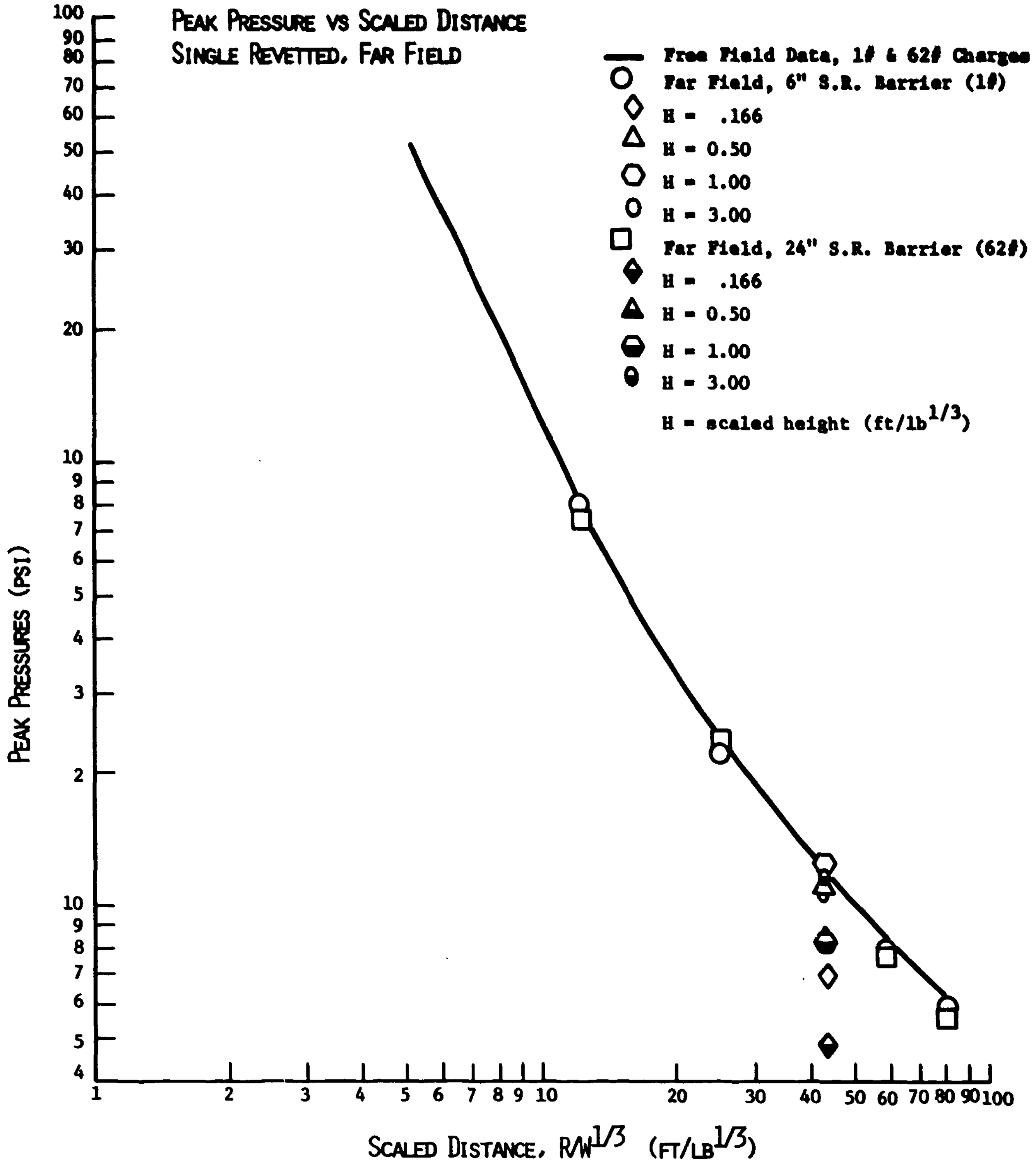

Figure II-10. Peak Pressure vs. Scaled Distance
Single Revetted, Far Field.

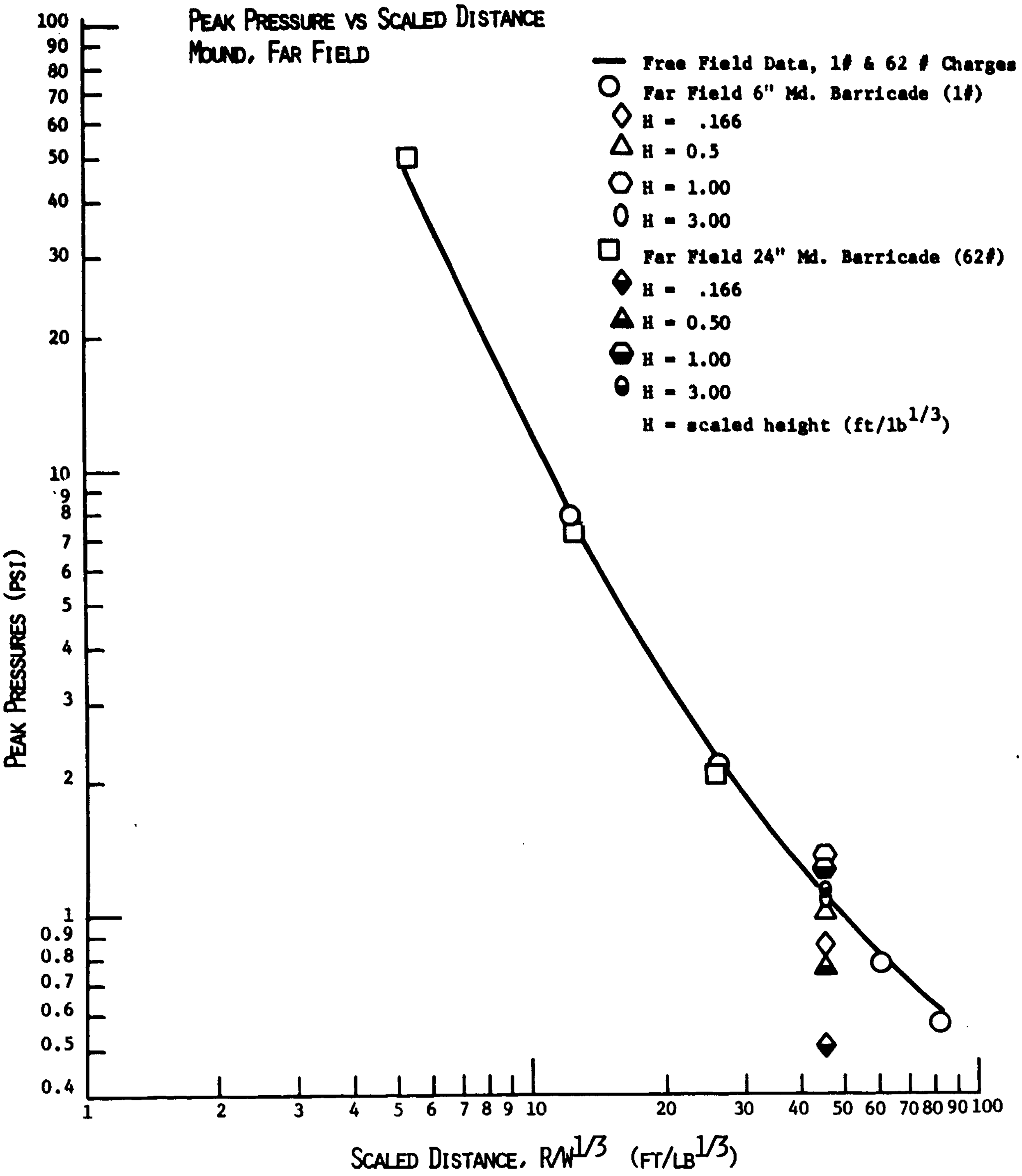

Figure II-11. Peak Pressure vs. Scaled Distance
Mound, Far Field.

results of these experiments are compared with BRL* data in Figure II-7 showing peak pressure versus scaled distance for the unbarricaded condition. It is observed that the current experimental data falls somewhat above that of the BRL, but it is in general agreement and does confirm the scaling law for this configuration.

The following confirmation of the scaling laws for the experimental program for barricade configurations (single revetted and mound) were run in the near field and in the far field geometries. The results obtained in these geometries are shown in Figures II-8 through II-11 giving data for peak pressures versus scaled distance for barricades located in the near and far field. In order to properly evaluate the data presented in these figures, special attention should be paid to the location of the gages relative to the barricade and the location of the gage relative to the ground. In the case of the single revetted near field, significant pressure reductions were observed up to about 5 barricade heights behind the toe of the barricade. Beyond the 5 barricade heights, the pressure tends to rapidly approach the unbarricaded condition. In the base of the mound barricade located in the near field, the following observations are made:

1) An increase in pressure is observed at a scaled height of H = 0.166 from the ground at a location Z = 4 as compared with the pressure observed at a scaled height of H = 0.5 at Z = 3.
2) Note the variation in peak pressure for the two gages located at Z = 45 at scaled heights of H = 0.75 and H = 1.50, respectively.
3) The effect of decrease in peak pressure by the mound barricade is not as great as that shown by the single revetted barricade. In the case of the single revetted and mound barricades in the far field condition, the pressure as a function of gage height was measured at a scaled distance of Z = 43. The results of

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* Goodman, H. J. "Compiled Free-Air Blast Data on Bare Spherical Pentolite," BRL Report No. 1092, Aberdeen Proving Ground, Maryland, February 1960.

measurements indicate that there is a considerable decrease in peak pressure within two barricade heights behind the toe of the barricade, and furthermore, that the pressure varies as a function of the height of the gage from the ground. It must be noted that there is evidence in the experiments that the peak pressure and impulse vary with gage height at each of the scaled distances and at the present time we cannot determine the pressure gradient as a function of height, especially immediately behind the barricades.

D. Experimental Observations

1) Barricades did reduce substantially the peak pressures and impulses immediately behind the barricades.
2) Single revetted barricades are more efficient in reducing peak pressure and impulse than mound barricades.
3) The values of peak pressure, impulse and time of arrival are greatly influenced by the gage height relative to the ground, the location of the barricade and the barricade dimensions and configurations.
4) In the case of the near field single revetted barricade, a significant reduction in pressure and impulse was observed out to a minimum of 5 barricade heights behind the toe of the barricade, and up to one barricade height above the ground. However, the exact pressure-time history as a function of height cannot be determined from these experiments.

Résumé of discussion of presentation "Influence of a Barricade Upon Blast Wave Parameters" during Specialist Sessions of 11th Annual ASESB Seminar.

The majority of the discussion concerned the experimental work done under the program. Questions were raised concerning whether side-on pressure gages gave true readings near barricades where the flow patterns are not known. This question was not resolved.

Several representatives of the Armed Services gave instances in their experience both supporting and negating the effectiveness of barricades.

It was pointed out that although the analytical model is called a 2-dimensional model, it should also truly represent an axi-symmetric 3-dimensional case (i.e., a ring barricade with charge at the center).

Discussions also concerned whether gently rounded natural hills could be counted as barricades. It was pointed out that this case had not been studied, but that indications were that a rounded, more streamlined body would have less effect on the blast wave than a body with steep faces and sharp corners.

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FRAGMENT HAZARD STUDY

Edward B. Ahlers
IIT Research Institute

ABSTRACT

A mathematical model for estimating fragment risks of various ground ranges and orientations has been formulated and programmed for electronic data processing. The model uses experimental data on initial fragment fields and target vulnerability data as inputs. Fragment trajectories are solved by numerical methods from the equations of motion, providing terminal positions and ballistic properties computed. A subroutine prints out fragment density contours for the munition and contours of equal probability of damage for the munition/ target combination. In its present form the model is limited to consideration of the single round without environmental protection.

A limited parametric study of fragment terminal properties shows that large fragments can travel considerable distances and fall in low density fields. Though few in number, their terminal properties are at injury and damage-producing levels. Light fragments which are produced in large numbers travel much shorter distances and fall in higher density fields at terminal velocities which are significant primarily as personnel injury agents.

FRAGMENT HAZARD STUDY

Edward B. Ahlers
IIT Research Institute

INTRODUCTION

The Fragmentation Hazard Study initiated in April 1969 is aimed at applying engineering analysis, supplementary experimental efforts, and currently available data on fragmentation and damage criteria to the problem of estimating fragment hazards at explosive manufacturing and storage sites. It was originally conceived as a five-phase program with a total duration of about two years. This presentation reviews the overall program content and the results of the first four months of investigation.

OBJECTIVES

Primary objectives of the Fragment Hazard Study are:

I. To develop a methodology for estimating the risks of injury and damage from fragments on a probability basis, considering

- a wide range of human, mechanical and structural targets,
- all ground ranges and orientations from the store,
- simultaneous and repetitive detonations,
- various munition types and quantities, and
- open stores and protective environments.

II. To apply the developed methodology to determine levels of risk for a series of actual sites.

III. To conduct analytical and experimental studies required to fill gaps in current knowledge in support of the development of methodology.

MOTIVATION FOR THE STUDY

Initiation of this study was motivated by the recognition that current quantity-distance standards provide unequal fragment safety levels at various distances and that methods were needed for realistically assessing fragment hazards. It is seen, for example, that current quantity-distance standards are based on:

- $W^{1/3}$ scaling for Class 7 materials, and
- Quantity-independence for Class 3, 4, 5, 6 materials.

There is no reason to feel confident that fragment hazards would scale as the cube-root of quantity. Neither are fragment hazards expected to be quantity-independent.

Fragment risk levels are a function of:

- Case fragmentation patterns,
- Fragment initial velocities,
- Intra-round shielding within the store,
- Airblast induced acceleration,
- Fragment interaction during flight, and
- Injury or damage criteria for vulnerable targets.

Case fragmentation patterns and initial fragment velocities are a characteristic of the individual munition. Airblast effects are a characteristic of the individual munition which may have a cumulative effect in a store, depending on firing sequence. Intra-round shielding and fragment interaction are affected by munition characteristics, configuration of the store and firing sequence in the store. Injury and damage criteria are generally some function of fragment mass, terminal velocity, and impact angle. There is little likelihood that the net effect of these factors would either scale as $W^{1/3}$ or be quantity-independent. Means for estimating fragment hazards based on the physical phenomena of fragment generation, fragment flight and target response were recognized to be needed.

PROBLEM APPROACH

The Fragment Hazard Study is outlined as a five-phase effort as follows:

Phase I:	Establishment of Damage Levels and Damage Criteria for Targets of Interest
Phase II:	Determination of Target Vulnerability from Detonation of Single Munitions in Open Stores
Phase III:	Determination of Target Vulnerability from Detonation of Multiple Munitions in Open Stores
Phase IV:	Modeling Fragment Mass, Velocity and Spatial Distribution for Enclosures Containing Large Munitions Stores
Phase V:	Determination of Fragment Risk Levels at Explosive Sites

Implementation of this program involves application of engineering procedures to develop a logical scheme for estimating fragment hazards, including:

- analytical procedures, such as trajectory analysis to determine terminal positions and terminal ballistic properties of fragments,
- fragmentation test results for munitions, defining the initial spatial field of fragment masses and velocities, and
- vulnerability factors developed on weapons tests and other programs.

This is a milestone in the development of explosives safety standards to recognize the differences in scaling laws for fragment effects as contrasted with blast effects as contrasted with blast effects.

PROGRAM STATUS

The current status of the overall program is as follows:

- The combined Phase I-II program is scheduled for completion before the end of October 1969. Formulation and programming of a mathematical model for computing fragment damage probability contours for the single munition are complete.
- Detailed work plans are completed for the Phase III study.
- General work statements are written for Phases IV and V.

Estimates indicate that the entire program can be completed by the end of fiscal year 1971.

CHARACTERISTICS OF THE FRAGMENT HAZARD MODEL

A mathematical model for computing damage probability contours for various munition/target combinations on a probability basis has been formulated and programmed for electronic data processing. The Phase II mathematical model, for which a simplified flow chart is shown as Fig. 1, is limited to the consideration of the single munition without environmental protection. The model is modular and can be refined in subsequent phases of the program to consider multiple munitions in various configurations, and environmental protection.

The Phase II model accepts as inputs:

- The spatial distribution of fragment masses and velocities for individual munitions, which are defined for each 5 deg sector of polar angle.
- "K-factors" for the individual munition, which express the relationship between fragment masses and projected areas for various munition types. These factors are needed to obtain projected areas for fragments in drag expressions for subsequent trajectory computations, and are not equivalent to the K-values used as coefficients in scaling formulae.
- Vulnerability criteria for targets of interest, in the form of mass-velocity relationships of impacting fragments.

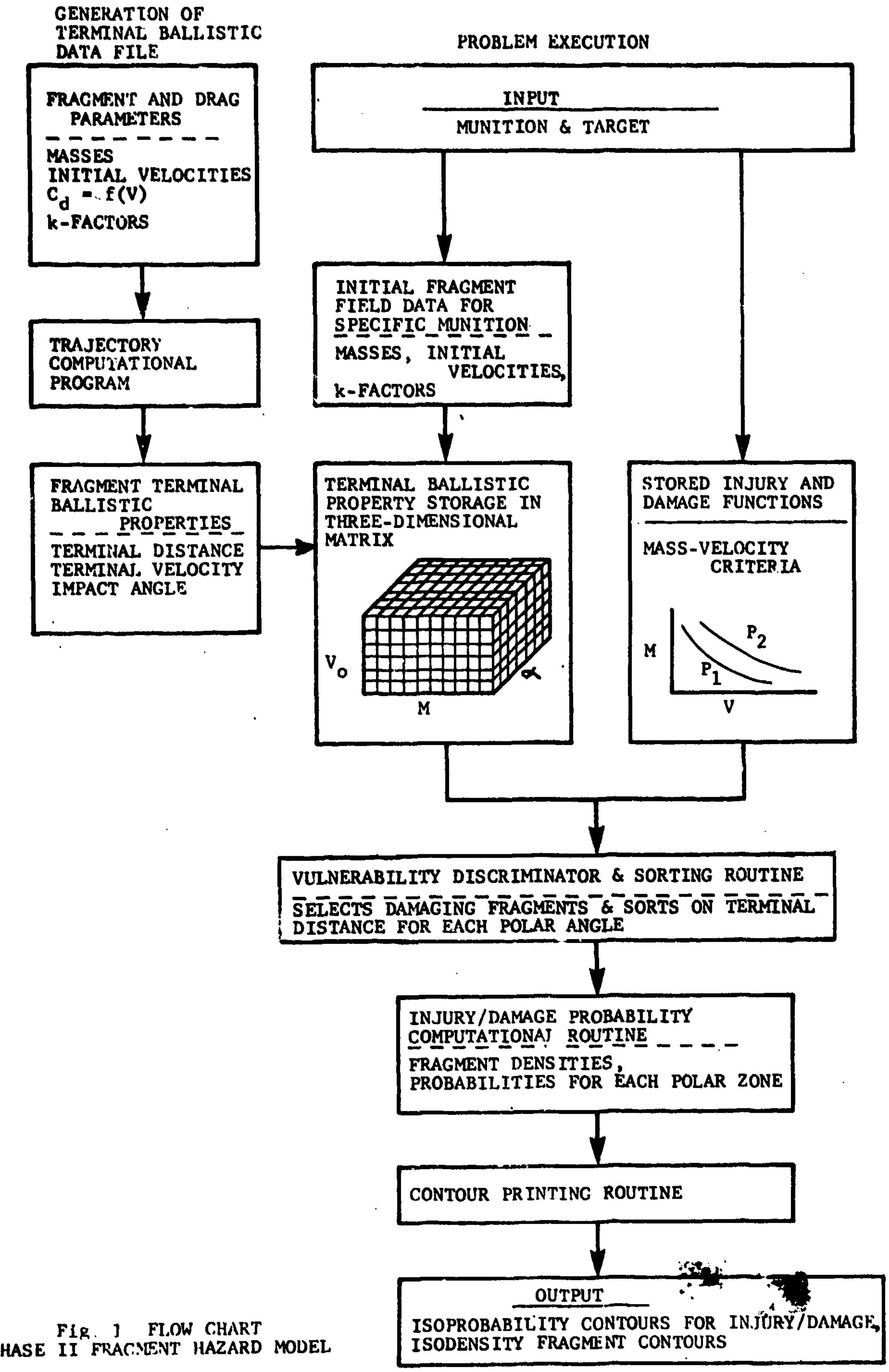

Fig. 1 FLOW CHART
PHASE II FRAGMENT HAZARD MODEL

Outputs of the model include:

- Fragment density contours showing distances at all polar orientations to isodensity lines. Contours can be printed for "all fragments" or for various classes of fragments.
- Injury/damage probability contours, showing ground distances at all polar orientations to isoprobability or "equal risk" curves for various munition/target combinations.

Large quantities of terminal ballistic property data are used in developing these outputs. These data are generated by numerical methods from the equations of motion for the fragments. Since these computations represent the bulk of the computational burden involved in exercising the model, a terminal ballistic data file has been generated which covers the range of fragment masses, initial velocities, initial velocity angles, and k-factors to be encountered in exercising the model. Terminal ballistic properties for trajectories which are common to many polar angles and munition types are computed only once, stored in a computer data file, and retrieved as needed for solving specific vulnerability problems.

Elements of this model include the following:

- Fragment and Drag Parameters

A series of twenty classes of fragment masses, eight velocity classes, eighteen initial velocity classes, and two k-factors were selected for generation of the file of terminal ballistic data. These parameters cover the range of values encountered in the munitions selected for exercising the model in Phase II.

- Trajectory Computational Routine

This routine is used to compute the requisite terminal ballistic properties of individual fragments--terminal distances, terminal velocities, and impact angles. Formulation of the equations of motion includes consideration of the drag coefficient as a function of fragment velocity.

- Terminal Ballistic Data File

Terminal ballistic data for fragments are stored in a computer file in a manner which can be likened to a three-directional matrix as shown in Fig. 1. Terminal properties of a fragment are retrieved for individual problem execution from cells corresponding to the actual masses (M), initial velocities (V_0) and initial velocity angles (α). As set up, the model uses linear interpolation among the parameters M, and V_0 wherever fragment parameters for the individual munition differ from those used in generating the terminal ballistic data file.

- Stored Injury and Damage Functions

Injury and damage functions define mass-velocity relationships for various probabilities of damage or injury.

- Vulnerable Fragment Discriminator and Sorting Routine

From among all munition fragments this routine selects terminal ballistic properties of fragments whose mass-velocity relations are above injury or damage levels and sorts them according to terminal distance. This is done successively for each 5 deg increment in polar angle on the munition.

- Injury/Damage Probability Computational Routine

Fragment densities and injury/damage probabilities are computed in this routine, bringing land and target areas into consideration. This routine is also exercised successively for each 5 deg increment in polar angle on the munition.

- Contour Printing Routine

This routine prints contours of equal fragment density and equal injury/damage probability for the various combinations of munition and target.

PROBLEM EXECUTION

The Fragment Hazard Model will be exercised for all combinations of the following single munitions and targets on the Phase II program:

Munitions

- 500 lb M82 Bomb
- 750 lb M117 Bomb
- 105mm Howitzer Shell M1
- 155mm Howitzer Shell M107
- 175mm Gun Shell M435
- 5 in./38 Projectile MK 49
- 8 in./55 Projectile MK 24

Targets

- Standing Personnel
- Open Bomb Store
- Open Shell Store
- Vital Building
- Parked Aircraft
- In-Flight Aircraft
- Moving Automobile

Sample exhibits of outputs obtained in exercising the model for the case of the 500 lb M82 bomb with standing personnel as the target are shown in Figs. 2 to 4. Total fragment density contours, considering all fragments produced in the detonation of a single bomb, are shown in Fig. 2. Injurious fragment density contours considering only those fragments whose terminal mass-velocity relationships are above the threshold of serious injury for standing personnel, are shown in Fig. 3. Isoprobability contours for serious injury to standing personnel are shown in Fig. 4. The latter family of curves provide data for selecting separation distances for various levels of risk of serious injury to standing personnel. The families of curves in Figs. 2 to 4 reflect the types of outputs obtainable for various munition/target combinations by exercising the Fragment Hazard Model in its present form.

INJURY/DAMAGE CRITERIA INPUTS

Injury/damage functions of the form shown for standing personnel in Fig. 5 are being incorporated into the Fragment Hazard Model. The threshold of serious personnel injury from fragment impact was selected from this family of curves as the personnel vulnerability criteria and all fragments having

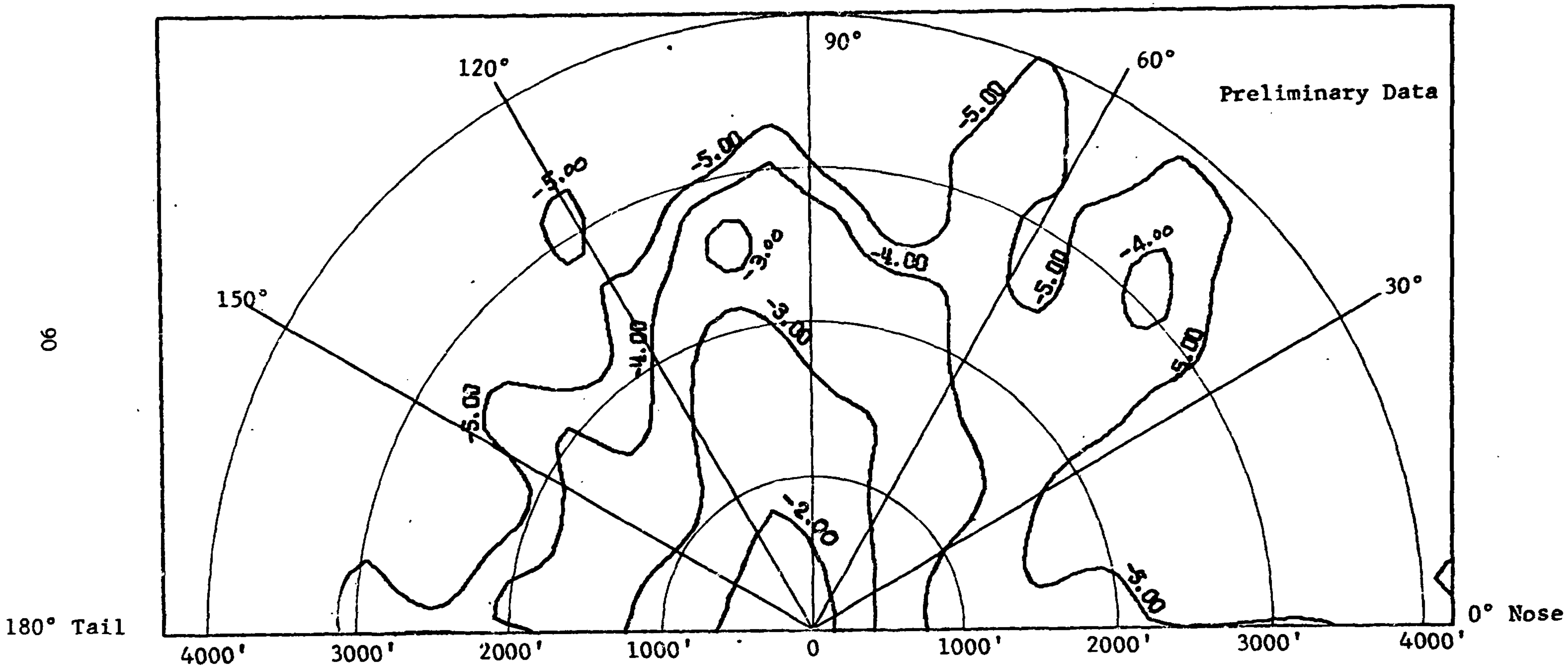

Fig. 2 FRAGMENT DENSITY CONTOURS - AIR FRAGMENTS
500 LB M82 BOMB - SINGLE MUNITION

<u>Note</u>: Fragment Density = 1.0×10^a Fragments per sq ft where exponent a is shown on contour line.

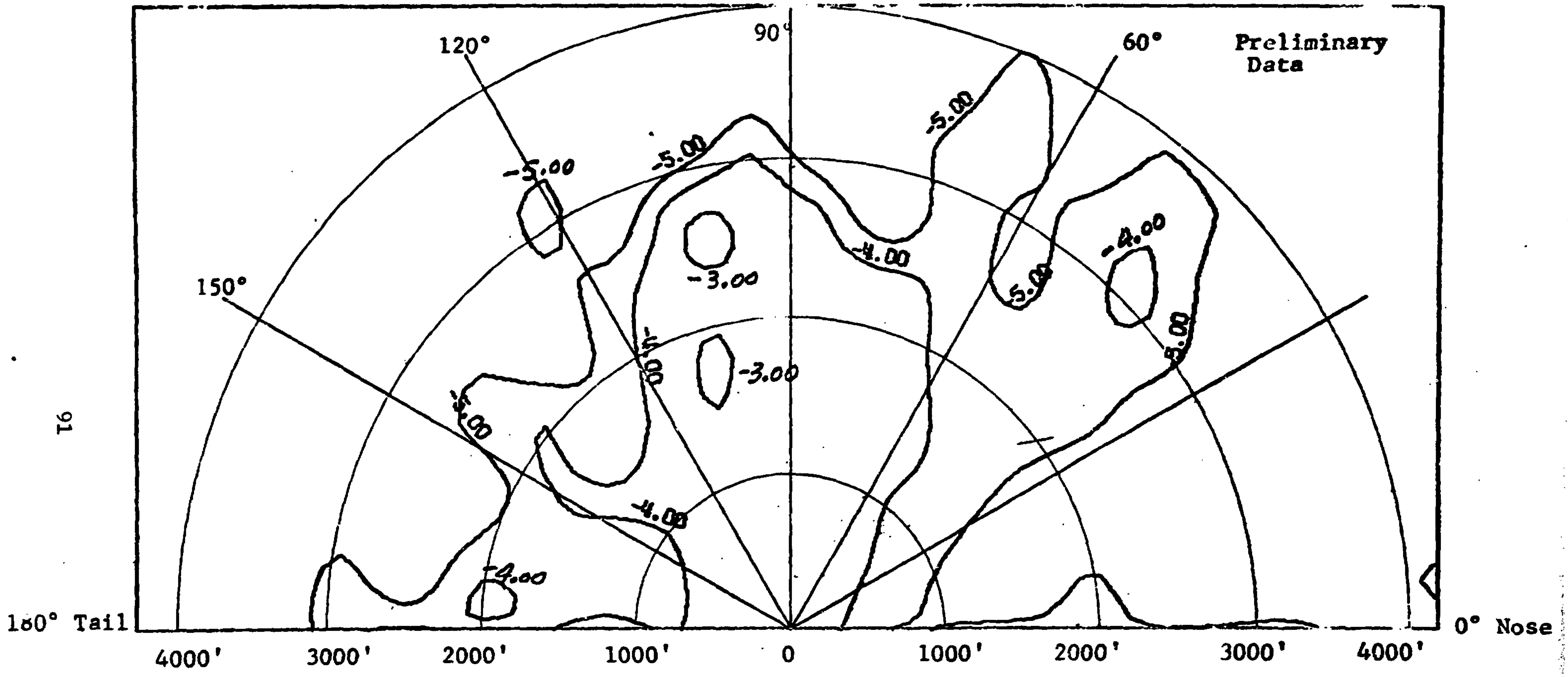

Fig. 3 FRAGMENT DENSITY-SERIOUSLY INJURIOUS FRAGMENTS
500 LB M82 BOMB-SINGLE MUNITION

<u>Note</u>: Fragment Density = 1.0×10^b Fragments per sq ft where exponent b is shown on contour line

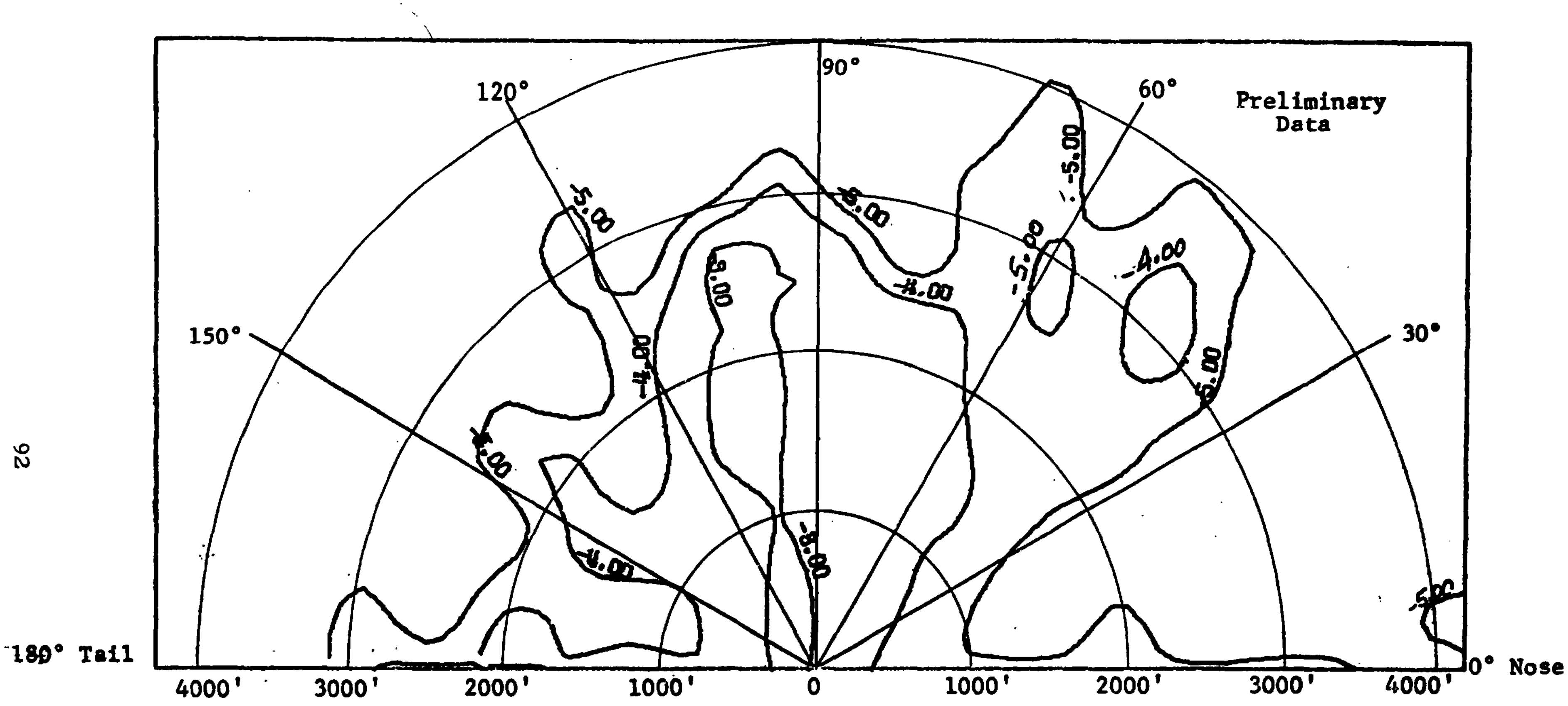

Fig. 4 SERIOUS PERSONNEL INJURY PROBABILITY CONTOURS
500 LB M82 BOMB-SINGLE MUNITION

Note: Fragment Density = 1.0 x 10^c Fragments per sq ft.
where exponent c is shown in contour line.

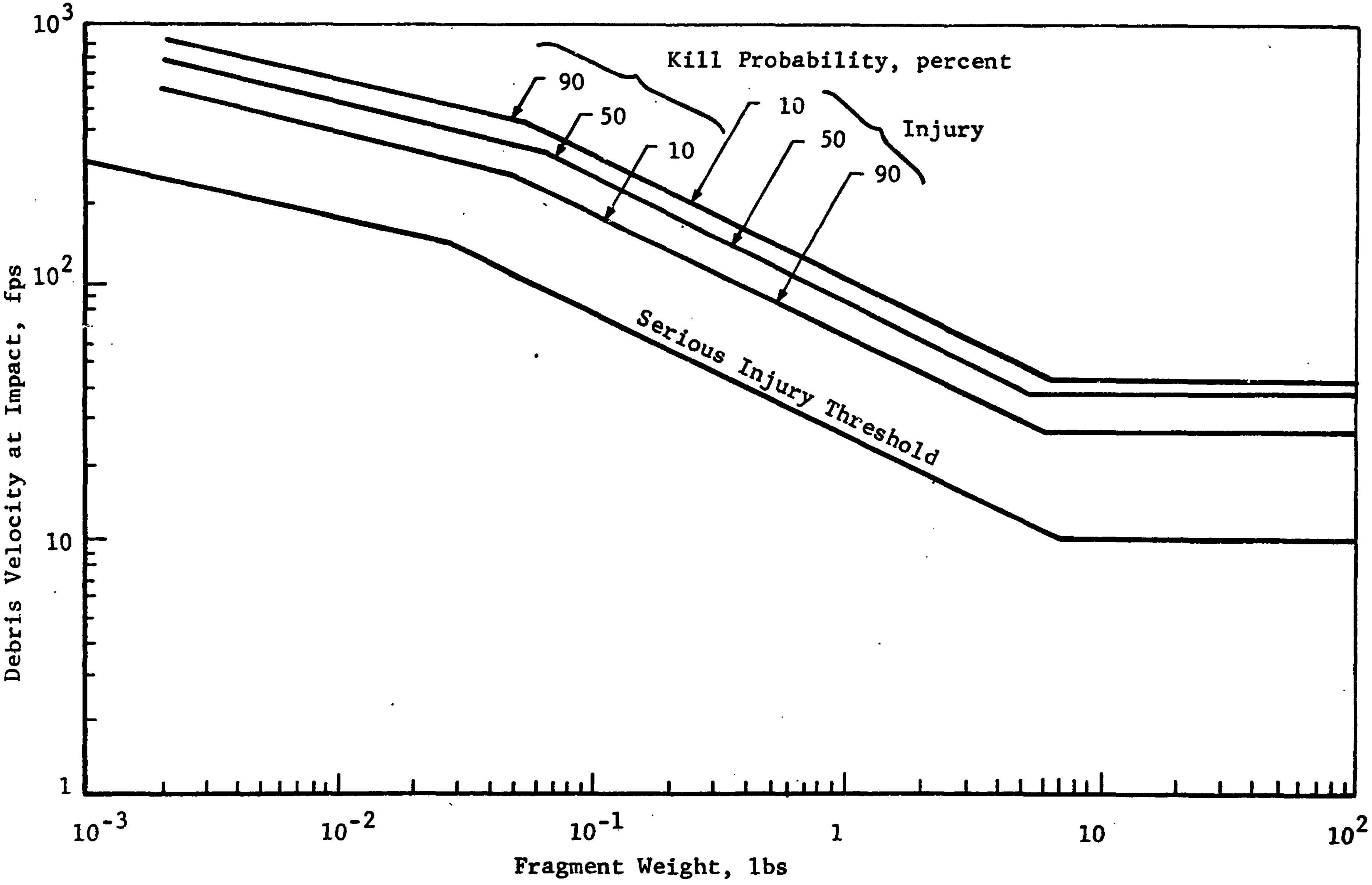

Fig. 5 PERSONNEL RESPONSE TO FRAGMENT IMPACT (Abdomen and Limbs)

mass-velocity relationships in excess of threshold level were included in developing vulnerability contours. It is noted that the contours then represent "serious injury and lethality" inasmuch as some fragments may be sufficiently above the serious injury threshold level to be in the mixed injury/lethality range.

Serious injury threshold curves for fragment impact on abdomen and limbs, thorax, and head are plotted together in Fig. 6. The curve for abdomen and limb injury was applied in the current model formulation because, i) these members represent a greater portion of body projected area than the thorax and ii) it represents a lower and more conservative threshold in the mass-range of most munition fragments--under 0.2 lb. The total projected area of the human body, as measured normal to the fragment impact angle, was taken as the target area in computing injury probabilities.

FRAGMENT TRAJECTORY CHARACTERISTICS

A corollary exercise in variation of trajectory parameters was conducted in preparing the trajectory computational routine, the results of which are shown in Fig. 7-13.

The general trajectory form, point of maximum trajectory heights, and terminal distances of a series of high velocity, low angle fragments of various weights are shown in Fig. 7. It is seen that, for these drag-influenced fragments, the point of maximum trajectory height is reached at about 65 percent of terminal distance for the lighter fragments and about 75 percent of terminal distance for the heavier fragments. Terminal velocity angles, at impact, have been found to be very steep, generally greater than 80 deg.

The relationship between terminal trajectory distance and fragment weight for light fragments with a constant initial velocity and various initial velocity angles is shown in Figure 8. It is seen that maximum terminal distance corresponds.

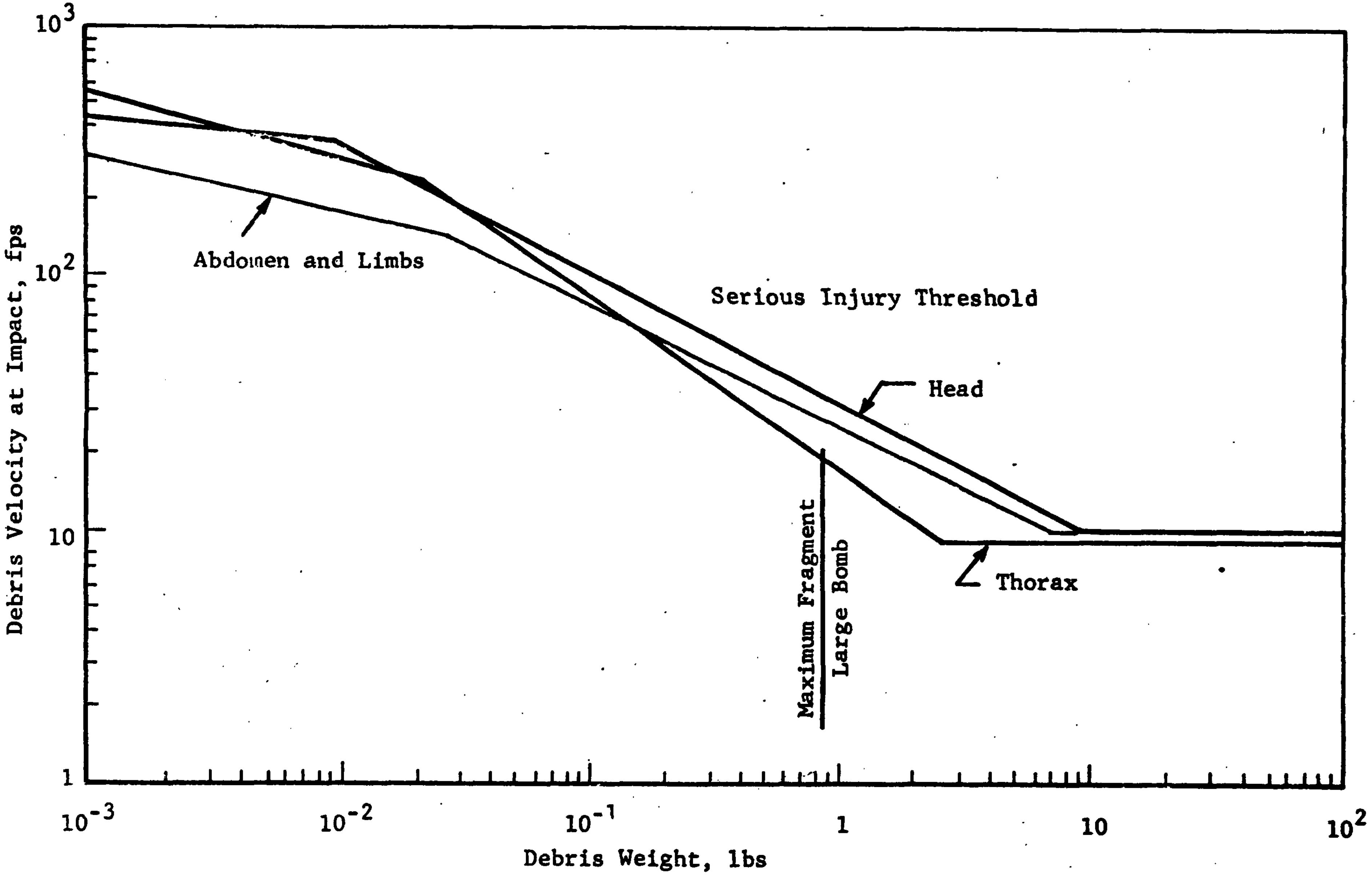

Fig. 6 PERSONNEL RESPONSE TO FRAGMENT IMPACT

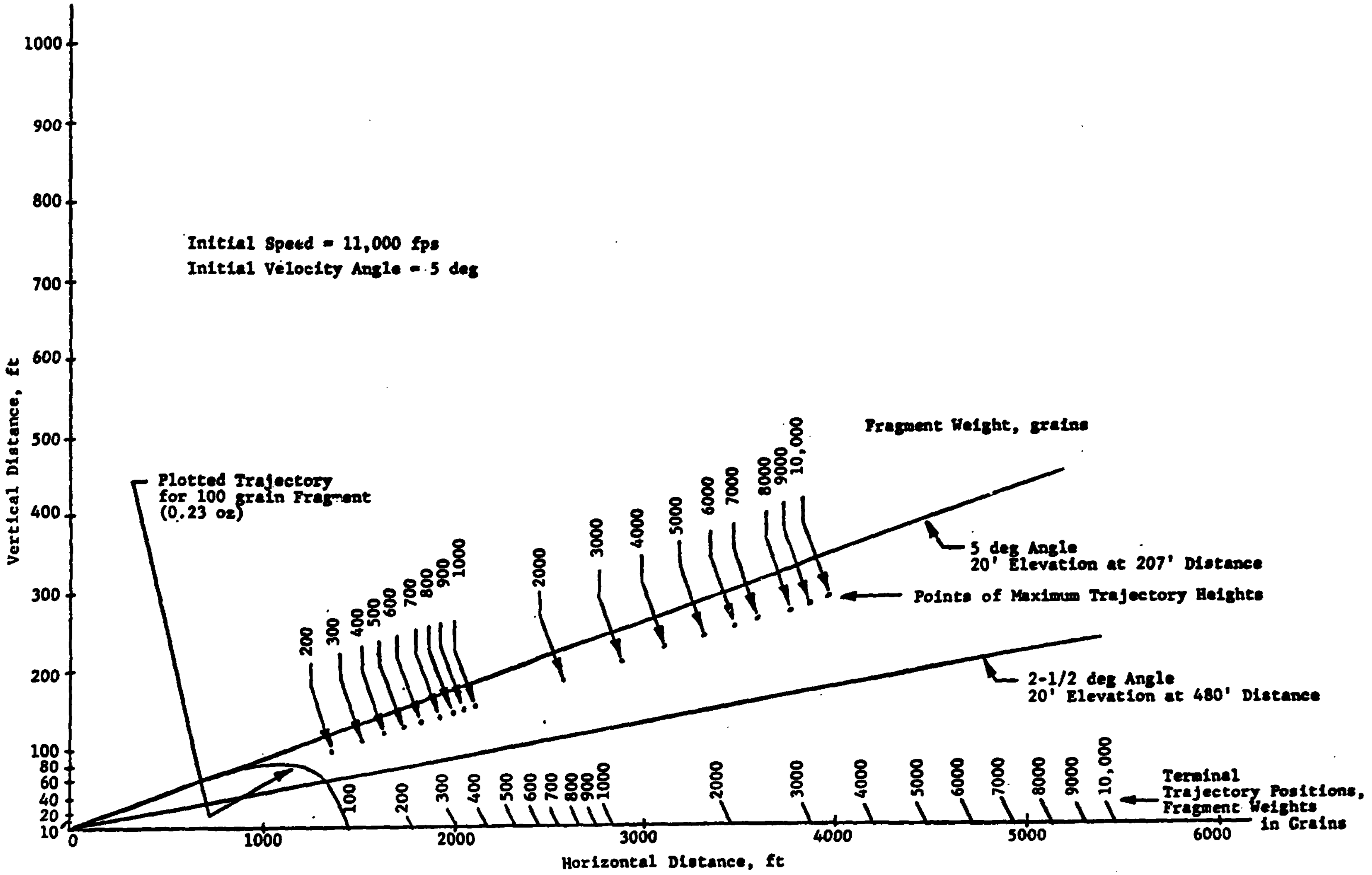

Fig. 7 SELECTED FRAGMENT TRAJECTORY CHARACTERISTICS HIGH VELOCITY, LOW ANGLE FRAGMENT

to an initial velocity angle of 20 de From the horizontal terminal distances are seen tobe far more sensitive to variations in fragment weight than to variations in initial elevation angle. It is also seen that the light fragments from munitions do not travel to extreme distances, even with very high initial velocities. A comparable chart for heavy fragments is shown in Fig. 9. Though relatively few in number, heavy fragments with high initial velocities can travel great distances. When considering these distances in the vulnerability context it must be remembered that an initial fragment velocity of 11,000 ft/sec is very high and that fragment densities at these distances are low.

The relationship between terminal distance, initial velocity and fragment weight, with initial velicity angle held constant, is plotted in Fig. 10. Terminal distances for heavy fragments are seen to be more sensitive to variations in initial velocity than light fragments.

Relationships between initial velocity, terminal velocity and fragment weight are shown in Fig. 11, with terminal distances noted at the end points of the curves. It is noted that terminal velocities of light fragments are quite low and are at levels where they are primarily hazards to personnel in the open at closer ranges. Velocity attenuation for heavy fragments is also seen to be very considerable. What appears to be an anomaly here, where fragments with the higher initial velocities have lower final velocities, is explained by the fact that, with longer trajectories they are subjected to drag forces for longer durations.

Terminal velocities for light fragments, with low initial velocity angles, plotted in Fig. 12, are also seen to be more sensitive to variation in fragment weight than to initial elevation angle. A similar trend is observed for terminal velocities of heavy fragments, as seen in Fig. 13. Terminal velocities in these figures are a result of the net effects of both drag and gravity.

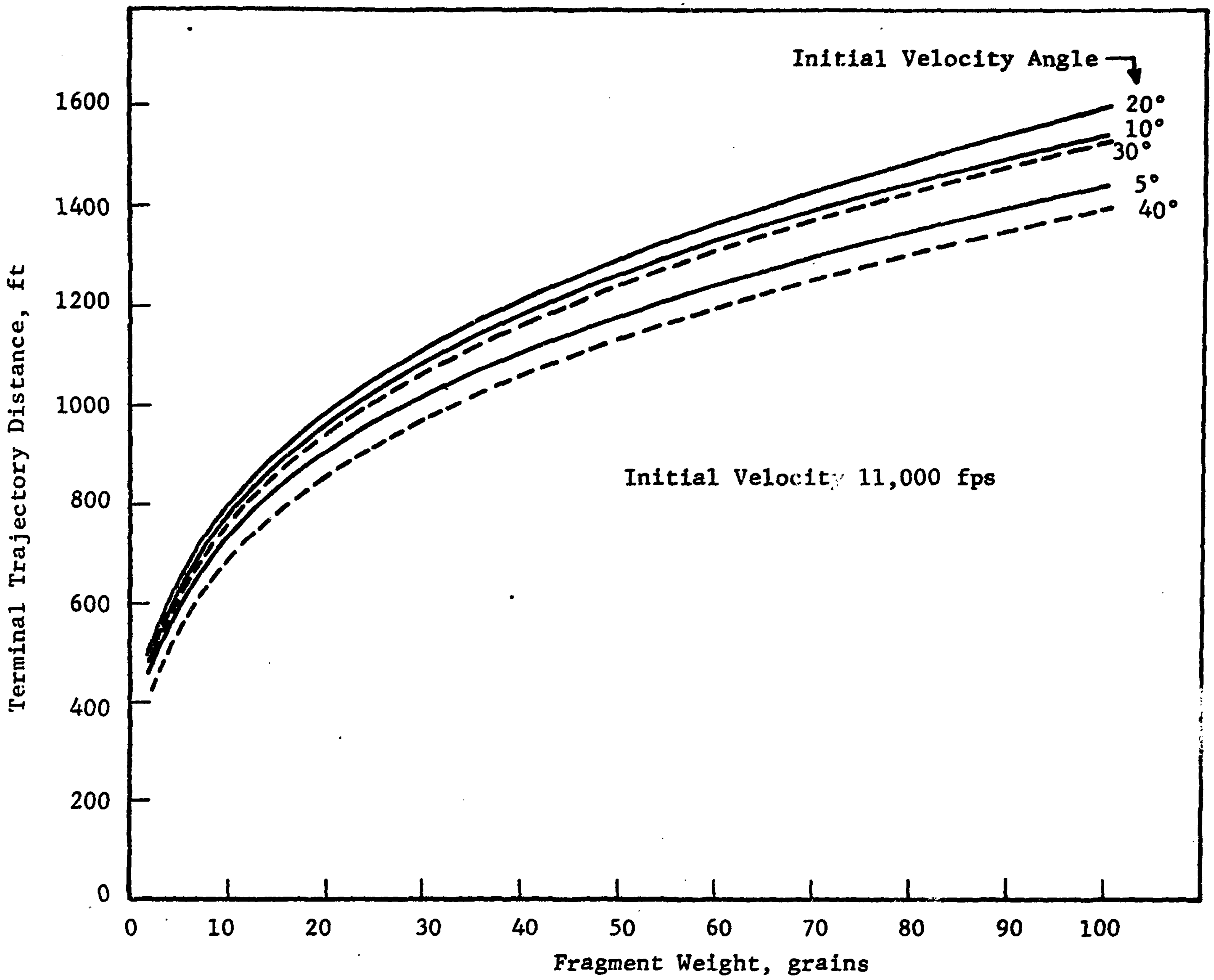

Fig. 8 WEIGHT VS TERMINAL DISTANCE - LIGHT FRAGMENTS

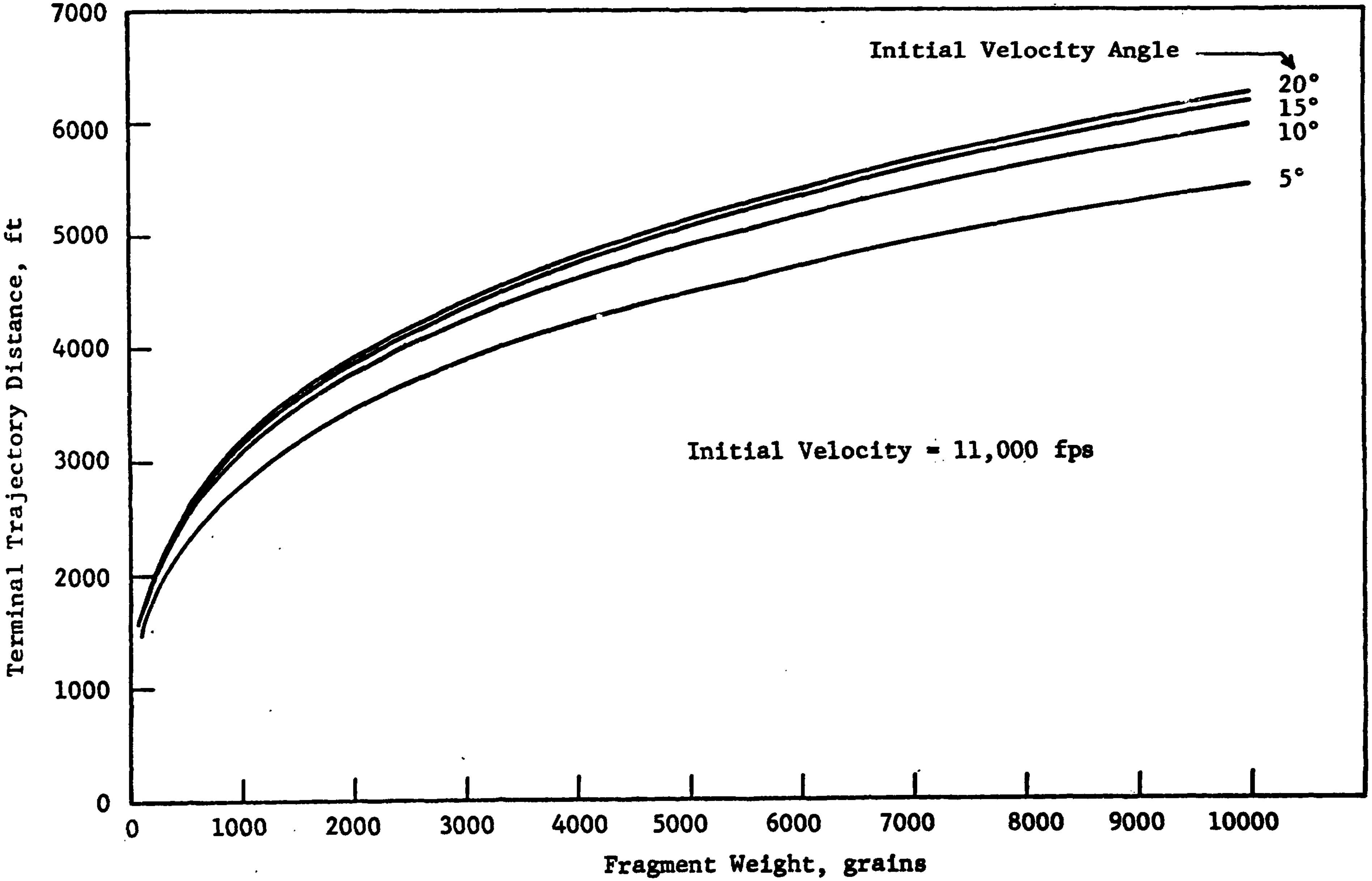

Fig. 9 WEIGHT VS TERMINAL DISTANCE - HEAVY FRAGMENTS

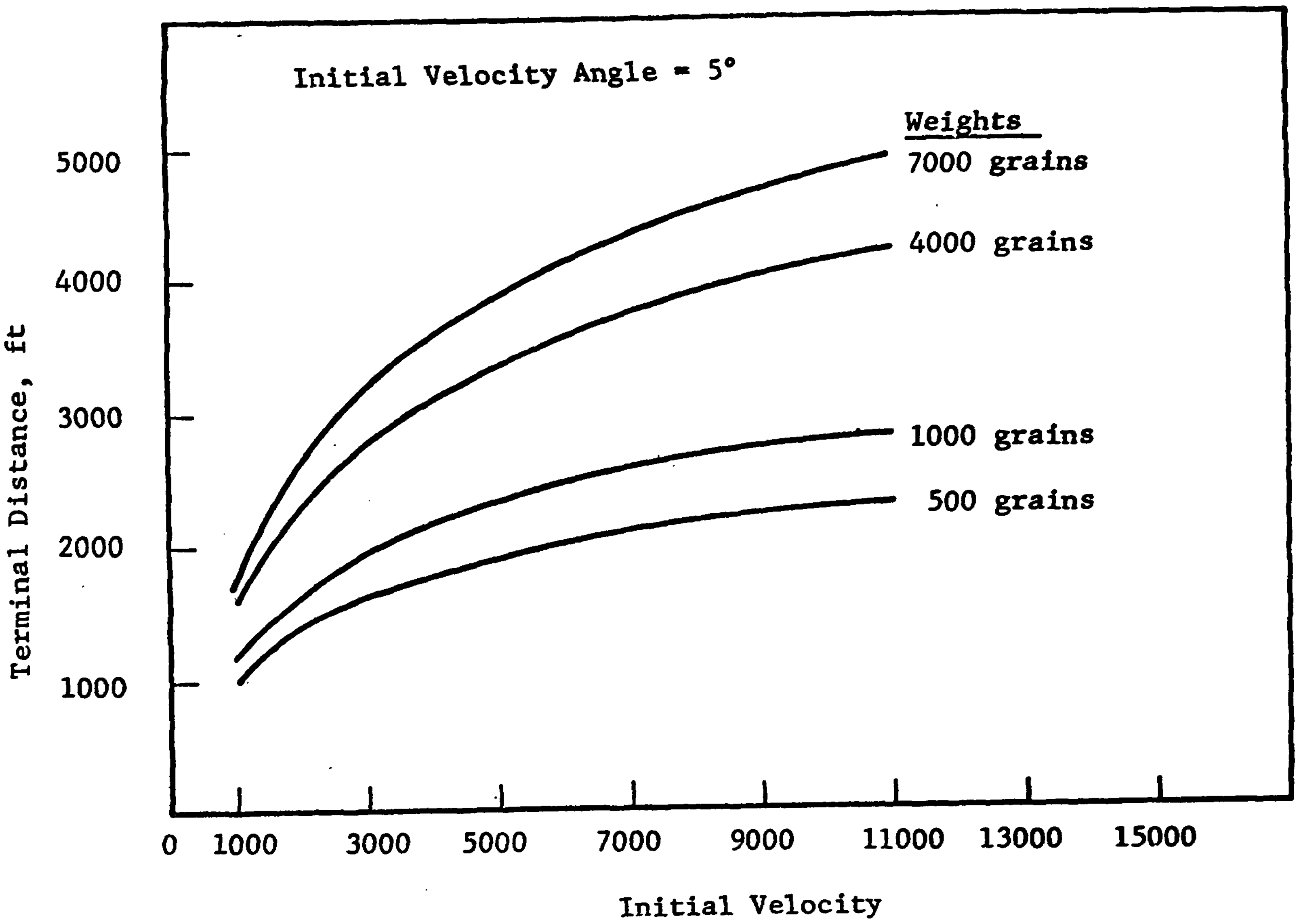

Fig. 10 INITIAL VELOCITY VS TERMINAL DISTANCE FOR VARIOUS WEIGHTS

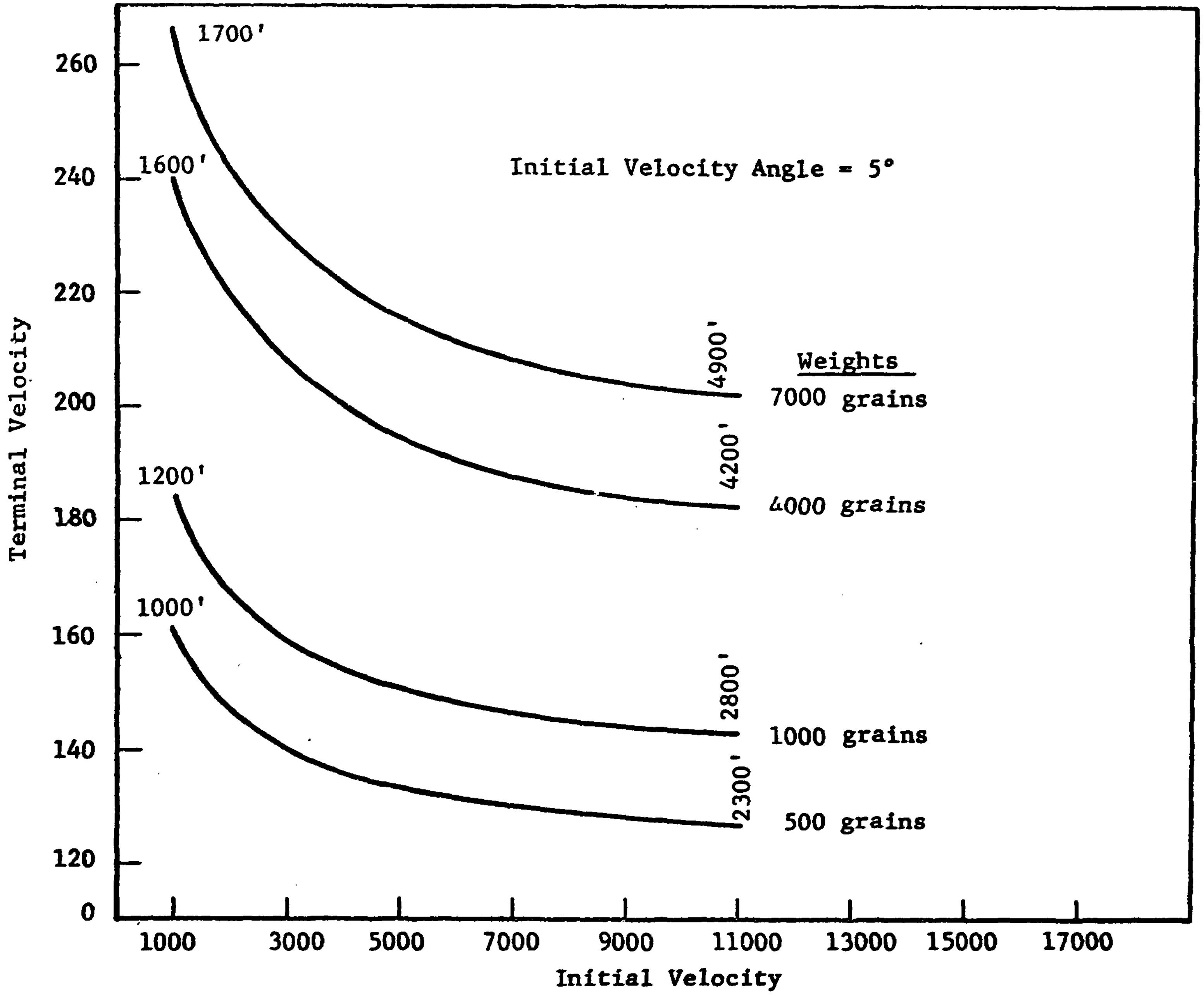

Fig. 11 INITIAL VELOCITY VS TERMINAL VELOCITY FOR VARIOUS WEIGHT FRAGMENTS

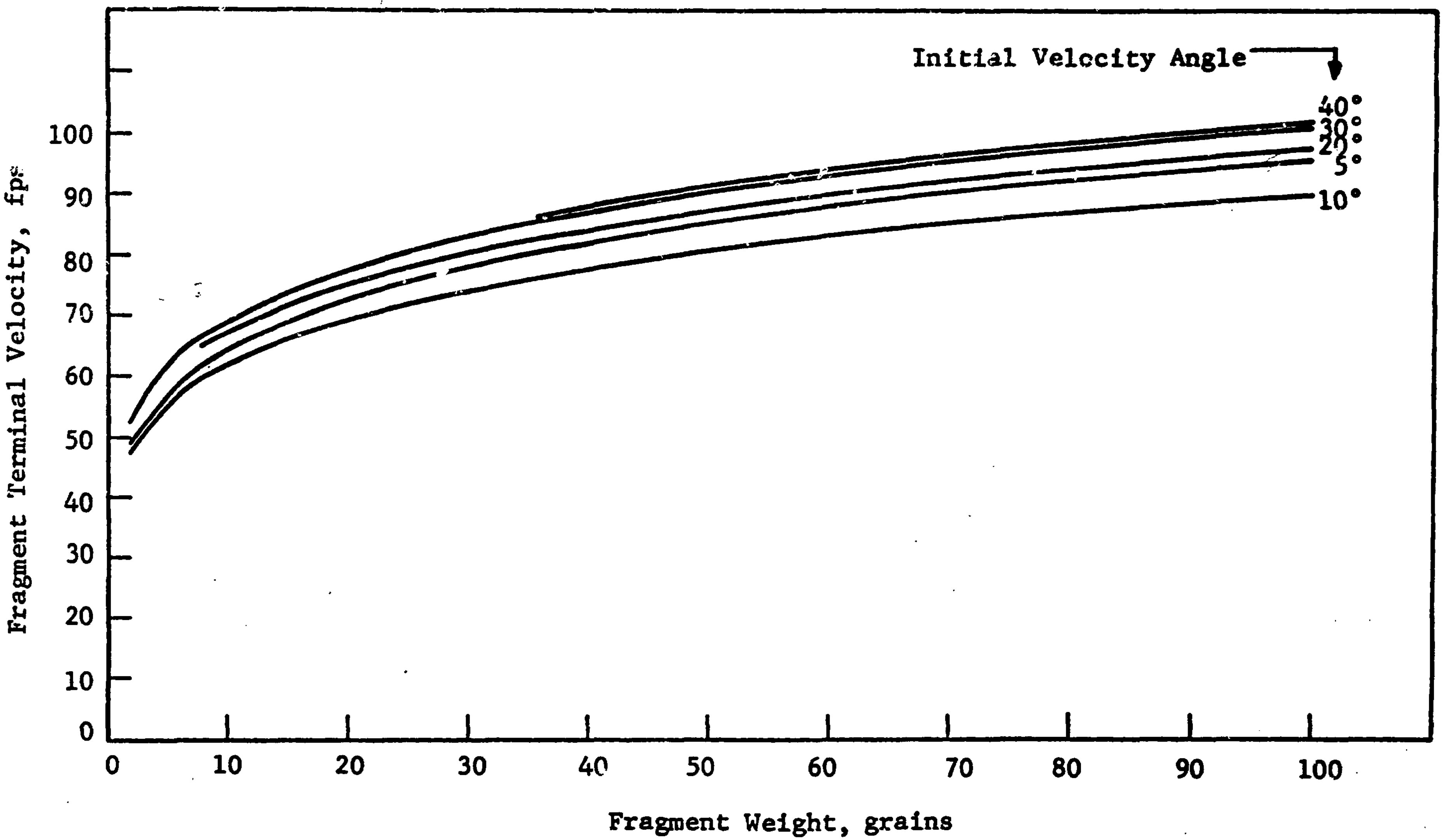

Fig. 12 WEIGHT VS TERMINAL VELOCITY - LIGHT FRAGMENTS

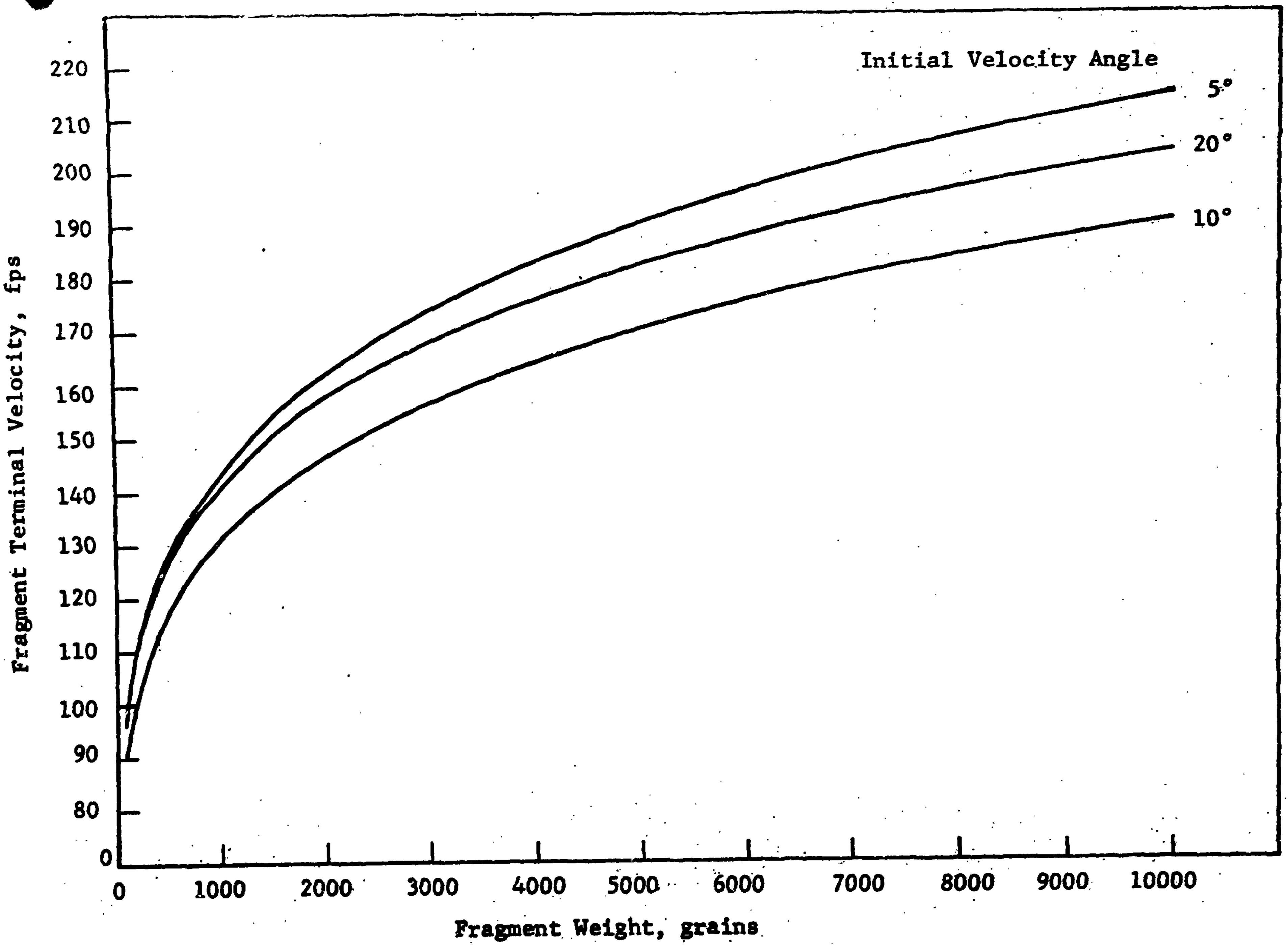

Fig. 13 WEIGHT VS TERMINAL VELOCITY - HEAVY FRAGMENTS

SUMMARY

A limited parametric study of fragment trajectories has shown that:

- Most munition fragments have small mass, travel relatively short distances, fall in regions of high fragment densities with low velocities.
- Though few in number, large fragments travel much further where they fall in low density field.

Using the technique of trajectory analysis, a mathematical model has been developed for estimating injury/damage contours for various combinations of targets and single munitions. It has been found possible to confine the computational burden of trajectory computations to essentially a "setup" operation through storage of terminal ballistic data in a computer data file for ultimate retrieval in solving problems.

Procedures have been outlined for extending the model to the case of the multiple munition in open stores. For the case of the nonmass detonating munition store the problem in considered one of computing injury/damage probabilities at linearly-increasing fragment densities.

Extending the model to the case of the mass-detonating munition store is a more complex problem, involving the following basic considerations:

- Accidental detonation of one munition leads in general to nonsimultaneous detonation of other units.
- Fragment fields from more than one munition will partially interfere mutually to preclude simple point-for-point addition of single munition fragment maps.
- Fragment from a covered munition cannot initially enter the effective fragment field prior to detonation of the covering munition.
- Some airblast induced acceleration of fragments may result from nonsimultaneity of detonation.

With these considerations in mind the fragment field for the mass-detonating munition becomes a linear multiple of the field for the individual round, plus airblast induced acceleration effects, less the effects of intra-round shielding and fragment interaction.

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Discussion of the Paper

INVESTIGATION INTO FRAGMENT AND DEBRIS HAZARDS FROM EXPLOSIONS

Attendee interest was expressed in the variations in trajectory parameters. Additional exhibits concerning munition fragment behavior were shown. Though exhibits these were not included in the technical presentation before the general session, they have been included in the foregoing paper to provide continuity in the subject matter.

Extensive attendee interest was shown in applying the Fragment Hazard Model to assess the risks involved in missile explosions. It was explained that the Fragment Hazard Model contains a ballistic trajectory computational routine and its exercise requires input data on the spatial distribution of fragment masses and initial velocities. The air-to-ground rockets are immediately amenable to treatment in the model since:

- the spatial distributions of masses and initial velocities have been measured,
- trajectories for these fragments are essentially ballistic, and
- characteristic "k-values" expressing the relationship between fragment mass and projected area have been measured.

It was shown that several differences exist between conditions for the explosion of large missiles and the ballistic Fragment Hazard Model in its present form:

- The munition was considered in a standing position, on end, in some of the missile problems posed; whereas, the Fragment Hazard Model considers the munition lying on its side. This does not preclude similar analytical treatment of ballistic fragments, though some modification of the model would be required by the change.

- In the larger missiles, skin fragments in large sizes may be generated whose trajectories may be influenced by lift. The model does not include provisions for considering lift.

- The missile explosion was said to sometimes follow partial combustion of the fuel. This could result in convection currents which could further influence the response of skin fragments susceptible to lift.

The question of potential applicability of the model to the problem of assessing risks to observers also arose. The model can be exercised to obtain data for evaluating observor risk levels, providing the required input data is available. Assuming observor sites to be relatively close-in, neglect of lift effects on trajectories of skin fragments might be permitted.

Interest shown in fragment behavior from past incidents prompted the showing of additional exhibits as follows:

- Correlation between maximum fragment distance and equivalent weight of explosives, which is shown in Fig. 1 for a large number of explosions. The extreme scatter of data points stems from dissimilarities in types of explosion, structures involved, and environments.

- Distribution pattern for concrete fragments from a Pantex Ordnance Plant explosion test. (Figs. 2-4) The test provided a thoroughly documented record of weights and terminal positions of about 35,000 fragments with a total weight of about 85,000 lbs. The missile map, Fig. 2, shows fragment densities of the order of one per 2500 sq ft were observed locally as far as 1400 ft from the detonation. The decidedly unsymmetrical pattern resulted from the environmental configuration. The overall dispersion of fragments is expressed in Fig. 3, with values being computed on the basis of circumferential areas. Variations in mean fragment weight with ground range is plotted in Fig. 4.

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QUANTITY-DISTANCE CRITERIA - A MORE FLEXIBLE POLICY IN FUTURE?

Reginald R. Watson
Ministry of Defence, United Kingdom

SUMMARY & DISCLAIMER

The objective of this paper is to present certain facts relating to serious accidents in general and quantity-distance criteria for explosives in particular. These are examined to try to reveal a national safety philosophy and to determine what is deemed to be an acceptable risk. It is concluded that the assessment of risks should take account of many factors which are arbitrarily excluded from current quantity-distance criteria. It is proposed that explosives safety policy should be more flexible and consistent in future. The change could be implemented by introducing a number of weighting factors into the existing system of quantity-distances.

The majority of the paper is factual. However, the juxtaposition of these facts leads to certain implications and comments. It is stressed that opinions expressed or implied are personal and must not be taken as those of the Ministry of Defence. On the contrary the paper has been written in the hope that it may have some influence on the views and doctrines which underlie the quantity-distance criteria of the UK, the US and other NATO governments.

INTRODUCTION

This paper uses the term "quantity-distance" rather than the British term "safety distance" partly out of consideration for the American audience today but mainly because the traditional British term is so misleading. Figure 1 shows the sort of damage to brick built dwellings that must be expected in a minority of cases (7%) even though the buildings were sited beyond the prescribed quantity-distance. The distance of isolation of inhabited buildings from an accidental explosion can hardly be said to ensure the safety of the property or the occupants. Although the majority of cases would result in much less severe damage it is arguable whether "safety" is achieved even there. 320 people were injured by flying glass in the Texas City explosion of 1947 although they were located mainly beyond the Inhabited Building Distance. $350,000 of property damage was caused by the 1950 explosion at a jetty near Portsmouth, England although there were no dwellings sited within 1½ times the so-called Outside Safety Distance.

It is impracticable to observe isolation distances which would guarantee immunity from the effects of an accidental explosion. At least this is so in the UK and many European countries and I understand it is rapidly becoming the situation in the USA. Instead the responsible authorities in NATO countries prescribe quantity-distances which represent a sensible compromise between public safety and economic or operational requirements. A compromise is also involved in the criteria for Intraline Distances since there is some accepted risk of injury to explosives personnel, though this may be merely the risk of indirect injury by such things as falling rafters, lobbed debris or ricochets. The criteria for Intermagazine Distances also involve a small risk, that of propagation, although the stated purpose is to prevent communication of detonation or mass ignition among magazines. This risk arises because it is impracticable to carry out sufficient of the expensive tests to ensure with complete confidence that every conceivable accident situation has been investigated. There is also the risk that the wrong hazard class might be assigned for quantity-distances. It is traditional to perform five replicate tests and to accept a score of 0/5 as sufficient evidence that the explosive item is not a mass detonation risk. To a statistician this score does not give very much confidence at all. It is quite impractical however to test, say, 100 large rocket motors in each simulated situation to make sure that the behaviour can be predicted with a high level of confidence. The ideals of the statistician must be weighed against economic realities and some reasonable compromise must be accepted. The basic question this paper asks is how these value judgments are to be made. Is there a national safety philosophy? Can the authorities derive a safety policy which will ensure consistent, rational judgments in all these applications of the doctrine of an acceptable risk?

AN EXPLICIT SAFETY PHILOSOPHY

The short answer to this question appears to be that there is not. In the UK and possibly in most countries there is a division of responsibilities for safety according to the particular activity involved. The Home Office has an historical role concerning the preservation of public law and order. This has lead to legislation making the Home Office responsible for explosives safety wherever commercial explosives and fireworks are involved. The Ministry of Defence and the Ministry of Technology are responsible for the safety of military explosives. Other departments have responsibilities concerning the conveyance of dangerous goods including explosives. When we look at other hazardous materials and operations, such as radioactive substances, pollution of the environs, public health, safety of employees in factories and stores, road safety, etc. we come to the conclusion that every government department has some responsibility for safety. Do they all make mutually consistent value judgments concerning public safety or are standards diverse? Are there inter-departmental committees to harmonise the safety doctrines in the various fields of hazardous activity?

One can answer in the affirmative in relation to one type of hazard - ionising radiation. Owing to the traumatic effect of atomic explosions on public opinion, governments have been forced to make comprehensive arrangements to secure protection of the public against the hazards of ionising radiation. All departments base their safety criteria on a single set of standards (maximum permissible doses) which represent a balance between the risks of somatic and genetic injury and the social or economic benefits accruing from the use of such radiation. Indeed the standards are internationally accepted thanks to the work of the International Atomic Energy Agency and the International Commission for Radiological Protection.

There does not appear to be any comparable national or international guide relating to the various hazards associated with explosives and propellants. Although a NATO Group of Experts has achieved a modicum of agreement on quantity-distances, some countries still have particular standards which differ significantly. The differences reflect the differing judgments as to what constitutes an acceptable risk.

Although the UK has no explicit safety philosophy, public opinion and democratic government provide an effective control over the authorities. For example, if the Ministry of Defence were to abandon all attempts at observance of quantity-distances, in order to achieve dramatic savings in land and buildings, there would be an outcry when the public became aware of the serious hazards to which they were exposed. Probably the public would become aware only as the result of a serious accident. It is common practice for the government to set up a Public Inquiry or Tribunal after a disaster. The reports of these bodies give valuable clues as to what level of risk is in practice deemed to be acceptable. We shall now look at some recent disasters in the UK with a view to learning the views of interested parties, of independent investigators and of members of the general public as to what is an acceptable risk.

ABERFAN

Figure 2 shows a colliery and adjacent dwellings at Aberfan in South Wales. In the background are tips constructed from colliery waste. On 21st October 1966 one of the tips, about 110 feet high, suffered a landslide. Many thousands of tons of rubbish swept swiftly down the hillside and engulfed a school and eighteen houses (Figure 3). 116 children and 28 adults perished. We are not concerned with the causes and the blame for the disaster but rather with a particular quotation from the Report of the Tribunal and with the safety doctrine involved in tipping policy. Figure 4 records part of the evidence of the local Member of Parliament who was alleged to have foreseen the possibility of the tip-slide; he was called to account for his decision not to pursue the matter. Safety engineers present here today may sympathise with Mr. Davies. You too have had to make decisions after weighing possible hazards against economic considerations. Have you not experienced the awful thought that one day you might be questioned by a formal inquiry and be required to justify your decision? How reassuring it would be if you had been guided by some written safety philosophy or doctrine of acceptable risks, agreed departmentally, or better still, internationally.

A second notable result of the Aberfan disaster is that public reaction weighed very heavily in favour of greater safety in subsequent decisions on the location and assessment of tips. Each and every tip which presents the physical possibility of slipping is to be made safe by re-construction, using shallow compacted layers instead of a single porous heap, or by relocation. The whole project may cost about 15 million pounds, which could add a significant burden to the price of coal at a time when the industry is fighting for survival. There has been no question of ranking the tips in order of likelihood that slippage might occur, so as to limit expenditure to the worst risks. If there is any possibility at all, no matter how small the chance, the hazard must be eliminated. This corresponds to the doctrine in explosives safety that no matter how unlikely an accidental explosion may seem to be, the possibility must be taken into account and the damage potential must be controlled by observation of conservative isolation zones. Sceptics who have lived through the aftermath of earlier disasters and public inquiries may care to predict how many years will elapse before the public loses interest, and before economic considerations reassert themselves. Perhaps after the worst twenty or thirty tips have been made safe over a period of two or three years the policy might quietly revert and someone might judge the remaining tips to be reasonably safe, an acceptable risk - until next time.

THE TORREY CANYON

On 18th March 1967 the tanker Torrey Canyon, dead weight 118,000 tons on charter to the Union Oil Company of California, with further charter to British Petroleum Company Limited for a single voyage, registered in Liberia, insured partly in London and partly in the USA, ran aground on the Seven Stones Reef off Lands End, Cornwall, England. Many of the cargo tanks were damaged and some 60,000 tons of the total of 117,000 tons crude oil were released into the sea during the first 36 hours. After a period of intense government activity involving assessment, study of technical proposals and legal wrangling, it was decided to bomb the ship in an attempt to set fire to the remaining oil. For many weeks afterwards the local authorities along British and French coasts were obliged to carry out expensive cleansing operations of beaches, rescue of wild life and preservation of marine farms for shell fish.

The fact that this disaster and its harmful effects continued over a long period served to maintain press coverage and public interest for many weeks. It gave rise to numerous technical and political debates about what should have been done and, more important, what should now be done to prevent a recurrence. The incident illustrated how complex are the factors in modern commerce and international law. The first problem for the government was to decide who had the right to do what. The Dutch salvage team who had staked their claim to the booty in the time honoured manner were naturally opposed to the proposal to destroy the ship and oil. The Government made it clear that the salvor would not be allowed to tow the ship into British territorial waters. Unfortunately oil pollution is not bounded by such conventions and release of so great a quantity beyond the territorial waters would have been hardly less harmful. The Government initiated arrangements to buy out the salvors if necessary.

The protracted public debates on the disaster have led to considerable government activity in the fields of disaster control and contingency planning. As regards the carriage of hazardous cargoes through waters where an accident may affect British interests, the Government has initiated changes in international agreements and maritime law and practice through the Inter-governmental Maritime Consultative Organisation. This may have direct repercussions on the carriage of explosives in ships. Figure 5 illustrates by means of press clippings some of the related matters which have received attention and criticism as a result of the disaster.

RONAN POINT

Figure 6 shows a tower block of apartments at Ronan Point, London. One corner suffered progressive collapse early in the morning of 16th May 1968. An ordinary gas explosion in an apartment on the eighteenth storey of this 22 storey block pushed out its external, load-bearing flank wall. Unfortunately in this Larsen Nielsen system of construction this wall supports the floor slab of the storey above it. The apartment above collapsed and consequently that on the storey above it. The weight and impact of this debris on the floors below led to progressive collapse of the whole of that corner of the block, like a house of playing cards. Figure 7 shows the remaining suspended floor slabs and walls. Figure 8 indicates how vulnerable this type of construction is to progressive collapse resulting from displacement of a single flank wall. It also shows that this type of block is by no means unique in England.

The Public Inquiry into this disaster, which by sheer good luck resulted in no fatalities, revealed an apparent blind spot in the many people who should have foreseen the possibility. Not only an explosion of leaking town gas, as in this case, but also an explosion of many common fuels or solvents could have pushed out the flank wall; about

3 lb in^{-2} acting for one tenth of a second would suffice. The Inquiry also revealed how inadequate was the current code of practice relating to wind loading and suction on tall buildings.

The main reason for our mentioning the Ronan Point accident relates to the level of risk which, even after the event, appears to be accepted as "safe." I referred earlier to "an ordinary gas explosion." So commonplace are these town gas mishaps in domestic premises in the UK that one must conclude the public places them in the same category as road accidents - something we must become accustomed to. The Inquiry was surprised to find that neither the Gas Council nor the supplier, the North Thames Gas Board, kept any record of domestic gas explosions or gave any special consideration to the incidence or causes of such explosions. A statistical analysis was undertaken on the basis of data supplied by fire brigades. The result shows that there were 42 town gas explosions which caused structural damage in UK domestic premises in 1966, and a further 55 explosions which caused only superficial damage. The Inquiry considered that the results confirmed the acceptance by the public of town gas as a safe domestic fuel. It is only the nature of the risk that is unacceptable in the case of tower blocks. In a tower block such as Ronan Point there are 110 apartments. Assuming a useful life of 60 years there is a 2% chance that a gas explosion would cause structural damage to one of the apartments during its existence. The Report concludes: "It is clearly not acceptable to run the risk of progressive collapse following such an explosion." In its Recommendations the Inquiry suggests that "Provided the effects can be localised and do not lead to progressive collapse, the risk of such an explosion occurring can be accepted, as it is for other types of dwelling."

This authoritative statement could be very useful to explosives safety engineers. It gives a quantitative indication of the level of risk which is acceptable to government and the public. It also draws a clear distinction between the likelihood of an accidental explosion and the severity of its consequences and shows that it is the joint effect which is the "risk" to be assessed and controlled.

HIXON LEVEL CROSSING

As a final example of the lessons to be learned from accidents and Public Inquiries I shall describe briefly a remarkable train crash. Figure 9 shows a model of a road transporter used for abnormal loads such as heavy electrical transformers and Figure 10 shows such a vehicle under way at its top speed of 2 miles per hour. On 6th January 1968 a vehicle of this type was negotiating an automatic, half-barrier railroad crossing at Hixon, Staffordshire when the warning bell and lights operated. The barrier descended on the forward part of the transformer and the drivers accelerated in an attempt to get clear of the rail tracks. Meanwhile, the Manchester to London express, which had actuated the crossing barriers when it traversed a treadle set 1,000 yards up the line, was approaching at 75 miles per hour. Owing to a long gentle bend the train driver could not see the crossing until he was within 400 yards after which he applied the brakes. However, a train of this mass and speed requires nearly 1,500 yards stopping distance.

Nobody appears to have foreseen that a 120 ton transformer transporter takes 72 seconds to negotiate this type of crossing whereas the alarm and barriers give only 24 seconds warning. It was accepted as deliberate policy that the express train would not be able to halt if anything should be stuck on the crossing. The foreseeable but unforeseen consequence is illustrated in Figure 11. Fortunately the train was relatively empty and did not strike the transformer squarely. There were only eleven fatalities.

AN ACCEPTABLE RISK

Figure 12 shows some press clippings on the theme of acceptable risks, in connection with the Hixon accident and the Torrey Canyon disaster. It also shows extracts from the official reports on Hixon and Ronan Point. A-A records the sort of statement which is widely used, in explosives safety as well as other fields of hazard, but it sounds rather less convincing when given in evidence after the postulated event has actually occurred. B-B is a wonderful testimony to the resilience of management (if that is the right word!); the statement was made within a year or so of the Torrey Canyon disaster. C-C records the view of the Inquiry into the gas explosion in Ronan Point and shows how accommodating the public can be when it suits them to accept a risk.

D-D cautions us officials that we should not get carried away by statistics. The Courts are wont to adopt the view of "the reasonable man", rather than the expert. This and the following two quotations (Figure 13) are from the Hixon Report. They help us to clarify the concept of an acceptable risk.

LIKELIHOOD AND CONSEQUENCES

One important lesson can be learned from each of the foregoing disasters, a lesson that is directly applicable to explosives safety criteria. It is that we should assess not merely the chance or likelihood of a particular accident nor simply the severity or magnitude of the consequences of that accident, but rather the joint effect of the likelihood and the consequences. At Aberfan there would have been much less effect on public opinion if the landslide had engulfed a few farmhouses only; it was the loss of the majority of the village's children in the age group 7 - 10 years that hit the headlines and made the disaster an international talking point. The Torrey Canyon would not have become notorious if it had been just one of the two tankers which every week are involved in maritime collisions; it was the magnitude of the quantity of oil released which made it a disaster. The Ronan Point Inquiry confirmed that a frequency rate of 3.5 gas explosions per million dwellings per annum is acceptable so long as the structural damage is localised; it is quite another matter when the consequences lead to the progressive collapse of twenty or so apartments. The Hixon Report concludes that it is reasonable to accept the risk of stalled vehicles in general being struck by a train on an automatic crossing because the cost of providing against this risk would be very great. If however a vehicle were itself hazardous, such as one laden with explosives, radioactive material, gasoline or corrosive liquids, the consequential damage and injury might be so great that the risk would no longer be acceptable. For this reason modifications to the existing arrangements were recommended in the case of abnormal loads on road vehicles.

Since the overall risk to be assessed and controlled is the joint effect of likelihood and consequences, it is unfortunate that the English language tends to confuse the issue through ambiguity. Sometimes the words 'risk,' 'hazard' and 'danger' are used to refer to the chance of an accident and at other times they refer to the magnitude of the consequences. One must examine the context to determine which sense is intended. This ambiguity of language tends to lead to looseness of thought. Often one hears pointless arguments in which the parties are using the words in rather different senses. The recent proposals of the United Nations Group of Experts on Explosives include a definition of explosives Compatability Groups which explicitly draws a distinction between anything which increases the chance of an accidental explosion on the one hand and anything which increases the magnitude of the effects of such an explosion on the other hand. This distinction should be borne in mind as we relate the lessons from the foregoing considerations and try to derive conclusions relevant to quantity-distance criteria.

It was suggested earlier that, with the notable exception of the hazard from ionising radiation, there is little formal machinery or attempt to correlate the degree of risk to public safety accepted in the various fields of hazardous activity. Explosives safety authorities, such as the ASESB and the UK Explosives Storage and Transport Committee, must make their own studies to guide them as to what level of risk is likely to be acceptable, not only in the case of postulated accidents but also after the event when they may be called upon to justify their decisions. It is proposed that such authorities could achieve a more flexible and consistent policy if they were consciously to review all the factors involved in the assessment of overall risks instead of arbitrarily excluding certain factors.

This review of the basic doctrine underlying quantity-distance criteria should be carried out with two important points in mind.

First that safety is a relative matter and we should be prepared to accept risks if the cost of their elimination outweighs the benefits to be gained by their elimination. Figure 13 records two passages from the Report of the Hixon Inquiry which support this tenet. The second point is that assessments of risk involve judgment because it is not possible to know all the facts or to evaluate all the factors; and that in consequence such assessments are highly subjective and therefore susceptible to subconscious influence. A report published in 1964 for the Legislative Drafting Research Fund, Columbia University New York, entitled "Some Major Hazards in Government Sponsored Activities," provides some stimulating thoughts on this point. It warns against assuming that an incredible accident is necessarily an impossible accident. No matter how small the probability of an event it can happen today; indeed it can happen twice today and then not again for centuries. There is no comfort in a low probability if the occurrence leads to catastrophic losses.

REVIEW OF QUANTITY-DISTANCE CRITERIA

Let us now look at Figure 14 and discuss some specific limitations of current explosives safety criteria in order to see how a review might lead to a more flexible and consistent policy and, in some instances, effect savings in money and resources.

Item 1 refers to the extensive and sometimes elaborate systems adopted in many countries to make the formal, rigid quantity-distance regulations into workable procedures. Many exemptions arise when standards are raised in the regulations thus making existing facilities sub-standard. Others arise when the regulations do not take sufficient account of practical problems of implementation. If the policy for quantity-distances were more flexible many of these exemptions and waivers would be unnecessary. Authorities would have a better appreciation of the actual risks which are being accepted. There could be savings in the cost of administration of elaborate systems of exemption and annual reviews of waivers.

Item 2a is best explained by specific illustrations. The situati in Figure 15 complies with the quantity-distance criteria for inhabited buildings; that in Figure 16 does not because there is an inhabited castle within the prescribed Inhabited Building Distance. Which situation presents the greater hazard? Which would involve the greater costs for compensation in the event of an explosion? Which would have the greater political repercussions? It is not unknown for the man with operational responsibility to accept the presence of isolated dwellings and to apply for the necessary waiver (or whatever euphemism we care to use). Is this not an intuitive criticism of the quantity-distance criteria?

Item 2a would take into account the density of occupation, as well as the density of exposure, of buildings within and without the mystical radius called the Inhabited Building Distance. The provision of more flexible and more realistic criteria would enable authorities in Australia and the UK to insist on their observance in such places as commercial ports. Until recently the view prevailed that since the formal requirements for inhabited buildings were impracticable then there need not be any attempt at all to safeguard dwellings around ports. Surely it is not necessarily a choice of all or nothing? Even if Australian and UK Governments are not prepared to adopt the bold measures taken in Port Chicago there can be some measure of safeguarding of dwellings. A more flexible set of criteria will provide the means.

Inhabited Building Distances are based mainly on observations of blast damage to dwellings 25 years ago. You will have noticed that building materials and techniques have since changed considerably. The UK has introduced special quantity-distances for curtain wall construction but this deals with only one aspect of the problem. Should not our criteria take account of the vulnerability or resistance to blast of various buildings used for schools, hospitals and office blocks? Should we not distinguish between buildings with numerous people behind vast areas of glass and buildings where the glass would merely strike machinery in the event of an explosion in the neighborhood?

I understand the ASESB has sponsored a study of the density of harmful fragments and debris at various distances from explosions. To apply this data meaningfully we must multiply the chance of a fragment landing at a particular spot by the probability that there will be a target at that spot. Density of occupation by buildings and people must be taken into account otherwise we shall base our criteria on only half the story. There is also some scope for a review of the controversial assumptions which underly current criteria for highways. Both the UK and NATO are engaged in a new attempt to classify roads on the basis of the chance that a significant number of people will be exposed at the instant of an explosion.

Item 2b would take account of the containment of blast and flame by a primary building. This effect can be significant in the case of modest quantities of explosives in robust structures. On the other hand it is important to allow for the increased debris hazard when such a building does break up. Under this heading one would take account of barricades. I gather the subject of barricade effectiveness is a delicate one in the Department of Defense. Terrain also can affect blast and debris hazards under certain circumstances. Although these cases are relatively infrequent they could be taken into account under 2b.

Next we consider significant differences in the order of magnitude of the probability of an explosion during various activities (3a). These range from a value of unity in the case of deliberate detonations on proving grounds, through somewhat smaller values during high risk experiments such as rough usage tests, intermediate values for rocket launching and the manufacture or transhipment of explosives, down to minimal values during static storage under ideal conditions. There is little formal attempt at correlation. Quantity-distance criteria are applied to a variety of manufacturing and storage buildings without any regard for the significant differences in the chance of explosion in, say, a building for NG processes and another for long term storage of TNT. When the chance is considered really significant, as during the machining or pressing of explosives, robust cells are constructed to restrict the consequences. By implication the quantity-distance criteria are judged to be inadequate for these situations. Why not modify the criteria throughout the spectrum of explosive operations? A number of weighting factors could relate the particular activity and risk to the appropriate quantity-distance. This would unify the decisions of the various authorities involved.

There are also significant variations in the likelihood of an accidental explosion due to intrinsic features of the explosive items (3b). The presence or absence of its own means of ignition or initiation is already recognised as an important factor in certain railroad regulations and in the latest UN system of classification of explosives for transportation. Should it not also feature in quantity-distance criteria? Another aspect of the likelihood of an explosion in a given location concerns transient risks (3c). During the conveyance of a particular consignment of explosives by several modes of transport the explosives pass through towns, stations and ports and there is a certain amount of transhipment. The overall risk to each centre of population could be assessed, giving due regard to the duration of the risk as well as its intensity or magnitude. Some form of integration over the year for all consignments and for all the principal danger points en route would permit a sensible ranking of overall hazards and show where money could best be spent to provide greater safety. There is little point in spending vast sums to observe full Inhabited Building Distances in a port, for example, if there is only one shipment per year through it, while at another port which is continually exposed to risks from one consignment or another there is complacency since the prescribed quantity-distances can be observed. This situation would be aggravated if the latter port had thousands of dwellings in the zone just beyond the Inhabited Building Distance.

Finally we should look at certain factors which relate to the joint effect of likelihood and consequences, what we have called the overall risk. This is analogous to what an actuary calls the risk to be underwritten, depending on both the chance of a claim and the magnitude of the insurance cover. Item 4a refers to the statistical uncertainty or low level of confidence we suffer in Hazard Classification owing to the limited number of tests that can be performed. If a mass detonating item is mistakenly classified as Quantity-Distance Hazard Class 2, 3 or 4 then it is much more likely that serious consequences of an accident could ensue. It is arguable whether the mistake affects the consequences of the initial incident, such as the actuation of a fuze or blasting cap fitted to the item, or whether it affects the likelihood of a mass explosion which ought to have been zero. It depends how we define the system. Another system in which we must assess the total risk is the bulk container used for modern transportation by land and sea (4b). At first the UK authorities were diffident to allow the shipment of commercial explosives to Australia in containers because the unit quantity would be so great. However it was soon realised that containerisation provided safeguards which outweighed the increased hazard potential. A container could be specially designed for explosives and could incorporate better mechanical protection and resistance to external fire. It would be stowed by specialists at the explosive factory whereas individual packages of explosives are stowed into a ship's hold by ordinary stevedores. There would be far less chance of the load being dropped on the wharf or into a hold. If we assess the overall risk we conclude that containerisation of explosives may actually improve safety. The third application (4c) concerns the observance of some form of quantity-distances around explosives held in readiness for operational use in the event of an emergency or declaration of war. Such sites are not strictly storage depots nor are they truly transhipment areas. A flexible policy is necessary to afford some measure of protection to dwellings in the vicinity of such holding areas without creating an impossible situation for the field commander. Strict implementation of current, rigid quantity-distances would probably result in another batch of waivers.

The last item (4d) raises some rather profound thoughts and intractable problems. We have implied that the aim of a flexible and rational doctrine of acceptable risk should be to maintain reasonably constant levels of overall risk throughout the many activities and departments concerned with explosives. In fact the risk which is acceptable will vary somewhat according to how popular or beneficial the activity is in the view of the government and public opinion. There is however a more important limitation to our doctrine. If the damage potential of a postulated accident is great then the design of protective procedures should ensure that the chance of that accident occurring is small. What if the magnitude of the damage potential becomes extremely great, as in the case of a megaton nuclear explosion or a Saturn V rocket landing on Miami? Our mathematical relation requires us to compensate by making the chance of such a calamity correspondingly small. However we indicated earlier that there is no comfort in low probabilities if the occurrence leads to catastrophic losses because however small the chance may be, it could happen today. There may be an upper limit to the magnitude of the damage potential for which our relation is valid. It would be interesting to learn how the authorities responsible for assessing safety standards in nuclear devices and space systems have dealt with this problem. As the number of technological activities increase which involve the risk of calamitous losses, so do the chances increase that sooner or later one of these calamities will happen. It is to be hoped the authorities will have applied the lessons from the minor disasters we have examined today and that there will not be a repetition of the blind spots and lack of foresight revealed by those inquiries.

CONCLUSION

In conclusion I should like to reiterate the proposals we have discussed:

1. It would be helpful and reassuring for explosives safety authorities if they were to be given an explicit safety philosophy from which to derive safety criteria and against which to judge what risks are deemed to be acceptable.

2. In the absence of any such philosophy we can find clues as to what is likely to be acceptable, after an accident has occurred as well as when it is merely postulated, by studying the records of Public Inquiries and Tribunals which have investigated disasters.

(" 'tis held that sorrow makes us wise."

" Out of this nettle, danger, we pluck this flower, safety.")

3. A more consistent and flexible safety policy can be formulated by taking account of all factors which determine the overall risk, comprising the likelihood of an accidental explosion and the magnitude of its consequences, instead of arbitrarily excluding some of the factors.

4. Such a policy could be implemented by a relatively minor modification to the current system of quantity-distance criteria. A number of weighting factors could be introduced to take account of the various factors which determine the overall risk.

5. The application of modified quantity-distances could promote public safety in certain areas, could effect savings in money and real estate in other areas, and would eliminate many existing waivers and relaxations.

ACKNOWLEDGMENTS

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Figure 2 by courtesy of Topix, Thomson Newspapers Ltd.
Figure 3 by courtesy of Chief Constable, Merthyr Tydfil.
Figure 6 by courtesy of London Express News and Feature Service.
Figure 7 by courtesy of The Evening Standard
Figure 10 by courtesy of Associated Electrical Industries Ltd.
Figure 11 by courtesy of Daily Mirror Newspapers Ltd.

FIGURE 1 Grade B damage (above) or worse occurs in 7% of cases at the Inhabited Building Distance

FIGURE [illegible]

FIGURE 3

FIGURE 4

Extract From the Proceedings of the Aberfan Tribunal

Chairman to the local MP: You have told us that you had entertained a fear that not only might the tip slip but it might reach the village and, reaching the village, might involve risk to life. Is that right so far?

Answer: Yes, certainly.

Question: What each and every one of the members of the Tribunal want to establish is this: If you entertained in your mind the substantial fear of risk to life, what did it matter whether people asked you to take steps or not? Why not take them if there was risk to life?

Answer: If I had taken them, I have my lord - permit me to say this --

Chairman: Certainly.

Answer: ---more than a shrewd suspicion that the colliery would be closed.

Question: Then are we to understand that you went through the tortuous, and no doubt tortured, process of thought of weighing one against the other, the risk of life on the one hand and the risk of colliery closure on the other, and came down in favour of taking no action which might risk colliery closure? Mr. Davies, think about the question. You understand it is a question of considerable gravity.

FIGURE 5

Scientists vote for national disaster plan

A

THE critical report on the Torrey Canyon disaster from the House of Commons Select Committee on Science and Technology coincides with a move to do something about disasters in general.

A

B

The Select Committee's report underlines the potential usefulness of much more contingency planning, which demands both scientific research and advice, and a close look at administrative arrangements.

B

D

There is no doubt that technology is capable of generating disasters on a new scale, and involving new problems.

What, for example, would be the effects of a jumbo-jet crashing on a large chemical plant handling corrosive and dangerous liquids and gases?

D

E

Tankers have been allowed to get bigger with quite insufficient work on emergency braking and manoeuvring arrangements, while extraordinary numbers of collisions at sea continue —two accidents a week involving tankers alone

E

F

Suppose a lorry full of a potent toxic chemical crashed unseen, at midnight, into a large metropolitan reservoir? Fertile imaginations will have no difficulty in conceiving further possibilities.

F

G

All this suggests that a continuing study, starting with more likely disasters, but working on to less probable ones, could be an important insurance.

G

Torrey Canyon

C

The Government was sharply criticised yesterday for inadequate preparations to deal with the "very great possibility" of another Torrey Canyon disaster.

A report by the all-party Commons Select Committee on Science and Technology says it is "gravely disturbed" by the lack of action and complacency in Whitehall.

And it pins the ultimate responsibility firmly on the Prime Minister.

C

FIGURE 6

FIGURE 7

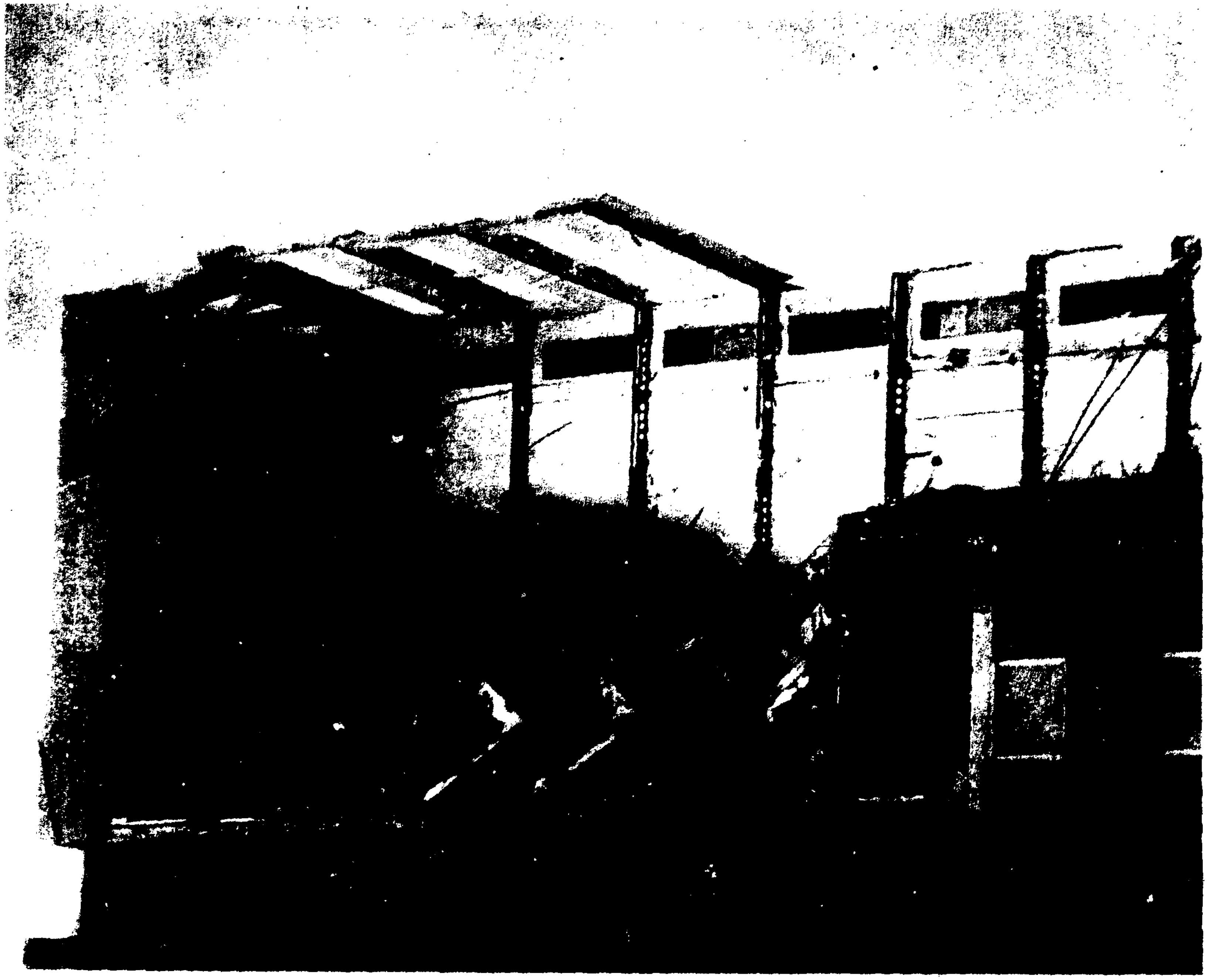


FIGURE 8

Press Clippings Relating to the System Built Flats at Ronan Point

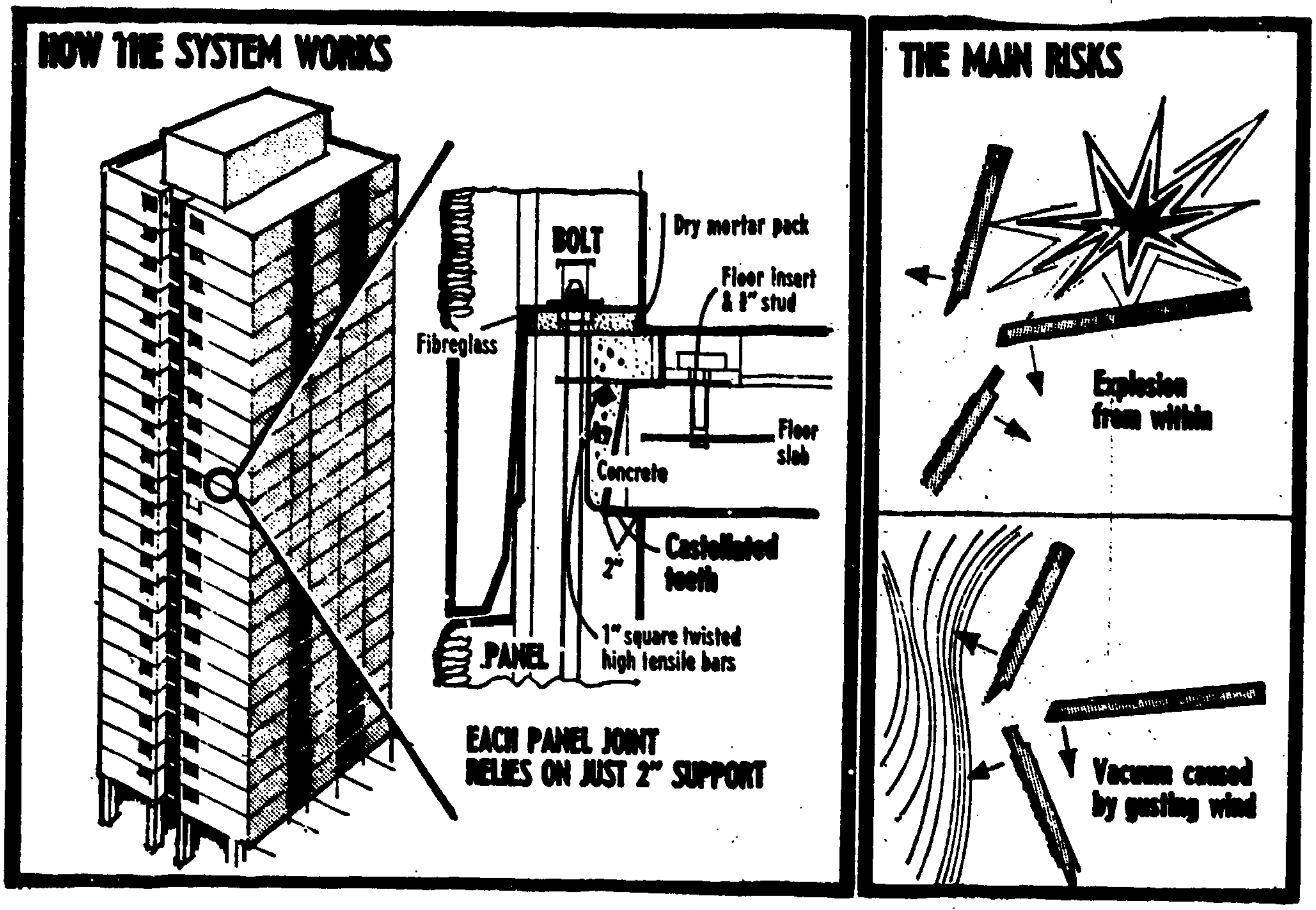


FIGURE 8 (cont'd)

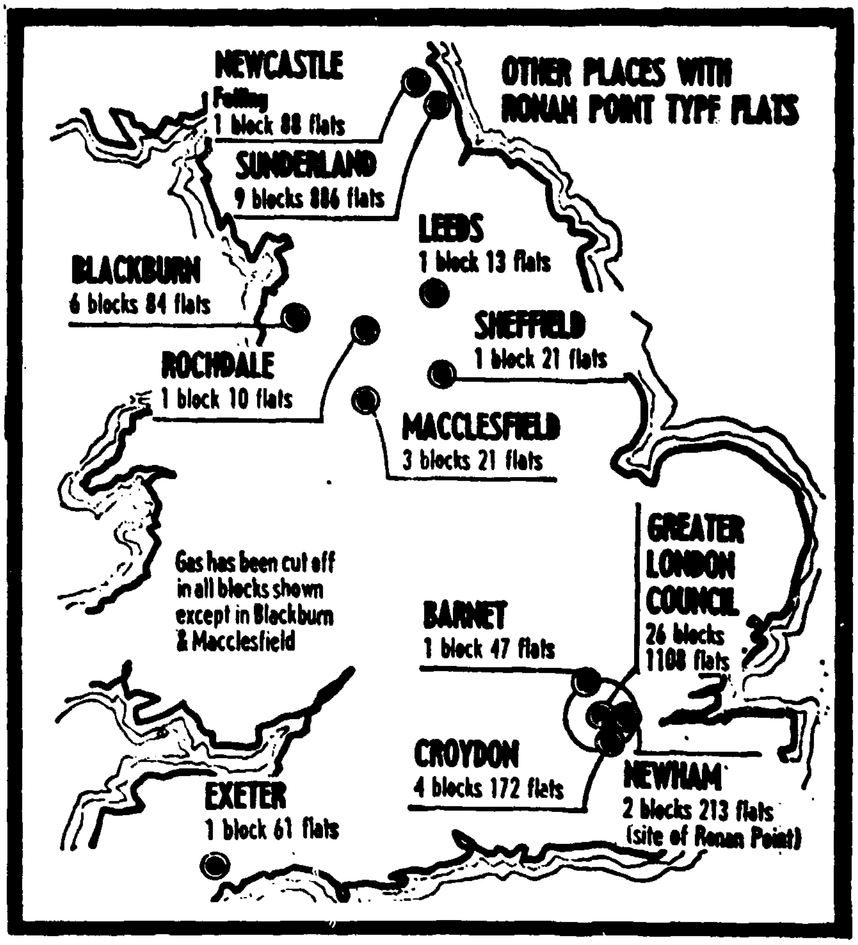


FIGURE 9

Model of road transporter

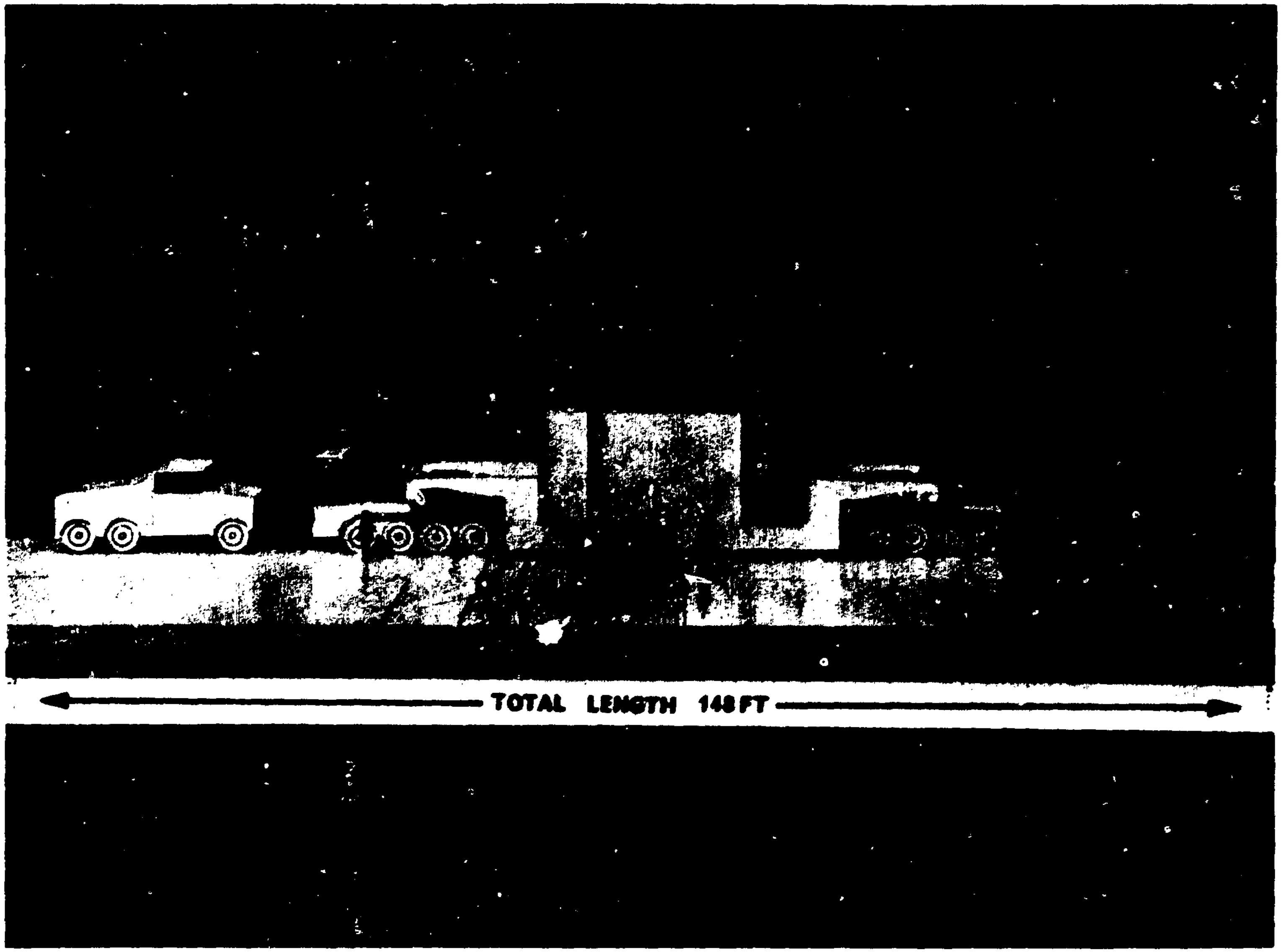


FIGURE 10

Transporter under way with heavy transformer

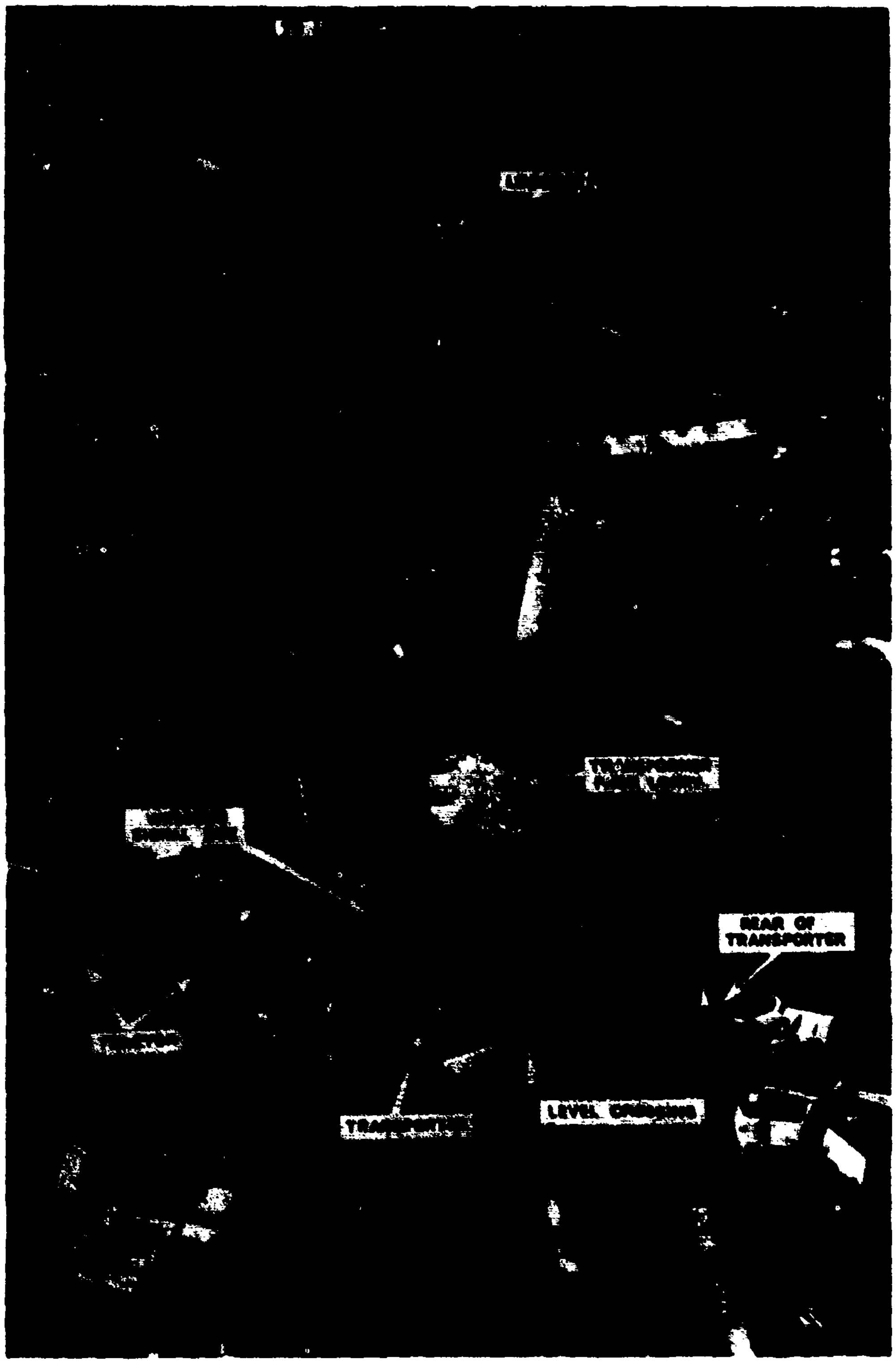


FIGURE 11 After the crash

FIGURE 12

Press Clippings and Extracts From the Reports on the Four Disasters

Level crossing breakdown risk 'acceptable'

Mr Brian Cobb, superintendent engineer at the Ministry of Transport, told the Hixon rail crash inquiry in London yesterday that the risk of a vehicle becoming immobilised on an automatic level crossing was so small as to be acceptable.

Mr W. M. Klune, chairman of the Mobil Shipping Company, said that a pollution disaster like that of the 'Torrey Canyon' was considered by tanker operators to be "a one-in-a-million chance.'

As we have said, gas is justifiably regarded as a safe and acceptable fuel in domestic premises generally. In 1966, of approximately 18,000,000 dwellings in the United Kingdom, 12,260,000 were supplied with gas.

The 1966 figures show that the frequency of explosions involving town gas in premises supplied with gas is approximately 8 per million dwellings, of which only 3·5 per million will be of sufficient violence to cause structural damage.

I think the failure to appreciate the problem was due to a wrong approach in two ways. Firstly, the officers of the Ministry relied too much on statistics. For instance, the risk of a vehicle stalling on a crossing, rather than anywhere else on the 200,000 miles of roads in Britain, was accepted as very remote because it is statistically minute.

FIGURE 13

Extracts From the Report on the Accident at Hixon

Safety is a relative concept varying in proportion to its opposite, danger. It is almost impossible to remove absolutely the risk of accident from any form of human activity, and it is a truism that many forms of progress, though producing greater safety than of old, bring with them possibilities of greater catastrophe: the jet aeroplane, the motor car, motorways, and express trains, all are liable to produce serious loss of life but they have been accepted by the public because the advantages they bring outweigh the inescapable risks.

Safety can, in a sense, be bought like any tangible commodity—the higher the price paid, the better the safety; and, in assessing the degree of safety to be acquired, one must put into the balance, on the one side, the magnitude of the danger to be eliminated and, on the other, the sacrifice in money, time, convenience, material resources (and the neglect of other pressing safety needs elsewhere) involved in eliminating that danger.

FIGURE 14

Factors Involved in Quantity-Distance Criteria

1. Exemptions, waivers, concessions, relaxations, deviations and derogations.
2. Factors which determine the consequences of an explosion:
    a. Density and duration of exposure of people, buildings and vehicles.
    b. Interaction of blast and missiles with the environment.
3. Factors which affect the likelihood of an explosion:
    a. Nature of the activity.
    b. Nature of the explosive or device.
    c. Frequency and duration of the activity.
4. Factors involved in the assessment of overall risk:
    a. Uncertainty in estimates and predictions.
    b. Compensating features (e.g. shipping containers).
    c. Novel circumstances (e.g. basic load holding sites).
    d. Limits to the validity of the concept of acceptable risk.

FIGURE 15

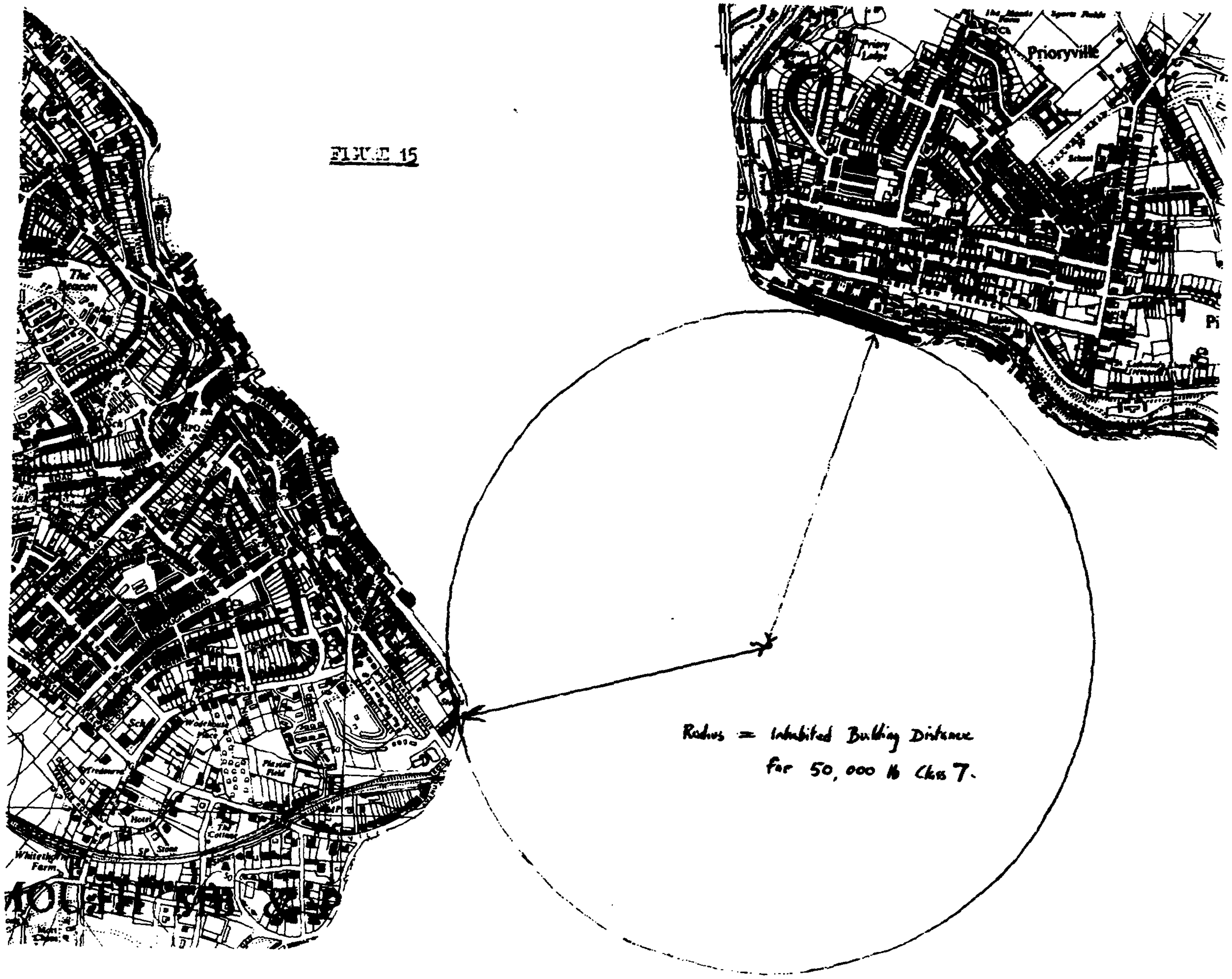
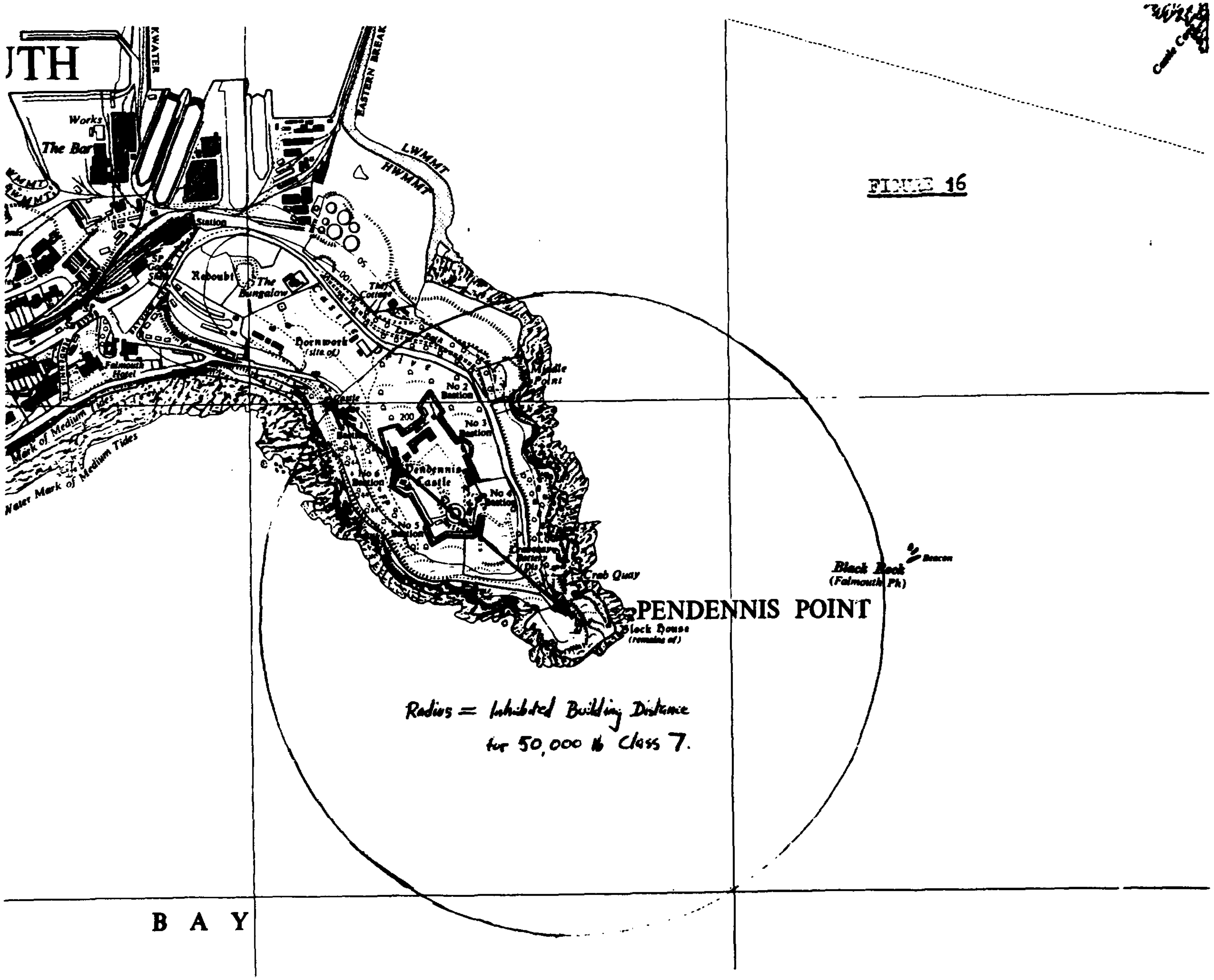

Prioryville
Priory Lodge
The Beacon
School
Playing Field
Hotel
The Cottage
Whitethorn Farm
Radius = Inhabited Building Distance for 50,000 lb Class 7.

FIGURE 16


UTH
KWATER
EASTERN BREAK
Works
The Bar
LWMMT
HWMMT
Station
Redoubt
The Bungalow
Hornwork (site of)
Falmouth Hotel
Middle Point
No 2 Bastion
No 3 Bastion
No 4 Bastion
No 5 Bastion
No 6 Bastion
Pendennis Castle
200
Crab Quay
PENDENNIS POINT
Block House (remains of)
Black Rock (Falmouth Pt)
Beacon
Water Mark of Medium Tides
Mark of Medium
B A Y
Radius = Inhabited Building Distance
for 50,000 lb Class 7.

Discussion of Paper Entitled
"Quantity-Distance Criteria - A More Flexible Policy in Future"

About 40 persons participated in a discussion of risks and hazards after the formal presentation. Each person drew upon his own experiences in a particular field. Comparisons were made between the level of risk deemed to be acceptable in road safety, in the carriage of hazardous materials by railroad and by air, and in experimental work with sources of tremendous destructive power such as hurricanes and nuclear energy. A distinction was drawn between those activities in which the potential victim is largely responsible for his own safety, such as when he chooses to drive an automobile, and those in which safety is determined by factors out of his personal control. Reference was made to the National Safety Council and to the benefit which could derive from a national study of hazard levels in all fields of human activity. Such a study could show where funds might best be directed to the promotion of safety.

The discussion then reverted to the particular hazards of ordnance. Future problems to be solved concern the formulation of quantity-distance criteria for basic load holding sites in Europe; the rationalisation of regulations for the conveyance of explosives, toxic chemicals and other hazardous materials by air or railroad; and modification of current Q-D criteria for inhabited buildings and highways to achieve a more consistent level of protection which would take account of the probable numbers at risk. The ASESB project on fragment hazards created particular interest as an example of a field in which many probabilities or possibilities must be compounded before an overall judgment can be made as to what constitutes an acceptable criterion of residual risk.

Evaluation of Explosion Hazards in Industry

by

R. F. Chaiken and R. W. Woolfolk[†]

Physical Sciences Division
Stanford Research Institute
Menlo Park, California 94025

[†] Physical Chemist, presented paper.

The evaluation of explosive hazards for industrial application is becoming ever more important as our highly technical society uses larger and larger quantities of hazardous chemicals and materials. As plant facilities and population density increase, the danger of a catastrophic accident with its large economic losses becomes an ever more probable event. We feel that a fundamental scientific approach to industrial explosive safety will lead to an effective loss prevention program. Is this scientific knowledge of explosives available? The answer is yes.

The military has for many years supported a large effort to understand explosives, explosions and explosive safety. This effort has been lead by the Armed Services Explosive Safety Board and these efforts have accumulated a vast pool of fundamental and applied knowledge which is directly applicable to an industrial loss prevention program.

We feel the time has arrived for a technology transfer of this knowledge. The purpose of this paper is to discuss some areas that bear directly on industrial hazards evaluation.

This discussion takes the format of pertinent questions that need answering and where we stand with regard to being able to supply the answers. We hope to show how presently available knowledge in the form of modeling studies and computer codes can provide an effective program for loss prevention. I will discuss only some of the areas that are important and concentrate on those areas of greater familiarity to me. However, the general approach can be expanded to cover all the important factors.

The first slide (Slide 1) contains some of the questions to be explored in this discussion. First, one must determine what is the available chemical energy. Is there, in fact, enough chemical energy to cause an explosion. Second, if an explosive release of energy is possible, what are the conditions for this release. Third, after the energy has been released, what are the factors in the production of the blast wave and fragmentation. These are the means by which the explosive energy is transferred to the target. We will not discuss fragmentation to any great extent but will concentrate on some of the questions related to blast waves. The next important question is what is the response of the targets, personnel and structures to the energy release. Finally, a question not seen in the slide but fundamental to this discussion: How can technical knowledge be utilized to estimate the hazard and to minimize the potential damage.

I will now discuss various aspects of each of these questions. As I stated in the beginning I will be emphasizing the use of modeling and computer codes as a useful means for solving hazards evaluation. Recently a computer program has been developed to calculate the explosive potential and detonation conditions for almost any chemical system. This program or code is called TIGER. While I cannot show you the code, I can show you a TIGER. (Slide 2)

TIGER is a program designed to calculate the theoretical chemical energy and hydrodynamic conditions of a detonation. It basically works by calculating the chemical thermodynamic equilibrium of the possible detonation products and using hydrodynamic equations and the Chapman-Jouguet (C-J) theory to give the detonation velocity and other important parameters. For those not familiar with the C-J hypothesis, it is simply that the detonation velocity is equal to the sum of the sound velocity and the particle velocity of the chemical product gases. However, to use TIGER, one need not understand the details of the method of calculation. Let's look at a sample calculation from TIGER (Slide 3). Here we have listed some of the information for the C-J condition (detonation) for two explosive systems. TNT was chosen because of its familiarity. The mixture styrene-air is of importance for industrial hazards evaluation. The input parameters are P_0, V_0, and E_0, the initial pressure, specific volume, and energy. I have chosen only a few of the output data from TIGER. In addition such parameters as composition, entropy, and enthalpy are also available.

Some interesting observations about gaseous and solid explosives can be made by comparing these two systems. The energy of the styrene-air system is actually greater on a per gram basis than TNT. Although on a density or volume basis TNT is much more potent. However, in industrial situations where tons of styrene are used, this constitutes a real hazard if it should become mixed with air.

Let us now view the next question (Slide 4). What are the conditions for explosive release of chemical energy? This is the area of initiation about which we know considerably less than in the potential energy case. For those familiar with solid and liquid explosive, this is usually referred to as sensitivity. There are a wide variety of sensitivity tests to study the responses of an explosive system to various stimuli such as shock, heat, friction, etc. In the case of gaseous explosive mixtures, such as a mixture of air and hydrocarbons which are of importance to industrial accidents, persons usually speak of ignition characteristics.

Let's examine briefly a case of industrial interest. The next slide shows the limits of flammability for a natural gas-air mixture and the effect of various additives on its flammability limits. (Slide 5) Along the side we have the per cent of methane in the mixture. Along the top and bottom we have the per cent of oxygen and dilute gas respectively in the gas mixture.

Outside of the enclosed regions are the areas of nonflammability. One notes that a large amount of argon is needed to render the gas mixture nonflammable. Lesser amounts of N_2, H_2O, and CO_2 are needed. This is primarily a heat capacity effect. The inert polyatomic gases absorbed more heat from the methane-air reaction and are therefore more effective in reducing the flammability limits than argon. The dotted line represents the effect that can be achieved by using chemically active material such as organic halides. It is interesting to note that just addition of fuel or air can render a gas mixture nonflammable by moving the mixture outside its flammability limits.

It should be emphasized that to be effective all of the diluents must be well dispersed within the gas cloud. This suggests that the use of an aerosol dissemination device such as those developed for military use would be a useful tool in reducing the danger of an explosion from large gas clouds. This is another example of possible "technological transfer" from military to civilian use.

Despite all precautions, industrial explosions will take place and therefore we must be prepared for the consequences of an explosion. One of the primary ways in which an explosion causes damage is by the release of a blast wave. The next slide asks the question what is the strength of the ensuing blast wave (Slide 6). There are two points I would like to discuss concerning the blast wave, the residual energy and the scaling laws or TNT equivalence. A blast wave is a mechanism for distributing the energy of an explosion from its source to the far distances. The energy of blast wave at any point is the difference between its initial energy and that which has been dissipated by passage through the air. We will call this the residual energy of the wave. This energy is characterized by the peak overpressure and the wave shape. I will discuss this question more fully in a few moments. I would like now to discuss some interesting aspects of scaling laws and in particular the case of nonideal explosives. A nonideal explosive is one in which the explosive energy is released at a rate slower than in a detonating explosive such as TNT. The consequence of this factor in terms of the ensuing blast wave can be illustrated by the next slide (Slide 7). Here we have a plot of the peak overpressure versus distance for TNT and an aluminized propellant. These experimental data were obtained by BRL for TNT[1] and by Aerojet for the propellant.[2] In the propellant case because of the slower burning aluminum the initial peak pressure is lower than for TNT. But because a blast wave decays in proportion to its peak pressure more of the energy of a TNT wave is lost close to the source of the blast. Therefore the overpressure curves tend to cross one another, in this instance at about 10 psi. One measure of an explosive's strength is to relate it to TNT, the so called "TNT equivalency." This can be measured by taking the ratio of the overpressure at different stations for equal amounts of explosive. In the present case one can see that the TNT equivalency will vary from less than one in the near field to greater than one in the far field. In this instance the concept of TNT equivalence is not valid. The situation becomes even more complicated in that as the charge size is increased a propellant-like explosion would deviate even more. Therefore scaling from small experiments with present scaling laws is not possible. The type of explosion most likely to occur in industrial situations are of the nonideal type (i.e. gas clouds and pyrotechnic materials) where present scaling laws will not correctly indicate the strength of the blast wave.

Let us now look at what happens when the blast wave interacts with targets. The next slide asks that question (Slide 8). First we have two important problems. These are the properties of the wave as characterized by its construction, material and shape. The wave properties are again a measure of the residual energy we were speaking of earlier. Therefore we have an energy delivering device, the blast wave, and an energy receiving device, the target. The extent of damage is the interrelation between these two. Before we discuss this in detail let's look at some overpressure levels at which damage can occur for various types of structures (Slide 9). These data are for a nuclear blast wave. The overpressure levels do not apply to typical explosions because nuclear blast waves have a much longer duration. Let's look at how the properties of a blast and properties of a target interact. The next slide shows the data obtained for an aluminum cylinder with a radius to thickness ratio of (a/h) 61 subject to various shape blast waves (Slide 10). Here we have plotted equal damage lines (iso damage) for various coatings. The data are plotted on the plane of overpressure and impulse. The impulse is in cgs units. One immediately notes that as the impulse is increased the overpressure at which damage occurs is decreased. This is why one must be careful when extrapolating nuclear data to other explosive sources since they typically have greater impulse for a given overpressure level. The properties of the target are also clearly indicated by the fact that as coatings are added the target can sustain greater overpressure and impulse before damage occurs. While this is only one illustration of the information available, one can see how extrapolation to real structures can be made. To sum up, one must know both the properties of the blast wave and the target before a realistic estimate of the damage can be made.

As I stated earlier, I do not intend to discuss the problem of fragmentation but only to state that in this area the situation is further complicated by the fact that there are three important factors. The energy of the explosive, the target response and way in which fragments are formed (i.e. size and distribution). I would now like to show how a modern 2-dimentional time dependent computer code may help solve at least one of these problems. Since this is a time dependent problem it would be more informative to show a short movie of the output from such a program. However, the problem is illustrated in the next slide (Slide 11).

The model consists of a steel projectile impacting a ceramic plate. Because of the symmetric nature of the model the computer output shows only the upper half of the problem. The program will calculate the principle planes of stress and the hoop stress. In a typical problem the projectile impacts at a velocity of 2400 feet/sec and the stress levels greater than

7 kbars are calculated. The total time elapse is about 3.5 μsec. A movie of the output would show the stress moving into the plate and back down the projectile. By knowing the stress level at which cracking occurs one can estimate probable damage. This illustrates how 2D-time dependent codes now available might be used to solve problems associated with exposion hazards. The value of such an approach is that by changing the parameters of the model one can create a realistic problem.

How can we bring all of the factors in the industrial hazards evaluation into focus? Let's look at how the technical knowledge of explosions can be used to evaluate the hazards (Slide 12).

First of all there are model studies that have been performed either for safety problems or in other fields as I indicated by the illustration of blast damage and projectile studies. Secondly, we can computerize this modeling problem study as I illustrated by TIGER and the 2D code and finally a total model, computerized, can be pointed toward a solution. Let's summarize what we feel is a realistic approach (Slide 13).

We have discussed how the potential energy might be estimated (TIGER), how one can investigate the probability of an explosion (initiation). Here is where prevention devices such as aerosol disseminators for gas clouds could be used. Should an explosion take place, we have discussed blast wave properties and some problems associated with their estimation. The area of fragmentation was touched on only briefly, but there are current programs sponsored by the ASESB studying this very problem. Once we have the properties of the blast wave and the fragment density we can begin to assess the potential damage. These damage estimates lead to an estimation of the secondary hazards such as fire and release of toxic materials. Frequently a relatively small explosion will lead to a large loss due to the release of other dangerous materials. Such a case is illustrated by the recent explosion of a rail tank car which led to the release of large quantities of cyanide chemicals. For a complete solution to industrial explosion hazards it is necessary to include such non-technical factors as economics. At this point the job becomes one for safety personnel and systems engineers. They must design the optimum system. Close coordination between safety personnel and technical workers is necessary in any solution to the problem of explosion hazards.

In conclusion we feel that the use of presently available technical knowledge about explosions can lead to realistic evaluation of industrial hazards. This will be accomplished by judicious use of computer modeling techniques, coupled with existing as well as newly acquired data.

In general we feel that with a concerted multidisciplinary effort it should be possible to put more science into safety and make safety more of a science.

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WHAT IS THE AVAILABLE CHEMICAL ENERGY?

WHAT ARE THE CONDITIONS FOR THE EXPLOSIVE RELEASE OF THIS ENERGY?

WHAT ARE THE FACTORS IN THE PRODUCTION OF THE BLAST WAVE AND FRAGMENTATION?

WHAT IS THE RESPONSE OF PERSONNEL AND STRUCTURES TO THE ENERGY RELEASE?

Slide I

TIGER
DOCUMENTATION
VOLUME ■■■■

Slide 2

THE C-J CONDITIONS FROM TIGER

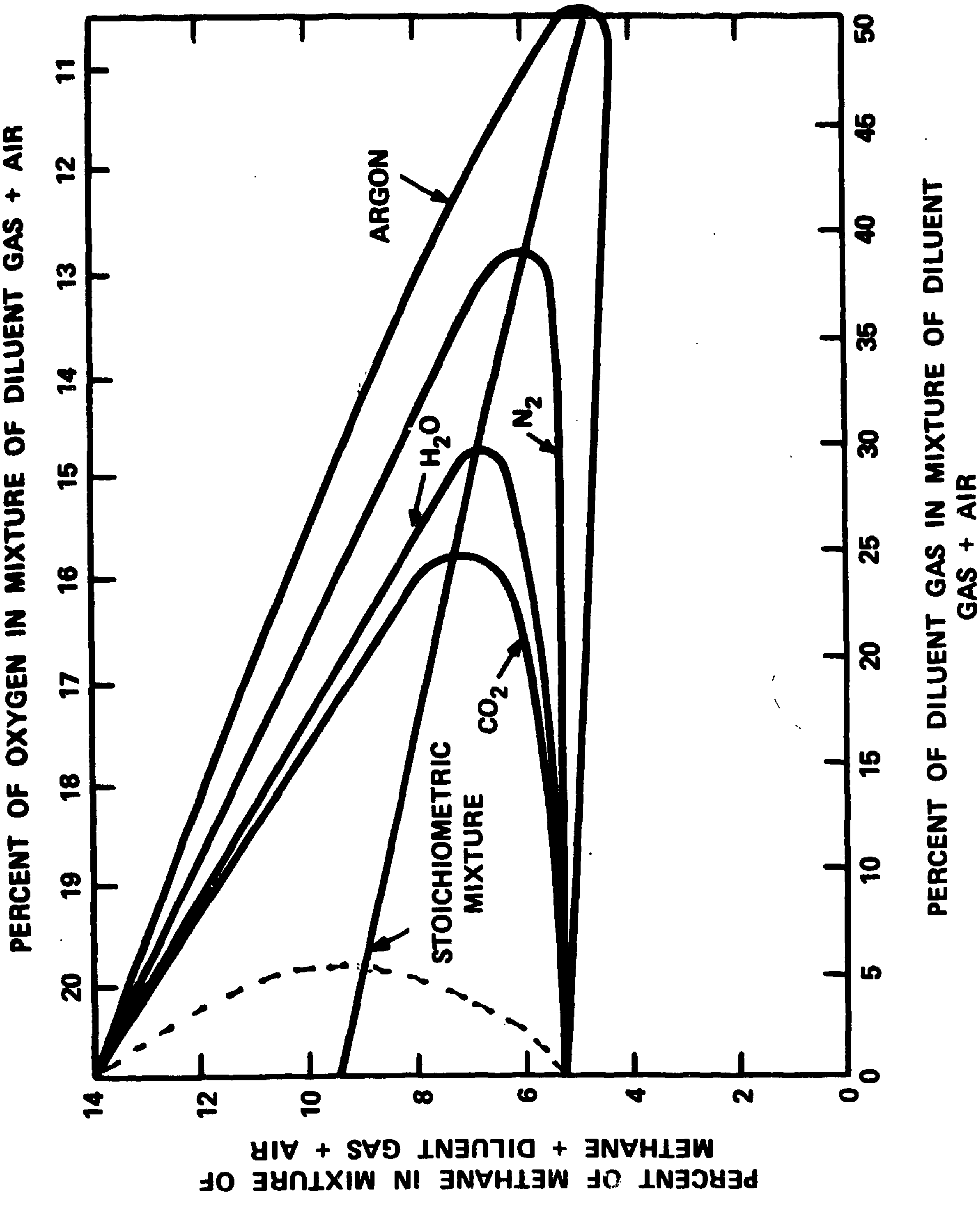
DETONATION VELOCITY	TNT	STYRENE/AIR (1/10)
	7.25×10^3 M/S	1.69×10^3 M/S
P_o (atm)	1.00	1.00
$1/\rho_o = V_o$ (cc/gm)	0.625	820.00
E_o (cal/gm)	-78.41	-11.65
P (atm)	2.14×10^5	13.5
V (cc/gm)	0.463	555.
T (ok)	2715	2662

Slide 3

WHAT ARE THE CONDITIONS FOR EXPLOSIVE RELEASE OF CHEMICAL ENERGY?

- INITIATION
  - SENSITIVITY
  - IGNITION

Slide 4

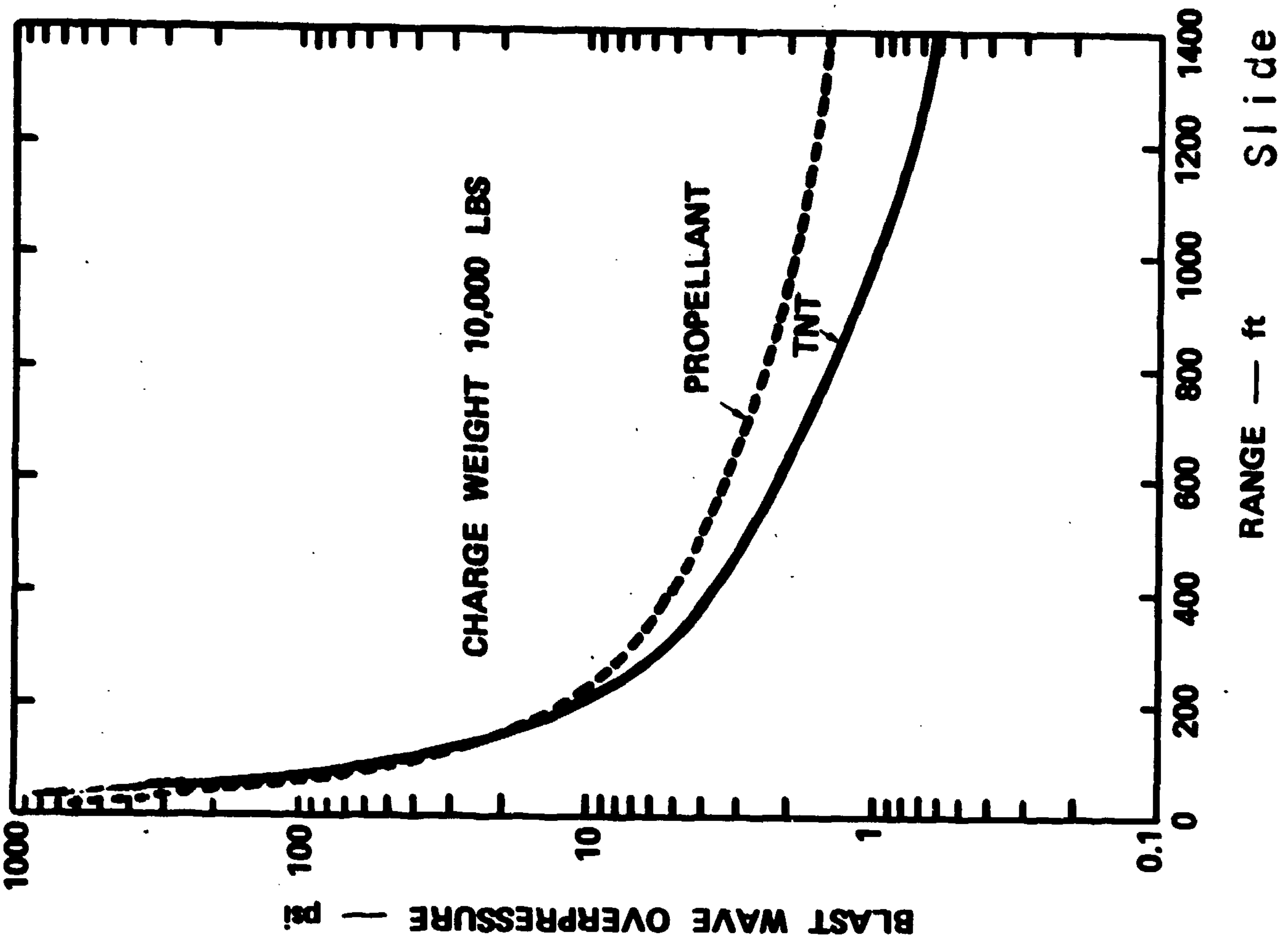

PERCENT OF OXYGEN IN MIXTURE OF DILUENT GAS + AIR
20
19
18
17
16
15
14
13
12
11
PERCENT OF METHANE IN MIXTURE OF METHANE + DILUENT GAS + AIR
14
12
10
8
6
4
2
0
PERCENT OF DILUENT GAS IN MIXTURE OF DILUENT GAS + AIR
0
5
10
15
20
25
30
35
40
45
50
ARGON
H_2O
N_2
CO_2
STOICHIOMETRIC MIXTURE

Slide 5

WHAT IS THE STRENGTH OF THE ENSUING BLAST WAVE?

- RESIDUAL ENERGY
- SCALING LAWS

Slide 6


CHARGE WEIGHT 10,000 LBS
PROPELLANT
TNT
BLAST WAVE OVERPRESSURE — psi
1000
100
10
1
0.1
RANGE — ft
0
200
400
600
800
1000
1200
1400

Slide 7

WHAT IS THE EFFECT OF THE BLAST WAVE ON PERSONNEL AND STRUCTURES?

- WAVE PROPERTIES
  - OVER PRESSURE
  - IMPULSE
- TARGET PROPERTIES

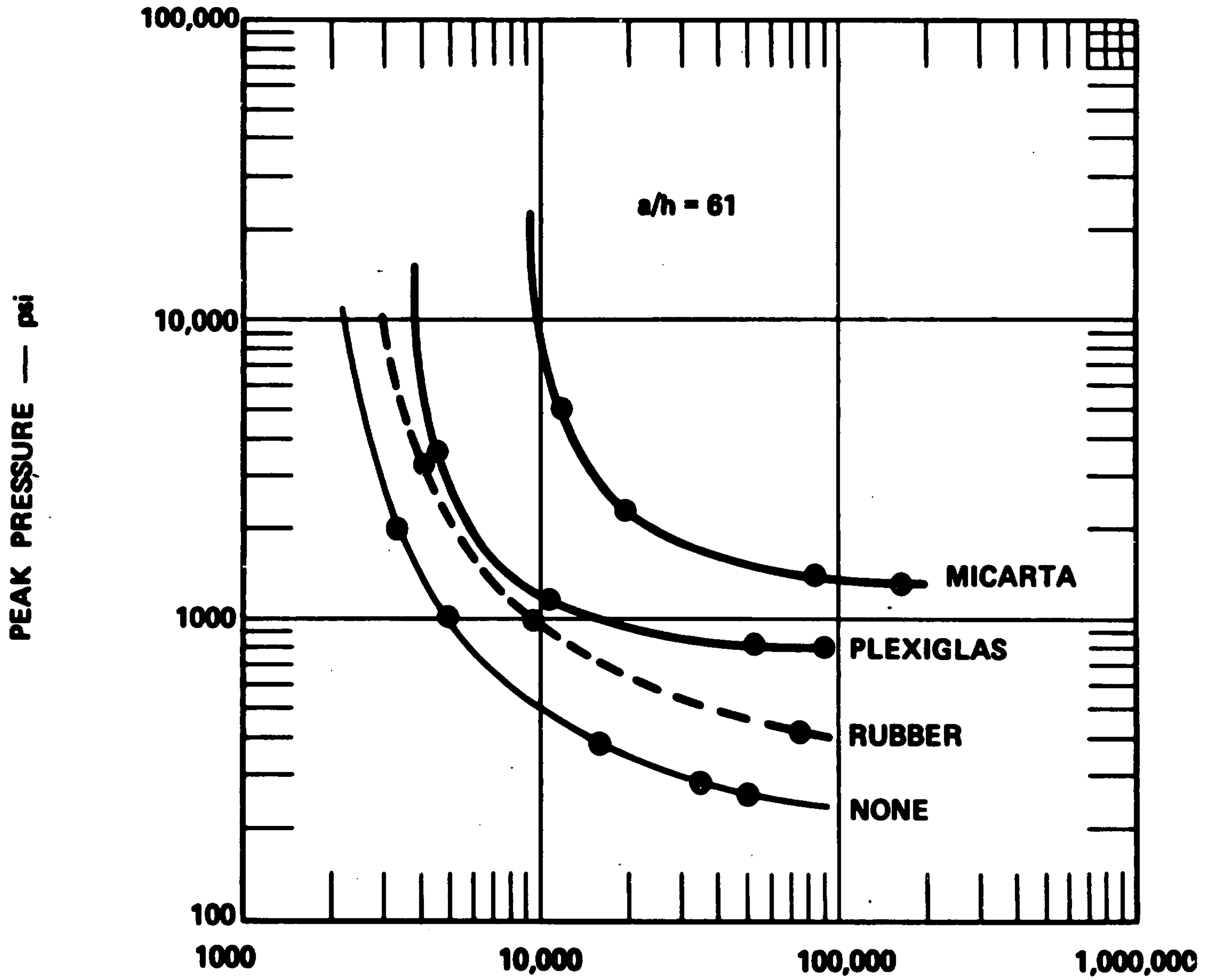
Slide 8

Table I

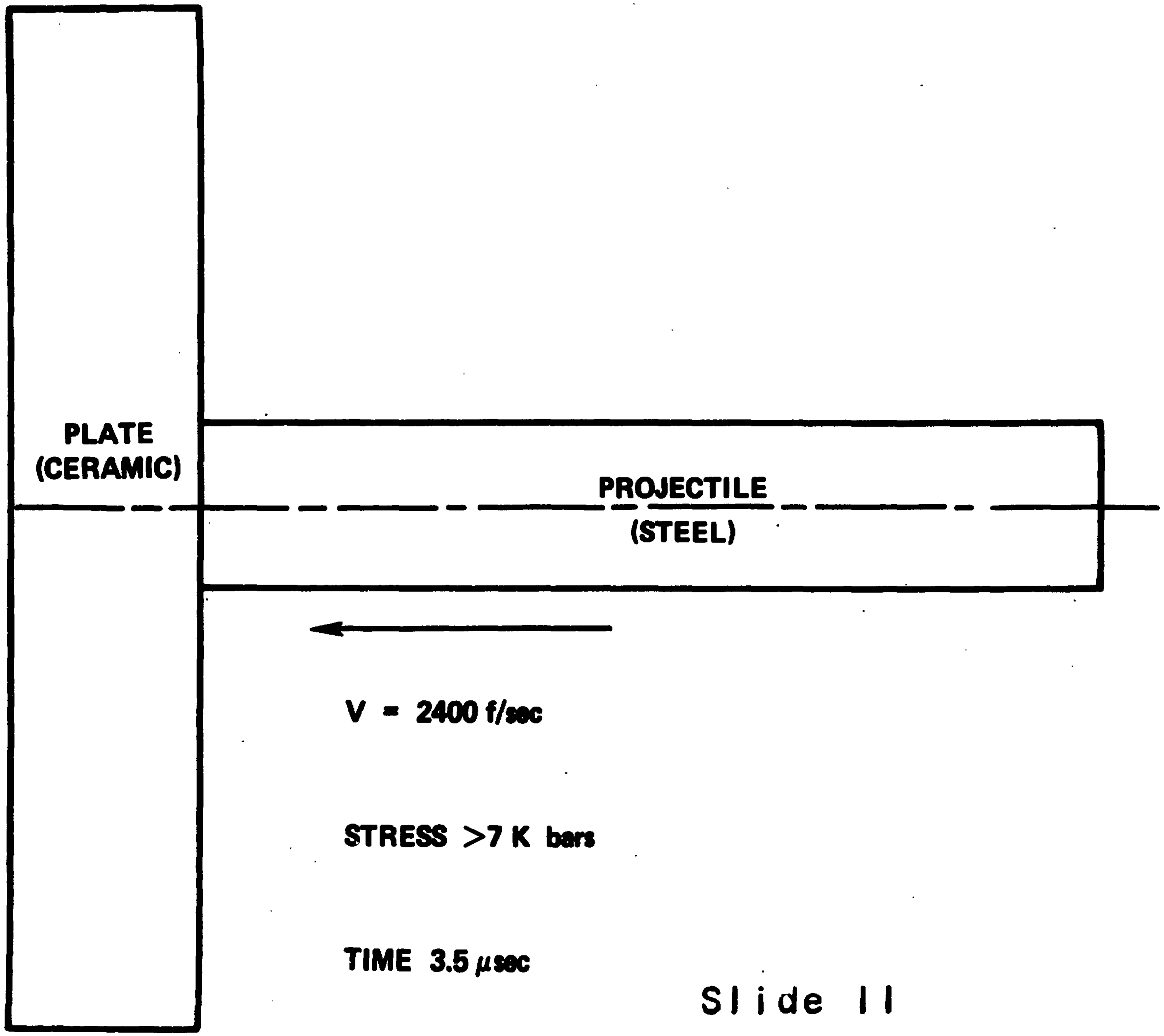
CONDITIONS OF FAILURE OF PEAK OVERPRESSURE-SENSITIVE ELEMENTS

Structural Element	Failure	Approximate Incident Blast Overpressure (psi)
Glass windows, large and small	Shattering usually, occasional frame failure	0.5 - 1
Self-framing steel panel building and oil storage tanks	Collapse or rupture	3 - 4
Brick wall panel, 8 in. or 12 in. thick (not reinforced)	Shearing and flexual failures	7 - 8
Personnel	Safe if lying down inside reinforced structure or lying on ground out of doors	1 - 2
Personnel	Eardrum rupture	5

Slide 9


a/h = 61
PEAK PRESSURE — psi
100,000
10,000
1000
100
1000
10,000
100,000
1,000,000
MICARTA
PLEXIGLAS
RUBBER
NONE

Slide 10



V = 2400 f/sec

STRESS >7 K bars

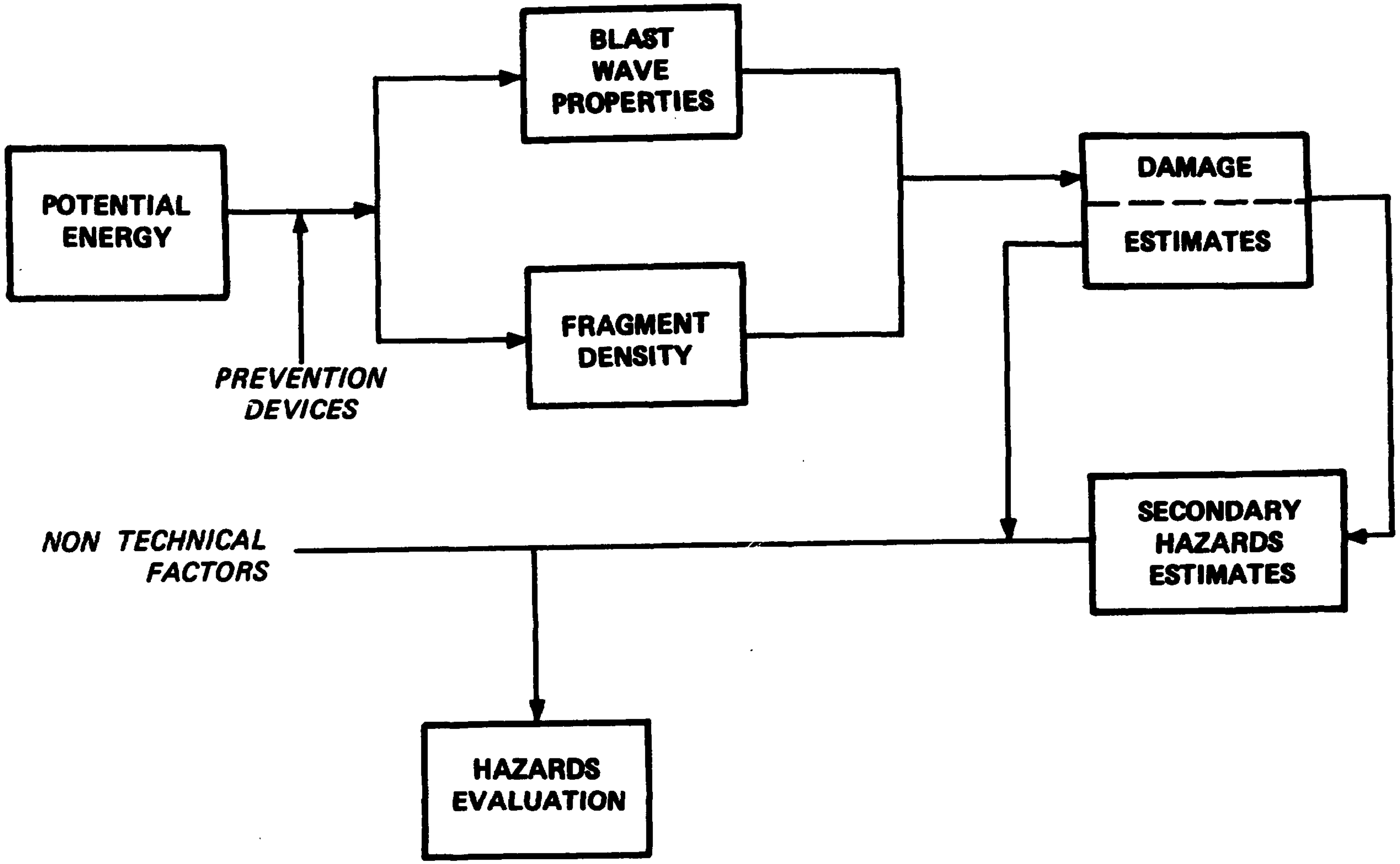
TIME 3.5 μsec

Slide II

HOW CAN TECHNICAL KNOWLEDGE BE USED TO EVALUATE THE HAZARDS?

- MODELING STUDIES
- COMPUTER PROGRAMS
- SOLUTIONS

Slide 12


POTENTIAL ENERGY
PREVENTION DEVICES
BLAST WAVE PROPERTIES
FRAGMENT DENSITY
DAMAGE
ESTIMATES
SECONDARY HAZARDS ESTIMATES
NON TECHNICAL FACTORS
HAZARDS EVALUATION

Slide 13

CURRENT BRITISH EXPERIMENTS

Reginald R. Watson
Ministry of Defence, United Kingdom

SUMMARY

This paper presents results and conclusions from some recent experiments in Britain and indicates the scope of current trials, some of which are sponsored jointly by the UK and US authorities. Ways are suggested to promote further rationalisation of test programmes in the field of explosives safety in order to achieve a better standard of experimentation and to effect savings.

INTRODUCTION

In the Ministry of Defence there is already a measure of rationalisation of testing in certain aspects of explosives safety because the Director of Safety (Army Department) organises most of the tests for the Interdepartmental Explosives Storage and Transport Committee. A distinction is made between tests concerning single service problems and those of a joint service nature in order to apportion the costs of trials but the technical aspects are unified. Recent tests on the safety of pyrotechnic compositions will be reported through the Technical Collaboration Programme (TTCP). Two current trials have arisen through NATO requirements for the storage of ammunition and the opportunity has been taken to avoid duplication of effort by running joint US/UK tests. Another series of tests proceeding concurrently in the UK and the US are being matched so that they cover complementary aspects of the problem. It is hoped that discussion of these various tests will promote better and more uniform standards of experimentation and will lead to still closer cooperation between the UK and the US in particular and among NATO and Commonwealth countries in general.

PYROTECHNIC COMPOSITIONS

Figure 1 shows what must be expected when about 20 lbs. of pyrotechnic composition explodes in a mixing cell. The damage is indicative of a relatively low peak overpressure but large positive impulse. D Safety and DRARDE jointly initiated tests to determine the explosive effectiveness of the range of pyrotechnic compositions used in UK and to investigate the propagation hazard during their manufacture.

The first phase of the study involved measurement of blast, flame radius and ejecta when typical compositions were ignited in a standard mixing/storage can containing 100 oz net. Type HE3b blast gauges were used in conjunction with high speed colour photography. Fig. 2 shows the experimental layout. Figure 3 presents the derived pressure/distance data, the curves being fitted by eye to the mean values for each composition. The names of the compositions are fictitious so that this presentation may be unclassified. The least powerful one, composition J, is that which caused the damage to the cell in Figure 1. Figure 4 shows the derived curves relating positive impulse and distance. Some inversions in ranking occur. Figure 5 indicates the range of values obtained for the arbitrary "Mean TNT Bare Charge Equivalent" using either a peak pressure or an impulse criterion. Note the eighteen-fold increase from one criterion to the other in the case of composition J. This exemplifies how misleading it can be if safety authorities rely on a single TNT equivalent. These tests enabled D. Safety to take account of the reduced power of many pyrotechnics, compared with TNT, when assessing explosives quantity limits for buildings in the research and production establishments of MOD.

Further tests observed the behaviour using different conditions of confinement and larger unit quantities. The results with the standard of comparison, gunpowder, were particularly interesting (Figure 6). The ignition of 100 lb net in a standard wooden case forced the metal base plate down into the earth without deforming it. An explosive of high brisance would have deformed or shattered the plate. A notable disparity in the peak overpressure patterns from two tests, which contrasts with quite good agreement between the impulse patterns, has been attributed to different rates or continuity in the explosive reactions possibly owing to differences in bulk density or composition (the two samples were from different batches).

A third phase of the programme studied the process of sympathetic initiation between cans of pyrotechnic composition. Figure 7 shows the experimental layout. The standard cans were stood on dunnage upon metal plates to simulate storage in a factory magazine. Separation distances ranged from 2 to 15 feet and in some cases a wooden partition was introduced to attenuate the explosive effects from the donor charge. High speed cine photography with space and time markers was used for the investigation. The results are tabulated in Figure 8.

Composition B, one of the most powerful of the pyrotechnics studied, communicated within 0.2 to 0.8 seconds to cans within 8 feet. The more distant cans were sometimes displaced a few inches by the blast but were never apparently struck by fragments from the donor. Two tests using a 2 inch wood partition resulted in disintegration of the barrier and violent explosion in the acceptor. Composition J, the least powerful one, gave less conclusive results. Two of the surviving acceptors were found with small holes above the level of the composition inside the can. The holes were attributed to fragments from the donor although sifting failed to reveal any metal particles within these acceptors. Four tests using wood barriers resulted in two instances of propagation, the partition being broken into a few large pieces and scorched badly.

It was concluded that there is no "safe distance" which will eliminate the risk of propagation among cans in a magazine. Increasing separation obviously reduces the fragment density and thus the chance but some risk remains throughout the practicable range of distances. It is not known whether the fragment itself ignites the composition or whether it merely permits ingress of hot gases which cause ignition of the acceptor. At close range the blast is probably dominant in disrupting the can. Simple wooden partitions are not effective. A major redesign of cans might reduce the chance of propagation significantly. Either cans with minimal effective fragmentation or cans with robust sides but blow-out lids could be tried. All these tests are fully described in three RARDE memoranda which are to be distributed in the US, etc., through the TTCP. They should provide an interesting comparison with the paper "Explosive Classification and Hazards Evaluation of Pyrotechnic Compositions and End Items" by Mr. Henderson of Edgewood Arsenal.

PROPELLANT PASTES

Trials by the Department of Supply of Australia a few years ago indicated that cordite pastes containing NC with not more than 12.6% N do not constitute a mass explosion hazard under conditions of mild confinement. D Safety and DROF Bishopton in the UK planned and executed further tests to investigate the limits within which this conclusion is valid.

Mock-up sections of a paste drying trolley were made having 2, 4 or 25 trays stacked vertically on shelving (Figure 9). Hardboard sheets were nailed or slotted on to the timber framework to provide roof, floor and rear. Thin polythene sheet was laid on perforated aluminum trays so that 10 lb of propellant paste could be spread to a depth of about 1/2 inch in each tray. One tray was ignited by an electric "puffer" fuze, sometimes with a few strands of fine propellant.

Tests using either SUK sheet paste or PU powder paste (NC with N content between 12.1 and 12.3%) gave consistent results in all three types of mock-up. The behaviour was typical of Category Y (US Q/D Hazard Class 2). Next, two units, each having 25 trays totalling 250 lb paste, were sited 34 inches apart, the sides being closed by hardboard. This arrangement represents the separation between trolleys in a paste drying unit. The bottom tray in the left hand unit in Figure 10 was ignited. After 2 1/2 seconds flame propagated to the other unit and the frame continued to burn for several minutes. The burning was noticeably more fierce in the case of PU paste in this test rig. The sides and ends of the donor unit were blown out and the acceptor unit collapsed (Figure 11). The corner of one tray was partially fragmented probably owing to a buildup of powder thickness at this point when the collapse occurred. Subsequent tests with piled trays to simulate a collapsed trolley gave normal burning even when there was little air space between trays.

It was concluded that there is no explosion hazard in these paste drying units provided care is taken to avoid excessive layers in the trays. Although there is a time lapse, the propagation among units and the duration of individual fires are such that the contents of the whole collection of trolleys must be taken as the effective explosives quantity, not merely the contents of one trolley, when assessing quantity-distances.

Tests were also performed using N paste (guncotton paste containing NG and NC with N content 13.0 to 13.2%). Tests simulating collapsed trays, either tilted to provide air spaces or squarely one on another, gave no indication of explosion. There was merely violent burning accompanied by a "woof" noise. Upper trays were dislodged but not projected. A single unit with 25 trays was ignited at the bottom but that too gave only fire. The trays were scattered but not distorted. The framework broke into its component parts owing to the violence of the burning.

A final test with N paste employed two units of 25 trays sited 34 inches apart. The fireball from the donor unit resulted in such rapid and extensive heating of the acceptor unit that the latter exploded violently. Both units disintegrated completely and small fragments were projected far and wide. The explosion severely damaged the roof and reinforced concrete walls of the tunnel behind the site (Figure 12). It made a crater 8 to 9 feet in diameter and 2 feet deep through the 6 inch thick concrete base slab. This last test shows how misleading the earlier tests with N paste might have been, taken in isolation. It confirmed the necessity to take account of the risk of mass explosion of N paste in drying units and to assess quantity-distances accordingly.

PALLETS & CONTAINERS FOR AMMUNITION

The pallet and container revolution offers the prospect of substantial economies in the transportation and handling of ammunition and bulk explosives. It is important that packaging authorities should take account of the phenomenon of mass explosion. The extent of the mass explosion hazard associated with a particular consignment will influence freight charges and may even determine whether or not it is acceptable for certain modes of transportation. D Safety (AD) has initiated trials over the last two years to investigate the process of sympathetic explosion among HE projectiles in test rigs designed to simulate pallets or containers. The intention is to provide package designers with the required information on mass explosion hazards and relevant parameters.

It should be possible to predict the hazard for any particular arrangement using a theoretical model akin to that recently proposed by Rindner of Picatinny Arsenal. In practice there are so many parameters whose values must be known and such a compounding of uncertainties in the equations that it is expedient merely to test an actual pallet or stack. As more and more ad hoc tests are performed in the UK and elsewhere the gaps in our knowledge of the propagation process could be filled and the uncertainties in the value of parameters could be reduced provided the test data were properly collated and analysed. In five to ten years it might be practicable to rely on the predictions based on a theoretical model.

Whereas many traditional items of ammunition are clearly either a mass explosion risk or not (Category Z or X in the UK, Q-D Class 7 or 4 in the US), these tests on rigs representing pallets have resulted in a much more confusing picture of the mass explosion hazard and the classes. Tests with 105 mm, 5.5 inch and 155 mm HE projectiles have produced effects ranging from explosion of the donor alone to propagation throughout the aggregate, depending on the particular orientation, spacing and partitions used. Frequently there has been a partial propagation which faded out after two or three shell along each axis. A certain 105 mm round can be converted from a single round hazard to a mass explosion hazard simply by a change in orientation of the rounds in the assembly. Modern shaped charge ammunition presents obvious problems of asymmetry in the propagation process.

In these circumstances a slight change in the arrangement of projectiles or partitions can be critical. There is an analogy here with the behaviour of the tests with N paste. It becomes vital that the test rig should simulate properly all the relevant factors in the actual pallet, stack or container. This raises difficult questions concerning the number of replicate tests to be performed and the acceptable costs of testing. The traditional five replicate tests are fine when the result is clear cut and consistent. What is one to make of five tests which give results ranging from none of the acceptors exploded to nine of the 32 acceptors exploded? Is 9 out of 32 to be considered a mass explosion or not? What other factors, which were not simulated in the tests, might convert this into 32 out of 32 acceptors i.e. truly a mass explosion? How likely or realistic does a contingency have to be before it is included in the factors tested? Should a donor be initiated in a pallet at an elevated temperature or after a fire has charred the vital wood partitions?

These tests and considerations have led the Explosives Storage and Transport Committee to review the traditional system of hazard classification for quantity-distances and transportation. It is likely that Category X will be split into several categories akin to the US and NATO Hazard Classes 1, 3 and 4. This will avoid the critical and arbitrary decision as to whether an HE projectile such as the 105 mm is a mass explosion risk requiring large quantity-distances or a unit risk requiring minimal distances. Class 4 distances would provide an intermediate standard of protection. A mistake in classification, due to inadequate replication or representation, would then be less critical. This would help but the whole concept of mass explosion needs reviewing in the light of the phenomenon of partial explosion.

SEPARATION OF STACKS OF HIGH EXPLOSIVE SHELL

Trials at Aberdeen Proving Ground in the 1920s showed that certain types of massive shell, such as the 155 mm, can be arranged in stacks in such a way that although an accidental explosion would propagate throughout a stack it would not immediately communicate from stack to stack. Sympathetic detonation studies usually identify the fragments as the agent of propagation among cased charges of explosive. It is puzzling that the prescribed separation of a few feet only should suffice to prevent propagation.

A recent NATO storage problem was resolved by a trial sponsored jointly by the Department of the Army and the UK Army Department. The matter had to be settled urgently so the test programme was a compromise between the ideals of the experimentalists and the practical needs of the Services. To expedite the firings and to limit the cost the stacks tested were less than half the full size. Nevertheless the 66 firings involved over 2600 shell, the US providing 155 mm M107 filled TNT and some 8 inch howitzer shell and the UK providing 5.5 inch shell filled RDX/TNT 60/40.

Donor and acceptor stacks of size 9, 36, 72 and 240 shell were tested (Fig. 13). The trial also sought basic data which might explain why larger stacks are allegedly more hazardous than small stacks or single shell as regards their capacity to transmit detonation across an aisle. Traditional fragmentation studies do not give direct observations close to a shell and give no information on the behaviour of a stack of shell. It was suspected that fragment speeds might increase with stacks of shell but available theoretical models could not be applied to stacks to evaluate this effect. There were many difficulties in measuring fragment speeds close to the stacks and in deriving statistically valid inferences from the small samples of fragments which could be intercepted by the instruments (Fig. 14). For these reasons it would be unwise to jump to conclusions before the whole mass of data has been properly analysed. Nevertheless certain salient features have been noted and used as the basis for decisions by the explosives safety authorities concerned with the NATO problem.

The leading fragments from stacks do appear to be faster on average than those from single shell. Owing to contact between shell in a stack, some abnormally large fragments are formed but these do not represent a large proportion of the population and it is considered that they are unlikely to be responsible for propagation of detonation to other stacks.

The trial showed that the early Aberdeen data on amatol-filled shell could be applied to modern 155 mm shell filled with TNT. It drew attention to the variety of nose plugs used nowadays, some with hollow cores which may not provide the necessary protection to acceptor shell (Figs. 15, 16). It also showed very clearly the difference between TNT and RDX/TNT fillings. The British 5.5 inch shell gave high order detonations three times out of five with stacks of 9 shell separated by 20 inches, and once out of three tests with stacks of 36 shell separated by 8 feet. The trial was thus disappointing for the British Army which had hoped to adopt the stack separation technique for palletised shell filled RDX/TNT. However the results with TNT-filled shell will permit economies in storage which will offset the cost of the trial many times over (Fig. 17).

An incidental benefit of this trial is that it improved the lines of communication between the US and UK authorities responsible for explosives safety trials and established procedures which could be useful on future occasions. There is little point in nations working in isolation and duplicating trials effort and expense if there is the will and the way to work together and share the costs. This is particularly important at a time when defence budgets are being cut.

CURRENT TRIALS

A current trial sponsored jointly by the US and UK authorities concerns the effective explosive content of complete rounds of mass detonating ammunition. The US regulations permit one to ignore the quantity of propellant, for the purpose of assessing quantity-distances, on the grounds that the propellant will make a negligible contribution to the air shock. Pre-war the UK regulations permitted one to equate the propellant to half its weight of high explosive for this purpose. Following tests in the late 1940's in which cordite was made to explode violently under conditions of severe confinement and stimulus, the ESTC amended its prescription and required one to equate the propellant to TNT. This was based on judgment rather than quantitative measurements of the observed blast effects. The US and UK views came into direct conflict when a NATO working group recently attempted to draft common principles for the storage of ammunition. In order to resolve the deadlock the necessary facts are to be acquired by testing instead of trying to achieve a compromise between the two views. Small stacks of ammunition will be initiated and the blast observed with the propellant present and with it absent. The types of ammunition chosen as being significant for this purpose are 4.2 inch mortar, 105 mm HEP and 120 mm BAT rounds.

Another current trial investigates a particular problem arising from application of the ASESB Manual on "Structures to Resist the Effects of Accidental Explosions." Most available data relates to cells with at least one open face whereas in the UK most cells require protection against the weather or intruders. MOD establishments contain a multitude of designs of so-called "blow-out walls." Some of these have been proved by events to be next to useless for brisant explosives, though they might have been alright for pyrotechnic or dust explosions; many others give rise to serious doubts as to their efficacy. In order to derive valid design criteria for explosion vents, suitable for explosions ranging from propellants to initiators, D. Safety (AD) has initiated a series of tests of prototype blow-out panels. A robust, re-usable test rig has been fabricated from a steel splinterproof shelter leaving one face open to take the blow-out panels. Instrumentation comprises overpressure, impulse and strain gauges to yield data which will enable us to rank the designs in order of their effectiveness and cost, with due regard to the type of explosion.

A related study concerns the design parameters for steel tanks and cylindrical pipes used to contain or restrict the effects of an internal explosion. Sometimes a design is required which will guarantee complete containment; at other times an accidental explosion can be allowed to cause failure of the tank or pipe provided it stays in place long enough to contain harmful overpressures and does not itself produce dangerous missiles. Some data is available from BRL tests some five to ten years ago on models of nuclear reactor containers. More data is required in the UK in the region of plastic response and failure, for normal explosives and for pyrotechnic compositions. D. Safety staff are constantly on the lookout for redundant steel tanks etc. which can be blown up with minimal costs but maximum data acquisition.

SCOPE FOR RATIONALISATION

The foregoing descriptions of experiments in Britain indicate ways in which Australia, the US and the UK have benefitted from technical cooperation in the field of explosives safety. Unfortunately they have also shown areas in which a lack of awareness of one another's tests and data has led to duplication of effort and to conflicts of safety regulations. The general problem of communication in our rapidly developing technological world is receiving attention at many levels. In our particular field of explosives safety I am sure the ASESB seminars make a unique contribution to the promotion of knowledge in the USA. I am grateful to the Chairman of the Board, Colonel Abrams, for extending the scope of the seminar this year so that Australia, Canada and the UK could participate and benefit. Trials are expensive particularly in the case of the larger types of ammunition and weapon. The need for considerable replication of tests, to permit classification of marginal items with a sufficient level of confidence, raises costs still further. It is therefore important that there should be as much rationalisation as possible of test programmes.

Another valuable focus for the exchange of information on explosives safety is the NATO Group of Experts on the Storage and Transportation of Explosives (AC 258). In recent years there has been considerable discussion of the criteria and procedures for hazard classification tests. It is hoped that the group will produce a standard specification for such tests to ensure consistent and acceptable standards of experimentation. In the absence of confidence in one another's tests, it is sometimes necessary to duplicate them when an item of ammunition is introduced into another country. It is also intended to set up a simple card index giving references to all hazard classification tests that have been performed on items that are used in more than one country, or that are likely to be.

On a still broader plane there is increasing international rationalisation through the work of the United Nations Group of Experts on Explosives which reports to the Committee of Experts on the Transportation of Dangerous Goods set up by the Economic and Social Council in Geneva. This Group also is considering the need for standard tests for hazard classification of both commercial and military explosives. Here however, there is a problem arising from the difference in outlook between commercial and military interests. Commercial explosives are generally stored and conveyed as bulk chemical substances or in devices with a high explosive content. The packaging rarely alters the hazard classification of the basic substance. Commercial authorities therefore tend to question the need for hazard classification tests relating to the risk of mass explosion; instead they concentrate on tests for thermal and chemical stability. Regulations for certain modes of transport reflect this attitude. Military ammunition on the other hand is tested and classified in a specific package since frequently the packing determines the susceptibility to mass explosion. It remains to be seen which attitude or what compromise prevails in the forthcoming UN recommendations for the transportation of explosives. Whatever the outcome the work of the UN Group will have succeeded in fostering the exchange of information on explosives safety. We look forward to the day when there are international seminars on explosives safety to extend the aims of the ASESB's annual seminars.

ACKNOWLEDGMENTS

The author wishes to thank the Ministry of Defence for permission to present this paper and the following Heads of Army Department establishments for performing the tests and assisting in the preparation of the viewgraph transparencies:

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Director ROF, Bishopton
Superintendent, PEE, Shoeburyness

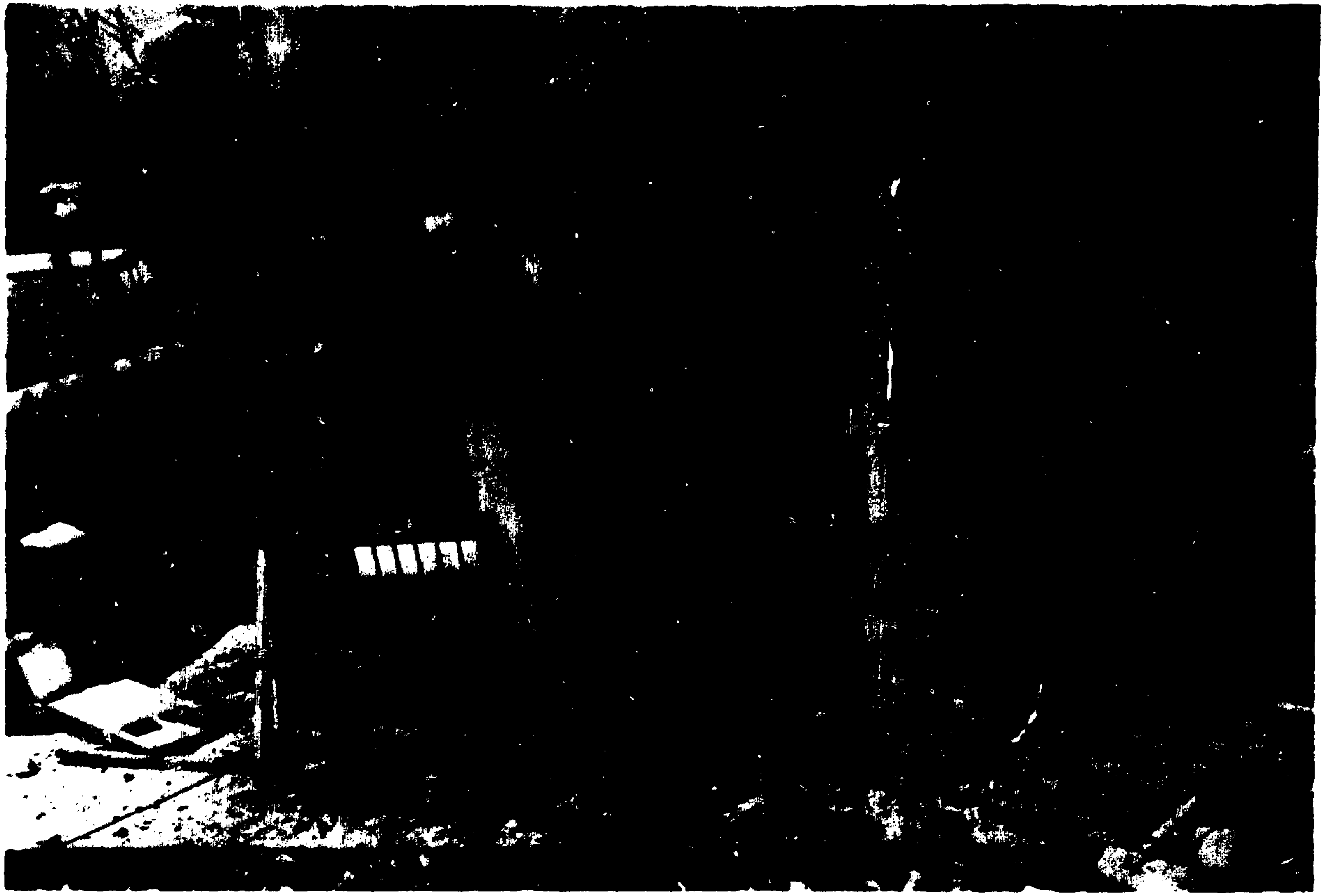


FIGURE I.

FIGURE 2

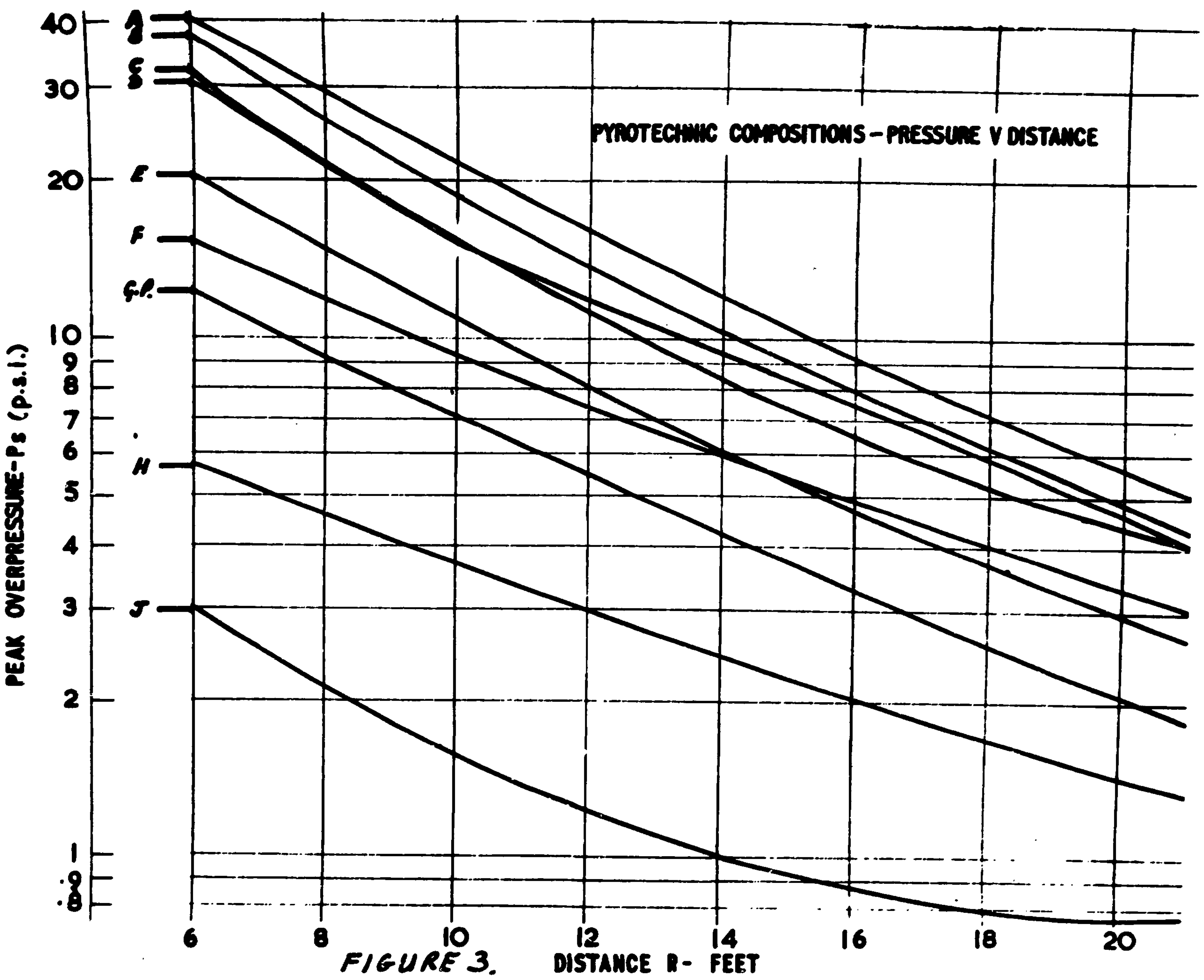
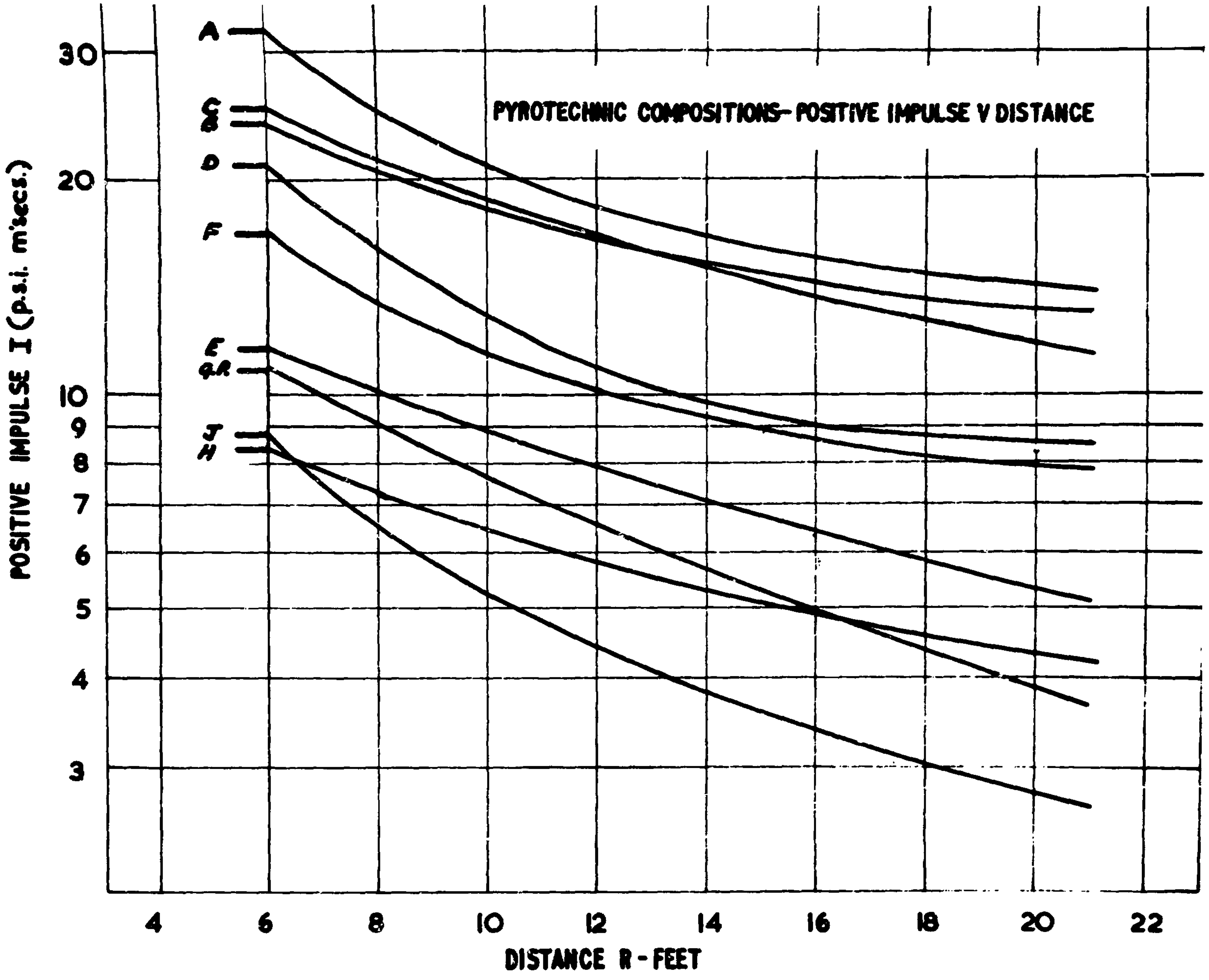

PYROTECHNIC COMPOSITIONS - PRESSURE V DISTANCE
PEAK OVERPRESSURE-Ps (p.s.i.)
40
30
20
10
9
8
7
6
5
4
3
2
1
.9
.8
A
B
C
D
E
F
G.P.
H
J
6
8
10
12
14
16
18
20
DISTANCE R- FEET

FIGURE 3.



PYROTECHNIC COMPOSITIONS– POSITIVE IMPULSE V DISTANCE

FIGURE 4.

T.N.T BARE CHARGE EQUIVALENT WEIGHTS

COMPOSITION	MEAN T.N.T. EQUIVALENT WEIGHT FOR EQUAL PRESSURE. [lbs. wt.]	MEAN T.N.T. EQUIVALENT WEIGHT FOR EQUAL IMPULSE [lbs. wt.]
A	2·86	5·96
B	2·32	4·60
C	1·89	4·60
D	1·76	2·64
E	1·00	1·33
F	0·860	2·18
GUNPOWDER G.12.	0·491	0·97
H	0·168	0·82
J	0·031	0·56

FIGURE 5.

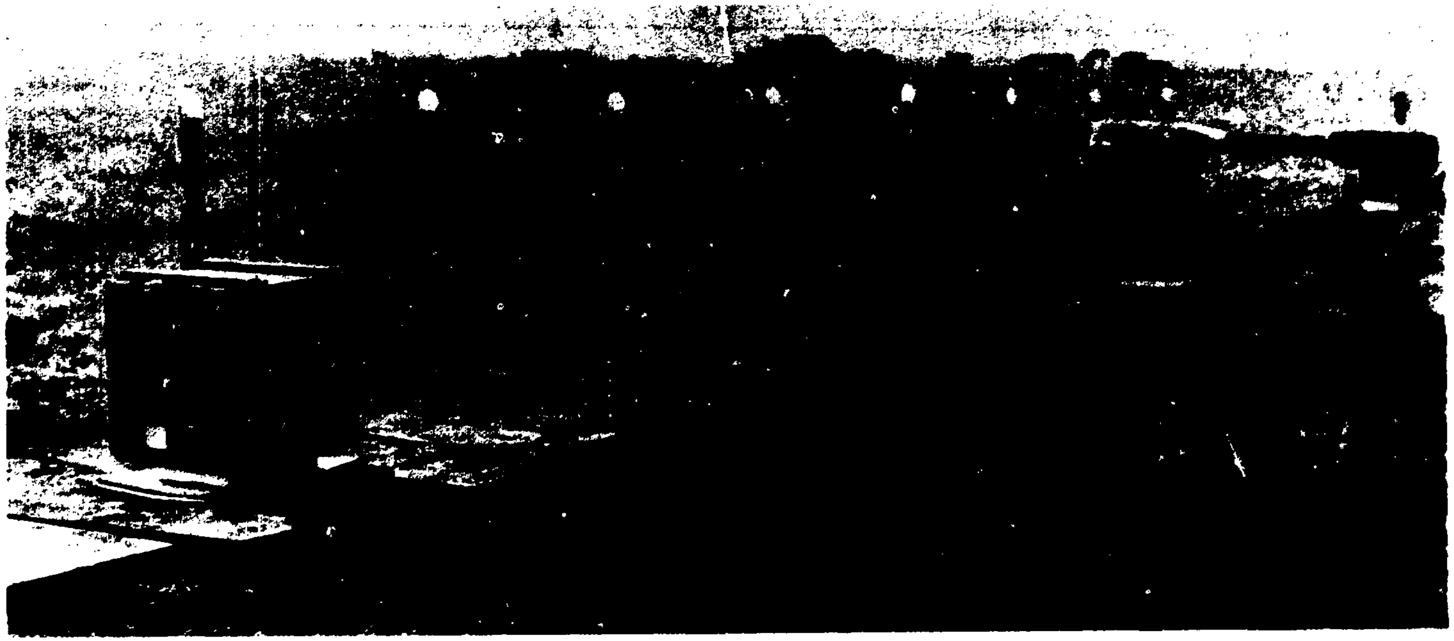


FIGURE 6. BEFORE AND AFTER EXPLOSION OF 100 lbs. G.P.

BEFORE FIRING - 5 ACCEPTOR CANS 10 ft. FROM CENTRAL DONOR

FIGURE 7.

RESULTS OF SYMPATHETIC INITIATION TESTS.

COMPOSITION	SEPARATION OF DONOR AND ACCEPTORS		RESULT
	MEDIUM	DISTANCE, ft.	PROPORTION OF ACCEPTORS EXPLODED.
B	AIR	2	1/1
		4	1/1
		6	1/1
		8	2/2
		10	0/1
		12	0/4
		15	0/7
B	AIR AND WOOD	2	2/2.
J	AIR	7	4/15
		10	3/10
J	AIR AND WOOD	2	2/4

FIGURE 8.

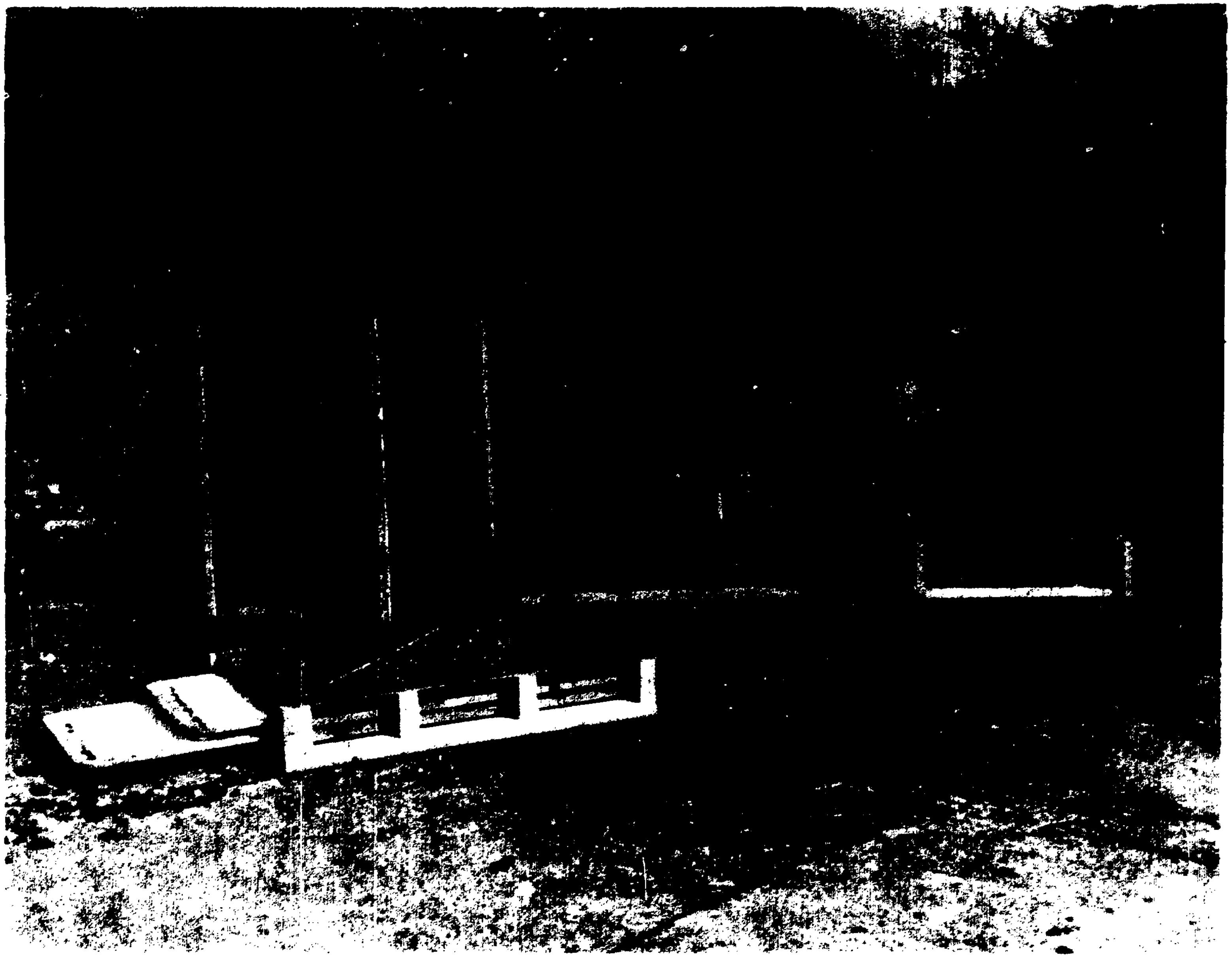


FIGURE 9.

FIGURE 10.

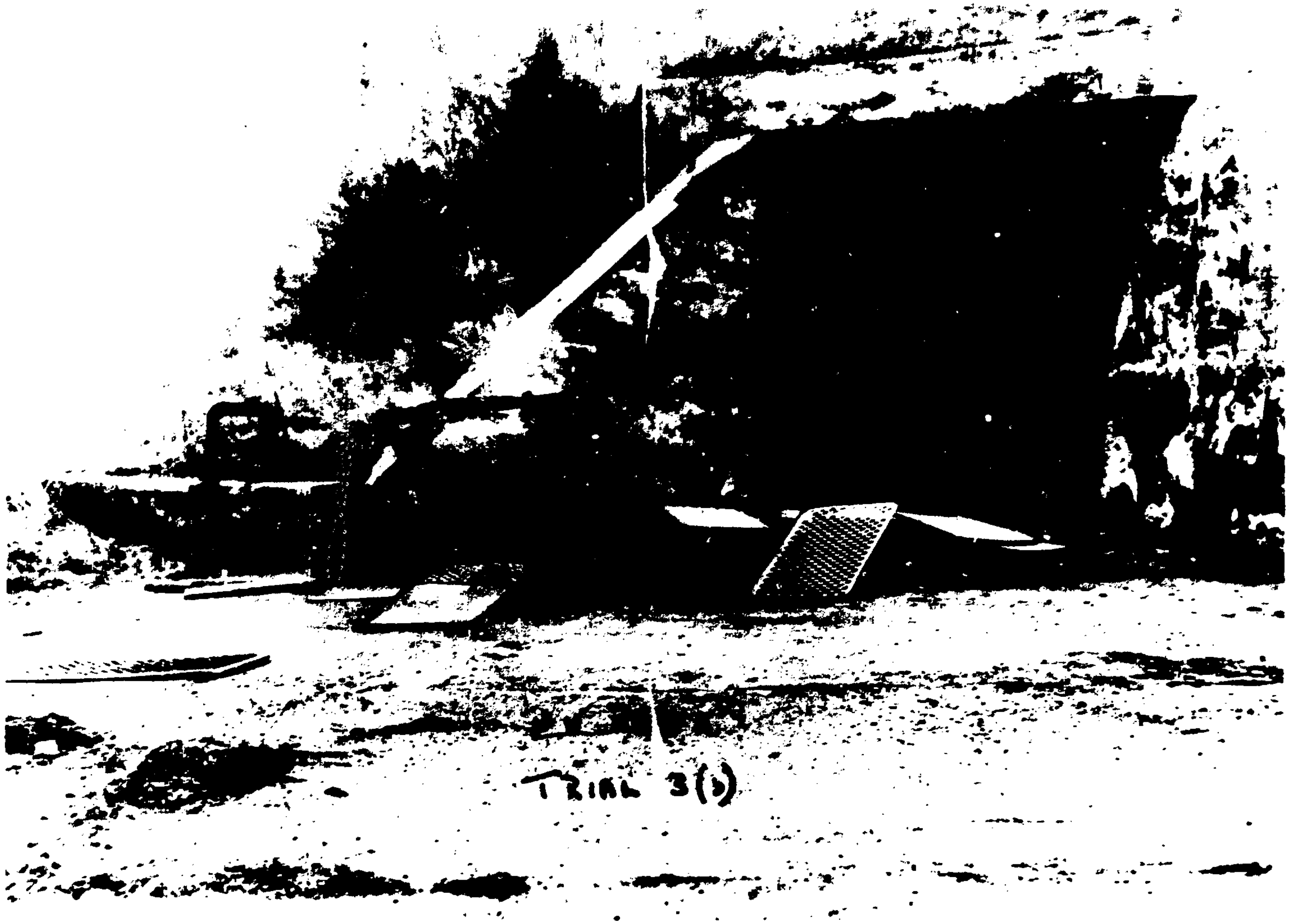


FIGURE 11.

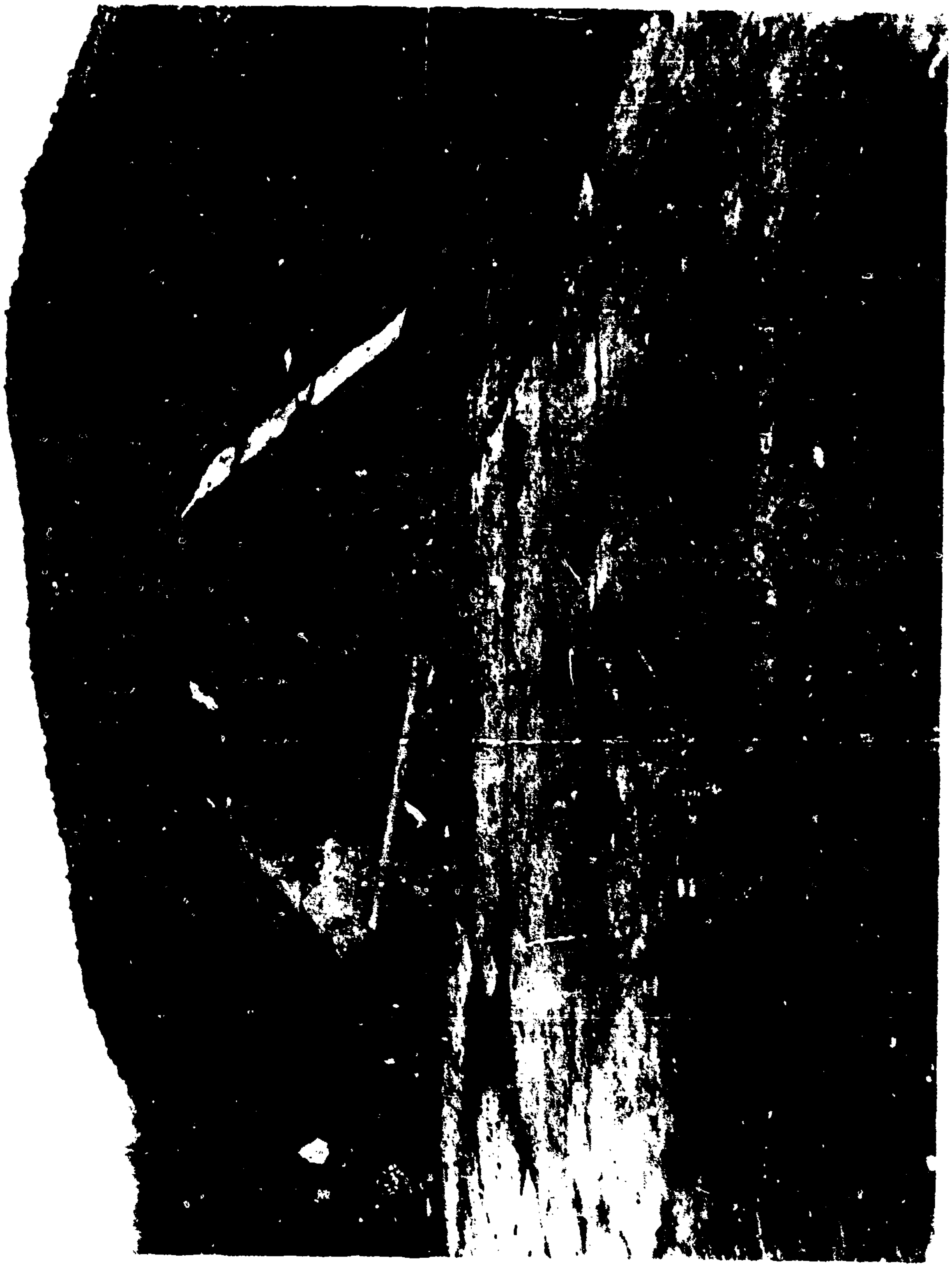


FIGURE 12.

Figure 13

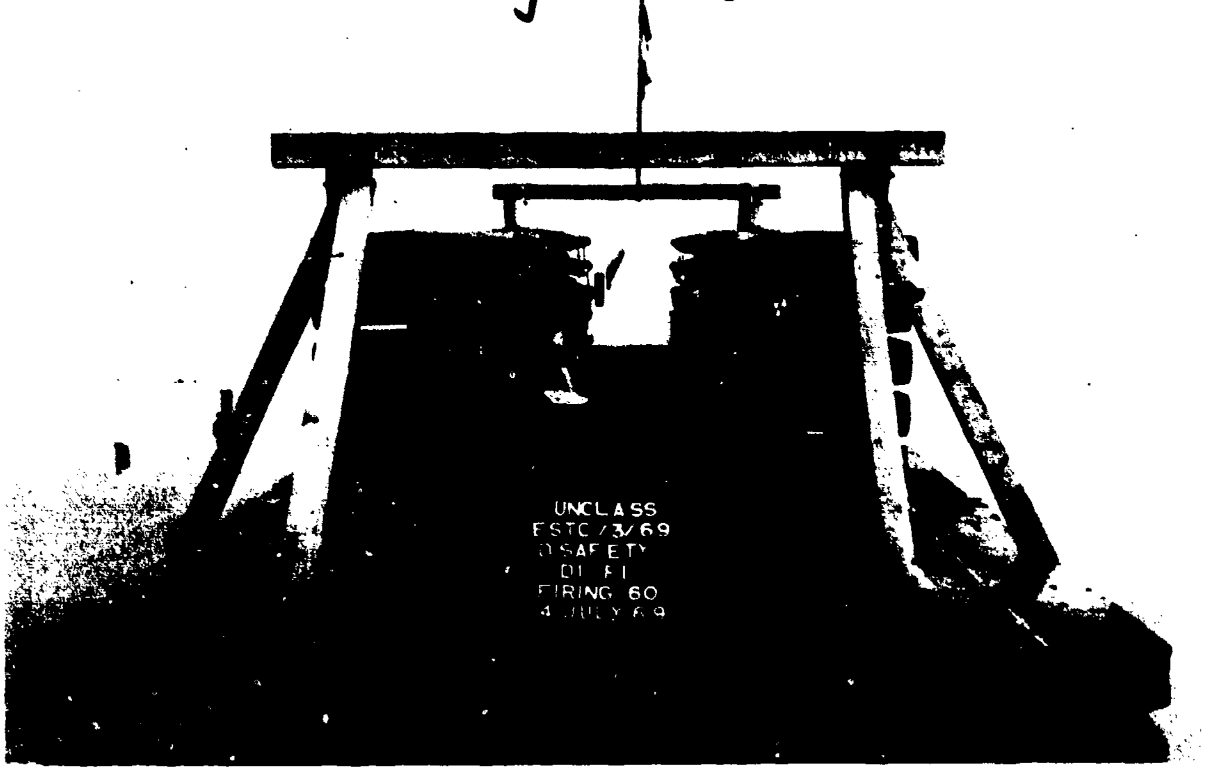
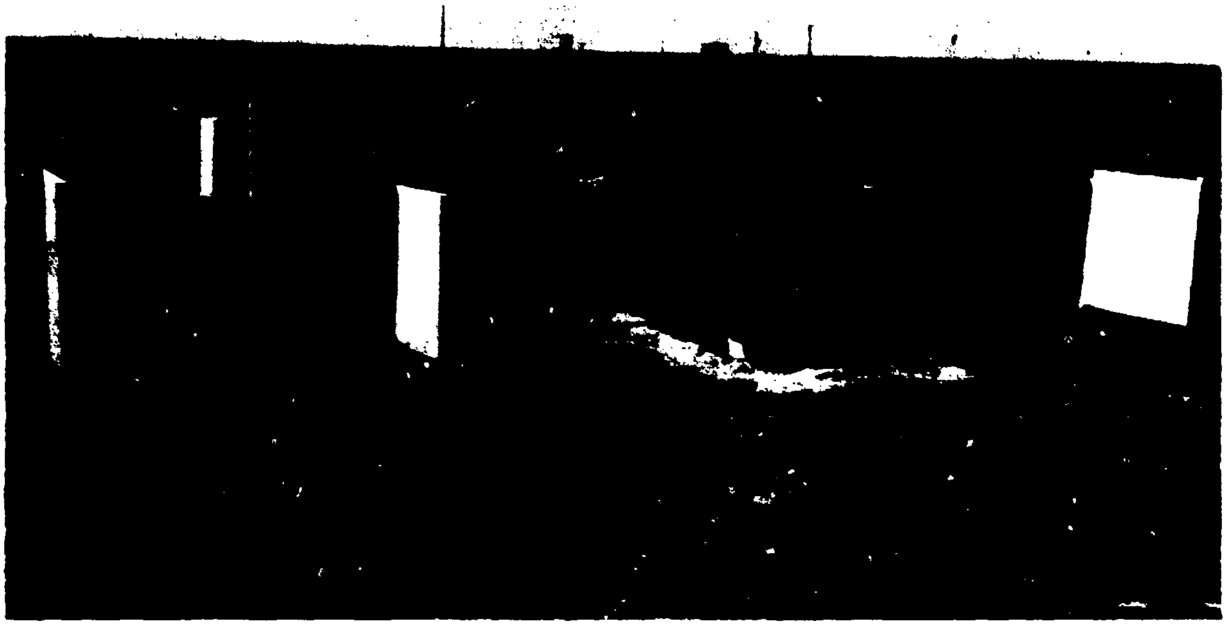


Figure [illegible]



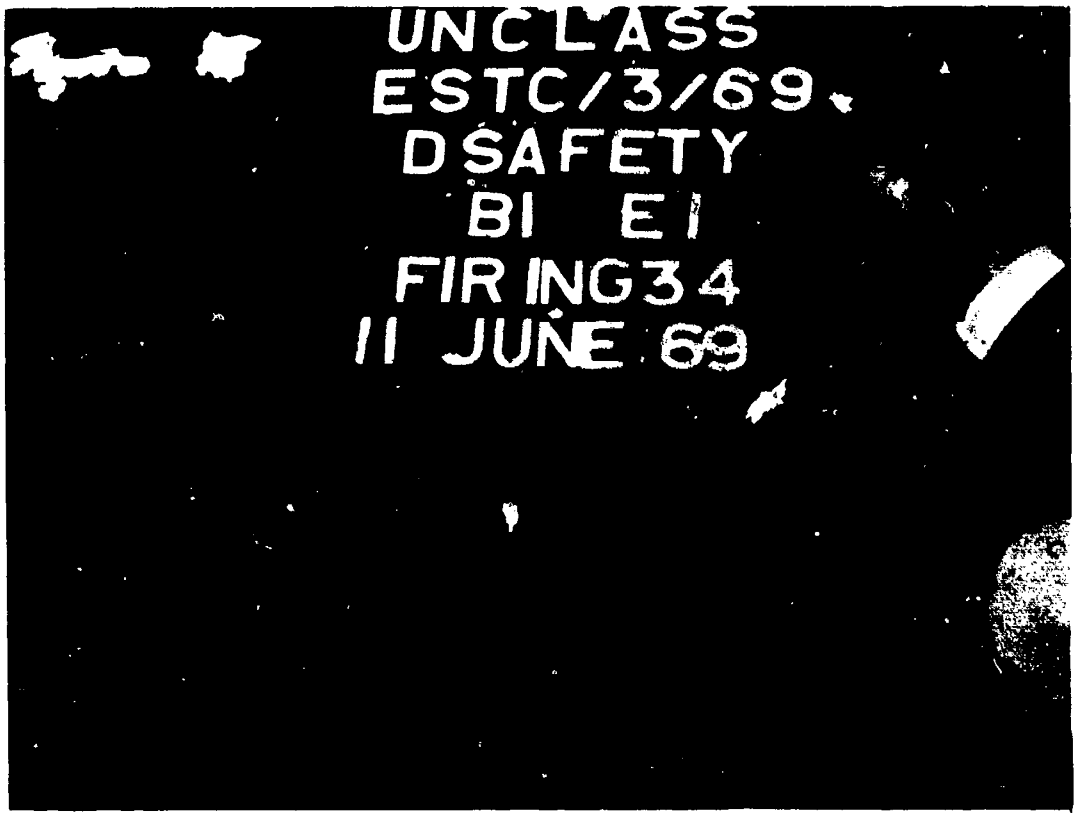
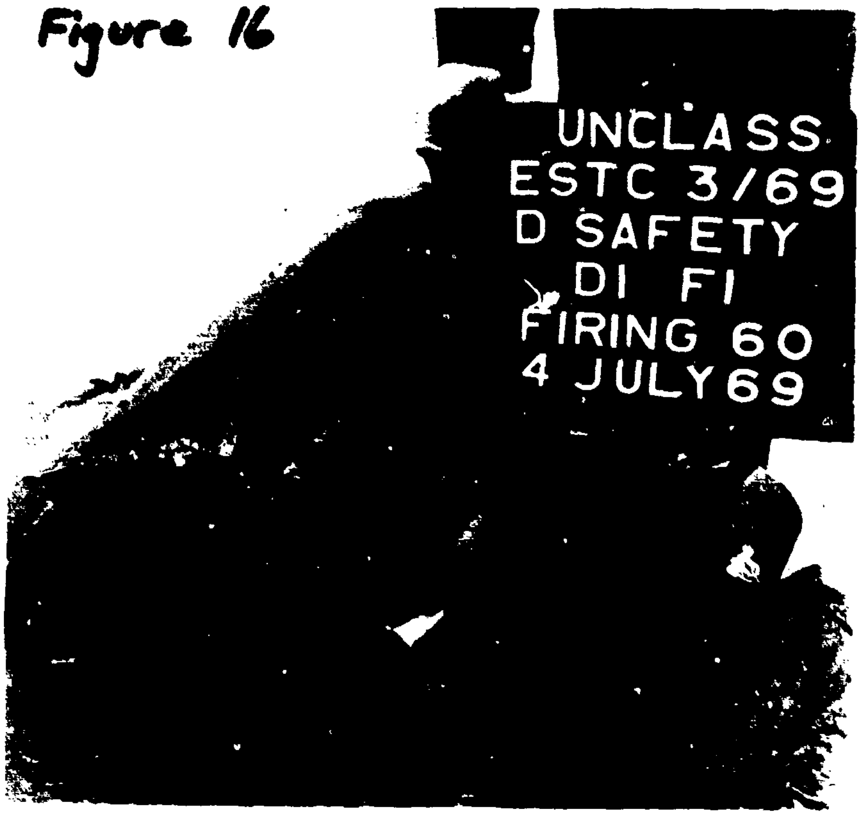


Figure [illegible]

Figure 16



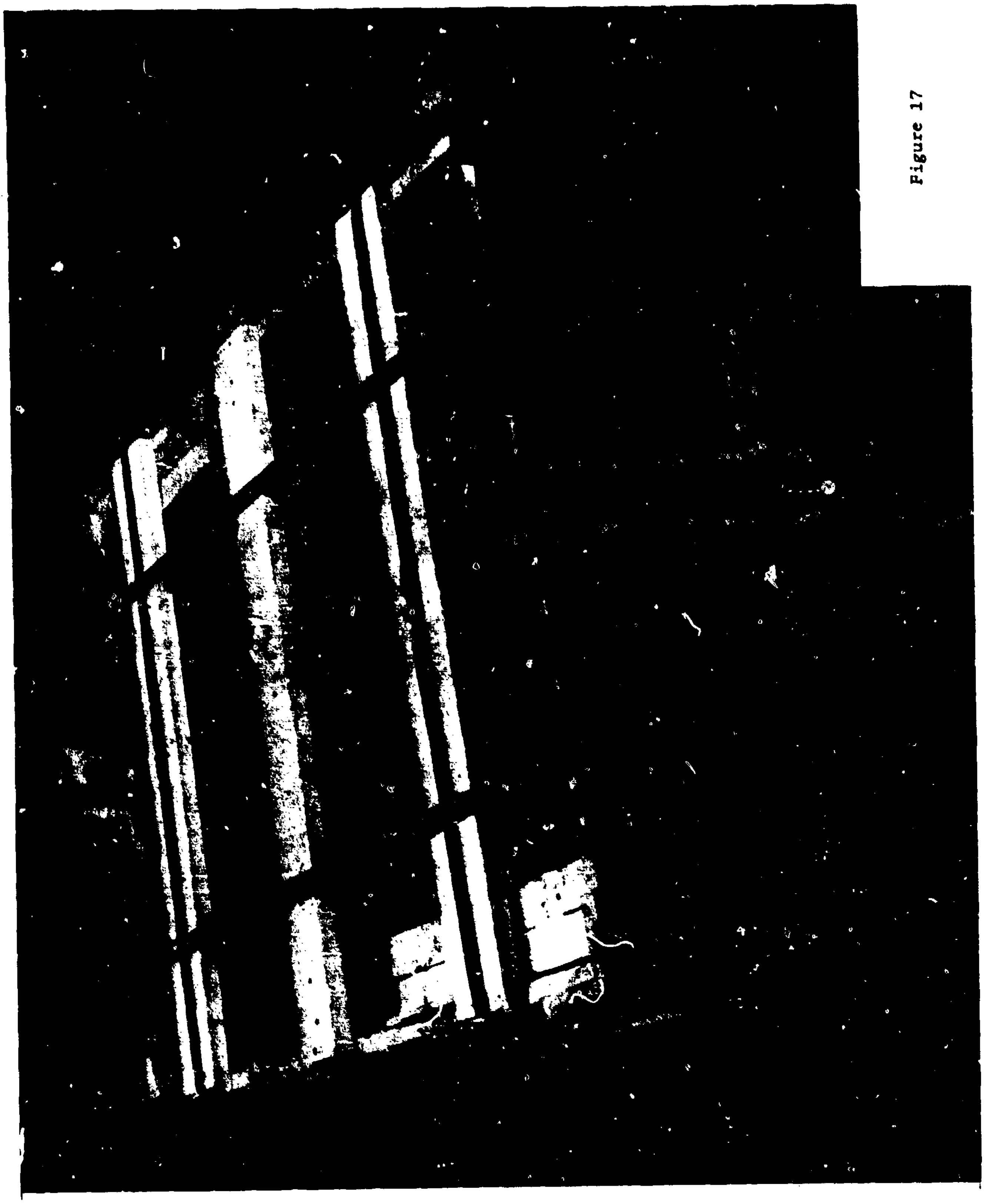


Figure 17

Discussion of Paper Entitled "Current British Experiments"

Some 30 persons participated in discussion of three of the experiments described in the formal presentation. The tests on pyrotechnic compositions were of interest to Edgewood Arsenal and showed how similar are the problems faced by US and UK workers in this field. There is, however, an important difference in the scope of compositions covered by the word "pyrotechnic" in the two cases; the British tended to exclude toxic agents. There was general agreement on the need to provide safety authorities with more data on the destructive effects of compositions used for signals, illumination, smoke screens, etc., and as vehicles for the dissemination of toxic agents. It was important to avoid the pitfall of quoting values of TNT equivalence without taking account of the rate of the explosion or deflagration process. The concept of TNT equivalents had fallen into disrepute, to some extent, in the propellant field owing to abuse and a failure to appreciate the limitations of the parameter.

Picatinny Arsenal staff expressed interest in the tests of frangible "blow-out" panels. These should provide early data required for the Picatinny project on donor/acceptor systems and the effects of explosions on structures designed to prevent propagation. The imminent manual by Picatinny and their contractor, Ammann & Whitney, Inc., will not provide data on the effect of explosion vents upon the internal blast loading, resultant structural strains, and the extent to which a frangible panel modifies the blast outside a structure. It was suggested that the US and UK experimenters should collaborate to avoid duplication of effort and to expedite data acquisition.

Staff of Ballistic Research Laboratories, Aberdeen pointed out that the extensive data being generated from the joint US/UK trial on the explosive effects of stacks of shell could be used to good effect for vulnerability studies. Although the object of the trial had been to establish safety criteria for peacetime storage of stacks, the same data was required to predict offensive and defensive possibilities for destruction of operational stacks. Theoretical models such as that of Gurney are available for single rounds but it is doubtful whether they can be extended to stacks. The present tentative conclusion, namely that the fragments from stacks are appreciably faster than those from a single round, will be significant for these other studies. There was some discussion of the status of the "mass explosions" in the tests. Safety authorities are not really concerned with subtle distinctions between high order detonation and something of a rather lower order; if the whole stack or series of stacks is consumed in a few tens of milliseconds then the effect on neighbouring dwellings, and thus on quantity-distances, is the same as if a classical detonation had occurred.

The discussions ended with suggestions for future work to elucidate the mechanism of the propagation between stacks at close quarters. There are many practical difficulties in the instrumentation and obvious financial restrictions on the replication of full scale tests.

BLAST VULNERABILITY OF PERSONNEL, SELECTED STRUCTURES, AND VEHICLES

D. K. Parks
Falcon Research and Development Company
Denver, Colorado

This program, which began on the first of July of this year, is concerned with the evaluation of explosives storage safety criteria, with the objective of performing a parametric study of the blast effects of explosions on certain targets of interest to the Armed Services Explosive Safety Board (Figure 1). It is intended to provide analytical criteria for establishing minimum separation distances between various quantities of stored explosive materials and a wide spectrum of targets, and to furnish such data for selected targets.

The study is being conducted in two phases, running concurrently and beginning at the onset of the program. The initial task under Phase I is a selection (made in cooperation with the technical monitor) of a list of ten specific civilian targets for which quantity-distance explosive storage criteria will be formulated. Having selected these targets a detailed analysis is being conducted of the structural properties and techniques used in their construction. In the conduct of these analyses, the construction of the targets will be related to external blast loading in terms of their anticipated response.

The initial task under the second phase of the program is to gather and evaluate documented experimental blast effects studies pertaining to structures and structural elements such as wall sections, aircraft, trucks, etc. Those experimentally treated targets which can be related to similar structural properties and construction techniques will be used in evaluating the blast response of the designated civilian targets or structural segments thereof. Acceptable damage levels for each designated target will be mutually selected with the technical monitor for use as guidelines in establishing minimum quantity-distance storage criteria. With these levels in mind, analytical techniques suitable for prediction of blast effects and response on the designated targets will be developed. In this portion of the work, it is anticipated that much help will be obtained from past work both by this laboratory and other investigators in similar technique development, primarily for use against military targets. Based on these techniques, a separation distance for each explosive quantity-target combination will be established which minimizes the risk that blast damage resulting from accidental detonation will exceed the designated acceptable level. Further, it is intended that analytical methodology be established which will allow or facilitate the reviewing of current explosive storage safe distance criteria and establish a basis for the formulation of similar criteria for new targets not previously considered.

Based on this methodology and applicable experimental data, a computer program will be developed which will generate explosive storage quantity-distance criteria. This program will be used to generate recommendations of separation distances for the selected targets and the designated quantities for explosives. It is intended that this program be written in the FORTRAN IV language, which can be adapted to a wide range of computers. The program will of course be accompanied by documentation and operation instructions.

At our first conference with the technical monitor in July, a list of representative targets was selected (Figure 2). This list is not intended to cover the complete spectrum of all targets of interest to the Safety Board; it represents typical targets in each of several categories. The first item, namely the split-level combination masonry and frame home, covers both the typical frame and brick dwellings found in our urban or suburban areas. The school was intended to be typical of many of the new single-story schools we find around the country. The multi-story office building is 10 stories high and of a construction not intended for an earthquake area; that is, there are no special structural provisions for earthquake loading.

The personnel target in this study is intended to represent people standing outside of buildings in the open. Two categories of aircraft are being considered at the present. One, a large commercial airliner, such as the Boeing 707; the other, some small single-engine general type aircraft. In the case of the explosive bunkers, only that portion which is generally not covered by earth (for example, a front wall or a door) is considered. The modern church is intended to be representative of high-occupancy type targets such as theaters, convention halls, or other gathering places. Due to the growing use of mobile homes or trailer homes, particularly in areas near possible explosives storage, it was decided to include this as representative of temporary housing. The last two items on the list are intended to be typical of the more vulnerable vehicles, from the standpoint of accidental blast of large quantities of explosives in storage areas near highways.

The first step in performing the structural analysis on the individual targets is that of a target description. The next few slides are drawings of some of the targets which will illustrate the type of construction under consideration. Figure 3 is an isometric pictorial of the tri-level or split-level home. As can be seen, the one-story portion of the building is conventional all-masonry construction while the portion over the basement on the right is of frame construction. Wooden beams are employed to support floor joists as shown and conventional construction with respect to floor joists, studding, rafters, ceiling joists, etc., is employed. The next drawing (Figure 4) is of a small one-story school which employs brick veneer and stone wall construction, a flat roof, and considerable glass.

Figure 5 shows one type of multi-story building; this construction consists of a steel frame with the wall panels laid up of concrete blocks, and again includes a great deal of glass. Also being considered for this target is a curtain wall type construction. Preliminary analyses seem to indicate that this steel frame-concrete block construction is somewhat more susceptible to blast damage than is the curtain wall type; however, the final selection has not been made. Figure 6 is a drawing of a standard man composed from Henry Dreyfuss' treatise on The Measure of Man, as updated in 1959. The following figure (Figure 7) illustrates a derivation of this man which is being employed in the computer analyses developed for vulnerability studies by the Target and Vulnerability Analysis Laboratory of Falcon Research and Development Company.

Based on drawings supplied by the Explosive Safety Board, the drawing shown in Figure 8 was made of the front wall and entrance of a typical explosive storage igloo. As can be seen, the doors consist of channel iron frame covered on the front with 3/8-inch plate and on the rear with 16-gauge plate. Insulating material is placed within the door. The surrounding front wall consists of 12-inch reinforced concrete. Figure 9 is a pictorial representation of a typical A-frame type church, such as is seen very frequently across the country. The beams are of a laminated construction, and the decking is tongue and grooved in accordance with normal practice. The last of the target drawings we have is one of a typical mobile home or trailer (Figure 10). The frame is 8.5-pound channel iron and exterior walls are of .020-inch aluminum side panels. The studding or frame members are of 2x3 kiln dried spruce, 16-inch centers, cross braced with 1x3 lumber. Floor joists are 2x4 on 16-inch centers and the ceiling frame members 2x2 spruce with 2x4 center pole. These drawings serve to illustrate the types of targets being considered in the program.

The damage limit criteria (Figure 11) selected for consideration in this study are of course somewhat less severe than are frequently considered in vulnerability analyses o military targets, since safety, not destruction, is the objective. Throughout the program the primary concern is with damage to personnel within the target or immediately surrounding the target. In the case of the buildings, two levels of damage are being considered: the first is that level which will cause broken glass or other debris to move within the building with sufficient velocity to cause damage to personnel or equipment; secondly, we are concerned with collapse of a wall, ceiling, or other structural element. For personnel, the consideration is the force required to knock down or do other physical damage to the individual. It is assumed that no warning was given and therefore personnel are caught by surprise and are unable to brace or protect themselves against damage. For the aircraft targets, forced loss of control will be the criterion, unless structural damage occurs first. The concern here is with an aircraft in the act of taking off or landing, and therefore forced loss of control would undoubtedly cause a crash.

The damage criterion for the passenger bus and the camper-pickup truck is to be physical removal of control from the driver through a loss of traction on the highway causing the vehicle to swerve to another lane of traffic, or tipping the vehicle. The vehicle must be actually forced out of its lane of traffic or to some other orientation causing an accident. Of course, should structural failure occur first, this would be considered a failure.

The ability to accurately relate the loading (or load inducing) characteristics of an explosive shock to the structural properties of a specific target is required to make valid predictions as to the target response. Theoretically, the structural response of the target to dynamic blast loading can be estimated with the knowledge of the complete dynamic response of the target and the pressure-time and position characteristics of the blast wave relative to that target. As is well recognized, the complexities of this problem are many, and except in the most simplified targets, are such that a complete solution is precluded. There have been innumerable analytical and experimental programs conducted which were designated to aid in obtaining solutions; particularly the blast wave characteristics from idealized charges are well tabulated and can be accurately predicted.

A series of tests particularly useful for determining the blast parameters as a function of distance from surface bursts was sponsored under The Technical Cooperation Program (TTCP) and reported by Mr. Charles Kingery of the Army Ballistic Research Laboratories, Aberdeen Proving Ground. These tests covered the range of charge sizes from 5 to 500 tons which nearly encompasses the range of interest in this explosive storage problem. The graph shown in Figure 12 represents the peak pressure as a function of distance from TNT surface bursts for the charge weights selected for this program. These curves were scaled directly from the curves presented by Charles Kingery in the BRL report. The following graph (Figure 13) is a similar presentation for impulse. These values are of course the incident or side-on values for the parameters, and where appropriate, will be used to calculate expected reflected values and blast loading.

The final objective of the program is to develop an analytical method with which to determine separation distances for any designated explosive quantity and type of targets. These minimum distances will be established with respect to minimizing the risk of blast damage resulting from a given explosive detonation. In order that such a model be practical, it should be as simple and straightforward as possible but still capable of yielding realistic results. One such procedure which was developed primarily for use with military targets and weapons effectiveness analyses is that of Mr. O. T. Johnson of BRL. This technique is based on experimental results from a large sample of firings against a wide range of target types and explosive sizes. His approach is based on the derivation of a relatively simple relationship which characterizes all combinations of explosive weights and charge target separation distances which produce one identifiable damage level to a target. Admittedly, the use of this approach as a possible solution to the problem at hand does involve extrapolation to entirely different targets, and to lesser damage levels than those used to obtain the experimental data utilized in the derivation. However; the assumptions and procedures utilized in the development were not target dependent nor damage level dependent. Moreover, one author, namely, Col. Emory Hackman, a consultant to the Naval Weapons Laboratory at Dahlgren, Virginia, has developed what he believes to be a theoretical basis for Johnson's damage rule, based primarily on fundamental laws of physics with some necessary assumptions.

The large spectrum of targets utilized in the development of Johnson's rule, together with the theoretical evaluation, lead us to feel justified in attempting to apply this approach to the civilian targets of interest in this program. As the work developes, it may be that slight modifications to the exact form of the model will be indicated. Even with such modifications, it is believed that a model based on this approach will be simple to apply and, based on our investigations to date, as valid as the more complex procedures which could be adopted. Briefly stated, Johnson suggests that the usual damage threshold curves, based on experimental pressure-impulse data on each target, be replaced by a more simple relationship between charge weight and distance. Since pressure and impulse are uniquely determined from explosive weight and distance from the source, this relationship is used to calculate the distance required to achieve equivalent damage with various explosive weights as a function of some arbitrarily selected weight and distance. For his work in weapons effectiveness analyses (Figure 14), Johnson chose 100 pounds as his base weight and showed that the ratio of the distance, R_{100}, at which a certain level of damage is achieved from 100 pounds, to that for some other weight, R_w, causing similar damage can be parametrically stated as

$$\frac{R_{100}}{R_W} \simeq C_W .$$

The experimental data indicates that this ratio is related to the charge weight in the form:

$$C_W = aW^b$$

and that the values of the constants give

$$C_W = 7.64\ W^{-0435}$$

where W is explosive weight in pounds. Based on the data, the standard deviation for "a" is 0.219 and for "b" is 0.010, indicating that the curve is a fair fit of the available data.

The explosive weights for the data included in Johnson's study range from about 8 pounds up to 10,000 pounds, and the targets range from simple structures such as cantilever beams and cylindrical shells to more complex items such as aircraft, radar antennas, and 2-1/2-ton trucks. Thus, it must be recognized that the use of this procedure for the range of explosive weights and civilian targets of interest in the current study does involve a good deal of extrapolation.

In order to apply this technique, the selected damage level must be related to a specified explosive weight and distance. This can be done from experimental data when available, or by an estimate based on target response analysis and the explosive characteristics. The making of such an estimate, where experimental data are not available, is complex and subject to many assumptions. Different targets will react differently to a given blast loading, and therefore, a detailed structural study of each target is necessary in order to make predictions as to the blast response. This phase of the program is just getting underway as the target descriptions are being finalized. As implied previously, experimental results will be utilized whenever applicable data can be found.

Generally, the estimate is determined by calculating the resistance of the target or target component (such as exterior walls, roof, windows, etc.) in terms of the force required to cause structural failure. This force is related to pressure and/or impulse and the corresponding blast loading, and the distances determined for the various explosive weights from the available data on explosive output characteristics.

As an example of the use of the Johnson blast-damage rule, consider the tests conducted at the Naval Weapons Center, China Lake, California, by the Armed Services Explosive Safety Board with results reported by URS Research Company (Figure 15). In this program, two explosive tests were conducted with 10,000-pound TNT hemispherical charges placed in the center of a donor structure constructed to storage-bay standards. In the first test a single 10,000-pound charge was fired, whereas the second test employed two 5,000-pound charges fired at an interval of approximately 20 milliseconds. The results indicated that there was no significant difference between the two tests and also, that the presence of a barricade near the charge and shielding the two-story frame house target did not affect the air blast parameters.

The frame house was placed at a distance of 865 feet which is the minimum distance from a barricaded charge of 10,000 pounds as given in the quantity-distance tables. As indicated, the damage achieved was marginal in terms of structural failure (one broken rafter), but did cause broken windows, doors torn from the hinges, cracked plaster, etc. Assuming this to be the acceptable damage level, the Johnson rule yields the indicated values for the five selected charge weights. For comparison, the corresponding values from the quantity-distance tables are also listed. It must be emphasized that these are preliminary results presented as an illustration and by no means should they be construed as recommendations.

In the last column of the table are listed distances based on minimum pressure calculations for structural damage and Hopkinson's scaling. The distance for 1,000 pounds is in good agreement, but due to the use of cube root scaling, the remaining values differ considerably. If the Johnson technique were employed, based on the prediction for 1,000 pounds, the results would, of course, be in close agreement for all weights considered.

In summary (Figure 16), the purpose of the program is to provide an analytical basis for the establishment of blast criteria for the development of recommended minimum separation distances between stored explosives and surrounding facilities. This is to be accomplished by first developing target descriptions, applying appropriate experimental and analytically derived data to determine expected blast-target interactions, and utilizing this information in the formulation of a predictive model. As stated previously, the program is in the beginning stages and it is believed that, as the work progresses, a realistic method of predicting damage-distance levels will be evolved.

BLAST VULNERABILITY
OF PERSONNEL, SELECTED STRUCTURES, AND VEHICLES

OBJECTIVES:

1. Perform a parametric study of the blast effects of explosions on certain targets of interest to the Armed Services Explosives Safety Board.

2. Provide analytical criteria for establishing minimum separation distances between various quantities of stored explosive materials and civilian targets.

Figure 1

SELECTED REPRESENTATIVE TARGETS

1. SPLIT-LEVEL HOUSE, MASONRY AND FRAME
2. TYPICAL MODERN GRAMMAR SCHOOL
3. MULTI-STORY OFFICE BUILDING
4. PERSONNEL
5. AIRCRAFT
6. FRONT WALLS OF STANDARD EXPLOSIVE STORAGE IGLOOS
7. MODERN CHURCH
8. MOBILE HOME
9. PASSENGER BUS
10. CAMPER PICKUP

Figure 2

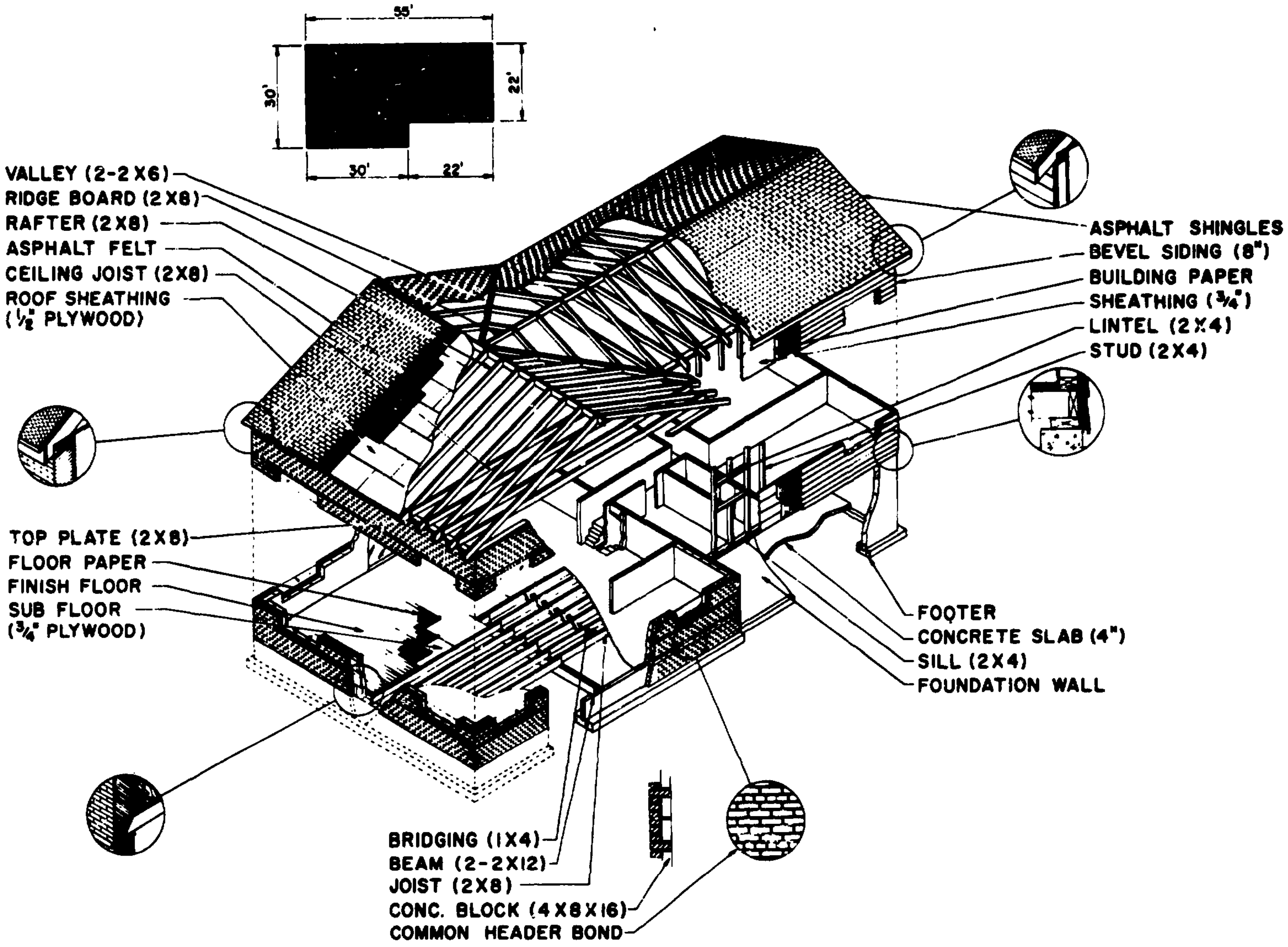


Figure 3. Split Level House

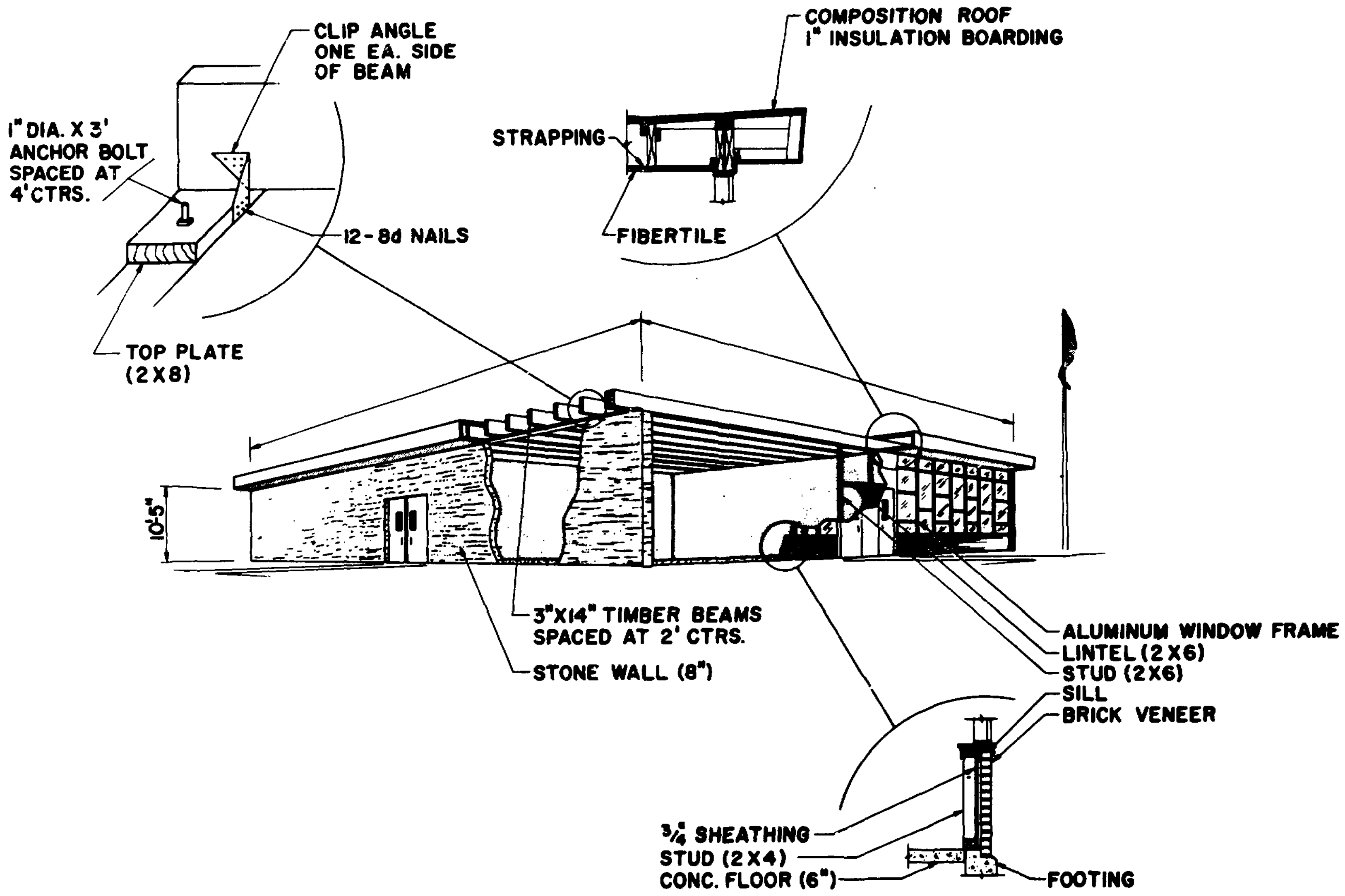


Figure 4. Typical Elementary School

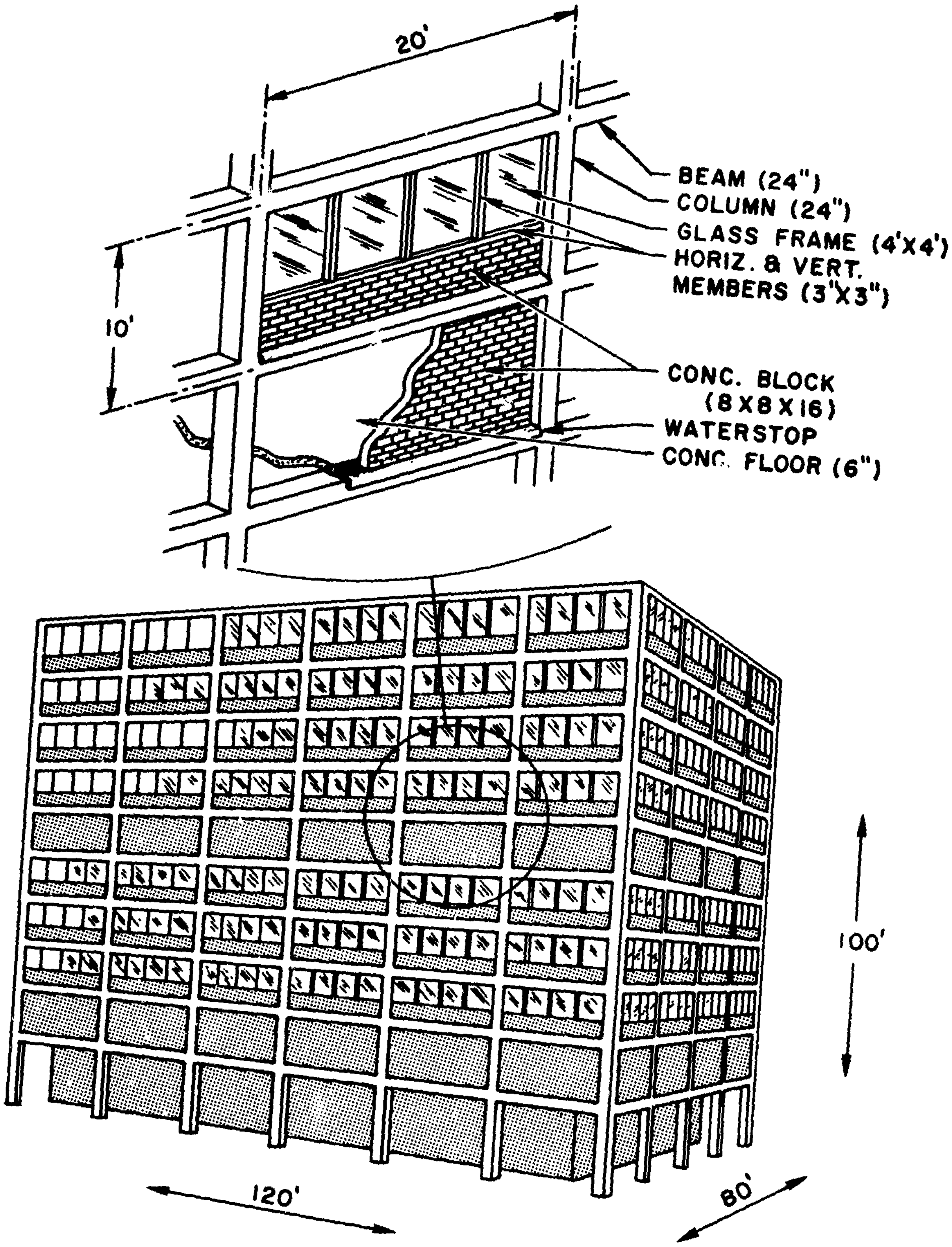


Figure 5. Multi-story Building

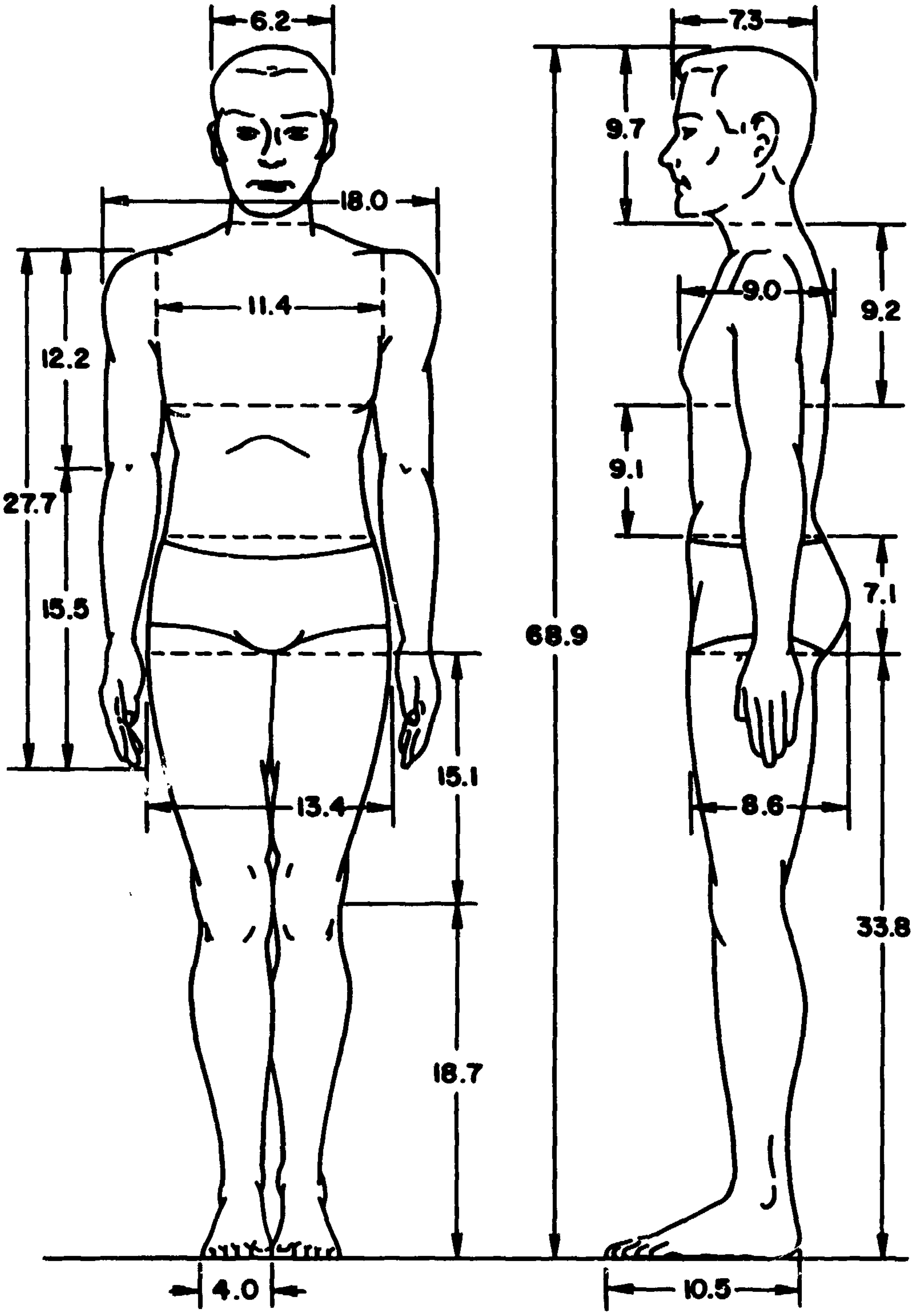


Figure 6. Standard Man

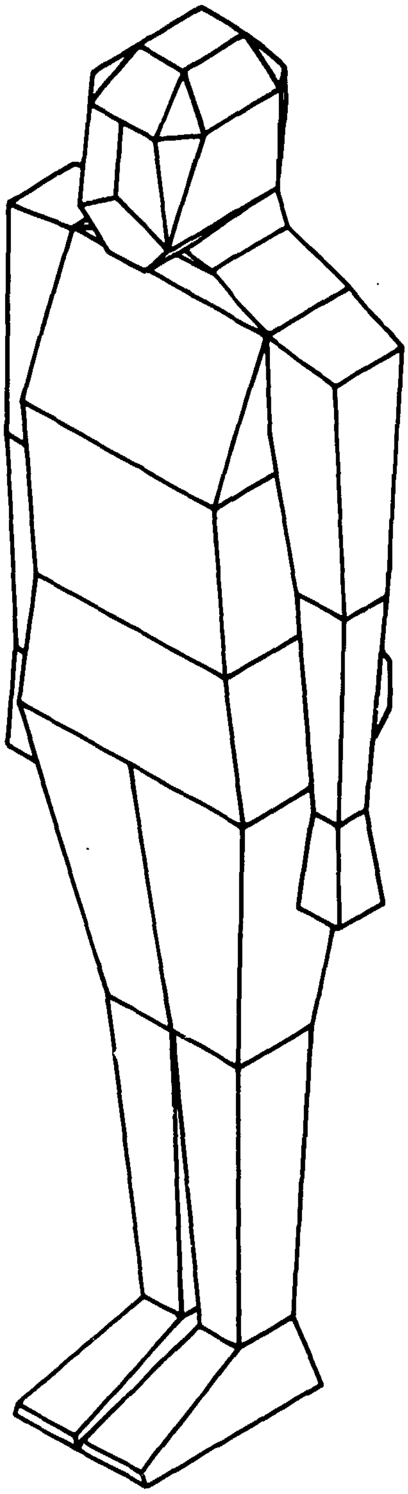


Figure 7. Approximation of Standard Man for Vulnerability Analyses

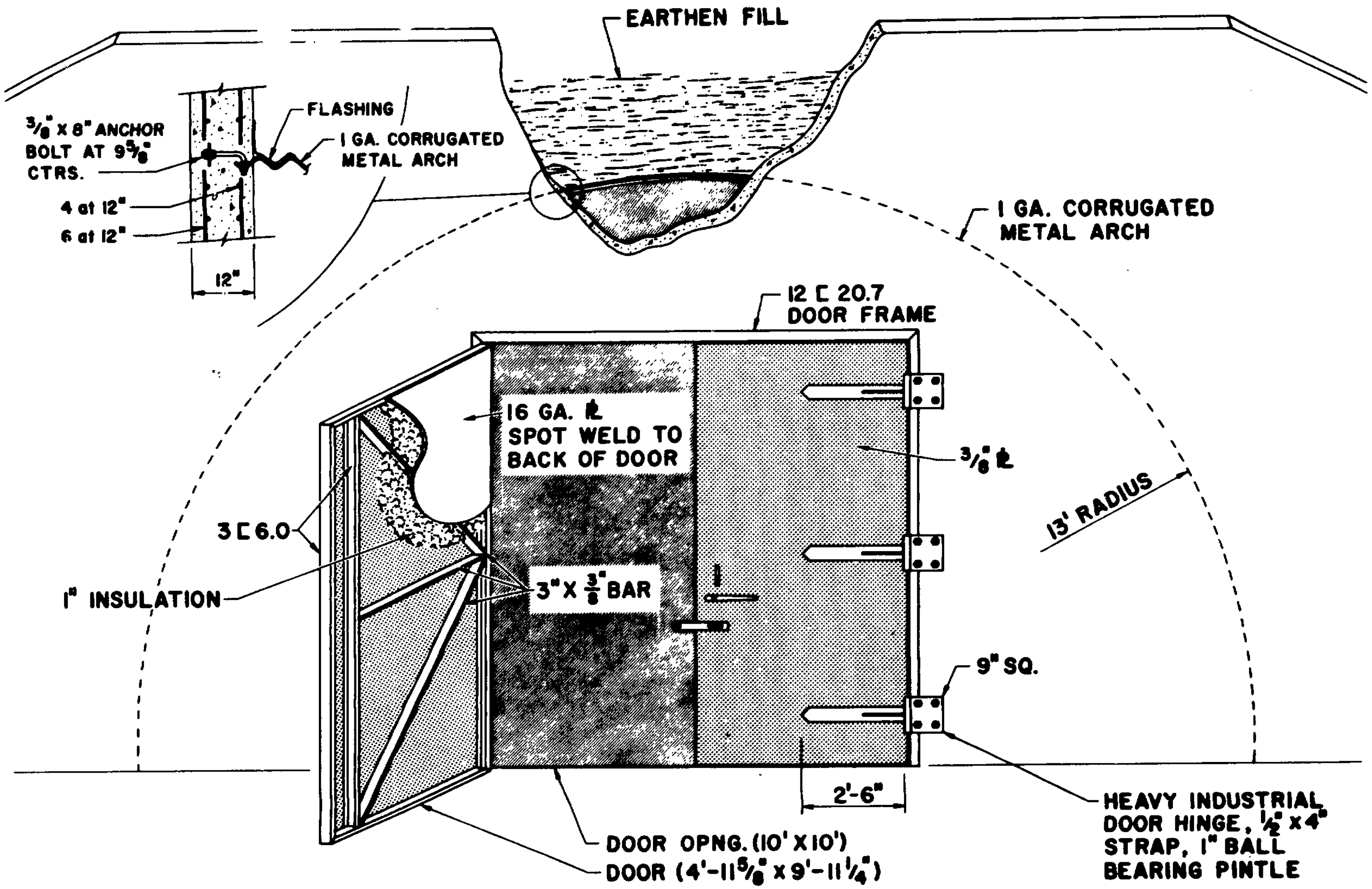


Figure 8. Standard Explosive Storage Igloo, Front

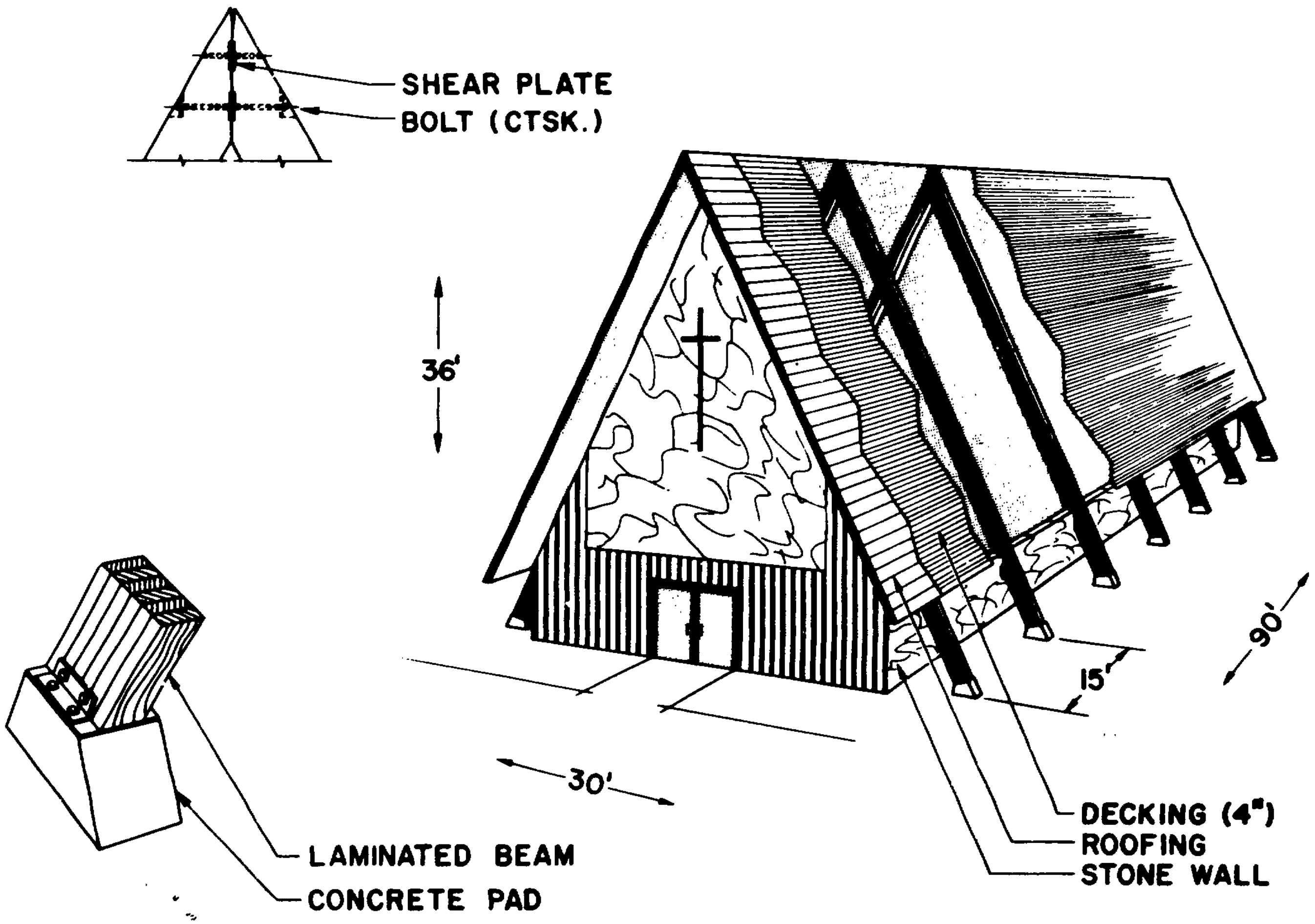


Figure 9. Typical Modern Church

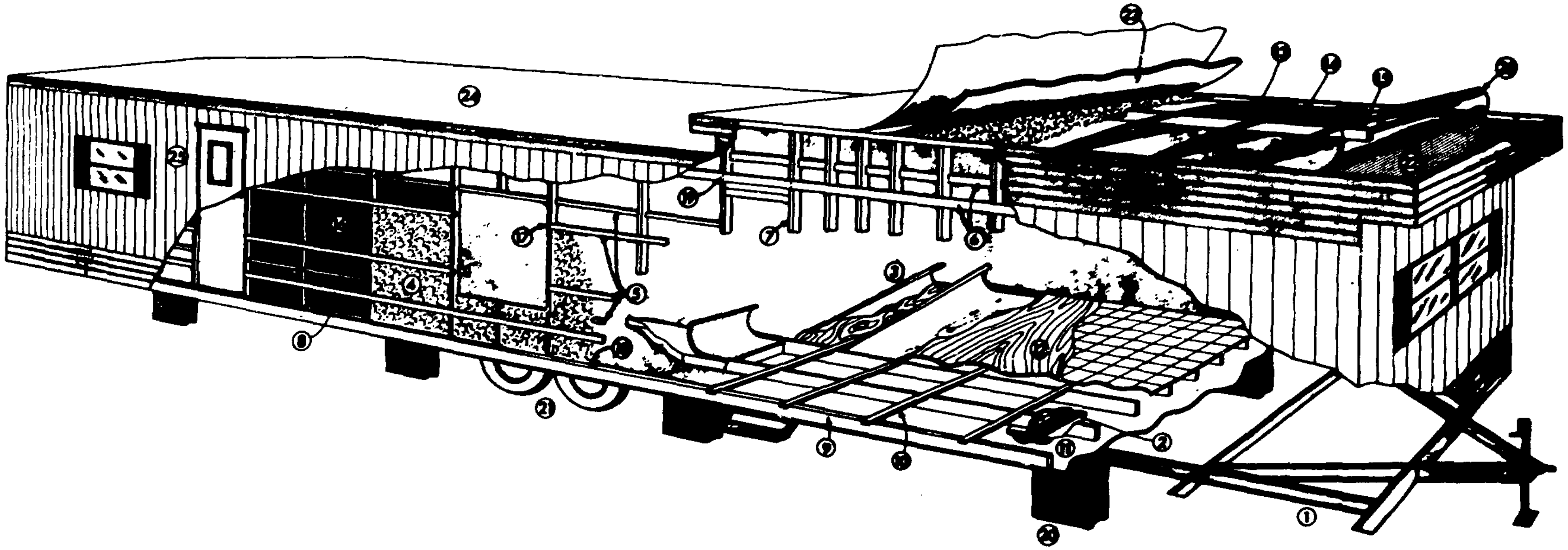


Figure 10. Mobile Home

DAMAGE CRITERIA

BUILDINGS – 1. WOUNDING GLASS FRAGMENTS
2. STRUCTURAL FAILURE

PERSONNEL – KNOCK DOWN

AIRCRAFT & VEHICLES – FORCED LOSS OF CONTROL OR STRUCTURAL FAILURE

Figure 11

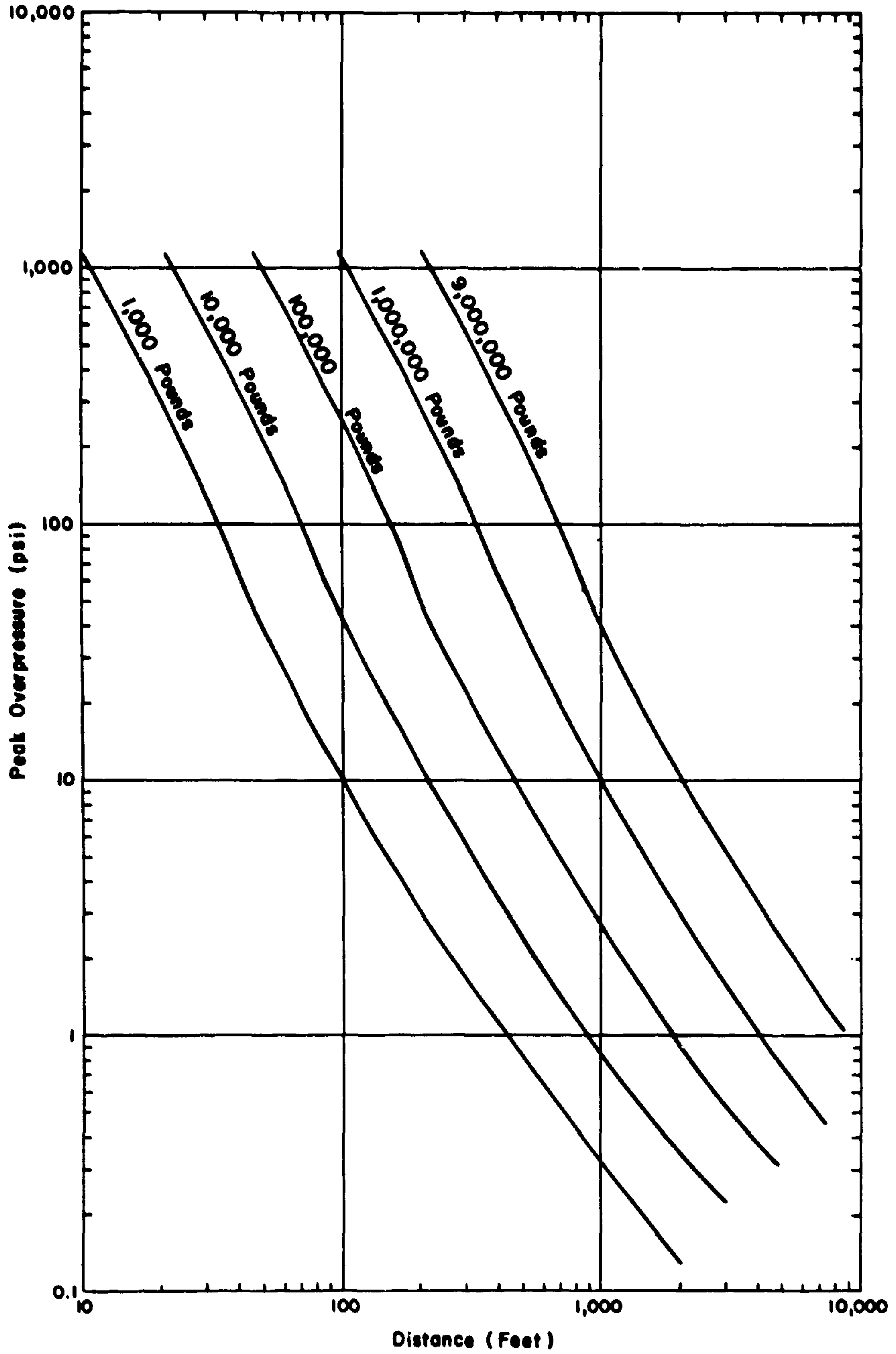


Figure 12. Peak Overpressure as a Function of Distance From TNT Surface Bursts

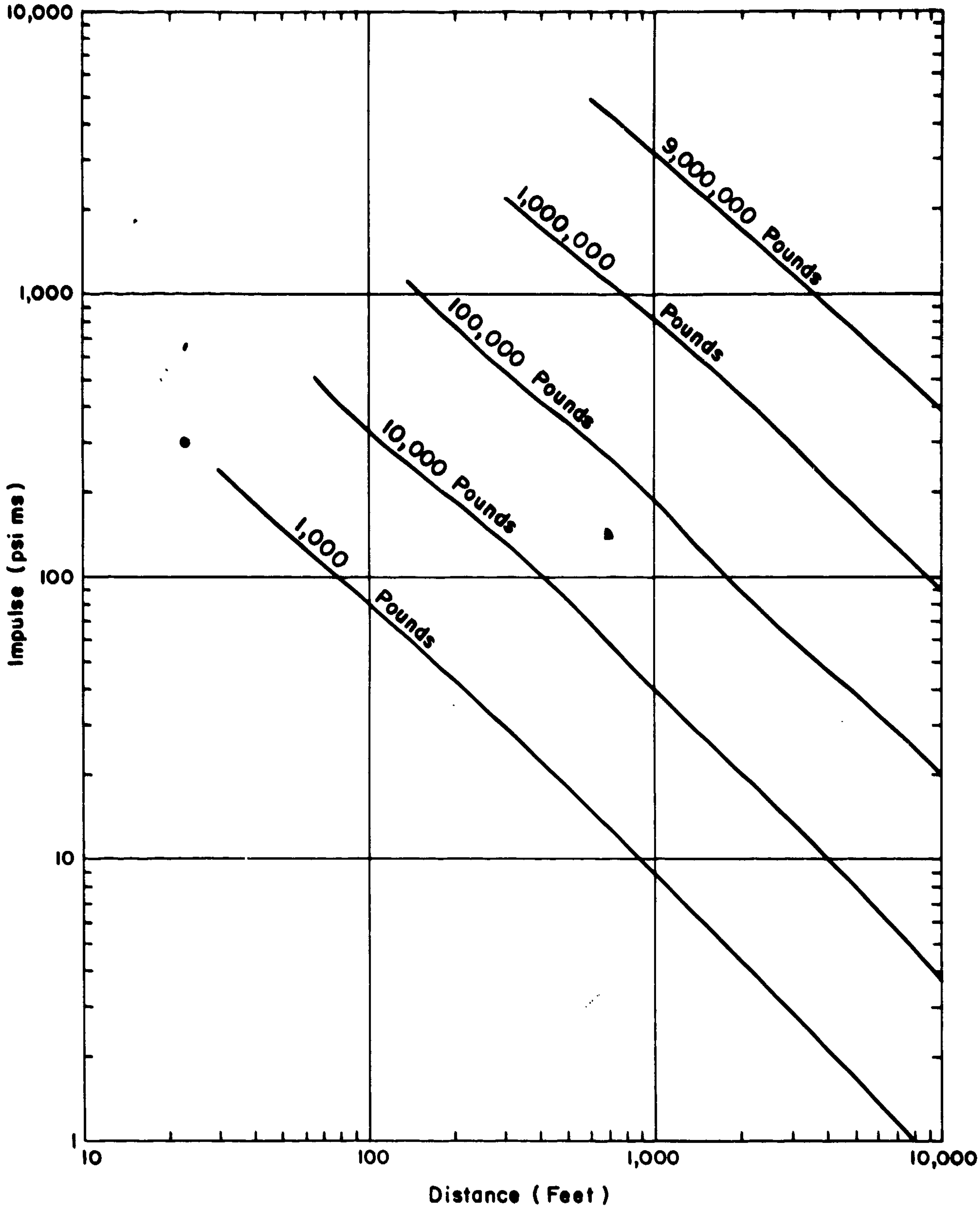


Figure 13. Impulse as a Function of Distance From TNT Surface Bursts

CONSTANT DAMAGE LEVEL
QUANTITY-DISTANCE RELATIONSHIPS

$$\frac{R_{100}}{R_W} \simeq C_W$$

$$C_W = aW^{b}$$

$$C_W = 7.64\ W^{-0.435}$$

1 SIGMA FOR "a" = 0.219
1 SIGMA FOR "b" = 0.010

Figure 14

NWC TEST EXAMPLE

EXPLOSIVE - 10,000 LBS. TNT

TARGET - TWO STORY FRAME HOUSE AT 865 FT.

DAMAGE - WINDOW BREAKAGE, CRACKED PLASTER, DOORS TORN OFF HINGES AND ONE RAFTER BROKEN

QUANTITY - DISTANCE FOR SIMILAR DAMAGE

EXPLOSIVE WEIGHT (LBS.)	DISTANCE (FT.)		
	JOHNSON TECHNIQUE	MINIMUM TYPICAL INHABITED BLDG. REQUIREMENT	THRESHOLD PRESSURE ($W^{1/3}$)
1,000	317	400	310
10,000	865	865	660
100,000	2,350	1,855	1,400
1,000,000	6,550	5,385	3,000
9,000,000	17,100	10,400	6,400

Figure 15

SUMMARY

PURPOSE – THE PURPOSE OF THE PROGRAM IS TO PROVIDE ANALYTICAL BLAST CRITERIA ESTABLISHING MINIMUM SEPARATION DISTANCES BETWEEN STORED EXPLOSIVES AND SURROUNDING FACILITIES.

METHOD –
1. TARGET DESCRIPTION
2. EXPERIMENTAL DATA
3. BLAST-TARGET INTERACTIONS
4. PREDICTIVE MODEL

Figure 16

EXPLOSIVE CLASSIFICATION AND HAZARDS EVALUATION OF PYROTECHNIC COMPOSITIONS AND END ITEMS

Moderator:

W. Paul Henderson
Edgewood Arsenal
Maryland

SUMMARY

The following speakers participated in this session:

Mr. Paul V. King, General Electric Co., subject: The Hazard Classification of a Selected Group of Pyrotechnic Compositions and End Items

Mr. J. F. Voeglein, Jr., Edgewood Arsenal, subject: Safety in Pyrotechnic Munitions Industry - Lack of Standards

Mr. Garry Weingarten, Picatinny Arsenal, subject: Hazard Classification of Pyrotechnic at Picatinny Arsenal

Mr. Erskin Harton, Department of Transportation, subject: Hazard Evaluation of Pyrotechnic Compositions for Transportation Purposes - The Regulatory Viewpoint

Subject session was held on 9 and 10 September 1969 from 1000 hours to 1145 hours. After the above speakers had completed their presentations, a discussion period followed which lasted until 1200 hours on both days. The attendance for both sessions was excellent, however, on the second day there were few empty seats. These were very spirited and active question and answer periods in which most of the audience participated. They were extremely interested in the hazard classification and test program to determine the TNT equivalencies. Mr. Harton of DOT was asked many questions concerning the relationship of DOT to ICC and if the old shipping regulations would be brought up-to-date as new data became available.

It was the consensus of opinion that the new pyrotechnic classification and hazard evaluation program was long overdue and that some means of quickly disseminating the information, as it becomes available, should be made possible rather than waiting for the publication of formal reports.

They also requested that the ASESB be kept informed so that "Quantity Distance" tables could be revised as quickly as possible.

FACILITY PLANNING & PLANS SUBMISSION

Moderator:

Virgil L. Carpenter
US Army Munitions Command
Dover, N. J.

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FACILITY PLANNING & PLANS SUBMISSION

One of the most important controls of any installation safety program is the local preparation and coordination of facility planning and the safety review of plans submitted. It is imperative that safety personnel at the installation level become involved in all facility planning at the "grass root" level. This is necessary to assure that all safety factors are considered and that the best safety measures be incorporated into these plans. I am sure that many of you are quite familiar with this area and have on previous occasions held lengthy discussions on the subject. However, with the continuous build-up in our operational activities, we continue to encounter problems which are resulting in excessive time delay in project approval, duplication of effort in many areas, and unnecessary expenditure of funds. Also parallel with these problems, many questions still arise such as:

a. Who is responsible for the preparation and submission of projects?

b. Who is responsible to insure that adequate safety information is included in the project?

c. Does the cost of the proposed construction or modification of existing facility have any bearing on when a project must be submitted?

d. Is a project submission required for proposed construction or modification of explosives operating buildings only?

e. Who determines when a project is required and when it must be submitted?

All of these questions are reasonable, have merit and are deserving of a definite answer or clarification, whichever the case may be. However, there are no pat answers and each question must be evaluated on its own merits.

Review of projects previously submitted for safety or site location approval has indicated the need for closer adherence to applicable safety standards and more emphasis on the review of the projects prior to forwarding through command channels to the Armed Services Explosives Safety Board (ASESB) for approval. Examples of problems more frequently encountered during review of projects are:

a. Plot plans and related data are not of good quality or clearly printed so as to indicate all facilities adjacent to proposed construction sites.

b. Distances between all facilities are not reflected on drawings or mentioned in letter of transmittal.

c. Scaled drawings are not provided so that distances can be measured.

d. Complete details of the mission proposed for the new or modified facilities are not clearly identified.

e. Mission or activities in adjacent facilities are frequently omitted.

f. Personnel and explosives limits are not always indicated for all bays or rooms (work areas) within the new or modified facility as well as adjacent facilities.

g. In a number of instances projects have been submitted after project funding and in some cases construction had been initiated prior to safety approval.

h. In some instances after site location was approved, subsurface construction was initiated prior to project safety approval.

i. In some projects, complete details relative to the type and arrangement of explosive operating equipment, operational shields, exits, ventilation, etc. were not clearly defined.

The requirements for safety approval of plans for new construction or major modification by ASESB are outlined in Army Regulation (AR) 385-60 and supplemented by paragraph 527, AMCR 385-224 and MUCOMR 385-6.

Paragraph 3G of this AR outlines the ASESB responsibility.

Paragraph 8 of this AR outlines the requirement for submission of projects for safety approval with exceptions as follows:

a. Modifications to existing facilities which are of a temporary or transient nature and which are necessary to --

(1) Support an emergency requirement for a limited period of time.

(2) Provide for operating or maintenance line modifications as a result of manufacturing process changes or adaption of a line to other end items.

The requirements for preparing and submitting projects for safety approval are further outlined in paragraph 527, AMCR 385-224 which states that, general plans for new construction or major modification (i.e., modification costing $25,000 or more) of the following type facilities shall be forwarded through command channels for safety review and approval at least one month prior to completion of detailed plans or initiating of any construction work or contractual obligations. The type of new construction work or modifications that are affected by AR 385-60 and paragraph 527, AMCR 385-224 are:

a. Facilities for ammunition and explosives activities.

b. Facilities for activities involving hazardous materials other than ammunition and explosives. Chemical loaded items and chemicals of a hazardous or toxic nature would come under this category.

c. Facilities for activities not involving hazardous materials which would be exposed to such hazards if not properly located.

The term modification does not include the reactivation of a standby facility and equipment or replacement of the original equipment for the handling of materials or operations which the facility was originally designed for.

Modification does include reactivation of an existing facility and equipment for manufacturing the original items when the operational processes will require that additional equipment be added such as increase in number (duplexing) of melt units, mixing kettles, etc. or when the facility is to be used for operations other than which it was originally designed for. Example: original design for fuze manufacture but to be reactivated for loading gravel mines.

AMCR 385-224, paragraph 527c and US Army Munitions Command Regulation 385-6 prescribes the policy, responsibility and information that must be included in a project submitted for safety review and that each project must contain or indicate as a minimum, drawings, plot plans and similar technical data which is of good quality, clearly printed and legible.

Drawings for buildings or structures are not required to be submitted where standard drawings are utilized. In such cases, only a site plan is required noting the standard drawings for each building or structure to be constructed.

a. Distance between the facility to be constructed or modified and other installations facilities, the installations boundary, public railways and public highways including power transmission and utility lines.

b. Identification of and a brief description of the activities at all other facilities within inhabited building distance of the facility to be constructed or modified.

c. General description of items, components or other hazardous materials to be in the new or modified facility, i.e., rockets, artillery ammunition, fuzes, etc.

d. Explosive limits and class(es) of ammunition, explosives, or other hazardous materials in facilities located within inhabited building distance of the new or modified facility.

e. Explosive limits and class(es) of ammunition, explosives, or other hazardous material proposed including a breakdown by room or bay when appropriate.

f. Anticipated personnel limits for the new or modified facility, including a breakdown by room or bay when appropriate.

g. Construction details regarding substantial dividing walls, vent walls, fire walls, roofs, operational shields, barricades, exits and types of floor finish, as well as general materials of construction.

h. Data relative to the type and arrangement of explosives operating equipment, operational shields, fire protective system installations, electrical systems and equipment, ventilation systems and static grounding systems.

i. Topography map with appropriate contours when terrain features are considered to constitute nature barricading or when topography otherwise influences layout.

For safety review of accelerated projects (expedited design and cost plus fixed fee contracting) which require expedited handling. The safety plans need only to incorporate the requirements of a. thru f. above and the letter of transmittal will include a statement pertaining to the detailed construction plans for g. and h. above. This statement will denote that these plans will conform to the requirements of USAMC safety standards including tests of any operational shields as required by paragraph 2622, USAMCR 385-224. Single line sketches with descriptive notes should supplement the narrative particularly for modifications involving new construction. The letter will also provide that detailed plans will be submitted as soon as they are completed. Any deviations from published safety standards must be included in the letter of transmittal. All of the above plus other safety factors which are omitted or overlooked during project preparation and/or review results in any number of undesirable situations such as:

a. Delay in approval.

b. Delay in start-up of construction as well as production operations.

c. Unnecessary expenditure of funds for relocation of facilities or parts thereof which have been partially completed.

d. Dismantling partially installed equipment and modifications to existing facilities.

When we take a good hard look and evaluate the conditions that I have mentioned, it clearly demonstrates that:

a. Safety submissions must provide all information required by previously mentioned regulations.

b. Close attention must be given to the preparation of projects to insure the adequacy and completeness of information contained therein.

c. Close coordination must be maintained between the engineering and safety personnel during the preparation and processing of projects for safety approval.

d. Sufficient time must be given to the preparation of safety projects soas to preclude the omission of certain design principles which would otherwise add to the safety of the operation.

In the preparation and submission of projects, for safety approval, it must be a coordinated responsibility between the Commanding Officer, plant manager and safety director to assure that:

a. Site plan approval is obtained prior to submission of projects.

b. Construction plans for safety review are submitted thru channels, to Hq USAMC, prior to or simultaneously with project submission. Safety submission must not be delayed awaiting project funding.

As soon as planning for construction of a new or modified facility is firm, a site plan submission must be made in accordance with the requirements of AR 385-60. This applies to all construction involving hazardous materials and other construction if exposed to the hazardous materials. The site plan must show existing and planned facilities in the area together with quantities of explosives currently or proposed to be stored or handled. A site plan must show existing and planned facilities in the area together with quantities of explosives currently or proposed to be stored or handled. A site plan does not take the place of a technical safety submission in accordance with paragraph 9, AR 385-60 and paragraph 527, AMCR 385-224. However, a site plan can be incorporated as a part of the technical safety submission.

Site plan approval must be obtained prior to the submission of projects for budget funding. In addition, the technical safety submission must be submitted prior to or simultaneously with construction project submission. Many installations are not complying with this requirement. Trouble frequently ensues. For example, a project was funded for three new lines at a USAMUCOM plant about two years ago based on a site plan approval. Construction was started prior to completion and review of the safety submission six months later. The technical safety submission review was completed, a serious error was discovered. The installation had failed to provide for proper distances between the lines. This error resulted in additional costs of over 1 1/2 million dollars. This is extremely embarrassing for which there is no excuse. Many people feel that the site design effort must be accomplished professionally by Corps of Engineer personnel. This is erroneous. The information the installation provides to the Corps of Engineers must be of good quality and must include the same data needed for a technical safety submission except for the detailed construction drawings. It is most important to submit the plans for approval without construction details when time does not permit. The construction details must be submitted as soon as available but in all cases prior to start of construction.

DESIGN CRITERIA FOR BARRIERS

For many years the practice of separating quantities of explosives into smaller groups has been followed for the purpose of minimizing the effects of an explosion and permitting a reduced safety distance. Separation of explosives has been provided by distance, intervening walls termed "substantial" or a combination of substantial walls and appropriate, approved barricades. Recent investigations relative to the overall protection provided by substantial type walls and model test to include large scale confirming test and theoretical calculations indicated that the basis applied to these walls were not sound for some combinations of quantity of explosives and separations applied.

In brief it was previously believed that if there were two or more discreet quantities of explosives separated by substantial walls, detonations would not occur instantaneous and that the resulting effects would be of two explosions and the maximum damage would be that of the larger amount. Based on the results of aforementioned investigation and test, it has been demonstrated that under certain conditions, the force of the later explosion(s) move faster and at most practical distances the effect is that of the entire quantity exploding en masse.

In June of 1968 a manual outlining new design criteria for barriers was published in draft form, but was of sufficient quality for publication. On 15 July 1968, AMC made this manual effective and directed that the new design criteria be applied to all future projects for new construction or major modifications.

The primary objective of the new design criteria is to prevent propagation of explosions from one building or part of a building to another to preclude mass detonations. Secondary objectives are:

1. Establish blast load parameters.

2. Methods for calculating the dynamic response or reinforced concrete and other materials.

3. Guidelines for siting explosives facilities.

This new design method accounts for the close-in effects of a detonation, including associated high pressures and non-uniformity of the blast loading on protective structures or barriers. The dynamic response of the structures can now be calculated and details have been developed to provide the properties necessary to supply the required strength. This manual is limited only by variety and range of the assumed design situations. An effort has been made to cover the more probable situations. However, sufficient generalities have been included in order that many varied applications can be made. The manual also provides for a safety factor of 20% since there usually are unknown factors which can result in either an over-estimate or under-estimate of the protective structures capability to resist the explosive output.

During the past year, there have been any number of complaints to include Corps of Engineer architects, project managers and installation personnel, that they could not understand this manual. However, when MUCOM offered to conduct a training program, the results from personnel at management level that training was not needed. There has been indications on many occasions that the additional costs for the new design barriers is of significant interest to you. Some research has been done on this and the results were no valid data on an Army procurement of equipment and missile project. However, some significant factors were uncovered regarding an Army military construction project. The cost figures would be similar for any construction activity.

Basically, the findings were that the raw materials for the new design walls would cost 15% more than the old 12 inch reinforced concrete walls. However, there were a number of other factors which were not addressed. The Corps of Engineers has estimated costs for a new assembly building at one of MUCOM installations and significant factors were:

1. The additional cost of raw materials for the new walls was approximately 15% more than for the old 12" reinforced concrete wall.

2. This cost factor did not include the fact that the foundation must also include these raw materials due to the requirement for monolithic construction.

3. The extra costs for pouring this type wall in a monolithic attitude and the complicated construction of the walls makes the labor costs 250% of the materials cost.

Based on the Corps of Engineer estimates, the cost of the new design walls for this new facility will be between $575,000 - $625,000 as compared to $225,000 - $300,000 for 12 inch reinforced concrete walls. The funding of additional costs for existing approved projects is also an area of concern. Installations have queried the MUCOM safety staff as to how this is to be funded and we have replied that they must submit a request thru regular channels for supplemental funding based on this new requirement. For example, a MUCOM installation has an approved, funded, military construction project for a new facility. However, contracts had not been awarded when the AMC teletype was forwarded requiring the new design criteria. The addition of these walls costs a significant amount and they have had to delete other parts of the project in order to fund for these new walls.

It is recognized that this new design criteria will cost more money to install. However, the benefits are tremendous.

1. Drastically decreases personnel exposure.

2. Decreases the probability of damage to adjacent equipment and facilities.

3. Will decrease the potential of severe production base loss.

There is a most pressing need to have this draft design manual finalized. The final version should include tables for use by design engineers to readily determine the wall thicknesses needed for the quantity and type of explosives involved. It is understood that these tables are being prepared and it is most urgent that the Armed Services Explosives Safety Board place high priority on this aspect. These tables should be made available to the field as soon as prepared and not wait a final printing of the whole manual.

A summary of this discussion is:

1. Site plans should be submitted for approval as early as practical.

2. Technical safety submissions must be made prior to or simultaneous with project submission.

3. Data provided to the Corps of Engineers must be adequate and should be used for technical safety submissions.

4. This new design criteria must be included in each project submitted.

5. Data provided to the Corps of Engineers must include the requirement for new design criteria.

6. This new design concept in the form of guidance tables is badly needed.

7. The requirement for application of the new design criteria is mandatory and must be applied to all future projects when appropriate.

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FACILITY PLANNING AND PLANS SUBMISSION

F. P. Collinsworth
Hq USAF, Norton Air Force Base, Calif.

1. One of the major factors of a good explosives safety program is having adequate explosives facilities which have been properly sited. During WW II and shortly thereafter very limited explosives facilities were required by the Air Force. Due to the rapid build-up of SAC and ADC bases after the war, in many cases adequate explosives facilities were not available because of time phasing of construction or the lack of funds. This lack of adequate facilities was further complicated by the worldwide location of air bases in which explosives facilities were requirements.

2. Department of Defense Directive No. 5154.4, paragraph III, states this Directive applies to all DoD components worldwide and covers facilities under United States jurisdiction located within United States and overseas. Paragraph VI 7 states ASESB will review and evaluate all general site plans for the construction and modification of pertinent ammunition and explosives sites. This is further stated in paragraph 3-7 DOD 4145.27M. AFR 127-100 and AFM 127-100 state all site plans for proposed construction of such facilities (including modification and expansion) will be submitted for explosives safety review. Chapter 8, AFM 127-100 outlines the complete details for submitting explosives facilities plans for reviews. Plans will be forwarded for the following activities:

a. Military installation.

b. Contractor owned and contractor operated facilities on Air Force property.

c. Contractor operated Government owned facilities.

d. Contractor facilities affecting Government furnished explosives stored by the contractor.

3. Base or station Civil Engineers are responsible for forwarding explosives site plans to the intermediate headquarters (numbered Air Force). The intermediate headquarters will review and evaluate the plans and, if approved, forward them on to the major air command. The major air command (ADC, MAC, SAC, etc.) will review and evaluate the plans and, if approved, forward them on to Hq USAF (AFIAS-G2), Directorate of Aerospace Safety, Explosives Safety, Norton AFB. Information copies will be forwarded to Hq USAF, AFOCE-KB, and the appropriate

Air Force Regional Civil Engineer (AFRCE). If sonic hazards, toxic gases, radiation, X-ray, etc. are involved, an information copy will also be forwarded to AFMSP, Washington, D. C. (Surgeon General).

4. AFIAS-G2 will approve the site plan and grant final Air Force approval. The plan will then be forwarded to ASESB for concurrence with our approval. Approval will be returned to the base through Civil Engineer channels.

5. Site plans forwarded for explosives facilities will be legible and of not less than 1-inch equal to 400 feet scale. Standard facilities will be used and will be identified by Air Force definitive drawing numbers, when possible (AFM 88-2). If standard facility cannot be used, concept drawings will be furnished. The plan forwarded will identify all facilities within inhabited building distance for the explosives for which siting approval is requested.

6. Large quantities of real estate are required to support the function of an Air Force Base due to the missions assigned. Airfields (runways and taxiways) require large quantities of land to support modern aircraft. Support elements add to this. Aircraft may be loaded with explosives at a base located in the States. In a sense, an airfield could be considered a combat area. To provide the explosives storage support required, several explosives facilities may be required: hot cargo pads, alert aircraft parking pads, explosives storage area, and ready storage pad. One can see that vast quantities of land is required to support an Air Force Base.

SITE APPROVAL PROGRAM FOR AMMUNITION AND ELECTRONICS-ORIENTED FACILITIES

D. B. Pledger
Naval Facilities Engineering Command, Wash., D. C.

The consequences of the improper siting of facilities involving ordnance and electromagnetic wave generating and transmitting equipment can involve the loss of life as well as economic setbacks. For this reason, the Office of the Assistant Secretary of Defense (I&L) has directed that additional procedures be instituted to insure maximum safety in the siting of these facilities.

Although the ultimate decision regarding the siting of facilities for the construction and modification of explosives and electronics facilities rests with the Armed Services Explosives Safety Board, the responsibility for insuring that this procedure has been followed in the Naval establishment has been delegated to the Commander, Naval Facilities Engineering Command.

When a requirement for explosives or electronics-related facilities is recognized at the activity level, those with the responsibility for planning should make every effort to insure that both the design and the location of the facilities meet all established safety criteria. Explosives-related facilities include facilities intended for occupancy by personnel who are in the vicinity of ammunition stowages, transportation or handling, or other non-ordnance type facilities that are occasionally used for explosives handling such as piers and wharves. Explosives and electronics safety distances for proposed and all existing facilities should be clearly delineated on the activity GDM's General Development Maps). It is not sufficient to show only inhabited building distances in siting a project. Consideration must also be given to area separation distances, intraline distances, and intramagazine distances where they apply. Where storage or operating limits and classes of material have been restricted by existing limitations or inhabited structures, a note to this effect should be put on the drawing.

Submission of facility projects and site approval requests are made to NAVFACHQ via the appropriate NAVFAC EFD (Engineering Field Division) for review and comment.

Preliminary site approval requests must be accompanied by one full size (28-inch x 40-inch) reproducible or six nonreproducible copies of the general site plan, at a scale of not less than 400 feet to the inch, showing all existing and planned future facilities in the area. The drawing must indicate the quantities by classes of all explosives currently or proposed to be stored or handled in the area.

When electronics-oriented facilities exist in the area, or are planned, the location of the sites should be so indicated.

Since possible hazards can be best identified by personnel at the field level, every attempt should be made by planning personnel and NAVFAC Engineering Field Divisions to insure that proposed projects are reviewed and coordinated by NAVELEX and NAVORD specialists prior to formal submission. Cognizant NAVELEX Field Technical Authority (FTA) and appropriate NAVORD Support Offices, NOSSOLANT located at Norfolk, Virginia, and NOSSOPAC located at San Diego, Calif., have been assigned responsibility for identification of possible hazards and for coordinating the review of projects.

Requests for preliminary site approval should be submitted with a copy of the DD Forms 1391 and 1391C (Facility Study) for MCON and MCNR projects, if possible, at the time the project is submitted for approval or for inclusion in a budget or construction program. Requests for site approval of MCON and MCNR projects shall not be submitted later than the time of submission for the Program Cost Estimate.

Final site approvals are required at the 30-percent stage completion of final design of facilities. Submission is similar to that of the preliminary site approval request except that pertinent design drawings of the structures should accompany the previously requested data.

Where facility sitings are modified subsequent to the preliminary or final site approvals, requests for site approval of the proposed resiting must be submitted.

Hq, Naval Facilities Engineering Command is responsible for coordination with NAVORDHQ and NAVELEXHQ, and for obtaining the necessary approvals. A control file of all site approvals will be maintained in NAVFACHQ. The Commander, Naval Ordnance Systems Command has been designated to act as the official Navy point of contact with the ASESB with direct contact with the Board by all others prohibited. Therefore, all requests for site approval will be submitted to NAVFACHQ, Code 2021, for forwarding to NAVORD for approval from the ordnance and electronics safety standpoint. The ASESB and/or NAVORD often will approve the siting of a facility from an explosives or electronics standpoint, subject to certain conditions, that is, limitations on the quantity of explosives stored, the provision of various protective construction features, establishment of safety regulations, and other similar situations. When site approval is granted subject to an operational restriction, approval or certification by the responsible command is required. A copy of this certification shall be furnished to NAVFACHQ, Code 2021, for retention in the NAVFAC permanent site approval file. Projects must also be in accordance with approved master plan documents and general development plans in order to receive approval.

To insure that site approvals are obtained for all projects under the jurisdiction of the ASESB, a check system has been established. The system is directed toward the accomplishment of the following goals: (a) provide positive identification of facility projects for which site approval must be obtained from the ASESB; (b) insure that timely action is initiated to obtain approvals from the ASESB; and (c) insure that the ASESB has approved site plans of appropriate facilities prior to award of construction contracts. Accordingly, the following certifications are required regarding the siting of all facilities, regardless of cost or source of funding.

A. Projects for Which PCE's (Project Cost Estimates) Are Prepared.

The following statements shall be included on DD Form 1391C in all PCE's:

(1) Site approval by the ASESB (is) or (is not) required in accordance with NAVFACINST 8020.2B.

(2) Action to obtain site approval by the ASESB (has) or (has not) been initiated. (Cite reference.)

B. Projects for Which PCE's Are Not Prepared.

Program cost estimates usually are not prepared for minor construction projects, replacements of damaged facilities, special projects, nonappropriated funded projects, projects costing less than $25,000, and late submission of projects in the regular MCON and MCNR programs. Site approval certifications, as indicated in paragraph A(1) above, shall be included in the following:

(1) Requests submitted to higher authority, via this Command, for approval of minor construction projects, replacements of damaged facilities, and special projects.

(2) Requests submitted to the major claimants, copy to NAVFACENGCOM, for approval of non-appropriated funds expenditures.

(3) All other project approval requests involving new construction or redesignation of building use.

C. Projects That Are Resited Subsequent to Initial Site Approval.

Where facility sitings are modified subsequent to submission of the PCE or to the initial request for site approval, the requests for approval of the facility resiting shall include certifying statements as indicated in paragraph A(1) above.

The complete implementation and adherence to the site approval program for ammunition and electronics-oriented facilities will assist planning personnel in their effort to promote "safety first." The program will help to avoid costly errors in site planning.

VERSATILITY OF GOCO LOADING PLANTS

Moderator:

Royal J. Kahler
Mason & Hanger-Silas Mason Co., Inc.
Cornhusker Army Ammunition Plant
Grand Island, Nebraska

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General Summary

The following is a compendious presentation of the most significant features of the potentials relative to the versatility of GOCO loading plants. The judicious ideologies were affirmed only after a thorough investigation and engineering studies.

We are of the unbiased opinion that the ultimate potential versatility and end item output of any GOCO loading plant will, in most cases, require automation and modernization of same. Our foresight and planning of such a program reflects the grouping of various explosives end items and then categorically assigns the loading of them to plants most practical for adaption. Therefore, it is obvious that each and every plant's capability and assignment to load explosives end items will also depend on its physical layout. The definition of a plant's physical layout should include, among other items, the square miles the plant encompasses, sites of existing facilities, topography, geographical location, roads and railroads.

The reasons for prompting the upgrading, automation and modernization of GOCO loading plants are manifold. Some of the controlling factors dictating postural realignment in order for plants to qualify for versatile loading of end items are: time required for retooling, reduction in cost of end items, greater number of end items, improved quality of end items and improved safety.

Presentation of subject matter was as follows:

1. Louisiana Army Ammunition Plant

Changes that were effected on "C" Line since its inception during WW II to date in order to cope with production requirements as to type of items and quantities desired by higher headquarters. Effect of modernization program on present and future compatibility of LAAP for item change-over. Presented by Mr. J. M. Richardson, Safety Director, Sperry Rand Corp., Louisiana Army Ammunition Plant.

2. Lone Star Army Ammunition Plant

Description of equipment and line layout of IBM automatic fuze assembly line; items that can be loaded; production capability; length of time involved to change over from one item to another; what is involved engineering-wise to effect changes from one item to another. Presented by Mr. C. R. Goff, Director, Safety & Plant Protection, Day & Zimmermann, Inc., Lone Star Army Ammunition Plant.

3. Longhorn Army Ammunition Plant

Versatility of GOCO plants, as reflected in the history of production of explosives, solid propellant rocket motors, artillery and mortar pyrotechnic items, and hand-held signals. The response of personnel in support of production activities and in responding to situations arising out of catastrophes, such as fire and explosion. Presented by Mr. H. Q. Holley, Planning Director, Thiokol Chemical Corp., Longhorn Army Ammunition Plant.

4. Cornhusker Army Ammunition Plant

The revelation of the mutual concurrent loading operation techniques of the 8" projectile and MK 82 bomb. Explosives screening equipment, pre-heaters, etc., required to support TNT, Tritonal and Minol loaded items. Presented by Mr. Joe O'Dea, Safety Director, Mason & Hanger-Silas Mason Co., Inc., Cornhusker Army Ammunition Plant.

LEGAL LIABILITIES OF SAFETY OFFICERS

Moderator:

Bruce M. Docherty
Assistant General Counsel
Office, Secretary of the Army
Washington, D.C.

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LEGAL LIABILITIES OF SAFETY OFFICERS

RESUME

A Specialist Session on the Legal Liabilities of Safety Officers on 9 September was devoted to consideration of the following topics:

a. The legal liability of a safety officer when an explosives accident occurs at the plant.

b. May a person injured in the accident sue the safety officer?

c. Will the safety officer be liable to pay damages out of his own pocket in such a situation?

The session was repeated on the following day with another group in attendance. The following panel members participated in each session:

James W. Crowley, Legal Manager and Counsel, Susquehanna Corporation, Alexandria, Virginia

Louis Jezek, Safety Office, Headquarters, Army Materiel Command, Washington, D. C.

Lawrence F. Regan, Office of the General Counsel, Headquarters, Army Materiel Command, Washington, D. C.

Lt. Col. Joseph H. Rouse, Chief, General Claims Division, OTJAG, Fort Holabird, Maryland

S. Maynard Turk, Senior Counsel, Hercules, Incorporated, Wilmington, Delaware

The moderator opened each session with brief introductory remarks intended primarily to stimulate general discussion among all attendees.

There were no formal presentations but each member of the panel contributed to the discussion by answering questions from the floor and by pertinent comments on matters within his particular field of interest.

Following is a consolidated resume of both sessions. No recommendations or conclusions were arrived at by consensus. The resume should be understood as representing the moderator's view as to the gist of the discussions and the general, if somewhat tentative conclusions, which might reasonably be drawn therefrom.

The personal legal liability of plant safety officers does not seem to be a serious present problem nor has it presented serious difficulties in the past. No one at either session knew of an actual case in which a safety officer had been sued in his individual capacity as a result of an explosives accident at a plant. The question is one of concern to a number of safety officers, however. Some Contractors apparently have provided, or may be considering some provision for, insurance coverage which would protect their safety officers from personal liability for explosives accidents.

Interest in the problem is quite understandable. There is today what might be described as a general feeling that a person injured in an accident should receive adequate compensation. If such compensation is not available from the Government or from a Contractor, the attorney for the injured party may well look to other sources. An inclination to seek new and different sources of compensation, when coupled with increased monetary awards in negligence cases, might lead to a serious future problem for a plant safety officer.

In many instances the injured person may be able to obtain compensation from the Federal Government. The Federal Tort Claims Act permits suit against the Government in certain instances for accidents caused by the negligence or wrongful acts of Federal employees. The Federal Employees' Compensation Act provides for compensation to a Government employee who is injured on the job. There is a statutory compensation system for military personnel injured in line of duty. Contractor employees injured in an accident on the job would presumably be entitled to benefits under a state Workmen's Compensation Act.

Cases may arise, however, where the compensation thus provided either is not available, or is regarded as inadequate. By way of example the injured party, for one reason or another, may not be entitled to sue the Government under the Tort Claims Act. In cases of this nature a plaintiff's attorney might consider bringing suit against a plant safety officer.

There is usually nothing to prevent the injured party from bringing suit against a safety officer although the provisions of some state Workmen's Compensation Acts may prevent one employee of a Contractor from suing a coemployee. Also an individual who obtains a judgment against the Government under the Tort Claims Act may not thereafter sue a Government employee to recover damages for the same injury.

If a plant safety officer should be sued, it would probably be necessary for the plaintiff to show that the safety officer had been careless or negligent, and that his negligence caused the plaintiff's injury. These would be matters, however, for consideration during the course of the litigation when the facts of the particular case could be ascertained.

There was considerable feeling that, as a practical matter, it would be well for safety officers to find out whether they have or could readily obtain insurance coverage against this type of liability. Inquiry might be addressed to an individual's insurance agent. Contractor personnel might wish to raise the question of insurance with their employer. There was some indication that a Contractor carrying public liability insurance may already have or might be able to obtain coverage for its professional engineers as to acts or omissions within the scope of the policy. It was observed that there may be an identity of interest in that the negligence, if any, of the Contractor's employee may be the negligence of the Contractor as well.

A Government employee would probably have to obtain his own insurance if any were available to cover this type of risk. On the other hand he may have certain advantages in the defense of such a suit.

The Department of Justice will sometimes provide counsel for the defense of an action against a Federal employee. This is apparently done on a case by case basis at the request of the employee's agency and if it is considered that defense of the action is for the benefit of the Government as, for example, by aiding employee morale or protecting a Government program. It may be possible also to have the case removed to a Federal court if it is originally brought in a state court.

The Government employee might also benefit from a doctrine of immunity which appears to have been broadened by recent decisions of the Federal courts. It is by no means certain that immunity from personal liability will be granted to a Government employee in a particular case. The courts have shown a tendency, however, to protect Government officials or employees from liability when they are exercising discretion in performance of an important Government function. Apparently the courts have felt, in some instances at least, that exposure of an official to damage suits might have an adverse effect upon the performance of the Governmental function. It might be helpful if the safety officer's job sheet stressed the discretionary nature of his duties and the exercise of judgment required in their performance.

It was also observed that there is being coordinated within the Executive Branch of the Government a Department of Justice legislative proposal intended to provide for the immunity of Federal employees from personal liability in tort for actions done in the scope of their employment. If such a proposal should become law a Government safety officer, if acting within the scope of his employment, would not be liable to a person injured in an explosives accident. The remedy of the injured person would be against the Government under the Federal Tort Claims Act. Such immunity from liability is presently enjoyed by two classes of Federal employees -- Government drivers and medical personnel of the Veterans Administration.

As indicated above the negligence of a Contractor's safety officer is likely to be the negligence of his employer. This identity of interest is also present in the case of a Government safety officer. If the Government is liable to the injured party the safety officer whose action caused the explosion will, presumably also be liable. It was suggested therefore that Government accident reports be carefully prepared so that all pertinent facts will be available to the attorney who will defend the Government in event of suit. This will be of benefit not only to the Government but also to the safety officer if he should be sued in his individual capacity. For similar reasons it might be well to keep in mind that it is dangerous to "guess" publicly as to the cause of an accident before the matter has been fully investigated. Statements made under such circumstances, even if incorrect, might prove to be damaging to the Government's case and also to the safety officer's defense if he should be sued in his individual capacity.

The moderator considers that these sessions were of value in permitting the exploration, in some depth, of a topic as to which interest has been expressed by a number of Seminar attendees. The moderator wishes to express his sincere appreciation to the members of the panel and to all the other participants in these sessions.

NEW EXPLOSIVES COMPOSITIONS -
THEIR SAFE UTILIZATION IN EXPLOSIVE ORDNANCE

Moderator:

Lionel A. Dickinson
U.S. Naval Ordnance Station
Indian Head, Md.

Summary

General: The workshop on New Explosive Compositions was limited to discussions on a) gelled slurry explosives (GSX), b) a proprietary type of explosive and c) qualification procedures for new explosives in projectiles.

A serious problem was uncovered in relation to proprietary explosives. Often the true nature of problems cannot be discussed and resolved because of industrial secrecy agreements. Mechanisms exist within D.O.D. for protecting technical data which is covered by a patent application but if supposed trade secrets are involved a difficult situation on the transfer of information relevant to safety arises. (Many contractors are unwilling to enter into industrial secrecy agreements and those that do will not discuss points of detail.)

Confusion arises because proprietary compositions can be confused with one another resulting, perhaps, in wrong safety procedures being applied in the event of a mishap.

It is strongly recommended that a review be made by the ASESB of hazards "built" into the use of explosives if a free exchange of data within the defense community is precluded.

GSX: Highlights of GSX were introduced by Dr. R. B. Clay (IRECO) and Mr. T. J. Sullivan (U.S. Navy). Trade-offs are involved between cost effectiveness, ingredient availability and different safety attributes. Thus, the enhanced cook-off resistance of aqueous GSX must be traded off against current short shelf life arising from a slow rate of gassing (hydrogen evolution).

The GSX look very attractive for very large devices that are "custom" loaded or loaded at forward bases; here a life of one or two months may be quite adequate.

Astrolite: Specific problems were reviewed but discussion was limited due to industrial secrecy agreements. (Paul Tweed of Martin Marietta reviewed weapon problems.)

Qualification of New Explosive: William McBride introduced the topic and expounded on safety aspects of substitutes and alternate explosives for Explosive D.

Copies of all papers were made available to the workshop attendees.

EVALUATION OF ASTROLITE AS A FILLER FOR FRAGMENTING MUNITIONS

Paul Tweed
Martin Marietta Corporation

For the past six years, the Explosives Corporation of America (EXCOA) has been developing a family of explosives, under the trade name of Astrolite, for various applications. Astrolite G, a liquid made by mixing two inert non-detonable chemicals, was recently selected by the Martin Marietta Corp. at Orlando for investigation as the main bursting charge in small fragmentation munitions.

As shown in Picatinny Arsenal Technical Report 3633, Astrolite G is safe to handle and store as a secondary explosive. It can be initiated with a blasting cap or by a rifle bullet where a metal backing is present. It is compatible with polyethylene, mylar, glass, Teflon, and certain types of rubber, aluminum alloys, and stainless steels. It is not compatible with copper, brass, steel, malleable iron, magnesium, lead, zinc and nitromethane. It explodes in 7 minutes at 270°C, loses 15% of its weight at 100°C, and salts out at 5°C. The crystals which form upon evaporation or on cooling have about the same sensitivity to impact as the liquid material. It is mildly toxic, definitely hygroscopic, and has a density of 1.4 grams per cc. Its brisance is similar to that of TNT and its rate of detonation is similar to that of 75/25 octol.

Slide 1 shows a small fragmentation bomb modified for static firing. Composition B and 70/30 cyclotol were previously evaluated as a filler for this bomb, which contains discrete steel fragments embedded in a spherical Adiprene case. It is considered desirable to investigate Astrolite G as a filler for such bombs because of the projected high cost of loading conventional TNT - based explosives, the projected low cost of Astrolite G in mass production, and the projected low cost of loading Astrolite G.

Slide 2 shows the modifications used to load and test Astrolite G in a similar bomb. The Astrolite fixture was different from the cyclotol fixture in the following principal respects:

a. Aluminum was used between the case and bursting charge.

b. Lucite was used between the booster and bursting charge.

c. A fuze holding rod which allowed variation of the fuze location was used. This made it possible to vary the number of booster pellets.

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d. No felt pad was needed for the bursting charge.

e. A hollow threaded nylon plug sealed at the booster end was used to prevent Astrolite from leaking out when the bomb was fired with the blasting cap horizontal.

The steel/Adiprene hemispheres were prepared for loading by coating them with 3M 2216 adhesive, which was then covered with aluminum foil 10 mils thick. The dummy fuze was adjusted to the proper height so that one or three booster pellets in a Lucite container could be attached. The hemispheres were bonded together with 2216 adhesive. Each assembly was cured for 3 hours at 150°C.

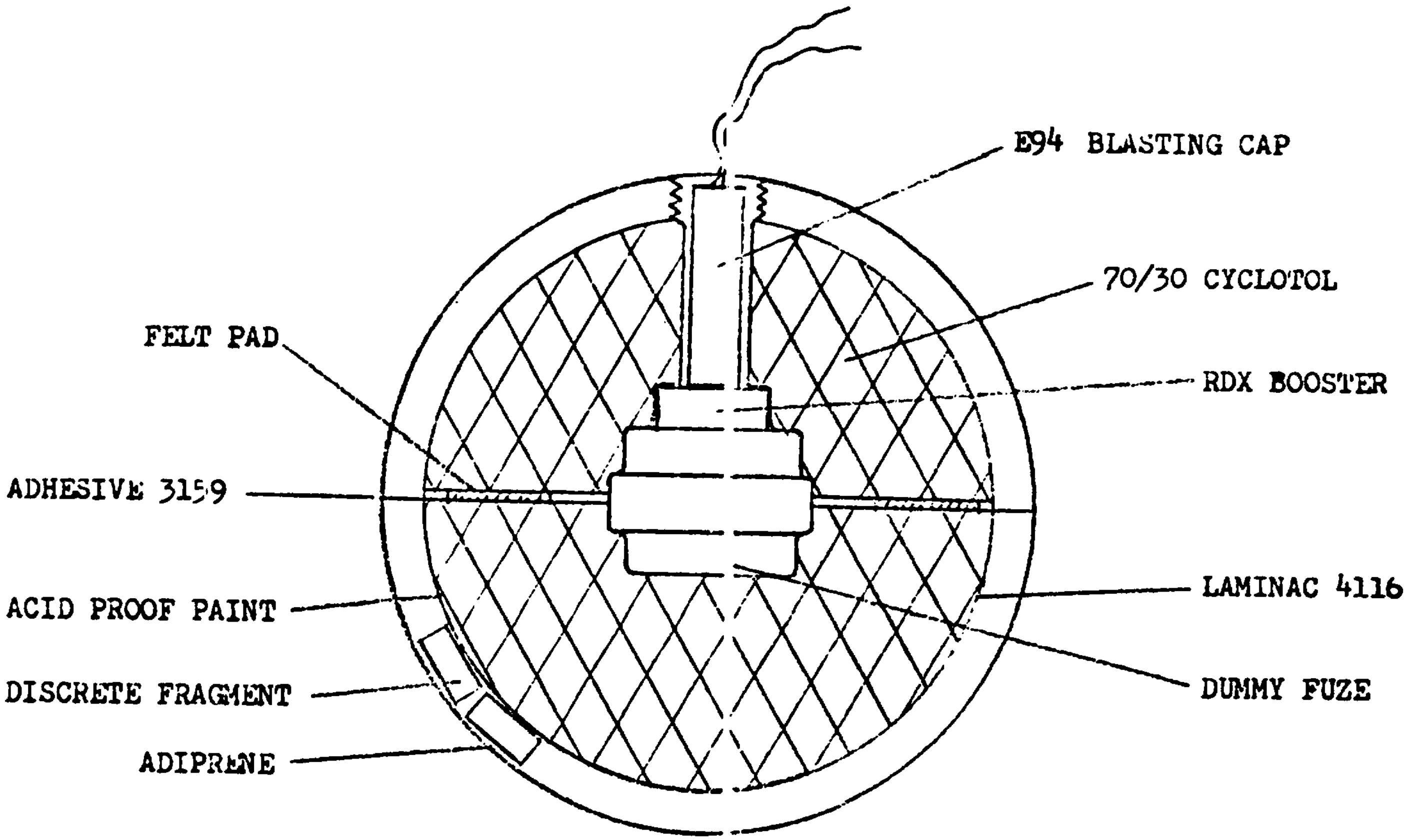
Hydrazine was poured into each sphere to test for leaks. The hydrazine was poured out and completely removed by washing with acetone. After thoroughly drying the sphere, Astrolite G, which has been supplied to Martin Marietta in a plastic bottle by EXCOA, was slowly poured into the sphere through a glass funnel. The funnel was removed, and the nylon plug was slowly assembled. Excess liquid which exuded past the nylon/steel/Adiprene threads was carefully wiped off with a paper towel. The weights of the bombs and explosive charges were:

Bomb No.	Weight grams	Booster Weight grams	Astrolite Weight grams
1	718.0	1.4	234.7
2	714.8	4.2	239.5

The two bombs were detonated with a duPont E94 blasting cap in the hole in nylon plug in a horizontal position. The aluminum screen on the Celotex recovery pack was 10 feet from the bomb. Fastax cameras operating at 7000 to 7450 frames per second were used to photograph the fragments in flight. Average fragment speed was similar to that obtained with Composition B and approximately 15% less than that obtained with cyclotol. There was no significant difference between the speed obtained with one booster pellet and that obtained with 3 pellets. Fragment breakup was very similar to that obtained with the two castable explosives.

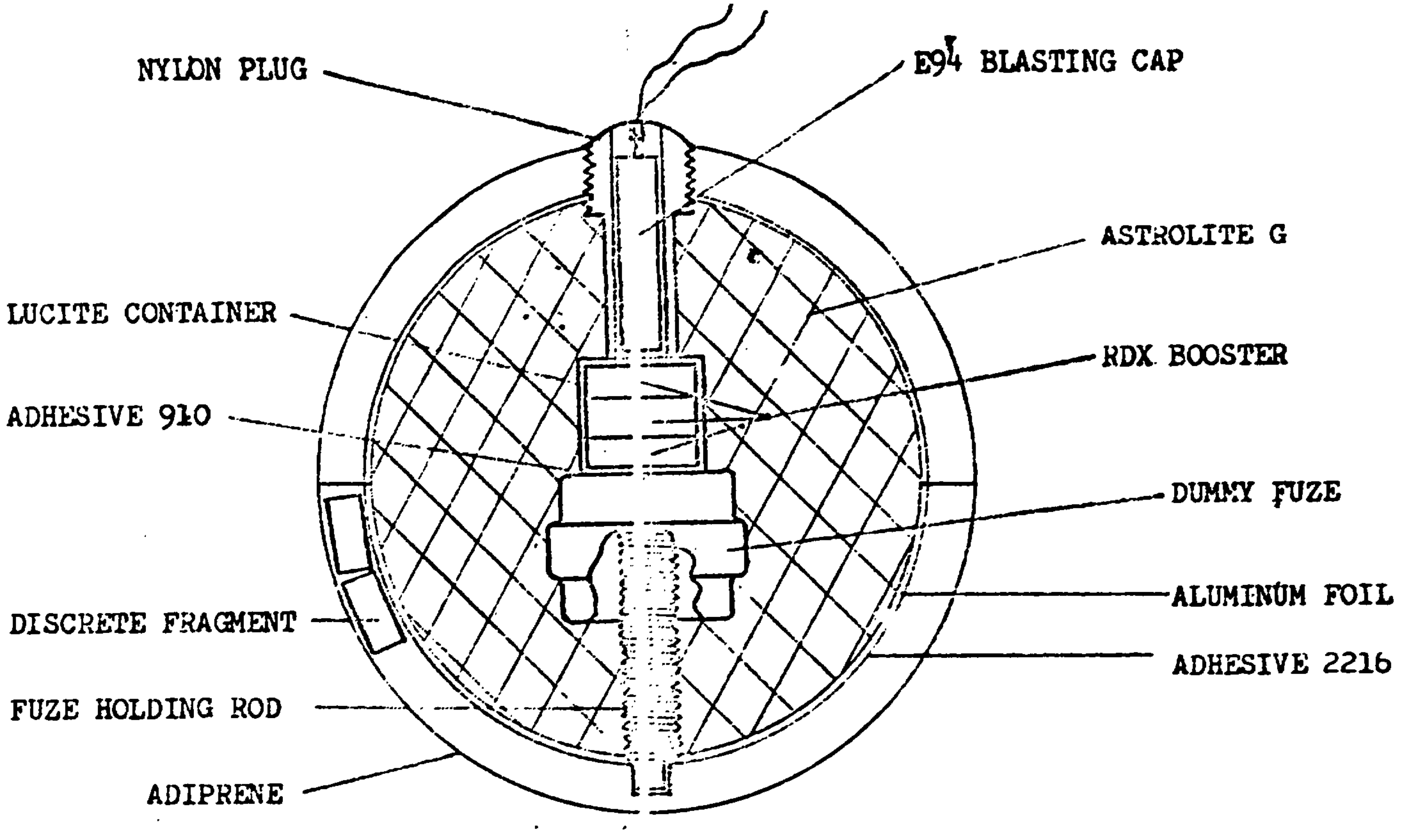
From the limited data presented, it appears that Astrolite G does not presently offer promise as a filler for small fragmentation munitions. However, it has excellent potential as a demolition explosive, especially in forward battle areas. Also, an aluminized Astrolite, A-1-5, is being used for initiating napalm bombs. It is possible that additives can be found which will increase the density, stability, and brisance of Astrolite G. If this can be accomplished, means can be found to solve other problems associated with liquid fillers, and reduction of loading costs for small fragmentation munitions can be realized.

SLIDE 1



CYCLOTOL STATIC TEST ARRANGEMENT

SLIDE 2



ASTROLITE STATIC TEST ARRANGEMENT

QUALIFICATION
OF
NEW EXPLOSIVES FOR PROJECTILES

by
William McBride

Explosives Engineering and Research Department
NAVAL WEAPONS STATION
Yorktown, Virginia

BACKGROUND

The objective of this paper is to report on the progress of a program to qualify several substitute explosives for loading of 8" and 16" Naval Projectiles. World War II-produced stocks of Explosive D, normally used in these projectiles, are nearly exhausted; there is no existing capability for new production in the United States. The first goal of the program is to achieve qualification of a substitute standard explosive for immediate use and then attempt to qualify a new plastic-bonded composition currently under development by the Naval Ordnance Laboratory, White Oak. The cast-cured plastic bonded explosive (PBX) is expected to improve target effectiveness of the projectiles, while reducing the hazard of premature explosions when subjected to the high set-back forces encountered in propulsion from gun barrels.

Qualifying an explosive for a new weapon is determined by its ability to satisfy two needs - 1) it must provide for adequate weapon performance and 2) it must be safe for service use. In this instance, we are confident that weapon performance will be improved by the candidate explosives, consequently, very little testing is being conducted in this area. Only fragmentation patterns are being studied and compared with the standard Explosive D so that effectiveness tables may be adjusted.

Of prime concern in this program are the safety aspects of the candidates and in particular, their ability to withstand the high shock loading of set-back forces of gun propulsion. Occurrences of gun barrel premature reactions are fortunately rare and their causes are not positively known, and that makes the evaluation of a substitute explosive extremely difficult. Therefore, the developer must decide what tests will provide the highest assurance that safety will not be degraded by the change in explosive.

Since Explosive D has demonstrated a fairly reliable history of low probability of premature gun barrel reactions, it was decided to outline a series of comparison tests of the proposed substitutes and Explosive D. These test results would provide a basis for determining the relative hazardness of each compound and serve as qualification criteria.

After resolving the basis for qualification, the overall program was outlined to be conducted in four phases:

I. Sensitivity Ranking of Candidate Explosives - review of available explosives, selection of candidate explosives, testing and sensitivity ranking.

II. Proçessability Studies of the Selected Substitute Explosives - study methods of processing candidates and loading into projectiles with emphasis on quality, safe plant processing, and determination of techniques for producing safer loaded projectiles.

III. Acceptance Testing of the Substitute Explosives - acceptance testing of 8" and 16" Projectiles loaded with substitute explosives in accordance with techniques and to qualities developed in Phase II.

IV. Documentation and Implementation in Production - generation and release of loading procedures and specifications, followed by pilot production in production plant.

SELECTION OF CANDIDATES (Phase I)

Selection of candidate explosives for testing was the result of several conferences with NOL White Oak and Naval Weapons Laboratory, Dahlgren personnel familiar with projectile requirements and explosive capabilities. The review of possible candidates disclosed the following:

1. Pressed Composition A was ruled out as too sensitive for use when some penetration was required and its questionable sensitivity for use in large projectiles.

2. Pressed Composition A with additional wax would probably result in small decrease in sensitivity.

3. Cast Composition B has had problems of sensitivity and prematures by U. S. Army, United Kingdom, and Australia without positive solutions. The Navy is not now equipped to cast load projectiles in quantity. Large expenditures in time and money would be required for plant construction or modifications.

4. Cast TNT would have problems of voids (as would Comp B) which is a suspected cause of prematures. Plants conversion would also be required.

5. Pressed TNT may be too sensitive from both a premature and penetration view. This could possibly be improved by the addition of a wax as a desensitizer. Pressed TNT would have the advantages of the use of existing equipment, availability, and could be started immediately.

6. A new PBX composition under development by NOL had little data, however, it has advantages that look very promising for projectiles.

From the above alternatives the following explosives were selected for the Phase I Sensitivity Ranking Tests:

Cast TNT

Pressed TNT

Pressed TNT with wax (5%) desensitizer

The PBX Compound

It was decided to select one of the forms of TNT, based on the results of the Sensitivity Ranking Tests, as a substitute interim fill for use when the stocks of Explosive D were exhausted. In addition, if the ranking tests did not produce any detrimental results for the PBX, it will later be developed as the replacement for Explosive D in 8" and 16" Projectiles.

SENSITIVITY RANKING TESTS (Phase I)

The tests selected for ranking the relative sensitivities included:

Impact (drop-hammer) Sensitivity

Card Gap Sensitivity

SUSAN Projectile Impact Test

Steel Target Impact Tests

Set-back Pressure Test (Gun Safety)

Exudation Test

Adiabatic Compression Test

The results of all the candidate explosive sensitivity tests are shown in Figure 1. The purpose of these tests as stated before, was to determine if any of the compounds under investigation posed any severe safety hazards for their use in service projectiles and to provide a ranking of the sensitivity of the compounds under each test. Each test will be described and test results discussed.

1. Impact Sensitivity

This test consists of dropping a 2-kilogram weight on a 35-milligram powdered sample of the test explosive from various heights. The height, in centimeters, at which there is a 50 percent probability of initiation, is reported as its impact sensitivity. Since the data is based upon a small powdered sample and different laboratories frequently report varying data on the same explosive, the results should be evaluated only in a relative manner and in conjunction with other tests.

These tests were conducted by the Naval Ordnance Laboratory. Since the test is normally run on a powdered sample, the results for cast or pressed TNT is the same in the context of this evaluation.

The data (see Figure 1) indicates that no candidate should be discounted purely on the basis of the impact sensitivity test. Of the candidates, the TNT/Wax (95%/5%) was the least sensitive.

2. Card Gap Sensitivity

The results of this test (see Figure 1) also indicate that no candidate should be discounted. Of the candidates tested, the cast TNT had the lowest sensitivity. The pressed TNT/Wax was better than pressed TNT and was in the same range as PBX and Explosive D at a 1.53 gm/cc density. Since many of the test results are density dependent, the densities normally obtained in projectiles for the compounds is given below for data interpretation purposes:

Cast TNT	1.60 gm/cc
Pressed TNT	1.50 gm/cc
Pressed TNT/Wax	1.57 gm/cc
PBX	1.66 gm/cc
Explosive D	1.50 gm/cc
Comp A-3	1.59 gm/cc

The card gap data also indicates that fuze initiation of the TNT/Wax should not prove to be a problem. The Explosive D was less shock sensitive than the TNT/Wax and is initiated satisfactorily in current service projectiles. However, this will be investigated more extensively by full scale projectile firing of 8" and 16" Projectiles during the Qualification Testing Phase. The card gap sensitivity tests were also conducted at NOL White Oak on samples prepared by NWS Yorktown. Figure 3 shows the set up for this test.

3. SUSAN Projectile Impact Test

The SUSAN Impact Sensitivity Test consists of firing projectiles (Figure 3) into steel armor plate targets at varying velocities. The head is loaded with the test explosive. The projectiles are fired from a 3.2-inch smooth-bore gun down a short (12 ft.) firing range at the armor plate target.

These data (see Figure 1) also indicate that no candidate explosive should be discounted. The highest "no reaction" velocity data is an estimate of the maximum impact velocity that would produce no chemical reaction. The lowest "violent reaction" impact velocity is an estimate of the minimum impact velocity that would produce a reaction greater than moderate burning accompanied by an overpressure at 10 ft. of 4 psi or greater.

The tests show that the pressed TNT is highly dependent on density levels, e.g., at 1.50 gm/cc the highest "no reaction" velocity was 435 ft/sec., however, at 1.60 gm/cc this velocity dropped to 275 ft/sec. The TNT/Wax at a 1.56-1.58 gm/cc density was the least sensitive of the explosives tested. Composition A-3 was most sensitive. The tests were conducted by NWL Dahlgren using projectiles loaded and assembled by NWS Yorktown.

4. Steel Target Impact Test

The objective of the steel target impact test was twofold, 1) to test actual configuration of the candidates to gun set-back forces, before testing the larger projectiles, and 2) to further investigate their sensitivity to high shock loads. 5"/38 (Mk 51) Projectiles were loaded with the candidate explosives (pressed TNT, pressed TNT/Wax, Cast PBX, and Cast TNT) and subjected to the following target impact testing:

No. of Shots	Impact Velocity (ft/sec)	Plate Thickness (in.)	Obliquity (°)
5	1400	1/4	0
5	2600	1/4	0
5	2600	3/4	45

There were no reactions at target impact.

The same test was also conducted on the Cast PBX by NOL White Oak under another program. The results of both are shown in Figure 1. The tests were also run previously by NWL Dahlgren on Explosive D and Comp A-3 and these results also indicate that no candidate explosive should be discounted for projectile use. The projectiles were fitted with steel nose plugs and inert fuzes before firing.

5. Set-back Pressure Test (Gun Safety)

The objective of the set-back pressure or gun safety test was to subject the candidates, in projectile configuration, to the highest set-back pressures that can be experienced in standard 5" and 6" Projectiles. The 6"/47 Mk 39 Projectile was selected since higher set-back pressure can be developed than in any other standard Navy projectile.

Five projectiles each were loaded with a candidate TNT explosive and fired at proof pressure. These rounds also had inert fuzes, and were fired from a 59% expended barrel. No explosive reaction occurred during these firings.

The second method of evaluation consisted of firing 17 rounds of Cast TNT and 20 rounds of each of the other explosives, including the Cast PBX, loaded in 6"/47 Mk 39 Mod 0 HC Projectiles. These projectiles were assembled with inert nose fuzes, wooden spacers behind the nose fuze and solid base plugs. They were fired at proof pressure in a new barrel. No explosive reaction occurred as a result of these firings. One of the Cast PBX projectile firings resulted in an abnormally high chamber pressure. However, a close inspection of the barrel did not reveal any damage or unusual wear. The reason for this high pressure could not be determined.

The tests were run previously by NWL Dahlgren on Explosive D and Comp A-3. The results indicate that no candidate should be discounted. This analysis is, however, made on the basis of a statistically small sample. The test will be repeated on larger samples of 8" and 16" Projectiles during the acceptance testing for qualification.

Filler E (an inert compound) was over-pressed onto the last increment of TNT/Wax loaded projectiles. This technique minimizes the possibility of adiabatic ignition of the explosive due to the shifting of the charge on set-back and compressing any air that may be present in the base. The technique allows an inert material to absorb any heat generated due to air compression rather than the explosive. The Cast TNT and cast cured PBX loads were poured through the nose of the projectile, resulting in few or no air voids between the explosive and the base of the projectile. Consequently, no inert material was installed in the base of these explosives. Several small (1/4-3/8" diameter) voids and slight porosity was present in some of the Cast TNT loaded projectiles. The pressed explosive loadings were done by the Naval Ammunition Depot, St. Juliens Creek, Portsmouth, Va. and the cast loadings by NWS Yorktown. The projectiles were fired at NWL Dahlgren.

6. Explosive Exudation Test

The objective of this test was to evaluate the exudation of wax and/or TNT impurities from the projectiles when temperature cycled thru -60° to +165°F. at a schedule similar to that specified by WR-50.

Three each of pressed TNT and pressed TNT/Wax loaded 6" projectiles were tested according to the temperature cycling schedule of WR-50. The projectiles had inert material pressed in both the nose and base. During the test the nose was open with no plugs installed.

No exudation of any material was observed during or after completion of the test. However, experience has shown that the possibility of the exudation is highly dependent upon the quality of the wax. Current military specifications for the waxes used in explosives have wide tolerances and it is known that some waxes made in accordance with the specifications do exude (Comp A-3 loaded projectiles) when cycled thru the temperature extremes of WR-50. However, there are no known reports of exudation of these projectiles in service use.

Radiographic examination of the projectiles after cycling revealed rather severe separation of the explosive at the pressing increment lines. However, this too has been experienced in service loaded projectiles as demonstrated in an intensive investigation conducted by this Station during the early 1950's.

This crude test was conducted for preliminary information only. Documented results will be obtained from the more rigorous scheduled WR-50 tests during the acceptance testing for qualification.

7. Adiabatic Compression Test

The adiabatic compression test is a small scale test to investigate the relative susceptibility of explosives to adiabatic ignition due to high rate compression of air over the charge sample. There are various forms of the test, such as the Picatinny Arsenal activator, however, the technique to be used on this program was developed by NWS Yorktown during the early 1950's to investigate prematures in Comp A-3 loaded projectiles.

The test consists of installing the assembly, shown in Figure 4, in a drop weight (impact sensitivity) machine and dropping a weight on the firing ram and compressing air over the sample in the firing cap. The sensitivity to adiabatic ignition is determined under varying volumes of initial air space over the explosive sample.

The apparatus necessary to run these tests is now being constructed and testing of the candidate explosives will begin when the fabrication is completed. Figure 1 reports the data for Explosive D and Comp A-3 determined in the earlier work previously mentioned. The values were obtained with an initial air gap of 3/4".

It is believed that none of the candidate explosives will be more critical than the Comp A-3 which is used in 5" and 6" Projectiles. However, for a ranking analysis it is believed that the tests should be repeated for all the candidates.

CONCLUSIONS FROM SENSITIVITY TESTS (Phase I)

Based upon the sensitivity test results, representatives of the participating activities recommend the selection of pressed TNT/Wax as the interim explosive for the following significant reasons:

1. The impact sensitivity tests indicated that TNT/Wax was the least sensitive of the three forms of TNT under consideration.

2. The gap or shock sensitivity test indicated that TNT/Wax was less sensitive to shock initiation than pressed TNT alone and Comp A-3. Since it was <u>more</u> shock sensitive than Explosive D, it is believed that no problem will be encountered in service fuze initiation.

3. SUSAN projectile sensitivity tests indicated that the TNT/Wax was the least sensitive of all the explosives being considered for projectile loading by the Navy, including Explosive D.

4. Existing Navy production plants for projectile loading are based upon a press loading process. The selection of a cast process would seriously effect the current work loads at these plants and/or require major investments in cast loading equipment.

5. The firing of TNT/Wax loaded 5"/38 Projectiles against steel plates with no reaction indicates that the compound will withstand high velocity impact.

6. Twenty (20) 6"/47 Mk 39 Projectiles loaded with TNT/Wax were fired at or near proof pressure with no premature reactions. Since the set-back pressures are the greatest in this projectile, the results indicate that the compound will safely withstand the set-back pressures in 8" and 16" Projectiles.

The data, from the sensitivity ranking, indicates that all candidates would probably be satisfactory for use in projectiles. Much emphasis is being placed on uniform loading methods for weapons by the DOD. The U. S. Army normally melt-cast loads its projectiles, and it has been suggested that the Navy investigate the cast loading of projectiles. The data thus far generated, on this program, indicate that TNT-melt cast or PBX cast-cure explosives are safe and producible for Navy projectiles. However, the overriding reason for the selection of a pressed TNT/Wax system as an interim fix was based on the fact that all existing production projectile loading plants, operated by the Navy, are designed for press loading. Existing Navy cast loading plants are currently used to near capacity for loading of other weapons (primarily bombs) and the conversion of the press-loading plants to cast-loading would be extremely costly and time consuming. The ultimate aim of this program, however, is the qualification of a PBX cast-cured explosive.

PROCESSABILITY STUDIES (Phase II)

The processability studies of both TNT/Wax and Cast PBX have been pursued concurrently with the test program. No major problems have been encountered, however, some problems are being experienced in forming fuze cavities in the case of the Cast PBX.

ACCEPTANCE TESTING (Phase III)

Acceptance testing of the substitute explosive is currently being conducted in 8" and 16" Projectiles. The tests being conducted are:

Fragmentation - To determine the effects of the new explosive, in currently produced hardware, compared to Explosive D. Three 8" rounds each of TNT, Cast PBX and Explosive D will be arena tested.

Steel Target Impact - This test will determine sensitivity of TNT and Cast PBX to high velocity impact in 8" Projectiles at proven explosive charge quality levels. Three 8" rounds of each explosive will be fired against 5/8" steel plate, at 30° obliquity, and velocity 1800 ft/sec. The projectiles will have steel nose plugs, dummy auxiliary detonators, and live Mk 48-4 base fuzes. Color film coverage behind the target plates will be provided for evaluation. Based on previous tests with Explosive D, no reaction should be experienced on target impact.

Proof Pressure Firings (Gun Safety) - The test will be run to obtain minimum statistical probability data on gun prematures with the new explosives. One hundred 8" rounds of both TNT and Cast PBX explosive will be fired at NWL Dahlgren using Mk 16 case type gun. Twenty-five 8" rounds of both TNT and Cast PBX explosive will be fired at either the Yuma P. G. or Barbados range.

Fuze Reliability Test - Twenty-four 8" projectiles will be loaded with explosives and temperature conditioned as follows:

No.	Explosive	Temperature (°F.)	Time held at temp.
4	TNT	-65	1 month
4	TNT	+160	1 month
4	PBX	-65	1 month
4	PBX	+160	1 month
4	Explosive D	-65	1 month
4	Explosive D	+160	1 month

One of each of the four projectiles will be periodically removed from storage and X-rayed in a manner similar to that specified by WR-50. After temperature conditioning, the remaining three projectiles of each explosive will be fired against 7/8" steel plates, at 30° obliquity and at a velocity of 1800 ft/sec. Each projectile will be equipped with steel nose plugs, dummy auxiliary detonators and live Mk 48-4 fuzes. Color film coverage behind the target plates will be provided for evaluation (only low and high order detonation will be counted). Data will be evaluated by NOL White Oak.

WR-50 Tests - The mandatory tests specified in WR-50 will be conducted. The mandatory tests are:

Environment and Shock Tests,
Bullet Impact Tests
Cook-Off Test

Nine Cast PBX loaded 8" and 16" Projectiles will be required for these tests.

CURRENT STATUS OF ACCEPTANCE TESTING

1. All acceptance tests for 8" TNT/Wax loaded projectiles, except the WR-50, have been completed.
2. No acceptance tests have been run on 16" TNT/Wax loaded projectiles, however, they are ready for shipment to the test site.
3. No acceptance tests have been run on the Cast PBX loaded projectiles. They are now being loaded for fragmentation and WR-50 testing.
4. All TNT/Wax tests to be completed by 15 October 1969. PBX tests to be completed by 15 December 1969.

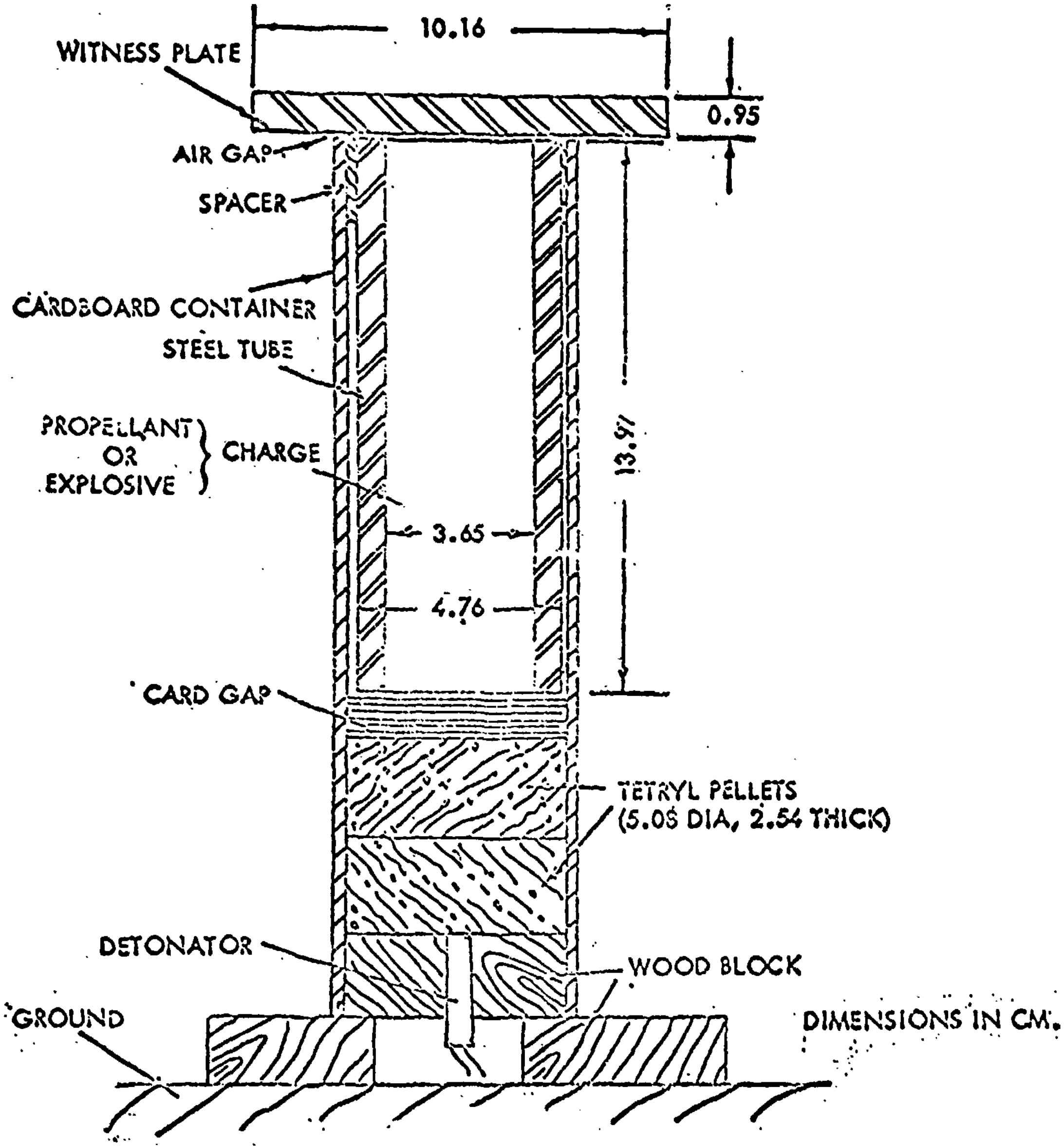
Although the final test results have not been received, progress to date on this program has been very satisfactory. Comments on the adequacy of the program or evaluation of test results are invited.

SENSITIVITY RANKING TESTS - RESULTS

TEST		CANDIDATE EXPLOSIVES					OTHER PROJ. EXPLOSIVES		
		CAST TNT	PRESSED TNT		PRESSED TNT/WAX	CAST PBX	EXPLOSIVE D		COMP A-3
IMPACT, 50% HT., CM		(1) 141	(1) 141		(1) > 320	(2) 43.	(1) 150-250		(1) 55-95
CARD GAP	TEST DENSITY	1.59-1.62	1.58-1.60		1.56	1.65	1.59	1.53	1.59
	NO. CARDS	133-108	193-183		176	181	150	163	210
	INPUT PRESSURE, KBAR	37-46	18-21		22.6	21.3	31	26.4	16
SUSAN IMPACT	TEST DENSITY	1.63	1.49-1.50	(3) 1.60	1.56-1.58				
	HIGHEST "NO REACTION" VELOCITY, FT/SEC	425	435	(3) 275	690	(3) 350	(3) 400		(3) 295
	LOWEST "VIOLENT REACTION" VELOCITY, FT/SEC	>1219	>1234	(3) >980	> 1261	(3) 600	(3) 987		890
STEEL TARGET IMPACT MK 51 - 5"/38 PROJECTILES		NO REACTION	NO REACTION		NO REACTION	(3) NO REACTION	(3) NO REACTION		(2) NO REACTION
SET-BACK PRESSURE (PROOF) MK 39 - 6"/47 PROJECTILES		NO REACTION	NO REACTION		NO REACTION	NO REACTION	(3) NO REACTION		(3) NO REACTION
EXPLOSIVE EXUDATION MK 39 - 6"/47 PROJECTILES		NOT TESTED	NEGATIVE		NEGATIVE	NOT TESTED	NOT TESTED		NOT TESTED
ADIABATIC COMPRESSION		TEST UNDER PREPARATION					71 CM (3) @ 1.50 GM/CC		7 CM (3) @ 1.60 GM/CC

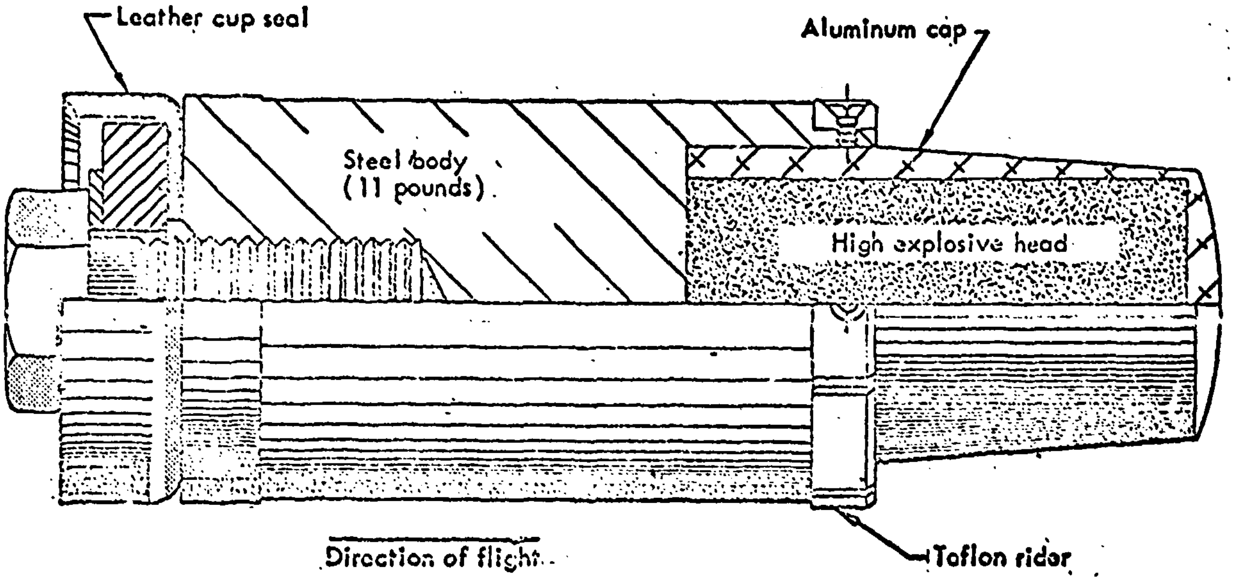
(1) TEST RUN ON POWDERED SAMPLE
(2) TEST RUN ON PELLETED SAMPLE AND IS THEREFORE NON-STANDARD DATA
(3) DATA OBTAINED FROM OTHER TEST PROGRAMS

FIGURE 1



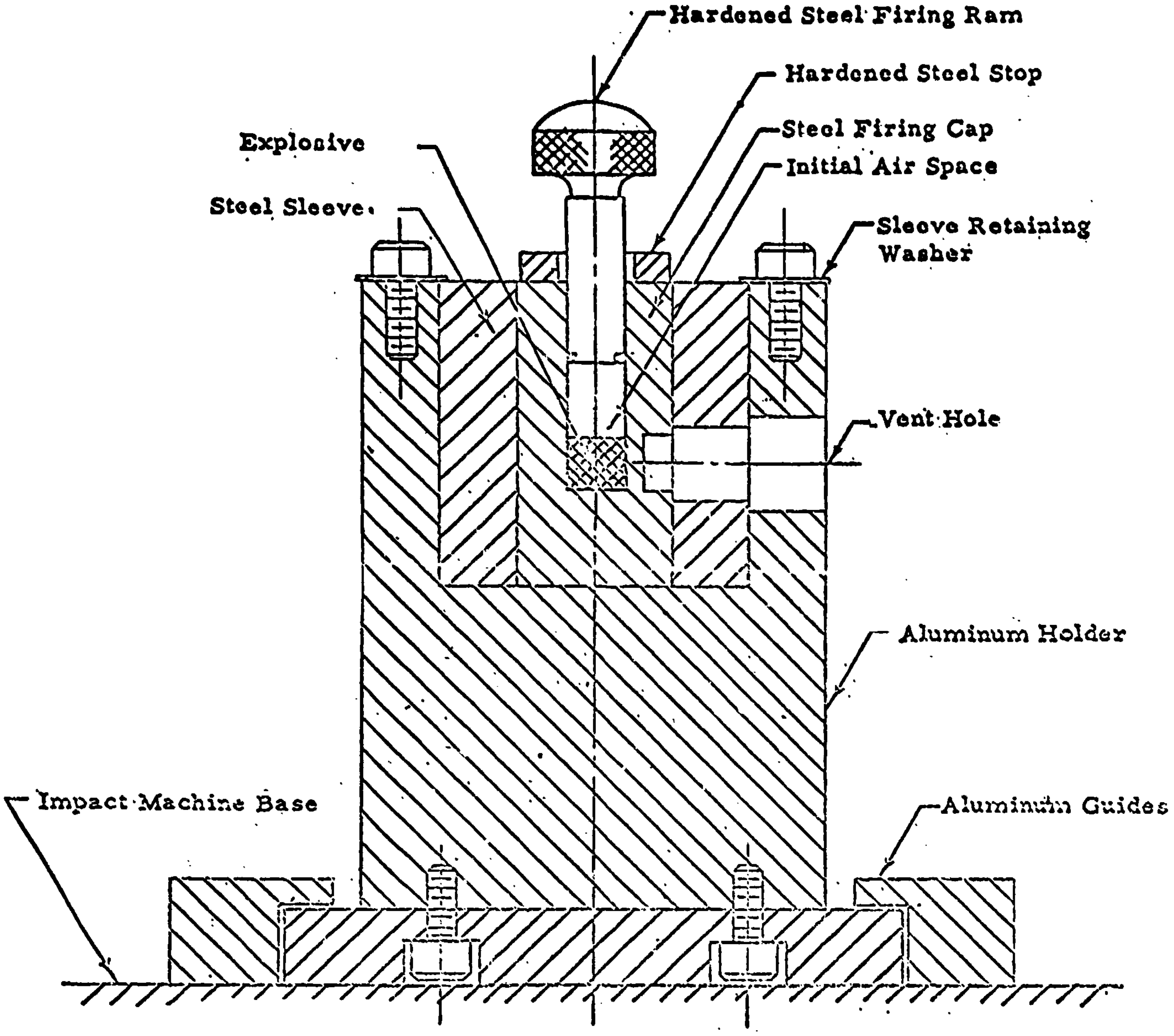
LARGE SCALE GAP TEST ASSEMBLY

FIGURE 2



Mod-1 Susan projectile.

FIGURE 3



Assembled Firing Device

FIGURE 4

SAFETY ASPECTS OF SLURRY EXPLOSIVES

R. B. Clay and L. L. Udy
Intermountain Research & Engineering Co., Inc.

Introduction

Although the use of slurry explosives or Dense Blasting Agents (DBA's) has revolutionized large open pit blasting throughout the mining industry (1), the potential of these explosives is only beginning to be realized for military applications. One of the major factors in the wide and rapid acceptance of slurry blasting agents in commercial applications is the exceptional safety properties of these products.

By adjusting the amounts and types of oxidizers and fuels used in formulating DBA's the detonation and physical properties can be varied over wide limits. The sensitivity can be controlled from cap sensitive explosives with critical diameters of only a fraction of an inch to very insensitive explosives of large critical diameter and requiring powerful, high-pressure boosters for detonation.

The unique characteristics of slurry blasting agents can be utilized in military applications to provide high explosives with minimum cost and maximum safety.

Composition

Dense blasting agents are formulated from: (1) fuels or combinations of fuels of the type represented by granular aluminum, solid hydrocarbons, and solid or liquid carbohydrates; (2) oxidizers or combinations of oxidizers represented by ammonium nitrate, sodium nitrate, sodium perchlorate, or other oxygen rich compounds; (3) water or other liquids in sufficient quantities to form a slurry (continuous fluid phase with solids dispersed therein); and (4) thickeners such as gums or starches to give the desired thickening rate and final viscosity. In some cases explosive sensitizers such as TNT and RDX may be used in which case the slurries are referred to not as blasting agents but as slurry explosives.

Water is a most important ingredient of slurry explosives from the standpoint of explosive safety. It imparts to the explosive compositions their liquid (slurry) character and prevents high local pressures from developing when impacted by relatively slow moving objects. Also, water greatly reduces the fire hazard because most of it must be vaporized before ignition, thus significantly delaying and in many cases limiting the temperature rise when the explosive is subjected to fire or other sources of heat. Not only does water act as a strong deterrent to accidental initiation, but also it contributes materially to the explosive force when the slurry is properly formulated and initiated. In all cases water serves as a source of gaseous products which are required to do useful work, and when used with sufficient quantities of aluminum, it actually acts as a source of oxygen for the powerful aluminum-water reaction to yield an energy of 1.8 Kcal/gm (over one and a half times the energy release of TNT).

In the case of nonexplosive sensitized DBA's i.e., formulations which do not use TNT, RDX, etc., the ingredients from which the slurries are formulated are nonexplosive per se and may be transported and handled as nonexplosives, thus eliminating the necessity of rigid controls and the hazards commonly associated with handling, transporting, and storing explosives. These ingredients are nontoxic. The final slurry compositions and their separate ingredients can be handled without gloves or other special clothing without hazard. Spills can be easily cleaned up with water. No hazardous fumes or vapors are generated or emitted either by the separate ingredients or the final slurry compositions.

Manufacture

Slurry blasting agents were originally (and still are to some degree) prepared in large quantities by mixing the individual ingredients together in simple turnover mixers and then packaged in polyethylene bags and transported to the place of use. Although this method of manufacture is completely satisfactory from a safety standpoint, the high cost of packaging and storing the slurry prompted the development of field mix-pump equipment (2). One of the major advantages of the field mix system is that all ingredients can be handled as nonexplosives until the need for the explosive arises. The ingredients are then blended together in the proper ratios and the fluid explosive is pumped into the receptical (borehole, cave, bomb, etc.). The slurry then thickens to the desired viscosity within a few minutes to several hours depending on the quantity and type of thickeners used in the formulation. The field mix system of slurry manufacture and delivery leaves no unneeded explosive to be stored or transported. Safety during the mixing process is insured by proper equipment design and material handling techniques. The sensitivity of the slurry composition is formulated to the desired level for each individual application. For example, the loading of large bombs like the M117 can be carried out using a slurry composition sensitized to a level that will not allow propagation through a 1" diameter loading hose, nevertheless, the slurry will perform as required in the large diameter bomb. This combination of slurry sensitivity control and field mixing equipment has given the explosive industry an apparent ultimate in explosive safety.

Mixing and loading at rates up to 1000 pounds/min are easily attainable on a continuous basis. Loading rates of 500 pounds/min are commonly in use in the commercial slurry explosives industry, where a three man crew employing a single unit can load up to 100,000 pounds in an eight-hour shift. Over 10 million pounds of slurry per month are presently being manufactured and delivered through the field mix-pump equipment by IRECO Chemicals and subsidiaries.

Another advantage of slurry explosives when used in receptacles such as bombs is that the shrinkage void common with cast explosives can be completely eliminated. This is accomplished by loading the compressible slurry under sufficient pressure that the additional material added exactly compensates for the shrinkage of the slurry upon cooling. The proper use of this loading technique results in the complete elimination of voids. The compressibility of the slurry also prevents excessive pressure build-up and possible case splitting, when loaded units are subjected to high ambient temperatures.

Safety Tests Conducted on Specific DBA's

Several slurry compositions have been undergoing characterization tests by various military agencies and privately owned testing laboratories for over two years. Results of some of these tests have been published (3-4). Other results are available but not yet published in report form (5-9). Some of the findings of these tests are presented below to provide a general overall view of the safety aspects of slurry explosives for military applications. For the most part four generic types of slurry have been examined: (1) NH_4NO_3/Al; (2) $NH_4NO_3/Al/TNT$; (3) $NaClO_4/Al$ and (4) $NaClO_4/Al/TNT$. The type most extensively tested is generic type (1), a nonexplosive sensitized ammonium nitrate-aluminum slurry designated DBA-22M.

Card Gap Sensitivity

Table I gives results of card-gap sensitivities of slurry compositions tested under identical conditions with Tritonal, TNT, and Composition B. DBA-22M and DBA-65T2 are representative, respectively, of generic types (1) and (2) above. For these tests donor charges were 2" (d) X 2" (L), 165 gms, 50/50 pentolite and the receptor charges were 6" (d) X 8" (L). Plexiglas was used as the gap material.

TABLE I. Card Gap Sensitivity Test Results

Explosive	Density (g/cc)	Gap (inches)	
		Detonated	Failed
DBA-65T2	1.65	7/8	1
Tritonal	1.75	1	1-1/4
TNT	1.60	1-1/2	1-3/4
DBA-22M	1.47	2-1/4	2-1/2
Composition B	1.65	2-3/4	3

Other card gap test results (4) show DBA-105T2, generic type (4), to be between Tritonal and TNT in sensitivity and DBA-100, generic type (3), to be more sensitive than Composition B. These results are only typical of each general slurry composition; within any generic type the sensitivity may be controllably spread over wide limits.

Bullet Impact

With 30 caliber ball M-2 ammunition at a velocity of 2800-3000 ft/sec, DBA-22M in standard 2" schedule 40 steel pipe capped on both ends was not initiated in five trials at temperatures up to 78°C. Evidently fluidity of the slurry allows the energy of the bullet to be expended over a wide area thereby keeping local pressures relatively low, thus reducing the probability of detonation.

Cook-off

At least three cook-off tests have been conducted on DBA-22M by Sandia Corp., Albuquerque, New Mexico. The tests consisted of suspending the slurry containing device so that the bottom was 30 inches above a pool of JP-4 fuel (this height had been determined from previous experimental tests to produce maximum heating of the device) and then igniting the fuel and recording the time of detonation. Camera coverage and in some cases thermocouple monitoring of the temperature at different points within the slurry charge were carried out during the entire test. Table II shows the results obtained in three shots.

TABLE II. Cook-off Tests Conducted by Sandia Corporation on DBA-22M

Charge Weight (approx.)	Container Size (approx.)	Time to Detonation	Remarks
1,000 lbs.	2' (d) X 4' (L)	-	Flare only, no detonation
8,000 lbs.	6' (d) X 4' (L)	9 minutes	Low order deflagration with low yield
36,000 lbs.	6' (d) X 14' (L)	6 minutes	8000 lb. equivalent yield

These tests demonstrated the effectiveness of water in keeping the temperature from increasing rapidly to values sufficiently high to initiate detonation. Low temperatures were recorded for several minutes (presumably until the water had vaporized) and then the temperature is rapidly increased just prior to detonation.

Drop-Test

Several drop tests, using large steel containers, and high speed impact tests, using unfused M117 bomb cases each filled with DBA-22M have been conducted.

Table III shows the results obtained by Sandia Corporation on drop tests of DBA-22M onto reinforced concrete. No detonation or reaction was observed in any of these tests.

TABLE III. Drop-Test Results With DBA-22M
Contained in Large Steel Cylinders
With Convex Ends, and Dropped
Onto Reinforced Concrete

Charge Wt. (approx.)	Container Size (approx.)	Height of Drop	Results
1,000	2'(d) X 4'(L)	20'-end on	No reaction
1,000	2'(d) X 4'(L)	20'-side on	No reaction
1,000	2'(d) X 4'(L)	20' end on with 6" air gap in impact end.	No reaction
1,000	2'(d) X 4'(L)	150'-end on	No reaction
36,000	6'(d) X 14'(L)	9'-side on	No reaction

Twenty-four M117 bomb cases were loaded with DBA-22M for AFWL, Kirtland AFB, New Mexico. These unfused bombs are being tested for reaction when impacted at high velocity into various hard rock formations. Three of the bombs were dropped from F-104 aircraft at near sonic velocity into a dry lake bed near Tonopah, Nevada; they penetrated approximately 10 feet into the bed. No reaction occurred in two of the bombs; the third produced a flare upon impact but only about 2/3 of the slurry burned.

Field Tests

Two containers, each holding 12,500 pounds of DBA-22M were dropped in Vietnam in May 1969. These explosives were field mixed and loaded at the IRECO Chemicals Plant located at Lehi, Utah. These two charges were transported by truck to Hill Air Force Base, Utah where they were loaded on cargo planes and transported to Vietnam. In Vietnam each bomb was dropped and detonated in a dense jungle area. The area cleared by each of these bombs was over twice that cleared by M121 bombs containing approximately 8,000 pounds of Tritonal.

Storage

Storage tests have been conducted on DBA-22M, DBA-65T2, DBA-105M, and DBA-105T2. These included constant high temperature storage, temperature cycling tests, and storage under ambient conditions.

The most extensive storage tests conducted so far have been on DBA-22M loaded in sealed pressure pipes and stored at 140°F and 158°F for 28 days or longer. Three types of pressure pipes were used: (1) schedule 40 black iron. (2) schedule 40 black iron coated with tar, and (3) schedule 40 polyvinyl chloride.

Two sealed black iron pipes coated on the inside with tar were loaded with CBA-22M, DBA-65T2, DBA-105M, DBA-105T2, Tritonal, Minol II and H-6. These were temperature cycled between minus 65°F and plus 140°F for 28 days. The sealed pipes were stored for 24 hour periods at each temperature (except on weekends when they were stored for a 72 hour period) and transferred directly from one temperature to the other for maximum "thermal shock."

Each of the blasting agents and cast explosives mentioned above was also stored under ambient (magazine) temperatures in a sealed, tar coated black iron pipe. In addition, DBA-22M was stored at ambient temperature in black iron without the tar coating and in uncoated polyvinyl chloride pipes.

Figures 1 and 2 show the pressure vs time history of DBA-22M at 140°F and 158°F. The pressure buildup for the first few days (about 10 psi) was due to the natural thermal expansion of DBA-22M. The subsequent pressure increase was apparently due to gassing. The polyvinyl chloride pressure pipes at 140°F and 158°F expanded under the high temperatures until leakage of explosive around the pressure gauge connection occurred. The pressure was less than 10 psi on the gauges before the leakage appeared. Even though no pressure readings were possible, the polyvinyl chloride pressure pipes were kept at 140°F and 157°F for 20 days and then examined and the charge then tested for minimum booster sensitivity.

Temperature cycling vs. pressure data are summarized in Table IV. The pressure pipes containing the blasting agents were filled to approximately two inches from the top. The pressure due to the expansion for each blasting agent was measured and also appears in the Table.

The pressures generated by the Tritonal, Minol II, and H-6 samples were largely due to gas evolution and gas expansion. These pressures were in the range of 5 to 10 psi. The pressures due to explosive expansion were much smaller, i.e., less than one psi, and were neglected in the data summary presented in Table IV.

The pressure pipes which were stored at ambient conditions remained at zero pressure throughout the entire period of testing.

The physical appearance of all the slurry blasting agents tested remained virtually unchanged after exposure to the above storage conditions. The explosives were still well thickened and had the same rubbery texture as when first formulated. There was only very slight corrosion of the uncoated iron pipes, and no unusual odors or evidence of segregation. One sample of DBA-22M was stored in a sealed, uncoated iron container at 158°F for 104 days without apparent decomposition.

TABLE IV: Summary of Temperature Cycling Pressure Data

Explosive	Sample Number	Maximum Pressure Developed (psi)	Pressure Due To Expansion (psi)	Apparent Pressure Due To Gassing (psi)
DBA-22M	1	10 *	9	1
	2	17	10	7
DBA-65T2	1	29	10	19
	2	26	18	8
DBA-105M	1	13	7	6
	2	14	7	7
DBA-105T2	1	69	35	34
	2	64	32	32
Tritonal	1	11	2	9
	2	10	2	8
Minol-II	1	8	2	6
	2	7	2	5
H-6	1	9	2	7
	2	2 *	2	0

* Leakage Assumed

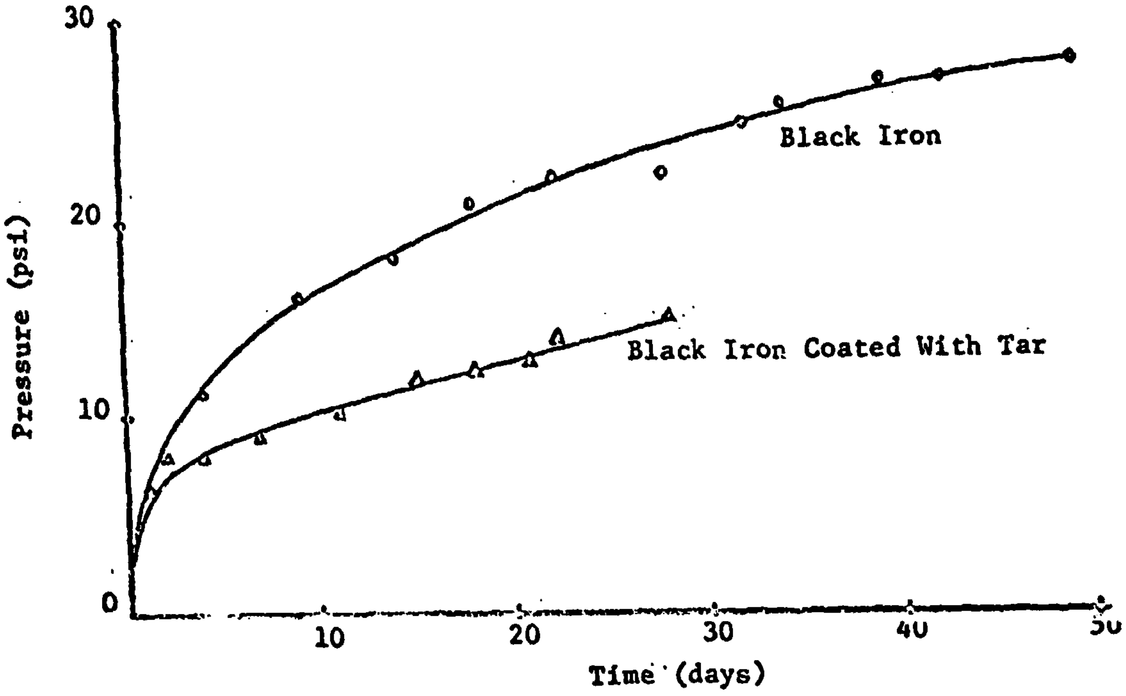


FIGURE 1. Pressure vs. Time for DBA-22M at 158°F

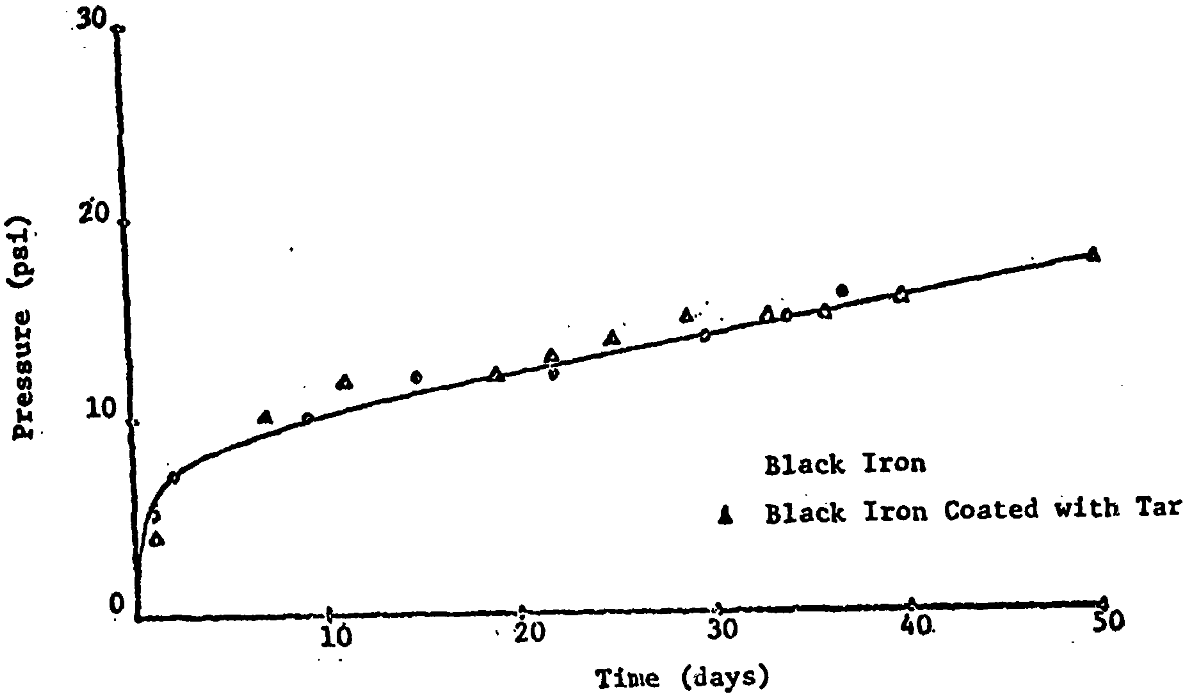


FIGURE 2. Pressure vs. Time for DBA-22M at 140°F

Minimum booster measurements were obtained on all of the explosives both before and after storage. The results of these tests are shown in Table V. They indicate no apparent difficulties in storing slurry explosives for long periods of time (3-5 years) in sealed containers.

Summary

The physical and explosive properties of IRECO slurry blasting agents are unique from the standpoint of safety. Such slurries appear to be the safest practical explosive in the history of the high explosives industry. Mixing, transporting, handling, and storing can all be accomplished with a minimum of risk to personnel and equipment.

The card-gap sensitivity of any slurry can be controlled to be less than for Tritonal or more than for Composition B or H-6 as desired. Drop tests and cook-off tests indicate that the IRECO slurry explosives are less susceptible to detonation from impact or fire than the standard military explosives. The results of storage tests indicate that the IRECO slurry explosives can be stored indefinitely under normal military conditions without significant decomposition.

Finally, the highly successful results obtained of two Helicopter Landing Zone Clearing Devices, each filled with 12,500 pounds of DBA-22M slurry dropped in the jungles of Vietnam in May 1969 demonstrate the safety and explosive potential of this IRECO slurry blasting agent for military applications.

TABLE V. Results of Minimum Booster Tests Before and After Storage

Explosive	Confinement	Storage Condition	Density (g/cc)	Minimum Booster Which Resulted in Detonation	Maximum Booster Which Resulted in Failure.
DBA-22M	Tar Coated Steel	Before Storage	1.52	9 grams Pentolite	3 grams Pentolite
DBA-22M	Tar Coated Steel	Temp. Cycled	1.47	3 grams Pentolite	No. 8 Cap
DBA-22M	Tar Coated Steel	Temp. Cycled	1.52	- -	3 grams Pentolite
DBA-22M	Tar Coated Steel	60°C Constant	1.52	9 grams Pentolite	3 grams Pentolite
DBA-22M	Steel	Before Storage	1.52	3 grams Pentolite	No. 6 Cap
DBA-22M	Steel	60°C Constant	1.48	3 grams Pentolite	No. 8 Cap
DBA-65T2	Tar Coated Steel	Before Storage	1.67	14 grams Pentolite	9 grams Pentolite
DBA-65T2	Tar Coated Steel	Temp. Cycled	1.53	9 grams Pentolite	- -
DBA-65T2	Tar Coated Steel	Temp. Cycled	1.58	3 grams Pentolite	No. 8 Cap
DBA-105M	Tar Coated Steel	Before Storage	1.80	14 Grams Pentolite	9 grams Pentolite
DBA-105M	Tar Coated Steel	Temp. Cycled	1.78	9 grams Pentolite	3 grams Pentolite
DBA-105T2	Tar Coated Steel	Before Storage	1.93	14 Grams Pentolite	9 grams Pentolite
DBA-105T2	Tar Coated Steel	Temp. Cycled	1.88	3 grams Pentolite	No. 8 Cap
Tritonal	Tar Coated Steel	Before Storage	1.75	9 grams Pentolite	3 grams Pentolite
Tritonal	Tar Coated Steel	Temp. Cycled	1.65	3 grams Pentolite	- -
Tritonal	Tar Coated Steel	Temp. Cycled	1.60	3 grams Pentolite	No. 8 Cap
Minol-II	Tar Coated Steel	Before Storage	1.68	9 grams Pentolite	3 grams Pentolite
Minol-II	Tar Coated Steel	Temp. Cycled	1.61	3 grams Pentolite	- -
Minol-II	Tar Coated Steel	Temp. Cycled	1.65	3 grams Pentolite	No. 8 Cap
H-6	Tar Coated Steel	Before Storage	1.71	No. 6 Cap	- -
H-6	Tar Coated Steel	Temp. Cycled	1.71	No. 6 Cap	- -

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GELLED SLURRY EXPLOSIVES FOR MILITARY USE (U)

By

T. J. Sullivan
L. A. Dickinson
NAVAL ORDNANCE STATION
Indian Head, Maryland

FOREWORD

(U) This report presents work performed at the Naval Ordnance Station, Indian Head, Md., to evaluate the use of gelled slurry explosives for ordnance use. Funding for this study was provided by the Naval Ordnance Systems Command, Code ORD-033.

ABSTRACT

(U) A study was made at the Naval Ordnance Station, Indian Head, Md., to evaluate the use of gelled slurry explosives as an effective replacement for conventional military explosives. The candidate gelled slurry explosives met safety and cost requirements. Further testing of selected gelled slurry explosives is recommended to improve engineering and chemical data.

INTRODUCTION AND BACKGROUND

(U) Gelled slurry explosives (GSX) encompass formulations based on gelled oxidizers, metallic fuels, and organic additives. In certain instances, explosive sensitizers at levels of 5% to 25% are used in place of entrapped air. Typical formulations for GSX are presented in Table I. Representative formulations given in the table show that a variety of inorganic oxidants at levels up to 85% by weight may be used. Aluminum is used to produce a higher density and a more energetic explosive although other metals are sometimes used. Gelled water is usually the dispersant and thickeners are often used as an auxiliary fuel. Nitrates and perchlorates are used as oxidizers; both are available at low costs.

Table I (U)

TYPICAL GSX FORMULATIONS (U)

Ingredient	Code (%)			
	A	B	C	D
Ammonium nitrate	55	12.2	–	35
Sodium nitrate	10	3.05	–	15
Sodium perchlorate	–	–	39	–
Barium nitrate	–	22.9	–	–
Aluminum	8	1.64	20	25
Water	14.4	20.6	15	20
Ethylene glycol[1]	–	2.3	–	–
TNT	–	–	25	–
Ball powder	12	30.5	–	–
Fuel (coal, sulfur)	–	–	–	3
Thickener/gellant	0.4	0.535	1	2
Stabilizer[2] (phosphate)	0.2	–	–	–
Relative density (g/cc)	1.4	1.55	1.88	1.4

[1] Freezing point depressant.

[2] Short-term gassing control.

(U) GSX has been used successfully for a variety of mining applications for about 10 years. Because the ingredients for GSX are readily available, mining explosives are being mixed in the field at a low cost.

(U) This report presents work performed by the Naval Ordnance Station, Indian Head, Md., on the evaluation of GSX for use as a military explosive. The GSX formulations that were used in the investigations are given in Table II.

Table II (U)

GSX CANDIDATE AND CONVENTIONAL EXPLOSIVE FORMULATIONS (U)

Ingredient	GSX Candidate										Conventional	
	1	2	3	4	5	6	7	8	9	10	H-6	MINOL
Ammonium nitrate	34	26	50-X	53	59	50-X	50	33	–	–	–	40
Sodium nitrate	15	15	X	10	10	8	–	–	9	6	–	–
Aluminum	–	–	25	15	9	23	34	35	34	35	22	20
TNT	–	–	–	–	–	–	–	20	–	20	31	40
Water	15	15	20	16	16	15	14	11	16	11	–	–
PR-M (nitrate sensitizer)	30	42	–	–	–	–	–	–	–	–	–	–
RDX	–	–	–	–	–	–	–	–	–	–	47	–
Sodium perchlorate	–	–	–	–	–	–	–	–	39	27	–	–
Other (gums, gellants and proprietary additives)	6	2	5	6	6	4+X	2	1	2	1	–	–

These candidate explosives were submitted to Indian Head in response to a letter (Appendix A). All of the suppliers on the distribution list submitted at least one GSX candidate. To characterize various physical, mechanical, and chemical properties of GSX candidates and to evaluate the use of GSX as an acceptable alternate to conventional military explosives, a series of tests were performed. Of special concern to the study were the following requirements that the GSX candidates had to meet to become acceptable alternates:

(1) Initially, the GSX must function reliably in existing stores using the current type of explosive trains. Since very variable initiation sensitivity has been observed with some GSX, tests must verify functioning throughout the service temperature range.

(2) Storage stability must be such that gel growth caused by gas evolution is not excessive and does not constitute a hazard.

(3) GSX should not exude out of loading ports or exploder pockets since design changes to improve sealing may be costly.

(4) Volume and phase changes upon temperature cycling must not pose detonation train problems or result in hydrostatic deformation of the casing or the exploder pocket.

(5) Corrosion of metals, such as typical ferrous bomb case steels, must not be a serious problem.

(6) Inadvertent formation of sensitive compounds must not cause a problem.

(7) Ingredients must be low cost and available on a large volume basis; GSX must contain a minimum of conventional explosives for sensitizers.

(8) The overall effectiveness of the store must not be so degraded that the component cost advantage is outweighed by increased delivery cost of warheads to the target.

(9) Processing and loading equipment must be simple, mobile, and of low initial cost.

(U) The program was designed to screen all candidate GSX in an orderly manner and to eliminate, as soon as possible, those candidates which did not meet critical criteria. First, sensitivity tests were conducted to establish guidelines for handling this type of explosive within the framework of established military procedure. These tests showed that certain GSX candidates were as sensitive as typical service explosives and that they offered no material improvements in field safety. Concurrently with the sensitivity investigation, dilatometer tests were run at 140° F to determine the long term volumetric stability of the GSX. After only a few days, several candidates were eliminated from further testing because of either the complete breakdown of gel structure or the foaming of the GSX (believed to be from the gas evolved from the aluminum-water reaction). The dashes in Tables III and IV indicate nontests because of the elimination of candidates.

(U) Sensitivity data were obtained for all GSX candidates, with the exception of the bonfire test which was only performed on three representative Class II types of GSX. Candidates GSX 5, 6, 7, and 10 were not cylinder-tested because of one or more of the following: (1) they were similar to other compositions, (2) they were too chemically reactive, or (3) they were not representative of commerically available formulations based on nitrate oxidizers.

SENSITIVITY TESTS

(U) Nine sensitivity tests were performed on the GSX candidates to determine the safety of the explosive. These tests are discussed below and the results are summarized in Table III.

Table III (U)

SENSITIVITY DATA[1] (U)

Test	GSX Candidate									
	1	2	3	4	5	6	7	8	9	10
Impact	n	n	n	n	n	n	n	n	n	p
Cavity drop	n	n	n	n	n	n	m	n	n	n
Friction	n	n	n	n	n	n	p	n	n	n
Electrostatic	n	n	n	n	n	n	p	n	n	n
Cap	n	n	n	n	n	n	p	n	n	n
Bullet impact	n	n	n	n	n	n	p	p	n	n
Card gap (no. of cards)	0	44	15	> 70	> 70	> 70	125	> 70	0	> 70
Bonfire (min to rupture)										
2 in. × 4 in. pipe	5	-	8	5	-	-	-	-	-	-
4 in. × 8 in. pipe	5	-	8.5	8.1	-	-	-	-	-	-

[1] n = negative; p = positive; m = marginal.

Impact Test

(U) This test is designed to determine the ease of initiation of detonation by impact applied to a material. The lowest height at which a 5-kilogram hammer in free fall will give three consecutive explosions is recorded. The material is considered insensitive if it does not explode after a drop of 600 millimeters. All of the GSX candidates that were tested were found to be insensitive.

Cavity Drop Test

(U) This test is designed to determine the ease of initiation of explosion by adiabatic compression of air bubbles that may be present in liquid or semiliquid materials. The material is confined in a known cavity closed by a piston. The lowest height at which a 5-kilogram weight will give five consecutive explosions is recorded. The material is considered insensitive if it does not explode after a drop of 50 centimeters. All of the GSX candidates except GSX 7 were found to be insensitive.

Sliding Friction Test

(U) This test measures the sensitivity of a material to initiation and to combustion by friction between two metal surfaces: a sliding block and a stationary wheel. The material is placed on the block and pressure is applied to the stationary wheel. A pendulum is swung at 8 ft/sec against the block. The sensitivity of a material is determined by the maximum force which can be applied to the wheel without causing the sample to decompose. The material is considered insensitive if after 960 pounds of force it does not decompose. Twenty consecutive negative results must be obtained to define the sensitivity of a material. All of the GSX candidates except GSX 7 were found to be insensitive.

Card Gap Test

(U) This test[1] determines the sensitivity of a material to detonation when shocked by an explosive donor through a barrier material.

Electrostatic Discharge Test

(U) This test determines the sensitivity of materials to ignition by discharge of electrical energy. A Tesla coil is discharged 20 times at varying voltages. If negative at 5000 volts, the test is discontinued and the material considered insensitive. All the GSX candidates except GSX 7 were found to be insensitive.

---

[1] Naval Ordnance Laboratory, White Oak, Md., Explosives—Effects and Properties, ed. by Norma O. Holland. TR 65-218, 21 February 1967.

Bonfire Test

(U) This test determines the effect that external fires have on a material. Some GSX candidates were loaded into capped pipes (2-inch diameter, 4 inches long) and heated in a timber crib fire; some were loaded into capped pipes (4-inch diameter, 8 inches long) and heated in a JP 5 fire. GSX candidates 1, 3, and 4 were selected for this test; all the sample containers exhibited an internal pressure rupture (end closure separation) after 5 to 8 minutes; no detonations or explosive deflagrations were noted.

Bullet Impact Test

(U) A .30-caliber armor piercing bullet is fired from an M-1 rifle into a 2-inch schedule-40, black iron pipe that is filled with an explosive and capped at both ends. The bullet is fired at a distance of 75 feet. When destruction of the pipe occurs, the test is reported as positive. All of the GSX candidates except GSX candidates 7 and 8 were found to be insensitive.

Cap Test

(U) This test determines if a material can be initiated by a standard military detonator (Ordnance Corps U.S. Army Special Blasting Cap). The material is placed in a Velostat cup (2-inch diameter, 2 inches high); the cup is placed on a lead cylinder that has a 1-inch diameter and is 4 inches high. The detonator is placed in contact with the test material. When the lead block is demolished, the material is considered sensitive. All of the GSX candidates except GSX 7 were found to be insensitive.

Differential Thermal Analysis

(U) This analysis determines the temperature at which the ingredients begin to decompose exothermally. A 3-gram sample is heated in a test tube in an oven controlled to give a 1° C per minute rise in temperature. The comparison-standard is a tube containing 3-micron glass beads. A plot is made of the temperature difference between the reference junction and the test sample starting at ambient temperature (20° C) and continuing until either the sample decomposes or a temperature of 300° C is reached. Differential thermal analysis curves of the GSX candidates are shown in Appendix B.

ENGINEERING EVALUATION

(U) After the conclusion of the sensitivity tests, a study was made to determine the engineering characteristics of GSX. The tests were designed to yield information which could be readily reduced for a comparison with appropriate standard military explosives.

(U) The standard tests were used to obtain numerical values for critical diameter, detonation velocity, and boostering requirements. A new fragmentation test using an explosive specimen 4.5 inches in diameter was developed since the critical diameters were larger than 2 inches (above the limit of the standard test hardware used to determine the Gurney constant for explosives).

(U) Using standard procedures, selected GSX candidates were evaluated by the Naval Ordnance Laboratory (NOL), White Oak, Md., to provide data on underwater applications. The WDd values and relative bubble energy levels were measured.

Critical Diameter Test

(U) This test determines the minimum diameter that a material will continue to propagate an explosive reaction. The GSX candidates were placed in cardboard tubes 27 inches long. The tubes were fitted at the top with a 1/4-inch steel witness plate; at the bottom there was the initiatory cone of Comp C-4 explosive; the base of the cone was the same as the diameter of the tube and the height of the cone was three times the base diameter. The cone was primed at the apex with a cap. The values for this test are given in Table IV: three negative results . . . lower limit, one positive result . . . upper limit.

Fragmentation Tests

(U) These tests determine the average velocity and size of fragments resulting from detonation in metal confinement, such as bomb casings. The GSX candidates were placed in a steel pipe having a 4.5-inch ID, a 5.5-inch OD; the pipe was 27 inches long. The bottom was closed with a welded steel plate and the initiator, a plane wave generator of 50/50 Pentolite, was at the top end. The pipe was placed 6 feet above the ground and 20 feet from witness plates of 0.020, 0.040, and 0.060-inch aluminum, and 0.25-inch cold rolled steel plate. All plates were 3 feet by 12 feet rectangles; these were placed adjacent to one another with the 3-foot sides on the ground and the 12-foot sides vertical. High-speed cameras photographed the initial detonation and the back sides of the witness plates as the fragments came through.

(U) The Gurney constant[1] was determined from the equation

$$k = \left[\frac{V_o}{(c/m/1 + 0.5c/m)^{0.5}}\right],$$

where

k = Gurney constant
V_o = initial fragment velocity
c = cross section area of GSX × density of GSX
m = cross section area of metal pipe × density of metal pipe.

The assumption was made that the initial fragment velocity was the same as the first fragment striking the witness plates.[2] The Gurney constant is given in Table IV.

Minimum Booster Test

(U) This test determines the amount of high-explosive booster necessary to initiate a stable detonation in a material. In the test, 50/50 Pentolite boosters of 15 and 27 grams were placed against the GSX candidates contained in 2- or 3-inch nonmetallic tubes. The minimum conditions of tube diameter and booster strength for positive initiation are given in Table IV.

Table IV (U)

ENGINEERING EVALUATION DATA (U)

Formulation	Critical diameter (in.)	Gurney constant (m/sec)	Minimum Booster		Underwater		Detonation velocity (m/sec)	Energy (relative to TNT)	Density (g/cc)	DOT Classification (as determined by Card gap)
			(g)	(in.)	WDd	RBE				
H-6	—	2630	—	—	—	—	—	1.373	1.75	A
MINOL-II	—	1760	—	—	1.18	1.54	—	—	1.68	A
GSX 1	>2.0; <3.0	2290	15	3	0.51	0.75	—	0.834	1.35	B
GSX 2	>1.5; <2.0	2100	27	2	—	—	3600	0.734	1.35	B
GSX 3	>1.0; <1.5	2080	15	2	0.85	1.59	3200	1.176	1.40	B
GSX 4	>1.5; <2.0	2260	15	2	0.71	1.39	3300	1.106	1.02	A
GSX 5	>1.0; <1.5	—	15	2	—	—	3570	0.984	1.20	A
GSX 6	>1.8	—	27	Negative	—	—	3900	1.348	1.15	A
GSX 7	<2.0	—	15	2	—	—	4000	0.978	1.50	A
GSX 8	—	2490	27	2	—	—	4600	1.078	1.65	B
GSX 9	—	—[1]	27	Negative	—	—	1750	0.946	1.80	B
GSX 10	—	—	27	2	—	—	4800	1.073	1.80	A

[1] Would not detonate using the standardized plane-wave generator.

---

[1] NOL TR 65-218, Holland.

[2] Private communication with Mr. Philipchuk of Naval Weapons Laboratory, Dahlgren, Va.

Underwater Tests

(U) These tests were performed by NOL to evaluate the underwater explosive yield of GSX in terms of relative bubble energy (RBE) and relative explosive force (WDd)—the weight (W) of 50/50 Pentolite needed to give the same damage (D) at the given distance (d). The RBE indicated the amount of 50/50 Pentolite required to give the same bubble periods and energies.

(U) An array of four Woods Hole UERL (Underwater Explosive Research Laboratory) gages were placed 9 feet under in 18 feet of water. The gages were mounted 90° apart at 42 inches from the test charge of 355 grams. A 100-gram Pentolite booster and an Ordnance Corps U.S. Army Special Blasting Cap were used to initiate the GSX candidates which were contained in 12-ounce aluminum cans. The WDd appeared to be in the range of 0.5 to 0.9. This test gave an indication of energy through deformation of the gage; data are given in Table IV.

(U) Future work will involve the testing of larger charges in deep water using tourmaline gages to obtain bubble period, pressure-time curves, and other data.

Detonation Velocity

(U) This test determines the velocity at which an explosive reaction propagates along a cylindrical sample having a diameter greater than the critical diameter. The detonation velocity for GSX was obtained by placing one triggering probe and three sensing probes at intervals of 0, 10, 30, and 50 centimeters along a Schedule-40 pipe; care was taken to eliminate wall shock triggering. The results of this test are given in Table IV.

Energy Value

(U) The energy values for GSX candidates were obtained by first order calculations of energy release in a simplified computer program covering the major products of reaction. Effectiveness calculations were made allowing for condensed phases and deviations from ideality. The energy values of GSX candidates relative to the energy values of TNT are given in Table IV.

Corrosion Test

(U) This test determines whether or not an explosive material will corrode the container material. A test tube (4 inches long, 1-1/2-inch diameter) was filled with a GSX candidate to cover an AISI-1018 steel cylinder (1 inch high, 1/2-inch diameter). These were placed in 140° F ovens for 2 weeks under static and dynamic conditions. The corrosion of mild steel was negligible (0.06% maximum weight loss). Results of this test are given in Table V.

Table V (U)

CORROSION TEST DATA (U)

GSX Candidate	Sample weight (g)	Weight loss (g)	Weight loss (%)
	Static		
1	26.2569	0.0094	0.036
2	24.5523	0.0015	0.006
3	25.1507	0.0123	0.049
4	25.4250	0.0007	0.003
5	25.4503	0.0003	0.001
	Dynamic		
1	25.4305	0.0107	0.042
2	24.7978	0.0018	0.007
3	25.2872	0.0156	0.062
4	25.0363	0.0006	0.002
5	23.8538	0.0006	0.003

Gel Growth Test

(U) This test was established to study the chemical incompatibilities that cause gas evolution and density changes during storage within the normal environmental temperature envelope. Approximately 200 milliliters of each GSX candidate were contained in dilatometers and placed in an oven controlled to ±5° F. The dilatometer consisted of a 250-milliliter two-neck glass flask with a stopcock fitted to one neck and a 2-millimeter diameter capillary tube fitted to the other. The bodies of the flasks were insulated from the periodic temperature fluctuations of the oven by a 4-inch layer of Styrofoam. The thermocouples were placed against the walls of the dilatometer. Any change in the volume of the GSX candidates was followed by recording the movement of a short bead of mercury along a horizontal length of the capillary.

(U) Figure 1 shows expansion rates plotted against time for a temperature of 125° F. GSX 1 formed two liquid phases after 6 days and there appeared to be no gel structure remaining. GSX candidates 5, 6, and 8 increased so much in volume that they are not considered suitable for closed systems. The results are reported in Table VI.

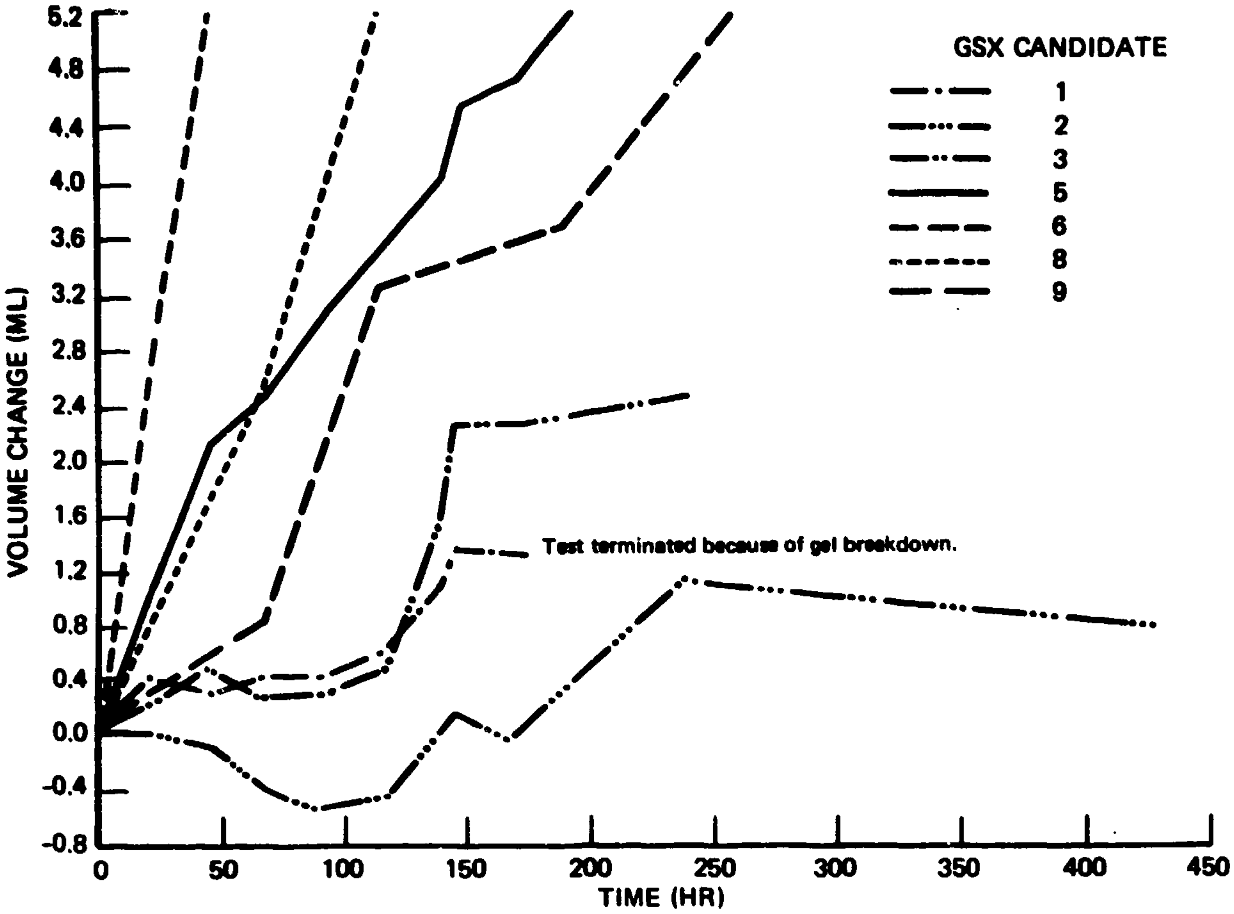

FIGURE 1. (U) EXPANSION RATE OF GSX: 125° F (U)

(U) The values quoted for 80° F were not measured directly. They were obtained by a calculation based on the assumption that there was a 50% decrease in expansion rate for a temperature drop of 10° C. After these initial screening tests had been completed, the experimental method was refined and long-term tests were started on the most promising materials which proved to be GSX candidates 2, 3, and 9. These tests are continuing with a reduced sample size: 50 ml. Two samples of each GSX candidate are being tested at both 100° and 125° F. The results obtained to date are shown in Figure 2.

Table VI (U)

GEL GROWTH DATA (U)

GSX Candidate	Expansion rate (ml/lb. min x 10^5)[1]		
	140° F	125° F	80° F[2]
1	31	22	3.9
2	14	3.8	0.68
3	—	40	7.2
4	160+	—	—
5	160+	140	25
6	—	480+	84+
8	—	120	20
9	—	36	6.4

[1] 1.5×10^{-5} ml/lb. min. is approximately equivalent to a volume increase of 2% in 1 year.
[2] Extrapolated data, see text.

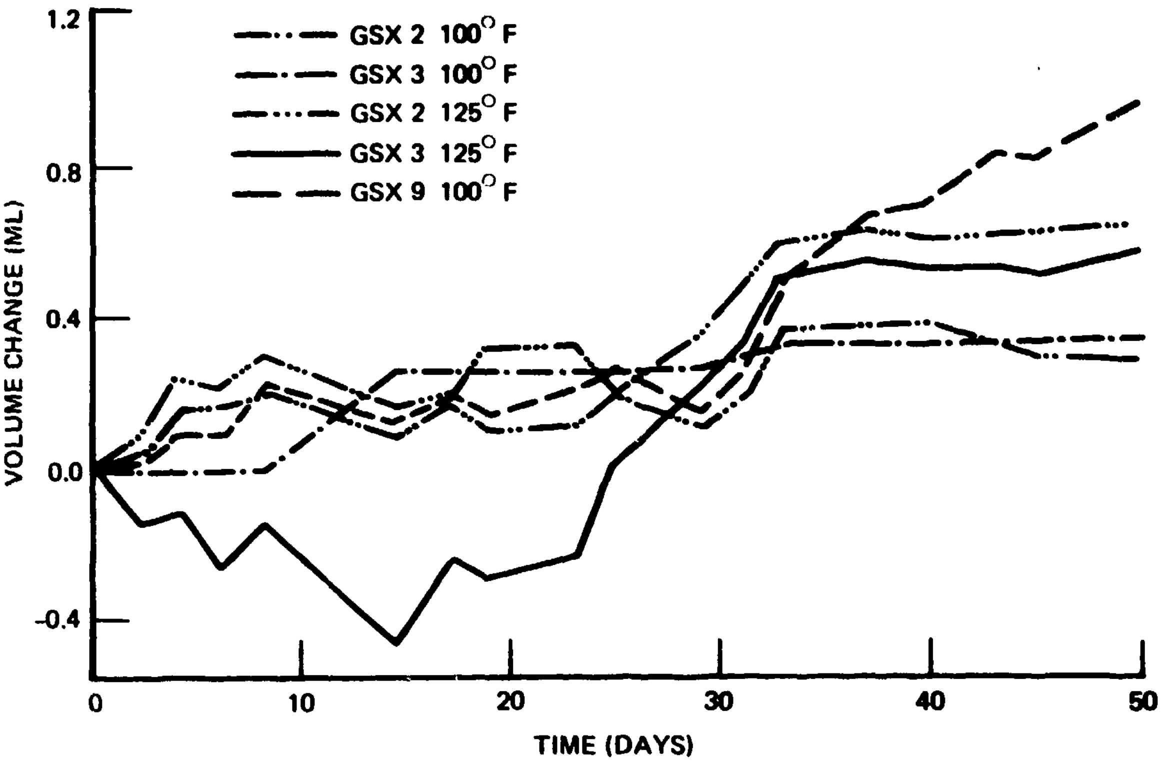

FIGURE 2. (U) EXPANSION RATE OF GSX: 100° AND 125° F (U)

Thermal Stability Test

(U) This test was conceived and performed by NOL. The test procedure and results were presented to Indian Head in a letter.[1] The following information is taken from this letter.

---

[1] Naval Ordnance Laboratory, White Oak, Md., ltr 233:HH:ba Ser. 401 of 23 January 1969.

(U) Candidates GSX 1 and 3 were placed in glass tubes then frozen and evacuated. "The tubes were sealed and placed in an oven at 70° C for 10 days. The gases in the tubes were then analyzed by gas chromatograph and showed only air (79.9% N_2 and 20.1% O_2) to be present. The air probably was adsorbed on the samples since they were evacuated to less than 1 mm Hg and a similar glass tube, run as a control, showed no pressure increase. After the test the . . . [GSX 1] sample was quite liquid indicating that the gel had broken. The . . . [GSX 3] sample appeared to have formed a two phase system."

COST EFFECTIVENESS STUDY

(U) A study was made of the components in the various GSX candidates to determine the supply availability, critical raw materials, if any, and establish prices on all materials. The study revealed that the cost per pound of raw materials for GSX candidates is as follows:

GSX candidate	Cost per lb ($)
1	0.053
2	0.058
3	0.10
4	0.12
5	0.09
6	0.16
7	0.15
8	0.18
9	0.19
10	0.20

The prices that were established for the critical raw materials are listed below:

Ingredients	Cost per lb ($)
Major:	
Ammonium nitrate	0.035
Sodium nitrate	0.10
Aluminum, flake	0.32
Aluminum, paint grade	0.55
TNT, Pelletol	0.22
PR-M, proprietary nitrate	0.07
Guar gum	0.29

Ingredients	Cost per lb ($)
Minor:	
Ammonium perchlorate	0.45
Sodium perchlorate	0.15
Formamide	0.10
Hexamine, pure	0.31
Boric acid	0.05
Borax glass	0.03
Borax	0.03
Cross-linking agents	0.46
Lecithin	0.02
Calcium chloride	0.31

(U) The average annual capacity was found to be more than 8,132,000 tons for ammonium nitrate, 24,100 tons for ammonium perchlorate, and 25,000 tons for sodium perchlorate. A list of the major suppliers for the raw materials is given in Appendix C.

(U) Small batches of various GSX have been manufactured at Indian Head to study procedures and to obtain materials for testing. The process is a simple one of preparing solutions of the inorganic nitrate and combining them with the dry solid ingredients in a suitable mixing vessel. The agitation does not appear to be critical, but temperature control is important for proper crystal formation. The gums and cross-linking agents may be added at various times and in various strengths to yield a finished GSX which has the desired physical or mechanical properties for further handling.

(U) The cost effectiveness study also involved an analysis of kill probability for weapons using GSX. Estimates on comparative GSX lethality were made in a theoretical analysis of the experimental data.[1] Calculated fragment sizes and weights were compared with predicted values for TNT (TNT fragment weight assumed to be 5.43 grams), the data for the GSX candidates are given in Table VII. The effective lethality of GSX against standing personnel is shown in Figures 3 and 4.

---

[1] Naval Ordnance Station, Indian Head, Md., A Computational Method for Predicting From Design Parameters the Effective Lethality Area of Naturally Fragmenting Weapons, by Michael Lindemann, IHTR 295, 30 June 1969.

Table VII (U)

LETHALITY DATA ON GSX (U)

Explosive	Detonation rate (fps)	Gurney constant (fps)	Average fragment size (g)	Fragment size (relative to TNT)	Lethality relative to	
					Comp A-3	Exp D
Comp A-3	27,000	8,400	3.39	–	–	–
Exp D	22,470	7,900	5.65	–	–	–
H-6	23,590	8,400	4.18	–	–	–
TNT	22,870	7,600	5.43	–	–	–
GSX 1	16,400	7,510	7.4	1.36	0.64	0.96
GSX 2	17,390	6,890	7.2	1.33	0.64	0.96
GSX 3	16,400	6,790	5.3	0.98	0.74	1.11
GSX 4	15,240	6,890	5.4	1.01	0.70	1.06
GSX 8	13,410	7,590	5.5	0.99	0.79	1.18

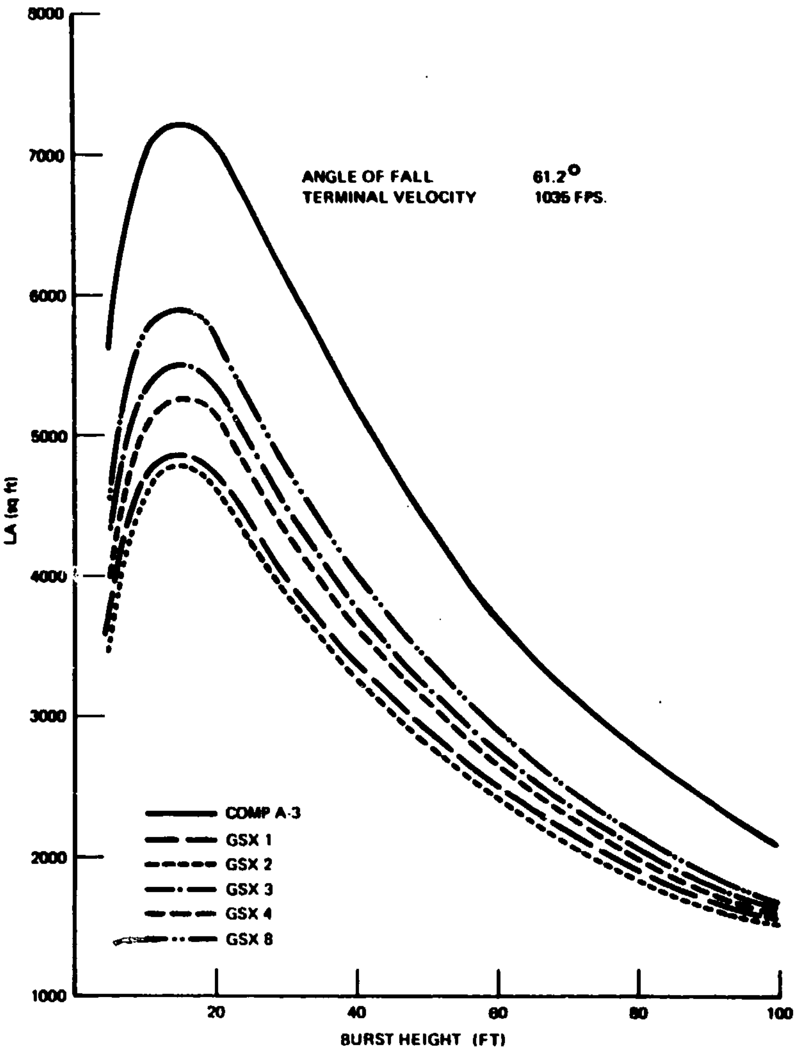

FIGURE 3. (U) EFFECTIVE LETHAL AREA OF A 5-INCH, 38-CALIBER PROJECTILE MK 49 (U)

Appendix A
PROMULGATION LETTER

COPY

NAVAL ORDNANCE STATION
INDIAN HEAD, MD. 20640

IN REPLY REFER TO

DA/LAD
5700

Dear

NAVORDSTA would appreciate necessary technical data on storable gelled slurry explosives suitable for applications requiring good blast and fragmentation characteristics.

The critical diameter should be over two inches and candidates should have a commercial production history of over one million pounds.

These slurries are to be based on water gels of the ammonium nitrate, sodium nitrate type with or without an explosive sensitizer and can be formulated with aluminum - basically they are to be similar to those used commercially in the mining or blasting industry.

The market potential is not immediate but could be tonnage quantities. Initial evaluations for engineering data acquisition will be based on small (up to five hundred pounds) quantities.

All data must be furnished concerning the material or materials used in the formulations supplied. This must include raw material specifications, finished material quality control procedures, and mixing procedures.

The above data is being requested for general information, planning, or estimating purposes only. It should not be construed as a request for quotation, as an order, or an indication that future procurement may result from this inquiry.

COPY

COPY

DA/LAD
5700

The contact for all information is Mr. Theodore J. Sullivan, Code DC-2, Naval Ordnance Station, Indian Head, Maryland 20640. Telephone area code 301-743-5511, ext. 631 or 632.

Sincerely yours,

/s/ Lionel A. Dickinson

LIONEL A. DICKINSON
Director of Advanced Technology
By direction of the Commanding Officer

COPY

COPY

~~DISTRIBUTION LIST:~~

~~Dr. Thomas E. Dykhouse~~
~~The Dow Chemical Company~~
~~Midland, Michigan~~

~~Mr. Herbert [illegible]. Schaaf~~
~~Explosives Department~~
~~E. I. du Pont de Nemours & Company, Inc.~~
~~Pompton Lakes, New Jersey 07442~~

~~Mr. Lee Holscher~~
~~U. S. Chemicals Department~~
~~Gulf Oil Corporation~~
~~1004 Baltimore Avenue~~
~~Kansas City, Missouri~~

~~Mr. Alan D. Hinkle~~
~~Explosives & Chemical Propulsion Department~~
~~Hercules, Incorporated~~
~~Wilmington, Delaware 19899~~

~~Mr. Charles E. Wood~~
~~Ireco Chemicals~~
~~P. O. Box 77~~
~~West Jordon, Utah 84084~~

COPY

Appendix B

DIFFERENTIAL THERMAL ANALYSIS CURVES FOR GSX CANDIDATES

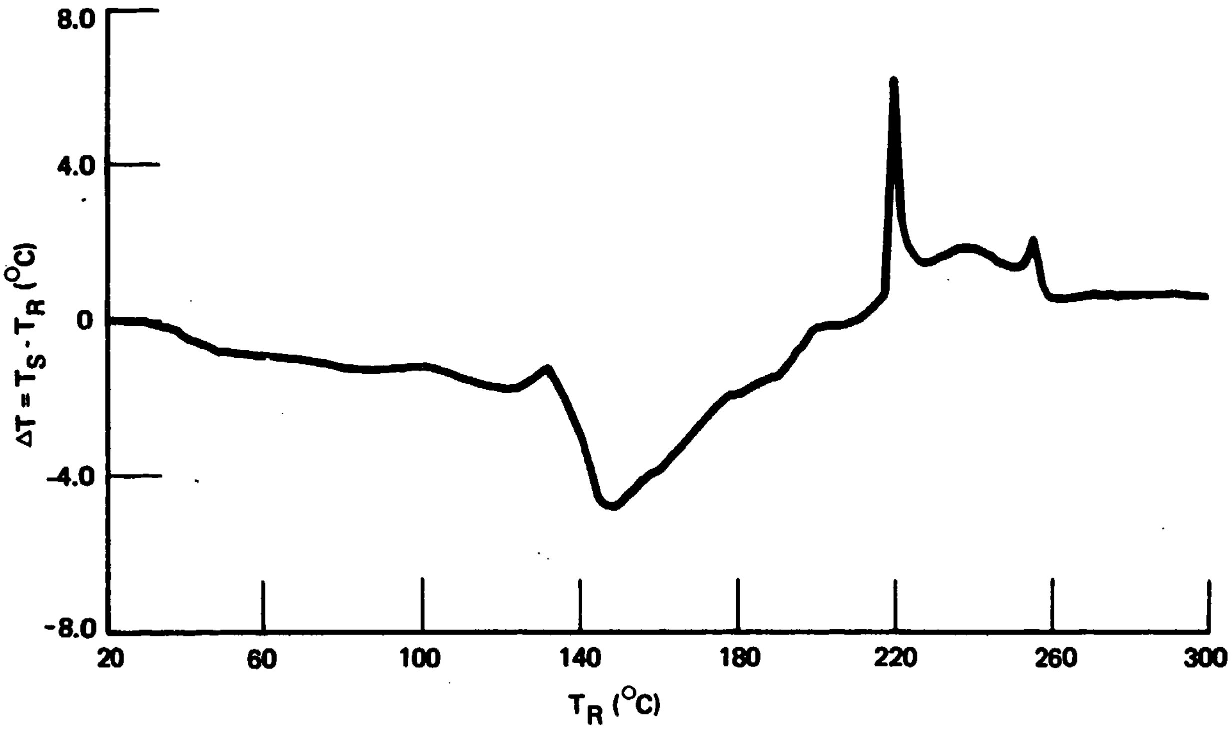

FIGURE B-1. (U) DIFFERENTIAL THERMAL ANALYSIS OF GSX CANDIDATE 1 (U)

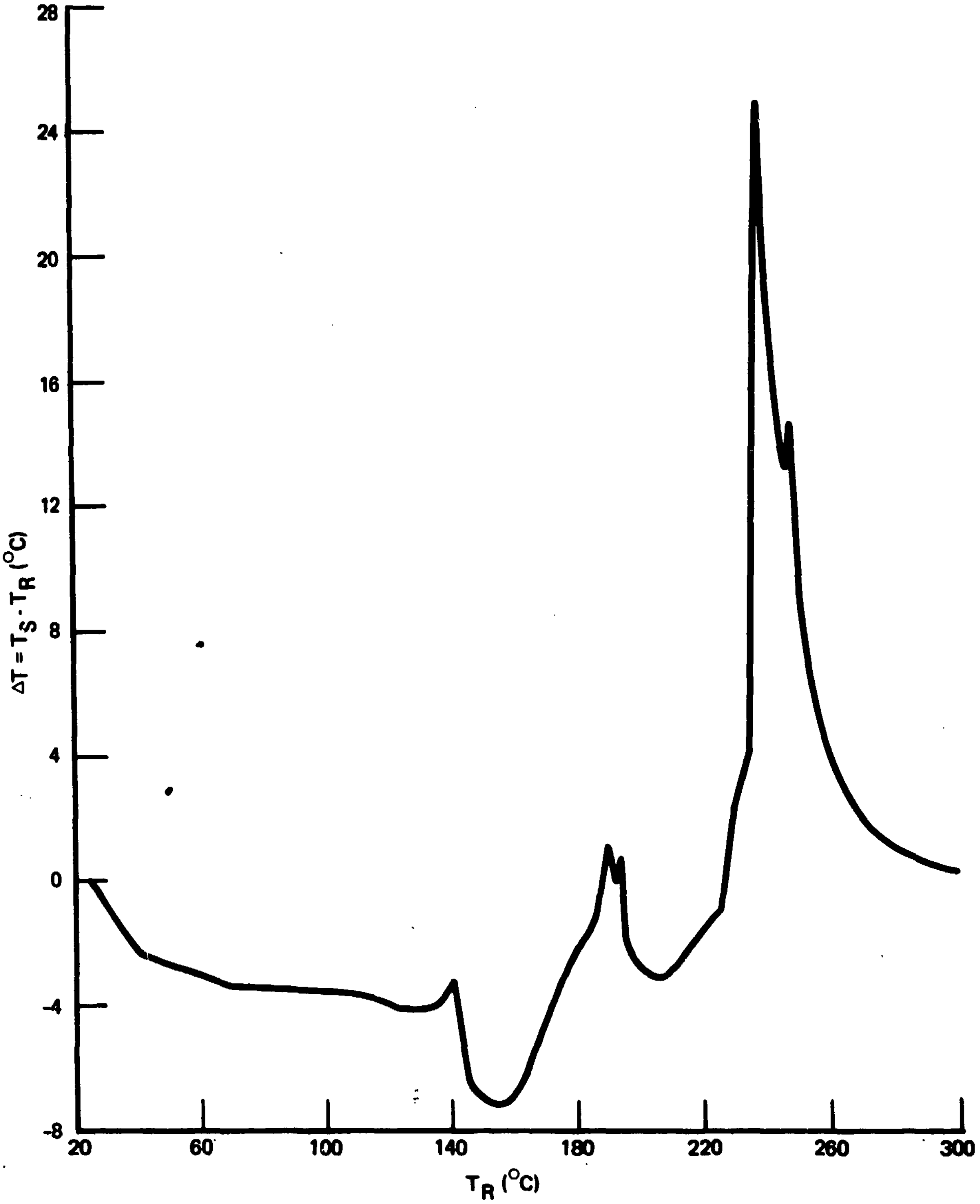

FIGURE B-2. (U) DIFFERENTIAL THERMAL ANALYSIS OF GSX CANDIDATE 2 (U)

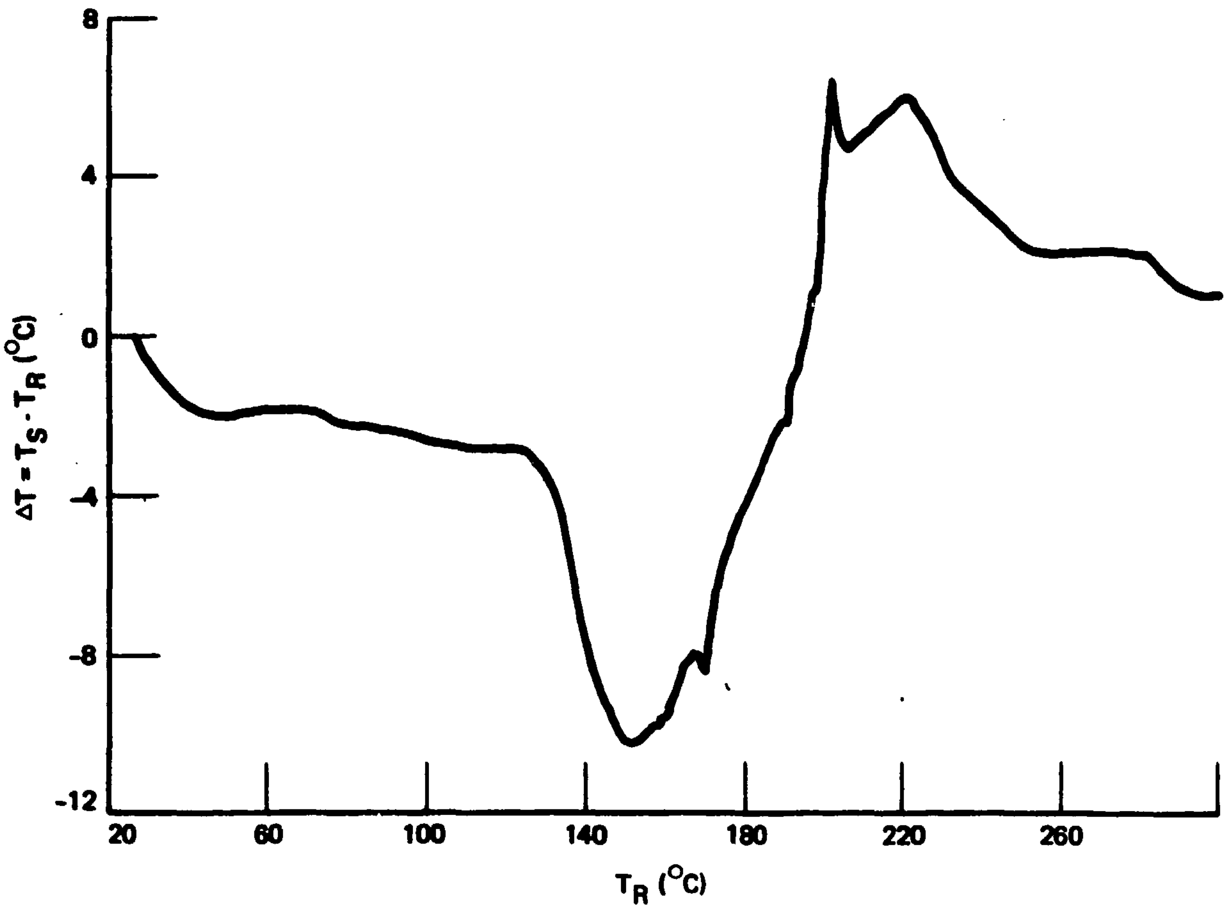

FIGURE B-3. (U) DIFFERENTIAL THERMAL ANALYSIS OF GSX CANDIDATE 3 (U)

[The sample remaining in the tube showed evidence of gassing—sample was forced to midway of tube.]

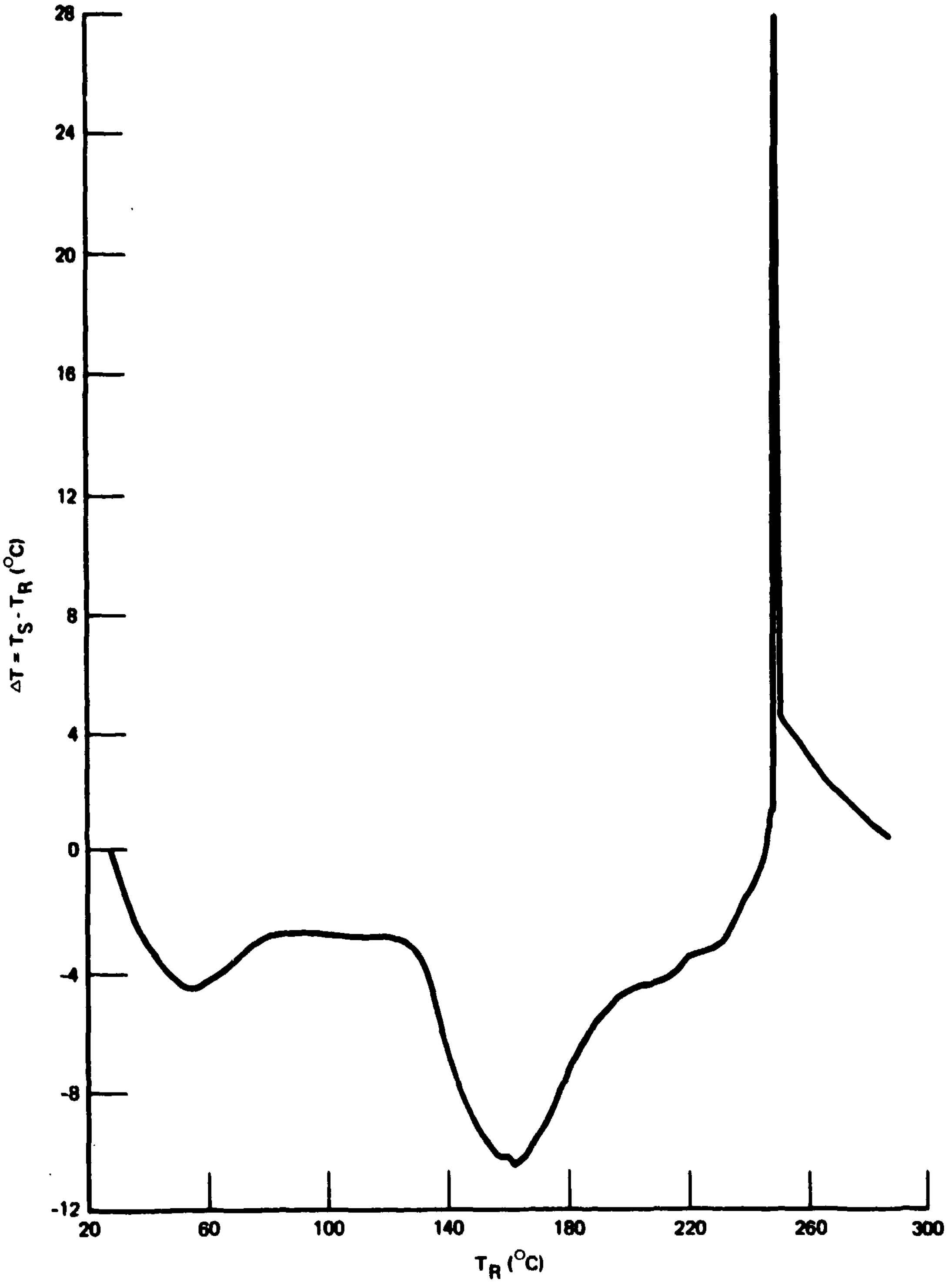

FIGURE B-4. (U) DIFFERENTIAL THERMAL ANALYSIS OF GSX CANDIDATE 4 (U)

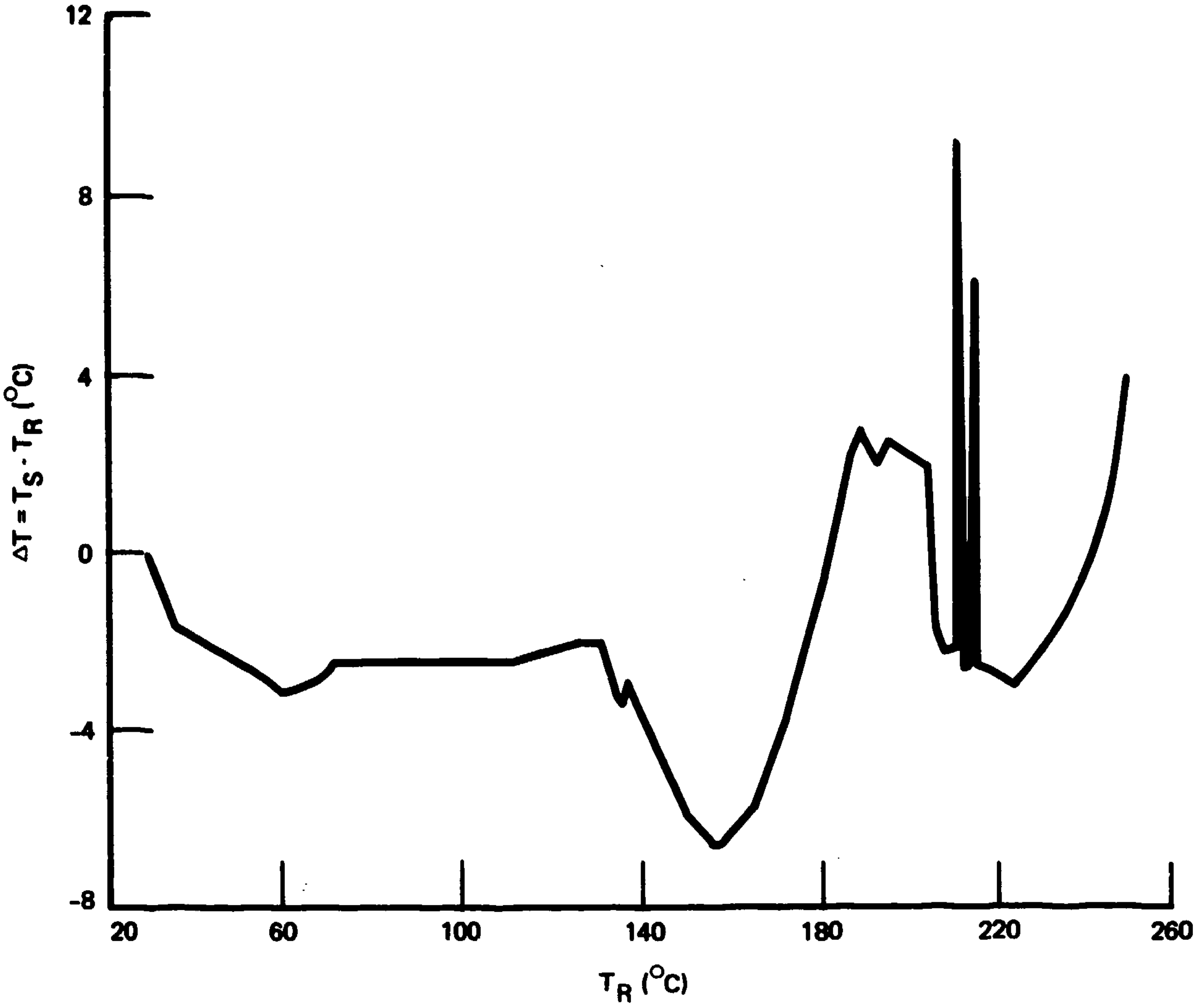

FIGURE B-5. (U) DIFFERENTIAL THERMAL ANALYSIS OF GSX CANDIDATE 5 (U)

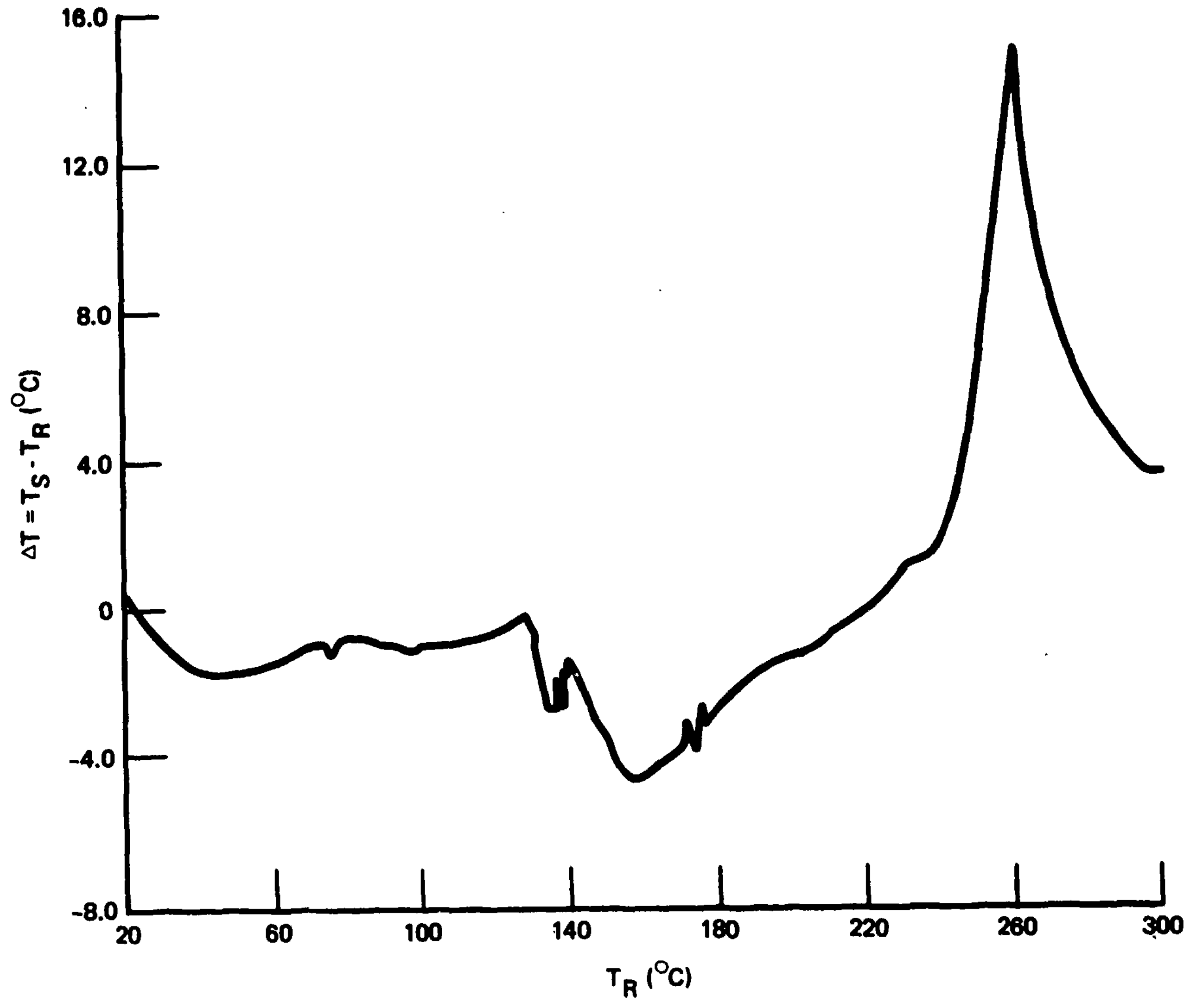

FIGURE B-6. (U) DIFFERENTIAL THERMAL ANALYSIS OF GSX CANDIDATE 6 (U)

[A considerable amcunt of brown foamed material mixed with flakes of metal occurred.]

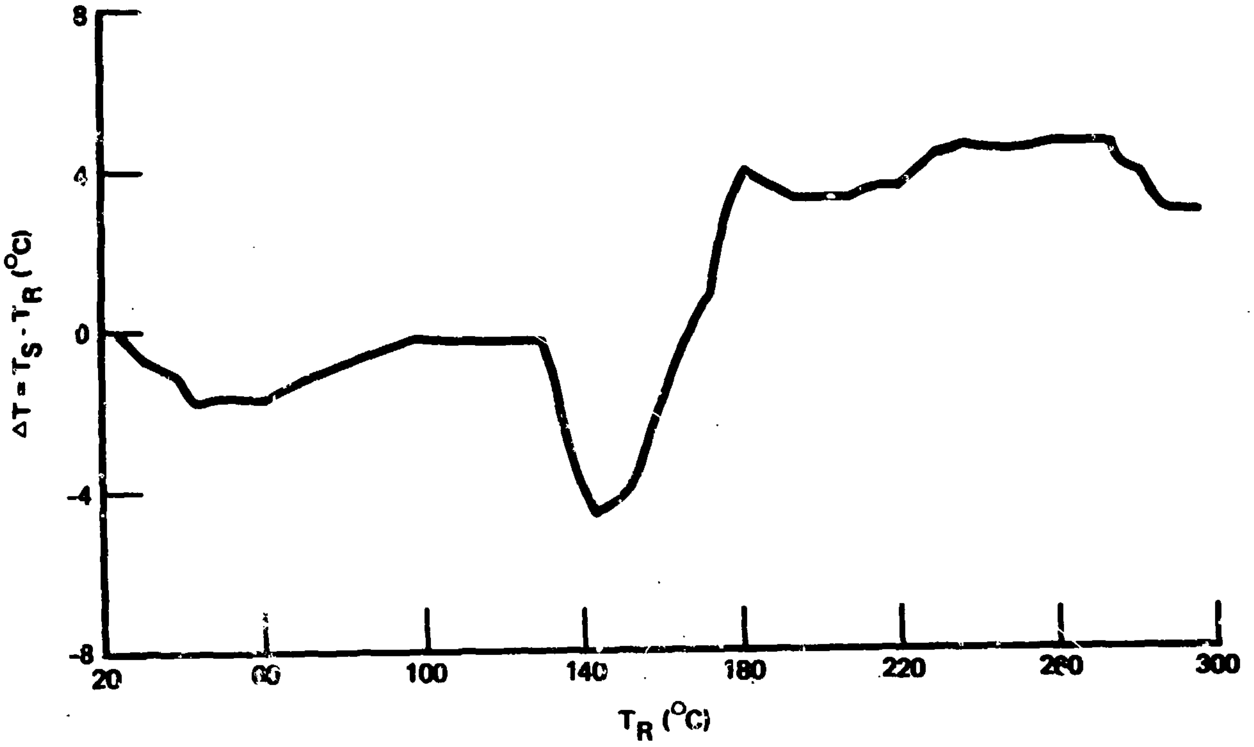

FIGURE B-7. (U) DIFFERENTIAL THERMAL ANALYSIS OF GSX CANDIDATE 7 (U)

[A large amount of loose material was obtained which resembled powdered aluminum.]

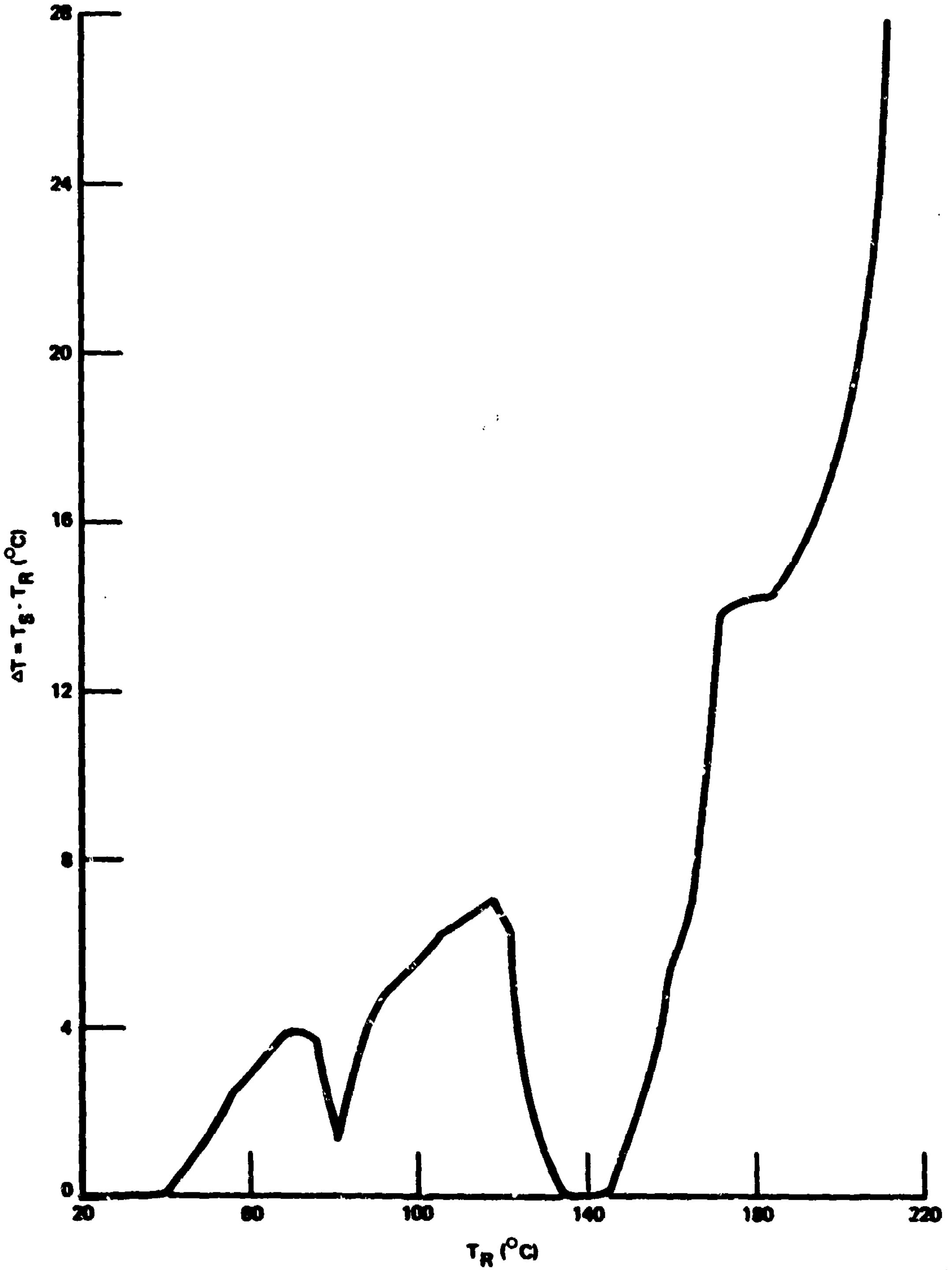

FIGURE B-8. (U) DIFFERENTIAL THERMAL ANALYSIS OF GSX CANDIDATE 8 (U)

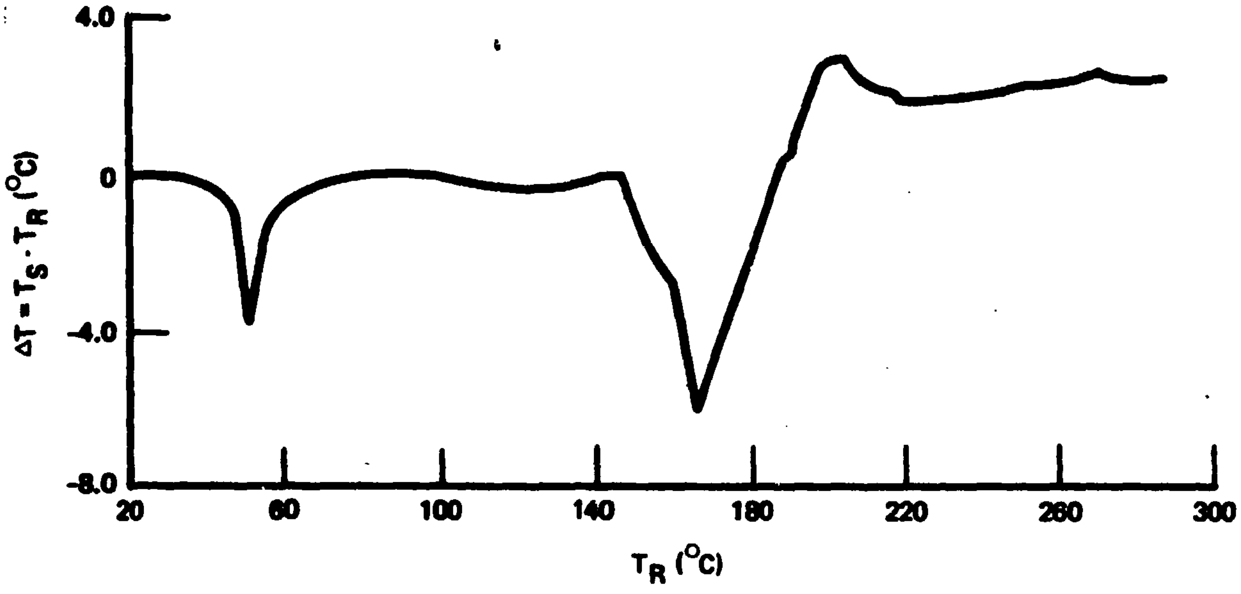

FIGURE B-9. (U) DIFFERENTIAL THERMAL ANALYSIS OF GSX CANDIDATE 9 (U)

[A residue double of the initial height of grayish-brown metallic material was obtained.]

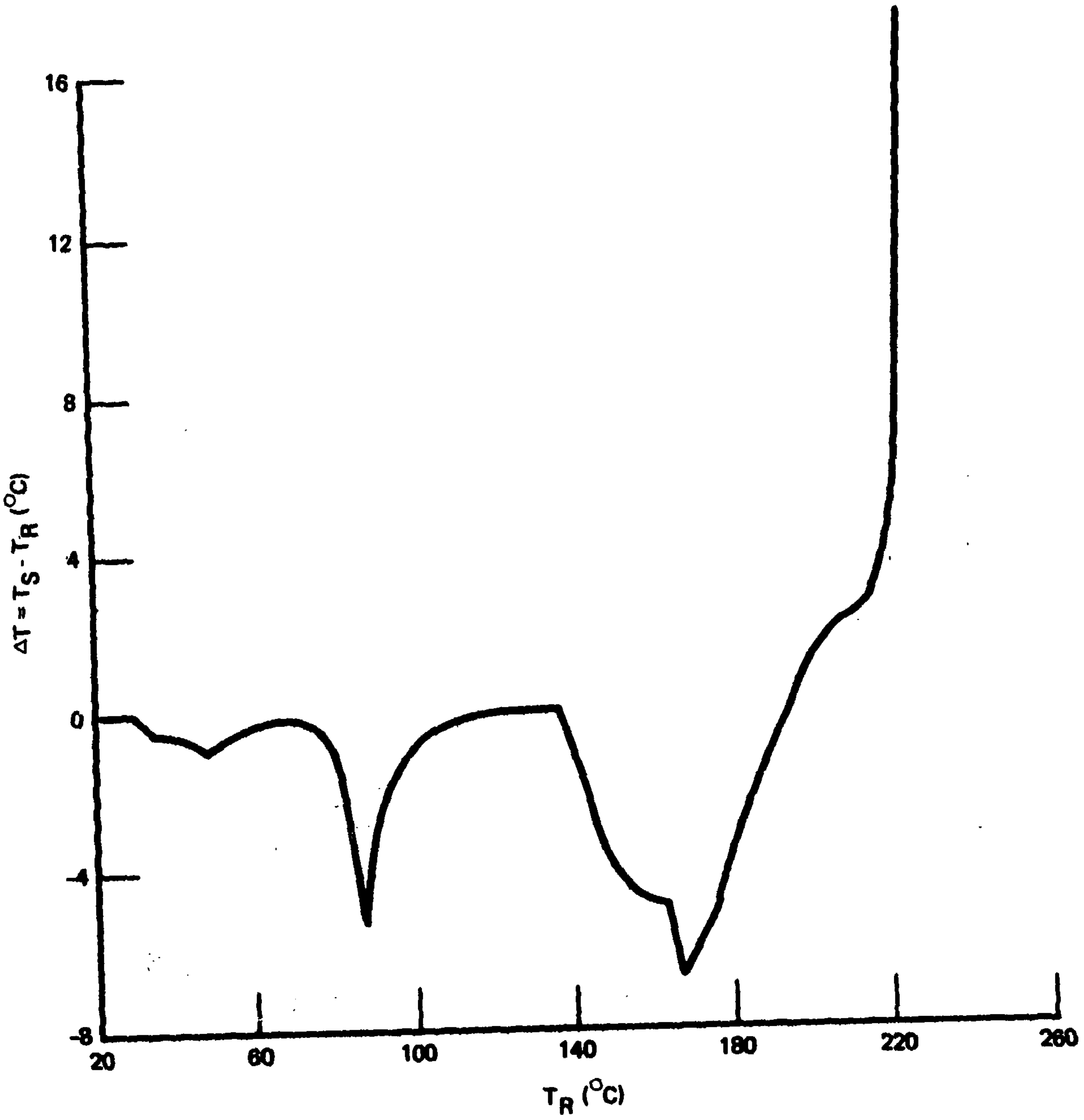

FIGURE B-10. (U) DIFFERENTIAL THERMAL ANALYSIS OF GSX CANDIDATE 10 (U)

Appendix C

MAJOR SUPPLIERS OF RAW MATERIALS FOR GSX

MAJOR SUPPLIERS

1. Ammonium Nitrate

Supplier	Annual capacity x 1000 (tons)
Allied Chemical Hopewell, Va.	907
American Cyanamid Hannibal, Mo.	170
E. I. du Pont de Nemours & Co. Seneca, Ill.	265
Gulf Oil Company Pittsburg, Kans.	500
Hercules Inc. Louisiana, Mo.	675[1]
Kaiser Aluminum & Chemical Co. Savannah, Ga.	388
Mississippi Chemical Corporation Yazoo City, Miss.	296[2]
Mobil Chemical Corporation Petrochemicals Division Beaumont, Tex.	200
Monsanto Co. El Dorado, Ark. Lulling, La.	570
Phillips Petroleum Company Etter, Tex.	262

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[1] Production capacity of two plants not available.

[2] May be expanded.

2. Ammonium Perchlorate

Supplier	Annual capacity x 1000 (tons)
American Potash & Chemical Corp. Henderson, Nev.	18
Pacific Engineering & Prod. Co. of Nev. Henderson, Nev.	6.1
Pennsalt Chemical Corporation Portland, Oreg.	
G. Frederick Smith Chemical Co. Columbus, Ohio	

3. Aluminum

Supplier

Alcan Aluminum
Riverside, Calif.

Harvey Aluminum
Torrance, Calif.

Alcoa (Aluminum Company of America)
Pittsburgh, Pa.

Reynolds Aluminum
Pittsburgh, Pa.

4. Sodium Nitrate

Supplier

Allied Chemical Corporation
Hopewell, Va.

Davies Nitrate Company, Inc.
Chemical Division
Metuchen, N. J.

Olin Mathieson Chemical Corp.
Chemical Division
Lake Charles, La.

5. Sodium Perchlorate

<u>Supplier</u>

American Potash & Chemical Corp.
Henderson, Nev.

G. Frederick Smith Chemical Co.
Columbus, Ohio

6. Guar Gum

<u>Supplier</u>

Stein Hall, Co.
New York, N. Y.

DECONTAMINATION & LAYAWAY OF PRODUCTION FACILITIES

Moderator:

John E. Jamison
Mason & Hanger-Silas Mason Co., Inc.
Burlington, Iowa

Summary

Panel members were W. C. Courtright, Safety Engineer, Los Alamos Scientific Laboratory and Fred L. Foltz, Safety Director, Newport Army Ammunition Plant.

Visual aids, 35mm slides, and 8x10" photographs were used to present three brief subjects to the group to create interest and to motivate discussion.

Subjects were:

1) Decontamination and Layaway of Production Facility Contaminated With Lead Azide and RDX

2) Decontamination, Demolition and Restoration to Natural State of Abandoned H.E. Facility

3) Decontamination and Demolition of Grossly Contaminated TNT Manufacturing Facility

The following points were made during the discussions:

Responsibility for shutting down and cleaning up contaminated facility upon the completion, or a temporary stoppage of its use, must be assigned and funds provided.

Standard Operating Procedures for decontamination, handling, disposal and layaway must be properly prepared and enforced.

Continuous updating and maintenance of permanent records of "as built" drawings of facilities and associated utilities.

Contaminated production facilities should not be abandoned. The cleanup problem and hazard of removal will have to be faced by someone at some time.

Mr. Albert H. Rock, Safety Director, Rocky Mountain Arsenal and Mr. Virgil L. Carpenter, US Army Munitions Command furnished most of the visual aids used in presentation and display boards.

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CONTAMINATION - DECONTAMINATION
LAYAWAY OF FACILITIES

Virgil L. Carpenter
US Army Munitions Command

Gentlemen, for the next one hour and forty five minutes we will discuss two most important areas which we are faced with in our current day production operations. Particularly where explosives, chemicals or related hazardous materials are involved and which will become more of a problem area when production schedules are reduced or production is completed and the installation or facility is placed in layaway or processed for disposal. These areas involve contamination and decontamination.

Area 1. Contamination

Throughout our manufacturing, load, assemble and pack and depot storage facilities today, many of our employees have been in this business long enough to be well aware of what contamination consists of and what procedures must be employed to preclude contamination of facilities or areas or to reduce it to an absolute minimum. However, there are any number of our employees who are not completely aware of the fact that contamination as applied in our current day activities includes but is not limited to the pollution by any type of explosives, chemicals or related hazardous materials, in any form and by any means, deliberately or by accident, a person, an area, buildings, equipment, terrain to include underground facilities and surface areas surrounding operating facilities.

Area 2. Decontamination

Decontamination which is the process of removing, destroying, neutralizing or changing these dangerous explosives, chemical agents or related hazardous materials into harmless substances. And past experience has proven that any contaminated facility or location must soon or later be decontaminated by one of the following methods: removal, neutralization, destruction by detonation or burning, evaporation, incineration and/or composition.

World War II

The construction of many of our current day ammunition, explosives and chemical facilities began in 1940. At this time little thought was given to contamination and subsequent requirement for decontamination. The facilities and equipment were new and due to the situation that existed at that time, primary emphasis were directed toward hiring and training new employees and achieving a maximum production capacity. Toward the later phases of WW II many incidents began to occur as a result of excess contamination and improper decontamination. As a result of this accident experience, Supply Bulletin No. SB5-52, Decontamination Procedure, was published in July 1945. This bulletin was based upon the best information available at that time and outlined requirements to be followed during layaway of contaminated facilities.

After WW II demobilization and cease of production developed at such a pace that proper disposition of plants, facilities, equipment, materials and other items could not be accomplished in complete detail as outlined in SB5-52. Therefore, in many cases they were placed away in an extremely hazardous condition.

During the time between WW II and the Korean situation, equipment was stored at the facility or it was shipped either for use or storage at another facility without any or improper markings as to its possible contamination. In many cases improper or inadequate types of decontamination processes were used and the resultant classification applied thinking that the decontamination fit the classification.

As for terrane, positions of underground facilities either contaminated or otherwise they were forgotten or in many cases, improperly located on maps and other papers. Sumps, settling basins, drainage ditches, underground flume lines and in some instances, locations where explosives and other related hazardous materials were disposed of by burying were allowed to become overgrown with vegetation and stay ready for detonation upon disturbance. To give you a better view of some of the conditions encountered during final decontamination of a number of areas and facilities some ten years plus after WW II, I would like to show you some slide pictures.

Korean Emergency

This emergency developed at such a rapid pace that it was demanded that many of our plants be immediately placed into a production status and that any required rehabilitation, modification or changes for new type production processes, be accomplished parallel with production activities. In many instances this rehabilitation included decontamination and as a result many undesirable accidents occurred. It was only because of the availability of technical knowledge that many more serious accidents were averted.

Standby 45-50

The job of cleaning up, decontaminating and placing the facilities and equipment in standby was accomplished. It was not the best job, but as good as could be expected under the circumstances. At completion of this operation the services of some of the contractors were terminated and the installations placed under Ordnance Corps personnel control. As a result, many of the people who were acquainted with all previous activities and conditions transferred to parent organizations. Detailed records and markings indicating the extent of contamination were not made and as a result these conditions created many problems. During this period the future status of installations was not known and many were dismantled, some were sold, other assigned to General Services Administration for disposal and other were placed in caretaker or standby status.

As a result much contaminated equipment and facilities did get into private hands and resulted in needless accident and large sums of monies.

At the end of the Korean situation we were again at that phase of activity where materials, equipment, facilities, etc. must be placed in standby status. At this time, based on the lessons we learned during previous reactivation, adequate layaway procedures should have been developed before layaway operations were started and that knowledge of the present and future hazards should have been recognized. Many of our plants or installations were placed in layaway status proper or in some instances only a portion of the installation was placed in layaway status and the remainder continued in operations on a restricted basis.

The current status of these installations is that they are again on a full production status and subsequently they will be placed in layaway or disposed of as excess. As a result they must be decontaminated and/or in some instances certified as free of hazardous materials which could result in injury to the public or damage to property. Prior to signing any such agreemen., appropriate representatives, mostly facilities and safety, must make a detailed survey of the facilities to assure that complete decontamination has been accomplished when the installation was placed in layaway status.

As a result of previous surveys and conditions noted it was most evident that we didn't remember the lesson we were taught during reactivation for the Korean situation and as a result some of the decontamination had to be redone.

In review of some of the operations currently in process again are not giving adequate emphasis to contamination-decontamination. It is evident that we do too much and this is an indication that in future operations, greater efforts than those demonstrated in the past must be enforced to assure that adequate decontamination is accomplished at the cease of operati s and during the course of operations.

Procedures

Decontamination procedures, marking and maintaining complete records, are necessary to prevent possible disastrous results. Proper decontamination procedures and marking instructions on contaminated buildings, equipment or terrane will prevent them from being erroneously designated or mistaken as decontaminated. The safest way to perform decontamination is the most effective way. Where safety rules or regulations are disregarded in order to accomplish the work more quickly, it is evident that neither the safest way nor the most effective way has been employed. It is the responsibility of the using service to prepare a detailed SOP for decontamination, applicable to specific areas to include facilities, equipment and any other items within each location. It is your responsibility as Safety Director to insure that these procedures are prepared, that adequate decontamination is performed during and at the cease of operations and that adequate markings and records are maintained of these activities.

In closing, I again want to place emphasis on accident prevention during decontamination operations. In the ammunition industry, the end product is made to kill, inflict serious injury and/or cause extensive property damage. They are as safe as any other product provided approved procedures are followed. In future operations we must remember that adequate records must be maintained because Joe, Sam and Bill may not be available to provide guidance during decontamination operations and you may be the one that must assume the responsibility for overall supervision of decontamination activities.

EVALUATION OF FRANGIBLE CONSTRUCTION FOR STORAGE OF AMMUNITION AND EXPLOSIVES

Moderator:

Dr. Floyd A. Odell
U.S. Army Ballistic Research Laboratories

"Evaluation of Frangible Construction for Storage of Ammunition and Explosives"

TOPICS FOR SPECIALIST SESSION

1. Types of Frangible Construction and Their Advantages.
    - Magazines
    - Above Ground Facility for Solid Rocket Testing
    - Facilities for Hazardous Operations
2. Observations of Fragment Ranges and Masses from Various Types of Structures.
    - Comparison with Munition Fragment Ranges
    - Soaring (lift effects)
3. Attenuation of Primary Fragments by Structures.
    - Single vs Repetitive Burst
4. Suppression of Fire and Flame by Frangible Structures.
5. Communication of Explosion through Frangible vs Non-Frangible Structures.
6. Damage Criteria for Safety Problems.

Welcome to the Special Session on the Evaluation of Frangible Structures. My definition of such a structure is one that provides environmental control but which in the event of an accidental explosion, will offer some attenuation to high velocity primary fragments and will fail in such a manner forming secondary fragments having poor ballistic flight characteristics. Our presentations which include both the pros and cons of frangible construction, will be followed by discussion periods so that our visitors may exchange information and express their opinions.

THE APPLICATION OF FRANGIBLE STRUCTURE CONCEPTS TO AEROSPACE AND DEFENSE ACTIVITIES

Paul V. King

General Electric Company
Bay St. Louis, Mississippi

The advent of the aerospace age, with its concomitant requirement for utilization of quantities of explosives (or propellants) which approached in terms of bulk quantities, the upper limits of our various "standard" safety tables, has indicated the desirability of exploring newer concepts of facility construction.

Elaborating a little on Dr. Odell's definition, we have characterized frangible construction as a type of construction which would:

1. Maintain its integrity sufficiently long to provide some degree of attenuation to primary fragments, i.e., fragments of weapon, vehicle, vessel, etc., in which the explosion originated;
2. Ideally, fail sufficiently fast to minimize build up of reflected pressures, and/or pressure of fragmentation initiated progression reactions, and
3. In failing, the structure, should not contribute fragments more damaging, or farther ranging, than the attenuated primary fragments.

As Mr. Dunn and Mr. Schlueter will show, a number of tests have been conducted which appear to indicate the feasibility of this type of construction.

I would like to concentrate on a brief discussion of potential applications.

First as to background, the concept of frangible construction, in the form of venting panels or areas is not new. The Bureau of Mines for example conducted a number of tests in the late thirties and early 40's which showed the advantages of venting panels, blowout doors, etc. I remember being particularly impressed by the fact that one series of tests indicated a significant reduction in damage in a test chamber when the vent panels were constructed of number 6 vs number 8 kraft paper.

In my own experience, we, at BRL adopted a standard vent panel for our blast chambers of 5# wt. per 20 sq. ft. of area in the period around 1950-1953.

Although the feasibility of utilizing frangible construction for minimization of blast pressures from condensed high explosives incidents may be questioned, it has, I think, been shown that a meaningful degree of fragmentation attenuation can be achieved.

Applications:

1. Magazines - As regards specific types of applications, the use of frangible concepts for construction of magazines might enable us to build "above ground" lightweight structures, with excellent thermal properties, with no greater danger radius than that required for an igloo magazine holding the same bulk. Similarly tests might show that in the case of complete rounds, a structure which fails in the first accidental event would be expected to minimize the total reaction by reducing the number of ricocheting fragments and venting blast overpressures.

   Again the benefits of this type of construction would become more apparent with increase in bulk. In my experience, the application of honeycomb types of frangible structures was proposed first by Mr. Ed Straight and Mr. Harold Buchanan, at the Army Ballistics Research Laboratories.

2. Aerospace Testing - Another potential use for frangible structures is in the area of static testing of solid or liquid propellant boosters. Most siting is on the basis of a blast overpressure parameter and a fragment parameter. Since the fragment danger radius exceeds the blast danger radius, in a given case the application of frangible shielding to provide some attenuation of primary fragments would have the effect of reducing the fragment danger radius to one equal to or less than the blast danger radius. In this way larger stages could be accommodated at existing sites, strap on solids could be safely tested without the necessity of using underground silos.

3. Other applications: Assembly, testing, or manufacturing operations involving propellants, pyrotechnics, etc., would appear to lend themselves to these concepts also. In each case the idea being to avoid the comfinement which permits transitory incidents - (deflagration to detonation) while at the same time minimizing secondary fragments, and attenuating primary fragments.

In large scale (100,000 lb. levels) it is believed that such approaches are mandatory, since conventional "hardened" construction is approaching the limits of applicability. In conclusion, I believe that a significant improvement in safety can be obtained with decreased cost, if we apply the appropriate frangible construction concepts. I feel that their concepts are especially applicable to low explosives, propellants, pyrotechnics, and that they are also useful in a variety of high explosives applications.

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OBSERVATIONS OF FRAGMENT RANGES AND MASSES FROM VARIOUS TYPES OF STRUCTURES

A. B. Brown

Technical Projects Operation
General Electric Company
Bay St. Louis, Miss.

INTRODUCTION

Having sat through Hurricane Camille in my house in Pass Christian this presentation on fragmentation is rather anticlimactic. We have billions of fragments, from minuscule to houses.

For this short survey we made a comparison of space vehicle fragment ranges with munition fragment ranges. A study was made of five major space vehicle explosions ranging from 231,000 lbs. of LO2/LH2 with 3.5% yield or 3200# TNT equivalency down to 25,000# LO2/RP-1 with 4% yield as 1,000# TNT. Maximum fragment range with a few exceptions was 1200' with 90% of the material falling within 700 ft. The fragment densities outside the major fragment radius ranged from .31 to .80 fragments per 10,000 sq. ft. The overpressure radius of 0.65 PSI in all cases exceeded the major (90%) fragment radius.

Observation of the data from some equivalent TNT explosions in the field of high explosive manufacturing indicate fragment ranges two to three times greater than space vehicle initiation.

CONCLUSION:

Fragmentation data from space vehicle explosions are more complete than munition explosions, (weight, range and description).

The longer range of the munitions fragments can be accounted for by the greater degree of confinement such as heavy concrete cubicles or blast walls as compared to the light corrugated sheet steel walls of space vehicle test stands.

During the presentations several people from the floor suggested explosions such as "big pappa" 250,000# with 90,000 well documented fragments, also the British "Ledsham" report of 1959 for munitions explosions was suggested for source materiel. For this particular study what were needed was fragmentation data for explosions in the 1,000#/5,000# area for comparison to equivalent TNT space vehicle explosions.

Another fragmentation area of interest was the soaring or lift effect of tank skins and plates due to their aerodynamic configurations. It was suggested that the fireball offered a contribution to this soaring. It undoubtedly does, but the average rate of rise is much less than the initial velocities of most fragments. Supersonic launching velocity is the main factor in producing long range skin fragments, that is if their major area is in the same plane as that of the trajectory.

SUMMARY:

If more complete fragmentation data can be accumulated in the near future along with a more definite determination of the center of explosion, for space vehicles in particular, it will be possible to develop more credible:

1. Design criteria
2. Operation procedures
3. Safety procedures
4. Safety ranges

The objectives being the safety of people and more economic and reliable facility installations.

FRAGMENT BEHAVIOR DISCUSSIONS FOR STORAGE OF AMMUNITION & EXPLOSIVES

Edward B. Ahlers, Manager
Illinois Institute of Technology Research Institute

Additional results of parametric study of fragment trajectories, not shown in the regular Technical Presentation, were presented in this session for review and discussion. Graphic materials on the trajectories are included in the paper of fragment and debris hazards rather than here, to provide continuity of the material in a single paper. It was demonstrated that:

Maximum terminal distances for high-speed fragments corresponded to an initial trajectory angle of about 20° from the horizontal. Maximum trajectory heights for low-angle high-speed fragments occurred at about 65-75% of terminal distance and impact angles above 75% from the horizontal were common.

Munition fragments experience great velocity attenuation -- attenuations from 3,000 - 10,000 ft/sec to 150-300 ft/sec is common for high-speed low-angle fragments up to 1 lb. in weight. Velocity attenuation results from the net effect of drag forces which retard the fragment and are opposite in direction to the instantaneous fragment velocity, and gravity effects which are decelerative in the vertical direction until maximum height is reached and accelerative thereafter.

Exhibits were also presented which showed results of observed fragment behavior from past explosions, including:

Correlation between maximum fragment distance and equivalent weight of explosives, which is shown in Fig. 1 for a large number of explosions. The extreme scatter of data points stems from dissimilarities in types of explosion, structures involved, and environments.

Distribution pattern for concrete fragments from a Pantex Ordnance Plant explosion test. (Figs. 2 - 4). The test provided a thoroughly documented record of weights and terminal positions of about 35,000 fragments with a total weight of about 85,000 pounds. The missile map, Fig. 2, shows fragment densities of the order of one per 25,000 sq. ft. were observed locally as far as 1400 ft. from the detonation. The decidedly unsymmetrical pattern resulted from the environmental configuration. The overall dispersion of fragments is expressed in Fig. 3, with values being computed on the basis of circumferential areas. Variations in mean fragment weight with ground range is plotted in Fig. 4.

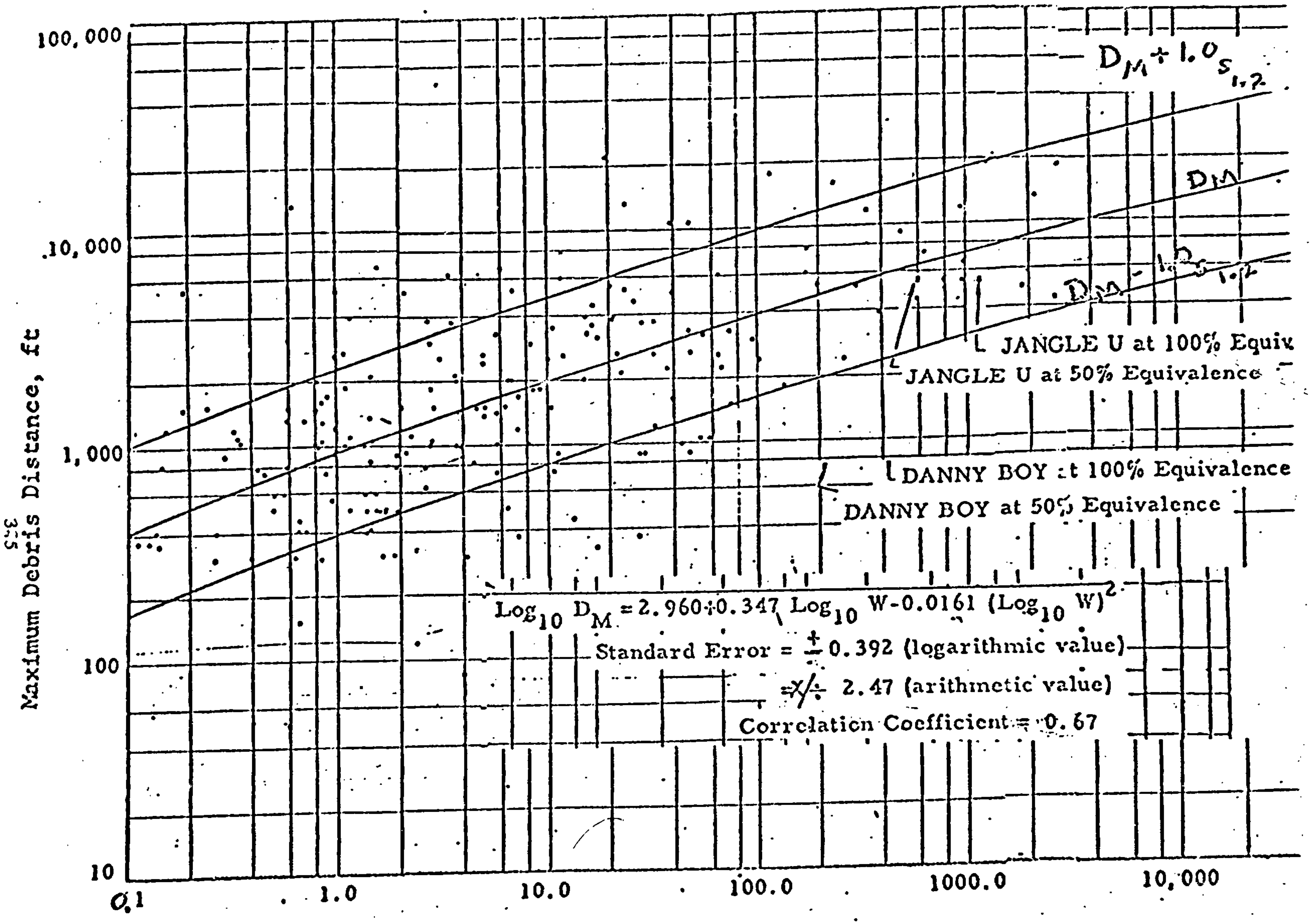


Figure 1. Equivalent Weight of Explosives, tons_{TNT}

QUADRATIC REGRESSION LINE: MAXIMUM DEBRIS DISTANCE VERSUS EQUIVALENT YIELD

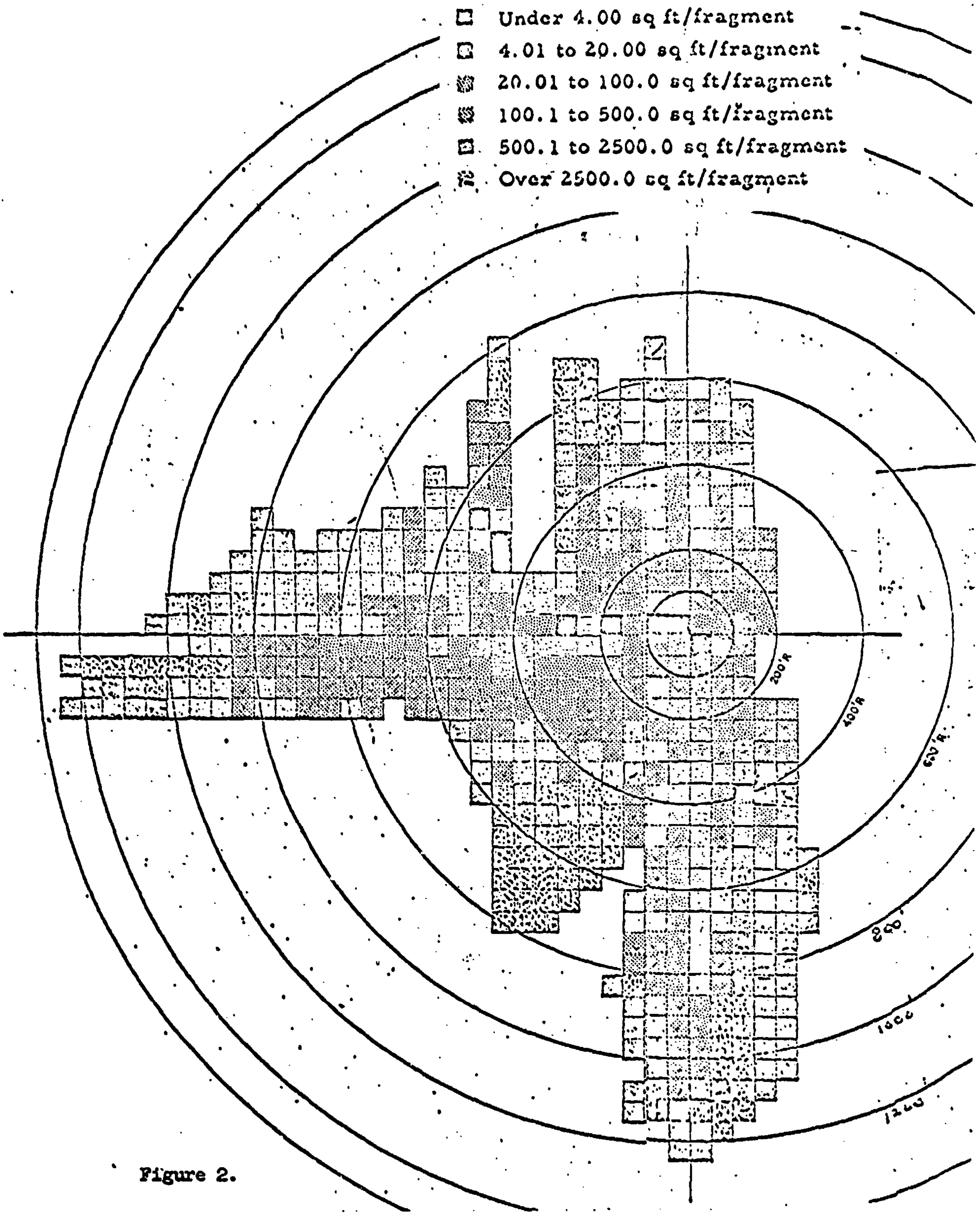


Figure 2.

AREA OF FRAGMENT DISTRIBUTION FROM PANTEX ORDNANCE PLANT TEST STRUCTURE

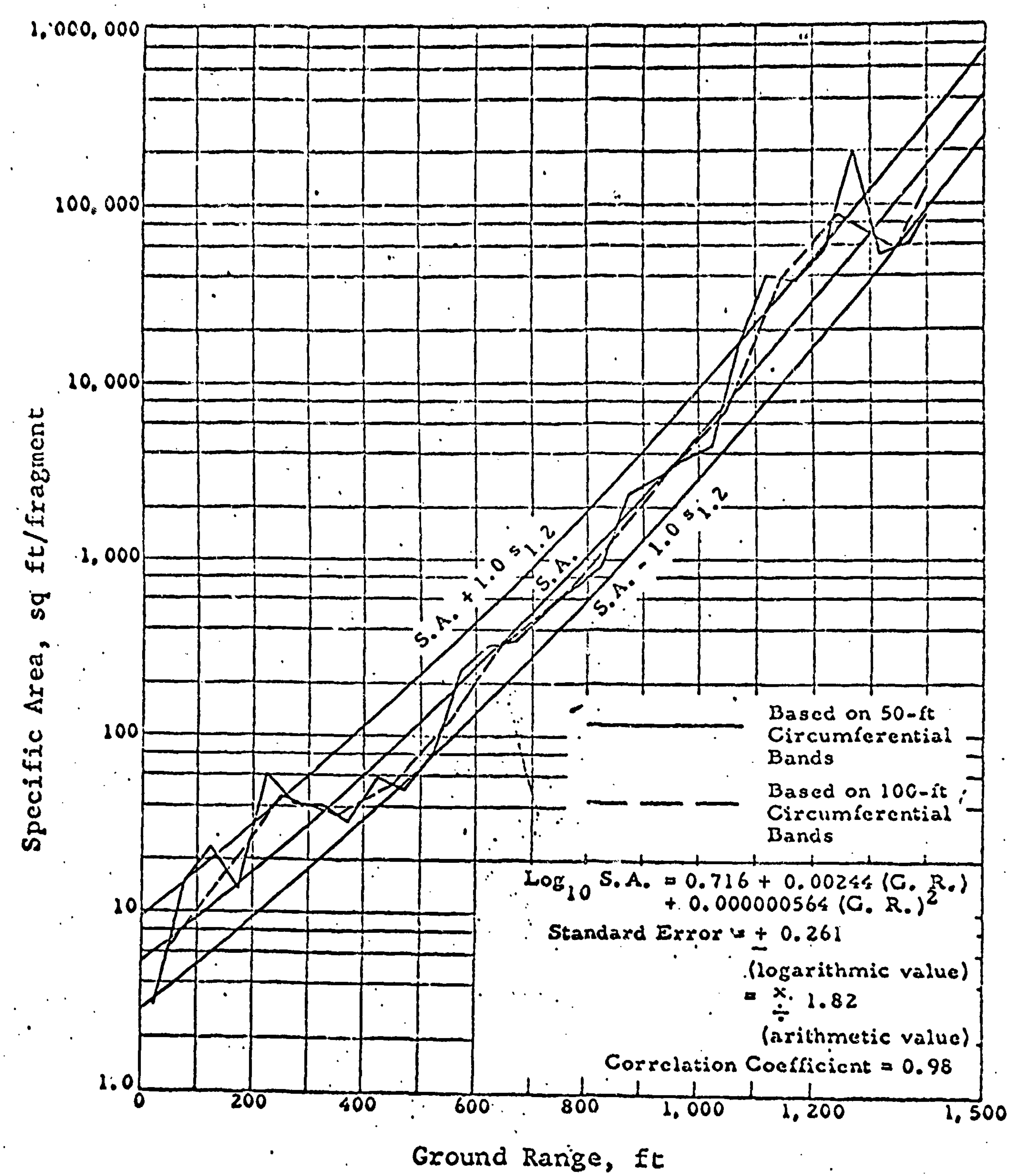


Figure 3. DEBRIS DISPERSION FOR REINFORCED CONCRETE STRUCTURE SEMILOG PLOT WITH SECOND-ORDER REGRESSION LINE

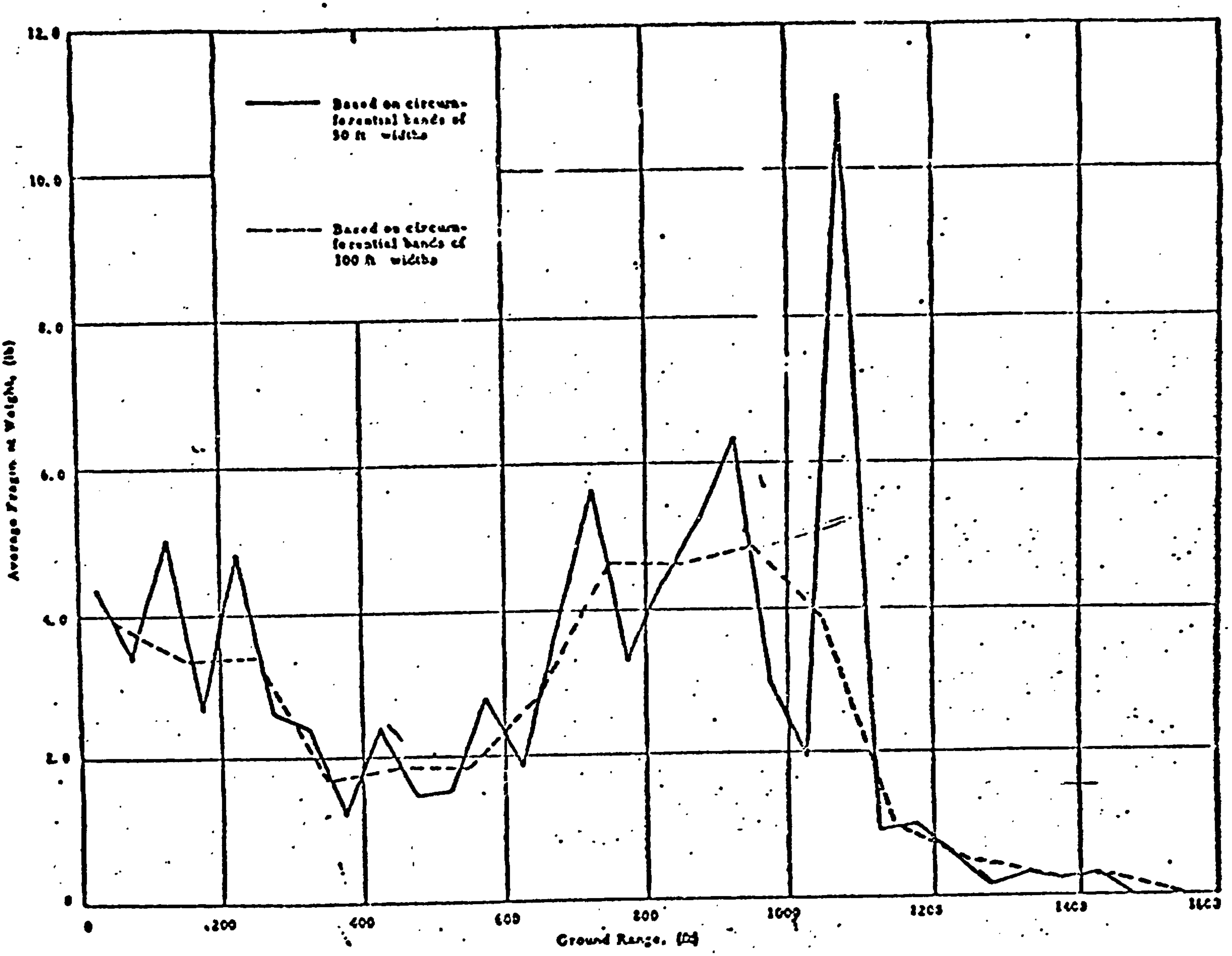


Figure 4. Average Fragment Weight versus Ground Range* for a Reinforced Concrete Structure

ATTENUATION OF PRIMARY FRAGMENTS BY FRANGIBLE STRUCTURES

S. Donald Schlueter

U. S. Army Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

Regarding the attenuation of primary or missile fragments that might be generated by an accidental explosion of a missile in storage or at the preparation facility, the BRL have produced data on the loss of velocity of chunky fragments which impacted light weight panels. These aluminum honeycomb panels as shown in Figure 1, weighed 12.2, 6.7, and 4.7 lbs/ft^2, and their skin thicknesses were .188, .091 or .063 inches respectively. Projectiles simulating the chunky fragments weighed up to 6 pounds. Residual velocity data was measured for striking velocities ranging between 500 and 2000 ft/sec. and panel protection criteria was determined by a series of 6 round, 50/50 ballistic limit tests.

First, let us look at the ballistic limit data which is summarized in Figure 2. A least square fit provides an equation which permits us to estimate the limit velocities of various panel-fragment combinations. The limit velocity (V_{BL}) equals the ratio of areal densities of the panel and projectile times the slope of the curve.

Concerning residual velocity, a sampling of the 75mm fragment data shown here shows the attenuation trend of these panels. Velocity attenuation increased with the weight of the panel and was proportionately less with the larger fragment and more with the smaller fragment. The following equation derived from the test data permits us to predict the

75MM FRAGMENT DATA

Target Panel	Striking Velocity Ft/Sec	Residual Velocity Ft/Sec	% Loss
Light	977	953	2
Medium	986	873	11
Heavy	995	690	31

attenuation of any fragment striking any aluminum honeycomb panel within the range of sizes described:

$$V_R^2 = \frac{V_S^2 - \bar{V}_{BL}^2}{1 + \alpha R}$$

where R = the ratio of areal densities of the panel and projectile.

In conclusion, it is apparent that these panels offer little attenuation to chunky type fragments; however, it is believed that for fragments having a large area to mass ratio such as missile skins or panels, attenuation will be much greater.

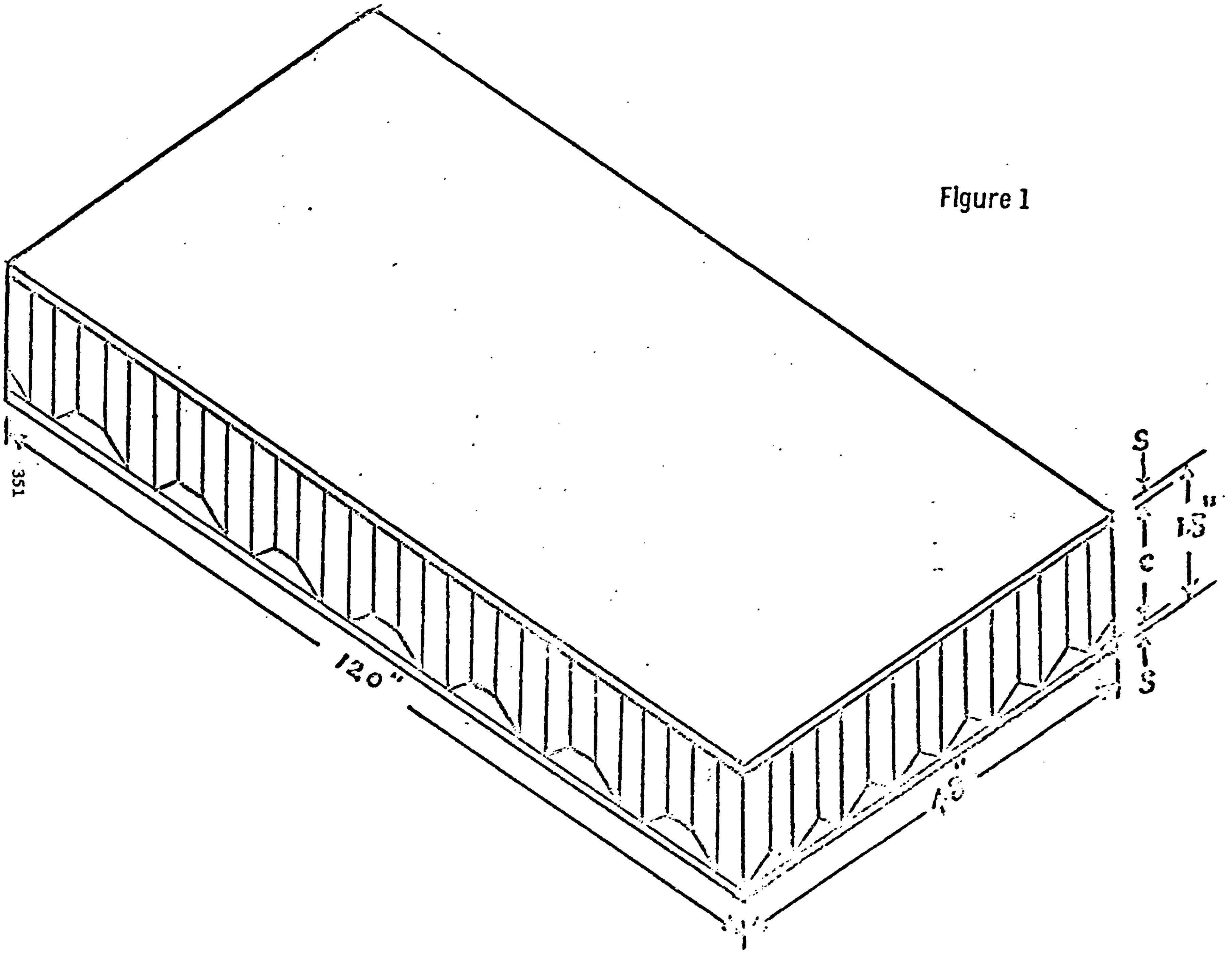
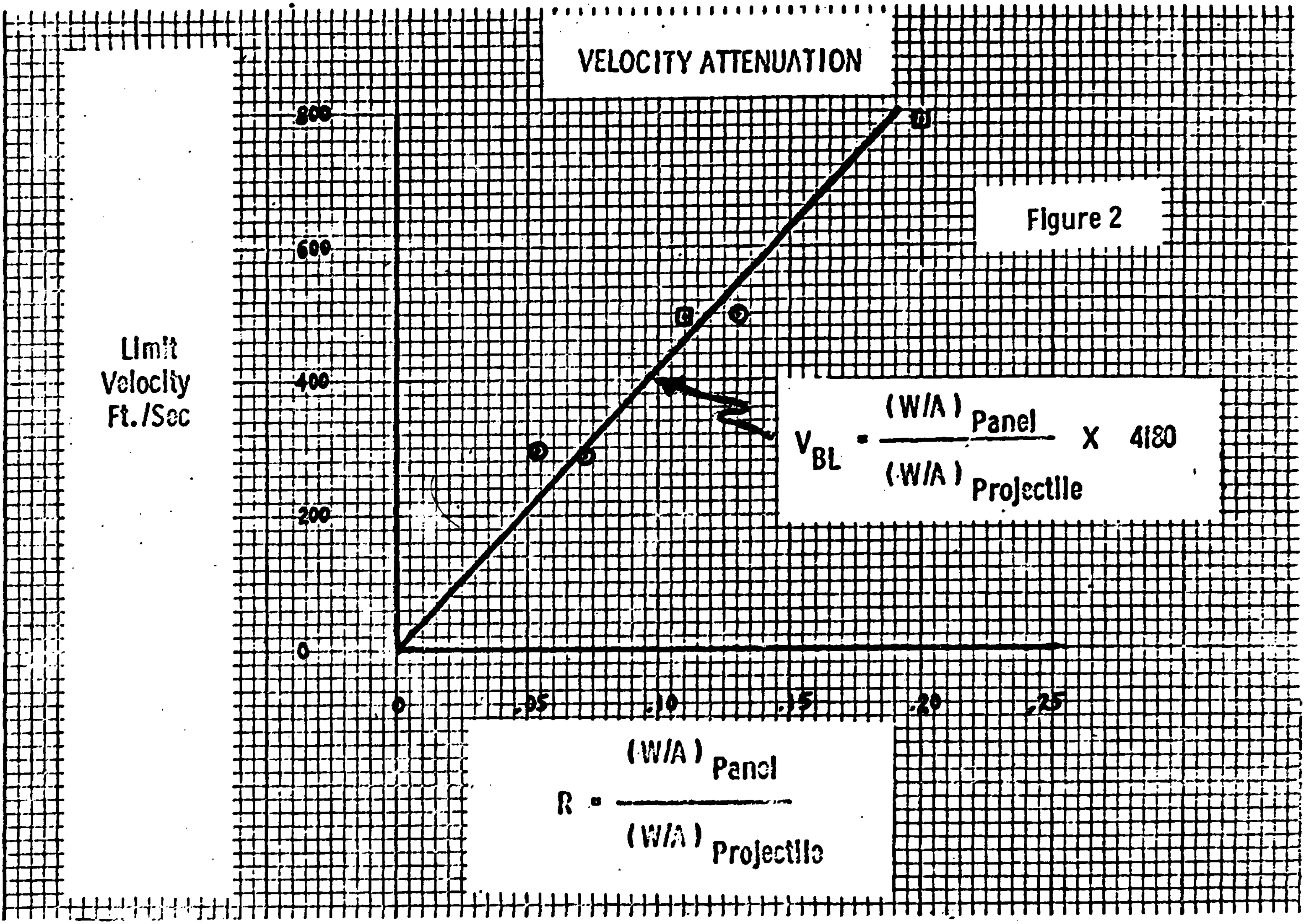


Figure 1



VELOCITY ATTENUATION

Figure 2

$$V_{BL} = \frac{(W/A)_{Panel}}{(W/A)_{Projectile}} \times 4180$$

$$R = \frac{(W/A)_{Panel}}{(W/A)_{Projectile}}$$

ACCIDENT EFFECTS LIMITATION IN OPERATING BUILDINGS: RECENT APPLICATION AT PANTEX PLANT

I. B. Akst

Mason & Hanger - Silas Mason Co., Inc.
Amarillo, Texas

At last year's ASESB Safety Seminar in Louisville we talked about limiting explosives accident effects in operating buildings to very narrow confines, and we showed some sketches of a possible design along with pictures of some actual operating buildings so designed and in use.

We had and have in mind quite complete limitation of effects on people, facilities and production from an explosive accident, and we defined "quite complete" as (1) no one will be killed or seriously injured beyond the bay or room of action and the immediate area (meaning close to the entrance and exit); (2) there will be no major equipment or facilities damage beyond the immediate area of the bay; (3) disruption of production will be minimal, (4) other effects such as the spread of hazardous materials will be held to a minimum consistent with the above aims and cost.

This year I would like to show you another design we are presently using and some pictures of three new facilities we are presently building or have in use which embody the effects limitation concepts.

The first slides show an earth covered steel arch, a single bay, where a hydrostatic HE pressing operation will be done. The difference between this construction and the others is that this one is designed to restrain very massive pieces of debris (e.g. heavy pieces of the press). This is accomplished by steel cables, netting, etc. in the overburden structure. The barricade in front limits low-trajectory debris.

The next slides show an entirely different design which uses orthogonal flat walls and roof, all of reinforced concrete, earth covered. One of the reasons for the design is to obtain ceiling and hook heights in operations where bridge cranes are desirable. As you can see, this is a multiple bay construction too, there being two rows of bays with ramps exterior to each row.

The last slide shows a multi-arch, earth covered structure much like the one in the sketch shown last year (that is, there is a central ramp and a series of steel arches).

We now have actual construction cost figures. Comparison to costs of standard one-foot dividing wall construction (with soft roof and exterior walls) depends somewhat on bay size, and the kind of operation (e.g. whether high ceilings are needed, how much floor area is useable, etc.). Based on total floor area, the earth covered multiple steel arch costs the same as the conventional or standard. The orthogonal reinforced concrete design costs, in the present application, one-third more than "standard," but has some quite high bays, and all of the floor space could be used for HE operations, whereas three-foot clearance from the wall is required in standard structures.

We intend to embody the concept of stringent effects limitations in new construction wherever feasible. Feasibility, we recognize, is higher where relatively moderate quantities of explosives are involved than where there are large quantities, which includes many military production operations. But we believe it is always worth considering the practicality of applying the concept each time new construction for HE operations is contemplated.

EVALUATION METHODS

Dennis Dunn

U. S. Army Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

Over the last 20 - 30 years the Services have developed sophisticated methods for evaluating the "on-target" effectiveness of weapons. Earlier today we heard Colonel Abrams stress the need for a more scientific basis for safety decisions. The existing military methods provide a starting framework for the evaluation of safety problems. The existing methods are Tri-Service in application and quantitative in nature. Many computer programs are available for applying them.

A typical evaluation procedure is outlined in Figure 1. Some relabeling will clarify the correspondence between the military and safety problems. "Weapon characteristics" might be called "explosion source characteristics"; the "on-target effectiveness" would read "risk probability - distance relation"; "target vulnerability" might become "materiel vulnerability"; and "logistics" would comprise "locating and/or resiting costs". The modified outline of Figure 1 would then show that risk probabilities are compared to costs. The results would serve to provide a scientific data base to decision makers.

Although there exists a large collection of military weapons characteristics and target vulnerability information in quantitative form, we can expect to encounter some fundamental differences between military and safety information requirements. Where differences arise, it will be necessary for the safety community to implement action to meet their particular information requirements. As an example of basic differences, some are listed below for fragmenting ammunition. At the explosion source the basic differences are as follows:

a. The number of exploding devices differs by one to several orders of magnitude.

b. Fragments from one exploding munition may be considered to act independently of those from another munition when assessing effectiveness. However, in the hazards problem the bursts are in such close proximity to one another that the fragmentation of one munition affects that of its neighbor; as a result the numbers, directions and velocities of fragments from a stack of munitions cannot be predicted from the existing fragmentation characteristics of one munition.*

c. In the hazards problem the environment about the exploding munitions may be a magazine, truck, boxcar, frangible structure, or other enclosure which may contribute significantly to, or even constitute most of, the hazardous fragments. In the effectiveness problem, the fragment contribution by the environment about the burst is usually negligible.

The straight line fragment trajectory involving medium as well as large fragments and resulting in appreciable values of damage probability is the principal trajectory for effectiveness problems. On the other hand, the long range curved trajectory involving large fragments and small damage probabilities is important to hazards problems.

At the target end, basic differences are not apparent. Vulnerability analysts are concerned with a wide range of environments and types of targets which include those of interest to the hazards problems, such as personnel, ammunition storage, buildings. Their analytical techniques are applicable to safety problems but their damage levels and criteria will usually be different. Nevertheless, it is felt that their data bank can be adapted to safety problems.

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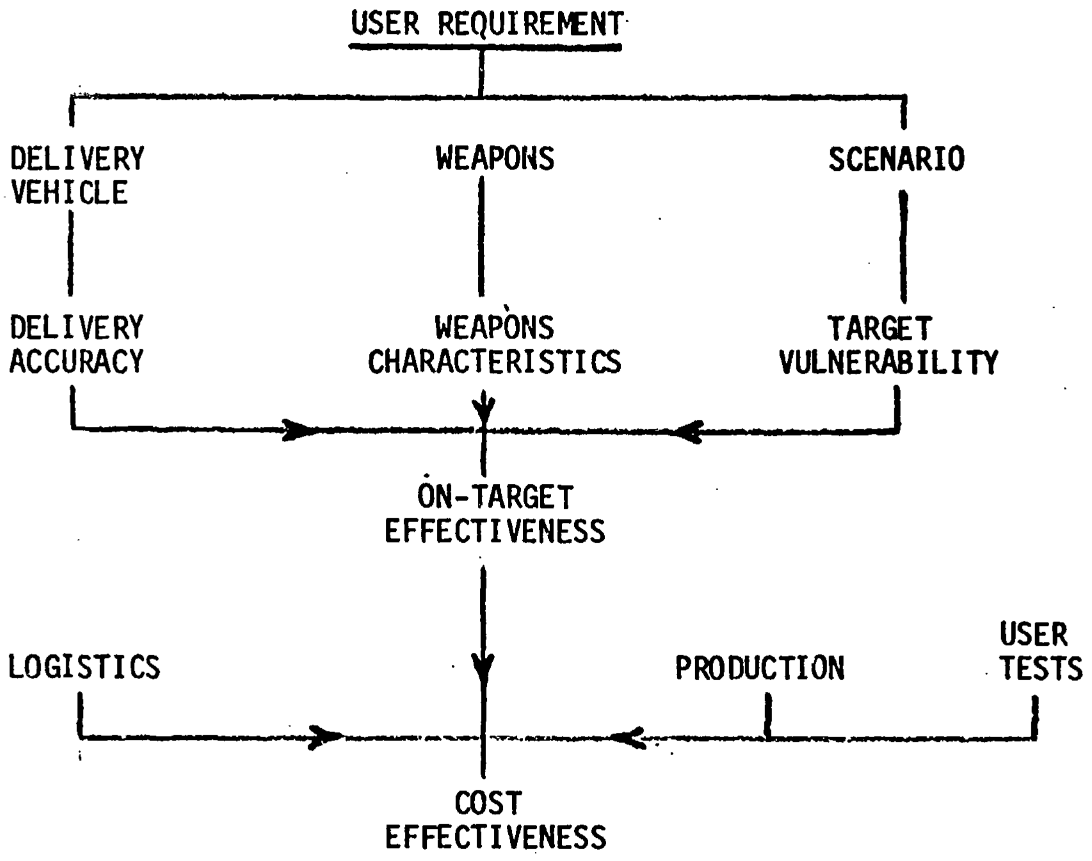
*The fragment mass, velocity and spatial distributions have been compiled for all air-to-ground U.S. fragmentation type munitions (bombs, rockets, missiles, shell, bomblets) in the Weapons Characteristics Report of the Joint Munitions Effectiveness Manual. Similar information is now being compiled for all ground-to-ground munitions (artillery shell, mortar shell, grenades, missiles). Given the basic fragmentation distributions for a particular munition, one can compute the expected fragment density, hit probability, etc., at any distance from the burst of one munition.

Figure 1. OUTLINE OF EVALUATION METHODOLOGY



WEAPON CHARACTERISTICS

- Frag.
- Blast
- Fire
- Penet.
- Cratering
- CB

TARGET VULNERABILITY (Frag sensitive)

- Personnel
- Trucks
- Stacked ammo
- POL storage
- Missile sites
- Aircraft
- Field & AA artillery

PERSONNEL PROTECTIVE EQUIPMENT

Moderator: Howard T. Scott
Director, Corporate Safety & Security
Atlantic Research Corporation
Alexandria, Virginia

PERSONNEL PROTECTIVE EQUIPMENT

SUMMARY

Four subjects were discussed at this session:

Mr. Edward R. Barron, Chief, Body Armor Branch, Clothing and Equipment Systems Division, U. S. Army Natick Laboratories, described personnel armor systems designed to protect personnel against battlefield hazards up to 30 caliber projectiles.

Mr. Gerald W. Marsischky, Safety Director, Naval Ammunition Depot, Crane, Indiana, discussed the effectiveness of various items of protective clothing when subjected to pyrotechnic fires.

Dr. M. F. Zimmer, Research Department, Naval Ordnance Station, Indian Head, Maryland, described studies of the effectiveness of safety glove materials against detonations of lead azide.

Mr. T. G. Grady, Safety Superintendent, Radford Army Ammunition Plant, discussed the use and effectiveness of conductive sole safety shoes.

A copy of each of these presentations follows:

The following points were made during discussions subsequent to these presentations:

1. Natick Laboratories will welcome requests for technical assistance in any area of personnel protective equipment or protective clothing.

2. Personnel armor is used in some disposal operations and may have application in others. It may be desirable to make personnel armor available to some fire-fighting personnel.

3. Improved effectiveness and reliability is needed in anti-static treatment of protective clothing.

4. Improvement is needed in conductive footwear assemblies. Conductive overshoes are being tested.

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PERSONNEL ARMOR SYSTEMS

by

Edward R. Barron and Abraham Lastnik
U. S. Army Natick Laboratories
Natick, Massachusetts

This paper is a discussion of the criteria, materials and application of materials to personnel armor systems, designed to protect aircrewman, vehicle crews and ground troops against battlefield hazards (fragments to 30 calibre armor piercing projectiles).

The best way to protect a man from the effects of explosives is not to have him in the vicinity. I have therefore apprised you of the ideal safety measure against an explosive hazard.

For those who would like to see and hear what's going on, and for those who insist on doing it themselves, we must then find ways to reduce the distance from the hazard.

The Army accomplished this by interposing a "protective shield" between the individual and the hazard. The shield consists of selected materials that have inherent properties for attenuating impact energy and impinging fragments or projectiles. As idealists, we seek for a universal protective material; as realists, the U. S. Army Natick Laboratories have developed a variety of materials that will provide protection against a spectrum of hazards.

The degree of protection of these materials is a function of the density. This relationship is relatively linear for each type of material. However, protection in itself is not adequate if it inhibits the function of the individual being protected. "A concrete pill box will provide protection, but you can't go walking in it."

The Army's Research and Development program in this area is directed toward providing maximum protection and maintaining full functionability. Emphasis on the research of lightweight armor materials (as compared to steel for equal protection) for personnel protection against the broad spectrum of fragments and small arms projectiles, has resulted in development of materials ranging in areal density weights from .04 oz. to 9.3 lbs. per square foot. The type of protection afforded and typical applications are shown as follows:

MATERIAL	AREAL DENSITY PER SQ FOOT	PROTECTION
Ballistic Nylon (Vests, Helmets)	18.6 oz. (plies)	Fragments
Titanium (Helmets)	17.5 oz.	Fragments

Needle-Punched Nylon Felt (Vests)	0.04-0.9 oz.	Fragments
Polycarbonates (Helmets, Visors)	8.4 oz.	Fragments
Titan/Nylon (Vests)	18.6 oz.	High Velocity Fragments
Ceramic/Fiberglas (Vests, Leg Armor)	6.5-9.3 lbs.	30 cal ball AP
Alum honeycomb/Steel (Combat Boots)	Variable	AP mines

Areal density is the weight per unit area. The Army has applied Ballistic nylon cloth (resin impregnated), Hadfield Steel, Polycarbonates, and Titanium in the form of rigid shapes to cover the head, design of which is relatively easy, as compared to covering the upper and lower torso and extremities. The head shape in itself doesn't change with dynamic movement. Head sizes and retention is a complex matter.

Protection to the eyes for pilots against low velocity fragments has been accomplished using a polycarbonate visor capable of defeating a 17 gram fragment simulator at 550 feet per second without shattering.

A useful protective combat boot was needed to reduce the severity of injury and to reduce the number of below the knee amputations resulting from contact with anti-personnel mines. The boot could not seriously reduce mobility, placing severe restrictions on the application of materials and design.

Studies were conducted to determine the shock wave characteristics of the M14 AP mine and the damage threshold characteristics of the human foot. Parameter studies indicated the gross impulse attenuating characteristics of balsa wood, fluids, foam plastics and metals in various configurations. The most effective was a 5-3/4 inch long steel wedge filled with an aluminum honeycomb (.006 5052 H-39 Alloy) with a crushing strength of 4200 psi. On top of the wedge is a .0156 inch aluminum plate. These units are incorporated into the rubber outsole used on the direct molded sole tropical combat boot. The unit is affixed to the heel area of the boot upper and molded into place when the outsole is vulcanized to the upper by direct molding equipment. Cadaver specimens protected by the boot were blast-loaded with the M14 Mine. Autopsies of the specimens indicated a 27 percent reduction in amputation. Conventional footwear without this feature results in zero percent reduction.

Covering the rest of the body represents a complex design problem. This is increased as the weight, thickness and rigidity of the armor materials increase.

The application of Ballastic nylon cloth to our current Body Armor Fragmentation Protective vest is relatively easy, other than consideration of the bulk, and today is a rather straightforward design and fabrication procedure.

The Titanium/Nylon vest is considered a semi-rigid vest because of the components.

The design of acceptable body armor using rigid materials becomes complex considering the many factors influencing acceptability. It must be confortable and lightweight, provide optimum torso coverage, not impede combat effectiveness, and be sized to fit the Army population.

Most previous work was done intuitively. It became apparent that data were necessary relating to changes in body shape, shrink-up and extension with body movement. The application of rigid materials to body armor was advanced through a study of the IIT Research Institute, Chicago, Illinois, for the U. S. Army Natick Laboratories, which defined these body dimensional changes.

A 2-inch square grid pattern was established on a human subject, front and rear. The subject moved through a prescribed range of motions typical of those which might be encountered in normal combat duties.

For each position, the lengths of the vertical and horizontal lines of the grid pattern were measured and recorded. The lines of the grid either extended or contracted with body movement. Using the new length dimensions, a distorted grid pattern was plotted.

By measuring the degree of extension of contraction of the grid pattern and comparing it to the grid pattern dimensions with the subject in a neutral position, it was possible to find the percent shrink-up or extension of the human body in various dynamic modes. Graphs wer then plotted, showing the percentage vertical displacement of the front torso, and similar data for the back torsos were compiled. Horizontal displacements were also derived in a similar way. These data have been applied to the design of aircrew and infantry armor using rigid armor materials, establishing plate sizes, configuration and overlap requirements for optimum mobility, maximum coverage and acceptable comfort.

Elements of these studies were utilized in the earlier flexible armored vests to permit the dimensional changes across the shoulder and back, that were difficult due to the bulk of the materials.

With the advent of ceramic/glass reinforced rigid composites capable of defeating high velocity fragments and small arms projectiles, application of these principles required a different approach from the Titanium/Nylon vest due to the fact that a single monolithic anatomically shaped plate is used, rather than overlapping platelets.

In the variable infantry armor vest, fragment protection is provided to areas of the body not covered by the plate and allows the individual a 5-way selective system of wear dependent upon the mission, tactics, and hazards. The vest weighs 5 pounds; with front plate, 12 pounds; and with front and back plate, 22 pounds.

In both these end item examples, anthropometrics in combination with measurements of the torso in the static and dynamic mode determined the shape of the armor plates, so that maximum coverage is obtained without interfering with arm, and body mobility.

Now that the tools are available, how do we proceed to select materials, determine the area of the individual requiring protection, and provide him with the maximum functionability?

1. Define the hazard, quantitatively and qualitatively. What are the sizes of the fragments, the material, the shape, velocity and distribution?

2. Define the work performance envelop, i.e., length of time, maximum weight he can carry, the movements required to perform the duties assigned, where his head, arms, and legs are in relationship to the hazard.

3. Select those areas of the man exposed, determine the most vulnerable and the most fatal areas.

4. With this information, the man's safety is in your hands. You now know materials and their capabilities, the weights, nature of hazard, functionability, exposure time and his physical limits. You must decide what areas you will protect, the degree of protection, and the limits of mobility and comfort.

Maximum protection can cost up to a few thousand dollars per man. This is a great deal of money, but considered in the light widow and disability pensions, hospital costs, loss of time, loss of experienced help, career potential, recruitment and training of other individuals, adverse publicity, high insurance, management will come to the conclusion, as the Army has, that regardless of cost, protective armor is inexpensive.

PERSONNEL PROTECTIVE CLOTHING AND EQUIPMENT TESTS BEING CONDUCTED AT NAD, CRANE, INDIANA

by

G. W. Marsischky
Naval Ammunition Depot
Crane, Indiana

I. The NAD, Crane Safety Department has, as have many others, become increasingly aware of the inadequacy of many existing standards for personnel protective clothing and equipment to meet the demands of explosive and pyrotechnic production job exposures. To provide a defensible position for purchasing specific safety materials, NAD, Crane committed itself to performing test work to establish the relative capabilities of many current products above and beyond national standards requirements. Test exposures have been chosen which approximate the maximum gross exposures ordnance production personnel may face.

II. At this time, the tests are far from being completed, but we have gathered sufficient data to make some "guesstimates" as to what paths our tests are apt to take. All of the tentative test results included in the following paragraphs must be considered "tentative and subject to change" at this time. Upon completion of the test series, NAD, Crane will publish a report on the test results.

III. The specific tests have been broken down into the commonly used areas of personnel protective equipment. The following paragraphs list each type of test, type of equipment to be tested, and where applicable, gives some indication of tentative findings.

A. Face and Eye Protection against impact and flash fire hazards:

1. Equipment involved includes:

   a. Polycarbonate visitor's type goggles (4 and 6 mil)
   b. Tempered safety glass spectacles
   c. Tempered safety glass clip-on glasses
   d. Acrylic visitor's goggles (4 and 6 mil)
   e. Polycarbonate face shields (6 mil)
   f. Acrylic face shields (plain) (4 and 6 mil)
   g. Acrylic face shields (aluminized) (4 mil)
   h. Welders helmets with various tempered glass and polycarbonate cover shields
   i. Wire mesh face shields
   j. To be included is aluminized 6 mil polycarbonate

2. Tests conducted include:

a. Standard drop ball test utilizing a steel ball in a guided drop. (See Figure #1) for basic impact capability test.

b. Standard needle penetration test utilizing a singer sewing machine needle in a weighted holder (See Figure #1) for sharp object impact capability test.

c. Measured velocity (calculated impact) at breaking or failure point apparatus (See Figure #2) for maximum impact capability.

d. Random shrapnel exposure test in an attempt to correlate findings of tests III.2(a), (b) and (c) with expected exposures.

e. Flame impingement apparatus (See Figure #3) to determine capability to withstand high temperature, direct flame impingement.

f. To be conducted: Exposure to flame of specially loaded sodium nitrate - magnesium flares having a flame temperature of 4500°F. to determine maximum capabilities for flame and heat resistance from flash fires.

3. Preliminary tests indicate that polycarbonate goggles and face shields of high quality polycarbonate are superior to all others when subjected to each of the above tests. Except that during the flame impingement tests involving face shields, the aluminized acrylic performed approximately as well as the non-aluminized polycarbonate. Future tests will include aluminized polycarbonate. There was also an indication that specific quality specifications will have to be prepared for the polycarbonates since a wide range of performance by various polycarbonates was noted.

B. Body Flame and Heat Protection from Flash Fires

1. Materials tested to date include:

a. Single layer Nomex (Aluminized)
b. 8½ ounce cotton sateen coveralls
Roxel 100 treated (2 suppliers)
c. 8½ ounce cotton sateen coveralls from GSA stock
d. Flame-retardant treated terry cloth
e. Aluminized Asbestos (3 different weights)
f. Aluminized rayon - fiberglass - asbestos
g. Aluminized rayon - fiberglass with neoprene backing
h. Aluminized asbestos with rubber and felt backing
i. Ceramic paper
j. Ceramic batting
k. Ceramic cloth with stainless steel wire with organic carrier
l. Ceramic cloth with nickel-chrome wire without organic carrier
m. Ceramic cloth with nickel-chrome wire without organic carrier and with aluminized 10 ounce Nomex backing

2. Tests conducted include:

a. Calibrated flame impingement (See Figure #3)

b. Exposure to pyrotechnic flame tests will be conducted on best of the above materials.

c. After evaluation of tests III.A2(e), A2(f), B2(a), and B2(b), full size garments will be designed and tested under production type conditions.

3. Preliminary test data indicate that most of the synthetic based filaments and the fiberglass filaments (including Beta cloth) do not have sufficient physical integrity at high flame temperatures to provide protection for pyrotechnic fires. The possibility of combining one of the excellent high temperature flame resistant materials such as ceramic cloth and one or more of the insulating materials such as terry cloth or Nomex looks extremely promising at this stage. These results are not surprising and could, in fact, be predicted by analysis of available data on material failure.

C. Permanently Flame-retardant Treated Coverall Tests

1. Material used in the tests included:

a. GSA issue 8½ ounce flame-retardant treated coveralls
b. Roxel 100 flame-retardant treated coveralls from two different manufacturers.

2. Tests included:

a. Flame Resistance Test of Fed. CCC-T-1916; method 5903-T.

b. Samples of each garment were washed in the Depot Laundry and in an outside laundry. The samples included coveralls worn on the job and coveralls that were never worn. The samples (containing one garment of each of the three types) were not mixed, but each sample of three was kept separate from all dissimilar samples. Samples were taken at cycles of six washings to a total of 60 washings.

c. Infra-red spectrography was used to help identify contaminants.

3. Test results at this time show failure for all samples beyond six to twelve washings due to suspected contamination of the garments during washing with flammable soap, oil and tar particle deposits. An ether wash has been used to successfully return the previously failed samples to a passing flame-resistant condition. As a result of these tests, NAD, Crane is continuing with its secondary treating, after washing, of all flame-retardant coveralls with DuPont X-12. Garments that are retreated in this manner do pass the flame-resistance tests. Further tests to find a non-depositing soap are planned.

D. Conductive Safety Shoe Tests

1. Equipment tested includes samples of various manufacturer's men's shoes, women's shoes and the Federal Stock Mil-Spec conductive safety shoe.

2. Tests include:

a. QA tests of Mil-Spec 3794B for conductivity.
b. High energy impact test - dropping a 75 pound projectile three feet onto the toe of the shoe.

3. Test results to date indicate that there is a wide range of design of the conductivity path in non-federal stock shoes; that some of the existing designs have a basic conductivity path that is easily interrputed in service; and that the quality of the conductive shoes varies greatly when purchased on the open market. Federal stock shoes have been consistently of good quality primarily due to the design criteria which provides two conductive paths which are independent of one another. In addition, the high impact level tests have indicated that the women's safety toe shoe does not offer as much protection as the man's safety toe shoe. Variances were also found in Rockwell hardness and metal thickness (some were below standard requirements) of the steel box toe. New standards are needed for the conductive shoe and for the safety toe shoe to meet the hazards encountered on the job.

IV. In summary, I would like to say that we have not found the answers to these problems; but as the preliminary results reported indicate, we have only confirmed our basic hypothesis that present equipment is not satisfactory. This program of tests was started because of a generally held feeling amongst Safety, Production and Research personnel at NAD, Crane, that existing materials, standards and quality tests were not adequate for our hazardous exposures. The data developed to date have underlined this feeling of inadequacy. We hope to prove our point and in some cases develop solutions as well when we complete our test cycle. It is hoped that future development of adequate materials, standards and quality controls will be the ultimate result of our program.

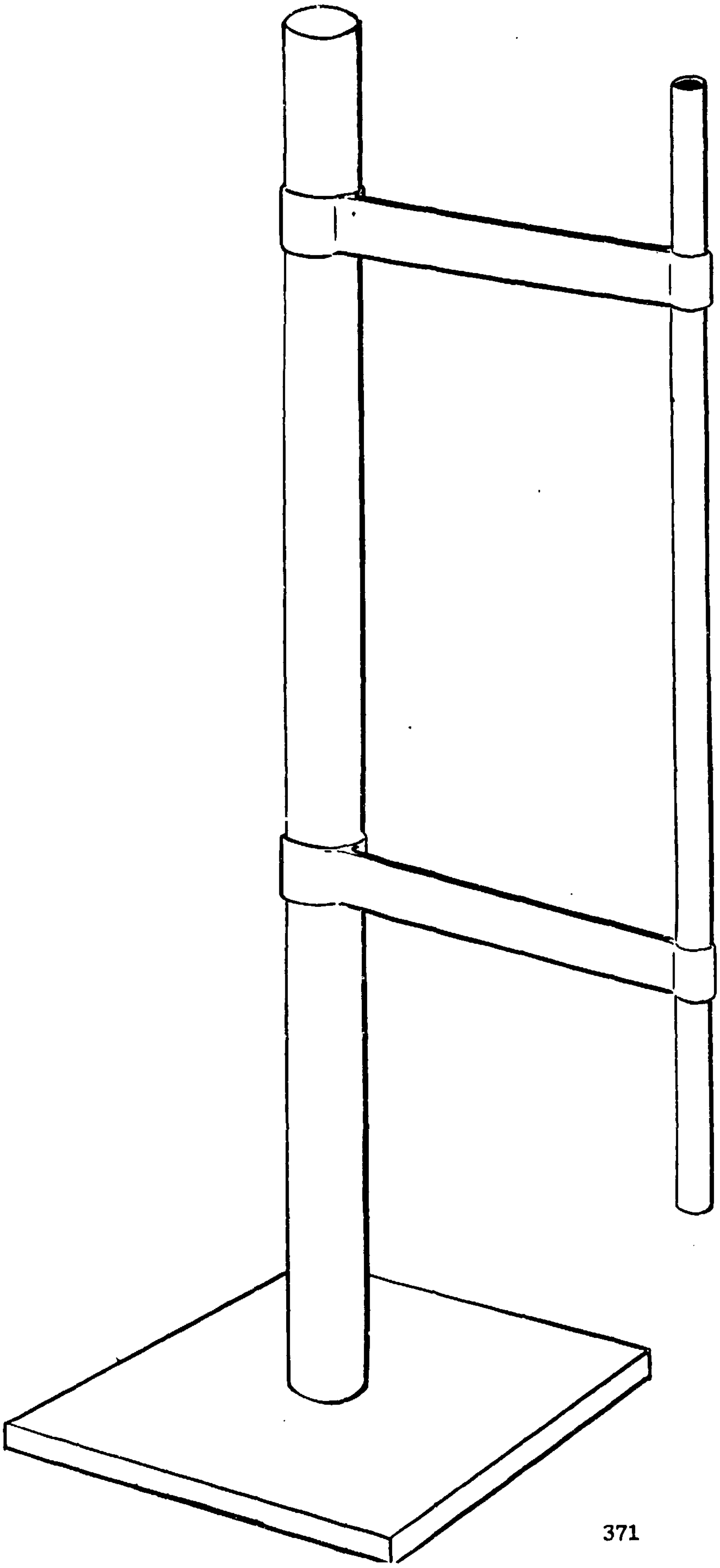

Figure 1

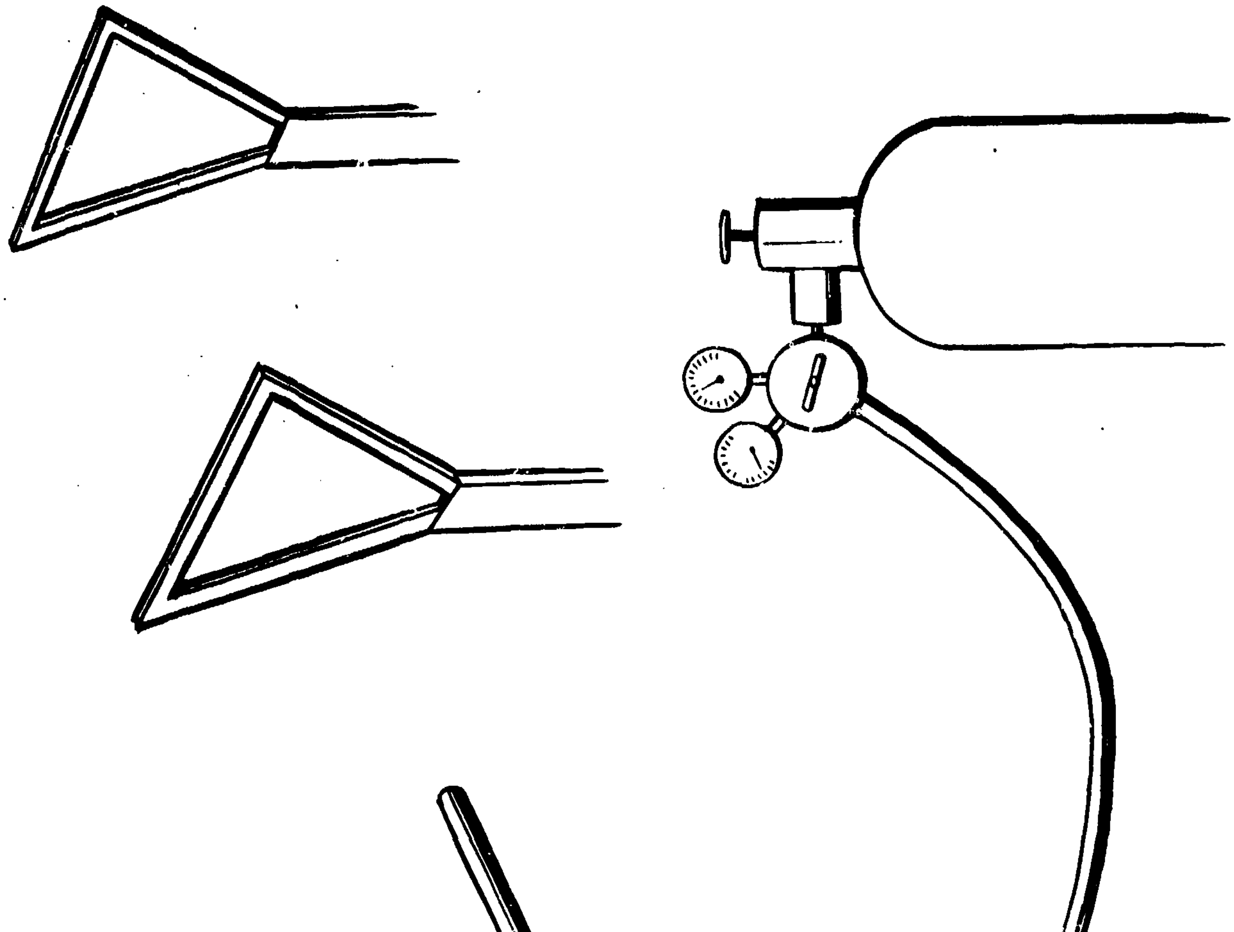

Figure 2

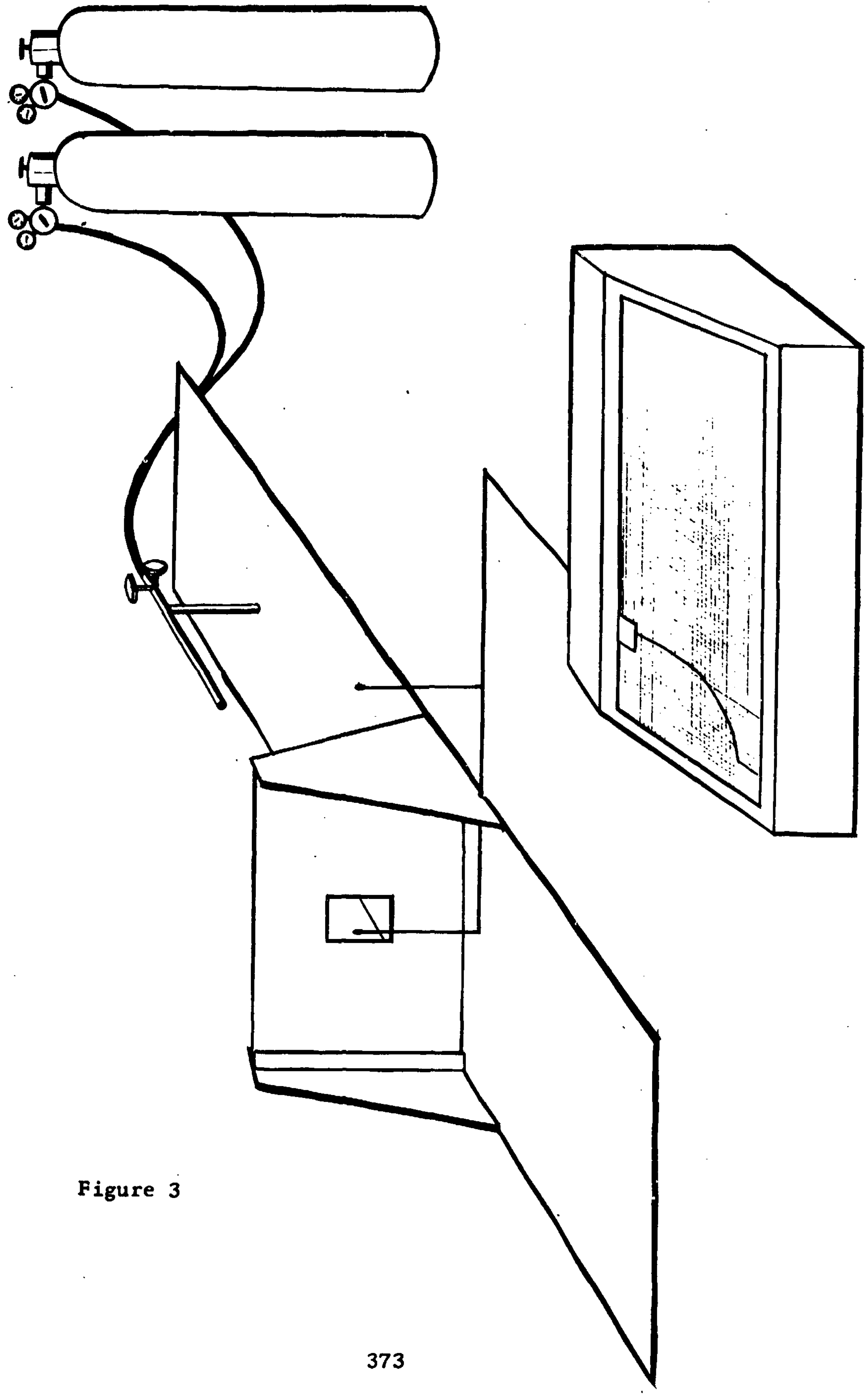

Figure 3

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DYNAMIC PRESSURE MEASUREMENTS ON SMALL AMOUNTS OF DETONATING LEAD AZIDE

by

M. F. Zimmer and L. Lipton
Naval Ordnance Station
Indian Head, Maryland

The study has been undertaken to establish the hazards of small lead azide detonations and to characterize the resulting pressure waves. At the same time some protective glove material has been tested. The material tested was a Nylon Polyfoam fabric (Ballistic Nylon Cloth) with polyurethane backing, made by Burgoin Glass Co., China Road, Waterville, Maine. The effects of detonation pressure waves of various lead azide charges were observed:

The work was performed in the following phases:

1. Measurements of peak shock pressure, both in air and through the fabric, as a function of charge quantity (up to 1 g) and distance (ranging to 30 cm).

2. Observation of direct-contact explosion damage for two different charge weights.

3. Observation of damage due to glass fragments during three different shots of lead azide in contact with glass.

The lead azide in all cases was initiated by a 3 KV spark, with a gap of approximately 0.5 - 1.5 mm. The fabric was oriented with the woven side toward the explosion in all cases. Where a "charge distance" is mentioned, it refers to either the distance from the charge surface to the fabric surface or to the transducer surface, as indicated in the text.

EXPERIMENTAL

Test Set-up for Pressure Measurements:

A Kistler type 603A quartz pressure transducer (probe) was mounted in a plexiglas holder. Below this rested an aluminum plate, about 6.5 cm X 6.5 cm X 0.8 cm, in which was drilled a shallow conical well with a small perpendicular hole at its center, penetrating the plate. (With charge quantities of 0.25 grams or larger the "well", a convenience for holding small charges, was not used.) A #18 solid copper wire was brought up through the hole, with insulation arranged to produce a spark at the center (bottom) of the well. The lead azide charge was placed in this well (Fig. 1).

The fabric under test was taped to the transducer mount and thereby was suspended directly above the lead azide charge.

A Kistler charge amplifier was connected to the output of the probe. An oscilloscope, in turn, indicated the output of the amplifier (Fig. 2 shows the arrangement for the pressure recording). The oscilloscope sweep was triggered by the spark itself. The actual data record consists of photographs of the oscilloscope trace; occasionally photographs were taken of the fabric itself after a test. A typical oscilloscope trace is shown in Fig. 3.

Charge: 30.9 mg
Distance: 1 cm (through fabric)
Horizontal scale: 5 μsec/division
Vertical scale: 2000 psi/division

The rise of the pulse begins at about t = 8.5 μsec. Decay is complete at about t = 19.5 μsec. The small "bump" at t = 6 μsec is a spurious electrical pulse.

To ascertain whether the "spark hole" significantly affected the data by allowing some reaction energy to leak downward, two shots were fired identical in charge and distance, but using different spark arrangements. One used the standard configuration; the other had no hole but had the "hot" spark wire taped directly to the top surface of the aluminum plate. The measured pressure difference was 3.3%, with the "hole" arrangement giving the higher reading. Since this is about the same as the readout error for the charges and distances used, and certainly less than the normal scatter observed in most of the data, it was inferred that the spark hole had a negligible effect on the data. The shock wave due to the spark alone was determined to be entirely negligible (<1% of the shock produced by 12.1 mg of lead azide, the smallest charge used.)

RESULTS AND DISCUSSION

1. Pressure Measurements at Constant Distances

Fifteen shots were fired through fabric at a charge-to-fabric distance of 1 cm, the charges ranging from 12.1-45.4 mg (Table I).

TABLE I

PRESSURE OF LEAD AZIDE DETONATION
AS A FUNCTION OF CHARGE WEIGHT
DISTANCE = 1 CM

CHARGE (MG)	TRACE HT. (CM)	PRESSURE (PSI)
12.1	0.4	800
12.7	0.25	500
15.3	0.60	1200
16.1	0.25	500
20.6	0.75	1500
24.7	0.55	1100
24.8	0.50	1000
25.4	1.00	2000
26.6	0.95	1900

30.9	1.25	2500
31.1	1.45	2900
33.0	1.40	2800
33.3	2.50	5000
39.9	3.40	6800
45.4	2.20	4400

Considerable scatter in the data was obtained and probably resulted at least in part, from the fact that the charge size was a significant fraction of the total measurement distance. Fig. 4 shows an average curve for all data points. A day to day shift was also observed, indicating a systematic variation of procedure of which we were unaware (Fig. 5). The day-to-day variation disappeared in later measurements at greater distances than 1 cm. The measured pressures ranged from 500-800 psi for approximately 12 mg charge, to approximately 5000-7000 psi for 33-45 mg charge. Approximate curve shape is non-linear, with increasing slope; it must be reemphasized however, that the large scatter makes an accurate curve impossible. Estimated readout error is approximately ± 100 psi.

At the distance of 1 cm the fabric side facing the explosion was scorched at all charge levels, the scorched area being usually 1-2 cm across; however, there was little or no damage to the foam side. The only effects visible on the foam were impressions of the transducer face (a circular area about 0.6 cm across) after the larger shots (≳ 25-30 mg) (Fig. 6).

10 cm

Ten shots were fired at the distance of 10 cm. The gage was covered with the fabric to be tested and the charges ranged from 39.3 to 220.9 mg. (Table II).

TABLE II

PRESSURE OF LEAD AZIDE DETONATION
AS A FUNCTION OF CHARGE WEIGHT
DISTANCE = 10 CM

CHARGE	TRACE HT. (CM)	PRESSURE (PSI)
39.3	0.35	3.5
55.1	0.95	9.5
70.7	1.15	11.8
86.1	1.20	12.0
114.5	1.65	16.5
117.7	1.80	18.0
133.3	1.95	19.5
156.1	2.00	20.0
190.2	2.50	25.0
220.9	3.20	32.0

At 10 cm the charge approximated a "point source"; consequently, the scatter is considerably less, and a linear plot results. (Fig. 7) No day-to-day fluctuations are observed. Pressures measured ranged from 3.5 to 32.0 psi for 39.3 to 220.9 mg respectively. Estimated readout error is ± 0.5 psi. Pressure may be taken according to the following relation:

$$P \text{ (psi)} = 0.145 \text{ M (mg)}$$

$$M = \text{charge mass}$$

$$\text{or } P \text{ (Atm)} \sim \frac{M}{10} \text{(mg)}$$

There was no damage to the fabric at this distance. Four shots were fired at the distance of 15 cm. The charges ranged from 42.6 to 157.8 mg. (Table III)

TABLE III

PRESSURE OF LEAD AZIDE DETONATION
AS A FUNCTION OF CHARGE WEIGHT
DISTANCE = 15 CM

CHARGE (MG)	TRACE HT. (CM)	PRESSURE (PSI)
42.6	0.60	3.0
71.1	0.90	4.5
99.3	0.55	5.5
157.8	1.70	8.5

All four points are fairly close to a straight line plot; the fairly small scatter is due probably to the larger distance-to-charge size ratio, than at 10 cm. (Fig. 8) Maximum pressure was 8.5 psi, at 157.8 mg charge. Estimated readout error is ± 0.25 psi.

The plot is linear, with slope: $\frac{\Delta P}{\Delta M} = \frac{5.5}{115.2} \sim .048 \frac{\text{psi}}{\text{mg}}$

or approximately: $\frac{\Delta P}{\Delta M} = 1 \text{ atm}/300 \text{ mg}$

The plot apparently does not intersect the origin, perhaps due to a constant error in the transducer in this low-pressure region. The complete indicated equation, including this constant error, would be:

$$P \text{ (psi)} = .048 \text{ M (mg)} + 1$$

2. Pressure Measurements at Constant Azide Charges

For protection studies of personnel working with limited amounts of lead azide (up to 1 g) the following test series was conducted. The quantities of lead azide were 0.25 and 1 g. The distances were changed from 10, 12, 15, 20, 25 to 30 cm. Nearly all charge-distance combinations were fired first without, and then with fabric to obtain actual attenuation data for the cloth. Table IV lists all results of this test series.

TABLE IV

SUMMARY OF RESULTS FROM CONSTANT AZIDE CHARGES

CHARGE (g)	DISTANCE (CM)	PRESSURE (PSIG)				ATTEN
		WITH/FABRIC		WITHOUT FABRIC		(WO/W)
0.25	10	94.4		277.7		2.94
	10	50.0		144.4		2.89
	15	25.0		111.1		4.44
	20	14.4		47.2		3.28
	30	10.0		20.0		2.00
0.50	30	10.0		31.1		3.11
1.00	10	277.7	264.8	-----		----
		297.2		-----		----
		219.4		-----		----
1.00	12	-----		444.4	444.4	----
		-----		444.4		----
	15	111.1	111.1	194.4	253.1	2.12
		111.1		233.3		
				277.7		
	20	48.8	47.7	119.4	127.8	2.68
		46.6		127.8		
		47.7		136.1		
	25	-----		48.8	47.5	----
		-----		47.2		----
		-----		46.6		----
	30	22.7	25.9	28.6	27.6	1.07
		34.4		26.6		
		20.5		27.5		

The measured attenuation factor (pressure without fabric divided by pressure with fabric) averaged 2.73 (probable error = 0.212) for all shots. Average attenuation for 0.25 g shots was 3.89; for 1.0 g shots, 1.96. The difference between the two series is probably not as great as the average would indicate, because there is no large number of test data available for "statistical" evaluation.

3. Lead Azide in Direct Contact With Fabric

Two different charge weights were initiated directly on the fabric surface. Two wires, from opposite directions, were taped to the fabric and brought to within about 1 mm of each other. Lead azide was placed directly upon the gap, initiated, and the results observed. No transducers were used. Control shots with spark only showed virtually no effect on the fabric.

21.4 mg Lead Azide - Fabric intact; woven surface scorched in area approximately 1 cm across; permanent "bump" toward explosion approximately 2-3 mm high; woven pattern scorched on foam side and clearly visible.

102.9 mg Lead Azide - Woven side intact, but foam partially destroyed under scorched area; scorched area on woven side approximately 1.8 cm across; bump 4-5 mm high; destroyed foam area approximately 1 cm across. (Fig. 9)

4. Fragmentation Tests

In these tests, the ability of the test fabric to protect against glass fragments was observed. Three shots were fired, one using a small (approximately 7 cm X 1 cm) Pyrex test-tube, the other two using microscope slides. (86 mm X 26 mm X 1 mm) In all cases, glass separated the charge from the fabric.

The test tube contained 41.7 mg of lead azide. Two fabric pieces were employed. One fabric was in direct contact with the test tube, the other fabric was 5 cm away.

- Direct contact fabric scorched, some woven side damage from glass (some fraying); no penetration. (Fig. 10)

- 5 cm; fabric showed occasionally frayed areas (< 1 mm across) from glass fragments; damage very slight, no penetration.

The microscope slide with a charge of 105.6 mg of lead azide was placed at a distance of 5 cm.

- Some fraying damage over area approximately 1.5 - 2.0 cm across and extremely small particles embedded in fabric were observed; no penetration, total damage fairly light. (Fig. 11)

The second microscope slide; with 153.4 mg of lead azide was in direct contact with the fabric.

- Slight scorching of woven side; slight fraying; very few embedded particles; foam side shows indentation effects (due to shock pressure); no penetration.

5. Test on Analytical Balance

In order to find the amount of lead azide which can safely be weighed in an analytical balance without shields, a test series on two balances (out of use) was performed.

Fifty mg of lead azide were initiated (the same way as previously mentioned) on one pan of the balance. The metal pan was dented slightly, no damage to the windows of the balance.

Approximately 650 mg were detonated in a second experiment. The balance was seriously damaged, most windows were broken and fragments thrown up to five feet.

Figures 12 and 13 show one of the balances after testing.

In a second test series the loads of lead azide were gradually increased until the window glasses broke under the pressure of the detonation. Three shots with 100, 200 and 300 mg lead azide in consecutive order were fired. The windows remained intact. At the level of 400 mg azide the windows were shattered.

CONCLUSION

From the data obtained in this work on the material in question the following conclusions can be drawn.

1. The material is effective in stopping glass fragments at all distances for charges up to at least 150 mg.

2. Transmitted shock pressures are probably acceptable for charges up to at least several hundred mg at distances of a few centimeters.

The material does not appear to afford sufficient protection at distances of 1 cm for charges greater than about 30 mg. For 1 gram charges the minimum distance would probably be on the order of 10 cm (the 3000 psi gauge was overloaded at closer ranges.)

3. Although the attenuation of the peak shock pressures was only about 2.7 times, the material probably affords more protection than this would indicate, due to the fact that the small reacting particles of azide are stopped by the fabric.

4. The material does not provide adequate protection in the case of direct contact explosives, except perhaps for charges of a few milligrams.

5. Up to 300 mg of lead azide have been detonated in a general type analytical balance without doing damage outside the balance.

ACKNOWLEDGMENT

The authors thank W. C. Eller for his support during this study and R. O. Petri for making the azide. The work was sponsored by Naval Air Systems Command AIR-53222A.

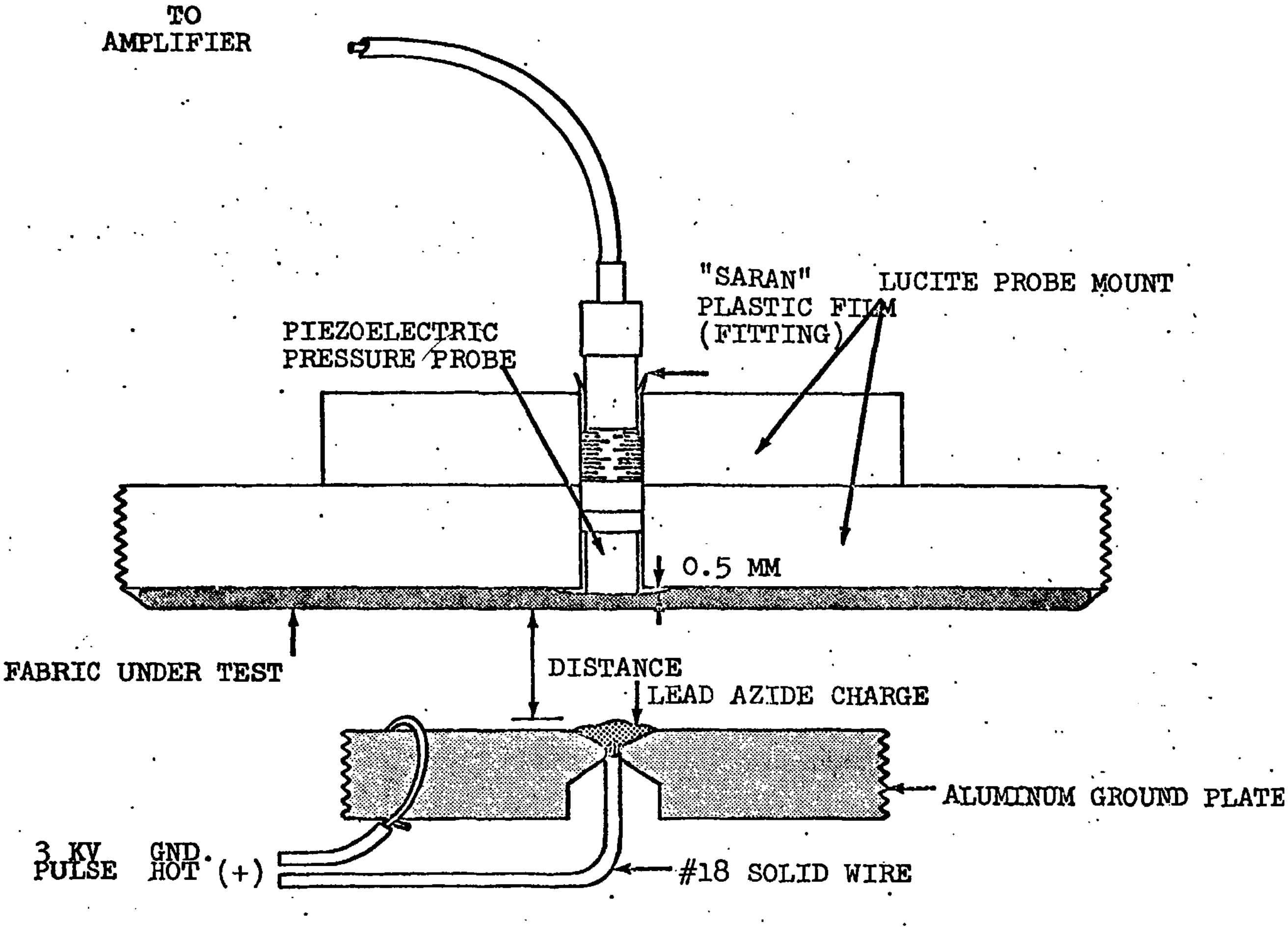


FIGURE 1. TEST DEVICE DETAIL - CROSS SECTION. (PRESSURE MEASUREMENTS)

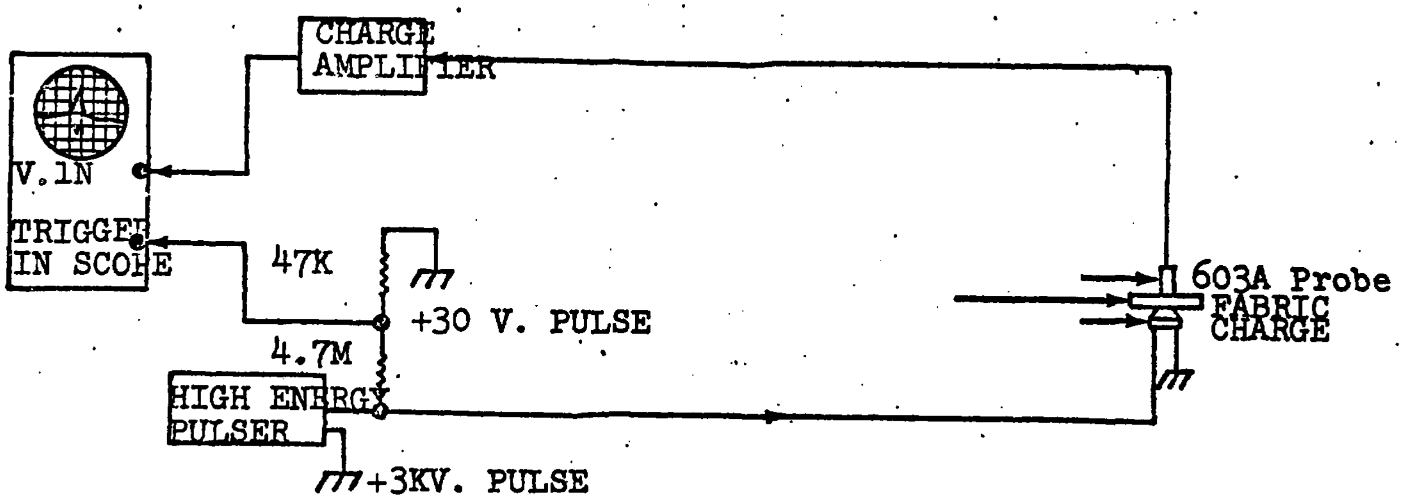


FIGURE 2. SYSTEM BLOCK DIAGRAM (PRESSURE MEASUREMENTS)

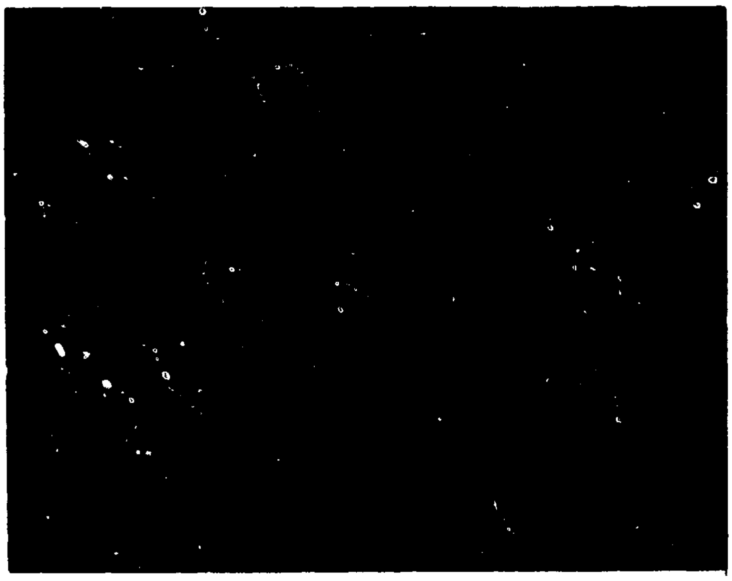


FIGURE 3. TYPICAL OSCILLOSCOPE TRACES (PRESSURE MEASUREMENTS)

A) With fabric
B) Without fabric

FIGURE 4. LEAD AZIDE DETONATION PRESSURES AS A FUNCTION OF CHARGE WEIGHT. CHARGE-PROBE DISTANCE: 1CM AVERAGE CURVE FOR ALL 1CM SHOTS.

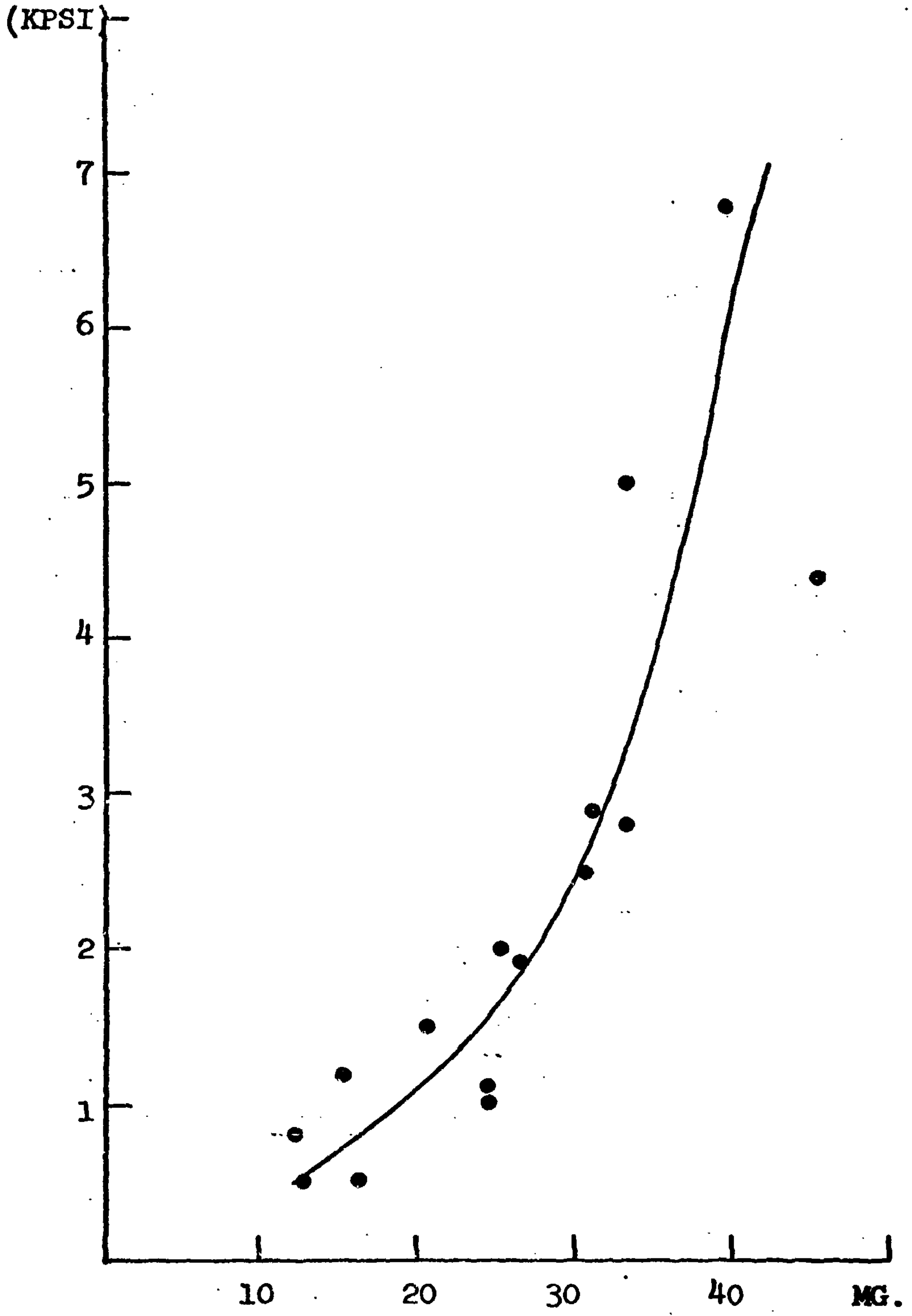
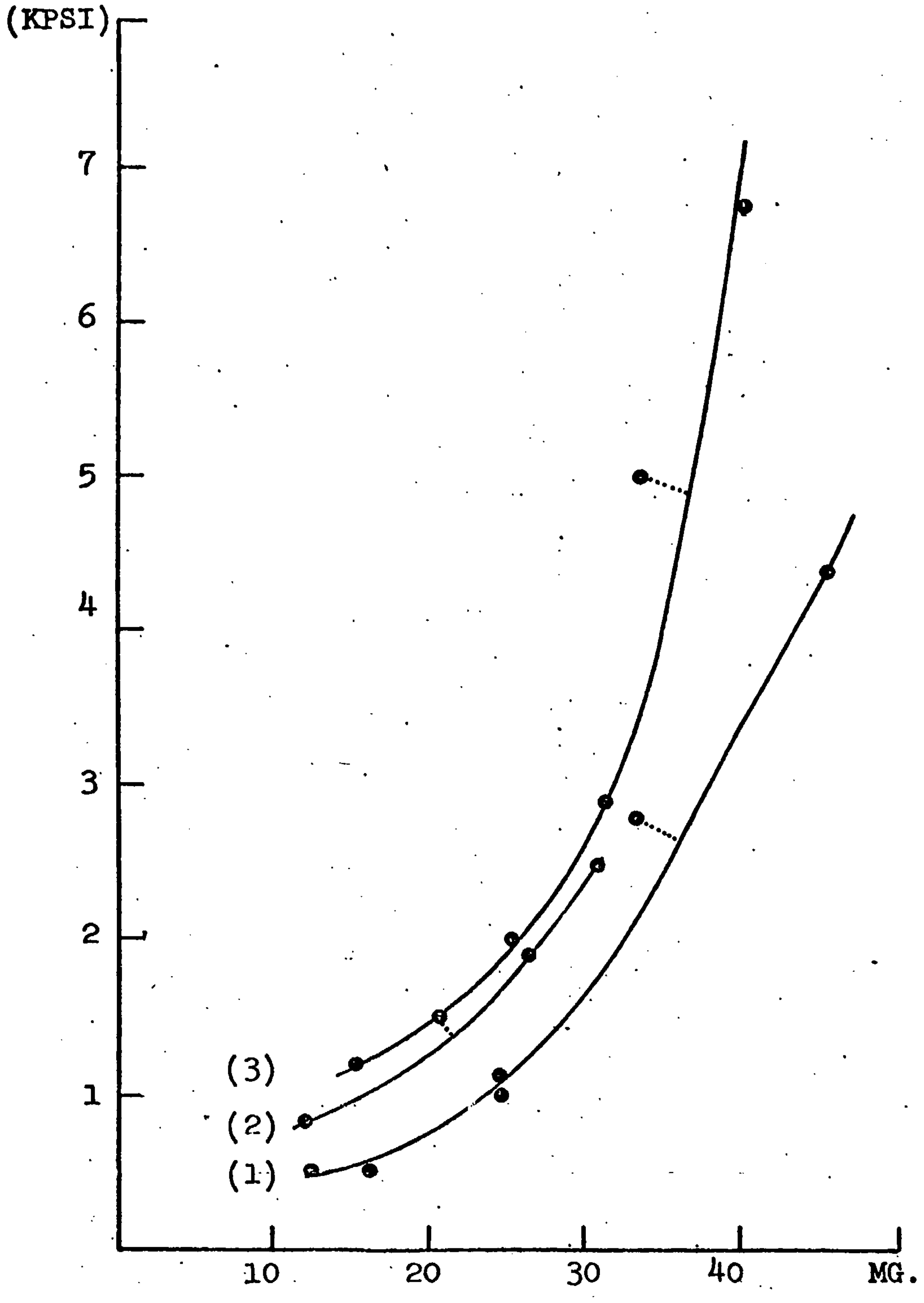


FIGURE 5. DAY BY DAY VARIATION ON THE TEST RESULTS SHOWN IN FIGURE 6. NUMBERS DENOTE DAY OF TEST.



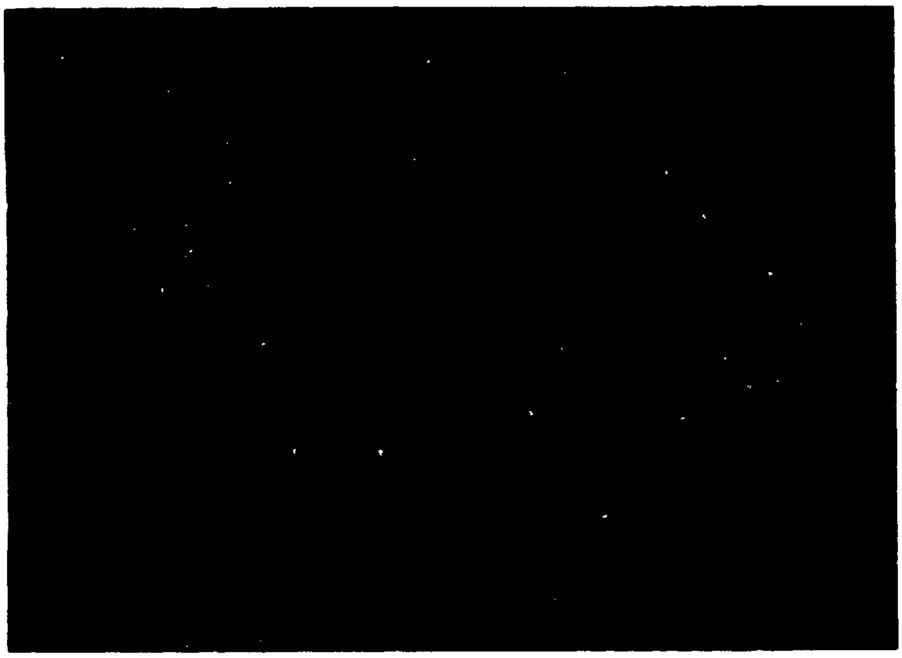


FIGURE 6. FABRIC AFTER TEST: 37.3 mg LEAD AZIDE AT 1 CM

FIGURE 7. LEAD AZIDE DETONATION PRESSURES AS A FUNCTION OF CHARGE WEIGHT. CHARGE-PROBE DISTANCE: 10 CM

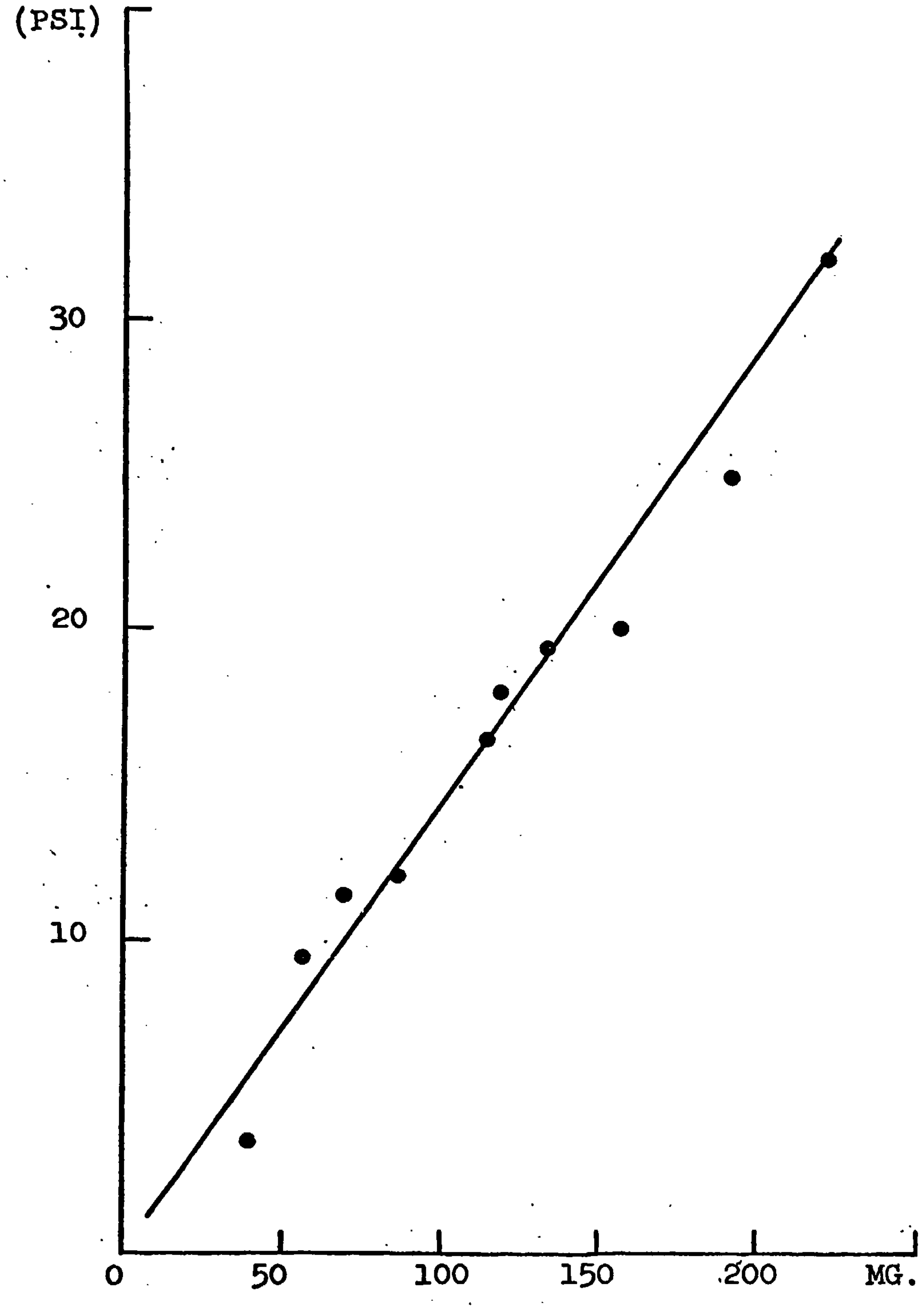


FIGURE 8. LEAD AZIDE DETONATION PRESSURES AS A FUNCTION OF CHARGE WEIGHT. CHARGE-PROBE DISTANCE: 15 CM.

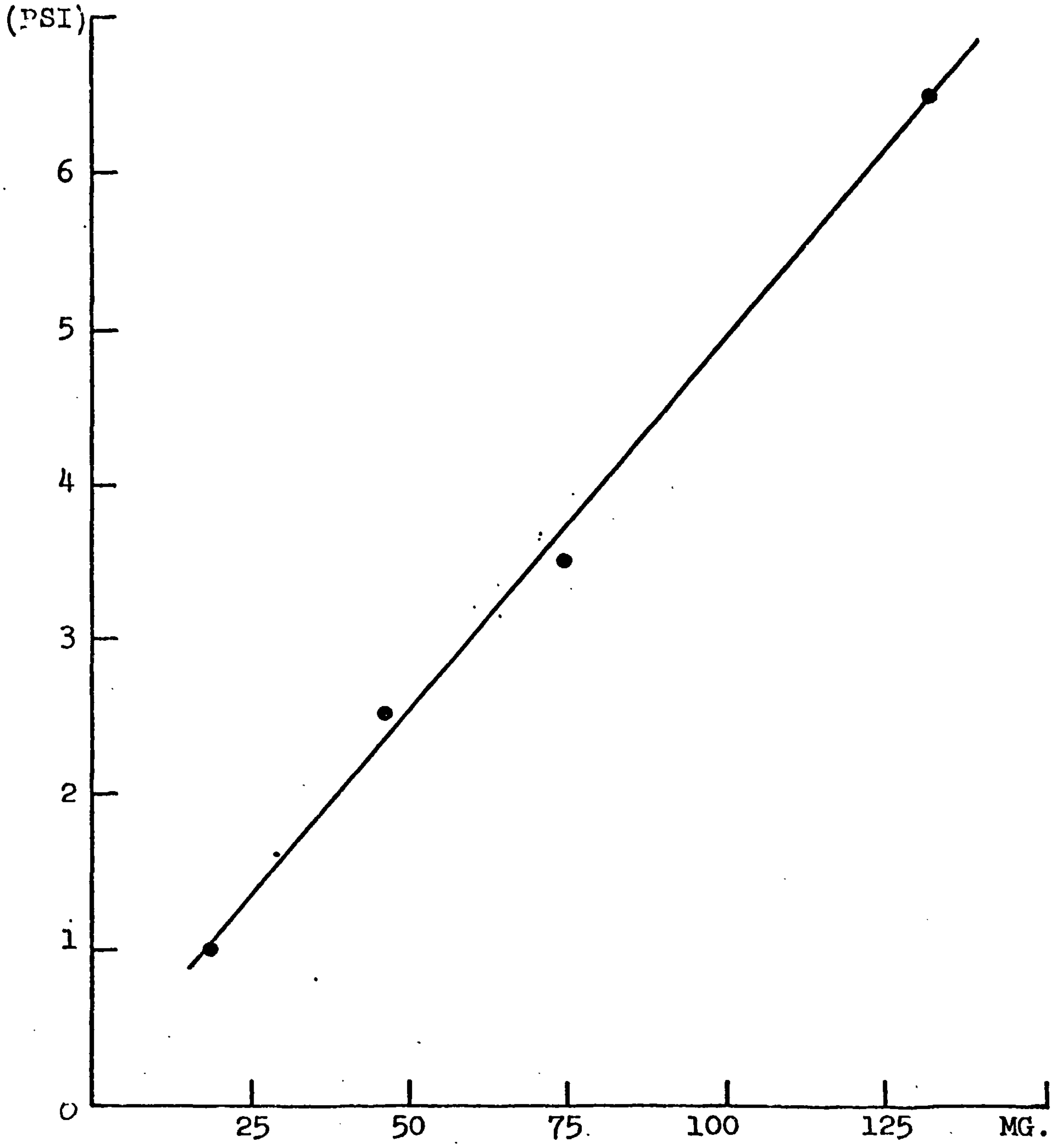


FIGURE 9. FABRIC AFTER TEST: 102.9 MG LEAD AZIDE IN DIRECT CONTACT

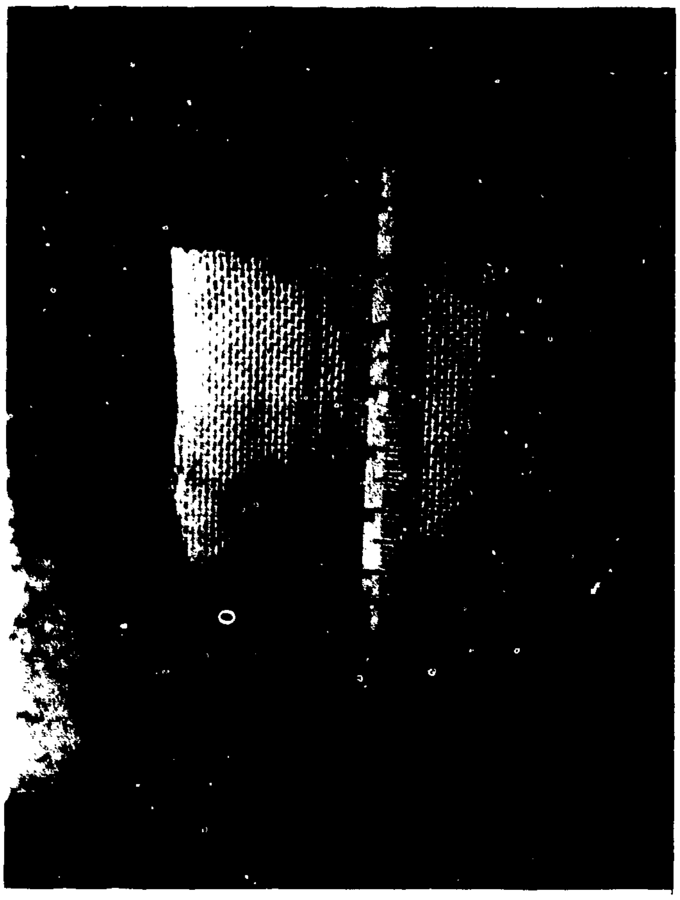


FIGURE 10. FRAGMENTATION TEST: RESULT SMALL TEST TUBE WITH 41.7 MG LEAD AZIDE DIRECT CONTACT

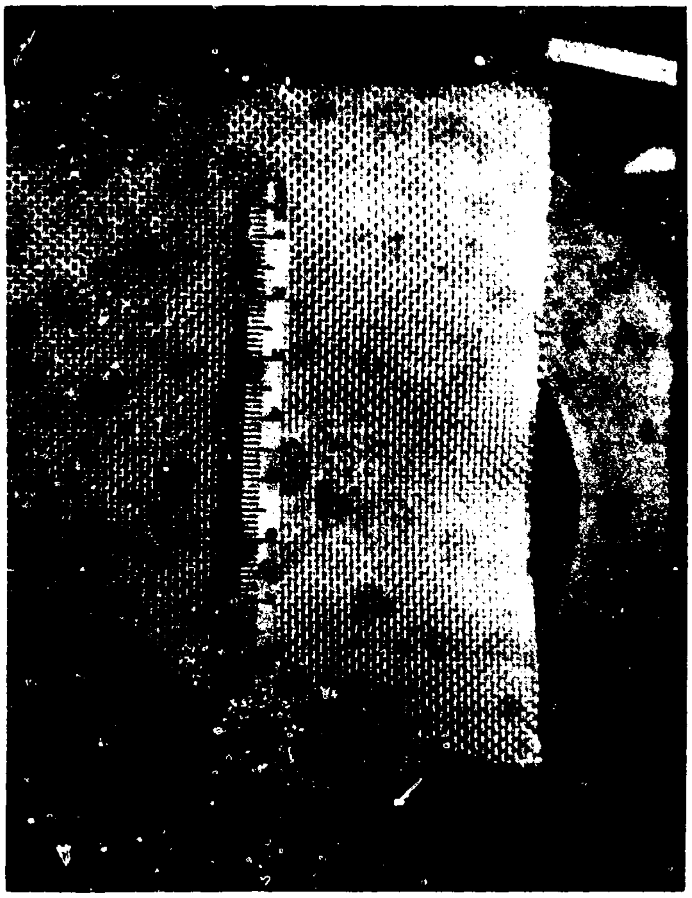


FIGURE 11. FRAGMENTATION TEST: RESULT GLASS SLIDE WITH 105.6 MG LEAD AZIDE
DISTANCE: 5 CM

FIGURE 12. BALANCE AFTER TESTING WITH 638 MG LEAD AZIDE

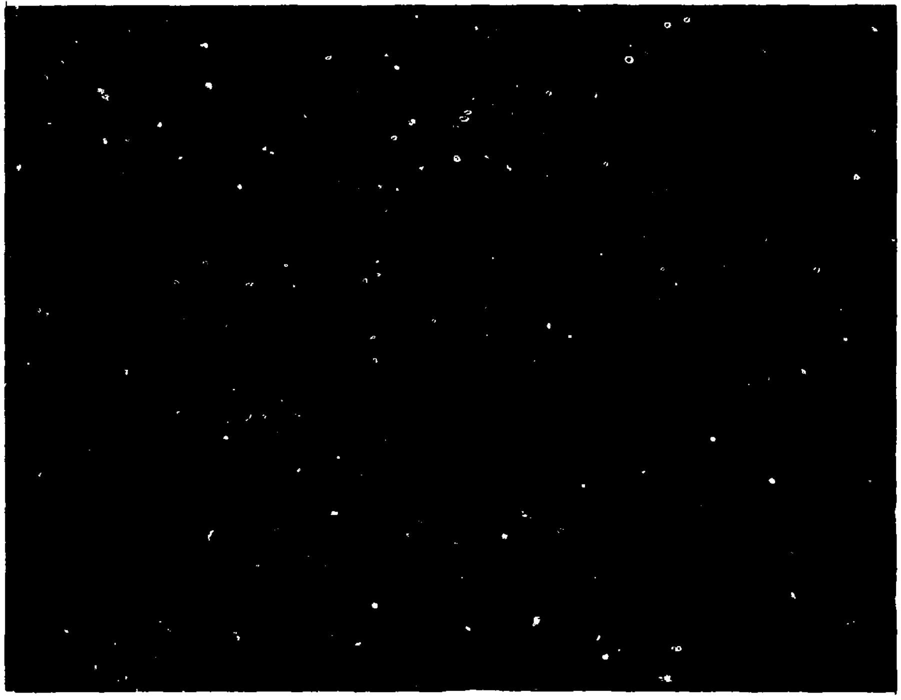


FIGURE 13. PAN OF BALANCE AFTER TESTING

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CONDUCTIVE SAFETY FOOTWEAR

by

T. G. Grady
Hercules Incorporated
Radford Army Ammunition Plant
Radford, Virginia

No discussion of personal protective equipment can be adequately completed without some consideration being given to footwear. The use of properly designed and fitted footwear will not only result in protection for the worker's foot, but will also do much towards elimination of fatigue and preservation of operators' efficiency. In addition, conductive safety footwear constitutes an accident or initiation preventive device in industries where explosives, volatile solvents, and other spark susceptible materials are handled. Properly selected and maintained, such shoes provide a direct path to ground for static charges when worn on an adequately conductive surface and kept in proper repair. Without such a path, as we know, the spark generated by contact or proximity release of static charges built up on person or clothing can be more than sufficient to ignite sensitive dust or liquids and atmospherically borne dust, gases, or vapors.

The conductive safety shoes now in use are available from several different manufacturers. They all conform generally to the requirements of USA Standard Z 41.3 which was issued in 1944. Available in oxford, high top, and boot styles, the various shoes all have mechanically secured linkage designed to provide electrical continuity from the innersole to ground. To be acceptable for use, the shoe must exhibit electrical resistance not in excess of 250,000 ohms when new, and should be removed from service when after use tests indicate resistance to have exceeded 450,000 ohms even after cleaning. The shoe, however, should also be comfortable to the worker. It should be of durable construction. It should be repairable without loss of its conductive quality. Unfortunately, I am sure many of us have experienced the frustration which sporadically accompanies shoe problems - the stitching is insufficient or improperly located; the soles come loose; the heels come loose; conductivity is gone, and "I have only had them two months." While we recognize that shoe manufacturers have individually wrestled with these problems and attempted to effect solutions, I wonder if it isn't about time that the ASA Standard was reviewed and revised. Perhaps shoe materials not available 25 years ago can be considered for use. Perhaps manufacturers can agree on a uniform construction method to give better and more uniform quality protection to workers in specific hazardous jobs. Perhaps also, evaluation should be made of the test apparatus described in Paragraph 4.3 of the Standard, since currently available machines conform only in principle to this description.

As for the use of the shoes themselves and the continuing adequacy of the protection they afford, gentlemen, let's not delude ourselves. Our job does not end with selection of the shoe and insistence that the worker wear it. To be sure our conductive shoe investment is paying off, we must test on a routine basis. Testing is the one means available to assure against inadequacy of the internal electrical bond - either through failure or through inadequate or improper repair. Test programs for conductive shoes should be established and closely monitored at each installation at which static initiation potential constitutes a hazard.

We must also provide conductive flooring surfaces. The conductive quality of the shoe is absolutely useless if the work area is covered with an insulating lining or cushioning material either for the purpose of faciliating housekeeping or of providing comfort for the operator.

We must insure against workers wearing socks made of an insulating material or using copious quantities of foot powder which both dries and insulates. The body to shoe bond must be maintained as well as the internal shoe bond if the footwear is to provide the protection sought.

We must assure continuing cleanliness of the shoe users' soles, since oil, grease, dirt, and other foreign material lodged on the sole may impair the effectiveness of the conductive shoe. This requirement, of course, mandates continuing emphasis be placed on housekeeping - or floorkeeping - a good idea in our business anyway.

One complaint frequently heard about many of the shoes now available concerns their slipperiness when wet. We are aware, I am sure, that the smooth or nearly smooth outersoles are so made in order to guard against packing of ripples or cleats with dirt, grease, or - worse yet - explosives material. Several manufacturers have proposed various outersole configurations designed to afford better antislip characteristics and, at the same time, minimize the potential for packing. So far, I haven't seen any of these which are wholly adequate; and I wonder whether the shoe industry shouldn't accept the challenge of coming up with such a design - - - ?

You will note that we have stressed the conductive shoe requirement be imposed in work areas in which a static spark initiation potential exists. To this end, each facility must evaluate the hazard present in each of their various operations and not go overboard by requiring that conductive shoes be worn in every area in which explosives are present. Many explosive materials do not exhibit static sensitivity sufficient to constitute a hazard. Cast double-base propellant grains and cured pourable composites, for instance, are in this category. While conductive shoes should be required where the hazard exists, sparkproof shoes also in conformance with USA Standard Z 41.3 are sufficient for wear in the vicinity of exposed explosives not susceptible to initiation by static spark of the energy that can be discharged from a person.

The conductive safety shoe, gentlemen, is a worthwhile, valuable tool for industry to use in preventing initiation by static. It does have its shortcomings, however, and without other precautions should not be relied on as the sole preventive means employed to eliminate personnel static hazard.

SYSTEMS SAFETY & PLANNING

Moderator:

MAJ A. F. Muller, USAF
Air Force Systems Command
Andrews AFB, D.C.

Summary

Panel Members

MAJ P. Stack Space & Missile Systems Org Los Angeles, Calif.	Mr. H. M. Roylance Naval Ordnance Systems Command Washington, D. C.
Mr. F. B. Hart U.S. Army Missile Command Redstone Arsenal, Ala.	Mr. A. D. Workum McDonnell Douglas Astronautics Titusville, Fla.
Mr. J. Nichols AF Development & Test Center Eglin AFB, Fla.	Mr. J. L. Umlauf Boeing Company Seattle, Wash.

This session was based upon three presentations providing the attendee with a short but comprehensive description of the Department of Defense System Safety Program, how its objectives are met by a contractor, and how it can reduce the explosive hazards associated with a specific system.

Mr. F. B. Hart, U.S. Army Missile Command, Redstone Arsenal, Ala., summarized the DoD System Safety Program defined by MIL-STD-882. This included the need for, the objectives of, and the definitions peculiar to the program. He then described the system safety activities as they occur in a weapon systems life cycle, and he described the DoD System Safety Standard and other documents peculiar to individual Services.

Next, Mr. A. D. Workum, McDonnell Douglas Corp., presented an example of a contractor's system safety program as implemented for the Army's XM47 Dragon weapon. He described in detail the: responsibilities of the Government, the primary and subcontractors; the contractual safety requirements; the scope of work; the safety engineering activities; and the man-rating procedure of the Dragon System.

Finally, Mr. J. L. Umlauf, the Boeing Company, related the concepts and methodology of system safety to the reduction of explosive hazards in the U.S. Air Force's AGM69A Short Range Attack Missile (SRAM). This was done by citing an example of how the numerical Fault Tree Analysis technique and a computer simulation was used to predict the explosive hazards associated with the first live launch of a SRAM from a B-52 aircraft. Based on this hazard prediction, the need for design or procedural change was then evaluated. (See Volume II)

DEPARTMENT OF DEFENSE SYSTEM SAFETY PROGRAM

Francis E. Hart
U.S. Army Missile Command, Redstone Arsenal, Ala.

I. INTRODUCTION. Perhaps one of the most challenging problems facing the Department of Defense (DOD) in this era of rapidly expanding technology is the development of versatile, complex military systems. This responsibility arises at a time when the socio-economic needs of our Nation imposes critical restraints upon Defense expenditures. This challenge is being met within the Department of Defense by innovation - taking new, major steps toward more effective, less costly development of mission responsive, military systems through the application of disciplined management procedures which provide maximum visibility of program status. In recent years great emphasis has been placed upon the concepts of system engineering management and systems effectiveness by DOD.

II. DOD SAFETY PROGRAM. With the advent of modern, military systems technology, the three Services (Army, Navy, Air Force) recognized a need to adopt a broader approach to safety; as systems have become increasingly complex, the safety problems have become more acute. Early in the 1960's, each Military Department published separate (safety) specifications approaching the System Safety concept of management and engineering. In October 1965, the Department of Defense directed that the Army, Navy and Air Force combine existing Service documents into a single, tri-service specification on System Safety to be used in the development of new military systems. The first DOD Specification, MIL-S-38130A, entitled "General Requirements for System Safety Engineering of Systems and Associated Subsystems and Equipment" was issued in June 1966. The use of this embryonic specification in new programs was successful; however, recently it has been (revised and) superseded by MIL-STD-882 to reflect the experience gained during three years of application in Defense contracts.

III. PROGRAM STANDARD. The Department of Defense's System Safety Program policies, objectives and requirements are identified in MIL-STD-882, entitled "General Requirements for System Safety Program for Systems and Associated Subsystems and Equipment," dated August 1969. The purpose of this Standard is to provide uniform requirements and general criteria for establishing and implementing System Safety Programs as an element of DOD procurement of military systems; the Standard, also, provides guidelines for preparing System Safety Program Plans (SSPP). Major points of interest for those who are unfamiliar with the provisions of MIL-STD-882 are:

A. The Standard is applicable to DOD procurement of all military systems (i.e., aeronautical, nautical, electronic, vehicular, missile, etc.), subsystems and equipment. In addition, it will be utilized on government in-house development and support activities.

B. System life cycle - safety activities are described for programs which include all procurement phases - Concept Formulation, Contract Definition, Engineering Development, Production and Operational.

C. Mission responsive system safety (qualitative and quantitative) requirements and objectives for the system/subsystem/equipment must be specified contractually. Achievement of minimum acceptable requirements must be demonstrated by test, or analyses - as required by the contract.

D. Program and technical (design) reviews are required to be held at appropriate milestones to assess results.

E. General safety criteria and precedence of technical effort are established as guidelines for design and specifications.

F. A System Safety Program Plan is required, as a response to the request for proposals, to define and establish an effective program; this Plan which defines the organization, activities and level of effort is a vital key to the management control and success of this program.

IV. OBJECTIVES AND DEFINITIONS. The System Safety Program provides a disciplined approach to control and evaluate safety features of the system's design; to identify hazards and prescribe corrective action. The objectives of this Program are to ensure that:

A. Safety consistent with mission requirements is designed into the system;

B. Hazards are identified, evaluated, and eliminated or controlled to an acceptable level;

C. Minimum risk is involved in the acceptance and use of new materials and production techniques;

D. Retrofit actions required to improve safety are minimized; and,

E. The historical safety data generated by similar system programs is used.

The following basic definitions have evolved and been adopted by DOD as peculiar to this new technical discipline:

A. Safety - Safety is freedom from those conditions that can cause injury or death to personnel, damage to or loss of equipment or property.

B. System Safety - The optimum degree of safety within the constraints of operational effectiveness, time and cost, attained through specific application of system safety management and engineering principles throughout all phases of a system's life cycle.

C. Hazard - A hazard is any real or potential condition that can cause injury or death to personnel, or damage to or loss of equipment or property.

D. System Safety Management - An element of program management which ensures the accomplishment of the system safety tasks including identification of the system safety requirements; planning, organizing, and controlling those efforts which are directed toward achieving the safety goals; coordinating with other (system) program elements; and analyzing, reviewing and evaluating the program to ensure effective and timely realization of the system safety objectives.

E. System Safety Engineering - An element of systems engineering involving the application of scientific and engineering principles for the timely identification of hazards and initiation of those actions necessary to prevent or control hazards within the system. It draws upon professional knowledge and specialized skills in the mathematical, physical, and related scientific disciplines, together with the principles and methods of engineering design and analysis to specify, predict, and evaluate the safety of the system.

Other definitions are contained in MIL-STD-882.

V. LIFE CYCLE - SAFETY ACTIVITIES. Let's examine briefly the safety activities for the system life cycle as defined by MIL-STD-882.

A. Concept Formulation Phase. Concept Formulation defines the mission and performance goals of the new system. It examines design alternatives to select the best technical approach and ensures needed technology is available. Also, system and cost effectiveness studies are performed. The safety activities include:

1. Conduct concept safety studies.
2. Perform hazard analyses.
3. Define system safety performance requirements.
4. Select system safety effectiveness measures.
5. Orient safety investigations during exploratory or advanced development.
6. Incorporate safety assessement into Technical Development Plan.

The next phase, Contract Definition (CD), is the competitive process phase which defines the system development and production effort in sufficient detail to select a contractor; establish firm management plans; and extend concepts to a system description and specifications. CD is normally conducted in three distinct phases.

B. Contract Definition - Phase A.

1. Incorporate safety requirements into the Statement of Work.

2. Identify safety data to be provided to the Definition contractor.

3. Identify safety data required from the contractor (System Safety Program Plan, Hazard Analyses, etc.).

4. Specify system safety performance requirements and criteria.

C. Contract Definition - Phase B.

1. Implement the approved Contract Definition System Safety Program Plan.

2. Update Hazard Analyses.

3. Update safety studies and test plans.

4. Define system safety requirements for CEI.

5. Insure highest degree of safety is maintained during trade-offs.

6. Submit SSPP For Engineering Development Phase.

7. Submit System Safety work breakdown statement.

D. Contract Definition - Phase C.

1. Evaluate System Safety Program Plan for Development Phase.

2. Review and evaluate:

a. Results of hazard analyses.

b. The safety requirements of the system specifications.

c. The contractor's system design.

3. Make required safety decisions based upon proposals for SSEB.

E. Development Phase.

1. Furnish safety design criteria; establish safety objectives; and, review preliminary engineering design for hazards.

2. Perform safety studies and hazard analyses.

3. Establish test requirements and ensure safety verification.

4. Review system operator and maintenance publications for safety instructions.

5. Review system engineering documentation (CEI spec's and drwg's) for essential safety data.

6. Provide safety input to training courses.

7. Coordinate with Reliability, Maintainability, Quality Assurance, Human Factors Value Engineering, etc.

8. Participate in design and in-process reviews.

F. Production Phase.

1. Identify safety critical production techniques, assembly procedures, facilities, etc.

2. Participate in configuration control program to monitor for changes and retrofits affecting safety of equipment.

3. Identify for Quality essential production safety tests, inspections and procedures.

G. Operations and Disposal.

1. Safety assessment the system performance in the operational environment.

2. Safety evaluation of design change and equipment modifications.

3. Review of operator and maintenance publication changes for safety.

4. Analyze system accidents/incidents for hazardous conditions and corrective action.

5. Safety data collection and analysis from system deficiency reports.

6. Review and approve system standing procedures for disposal of hazardous material.

VI. MILITARY SERVICES' PROGRAMS. The basic accident prevention policy of the Department of Defense is established in DOD Directive 1000.3. MIL-STD-882 implements this policy to insure that safety receives due consideration during all phases of (military) systems' development, production and field use. Each Military Department has promulgated this policy through internal regulations and directives.

Air Force system safety policy is contained in Air Force Regulation 127-1 which states the necessity to ". . . Incorporate safety engineering in equipment and properties being acquired by the Air Force." The Air Force Systems Command (AFSC) is responsible for determining the scope of system safety programs necessary to achieve system requirements.

The Navy policy for system safety of Naval material is stated in SECNAV Instruction 5100.10A. A NAVMATS directive is presently being prepared to supplement this Instruction for the Chief of Naval Materiel.

Within the Army, program requirements, in accordance with the provisions of MIL-STD-882, are implemented by Army Regulation 385-16 which prescribes that "Commanders . . . responsible for development of Army equipment and materiel are responsible for establishing an active safety engineering effort . . . to insure the incorporation of safety criteria, standards and practices during the design and development of Army systems . . ." The primary development responsibility for Army equipment rests with the Army Materiel Command.

VII. INDUSTRY'S ROLE. Industry has responded to the attention and support DOD has placed on system safety in contracts; recognizing the need to provide mature implementation of this discipline, industry has joined DOD by placing management emphasis on system safety in military systems.

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THE XM47 DRAGON
SYSTEM SAFETY PROGRAM

by
A. D. Workum
McDonnell Douglas Astronautics Company
Safety Engineering
Dragon Project

MCDONNELL DOUGLAS
CORPORATION

I INTRODUCTION AND SUMMARY

The purpose of this paper is to present a prime example of a contractor's System Safety Program. The method of administering and implementing system safety is dependent on the customer, the contractor and the nature of the program in which they are involved. The techniques discussed here are applicable to a U. S. Army tactical missile program, specifically the XM47 Dragon antitank weapon system. Some of these techniques and methods should not be applied to all programs. Certainly, I would think that some of the safety problems involved in designing, testing and mass producing an individually shoulder fired weapon would be somewhat unique. But despite this, I feel you will learn from our experience that the system approach to safety is a logical one - one that has more intrinsic value than the mere fulfillment of a data requirement. At the present time, our responsibility is the safety of a tactical weapon system - the Army's XM47 Dragon.

II FAMILIARIZATION WITH BASIC PROGRAM - XM47 DRAGON

So that you will have a better understanding of the weapon I will be referring to, I'd like to present a short film on the "XM47 Surface Attack Guided Missile System." (The Dragon is shoulder supported when fired, employing an impulse launched, impulse sustained and controlled, optically tracked, command guided, wire linked missile. The missile is launched from a smooth bore fibreglass tube. The major end items of the Dragon Weapon System are the tracker and the round. The round is a term used to describe the launcher and missile, since they are packaged together, and is the expendable item of the weapon system.

The tracker is the reusable item - it provides a sighting device, trigger and trigger safety, guidance device and support hardware.

II (continued)

The Dragon is a recoilless weapon, destined to replace the 90 mm recoilless rifle. The initial launch propulsion is provided by a high pressure canister and low pressure breech. The canister propellant burns at a high chamber pressure and the resultant combustion gases are exhausted through canister orifices into a relatively low pressure area of the breech nozzle and launch tube.

In flight propulsion is provided by sixty small solid propellant rocket motors located in the center section. They function in pairs upon command of the guidance system. The guidance system, in turn, depends upon inputs from the tracker in terms of measurements of the missile displacement from the line of sight.

The warhead is a HEAT type employing a standard safe and arm device for booster detonation of the shaped charge upon target contact or graze function.)

III RESPONSIBILITIES

1. Three basic responsibilities exist toward a meaningful system safety program: Government; the Prime Contractor; and his various subcontractors.

   A. Government

   The Government Agency responsible for the Dragon Weapon System is the U. S. Army Missile Command, Redstone Arsenal, Alabama. Our contacts for system safety are with the Dragon Project Office and the Missile Command Safety Division. This latter office provides weapon system safety technical support for missile programs to project managers, commodity managers and functional directorates. Engineers are assigned to each weapon system and function as members of the Project's organizational staff. As new weapon systems such as Dragon are developed, the prime contractors are required to establish a safety engineering program consistent with the policies established by the MICOM Safety Division (Reference (1)).

III (continued)

B. Prime Contractor

McDonnell Douglas Astronautics Company (MDAC), Titusville, Florida, is the prime contractor for the Dragon Weapon and presently operates under Engineering Development and Production Engineering contracts. The Project organization is shown in Figure 1. The activities which you would normally associate with the system safety such as design analysis, man-rating and hazard analysis are the responsibilities of our group, Safety Engineering. Those activities normally associated with Plant and Operations Safety are the responsibility of the Safety and Medical Department. An open line of communication between these two groups is essential to insure that information gained by our analyses and testing can be incorporated into the Safety and Medical Departments' plans for production safety requirements.

C. Subcontractors

The suppliers of major explosive components are required to submit a Safety Plan for our review and approval. The plan must include component description and characteristics, plant layouts, quantity-distance figures and assembly procedures. Additional data from these and other vendors is routed to us for review: this includes data such as Failure Analysis reports, Progress reports, Failure Mode Analyses, etc.

IV CONTRACTUAL SAFETY REQUIREMENTS

Contractual safety requirements are found in two sources: the Contract (DD Form 1423) Data Items, and the safety criteria specified in the Scope of Work (SOW) and System Description.

A. Contract Data Items

1. The Contract Data Items are shown in Figure 2. Data Item 13-001 requires submittal of a System Safety Engineering Plan (SSEP). This is the same document as that described in MIL-S-38130A (Reference 2). Our present SSEP (Reference 3) is the second revision, the original being prepared in June 1966 just prior to Engineering Development. Note that Contract Definition was waived for the Dragon Program. Normally a preliminary plan is submitted in response to an RFP prior to contract award. A final plan, which is really a revision to the preliminary, is submitted prior to Engineering Development. We are required to revise our plan on a regular basis throughout the life of the program and we use it to show safety progress. We have attempted to be as specific as possible in preparing our present plan and avoid general, vague statements. The format is such that each section is keyed to the system description and the data item description. As many of your are undoubtedly aware, MIL-S-38130A will eventually be replaced by MIL-STD-882, which I believe is now in its seventh or eighth draft. I can only say that this will be an immeasurable improvement.

2. Data Item 13-002 requires that Explosive Hazard Classification tests be conducted in accordance with TB 700-2 (Reference 4) which is the same as NAVORDINST 8020.3 (Navy) and TO 11A-1-47 (Air Force). We have here an example of the necessity of free and open coordination

IV (continued)

with the Project Office and customer safety representatives. Through such coordination plus a combination of using the revised 1967 TB 700-2 and Army Materiel Command confirmation we were able to reduce test quantities in our Hazard Classification test program. These tests will be conducted after round qualification.

3. Data Item 13-003, Safety Statement, requires the Contractor to submit a document to MICOM stating that the qualified weapon configuration is safe for manned testing by the services boards and includes a summary of test data supporting this conclusion. The Safety Statement is reviewed by the Project Office, MICOM Safety Division, and by an independent Army Agency, the Test and Evaluation Command (TECOM). With the exception of the Safety Plan, this is the most significant safety document that we will prepare. In effect it sums up our entire system safety program. It must be approved before the Army can begin the Engineering and Service Test program.

4. Data Item 13-007 requires that, upon determining the existence of real or potential safety hazards in any aspect of the Weapon System, the Contractor shall notify the Procuring Agency of the hazard and the recommended corrective action. The data item goes on to describe what analyses are to be conducted to identify these hazards. These include Failure Mode and Effect, Fault Tree, Maintenance, Operational and System Integration.

IV (continued)

5. Data Item 13-008 requires submittal of Range Safety data and impact envelopes for weapon system use. Formats for the envelopes and general guidelines for their development are given in two Army Regulations - AR385-62 and AR385-63. The impact envelopes are quite similar in basic construction to those required by the National Ranges.

6. Data Item 13-010 requires submittal of a report, via the fastest means available, in the event of a serious accident or incident.

B. SCOPE OF WORK AND SYSTEM DESCRIPTION

1. The Scope of Work, with regard to safety, specifies that the MDAC shall conduct safety engineering effort as described in the Safety Engineering Plan and that the Plan is to be continually revised to incorporate latest data. It also contains a standard safety clause pertaining to responsibility, since we have a contractor owned, contractor operated assembly plant.

2. The System Description, an appendix to the S.O.W., goes into more detail. We find that the Weapon System, for example, shall be safe to store, handle, transport, maintain and operate under the environments specified in the S.O.W. We are told that the Army Safety Manual, AMCR 385-224, shall be complied with, where applicable, in facilities involving hazardous operations. We are to include Safety provisions to cover all aspects of operational use, transportation and storage. Minimum structural safety margins are specified; limitations are placed on the signature of the weapon; the combustion gases in the launcher area shall not present a hazard to the gunner; high temperature

IV (continued)

surfaces are to be protected or located to avoid contact by the gunner during reload. We have taken these criteria, expanded and incorporated them into the Safety Plan, and given them wide internal publicity.

V SAFETY ENGINEERING ACTIVITY

System Safety became actively involved in the Dragon Weapon System just prior to the beginning of Engineering Development. At that time, we were also responsible for plant safety. Considerable attention, therefore, was devoted to the design and siting of our new test ranges and assembly buildings. This was a coordinated effort between MDAC and MICOM Safety and architectural personnel, resulting in our present facility which includes the explosive assembly building, explosive storage magazines, environmental test facilities, explosive testing cells, and launch pads.

A. GROSS SYSTEM ANALYSIS

1. Our first, and perhaps most important safety analysis, was a review of the system concept and requirements and a determination of applicable standards and specifications. This is commonly referred to as a Gross Hazards Analysis, but I choose to call it a Gross System Analysis since it necessarily involves much more than the study of the hazards.

2. An initial review of the system concept is essential since it naturally forms the basis for future and more detailed analyses and studies. However, it is totally incomplete unless based on an understanding of all contractual requirements. In reviewing the design, the answers to the following questions were found:

V (continued)

what does the Weapon System consist of; what are the system objectives, what are the system requirements, the specified environments; what safety criteria must be satisfied, and many others. The Safety Engineer must, in my opinion, know what the Customer has stated in writing that he wants and, of course, what company management has agreed to. We found that every hour spent in these areas, primarily in the early stages, was invaluable.

3. Just as essential, if not more so, was a review of all specifications and standards, but primarily those dealing with safety, which are listed in the Contract under the heading: "Applicable Documents." This review also determined what degree of compliance was required. This latter fact is not often apparent - phrases such as "as applicable," "where applicable," or "applicable to the extent specified herein" are commonly used but never very explicit. We found that coordination with the customer, especially our safety counterparts, was of immeasurable help in this area and from this experience, we can certainly recommend that these reviews and analyses be of highest priority in any system safety program.

B. SAFETY ANALYSES

1. General

Many studies and investigations can be identified as safety analyses but may not be performed by safety engineers or may not be any of those identified in MIL-S-38130A. Safety verification is a combination of many factors and is not limited to those activities

V (continued)

which would normally be considered a function of safety engineering. We attempt to personally monitor every test involving design safety considerations. We review all test data results and conclusions for possible application of the findings to our system safety program. Failure Analysis reports have particular significance in this regard - failures occuring during unmanned tests are analyzed to determine what effect, if any, similar failures would have had on crew safety.

We review analyses generated by other Dragon Engineering Groups, Stress, Aerodynamics, Reliability, Propulsion, etc. Their studies form an integral part of the System Safety program in general and our Man Rating documentation specifically.

I do not feel that all of the safety analyses specified in 38130A are essential to every program and that some accomplish very little except to fill the Contractor's and the customer's file cabinets with impressive but expensive reports. I will, however, briefly discuss some of the analyses we have conducted.

2. Failure Mode and Effect Analysis

We conduct FM & E in much the same manner as I suspect other safety departments do. This can be a very useful tool if used with the idea of providing a solid input to the weapon system rather than as part of a "white paper." We use the hazard classifications of

V (continued)

38130A and conduct extensive investigation into predicted Class III or IV hazards. These analyses provide a direct input to our safety testing. Class III and IV hazards are induced into a system test set up and the results monitored to determine just how serious the problem really is. If necessary, the next step would be Fault Tree Analysis to isolate the specific fault paths and determine the corrective action required. We have had several instances where the above process has been carried through to an eventual system redesign.

This analysis has another important aspect in the Dragon Weapon System. We will use it to aid in the determination and identification of those system failures which are to be considered safety failures during Production Acceptance Testing. These full range flight tests are conducted on samples from each Lot of production rounds - any one safety failure during Production Acceptance Testing would reject a given Lot.

3. Explosives Analysis

Each explosive component in the Dragon Weapon was analyzed to determine its characteristics both from a system standpoint and handling, testing and assembly. We have looked into the areas of chemical composition, electrical characteristics including insulation, dielectric values, static sensitivity and RF hazards, and classification. Results of these studies are being utilized by the Plant Safety department in the designing of production tooling and preparation of production safety procedures.

Particular attention has been given to the HEAT Warhead, which is GFE. We actively participate in Integration meetings and review all test data. Specific emphasis is being directed to verification of required safe-arm operation distance and compliance with MIL-STD-331 testing requirements.

4. Launcher Environment Analyses

This undoubtedly has required more effort on our part and in conjunction with Human Factors than any other single area of the Dragon Weapon System. The launcher environment during firing consists of hot combustion gases, flame, radiant and conductive heat, sound pressure and overpressure, and recoil for a very short period of time. The magnitude of these parameters must be such that not only will the gunner and the crew's safety not be endangered, but their ability to perform must not be degraded. The sound pressure and overpressure levels, and the radiant heat generated by the launcher firing has been measured extensively. Using the Army's Human Engineering Laboratory personnel as consultants, sound pressure levels have been mapped in the gunner area and various crew positions to determine what auditory protection is required. Radiant heat levels are measured by placing skin simulants, which were obtained from the Naval Applied Science Laboratory in positions representing various parts of the gunner's body. These simulants (References 5, 6, 7) are made of an inert material whose thermal inertia is equal to that of human skin. Temperature changes are transmitted to recorders from

V (continued)

thermocouples embedded in the material. Using the Navy Laboratory's criteria for skin temperature threshold (Reference 5) and the Human Engineering Laboratory criteria for impulse noise (Reference 8), we were able to commence manned testing with the gunner required to wear normal field attire and ear plugs.

The remainder of the Launcher analyses, but really the bulk of it, is a combination of development, design verification, qualification and safety testing. Through the first three, criteria are developed, verified and then formally qualified at all environments. The safety tests are a series of repeatability test firings at hot, cold and ambient temperatures which will verify our capability to produce man-rated flight hardware on a sustained basis. All of the tests provide structural integrity, recoil and velocity data which is required for safety verification.

C. MAN RATING

1. The culmination of all the previously described efforts is a Man Rated Weapon System. The development of the Dragon follows the philosophy of testing in an increasing order of complexity so that confidence in demonstrated equipment performance will be cumulative. This same philosophy is used in verifying the weapon's safety prior to manned tests. There are several series which are presented in Figure 3.

2. Prior to each of these manned tests, Safety Engineering prepares a Man Rating statement which documents the results of safety analyses, tests, structural verification, and states that the configuration to be tested is safe for a man to fire. This document is presented to

V (continued)

the Project Office and the Dragon representative from the MICOM Safety Division at a Safety Design Review. Each of the Man Rating statements builds upon the previous one so that a complete history of the safety of the Dragon Weapon may be maintained. The final document of the series will be the Safety Statement, submitted prior to ET/ST, in accordance with a Data Item which we discussed earlier.

VI CONCLUSION

I have presented one example of a contractor's system safety program. I have tried to emphasize the need for coordination with Project Office personnel early in the program and throughout its development life, so sound requirements can be established and met. I also want to emphasize that system safety can make a significant contribution to the development of any major system and I feel we are doing just that in the case of the Dragon.

A safety program can be as eleaborate or as simple as you want it to be, but realism will help to make it effective. And that, gentlemen, is a message for contractors and customers. I look forward to your questions and comments at the conclusion of the panel's presentation.

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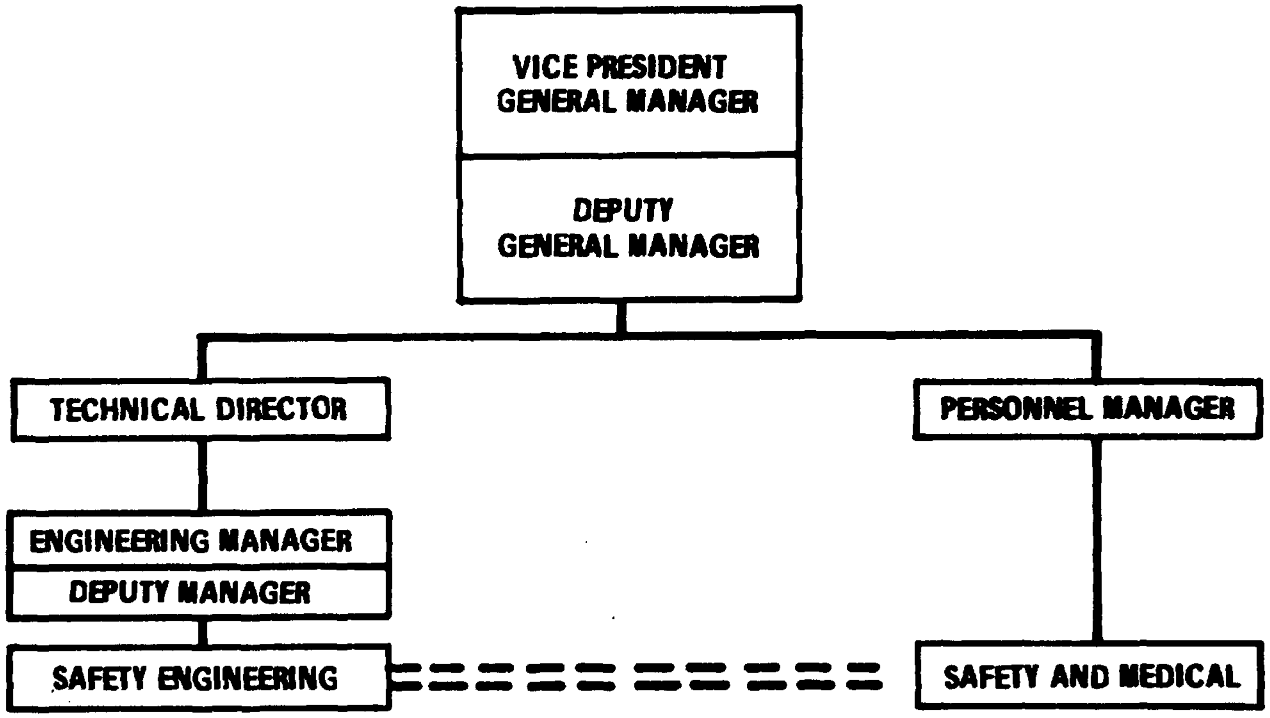

FIGURE 1 – SAFETY ORGANIZATION

DATA ITEM NUMBER	TITLE	DESCRIPTION
13–001	SYSTEM SAFETY ENGINEERING PLAN	CONTRACTOR'S SAFETY PROGRAM DESCRIPTION
13–002	EXPLOSIVE HAZARD CLASSIFICATION DATA	DATA FROM HAZARD CLASSIFICATION TESTS
13–003	SAFETY STATEMENT	SAFETY DATA SUMMARY, VERIFICATION TO CUSTOMER FROM MDAC OF A SAFE SYSTEM
13–007	SAFETY ANALYSES AND HAZARD EVALUATION	REPORTS OF HAZARDS AND RECOMMENDED CORRECTIVE ACTION
13–008	SURFACE DANGER AREA DATA	TRAJECTORY DATA, MAXIMUM RANGE AND LATERAL DISTANCES
13–010	REPORT OF ARMY ACCIDENT/INCIDENT	NOTIFICATION OF MAJOR ACCIDENT OR INCIDENT

FIGURE 2 DD 1423 DATA ITEMS

1. TRACKING TESTS
    a. MANNED BALLISTIC LAUNCH OF DUMMY MISSILES TO EVALUATE GUNNER TRACKING CAPABILITY.

2. GUIDED FLIGHT TESTS
    a. MANNED TESTS OF COMPLETE MISSILE AT STATIONARY AND MOVING TARGETS AT VARIOUS RANGES; INCLUDES ARCTIC AND DESERT TESTING.
    b. PRE-PROTOTYPE COMPONENTS USED.
    c. ALSO UNMANNED TESTS AT TEMPERATURE EXTREMES AND WARHEAD TESTS.

3. PROTOTYPE FLIGHT EVALUATION TESTS
    a. MANNED GUIDED FLIGHT TESTS USING PROTOTYPE (QUALIFIED) COMPONENTS.
    b. INCLUDES MANNED TESTS USING THE HEAT WARHEAD.
    c. ALSO UNMANNED TESTING AFTER EXPOSURE TO SEQUENTIALLY SIMULATED ENVIRONMENTS.

4. DEVELOPMENT ACCEPTANCE TESTS
    a. MANNED FLIGHT TESTS CONDUCTED BY THE MISSILE COMMAND.
    b. DEMONSTRATES TACTICAL CAPABILITY OF THE WEAPON

5. ENGINEERING TESTS/SERVICE TESTS (ET/ST)
    a. CONDUCTED BY THE U. S. ARMY TEST AND EVALUATION COMMAND AT VARIOUS ARMY FACILITIES.
    b. INCLUDES MANNED TESTING AT ALL ENVIRONMENTS, INCLUDING OFF-NOMINAL, TO DETERMINE EXTENT TO WHICH THE WEAPON SYSTEM MEETS THE APPROVED QUALITATIVE MATERIAL REQUIREMENT (QMR).

FIGURE 3 MANNED TEST PROGRAMS

AMMUNITION & EXPLOSIVES PRODUCTION LINE SAFETY PROBLEMS

Moderator:

W. R. McKeen
U.S. Naval Ammunition Depot
Crane, Indiana

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PRODUCTION LINE SAFETY PROBLEMS

SUMMARY

The session was conducted as a conference. No formal presentations were given. Several typical topics of production were listed on a chart and as the conference progressed each topic in turn was discussed and the following comments/discussions were generated:

TOXIC MATERIALS:

All recognized that several new toxic materials (chemicals) were appearing in the ammunition production field (Chlorine Trifluoride - CTF, Ethylene Oxide - EO). Each brought with it new and different safety precautions to shield its toxicity. Generally, each organization was handling its own problems adequately on an individual basis. One particular material brought up was Penta-Chloraphenol - a preservative impregnated/painted onto wooden pallet lumber in the Army. It was mentioned that user reports were still being received from forward areas that accumulations of crystals were being encountered on the pallets which were causing burns/blisters to men required to handle the pallets. These crystals were caused either by too high a concentration of the mixture at the impregnation/painting plant or hot humid weather "cooking" the solution out of the wood. A loading plant representative commented that new pallets were being received "freshly painted" and special measures were required to protect workers from fume inhalation and physical contact. A further statement was made by an Army representative that the matter had been looked into and resulted in the mixture being controlled to a one gallon of chemical to ten gallons of carrier mixture and curing time being established to insure that "freshly painted" pallets did not reach manufacturing plants. No further special handling was considered necessary unless crystals were present, in which case gloves were recommended.

USE OF SOLVENTS IN CLEANING:

Use of several solvents were discussed as generally acceptable - Alcohol, Tri-chlorethylene, Naptha, Acetone, etc. It was commented that Naptha required an extra measure of caution because of its low flash point. Acetone is very commonly used and requires positive ventilation due to its toxicity. The group was asked for recommendations on a cleaning solvent which would clean hardened compound from mixers, vats, containers, etc. The compound consisted of Magnesium, Ammonium Per-Chlorate, Tupersol, Taminac, MEK, Toluene, and Solac. Only recommendation given was to use Acetone and clean the mixer, etc., before the composition hardened. The procedure/material in use in the pyrotechnic loading plant at NAD Crane is Acetone after every other batch. NAD Crane has found that if the cleaning is prolonged past every other batch, the compound hardens too much.

FIRE DETECTING AND EXTINGUISHING SYSTEMS:

Some of the newer, faster reacting systems were discussed. Millisecond reaction time is obtained using explosive valves. Proper mounting of fusible links was discussed with added comments that painting of the links raised the temperature at which they melted. It was also commented that if the links were not painted, they would corrode and become weaker. There was a question on how smoke could be detected around pyro mixes. Information on Pyr-a-form fire and smoke detection systems can be obtained from Pyrotronics, Inc., 2343 Menis Avenue, Union, New Jersey 07083.

AMMUNITION PRODUCTION EQUIPMENT APPROVAL:

A general discussion occurred concerning the manner in which this is accomplished in the Army and the Navy. All Navy equipment is reviewed for approval by one central organization. Army contractors are required to meet Army criteria and, except for major policy changing processes, the designs are approved by the local Army Command. One pertinent comment was made regarding the polarity of electric motors. Several pieces of equipment had been saved from being ruined because the polarity of the power source and the equipment had been checked before hooking it up. There are commercially available instruments for checking polarity which are simple and quick to use.

PRODUCTION STANDARD OPERATING PROCEDURES:

Discussion on this topic centered mainly on the use of an SOP by production personnel and the importance of the first line supervisor. The extent to which this supervisor trained his employees on their particular steps of an SOP was directly related to how closely an SOP was followed. It was agreed that SOP's should be followed to the letter (with appropriate provisions for making changes) and that this was the direct responsibility of the first line supervisor. It was suggested that help could be provided the supervisor by assigning a man to train his people on appropriate steps in the SOP. One organization commented that they had an audit group reporting to the Plant Manager which checked jobs on an unscheduled basis to determine how well the SOP was being performed.

PERSONNEL LIMITS:

It was commented that personnel limits were mainly established by determining the number of production personnel required to do the job in a safe and economical manner, adding supervision and making a realistic allowance for transients.

PRODUCTION/QUALITY ASSURANCE PERSONNEL AS SAFETY OBSERVERS:

Discussion centered on who had the responsibility for safety. Again, it was agreed that production first line supervisors had the sole responsibility and it was commented that assignment of partial responsibility to "safety observers" would only weaken the emphasis on safety because the supervisor would rely on the "observer" to catch problems. A comment was made that the role of the Safety Departments was that of service or as monitor or advisor to the operating departments in helping them to achieve accident-free operations.

SPRINKLER SYSTEMS IN HI-EXPLOSIVE OPERATIONS:

Past practices observed in the construction of high explosive melting facilities called for installation of sprinkler heads in the melting kettles as well as in the kettle rooms. It was commented that larger kettles recently installed in Navy explosive melting facilities were not equipped with sprinkler heads in the kettles. It was considered that sprinkler heads in the kettle room would put out a fire which started in the room before it got to the kettles. However, if a fire started in a kettle, a detonation would likely occur before the sprinklers would have any effect and thus the sprinklers would be of no use.

PRODUCTION EQUIPMENT WITH/WITHOUT UL LABEL:

Several comments were made that in many cases the certification that the equipment purchased will withstand specific UL tests was compromised by customer breakdown and reassembly of critical parts of the equipment at the installation site. Opinions were mixed therefore concerning the necessity of requiring electrical equipment to bear the UL stamp or be certified to meet UL tests. NEMA and NEC codes were felt sufficient in most cases. In regard to type and class selection, it was commented that in many instances a dual rating or capability was warranted. For example, if a Class I Groups C and D motor were required, it might be appropriate to buy a motor rated Class I Groups C and D and Class II Groups E, F, and G to avoid the possibility of equipment shuffles in the future allowing a Class I Groups C and D rated motor to be installed in a Class II Groups E, F, and G location.

USE OF EXPLOSION-PROOF/SPARK-PROOF FORKLIFTS:

The groups felt a study should be made on the use of explosion-proof and spark-proof forklifts in and around explosive operations. The purpose of the study would be to change the requirements now stated in the Army and Navy safety manuals (AMCR 385-224 - OP 5 Vol I) to make them more realistic and commensurate with the latest technical advances in materials handling equipment.

RESUMES OF RECENT EXPLOSIVES ACCIDENTS

Moderator:

Gerald Marsischky
U.S. Naval Ammunition Depot
Crane, Indiana

RESUMÉS OF RECENT EXPLOSIVES ACCIDENTS

I. Introduction

A. Topics to be covered

1. Mr. Ewing's presentation of Volunteer Army Ammunition Plant explosion in a TNT nitrator.

2. Mr. Johnson's presentation of fire and explosion at Badger Army Ammunition Plant in a hydrojet house.

3. Discussion of what attendees desire for future accident/incident resumés at ASESB Conferences.

B. Introduction of Mr. L. C. Ewing, Safety Manager for Atlas Chemical Indus., Operator of Volunteer AAP.

C. Introduction of Mr. R. E. Johnson, Safety Officer, Olin Mathieson Chemical Corporation, Operator of Badger AAP.

II. Explosion at Volunteer AAP.

A. Investigation Report

B. Site Plan

C. Photographs taken during the incident.

D. Comments and questions by participants.

1. Mr. Ewing - "for the sake of this presentation, I will define high and low order detonations as low order - wooshing noise heard - high order-bang heard by observers."

2. Question - Are the power lines in the area above ground to the buildings?
Answer - Mr. Ewing - Yes, they are. This plant was built forty years ago.

3. Question - How much TNT was in the drowning tub?
Answer - Approximately 15,000 lbs. of explosive.

4. Question - How much water was over the explosive in the drowning tub?
Answer - Approximately four feet.

5. Question - Why so much explosive in the drowning tub?

Answer - The standard procedure called for cleaning of the drowning tub after dumping of four charges or whenever shutdown of that nitration facility was planned. Cleaning the drowning tub is a major operation requiring total shutdown of the nitration facility.

6. Question - In Recommendation No. 6 (of Investigating Report), do you mean a dry powder system?
Answer - No, a manual and automatically actuating water deluge system.

7. Question - How far was photographer from site?
Answer - Approximately 575' to 650'.

8. Question - Did the barricades work?
Answer - Yes, though the barricade failed at the nitrator, no sympathetic detonations occurred.

9. Question - would a sprinkler system have helped?
Answer - There was one, but the riser was broken during the original explosion. The sprinkler heads are heat actuated. No manual control.

10. The general construction, vegetation control, etc. does not appear satisfactory.
Answer - This is an old plant and it does not meet modern standards.

11. Question - I did not see any personnel shelters - are they provided?
Answer - No.

12. Question - Do you intend to provide personnel shelters?
Answer - No.

13. Question - Do you have any new thoughts on emergency procedures now?
Answer - Yes, we have prepared a company policy on who is to report to accident scenes. All others are to stay away. Employees are to evacuate the area and report to the supervisor's office to be cleared and if the incident warrants, sent to the change house.

14. Question - you mentioned the instruments in the foreman's shack. What are they for?
Answer - Primarily quality control. They are temperature - time gages. The safety department does spot check the gages and utilizes the recordings if an incident occurs.

15. Question - In your opinion, were the disciplinary measures taken for the previous infractions for the involved employees satisfactory?
Answer - No, but this is a complicated area. Previous precedent and a multitude of other factors enter such cases.

16. Question - Was the deviation from standard procedure known by the supervisor?
Answer - We are not sure, but we believe some supervisors have tolerated such deviations in the past.

17. Question - Were the waste or drain lines involved?

Answer - No.

18. Question - Were the charges drowned?
Answer - No, one man attempted to pull the release cable; but the first explosion damaged the housing jamming the cable.

19. Question - Was the agitation in the nitrator at the time of the incident?
Answer - We believe there was, but we do not know for sure. We only have the operator's statement to go on.

20. Comment - There have been 10 incidents recently due to a lack of agitation in the nitrator.

III. Explosion and fire at Badger AAP

A. Investigation report

B. Overhead slides used by Mr. Johnson

C. Mr. Johnson's Notes

D. Questions and Comments by participants.

1. Comments by Mr. Johnson -
Note the manner in which the poles for the pipe bridge were cut off. Also, the poles were flocked with asbestos on one side. The steel pipes were ripped open as in a boiler explosion rather than fragmented as in a detonation. One witness saw a piece of burning or red hot pipe land on canvas cover of a tram carrying smokeless powder to the hydrojet house that burned. The diagram and pictures do not indicate the multitude of bends and 90° elbows that actually exist in the piping.

2. Question - I saw an escape chute, but no personnel shelters. Do you have personnel shelters?
Answer - No, and truthfully, I doubt that personnel shelters offer any protection.

3. Question - Was there anyone in the building?
Answer - No one was in the hydrojet house where the explosion occurred. There were two men in the hydrojet house that burned. One man witnessed the flying piece of pipe land in the tram. The supervisor had checked the first hydrojet house a few minutes prior to the incident. The first hydrojet house had not been used for 34 hours.

4. Question - Had the slurry line been flushed?
Answer - The log shows that it had been, but we doubt this. There were copious amounts of smokeless powder in the remaining pipe sections and powder was plastered against the walls of the building and on the ground.

5. Question - Are the pipes flanged?
Answer - Yes, they are butt welded and flanged with very rough interiors.

6. Question - What is the cook off temperature of the smokeless powder?
Answer - I am not sure, but the stability test requires 110° C. for 40 minutes without breakdown. Samples of the powder taken did not pass this test. Breakdown occurred at 15 to 20 minutes.

7. Question - Have you considered using a rotor-rooter type device to clean the lines?
Answer - No, there are too many bends and angles.

8. Question - Have you considered any other means of heating the lines?
Answer - Yes, we considered electrical heat tape and several others and finally settled on hot water since it would be the least expensive and quickest with our present facility.

9. Question - Were there any fire protection systems in the buildings?
Answer - No, they were not considered necessary since this is a wet process. It does appear that a sprinkler system would have helped.

10. Question - Can the pipes be kept full of water?
Answer - Yes and we are now keeping them full of water.

IV. Discussion of presentations and what participants want for the future.

A. All present during both sessions preferred detailed presentations with open discussion and questions during and after the presentations where the incidents could be explored in depth.

B. It was suggested that some time be devoted to field use incidents.

C. All concurred that the program should be lengthened and possibly coordinated by ASESB directly with selection of the incidents made published in the program guide. The possibility of having more than one suggestion was also well backed.

D. Participants did not want short resumes of multiple incidents.

E. The following procedure was suggested and approved by the participants:

1. ASESB select incidents by 30 July each year.

2. Gather all documentation including pictures, site plans, investigation reports, etc.

3. Ensure that investigating officials can attend and make presentation.

4. Prepare approximately 25 minute presentation of the incident.

5. Open the floor to questions emphasizing a critical analysis of the how, what and why of the incident and effects of corrective measures.

6. When possible, use incidents that indicate trends or common faults.

7. Provide more than one type of incident resumé session, e.g.,

   a. Pyrotechnics
   b. Explosives manufacturing
   c. Cast loading
   d. Press loading
   e. Field use of ordnance

ATLAS CHEMICAL INDUSTRIES, INC.
VOLUNTEER ARMY AMMUNITION PLANT
CHATTANOOGA, TENNESSEE

February 12, 1969

INVESTIGATION REPORT

WHAT HAPPENED: At approximately 1320 hours 31 January 1969, a low order detonation occurred in the #1 nitrator in the tri-nitration house on TNT Line 14 resulting in a subsequent fire in the #2 nitrator and a high order detonation of the Bi-oil scale tank at approximately 1348 hours demolishing Building 802-14. There were 12 minor injuries and property damaged in excess of $200,000.

HOW IT HAPPENED: Charge #1010 arrived at the Wash House from #1 nitrator at approximately 1310 hours and was subsequently crystallized, soda ashed, and sellited. At approximately 1315 hours charge #1011 reached 235° (cooking temperature) in #2 nitrator.

Temperature charts indicate that a full charge of acid was dropped into #1 nitrator at approximately 1312 hours and cooled from 220° to 168° during the following 8 minutes. Two (2) minutes later, the contents of #1 nitrator took a sharp rise in temperature and the first detonation occurred.

This resulted in a fire at the SW corner of the building and blast damage to the building, barricade roof, and several steam lines. The fire department arrived on the scene. All Line 14 personnel were immediately evacuated. Firefighter Guards were pulled back to the SW side of the building and a few minutes later retreated to approximately 600 feet from the fire and set up road blocks. Operating personnel were evacuated from adjacent lines (13 & 15).

At approximately 1330 hours a large column of red-orange flame with black smoke erupted from the center of the building. After one (1) minute, this died down and white smoke and steam continued to come from the building.

At this time all remaining TNT lines were shut down and evacuated.

Approximately 3 minutes later a large column of red-orange flame erupted from the north end of the building. This was evidently the full content of #2 nitrator. The flames continued for 2 to 3 more minutes and then reduced in height and turned bright white accompanied by a loud roaring noise for 10 to 15 seconds. Then a high order detonation of the Bi-oil scale tank occurred destroying the building and severely damaging the east barricade.

THE INVESTIGATION REVEALED:

1. The acid in #1 nitrator (220° at time of entry) was reduced in temperature to 168° rather than to 195° as called for in the SOP.

2. There have been instances of heating up cold acid by adding Bi-oil out of sequence rather than applying steam to the coils as called for in the SOP. This is considerably faster than steam, however, this could cause a runaway chemical reaction.

3. The temperature recorded indicates that a rapid temperature rise occurred in #1

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nitrator immediately prior to the low order detonation.

4. The #1 nitrator operator had been disciplined for two (2) previous operating errors (overpumping oleum).

5. The #1 nitrator operator states that he had "just started" to add acid and could not account for the 8 minute interval between this action and when he sent charge #1010 to the Wash House. He also could not account for the unusually low temperature of the acid or the full charge of acid and presence of explosive material in #1 nitrator.

6. The #1 nitrator operator alleged that the #2 nitrator drowning cable did not work after the initial explosion.

7. The "Deadman" Bi-oil feed valve for #1 nitrator was found after the explosion in a partially open condition.

8. Striation and configuration of the #1 nitrator and "A"-frame indicate the presence of a small quantity of explosives which was detonated within the nitrator. This was the initial explosion.

9. Heavy missiles which were projected farthest were positively identified as parts of the Bi-oil tank assembly. Pieces of the Bi-oil tank proper were smaller and showed striation which indicates that they were intimate with the high order detonation.

10. Substantial structural damage was sustained by Buildings 802-14 Tri-house, 806-14 Wash House, 819-7 Change House, and 807-14 Conveyor.

11. The SOP was not followed regarding the drowning of charges and evacuation of personnel on Lines 13, 14, and 15.

12. The Domestic Emergency Plan was never formally initiated.

13. Spectators and Firefighter Guards approached to less than the 1000 foot limit concerning fires of Symbol 4 material as specified in AMCR 385-224.

CONCLUSIONS:

The #1 nitrator operator had completed the addition of acid to the nitrator with the cooling water and agitation on. An approximate 8 minute unexplained time interval allowed the acid to cool to 168° (27° below normal). Since applying steam to raise the temperature in accordance with the SOP would take 15 to 20 additional minutes, thereby making the charge even further out of cycle, he decided to take a "shortcut." To do this, he added a quantity of Bi-oil to the acid to "heat it up." Observing no immediate result, he continued to add Bi-oil. When the reaction occurred, an extremely rapid temperature rise took place resulting in a low order detonation.

RECOMMENDATIONS:

1. That the #1 nitrator operator be prohibited from working in any explosive operation.

2. The SOP should be reviewed with all TNT personnel to assure future compliance.

3. A study should be initiated to determine the feasibility of either providing a

drowning line or a venting system for the Bi-oil scale tank.

4. Installation of the proposed temperature actuated automatic nitrator drowning devices should be expedited.

5. Consideration should be given to the possible installation of a computerized sequential process control system similar to that presently in use at DuPont's Barksdale, Wisconsin TNT plant.

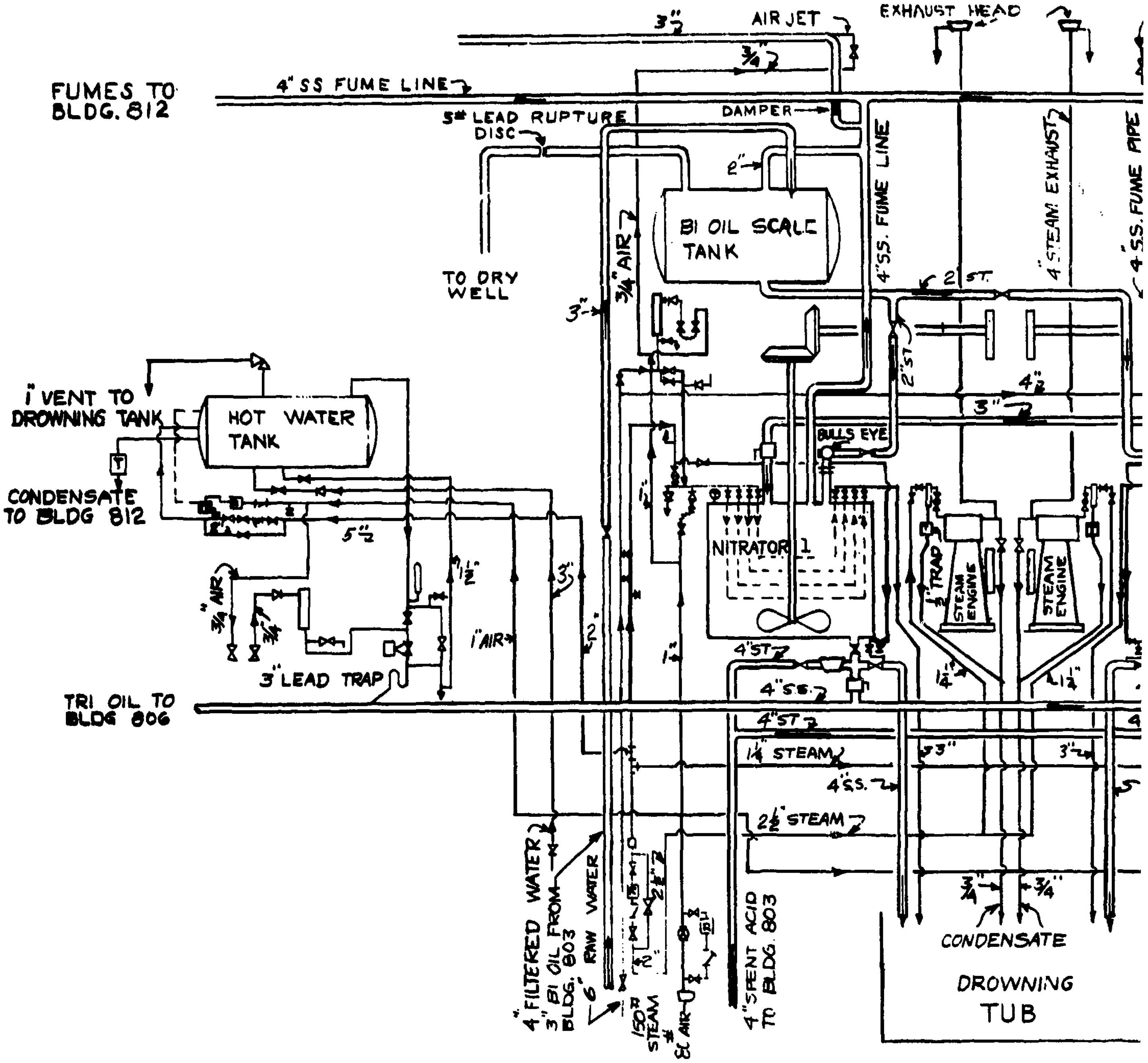
6. Consideration should be given to installing a manual (dry) deluge system to supplement the present heat actuated type.

7. That practice emergencies be staged to test our facility for handling disaster situations.

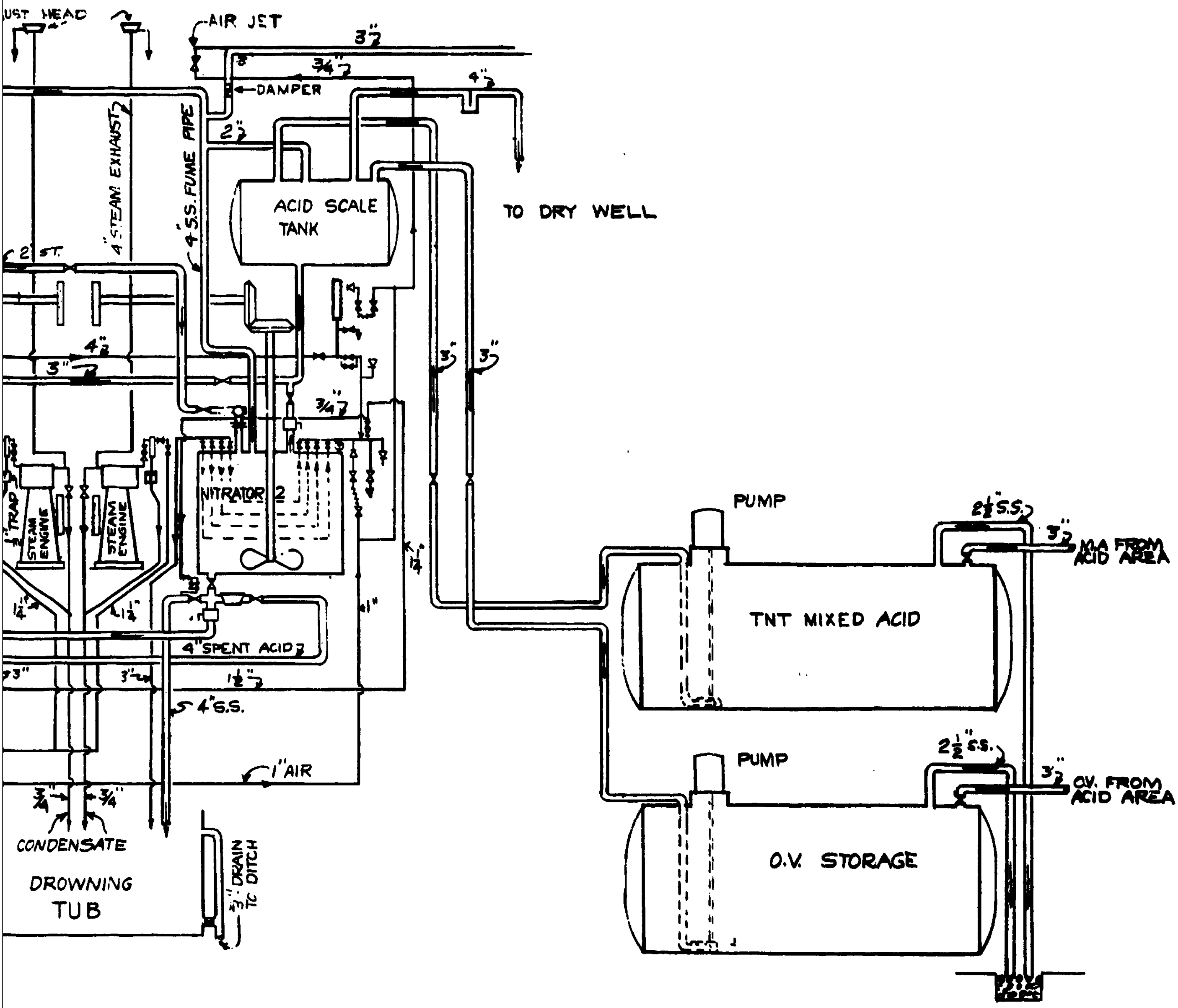
8. That the Domestic Emergency Plan be initiated in situations as severe as the subject of this report.

9. That badges be marked to facilitate better personnel control.

10. That a plan be developed to facilitate coordination with local emergency service groups.


3"
AIR JET
3/4"
EXHAUST HEAD
FUMES TO BLDG. 812
4" SS FUME LINE
DAMPER
5# LEAD RUPTURE DISC
2"
BI OIL SCALE TANK
3/4" AIR
4" SS. FUME LINE
4" STEAM EXHAUST
4" S.S. FUME PIPE
TO DRY WELL
3"
2" ST.
2" ST
4"
3"
1" VENT TO DROWNING TANK
HOT WATER TANK
CONDENSATE TO BLDG 812
5"
BULLS EYE
NITRATOR 1
1"
1 1/2"
3"
3/4" AIR
3/4"
1" AIR
2"
1"
1/2" TRAP
STEAM ENGINE
STEAM ENGINE
3" LEAD TRAP
4" ST
4" SS
1 1/4"
1 1/4"
TRI OIL TO BLDG 806
4" ST
1 1/4" STEAM
3"
3"
4" SS.
2 1/2" STEAM
4" FILTERED WATER
3" BI OIL FROM BLDG. 803
6" RAW WATER
150# STEAM
2 1/2"
2"
RV
SL AIR
4" SPENT ACID TO BLDG. 803
3/4"
3/4"
CONDENSATE
DROWNING TUB

A.



TRI- HOUSE
FLOW SHEET
21

B.

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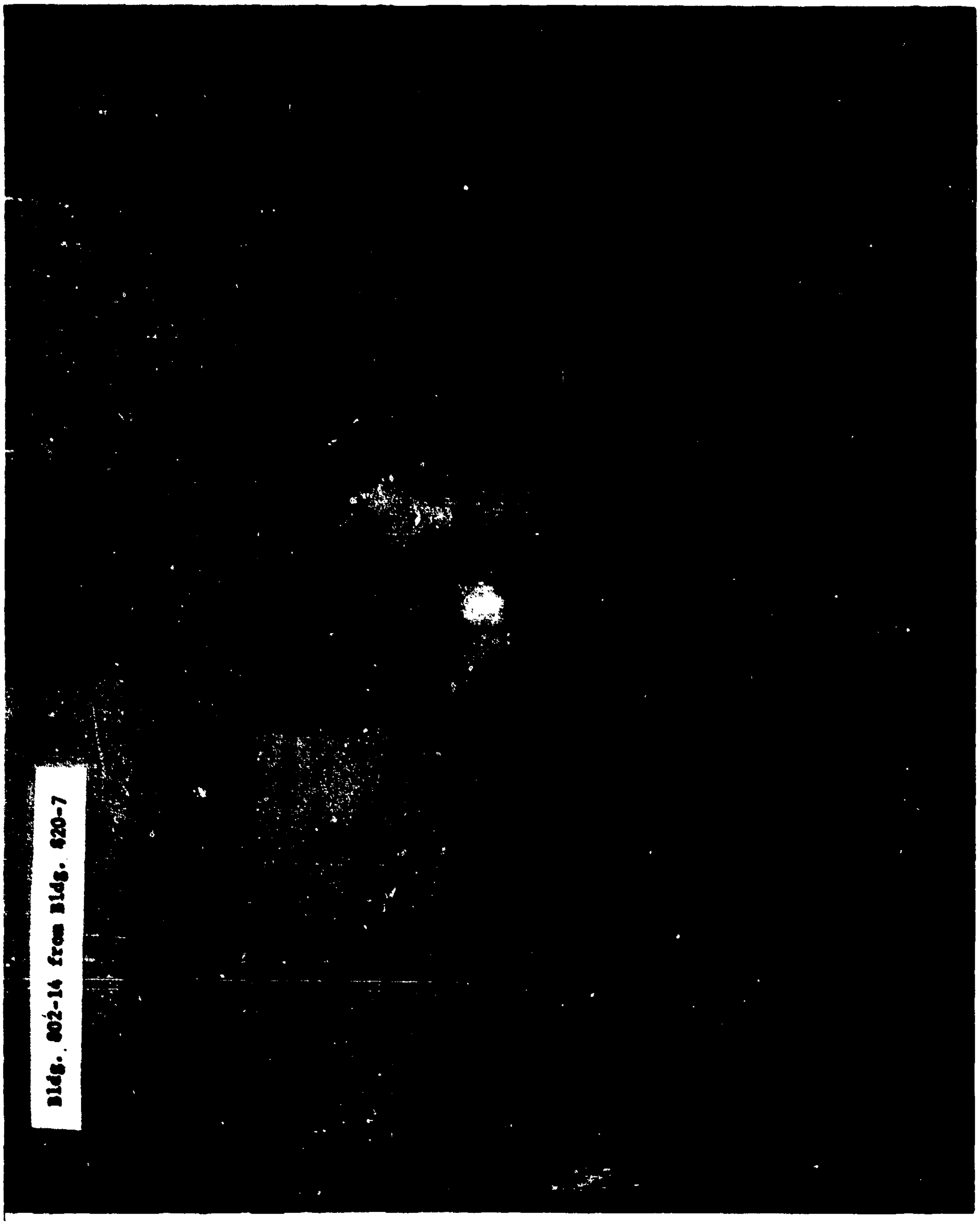
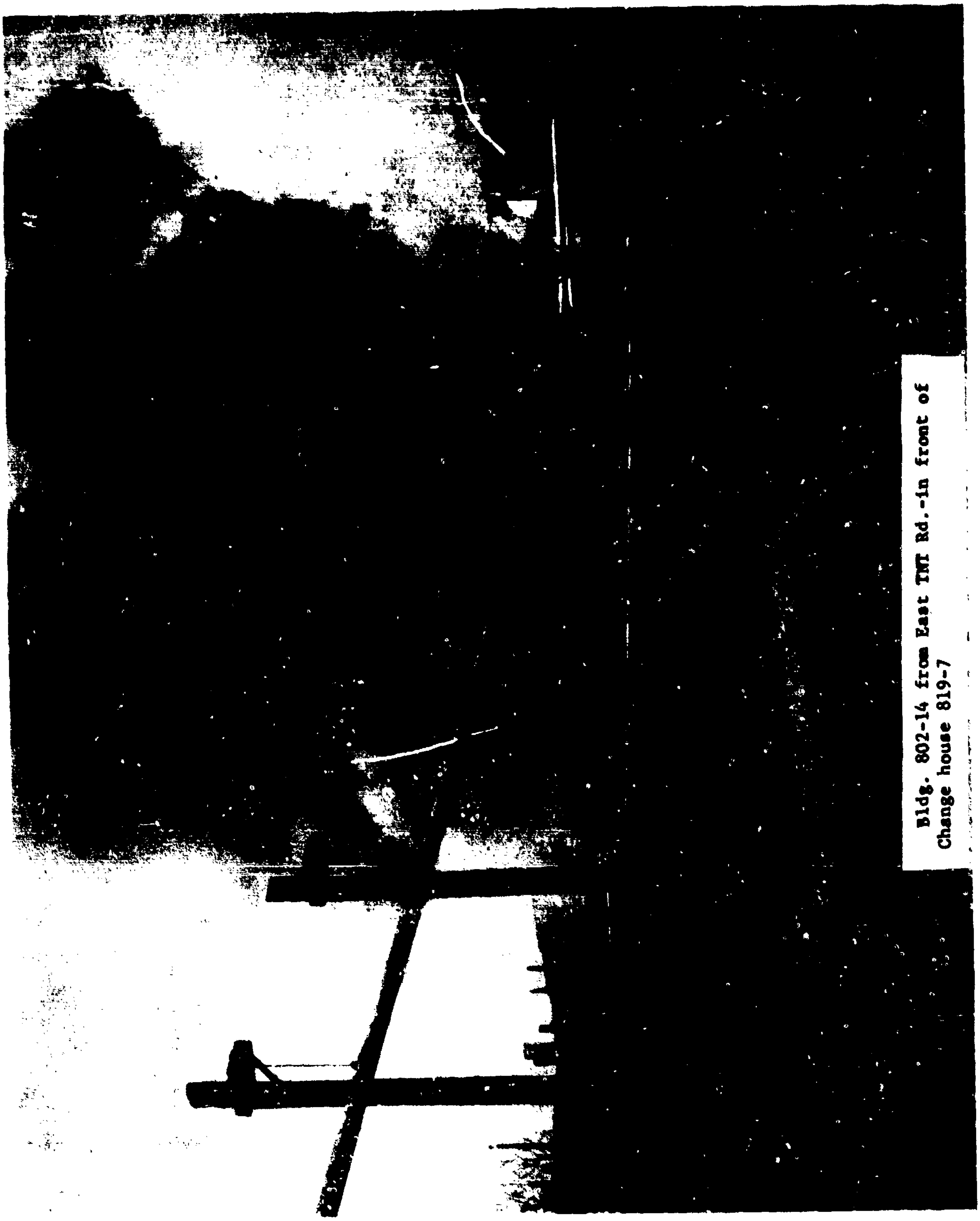
Bldg. 802-14 from East TNT Rd.


Bldg. 802-14 from Bldg. 820-7

Bldg. 802-14 from the east



Bldg. 802-14 from East TNT Rd.-in front of Change house 819-7

Looking at 802-14 from the north side of 806-14
North barricade of 806-14 in right background.

ACCIDENT REPORT
(AR 385-40)

REPORT TYPE
☒ INITIAL ☐ SUPPLEMENTAL ☐ CORRECTION

FILE IDENTITY (FOR CODER USE)

ITEM 4	ITEM 3	ITEM 5
I D	W O L N	0 1 4

REPORTS CONTROL SYMBOL CSGPA-147(R3)

1. THRU:

2. TO: (Office of Coding)
U. S. Army Safety Director
Badger Army Ammunition Plant
Baraboo, Wisconsin

3. FROM: (Unit or Activity and Address)
Olin Mathieson Chemical Corp.
Energy Systems Division
Badger Army Ammunition Plant
Baraboo, Wisconsin WULN

SECTION A - ACCIDENT IDENTIFICATION

4. COMMAND: U. S. Army Munitions Command

5. REPORT NO.: 014

6. TIME AND DATE OF ACCIDENT

a. HOUR	b. DAY OF WEEK	c. DAY	d. MONTH	e. YEAR
0221	Tuesday	22	April	1969

7. EXACT LOCATION OF ACCIDENT
Explosion at Building 1996-12
Fire at Building 1996-11
Both Hydro Jet Houses in Smokeless Powder, Solvent Recovery Area

8. TYPE OF ACCIDENT COVERED BY THIS REPORT (Check one) ☐ a. ARMY AIRCRAFT ☐ b. ARMY MOTOR VEHICLE ☐ c. NON-ARMY MOTOR VEHICLE ☐ d. MARINE ☐ e. FIRE ☒ f. OTHER (Specify) Explosion and fire

9. THIS ACCIDENT WAS INCIDENT TO OPERATIONS OR ACTIVITIES OF: (Check one)
☐ a. ARMY ☐ b. NON-ARMY ☐ c. BOTH ARMY AND NON-ARMY ☒ d. ARMY CONTRACTOR

10. COMPLETE ONLY IF ARMY AIRCRAFT (8a) ARE INVOLVED
a. TYPE OF AIRCRAFT: ☐ FIXED WING ☐ ROTARY WING ☐ OTHER TYPE
b. ACCIDENT WAS: ☐ MAJOR ☐ MINOR (See Section IV, AR 385-40)

SECTION B - PERSONNEL INVOLVED

REF NO	11. NAME (Last-First-Middle Initial), SERVICE NO. (Military personnel) OR SOCIAL SECURITY NO. (Civilian personnel)	12. ADDRESS	13. AGE	14. SEX
1	None			

15. MILITARY OR CIVILIAN GRADE

16. CHECK APPROPRIATE BLOCK TO DENOTE CLASSIFICATION AT THE TIME OF THE ACCIDENT ☐ a. ACTIVE ARMY
b. ARMY RESERVE: ☐ ACTIVE TRAINING ☐ RESERVE TRAINING ☐ c. ROTC ☐ d. NATIONAL GUARD
☐ e. ARMY CIVILIAN EMPLOYEE ☐ f. ARMY CONTRACTOR EMPLOYEE g. FOREIGN NATIONAL EMPLOYEE: ☐ DIRECT HIRE
☐ CONTRACT HIRE ☐ h. DEPENDENT ☐ i. OTHER (Specify)

17. WAS THIS PERSON ON DUTY AT THE TIME OF THE ACCIDENT? (Army only)
☐ a. YES ☐ b. NO

18. IF ITEM 17 IS "NO," WHICH OF THE FOLLOWING DESCRIBES THE STATUS OF THIS PERSON?
☐ a. ON LEAVE OR PASS ☐ b. AWOL ☐ c. OTHER OFF-DUTY STATUS

19. AT THE TIME OF THE ACCIDENT THIS PERSON WAS -
☐ a. ON POST ☐ b. OFF POST ☐ c. PCS TRAVEL ☐ d. TDY

20. IF ON DUTY, HOW MANY HOURS WAS THIS PERSON ON CONTINUOUS DUTY PRIOR TO THE ACCIDENT?

21. (MILITARY PERSONNEL ONLY) WAS THIS PERSON PERFORMING AN ACT OR ACTS INCIDENT TO TRAINING? (If "Yes," specify type of training)
☐ YES ☐ NO

22. WHAT ACTIVITY WAS BEING PERFORMED BY THE INDIVIDUAL AT THE TIME OF THE ACCIDENT?

23. INDICATE THE SEVERITY OF INJURIES TO THIS PERSON BY CHECKING ONE OF THE FOLLOWING: ☐ a. FATAL
☐ b. LOST TIME - PERMANENT HANDICAP - MAY NEVER WORK ☐ c. LOST TIME - PERMANENT HANDICAP - BUT CAN WORK
☐ d. LOST TIME - TEMPORARILY UNABLE TO DO ANY WORK ☐ e. NO LOST TIME - MAY NOT BE ABLE TO PERFORM REGULAR DUTIES TEMPORARILY
☐ f. FIRST AID ONLY ☐ g. NO INJURY ☐ h. UNKNOWN

24. NO. OF DAYS LOST FROM INJURY (Est)	25. INJURY (Explain, continue in Item 29 if necessary) a. NATURE	b. LOCATION	c. CAUSE

SECTION C - EQUIPMENT OR PROPERTY DAMAGED

LINE NO.	26. IDENTIFY ALL DAMAGED EQUIPMENT OR PROPERTY BY NAME, TYPE, MODEL, ETC. (Use Item 29, if necessary)	27. OWNERSHIP	28. ESTIMATE OF TOTAL DAMAGES (Labor and Parts)
1	Bldg. 1996-11 & Bldg. 1996-12 Hydro Jet Buildings Rogers 5 Ton Locomotive, narrow (36") gauge, 1957 model USA CO 27, Serial 107; Flat Car, narrow gauge	U. S. Army	$182,325
2	(Safety Car) USA CO 157, CO 205 & CO 206 Loco. OB 552, Safety Cars OB 2486, OB 2564 & OB 2566		
3			

IF ADDITIONAL SPACE IS REQUIRED FOR REPORTING MORE PERSONS, USE CONTINUATION SHEET, DA FORM 285-1.

DA FORM 1 APR 65 285

REPLACES EDITION OF 1 APR 61, WHICH IS OBSOLETE, EFFECTIVE 1 JULY 1965.

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SECTION D - NARRATIVE AND CORRECTIVE ACTION

29. GIVE A WORD PICTURE EXPLAINING THE WHO, WHAT, WHERE, WHEN, WHY AND HOW OF THE ACCIDENT. SUCH ITEMS AS WEATHER, EQUIPMENT, UNSAFE MECHANICAL OR PHYSICAL CONDITION, UNSAFE ACTS, AND UNSAFE PERSONAL FACTORS SHOULD BE INCLUDED *(Continue on blank sheets, if necessary)*

See Attached Sheet

30. STATE CORRECTIVE ACTION(S) TAKEN *(actual or anticipated)* TO PREVENT A SIMILAR ACCIDENT

None at this time, pending the findings of the Board of Investigation.

	a. PRINTED NAME AND TITLE	b. DATE	c. SIGNATURE
31. PREPARED BY	R. E. Johnson Safety Services Superintendent	29 April 1969	R. E. Johnson
32. REVIEWED AND APPROVED BY	J. DalSasso Resident Manager	Apr. 30, 1969	J DalSasso

SECTION E - ACCIDENT ANALYSIS DATA *(THIS SECTION TO BE COMPLETED BY CODER)*

33. ACCIDENT IS ☒ a. RECORDABLE ☐ b. NONRECORDABLE
(Recordable accidents will be forwarded to the appropriate Data Processing Activity for DA Processing)
(Nonrecordable accidents may be processed for local use only)

34. DID THE WEATHER HAVE ANYTHING TO DO WITH THE ACCIDENT? ☐ a. YES ☒ b. NO *(If "YES," what weather conditions existed?)*

35. CHECK THE SUPERVISORY OR MANAGERIAL ACTION THAT MIGHT HAVE BEEN TAKEN TO HELP PREVENT THE ACCIDENT: Under investigation at the present.

☐ a. IMPROVED SUPERVISION ☐ b. USE OF PROPER EQUIPMENT OR MATERIEL ☐ c. BETTER PLANNING
☒ d. MORE OR IMPROVED INSTRUCTION ☐ e. OTHER SUPERVISORY ACTION N.E.C. ☐ f. NONE

36. ENTER THE AGENCY *(Tool, material, machine, vehicle, or substance)* MOST CLOSELY ASSOCIATED WITH THE ACCIDENT

Single Base Propellant M1 Chg Propelling M1 (GB) for 8" how.

37. *(COMPLETE ONLY IF AN ARMY MOTOR VEHICLE ACCIDENT IS REPORTED)* SPECIFY TYPE OF VEHICLE COLLISION

38. WERE THERE ANY UNSAFE MECHANICAL OR PHYSICAL CONDITIONS ASSOCIATED WITH THE ACCIDENT? ☐ a. YES ☐ b. NO
(If "Yes," list the primary condition)

Unknown - pending findings of the Board of Investigation.

39. WERE THERE ANY UNSAFE ACTS COMMITTED BY THE PERSON IDENTIFIED IN SEC B, REF NO. 1? ☐ a. YES ☐ b. NO
(If "Yes," identify the unsafe act)

ACT: Unknown - pending findings of the Board of Investigation

40. WERE THERE ANY UNSAFE PERSONAL FACTORS ASSOCIATED WITH THE PERSON IDENTIFIED IN SEC B, REF NO. 1? ☐ a. YES ☐ b. NO
(If "Yes," identify the personal factor)

FACTOR: Unknown - pending findings of the Board of Investigation.

	a. PRINTED NAME AND TITLE	b. DATE	c. SIGNATURE
41. ANALYZED BY	Wm. N. CLAYTON Army Safety Director	2 May 69	
42. REVIEWED AND APPROVED BY	RUSSELL O. ENOCH, LTC, OrdC Commanding	2 May 69	Russell O Enoch

SUPPLEMENT TO DA FORM 285 ID WOLN 014

Olin Mathieson Chem. Corp.
Energy Systems Division
Badger Army Ammo. Plant
Baraboo, Wisc.

Item 29.

At 0221, 22 April 1969, an explosion of moderate force occurred in a slurry delivery pipe connecting Hydro Jet, Building No. 1996-12, and Water Dry, Building No. 1650-16. A shard of this pipe, either covered with burning material or at red hot heat fell in a buggy of wet 8 inch cannon powder parked alongside Hydro Jet Building 1996-11 approximately 300 feet from the explosion. This piece of pipe burned through the canvas cover and ignited the powder in the buggy. The fire quickly spread to powder in buggies on the tram and in Building 1996-11.

Building No. 1996-12 had last been used for the slurry transport, to Building 1650-16, of 8 inch cannon powder.

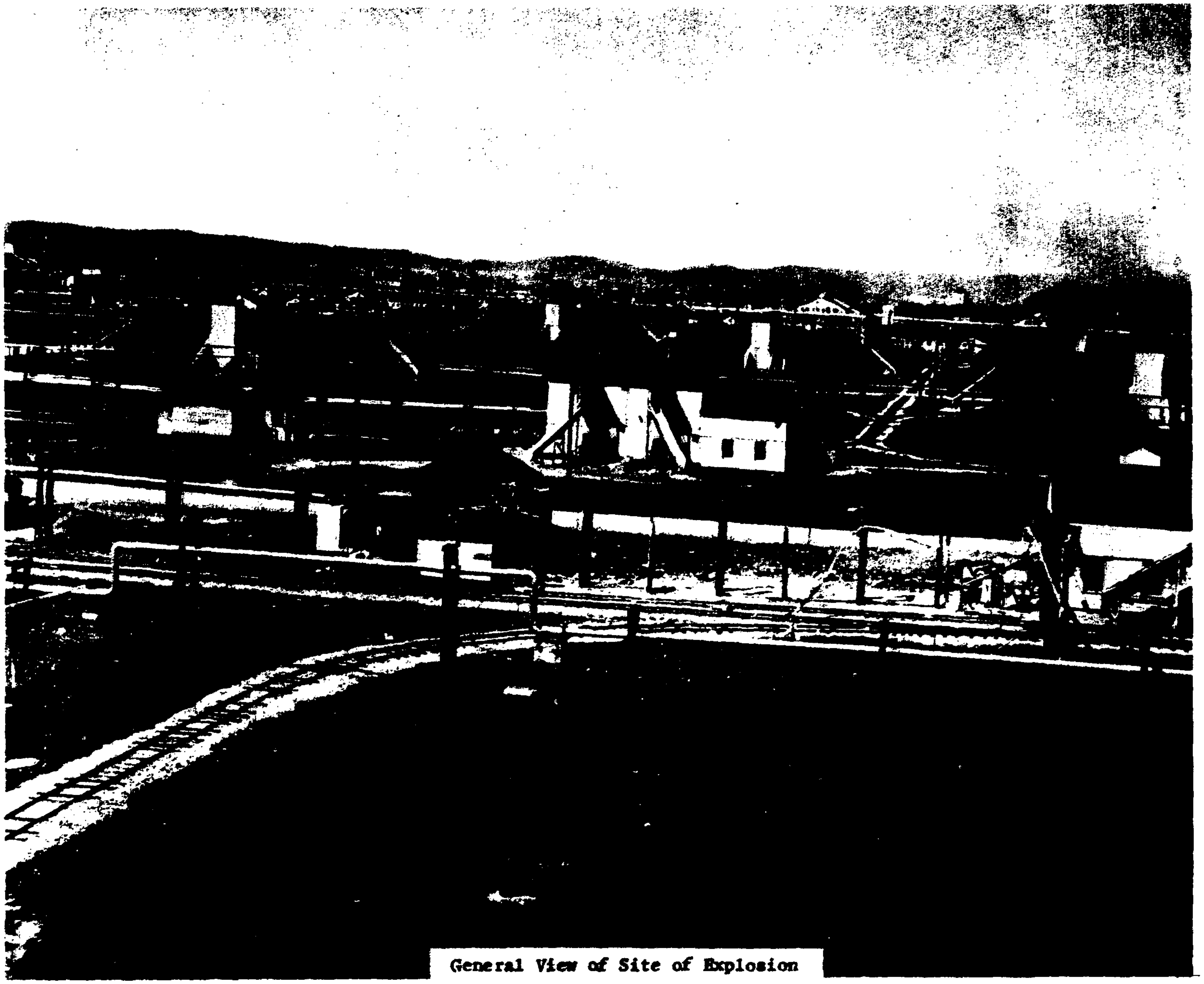
The explosion extensively damaged Bldg. 1996-12, slightly damaged Building 1650-16, completely destroyed the piping array between these buildings and broke some windows in nearby structures. Pieces of pipe, flanges, and pipe hangers, etc. were blown over a substantial area. There were no personnel present at the time of the explosion. There was no evidence of fire, there was no crater, and fragments were generally of substantial size.

The fire completely gutted Bldg. 1996-11. Tram engine and Safety Car No. OB 553 were slightly scorched. Tram Cars OB 2566 and 2564 and 12 smokeless powder buggies were substantially damaged.

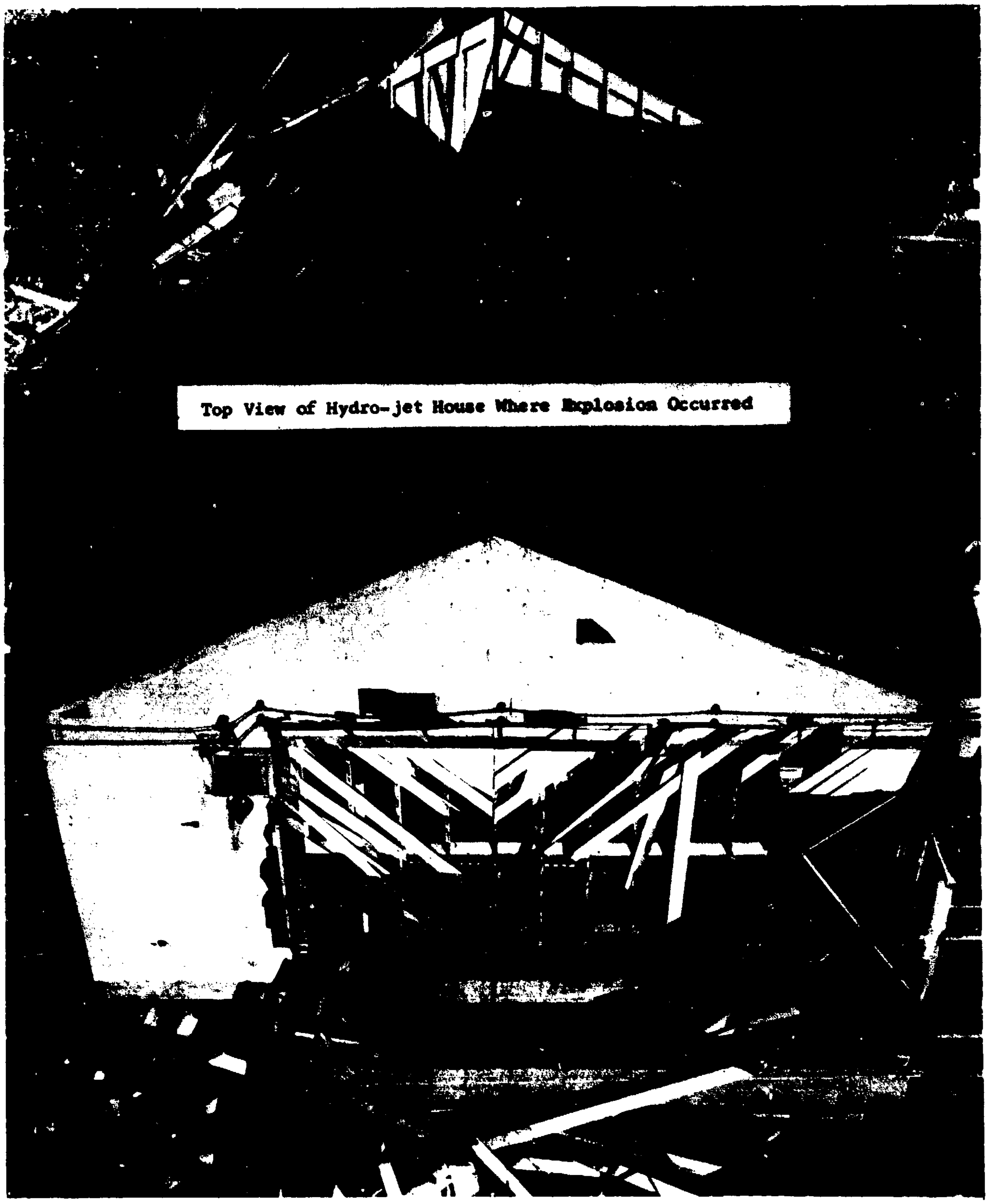
Two employees in this building were able to evacuate before fire enveloped the building. Efforts of firefighters confined fire damage to Bldg. 1996-11 and the tram train alongside.

Weather was clear, a slight breeze blowing from the N.W. assisted control of fire damage.

This accident is being investigated and will be further reported on by a Board of Investigation.



General View of Site of Explosion

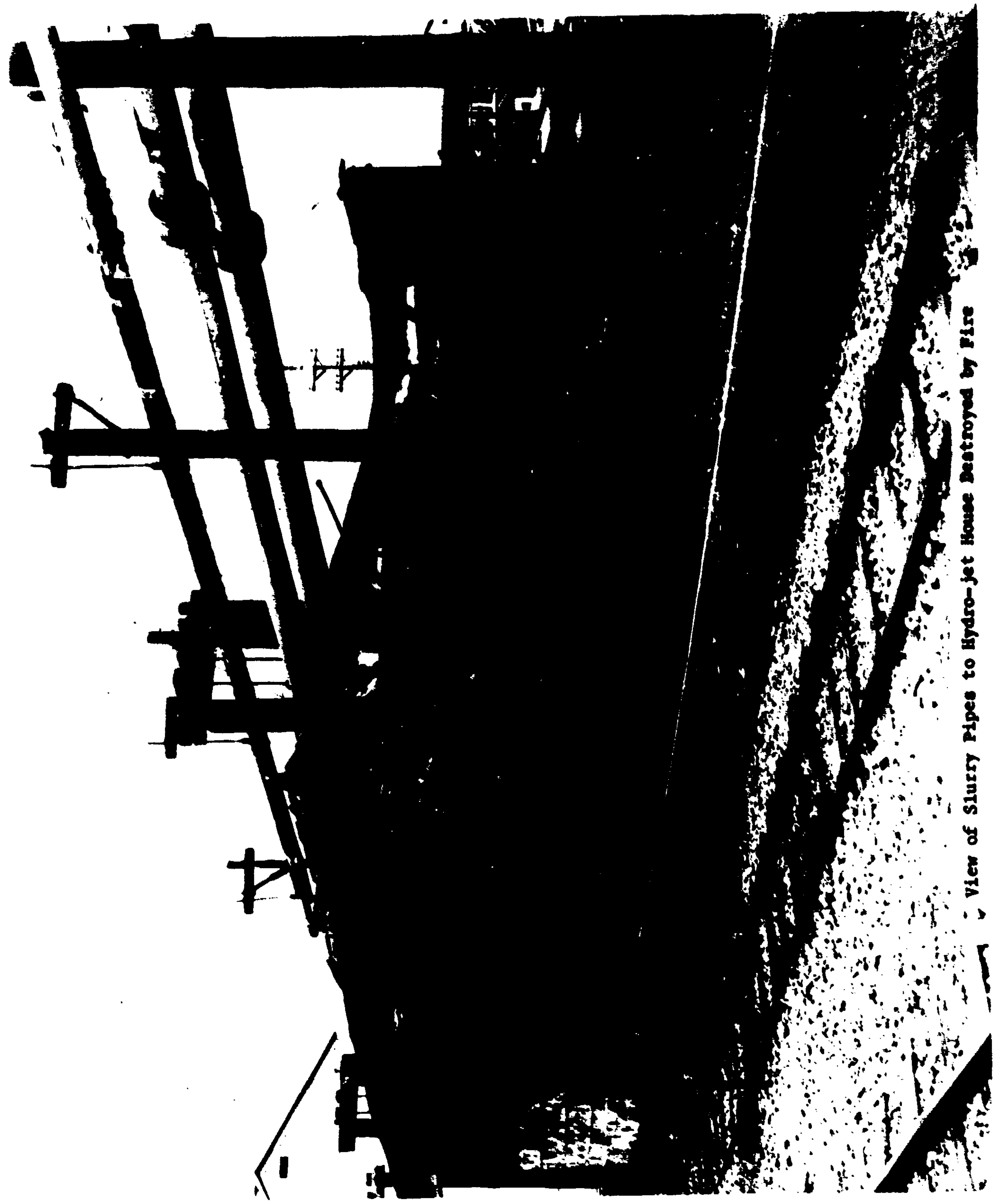


Top View of Hydro-jet House Where Explosion Occurred

View of Poles Used to Support Slurry Pipe Bridge

Shrapnel From Pipe Struck Escape Chute

View of Hydro-jet House Destroyed by Fire



View of Slurry Pipes to Hydro-jet House Destroyed by Fire

Interior View of Hydro-jet House Destroyed by Fire Showing Tram Cars

Piece of Pipe Shrapnel in Tram Car Which Caused Secondary Hydro-jet House Fire

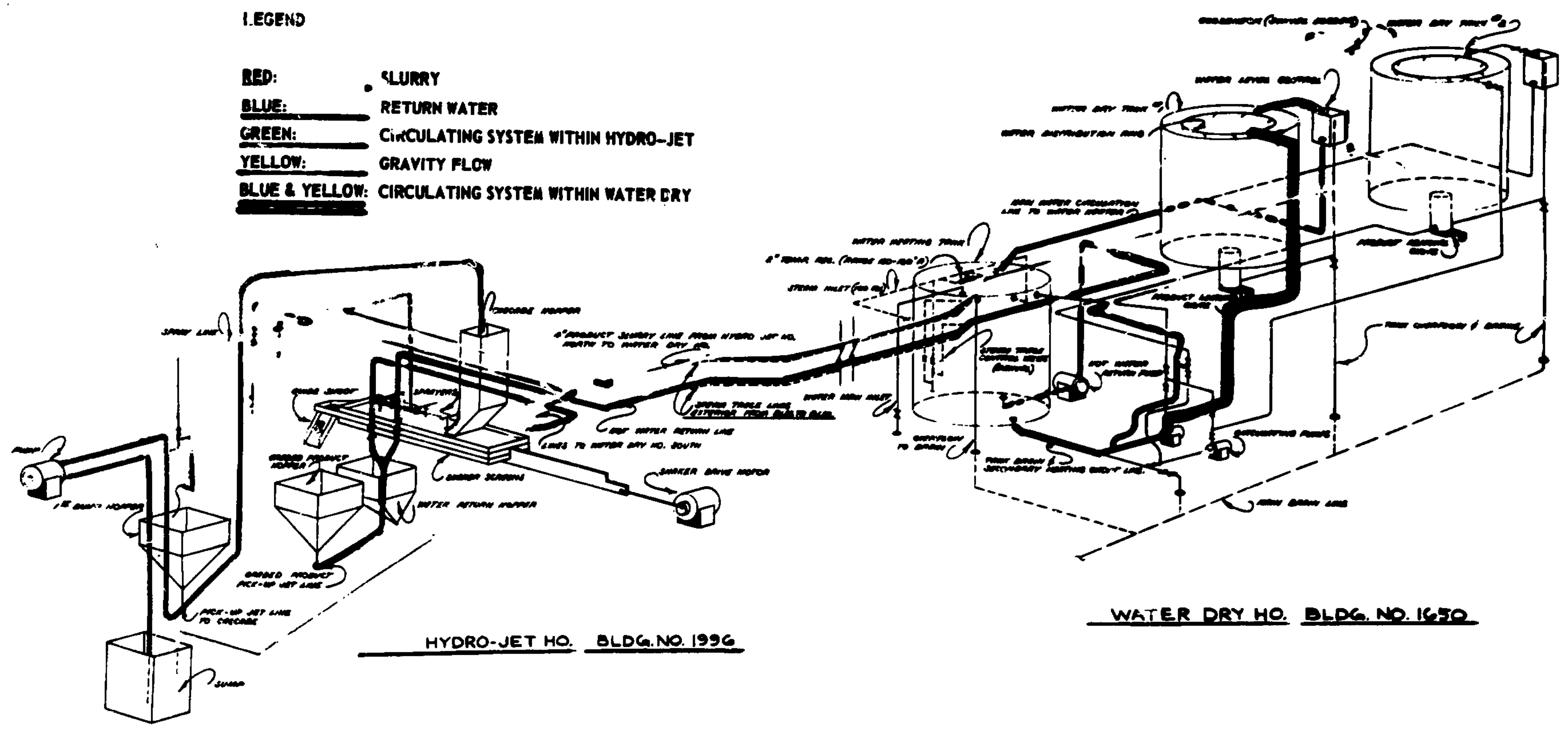


Diagram-Schematic of Piping-Transfer System Used in Propellant Manufacturing

Mr. Johnson's Notes

A hydro jet transfer of 8" single perf. charge, propelling, M1 Green Bag was carried out on 20 April.

M-1 powder is small, size 1/4 1(x 1/20 diam., .224" long x .051 single perf. Army Class 2A.

The transfer line was, or did not completely flush - there were substantial quantities of powder all along it.

Powder was in slurry line 34 hours exposed to tracer line heat.

A burning or heated shard of pipe, 12 lbs. in weight, was blown 302 feet landing directly in a buggy of 600 pounds of powder at Building 1996-11, another water jet, which was subsequently destroyed by fire.

Buggies on flat cars (tram), 4 full and 2 empty on that car, 6 full on next, 2 were in the house. All, about 6,000 pounds, were burned.

Powder dumped into floor dumping hopper. Picked up by water jet and put on Robinson Shaker screen. Screened off material goes to a catch hopper and is recovered as rework. Good goes to a hopper and is jetted to water dry house. Water temperature 65° C.

Two water dry houses and one jet house form a unit.

Water dry houses have two tanks of 50,000 pound capacity - 9 ft. wide stainless steel or wood, a surge tank, circulating pump, and hydro jet pump.

Pump in the jet house to take powder from floor hopper to screen is a 450 GPM 150 ft. head pump driven by 25 HP motor.

Pump to jet is located in water dry house - 60 HP, 450 GPM, 150 ft. hd.

The water dry circulating pump is small - 3 HP and circulates water from surge tank (injection heated) back to water dry preparation.

Investigation disclosed that slurry lines do not always flush clean (slurry line from hydro jet 1996-12 to the water dry to the south had about 1 pound of powder in it).

Flushing was advised and SOP stated carried out until they got a clean stream of water.

Slurry line open at water dry - over goose necks, and can be closed off at hydro jet.

Tracer line temp. 85# - 90# approx. 325°F. 162°C.

Water boils 100°C. 212 F.

Ether (ethyl ether 34.6 C auto ignition
ethyl alcohcl 78.32C 360°C

Some powder taken from the pipe section as it entered water dry had stability test of 15 minutes vs 40 acceptable.

110°C temp. of stability test

Slurry pipe 4" diameter

Steam tracer 1/2" diameter were banded together.

Insulated with 6" of asbestos - covered with aluminum sheet.

DOD CONTRACTORS' SAFETY MANUAL FOR AMMUNITION, EXPLOSIVES & RELATED DANGEROUS MATERIAL

Moderator:

W. J. Baldwin
Defense Contract Administration Services
Defense Supply Agency
Alexandria, Va.

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SUMMARY

The session was devoted to the discussion of the problems associated with the DoD Contractors' Safety Manual for Ammunition, Explosives and Related Dangerous Material (DoD 4145.26M) and Armed Services Procurement Regulations 7-104.78, 79 and 80, titled "Health and Safety Clauses."

The session began with a review of the history of the DoD 4145.26M and the ASPR Clauses. Mr. Baldwin explained that defense contractors appealed to the Secretary of Defense in 1965 to develop a single document containing the safety requirements to be used in connection with contracts being let by all three military services. A Department of Defense Task Force I headed by the late Hy Ackerman was formed to develop a single DoD Contractors' Safety Manual for Ammunition, Explosives and Related Dangerous Material. The Task Force I was also charged with developing the ASPR clauses which were necessary in contracts to require compliance with DoD 4145.26M. Following the death of Mr. Ackerman, the DoD appointed Mr. Romie Kieke of the ASESB to be the Task Force leader. Task Force I completed its work, and in October 1968 DoD 4145.26M was printed. The ASPR Clauses requiring compliance with DoD 4145.26M were promulgated by Defense Procurement Circular (DPC) No. 65 dated 20 Dec 68 and subsequently formally incorporated in the ASPR on 31 Mar 69 with some changes.

After the clauses appeared in contracts, many complaints were received by Contracting Officers, Contract Administration Offices, and the Department of Defense concerning the clauses and the manual. DoD Task Force II was organized under LTC Dan Wilson, USA, ASD(I&L), to develop a workable ASPR clause. The DoD Task Force II reviewed the complaints of the services, industrial representatives and the Council of Defense and Space Industries Association (CODSIA) and made certain recommendations to the Chairman of the ASPR Committee. The DoD ASPR Committee reviewed the recommendations of Task Force II and finalized the proposed changes to the ASPR. These were sent to industry by Captain E. C. Chapman, SC, USN, Chairman of the ASPR Committee, ASD(I&L). In discussing the matter, Mr. Baldwin said that the DoD and services recognized certain inadequacies of DoD 4145.26M and it was in need of revision. He said a DoD Task Force III would be formed to receive modifications of DoD 4145.26M.

Mr. Mitchell expressed the appreciation of CODSIA for the opportunity to present industry views on the ASPR clauses and DoD 4145.26M. He stated he had received the 2 Sep 69 letter from the Chairman of the ASPR Committee which forwarded the proposed new clauses. He said he received the letter a short time before departing for Memphis, and CODSIA did not have an opportunity to prepare a position in time for the 11 September Explosive Safety Seminar. He confined his remarks to the existing ASPR clauses and DoD 4145.26M.

Mr. Mitchell first discussed industry's objections to the original clauses. His main points were:

a. The manual was entitled DoD Contractors' Safety Manual for Ammunition, Explosives and Related Dangerous Material, but the ASPR Clauses which required the use went beyond this parameter and included ammunition, explosives and other dangerous materials or materials hazardous to the health of humans, animals or plant life and in any other contract when the Contracting Officer deemed it necessary. The CODSIA position was that this was an improper extension of DoD 4145.26M.

b. The Clauses contained many references to MIL STDs and specifications which were incorrect or inappropriate.

c. The Clauses were open ended in that they were minimum requirements and the contractors were bidding on an "unknown quantity."

d. That the Clauses stated that noncompliance with state and local laws would result in the contractors being forced to stop work and be subject to penalties.

e. The stop work provisions of the Clauses did not provide for equitable adjustment within the parameters of the disputes clauses of ASPR.

f. The provisions in the Clauses to hold the Government free of responsibility in all cases was not contractually sound and made obtaining insurance difficult, if not impossible in some cases.

Mr. Mitchell said he was unable to discuss in detail all the deficiencies in DoD 4145.26M but felt that the manual should be modified. These included:

a. Section 104 should be modified to permit facility-wide agreement on waivers rather than a contract by contract agreement. He pointed out the existing health and safety practices including other contractual, legal requirement or exempt under either the Walsh-Healey Act or state or local laws are permitted by Section 104, and this should be incorporated in the ASPR Clauses.

b. That deviation should be made a matter of record and a copy forwarded to the ACO.

c. That there was a paradox in the manual where compliance with referenced "publication" and standardization was required. Then in case of differences between the publication and standards and the DoD 4145.26M, the manual would be the final operational authority.

Mr. Baldwin stated that DoD recognized that the Clauses and the manual needed revision. He told how Task Force II had recognized many of the problems discussed by Mr. Mitchell. The following specific points were made:

a. Task Force II recommended revised clauses which:

(1) were restricted to ammunition and explosives and the ASPR Committee accepted the proposed revised clauses.

(2) excluded inert items.

(3) eliminated ASPR 7-104.78 related to health and the objectionable enforcement provisions described by CODSIA.

(4) defined radioactive materials (ASPR 7-104.80).

(5) defined what accidents had to be reported and investigated.

(6) eliminated many references to which CODSIA had objected.

(7) eliminated the open-ended provisions of the Clauses.

(8) established that it was the contractors' responsibility to comply with appropriate laws, ordinances and codes and the DoD had no intent to enforce local or state laws.

(9) modified the stop-work section to permit adjustment in case of an improper stop-work order.

b. That changes to ASPR Clauses could be sent to the Chairman, ASPR Committee, Department of Defense, Washington, D. C., thru military channels via the military department ASPR representatives. Industry could send recommended changes directly to the Chairman or through their industrial association.

c. DoD 4145.26M is undergoing changes. Suggested changes should be send to the Chairman, Armed Services Explosives Safety Board through military department channels. Industry may send their recommendations directly to the Chairman, ASESB, through their industry association or through the Contracting Officer with whom they have contracts. Changes in the following areas are needed but by no means the only subjects to be considered: (1) introduction, (2) responsibilities, (3) waivers and exemptions, (4) site and construction plan review, (5) definitions, (6) environmental pollution, etc.

COMMENTS AND DISCUSSIONS FROM THE FLOOR:

1. An industry representative stated a new DPC will soon be out stating ASPR 7-104.78 (Health and Safety) and 7-104.79 will be limited to ammunition and explosives.

MODERATOR RESPONSE - He understood that a DPC was in preparation but was unable to comment on it until he studied it.

2. An industry representative stated when the DPC is published, will that take precedence over the contract?

MODERATOR RESPONSE - No. The contract governs the work requirements and specifications to be followed. The contractor will have to comply with the terms of his contract until such time as the contract is modified.

3. An industry representative asked when contracts are amended there is usually an increase or decrease in the contract price. What will happen in this case?

MODERATOR RESPONSE - This is a matter between the contractor and the Contracting Officer, and is governed by ASPR.

4. A Government representative asked why does industry object to the manual when they asked for it in the first place?

SUMMARY OF RESPONSE FROM SEVERAL INDUSTRY REPRESENTATIVES - Industry does not object to the manual, we object to the ASPR Clauses which are not contractually sound and need revision.

MODERATOR RESPONSE - In all the moderator's conversations with industry, no significant objection was ever made, but many complained about the ASPR clauses.

5. Industry representative asked why DoD is requiring safety requirements? Why not let the Walsh-Healey people enforce the laws?

GOVERNMENT REPRESENTATIVE RESPONSE - The requirements for Safety of Government personnel and property and for timely completion of the product is an item of vital concern to DoD. The Walsh-Healey Act is generally limited to protection of the contractor's employee while they are engaged on Government contracts, and is not concerned primarily with the pre-award aspects of the contractor's facility, Government property or production schedules.

INDUSTRY REPRESENTATIVE RESPONSE - If DoD inspects, we don't need the Walsh-Healey inspector.

DEPARTMENT OF LABOR RESPONSE - The Department of Labor welcomes the assistance of DoD people in surveying contractors' plants and reporting significant violations to the Department of Labor for their enforcement. The Department of Labor has a limited force which precludes the frequent surveillance of all DoD contractors.

MODERATOR RESPONSE - The DoD does not intend to enforce the Walsh-Healey Public Contract Act. The contractor agreed to comply with the Walsh-Healey Act. If he fails to comply with this Act, the ASPR states the Department of Labor must be notified.

6. An industry representative stated the new Walsh-Healey Act referenced the three military services' safety manual and does not reference DoD 4145.26M.

DEPARTMENT OF LABOR RESPONSE - The next revision will reference DoD 4145.26M.

7. An industry representative commented that without pointing the finger at anyone it appears that there have been errors committed in the past, but it appears that everyone (industry, DoD and DCAS) now seems to be working to resolve the problems of the manual and ASPR clauses. It behooves all of us to work together to perfect these documents. We have been told how and we know when we must act, so let's get on with it.

MODERATOR RESPONSE - AMEN!

MANUAL "STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS"

Moderator:

W. P. Todsen
Omaha District, Corps of Engineers
U.S. Army
Omaha, Nebraska

DESIGN OF

THEATER RELIABILITY MONITORING FACILITY

by
Robert Selders
Omaha District, Corps of Engineers, Omaha, Nebraska

INTRODUCTION

This paper describes an application of the design procedures presented in the publication "MANUAL FOR THE DESIGN OF PROTECTIVE STRUCTURES USED IN EXPLOSIVE PROCESSING AND STORAGE FACILITIES" (Reference 1). A discussion is presented of the criteria and concepts associated with the design of a maintenance and reliability evaluation facility for the Improved Hawk missile. The facility is the Theater Reliability Monitoring Facility scheduled for construction this fall at the Pueblo Army Depot, Pueblo, Colorado. Primary emphasis is placed on the structural elements that are designed to resist the effects of the maximum credible accidental explosion.

FACILITY DESCRIPTION

The completed facility as shown in Figure 1 is essentially two separate buildings having a common end wall. The nonexplosive operating portion that provides complete personnel protection is (approximately) a 49' wide by 70' long reinforced concrete building with an eave height of 11'. The explosive operating portion is (approximately) a 32' wide by 104' long rigid-frame metal panel building having an eave height of 14'. A full width 24' long covered loading dock serves the explosive operating portion of the structure. A 10' wide by 24' long covered passageway, centered at the junction of the two building parts, forms a traffic way between the personnel protected portion and the explosive operating portion. The combined floor area of the structure is about 7,100 square feet.

PURPOSE AND FUNCTION

The purpose of the facility is to inspect the Improved Hawk missile and check the reliability of the guidance system. Some repair to the guidance system in the form of modular replacement can be performed.

The function of the facility may best be described by the simplified sequence of operation discussed below:

(1) The Improved Hawk missiles in storage cans are delivered at the loading dock by truck or fork-lift. A two-ton electric monorail crane is used to remove a missile and can from the conveyance and transport it into the Inspection and Canning/Decanning Room.

(2) In the Inspection and Canning/Decanning Room the missile is allowed to reach room temperature if required. Then the missile and its ailerons are removed from the storage can. The storage can is set aside with the aid of the two-ton crane.

The exterior of the missile and its ailerons are inspected. The hoist is then used to transport the missile through the Air Lock into the Assembly and Disassembly Room.

(3) In the Assembly and Disassembly Room the guidance section of the missile is removed and the remainder of the missile inspected. The guidance section of the missile is transported by dolly thru the door of the Repair and Replacement Area.

(4) The guidance section of the missile is removed from the dolly with a one-half ton electric monorail crane and transported to the TRME Area where it is checked. It is then repaired as necessary.

(5) The above disassembly procedure is reversed to return the missile to its storage can and removed from the site.

DESIGN CRITERIA

The design criteria for this facility is similar to other government facilities of the office-warehouse type except for two important requirements:

(1) The areas between the airlocks (Figure 1) are designed as "clean areas" with the requirements of positive air pressure, special air filtration, and stringent temperature and humidity control.

(2) The Improved Hawk missile was determined by test to have an explosive equivalency for close-in design purposes of 400 pounds of TNT. Consequently, the explosive operating areas are of frangible construction to minimize the containment of an accidental explosion. All non-explosive operating areas except the Mechanical

Equipment Room are designed to provide complete personnel protection against the maximum credible accidental explosion that might occur in the explosive operating areas. The two explosive operating areas are separated by a blast wall designed to prevent propagation of an explosion between the Assembly and Disassembly Room and the Inspection and Canning/Decanning Room. The maximum post-failure fragment velocity allowed was 100 fps.

Design explosive loadings are based on a maximum of two missiles in the Assembly and Disassembly Room and four missiles anywhere in the Inspection and Canning/Decanning Room and the Loading Dock.

DESIGN

The major structural elements that are designed to resist the blast loading are:

(1) Dividing Wall between the Assembly and Disassembly Room and the Inspection and Canning/Decanning Room.

(2) Concrete Building which may be further broken down into the following elements:

- (a) Front Wall
- (b) Side and Back Walls
- (c) Roof

(3) Blast Door between the metal and concrete portions of the facility.

A discussion of each of the above items follows including the configuration of the missiles for the maximum credible accidental explosion that produces the worst loading condition, the blast loadings used for design purposes, and the maximum structural response allowed.

DIVIDING WALL

The reinforced concrete dividing wall (shown in Figure 2) was designed in accordance with the design procedures recommended in Reference 1 for a protection category 3 described to "Prevent communication of detonation by fragments and high blast pressures." The wall (shown in Figure 2) is of laced reinforced concrete construction, 1'-6" thick at the base and narrows to 1'-5" at a point about 7'-3" above the floor. The height of the wall extends to the underside of the roof panel for its entire length between the building side wall and the Air Lock. The wall is integrally connected to a one foot thick floor slab with a 1'-6" haunch on each side and extends two feet below the floor slab to develop the flexural and lacing reinforcement through bond.

Two loading conditions were investigated; two missiles in the Assembly and Disassembly Room and four missiles in the Inspection and Canning/Decanning Room. The position of the two missiles in the Assembly and Disassembly Room is well defined in a direction perpendicular to the wall by the position of the overhead monorails.

The position of the missiles in the Inspection and Canning/Decanning Room is not as celarly defined, therefore, an assumption of equal spacing seemed reasonable and probable considering the size of the missiles. In both cases the center of gravity of the explosive portion of the missiles was assumed to lie on a line perpendicular to the centerline of the wall for the maximum inpulse.

The wall was initially designed for the arithmetic sum of the impulses from the two missiles in the Assembly and Disassembly Room and the adequacy of the design checked against the pressure-time loading of the four missiles in the Inspection and Canning/Decanning Room. The impulses for the two missiles in the Assembly and Disassembly Room were computed from the geometry and explosive weights by the method presented in Reference 1 for close-in explosions. The wall was then designed for impulse with a 100 fps fragment velocity by the method in Chapter 7 of Reference 1. The resulting wall is 1'-6" wide with minimum reinforcement which consists of #6 reinforcing bars at 1'-0" on center vertically and #5 reinforcing bars for shear lacing and horizontally at 1'-0" on center.

To determine the pressure-time loading from the missiles in the Inspection and Canning/Decanning Room the missile furthest from the wall was assumed to detonate first. Calculations using the Gurney equation indicated that the initial velocity of the fragments resulting from an exploding missile would be about 6000 fps and it was assumed that detonation of adjacent missiles would occur instantaneously upon being struck by a fragment. The mach stem of the blast wave was determined to be below the top of the wall for the two closest missiles and above the wall for the two furthest missiles, consequently, the method of determining the pressure-time history of the two types of loading varied.

For the two closest missiles the reflected impulse of each was determined from their scaled distances from the wall for a free-air burst. The duration of the positive pressure pulses were taken as the duration of the positive pressure pulse at the edge of the wall plus the difference in the arrival times at the center and edge of the wall. The peak reflected pressures were computed by assuming an initially peaked triangular load functions of the durations and total impulses determined.

The peak pressures for the two furthest missiles were determined from the pressures at their scaled distances from the free-air burst parameters chart of Reference 1. These pressures were increased by floor reflection factors and wall reflection factors to arrive at the peak reflected pressures. The reflected impulses for the center and edge of the wall for each missile were obtained from the free-air burst parameters chart for the reflected pressures calculated. The average values for the wall was taken as the center values minus one-third of the difference between the center and edge values of the pressures and impulses.

The calculated pressure-time curves are shown in Figure 5. Also shown in dashed lines is the dividing wall resistance function. By equating the moments of the areas of the pressure and resistance curves about the time of maximum deflection to the product of the effective mass and maximum deflection (taken as a 12 degree support rotation) the time of maximum deflection was determined. Once the time of maximum deflection is known, the post-failure fragment velocity (taken as the velocity of the wall at failure) may be obtained by dividing the difference in the areas of the pressure and resistance curves by the effective mass of the wall. The post-failure fragment velocity determined was less than the 100 fps allowed in the design criteria.

The shear lacing reinforcement and the diagonal bars in the base were designed for the ultimate strength of the wall. The wall was designed monolithic with the floor slab with the floor slab's ultimate moment capacity one-half that of the wall. The floor slab was extended into the Inspection and Canning/Decanning Room to develop its ultimate moment capacity.

CONCRETE BUILDING

FRONT WALL. The front wall of the concrete building portion is designed in accordance with the procedures recommended in Reference 1 to provide complete personnel protection; defined in Reference 1 as category 1 protection. The maximum support rotation is limited to 2 degrees and the interior wall surface is covered with a 1/8 inch thick steel plate to prevent the occurance of spalling fragments.

The front wall (shown in Figure 3) is designed as a one-way slab spanning vertically, fixed at the floor and partially fixed at the roof. The section is 2'-0" thick with a 1'-0" haunch at the roof slab. The reinforcing consists of #8 bars a 9" on center vertically and #5 bars for shear lacing and horizontally at 9" on center spacing. The wall is monolithic with the floor slab which extends sufficiently into the concrete building to develop the ultimate moment capacity of the slab.

The pressure-time curves for the front wall were determined in the same manner that was used for the two furthest missiles in the Inspection and Canning/Decanning Room because calculations indicate that all but a small corner of the wall would be below the mach stem of the pressure wave. The calculated pressure-time curves are shown in Figure 5 with a dashed line indicating the single triangle equivalent used in the structural response calculations.

The wall was initially sized by using the impulse method used for the check of the dividing wall response previously discussed. Because of the smaller allowable design deflections, the elastic, elasto-plastic, and plastic deflection and resistance values were calculated to determine an equivalent stiffness and effective yield deflection to find the natural frequency of the wall and maximum deflection, respectively. The ultimate resistance of the wall is approximately 70 psi, the natural period is approximately 10 milliseconds, and the maximum support rotation is less than the 2 degrees allowed in the design criteria.

The laced shear reinforcing bars and the diagonal bars at the support were designed for the ultimate resistance of the wall. The laced shear reinforcing bars are in the vertical direction at the supports and horizontally in the central portion of the wall.

The floor slab between the front wall and the dividing wall is designed to develop the moment capacity of both walls.

SIDE AND BACK WALLS. The side and back walls are designed as one-way slabs spanning vertically and assumed fixed at the roof and pinned at the floor slab. For personnel protection the maximum rotation of the plastic hinge at the roof slab is limited to 2 degrees. The walls are 1'-0" thick, The vertical reinforcing bars are #6 at 9" on center between the front wall and the first interior column and at 18" on center for the remainder. The horizontal reinforcing bars are #4 bars at 1'-0" on center throughout. The interior floor slab is thickened at the wall to insure adequate support. A cross-sectional view of the building is shown in Figure 4.

The peak pressure was determined for each missile for a point just beyond the front wall at the covered passageway. These pressures are increased by ground reflection factors and reduced by the dynamic lift associated with these pressures. The pressure-time function for this point and for a point on the first interior column line are shown in Figure 5. The dashed lines indicate the equivalent triangular load function of the same peak pressure and total impulse used in design.

Because of the relatively small deflections allowed, the elastic, elasto-plastic and plastic resistances and deflections were calculated to determine the equivalent stiffness and effective plastic deflection. The natural period was calculated and the maximum deflection determined from response chart in Reference 1. The computed maximum rotation at the roof support is less than the 2 degrees allowed.

ROOF. The roof is designed as a flat slab concrete roof with two interior columns. The maximum support rotation is less than 2 degrees in keeping with the personnel protection requirement. A 1'-0" haunch is provided at the roof-wall intersection to insure a moment-continuous connection. The roof slab is 1'-0" thick with #4 reinforcing bars at 9" on center for both directions and both faces.

The pressure-time function on the roof slab between the front wall and the first interior column was determined for each missile in the Assembly and Disassembly Room. The peak pressures and impulses were determined in the manner recommended in Reference 1 with minor modifications to average the load across the slab. The procedure is summarized below:

(1) Determine the peak pressure for each missile for a free-air burst at three points on the roof slab along the first interior column line for each missile. The points are at the column and at the two exterior walls on the column line.

(2) The pressures are increased by ground reflection factors.

(3) The three pressures are averaged to obtain a single net pressure.

(4) The shock front velocity, impulse, time of arrival of the shock wave at the front and back of the slab, and the length of the blast wave are obtained from the free-air burst parameters chart for the net pressure calculated.

(5) The effective pressure on the slab is determined from the ratio of the length of the pressure wave to the length of the roof slab. This value is reduced by the effect of the dynamic lift of the pressure wave.

(6) The duration of the pressure wave is determined by taking the sum of the duration of the pressure wave at the

column line and the transit time of the blast wave going from the front wall to the column line.

(7) To obtain the combined pressure wave from the two missiles, the impulses of the two pressure waves are added and the duration is taken as the time between the arrival of the first pressure wave and the end of the second pressure wave. The peak pressure is then computed assuming an initially peaked triangular load function of the duration and impulse calculated.

The resistance and natural period of the roof slab were calculated and the maximum deflection was obtained from the dynamic response figure in Reference 1. The maximum support rotation is less than 2 degrees.

The columns and footings are designed for the ultimate resistance of the roof slab.

BLAST DOOR

The function of the facility requires a doorway near the junction of the nonexplosive and explosive operating portions of the building. The blast pressure anticipated at this location dictated the need for a steel blast door. The door is designed to be motor operated because of the weight of the door and to encourage the operating personnel to close the door immediately after use.

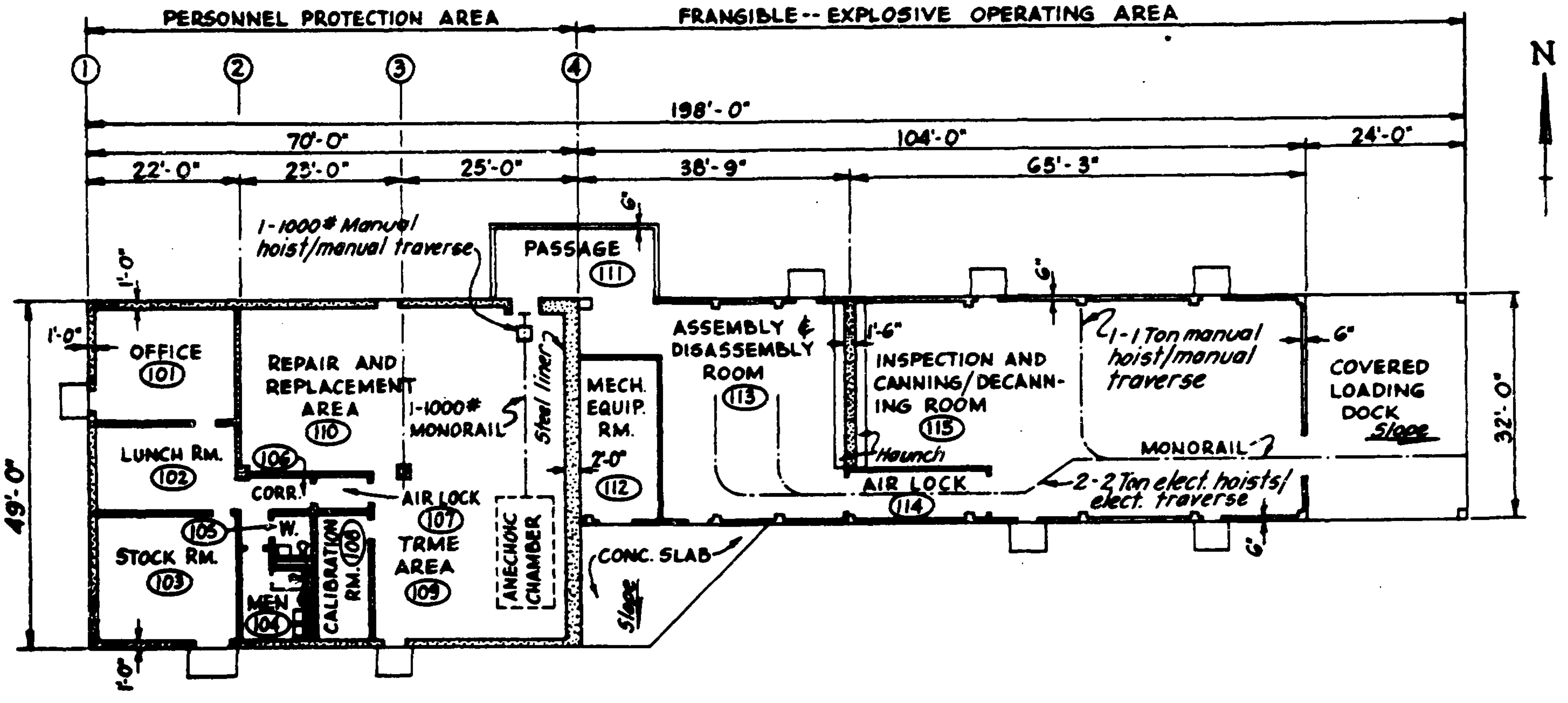
The blast door consists of 5" channels for the door frame and horizontal spanning members at 1'-4" centers. The explosive side of the door is covered with a 1/4" steel plate and the nonexplosive side by 10 gauge sheet metal. All connections are welded.

The blast loading on the door is computed in the same manner as was discussed for the side wall with the scaled distances measured to the center of the door. The pressure-time curves are determined for each missile and combined by using the peak pressure and the sum of the impulses to determine the duration of an initially peaked triangular load function.

The door was allowed to experience a small amount of inelastic action. The ductility ratio (total deflection divided by the yield deflection) was limited to about 3.5 for the horizontal channels and about 2.0 for the vertically spanning plate cover. Adequate provisions were made for rebound.

REFERENCES

1. MANUAL FOR THE DESIGN OF PROTECTIVE STRUCTURES USED IN EXPLOSIVE PROCESSING FACILITIES, Technical Report 3808, by Amman & Whitney, Consulting Engineer, and Picatinny Arsenal, Nov. 1968.



PLAN

FIG. 1 - THEATER RELIABILITY MONITORING FACILITY (TRMF)

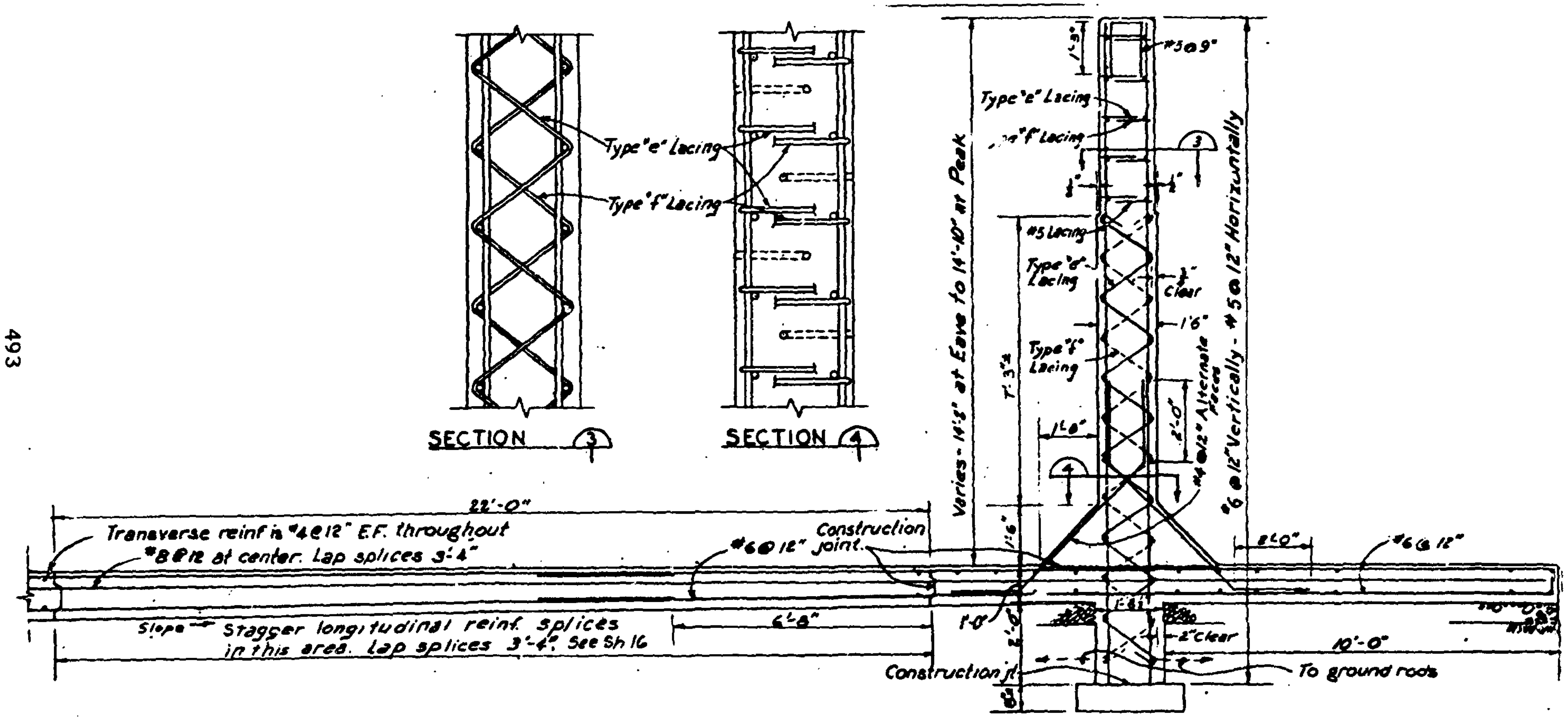


FIG. 2 DIVIDING BLAST WALL

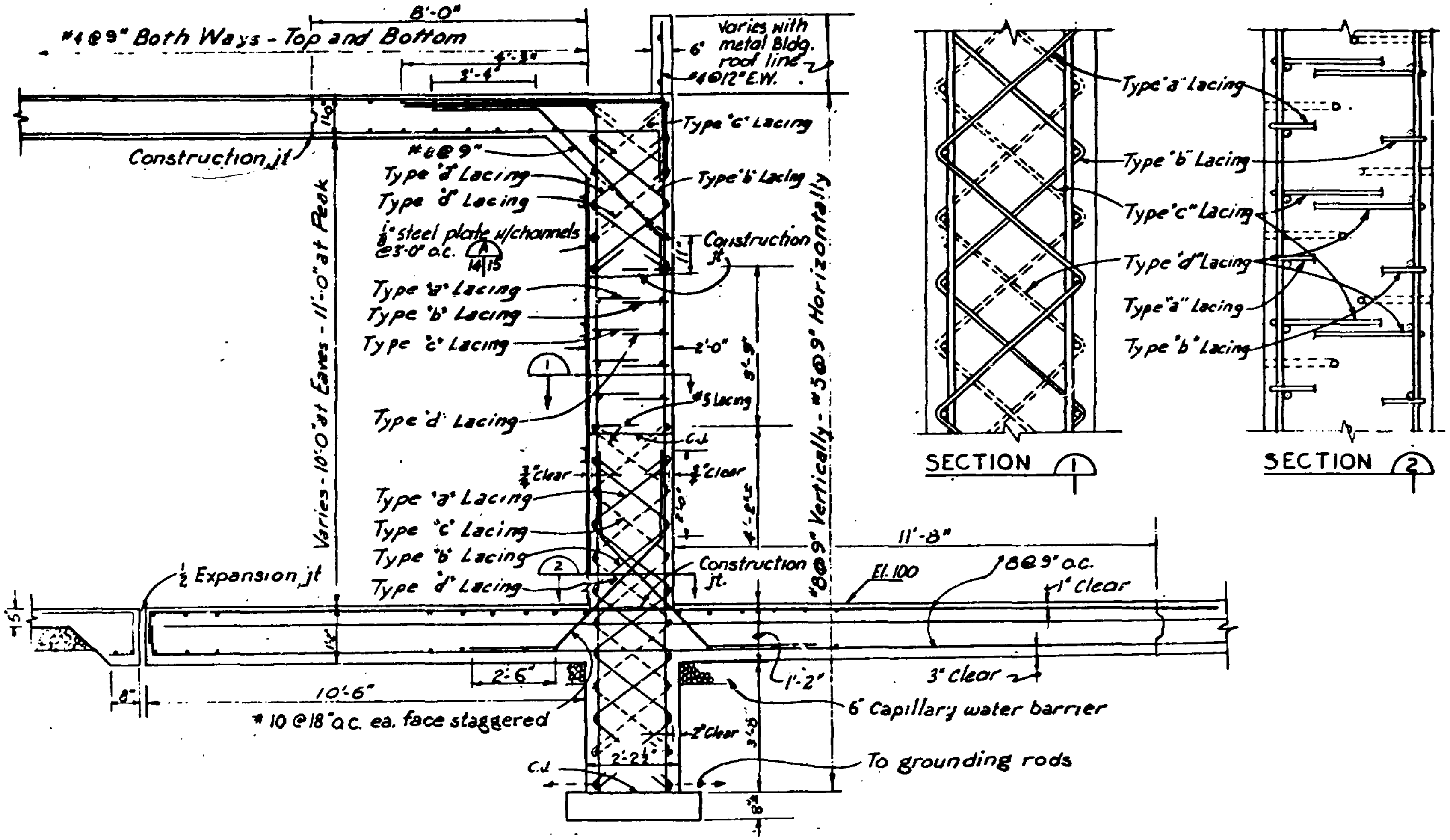


FIG. 3 FRONT BLAST WALL

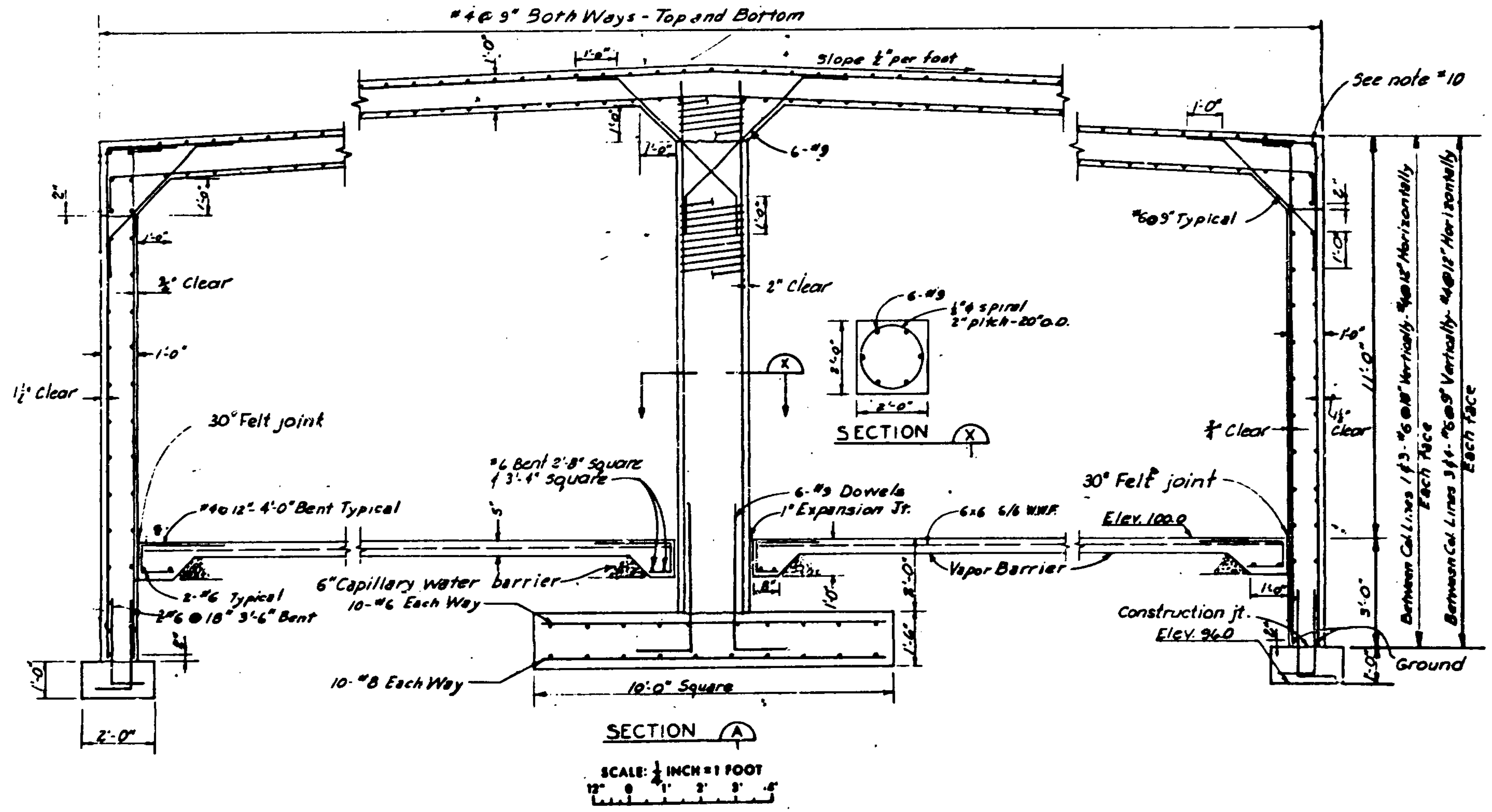


FIG. 4 BUILDING SECTION

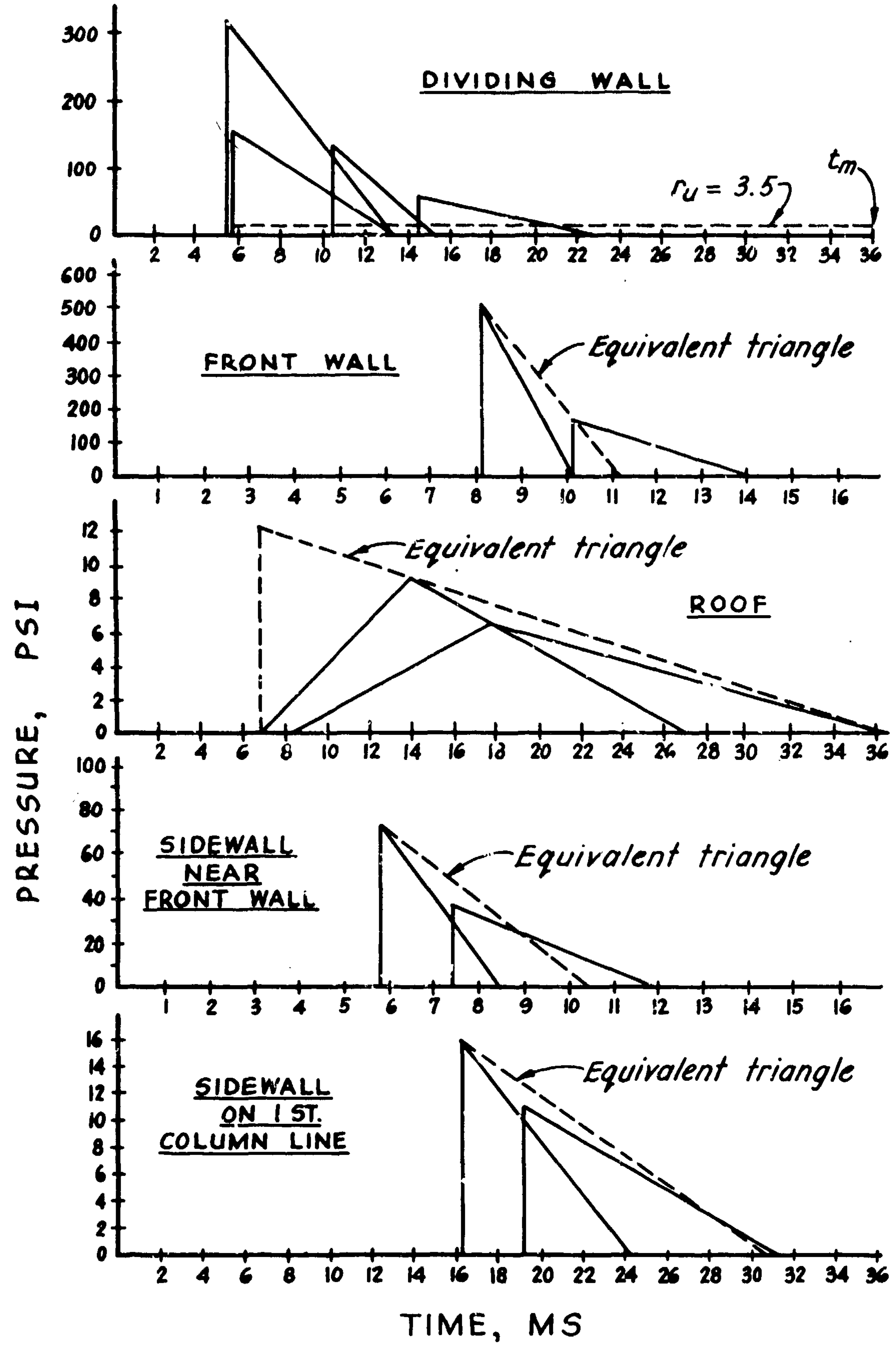


FIG. 5 - BLAST LOADING DIAGRAMS

LA-4145
UC-38, ENGINEERING
AND EQUIPMENT
TID-4500

LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California
LOS ALAMOS • NEW MEXICO

Internal Blast Loading of Scale-Model Explosive-Processing Bays

by

C. A. Anderson

INTERNAL BLAST LOADING OF SCALE-MODEL EXPLOSIVE-PROCESSING BAYS

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ABSTRACT

A Los Alamos Scientific Laboratory study of the protective capability of high-explosive-processing buildings subjected to internal blast loading is summarized. One-eighth-scale reinforced concrete models of the facility were tested against blast from a wide range of scaled explosive-charge weights. Shock overpressures, strains, and deflections were measured at critical points of the models.

The structural response of the models is compared with calculated dynamic response based on elastic and plastic material behavior, and spallation and excessive deflection of the models are compared with conventional explosive-effects data. From the test results, guide lines are established for the protection of personnel in typical Los Alamos explosive-processing buildings.

I. INTRODUCTION

In handling hazardous materials such as high explosives, great effort is expended in preventing accidents such as accidental detonations. Nevertheless, accidents can be expected to occur, however small the probability, and it is necessary to minimize their effects on personnel. Fabrication of high explosive (HE) systems involves a number of mechanical operations such as pressing, drilling, and cutting, in each of which accidental detonation can occur. In fact, a fatal accident at the Los Alamos Scientific Laboratory (LASL) involving drilling of HE prompted the study reported here.

To protect personnel from the effects of an accidental explosive detonation, it is standard practice to separate them from the potential explosion by a protective barrier, usually a reinforced concrete wall panel. If the barrier is not breached or spalled and the air shock from the explosion is channeled away from personnel, sufficient protection is ensured. Design of a protective barrier is thus well defined: it should not be breached by an explosion, should not spall, and should channel the shock wave away from personnel.

Reinforced concrete panels offer excellent protection against blast because they combine reasonable strength, ductility, mass, and economy. The ductility of correctly designed panels allows them to deflect greatly without breaking or breaching by absorbing energy through plastic flow in the reinforcing rod even though the loads greatly exceed the ultimate static carrying capacity of the panel. The use of this property of flow at constant stress without change of geometry has been incorporated in certain structural calculations for protective barriers at LASL

The difficulty in calculating an interior wall panel's response to blast loading lies in obtaining an adequate description of the pressure loading on the panel rather than in the resulting structural analysis. The pressure loading on a panel from internal blast varies with the distance of the panel from the explosion, the angle of blast incidence on the panel, and blast reflection at the panel. Additional complications are caused by shock-wave reflections from adjacent panels as well as reflections from corners. Therefore, we turned to a model study to evaluate the protective capability of a typical LASL explosive-processing building subjected to internal blast loading.

Conclusions and recommendations obtained from the scale-model tests are given in Section II, as are guide lines for protection of personnel in a typical explosive-processing building. Hazard limits for areas adjacent to the building are also discussed.

A typical processing building is described in Section III. Sections III through VI describe the fabrication, instrumentation, testing, and test results of the two structural models used in this study. Section VII gives the measurements of pressure and impulse imparted to the models by the internal blast and the measurement of external shock-wave effects produced by the venting of the explosion through a blowout panel.

Appendix A gives the scaling laws for a shocked fluid and for the dynamic response of elastic-plastic structures. In the absence of heat conduction and rate effects, scaling of the interaction of an explosively shocked fluid and a structure can be accomplished purely geometrically; i.e., the dimensions of the explosive loading source are reduced as the geometric model-scaling factor.

Structural calculations for protective barriers at LASL are reviewed in Appendix B, and a numerical example is also given.

We emphasize that the scale-model testing treats only the problems of personnel protection and structural damage occurring in HE operating or processing buildings from the accidental detonation of modest amounts of HE within the structure. Several investigations have been made of structural response to external blast loading produced, for example, by a nuclear explosion.[1,2] Other studies, often using models, have been devoted to sympathetic detonation involving "simultaneous" initiation of explosives separated by interior dividing walls.[3] The results of this study do not apply to either of these problems.

II. CONCLUSIONS AND RECOMMENDATIONS

From the scale-model testing described in this report we have arrived at the following conclusions and recommendations about the protective capability of typical LASL explosive-processing buildings.

A. Protection Afforded by a Typical Structure

1. Breaching Detonation of more than 400 lb of plastic bonded explosive (PBX 9404) would be required to breach (completely break up) a typical LASL explosive-processing bay. The scale-model blast from a 370-lb-equivalent weight of PBX 9404, although inflicting extensive damage to the model, was contained by its processing bay.

2. Spallation Some investigations[4] indicate that spallation of reinforced concrete can be avoided if the explosive is kept a scaled distance, $R/W^{1/3}$, of at least 1.5 from the concrete. (R is the distance from the concrete in feet, and W is the explosive weight in pounds.) From our scale-model tests, it appears that this requirement has a considerable safety factor, and that a smaller scaled distance could be used. We observed spalling in our scale-model tests (W and R are actual, not scale-model figures) as follows:

Test	W	R	$R/W^{1/3}$	Spallation
47	125	2	0.40	Yes
48	100	3	0.65	No
57	200	5	0.83	No
58	370	5	0.70	Yes

Spallation is to be avoided for the safety of personnel in corridors.

3. Overpressures The shock overpressure in the processing bay adjacent to that in which the detonation occurred indicated that if a mechanical operation is considered hazardous enough to be done remotely, personnel should not be allowed in the adjacent bay. The overpressures behind the remote control barrier of the model were considerably less than those in the adjacent corridors. For charge weights of less than 25 lb of PBX 9404, all corridor pressures are less than 5 psi.

4. The Effect of Blast Doors Blast doors can effectively seal off the personnel corridors, and probably should be used for processing of charges exceeding 25 lb of PBX 9404.

5. The Effect of a Blowout Panel A blowout panel did not seem to affect the model structural response, although corridor and adjacent bay pressures were considerably less without it. This was confirmed by the impulse measurements which

showed that the impulse applied to the structure was substantially the same with or without a blowout panel.

B. Structural Response

The entire model structure behaved elastically up to the equivalent of 50 lb of PBX 9404 with no permanent deformation of the wall and roof panels. Maximum elastic panel deflections of 3/16 in. (1-1/2 in. in the full-scale building) occurring 1 to 2 msec after detonation were measured in the model. Except for one instance of spallation the thick, heavily reinforced walls of the model behaved elastically even at the 125-lb-equivalent charge level, with some minor cracking occurring at the 200-lb-equivalent charge level. The model roof panel, being thinner than the supporting side walls, was much more deformed and behaved as expected, with clear evidence of purely elastic, elastic-plastic, and fully plastic regions of behavior. Finally, it appeared from analysis of the test records that the impulse delivered to the reinforced concrete wall and roof panels of a structure is the primary cause of deflection and that the exact shape of the pressure-time loading function is unimportant.

C. Personnel Effects

Various figures are given for the adverse effects of shock overpressures on personnel. From a Lovelace Clinic report[5] it is apparent that severe internal injuries from a conventional explosive charge require a uniform overpressure of hundreds of pounds per square inch (a man is reported to have survived an estimated 500-psi pressure from a World War II bomb burst) provided that the duration is short--of the order of tens of milliseconds. No pressures measured in the model corridors even approached this range. The part of the human anatomy most sensitive to overpressure is the eardrum, for which 2 to 40 psi cause rupture. A value of 5 psi appears reasonable, and was used for the recommendation concerning blast doors.

A human dummy, placed in an extension of the model personnel corridor, was unaffected by the 25-lb-equivalent charges but was upset by 50-lb-equivalent and greater charges. The dummy always fell in the direction of shock propagation although no translational velocity was observed. From high-speed films, it appeared that the dummy did not respond to the impulse of the initial shock but, rather, to the dynamic pressure of the longer duration, forward-moving wind accompanying the shock.

D. Significance of Calculations

Structural response calculations based on the simplified elastic, perfectly-plastic model described in Appendix B appear to agree well with the structural response of the scale-model roof panel, provided that the pressure-loading function or impulse acting on the panel is known. For calculational purposes estimates of this pressure-loading function were obtained by using reflected impulse values for the distance from the nearest point on the panel to the center of the explosive[6] and assuming that the impulse acted simultaneously and uniformly over the panel. For large deflections of the model structure, in addition to bending, it appeared that membrane effects should be accounted for in the response of the theoretical elastic, perfectly-plastic model; significant curvature in the model roof panel indicated the presence of membrane forces.

E. Reflected Impulse and External Overpressures

1. Reflected Impulse In assessing the effects of blast on structures, one must distinguish between peak pressure and positive impulse in free undisturbed air ("side-on" pressure and impulse) and the peak pressure and positive impulse applied to an infinitely rigid wall at normal incidence ("face-on"). For internal blast loading, the normally reflected (face-on) pressure and impulse are the important parameters. Measurements of the reflected impulse applied to the walls of the model were in fair agreement with published reflected-impulse data.[6] Although reflected peak pressures varied considerably over the internal surface of the model, the reflected-impulse values were distributed fairly uniformly. The influence of the location of the explosive within the model on the resulting overpressure and impulse distribution was also characterized by considerable variations in peak reflected pressures and a fairly uniform impulse distribution.

2. External Overpressures As expected, shock overpressures measured outside the model

in front of the blowout panel depended strongly on the distance from the explosive charge, with a smaller pressure variation with angle at a fixed radius. For the equivalent of 25 lb of PBX 9404, an equivalent of 50 ft from the charge will ensure that the peak overpressures are less than 5 psi (side-on). The 100-lb-equivalent charge of PBX 9404 produced pressures of over 5 psi at 100 ft, the greatest equivalent distance at which external pressure measurements were taken. We consider 5 psi without shrapnel the peak overpressure safe for personnel.

F. Comparisons with Conventional Explosive-Effects Data

Reflected impulses from normal incidence of blast waves generated by PBX 9404 were 30% greater than the corresponding impulses from TNT, and the reflected peak overpressures were 10 to 20% greater. As mentioned, the reflected impulse values agreed fairly well with published values. External peak shock overpressures measured near the blowout panel were about twice those given by the Explosion Effects Data Sheets[7] for TNT. This we attribute to the use of a higher energy explosive and to the fact that the air blast was directional in nature. We also found that internal shock overpressures in corridors and entryways could be estimated from the Explosion Effects Data Sheets by using the distance of shock travel together with the explosive weight even though the blast is no longer spherically divergent. These data afford a crude practical rule for estimating shock overpressures in personnel areas of other types of processing buildings.

III. THE STRUCTURAL MODELS

After considering the scaling laws developed in Appendix A, we decided to construct one-eighth-scale structural models of part of a typical LASL explosive-processing building and to subject them to internal blast loading from scaled explosive charges. The tests would determine the structural resistance of the processing building to internal blast loading and its ability to channel the explosion shock waves away from personnel.

A typical explosive-processing building consists of 25 bays in which mechanical operations on explosives are performed. The bays are arranged in pairs, with a single end bay, and with a common wall separating adjoining bay pairs. The floor plan of a typical bay pair is shown in Fig. 1. The supporting walls of the bays are 12-ft-high, 2-ft-thick, heavily reinforced concrete with 3 to 4 vol % of reinforcement. The bay is covered by a 15-in.-thick reinforced concrete roof panel (~3 vol % reinforcement) with substantial support at three edges. The wall and ceiling corners are haunched to provide there an approximately built-in support. The concrete floor of each bay "floats" on an earth fill. As shown in Fig. 1, the back of the bay pair is covered by a light frangible blowout panel to vent the blast from an accidental detonation and provide protection from weather during ordinary operation. The panels are two 1/16-in.-thick aluminum sheets with their 3-in. separation filled with insulation. Since most operations on explosives are remotely controlled, a "remote control" protective barrier for the operator is provided as shown in Fig. 1. During a mechanical operation on an explosive, personnel are restricted to areas behind the remote control barrier and to the personnel corridor.

The two structural models for this study were based on the bay pair shown in Fig. 1. The testing of each model would be an overtest of the actual building since we felt that adjoining bay pairs would contribute somewhat to the strength of an actual bay pair. Each model was a one-eighth scale geometric replica of a bay pair. It was often difficult to simulate in the model the exact placement and size of the reinforcing bar in the building; in these cases the available scaled reinforcing bar was positioned in the model so that the ratio of the ultimate plastic moment of the building section to that of the corresponding section of the model was 64 as dictated by the scaling laws.*

To maintain proper scaling, the mechanical properties of the materials making up the model must be held close to their values in the actual structure. To this end much effort was expended in scaling aggregate and duplicating strength values; the strength of the 3/32-, 1/8-, and

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*For example, the ultimate plastic moment of a uniform section is $\sigma_0 h^2/4$, where σ_0 is the tensile (and compressive) yield strength and h is the section thickness. If the model section thickness is λh, its ultimate plastic moment is $\lambda^2(\sigma_0 h^2/4)$. The same holds for composite sections.

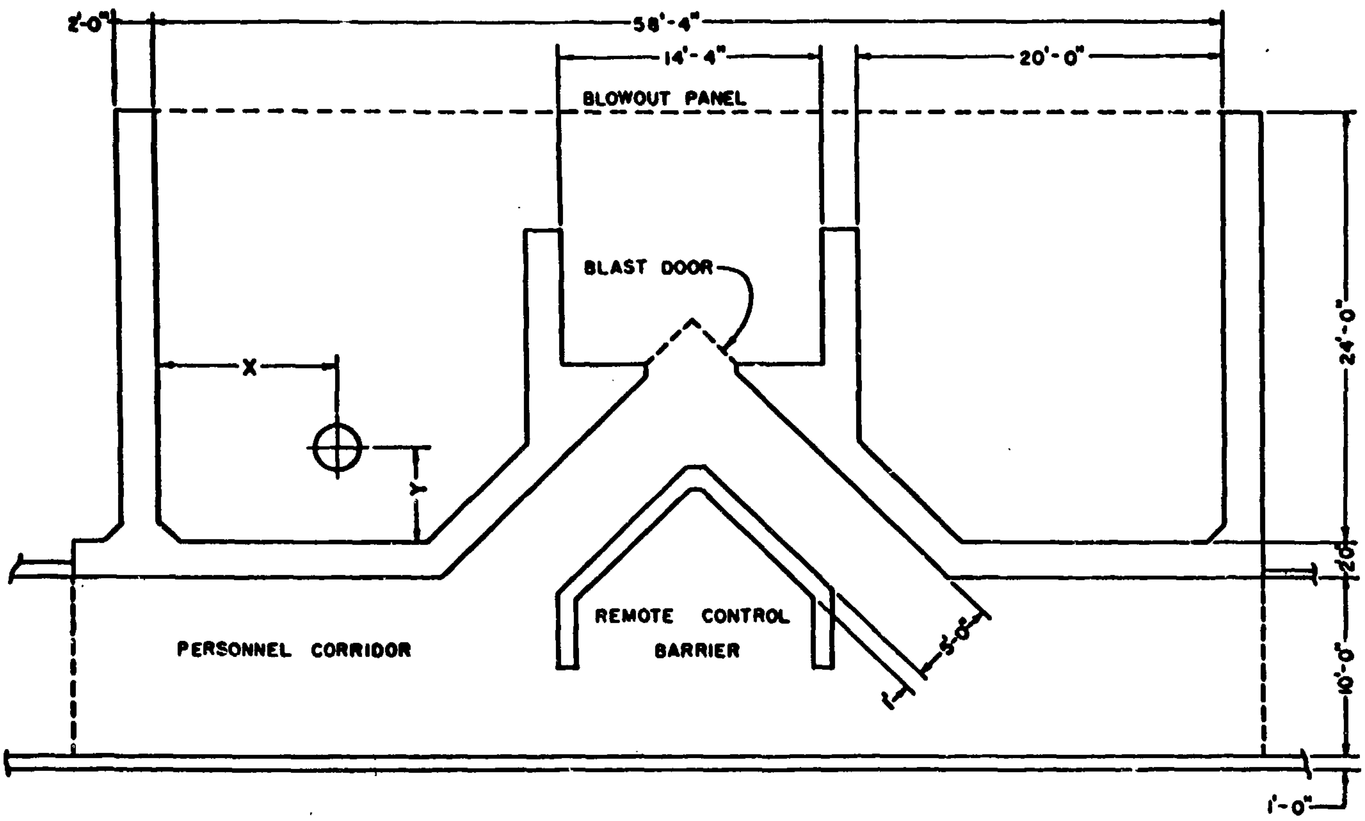
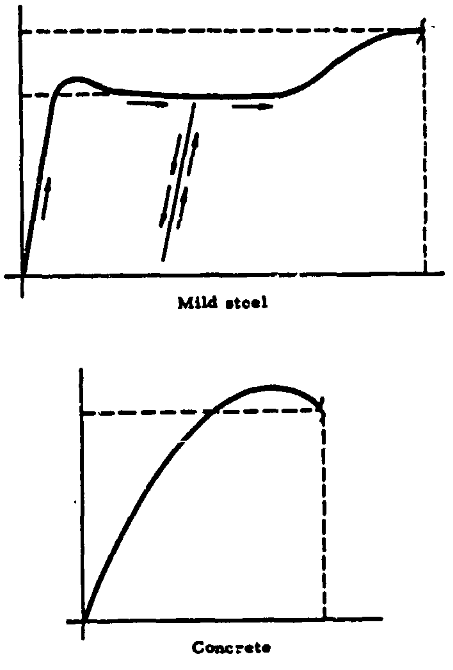


Fig. 1. Floor plan of a typical processing bay pair. X and Y coordinates are used to indicate charge location.

3/16-in. round and square wire rod simulating the reinforcing bar of the building was adjusted by annealing the wire to the desired tensile yield strength. The strengths of the concrete and reinforcing bar in the two models compared with those in the building are as follows.

Mechanical Property	Model 1 (psi)	Model 2 (psi)	Actual Building (psi)
Concrete compressive strength at 7 days, σ_o	3,800	3,800	
Concrete compressive strength at time of model tests	6,600	6,600	6,000
Tensile strength of reinforcing bar, σ_y	68,000	45,000	49,000
Ultimate strength of reinforcing bar, σ_u	80,000	72,000	75,000

The elastic properties of the materials making up the models were substantially the same as those of the actual building. Typical stress-strain curves for the reinforcing bar and concrete are shown in Fig. 2.


Mild steel

Concrete

Fig. 2. Typical stress-strain curves for mild steel and concrete.

As shown above, the second structural model is a more accurate strength simulation of the actual bay pair than is the first. Also the first model had a built-in condition at its base which did not simulate a foundation-type support; the second model attempted to correct this shortcoming.

The models had simulated blowout panels consisting of three pieces of 1/32-in. aluminum sheet stock held in place by pressure-sensitive tape. The equivalent weight of the model panel exceeded the weight of the actual panel by about 50%. The amount and placement of the pressure-sensitive tape were adjusted so that the model blowout panel response to a 5-lb-equivalent charge simulated some known actual panel response.

Figures 3 through 6 show the structural models in three phases of construction. Fig. 3 shows the detailed placement of the wire reinforcing bar in the walls of the two bays and the remote control barrier, while Fig. 4 shows the intricate detail of the reinforcement at a typical corner. Figure 5 shows a partially completed model with the forms for pouring the concrete. Figure 6 shows the completed model ready for instrumentation and testing. Details of the two structural models are given in LASL drawings ENG C-26468 through ENG C-26477.

IV. MODEL INSTRUMENTATION

We wished to measure dynamic strain, incident and reflected shock overpressures, and wall- and roof-panel motion in the structural models. Strain gages were bonded to the outer reinforcing bars embedded in the wall and roof panels at 16 locations where maximum strain was anticipated. These gages were 120-Ω, Bakelite-backed gages, 0.060-in. long, suitably waterproofed for use in concrete. In the first model, the gages were mounted on both vertical and horizontal reinforcing bar of the walls, whereas on the second model they were mounted only on the vertical bars. The strain-gage locations in one of the model bays are indicated in Fig. 7.

Fig. 3. Reinforcing bar assembly showing adjacent model bays and remote control barrier.

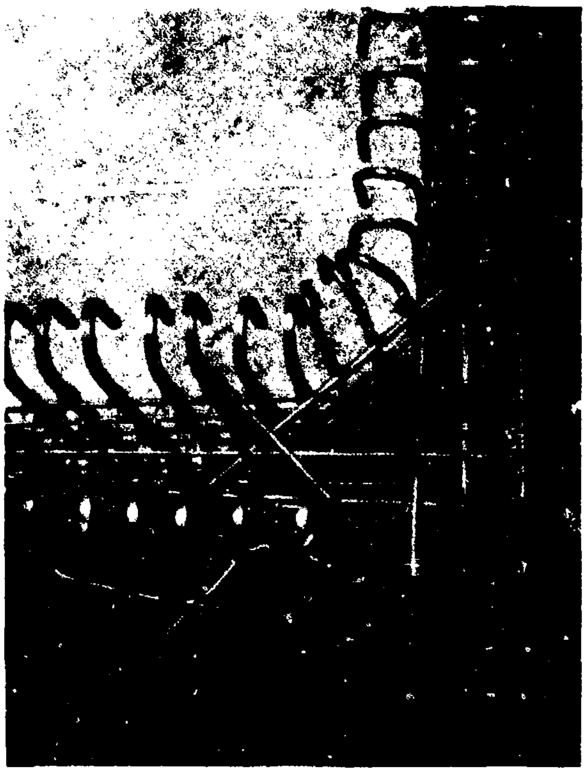


Fig. 4. Reinforcing bar detail at a typical corner.

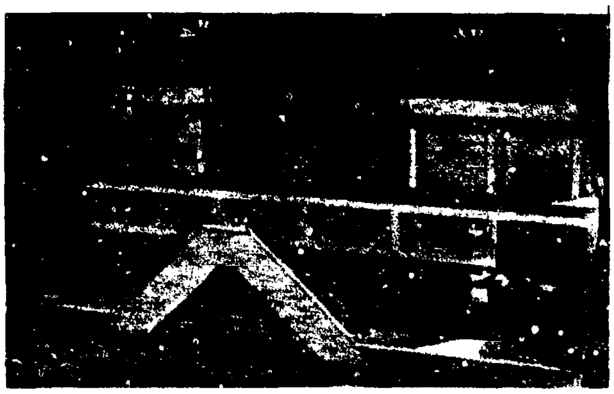


Fig. 5. Model assembly before concrete pouring.

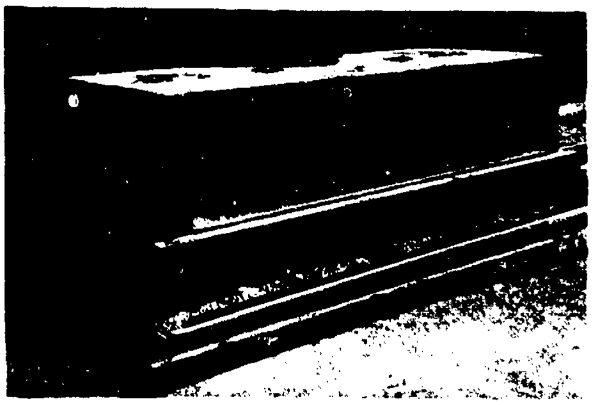


Fig. 6. Structural model ready for instrumentation and testing.

Shock overpressures throughout the structural model were measured by 14 Atlantic Research Corporation blast gages positioned as shown in Fig. 7. These gages presented a small frontal area to the incident flow and so perturbed the flow only slightly in their measurement of the incident free-field shock overpressure. The gages had a natural frequency over 100 kc with a sensitivity of approximately 500 pC/psi. Calibration of the blast gages with a step pressure change indicated linearity of response within ±5% for the range of pressures of interest. The blast gages were mounted on stands so that the gage itself was 6 in. above the floor of the model. None was placed in the bay in which the explosion took place.

Since we anticipated difficulties in measurement of wall- and roof-panel motion, we used two methods of measurement. High-speed cameras recorded the motion of pointers attached to the midpoints of the roof panel and side wall of the bay in which the explosive was detonated. The camera framing rate was approximately 6000 frames/sec. In addition, six Bently Nevada Corporation motion detectors measured the wall- and roof-panel motion in the 0- to 0.250-in. maximum deflection range. The frequency response of these detectors was somewhat limited for our applications, and some distortion of their signals was observed. Of course, permanent deformation of the structure by large-scale charges provided a measure of maximum deflection, particularly when the permanent deformation was large compared with the elastic deformation measured at low charge levels.

Reflected wall pressures and impulse were measured with quartz pressure transducers purchased from pcb Piezotronics, Inc. These transducers were mounted flush with the inside surfaces of the walls and roof of a geometric steel model of the bay in which the explosion took place (see Section VII). The transducers can measure pressures up to 5000 psi with less than 2% nonlinearity of response. The transducer sensitivity is 0.4 pC/psi, and they have an extremely high natural frequency (about 400 kc) which enables them to record accurately the severe shock signature caused by the reflection of the blast wave from the walls and roof of the model.

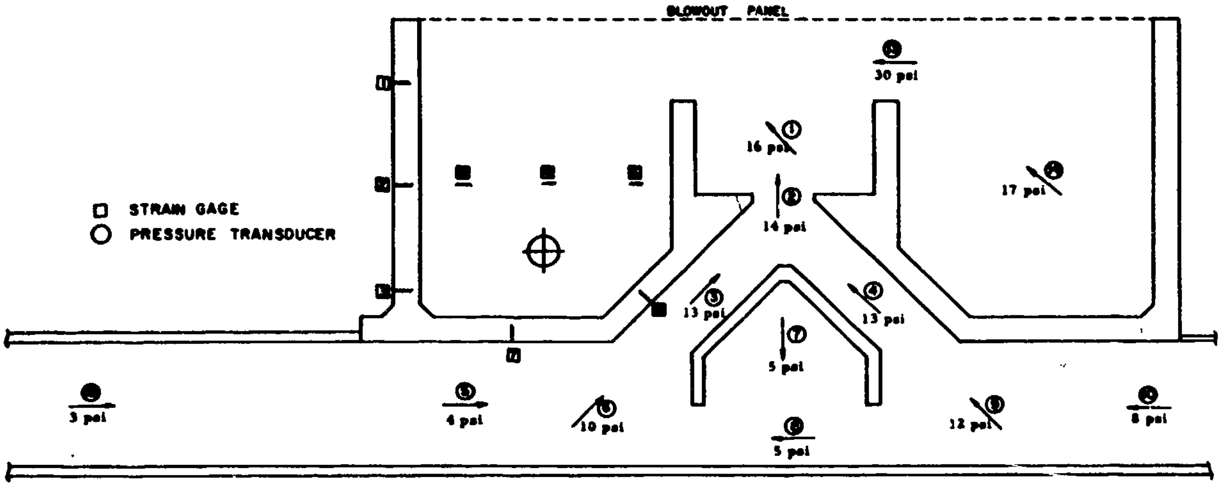


Fig. 7. Map of shock overpressures from 75-lb-equivalent charge, Test 55.

The signals from the strain gages, pressure gages, and motion detectors were recorded on a cathode-ray oscillograph, or oscilloscopes, or both after appropriate signal conditioning.

V. MODEL TESTING

The two structural models were tested at scaled explosive-charge levels of 25- to 370-lb-equivalent weights of a high explosive, PBX 9404. The weight of explosive detonated in the model ranged from 22 to 325 g, determined by reducing the full-scale charge weight by 512 (the scaling factor cubed). All charges were positioned a scaled 4 ft above the model floor, corresponding to average machining table height. Use of an SE-1 detonator ensured complete detonation of the scaled charge.

For the first structural model, hemispherical charges of PBX 9404 were employed, beginning with the 25-lb-equivalent charge. Firing of multiples of the 25-lb-equivalent charge followed until substantial damage to both bays of the model was observed. The blowout panel was used for all of the explosive tests on the first structural model. No tests of the first structural model employed blast doors. The amount and horizontal location of each explosive charge relative to the actual structure is indicated in Table I.

TABLE I

Tests of First Structural Model

Test	Full-Scale Charge (lb)	Scaled Charge (g)	Charge Placement Coordinates (ft) (See Fig. 1) Bay	X	Y
45	25	22	B	10	12
46	50	44	B	10	12
47	125	110	A	2	12
48	100	88	B	10	3
49	125	110	B	10	3

The test program for the second structural model is given in Table II. Here cylindrical charges of PBX 9404 were used. The detonation of the two large charge equivalents, Tests 57 and 58, ensured that the structure was driven well into the plastic range of behavior. In Test 51, we examined the structural response of the model to a 25-lb-equivalent charge without the blowout panel. All other tests employed the blowout panel. In Test 52, blast doors were placed over the entryway to the corridor (see Fig. 1).

TABLE II

Tests of Second Structural Model

Test	Full-Scale Charge (lb)	Scaled Charge (g)	Charge Placement Coordinates (ft) (See Fig. 1) Bay	X	Y
50	25	22	A	10	12
51	25	22	A	10	12
52	25	22	A	10	12
53	25	22	B	10	12
54	50	44	A	10	12
55	75	66	B	10	12
56	125	110	B	10	5
57	200	176	A	10	5
58	370	325	B	10	5

To obtain more extensive shock overpressure measurements in the personnel corridor of the model, we extended the corridor by adding a 15-in.-square, 7-ft-long duct at each end. The ducts did not simulate structural response; they were only to channel the shock wave from the explosion a greater distance within the confines of the duct. One of the ducts was fitted with a transparent panel to permit a high-speed camera to record the movement of small vertical threads spaced at 2-in. intervals along the duct.

The camera simultaneously recorded the response of a one-eighth-scale human model to the incident shock wave and following air flow. The properties of the rigid-body dummy placed in the add-on corridor are as follows:

Weight	~0.4 lb
Projected frontal area	13 in.^{2}
Center of pressure of projected area	4.5 in. from the base
Radius of gyration about the base	5.0 in.

Figure 8 shows the second structural model with the add-on ducts in place and with a blast shield, shown on the left, which was used to keep the detonation products out of camera view. Some of the instrumentation discussed in Section IV can also be seen.

Testing of both structural models was performed outdoors. The first model was tested during March 1963; the second, during October 1968.

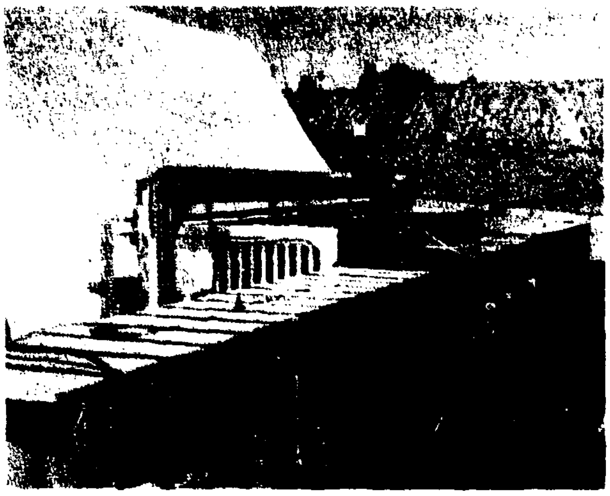


Fig. 8. Instrumentation setup before a scale-model test showing the blast shield and add-on corridors.

The air temperature during testing of the second model varied from 54 to 80°F; the atmospheric pressure was 11.1 psi.

VI. MODEL TEST RESULTS

Tests 45 and 50 through 53 (25-lb HE equivalent)

Since the entire model structure behaved elastically and returned to its initial configuration after blasting of the 25-lb-equivalent charges, repeated tests were conducted at this level to check instrumentation and verify certain hypotheses about structural response. Maximum strains in the reinforcing bar of the model wall and roof panels are summarized in Table III.

TABLE III

Maximum Strains (μ in./in.) from 25-lb Equivalent Charge at Positions Indicated in Fig. 7

Test	Average of Positions 1 - 3	Position 4	Position 7	Position 8
45	560	1610	300	200
50	330	1320	280	470
51	250	1370	260	190
52	320	1440	300	380
53	450	1340	410	370

Since the roof-panel strains recorded in Table III (position 4) are approximately the same, we conclude that at the 25-lb-equivalent charge weight the presence or absence of the blowout panel, or blast doors, or both has little effect on the structural response. The motion transducers indicated an average maximum displacement of 1/8 in. at the center of the roof panel.

B. Tests 46 and 54 (50-lb HE equivalent)

No structural damage was observed on Tests 46 and 54; the structure behaved elastically and returned to its original configuration. A maximum roof-panel deflection of approximately 3/16 in. was recorded on Test 54, and the maximum strain recorded in the reinforcing bar at the center of the roof panel slightly exceeded the yield-point strain.

C. Test 55 (75-lb HE equivalent)

The 75-lb-equivalent charge was the lowest charge weight at which permanent deformation of the model was observed; the roof panel of the bay being tested showed evidence of the formation of plastic hinges with a 1/8-in. permanent deflection of its central yield line. The thicker walls of the model showed purely elastic behavior, although there was some cracking at the support.

D. Test 48 (100-lb HE equivalent)

Severe cracking at the edge of the roof panel as well as the formation of plastic yield lines occured as shown in Fig. 9. The permanent deflection was 5/32 in. at the center of the roof panel. No spallation was observed, and the walls of the model behaved elastically.

E. Test 47 (125-lb HE equivalent)

Figure 10 illustrates the damage to the model caused by a 125-lb-equivalent charge placed a scaled 2 ft away from a side wall panel of the actual building. The only damage to the side wall

Fig. 9. Damage to the first structural model, Test 48.

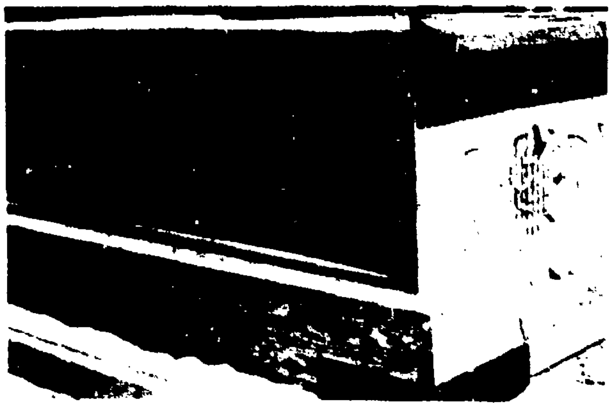


Fig. 10. Spalling of the first structural model, Test 47.

was spallation, whereas the roof panel cracked at the spalled wall-roof interface, probably because of large transverse shear stresses.

F. Test 49 (125-lb HE equivalent)

Test 49 with a 125-lb-equivalent charge was conducted in the same bay as Test 48, and accentuated the effects of Test 48. Appreciable transverse shear effects are seen in Fig. 11 as is the absence of wall failure. No spallation was observed although the charge was detonated only a scaled 3 ft from the actual corridor wall. We feel that the shear effects observed in the first structural model would not have occurred if the yield strength of the reinforcing bar had been lowered to the value achieved in the second model.

Fig. 11. Damage to the first structural model, Test 49.

G. Test 56 (125-lb HE equivalent)

Yield hinges and a yield-line pattern on the roof panel were clearly visible after this test. The permanent deflection of the roof panel was 3/8 in. (1/4 in. relative to the undeformed bay because Test 55 had already produced 1/8 in. permanent deformation of the roof panel). No permanent deformation of the side and corridor walls was observed, although large cracks appeared at the foundation of the model as shown in Fig. 12.

Fig. 12. Cracking at the foundation of the second structural model, Test 56.

H. Test 57 (200-lb HE equivalent)

A definite yield-line pattern was observed on the roof panel, with a permanent deflection of 7/16 in. This pattern, shown in Fig. 13, agrees with that predicted by rigid-plastic theory (see Appendix B). Small cracks on the side wall indicated the beginning of a yield-line pattern there

Fig. 13. Yield-line pattern initiated in the roof panel of the second structural model, Test 57.

too. This test damaged the floor considerably, and the outside wall as a whole rotated due to loss of integrity of the simulated foundation (Fig. 14). No spallation was observed in this test. The add-on corridors (which were not a structural simulation) and the blast shield were collapsed by the shock overpressures.

I. Test 58 (370-lb HE equivalent)

Test 58 with a 370-lb-equivalent charge drove the structure well into the plastic range of behavior, with excessive cracking and spalling of both the wall and roof panels of the bay. Figure 15 shows the interior of the bay and cracks which formed in the ceiling and the damage to the floor of the model. The yield-line pattern initiated by Test 56 was carried much further by this test; however,

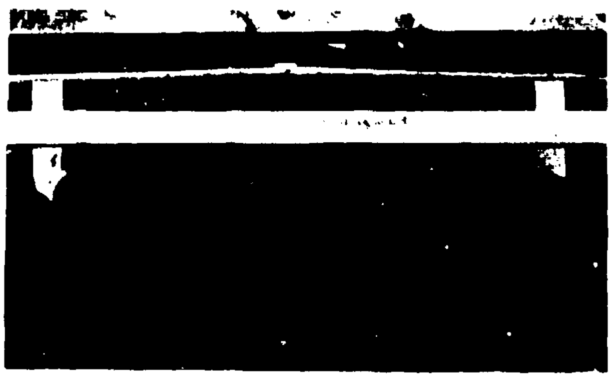


Fig. 14. Further evidence of the yield-line pattern after Test 57.

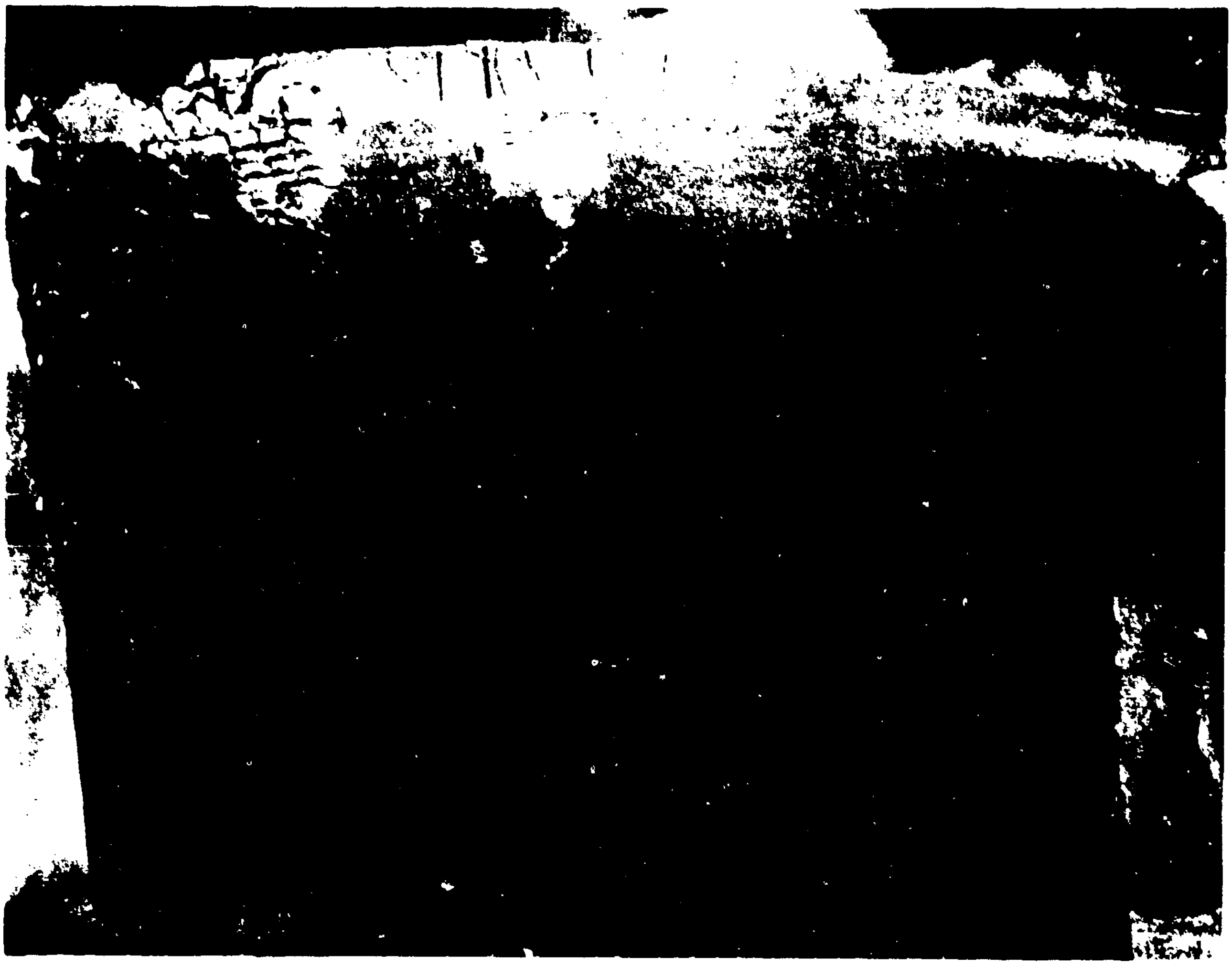


Fig. 15. Interior view of model damage caused by Test 58 showing extensive cracking of the model and roof panel curvature.

the curvature of the roof panel indicated in Fig. 15 suggests that large membrane stresses are beginning to act and that geometry changes are no longer insignificant. The permanent deflection of the model roof panel was 1-1/4 in. Figure 16 illustrates the crack pattern and spallation of the roof panel, and Fig. 17 shows the corridor wall spall. The high-speed camera records indicated spall velocities of about 100 ft/sec. Figure 18 shows the model after the completion of the test series; we emphasize that in spite of the severity of the 370-lb-equivalent test the model structure was not breached.

J. Summary of Test Results

Figures 19 through 21 summarize the structural data obtained from testing both models, with the quantities of interest plotted against equivalent weights of PBX 9404 detonated in the actual structure. We mention again that according to the scaling laws the strains, being dimensionless, are the same in the model and actual structure, and the deflections of the actual structure are eight times the values measured in the model.

The experimental values of maximum roof-panel displacement plotted in Fig. 19 are averages obtained with the 25- and 50-lb-equivalent charges. For larger equivalent charges, the deflection is the sum of the observed permanent deflection and an elastic deflection of 3/16 in. Figure 19 also shows the calculated maximum panel displacement based on the elastic, perfectly plastic model discussed in Appendix B. The measured displacements agree well with calculation. The material behavior regions of the roof-panel response are

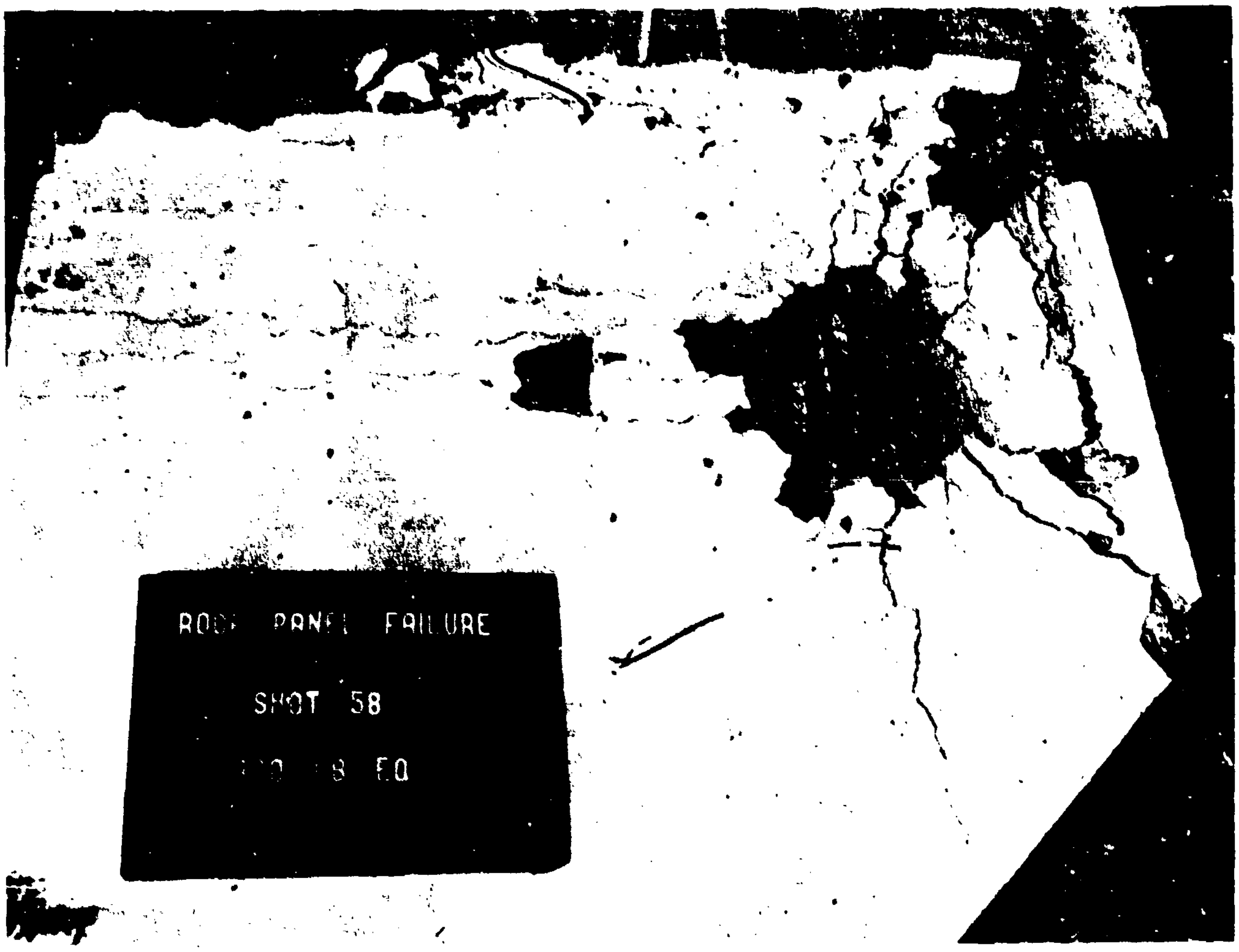


Fig. 16. Roof panel spall, Test 58.

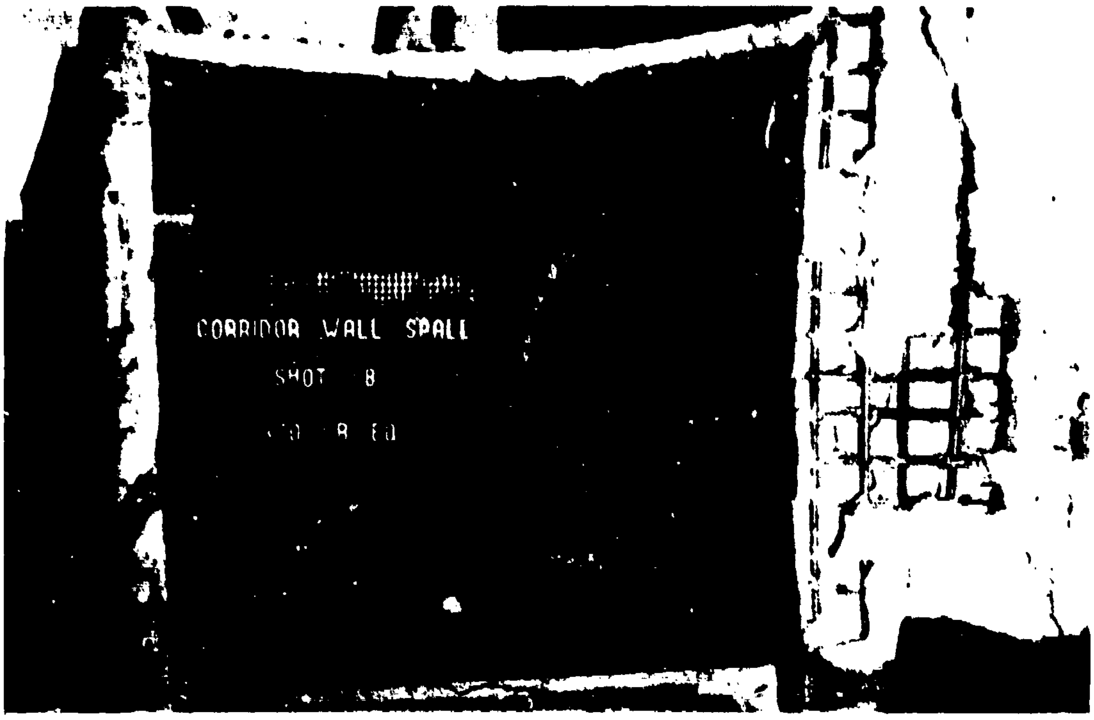


Fig. 17. Corridor wall spall, Test 58.

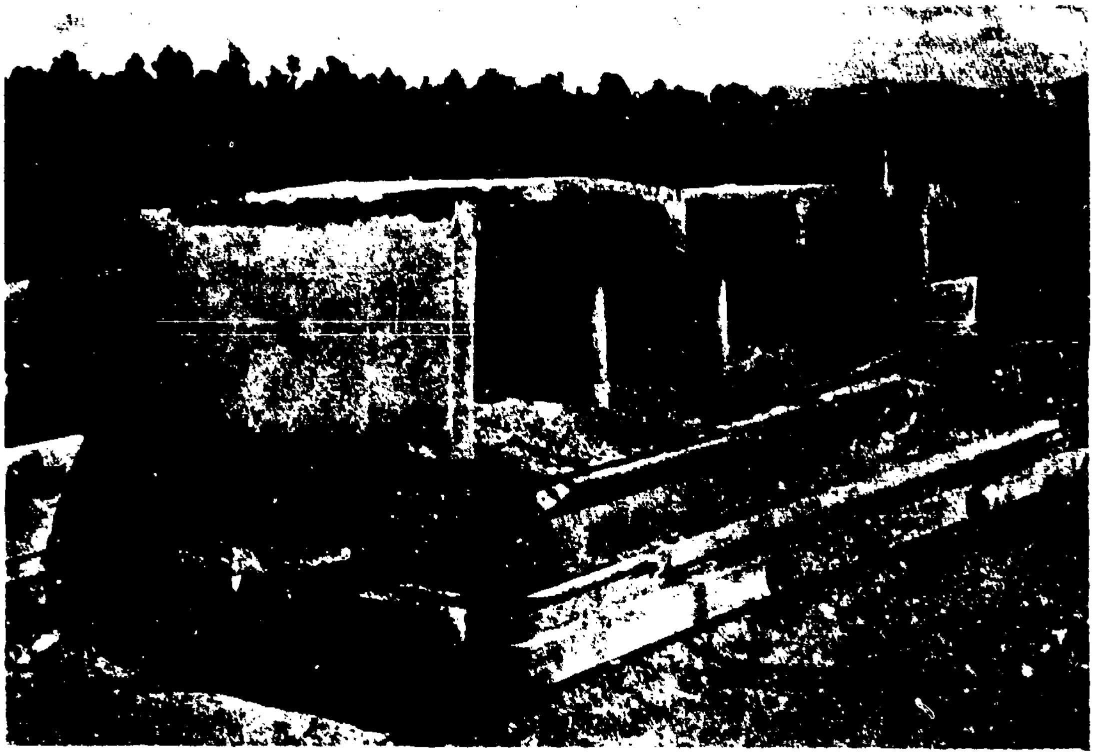


Fig. 18. Second structural model after completion of the test series.

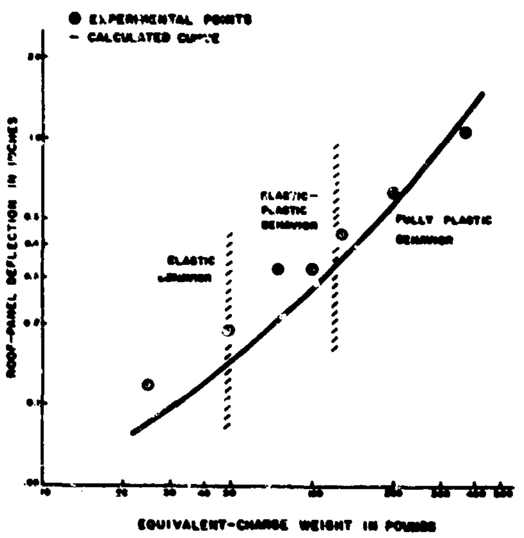


Fig. 19. Maximum deflection of the model roof panel as a function of equivalent-charge weight of PBX 9404.

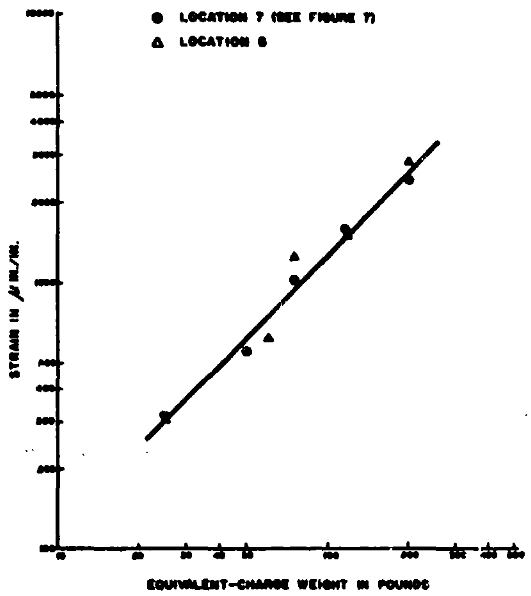


Fig. 20. Maximum corridor wall strain versus equivalent-charge weight of PBX 9404.

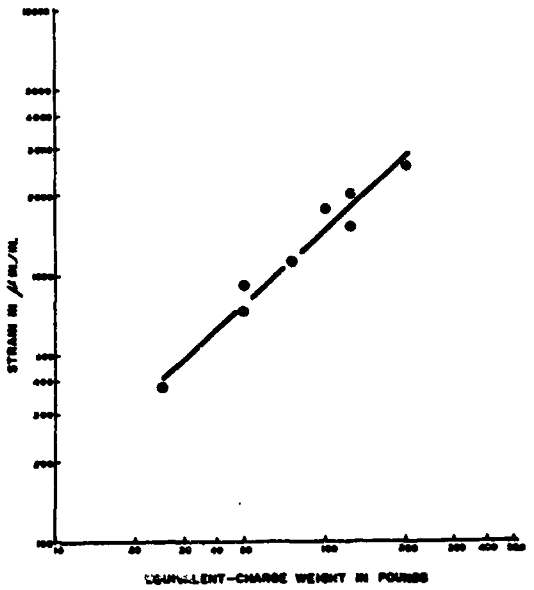


Fig. 21. Average side wall strain versus equivalent-charge weight of PBX 9404.

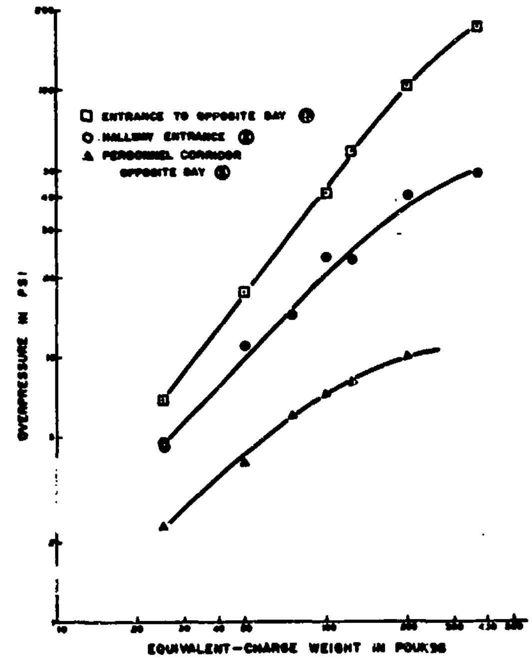


Fig. 22. Shock overpressures at three locations in the model versus equivalent-charge weight of PBX 9404. The numbers in circles are pressure transducer locations from Fig. 7.

also indicated: with up to 50-lb-equivalent charges, the structure behaved elastically with a maximum roof-panel deflection of 3/16 in.; from 50 to 125 lb, the plastic (or permanent) deflection was less than twice the maximum elastic deflection (3/16 in.); and with greater than 125-lb-equivalent charges the permanent deflection exceeded twice this elastic deflection.

Figures 7 and 22 summarize the free-field shock overpressures measured within the model in Tests 45 through 58. Figure 7 is an overpressure map at the 75-lb-equivalent charge weight (recall that shock overpressures are the same in model and prototype). In Fig. 22 the overpressures measured at three locations in the model are plotted as a function of equivalent-charge weight. Shock velocities computed from differences in shock arrival times agreed well with those computed by use of the Rankine-Hugoniot relations and the measured shock overpressures.

Figure 23 shows typical overpressure, deflection, and strain oscillograph records made in Test 51. The deflection and strain oscillograph traces are from the gages located at the center of the roof panel, and the overpressure measurement was taken at Station 1 (Fig. 7). From the half-period of the deflection oscillograph record, we conclude that the fundamental resonant frequency of the roof panel was approximately 170 cps.

Overpressure trace

Deflection trace

Strain trace

Fig. 23. Typical overpressure, deflection, and strain oscillograph records from Test 51.

The human model was unaffected by the corridor overpressure generated by the 25-lb-equivalent charge, but was upset by the 50-lb and greater charges (always falling in the direction of propagation of the shock) although no translational velocity of the model was observed. From an examination of the high-speed films it appeared that the model did not respond to the impulse of the initial shock but rather to the dynamic pressure associated with the longer duration, forward-moving "wind" or possibly to the ground shock generated by the explosion. For example, the wind (particle) velocity for the incident 8-psi overpressure air shock measured in the corridor during Test 57 was approximately 500 ft/sec, and the associated dynamic pressure ($1/2\ \rho V^2$, where ρ is the density of air and V is the particle velocity) was 1 psi. The high-speed movies focused on the particle motion indicators in the add-on corridor indicated a positive wind phase duration of approximately 13 msec at this overpressure value.

Finally, we were able to determine from films (144 frames/sec) of the blowout panel response approximate initial velocities of the blowout panel at some smaller equivalent-charge weights. For the 25- and 75-lb-equivalent charges, the initial velocities were 300 and 500 ft/sec, respectively; for a 5-lb-equivalent charge, we observed an initial velocity of approximately 80 ft/sec.

VII. IMPULSE AND EXTERNAL PRESSURE MEASUREMENTS

Reflected wall pressure and positive impulse (the area under the positive portion of the pressure-time pulse) were measured by subjecting a one-eighth scale, overstrong geometric model of one explosive-processing bay to internal blast loading. The use of an overstrong model for reflected pressure and impulse measurements is not new,[4] and is based on the premise that the structural response does not affect the blast reflection process as is the case for the relatively small deflections observed in the structural model tests. In addition to the impulse, we measured external shock overpressures caused by venting the explosion through the blowout panel in an area adjacent to the model blowout panel; these values were to be used to establish personnel hazard areas in the actual processing building.

The overstrong model geometrically simulated the inside surfaces of a processing bay and was made of 3/4-in.-thick steel boiler plate. The model was drilled and tapped to accommodate reflective blast gages (see Section IV) embedded in the walls and roof so that their pressure-sensing surface was flush with the model's inside surface. The spacing of the transducer mounting holes was such that an adequate map of the peak internal reflected pressure and impulse produced by the internal blast could be obtained; for instance, the transducer mounting holes in the roof panel were centered on 8-in. squares. The external overpressure field was measured by Atlantic Research Corporation blast gages; the location and orientation of the gages referenced to the scale-model processing bay are shown in Figs. 24 and 25 (full-scale distances are found by multiplying the indicated distances by eight). The scaling laws enunciated in Appendix A apply to this investigation, of course, and external and internal pressures are invariant between the model and actual situations. Since the time scales are reduced in the model by the scaling factor, the impulses calculated from the measured pressure-time pulses must be multiplied by the scaling factor (eight) to get the corresponding full scale values.

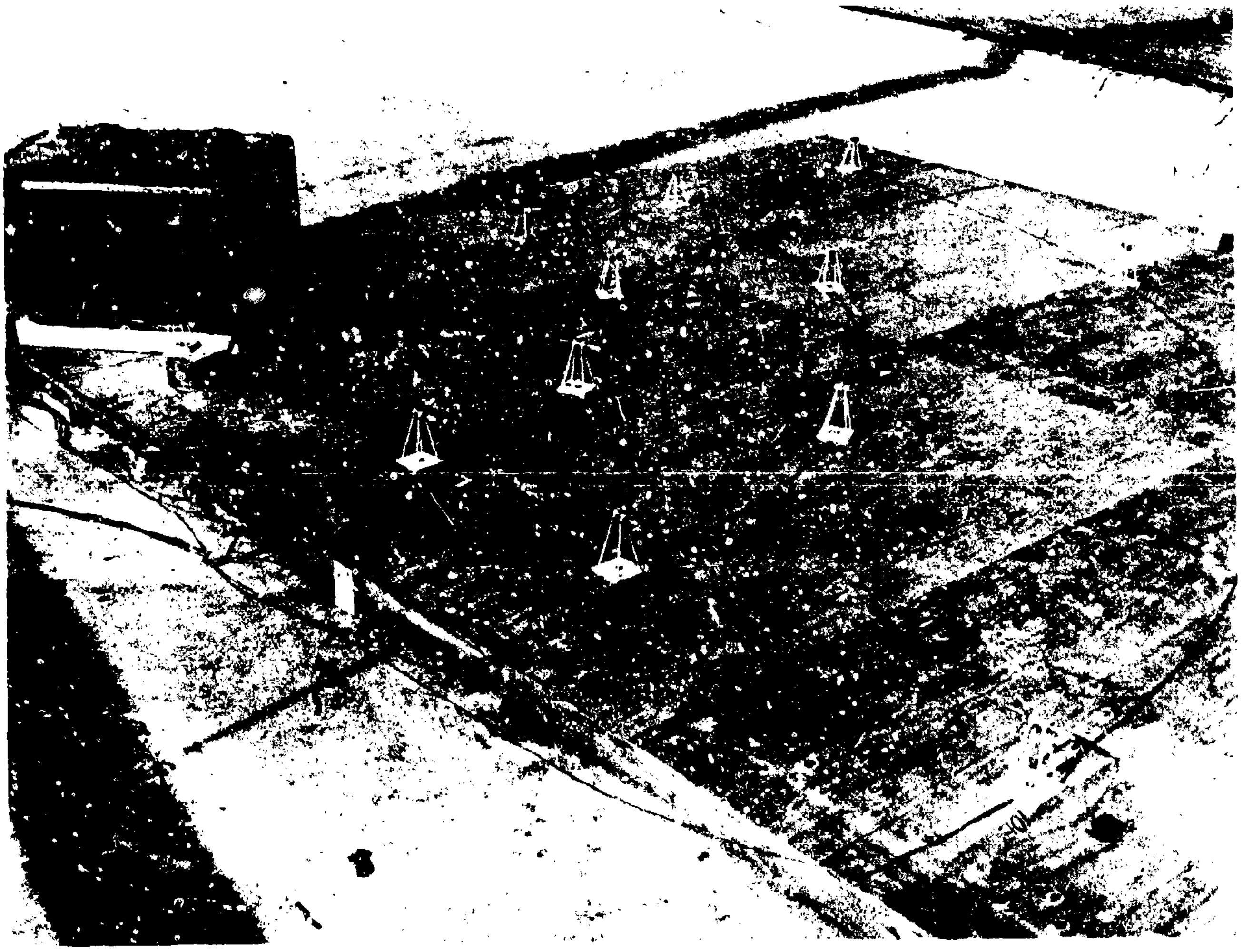


Fig. 24. The overstrong model.

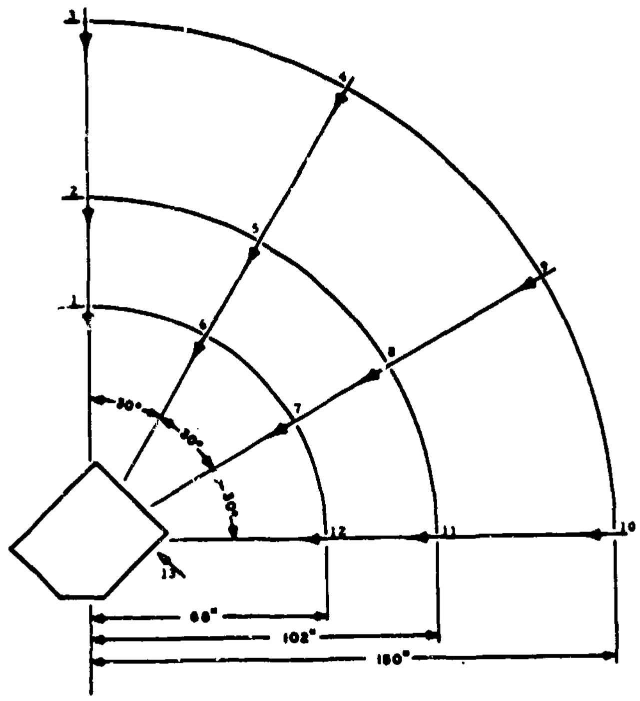
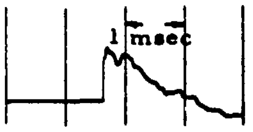


Fig. 25. Orientation of blast gages for external pressure measurements.

Table IV summarizes the tests of the overstrong model. Tests 60, 61, 62, 63, and 65 employed a blowout panel; the remaining tests did not. To prevent detonator shrapnel from flying about the inside of the model and damaging the pressure-sensing surfaces of the reflective pressure gages, the explosive charges were detonated with an MDF (mild detonating fuze) initiation system with the SE-1 detonator located outside the model. The charges were centered midway between the floor and ceiling of the overstrong model for Tests 60, 61, 66, 67, and 68, whereas in Tests 62 through 65 they were positioned a scaled 4 ft above the floor as in the structural model tests.

Figure 26 illustrates typical pressure-time traces obtained in Tests 60 through 68; the top trace is from a reflective blast gage, and the bottom from an Atlantic Research Corporation gage used to measure pressures outside the model. The areas under the reflected pressure-time traces (suitably enlarged) were determined by means of a planimeter, and provided the impulse values given in Fig. 27. The results of this testing and accompanying data analysis are as follows.

Reflected pressure trace



External pressure trace

Fig. 26. Typical reflected pressure and external pressure traces.

TABLE IV

Tests of the Overstrong Model

Test	Explosive	Full-Scale Charge (lb)	Scaled Charge (g)	Charge Placement Coordinates (ft) (See Fig. 1) X	Y	Pressure Measurements
60	PBX 9404	25	22	10	12	Internal at 20 locations
61	TNT	25	22	10	12	"
62	PBX 9404	25	22	10	5	"
63	PBX 9404	25	22	10	12	"
64	PBX 9404	25	22	10	12	"
65	PBX 9404	100	88	10	12	"
66	PBX 9404	25	22	10	12	External at 13 locations
67	TNT	25	22	10	12	"
68	PBX 9404	100	88	10	12	"

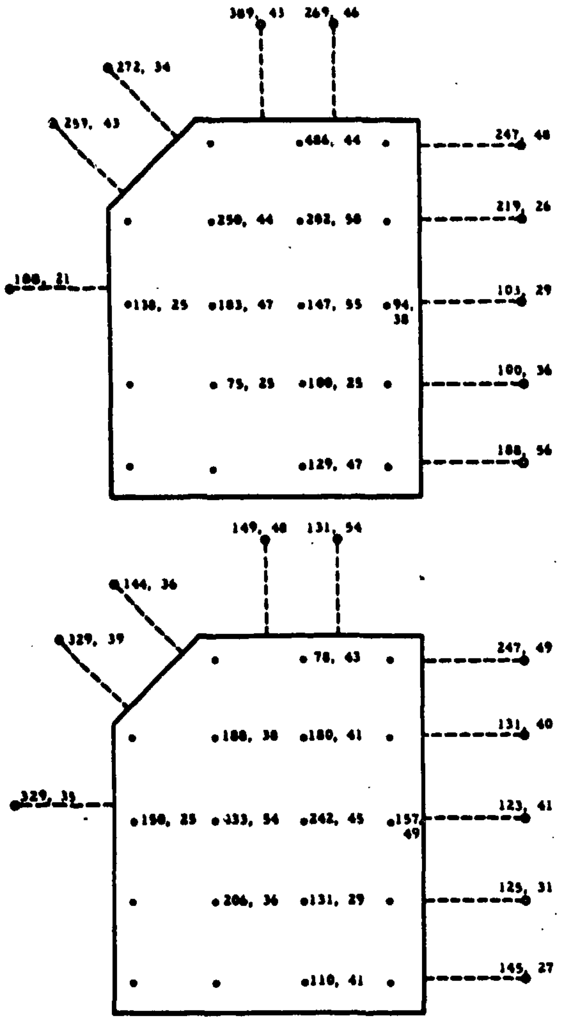


Fig. 27. Overpressure and impulse distributions in the overstrong model. Top, Test 62; bottom, Test 63. The first number at each position is peak reflected overpressure in psi, the second is reflected impulse in psi-msec.

Tests 60 and 61 compared the reflected impulse and pressure applied to the model by similarly positioned charges of the same weights of PBX 9404 and TNT. The reflected impulses measured at eight different locations on the model averaged 30% greater for PBX 9404 than for TNT. Substantially the same effect was observed in the case of reflected pressures although there was considerable scatter in the pressure data.

Tests 62 and 63 investigated the effect of charge location on the resulting peak overpressure and impulse distribution applied to the model structure. The peak overpressure and impulse distributions are shown in Fig. 27. The dashed lines lead to transducer locations on the sidewalls midway between the floor and ceiling of the model. Although there is a considerable variation in the peak reflected pressures throughout the structure, the impulse applied to the structure is seen to be fairly uniformly distributed. Impulse values were in fair agreement with those given in Fig. B3 in Appendix B and used in the calculations described there.

Test 64 again tested the hypothesis that the blowout panel had little effect on the response of the structural models. Little difference was observed between the peak reflected overpressures and impulses measured in Tests 63 and 64. Finally, on Test 65 we measured peak reflected overpressures and impulses produced in the structure by the 100-lb-equivalent charge of PBX 9404.

The external pressures caused by venting the explosion through the blowout panel area were measured at 13 locations in Tests 66 through 68. The peak overpressures measured in Tests 66 through 68 at the positions indicated in Fig. 25 are listed in Table V.

TABLE V

External Peak Overpressures (psi)

Position	Test 66	Test 67	Test 68
1	5.3	4.0	12.9
2	2.3	1.6	6.7
3	1.1	1.3	2.5
4	1.4	1.3	5.0
5	3.3	3.1	12.2
6	5.7	4.2	17.7
7	5.7	4.6	20.7
8	3.5	3.2	15.2
9	2.0	1.8	7.7
10	1.3	1.0	6.3
11	2.9	2.3	11.0
12	5.2	4.2	16.6
13	15.5	11.6	86.0

As expected, the overpressure field depends strongly on the distance from the charge. Some shielding from overpressure by the walls of the model bay is indicated by somewhat lower pressures recorded along the edges of the quadrant of Fig. 25. Overpressures recorded in Test 67 for a TNT charge were somewhat lower (10 to 20%) than those recorded in Test 66 for the same weight of PBX 9404. We also compared the external pressures measured in Tests 66 and 67 with pressures computed from the Explosion Effects Data Sheets[7] for unconfined, spherically divergent explosions. For equivalent explosive weights of TNT at equivalent distances these computed values are:

Explosive Weight	Pressure at 46 ft (68 in.)	Pressure at 69 ft (102 in.)	Pressure 100 ft (150 in.)
25 lb TNT	3.6 psi	1.7 psi	1.1 psi
100 lb TNT	9.8 psi	3.5 psi	2.0 psi

Overpressure values measured in Tests 66 and 68 were about twice those given by the Explosion Effects Data Sheets; this we attribute to the effects of the use of a high energy explosive and to the confinement provided by the processing bay so that the explosive energy is expended directionally through the blowout-panel area.

APPENDIX A

THE SCALING LAWS

Certain nondimensional factors or constants often appear in the basic differential equations describing physical processes, after the introduction of dimensionless independent and dependent variables. All solutions of the basic equations are then similar for the same values of these constant factors (as the basic equations are identical) with the result that a great deal of generality is achieved for the same amount of computing effort. Fluid mechanics provides numerous examples of dimensionless factors, the Mach number, Reynold's number, and dynamic pressure coefficient being particularly well-known. The number and form of the dimensionless constants undoubtedly depend on the complexity of the basic equations needed to describe the process, and will, in turn, determine what forms of scaling are possible.

The scaling laws for a shocked fluid such as air are embodied in the so-called similarity principle.[6] This principle states that the pressure and other properties of the shocked fluid are unchanged if the time and length scales are changed by the same factor as the dimensions of the explosive loading source; e.g., the overpressure from a 1000-lb charge of TNT measured 100 ft from the charge is identical with that from 1 lb of TNT at 10 ft, but lasts ten times as long. The assumptions inherent in such scaling are that heat conduction and viscous effects are negligible everywhere but in the shock itself and that gravity effects are negligible everywhere. This scaling law is easily verified by examining the partial differential equations of conservation in continuous fields of flow and the Rankine-Hugoniot equations expressing conservation of mass, momentum, and mechanical energy of a fluid element passing through a shock wave. The similarity principle has been shown by experiment to be valid for detonations of explosives in air and water over a large range of explosive-charge weights and distances.[9]

The scaling laws for structural response can also be obtained by examining the basic differential equations that describe the response.[10] Here, however, we proceed in the conventional (and more general) engineering style. Although our results apply to more general rate-independent constitutive relations, we assume for simplicity that the overall mechanical behavior of the structural material is characterized by elasticity with an effective elastic modulus, E (in psi), and a perfectly plastic behavior with yield strength, σ_o (in psi), or by brittleness with a breaking strength of σ_o or by a combination of these characteristics; strain-rate (or stress-rate) effects are neglected. Typical stress-strain curves for the ductile material (reinforcing bar) and for the brittle material (concrete) are shown in Fig. 2 in the body of the report. If we also assume that the structure is one-dimensional, as is the case for a simple beam, the dynamic response of the structure can be expressed in the form

$$u(x, t) = f(\ell, x, E, \sigma_o, \rho, p, t_o, t, \psi_s, \psi_p) \qquad \text{(A1)}$$

where u(x, t) is the structural deflection measured at point x on the structure at time t. (For more general structures u, x, and f are vectors.) The deflection, u, is caused by a pressure, p (in psi), applied to the structure over a time interval, t_o; the pressure distribution over the structure is specified by the dimensionless factor ψ_p. Note that p = p(x, t), and, in essence, ψ_p indicates the dependence of p on x. The quantity ρ is the mass density (in lb-sec^2/in.^{4}), ℓ is a typical structural dimension (such as beam length), and ψ_s is a dimensionless shape factor for the structure which relates all other structural dimensions to ℓ (e.g., beam thickness-to-span ratio). From dimensional analysis* we can write

$$\frac{u(x,t)}{\ell} = F\left(\frac{\sigma_o}{E}, \frac{p}{E}, \frac{t}{t_o}, \frac{pt_o^2}{\rho\ell^2}, \frac{x}{\ell}, \psi_s, \psi_p\right). \tag{A2}$$

To accomplish scaling with complete similarity, the dimensionless products in the right-hand side of Eq. (A2) must have the same values for the model as for the actual or prototype structure. We observe first that we must hold ψ_s, the shape factor, the same in the model and prototype which is termed geometric scaling. If the model and prototype are constructed [illegible] the same materials, the quantity σ_o/E will be identical in both (as will be ρ, the mass density). Suppose that the explosive-charge dimensions are reduced as the geometric scaling factor between model and prototype and the explosive charge is located at corresponding positions in both. Then, by the similarity principle for explosives, p/E, ψ_p, and $pt_o^2/\rho\ell^2$ will be identical in the model and prototype because p is identical at the scaled position and t_o is scaled as the length scale (provided, of course, that the same fluid and explosive are used for the shock process). Thus, at corresponding values of [illegible] and x/ℓ, F becomes a function of the same constants and u/ℓ is identical in the model and prototype. Since strain is dimensionless, the strain (and consequently the stress) is identical in model and prototype at scaled times and positions as is structural damage, provided that the damage is not rate-dependent. An experimental verification of this scaling principle for large deflection elastic and plastic response of cantilever beams to blast loading is given by Baker.[10]

The initial stress field produced by the weight of the structure itself and the effects of strain rate are not included in the scaling. The effect of the initial stress field is slight because the dynamic stresses developed in the structure are usually much greater than the initial stresses, while strain-rate effects are not pronounced for conventional (nonviscous) structural materials and for reasonable scaling factors of not less than 1/20.*

We emphasize again that in the absence of rate effects and heat conduction, the correct scaling for blast and structural simulation is purely geometric; the size and placement of the explosive is reduced by the model scaling factor.

APPENDIX B

CALCULATION OF ELASTIC-PLASTIC PANEL RESPONSE TO BLAST LOADING

A structural model of an elastic, perfectly plastic reinforced concrete panel is described, and a numerical solution for its response to blast loading is given. The calculated blast-loading response of a rectangular panel built-in on three sides and free on the fourth is compared with the structural response measured in the scale models. The techniques used to predict the structural response are not new and are largely described in Reference 13 although we have included in our analysis the elastic portion of the structural response.

Since the response of a single-degree-of-freedom, linear spring-mass system is particularly well known, it is customary in shock and vibration analysis to replace the complex multi-degree-of-freedom structure with a single-degree-of-freedom, spring-mass system, such as the one shown

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*Buckingham's theorem states that a dimensionally homogeneous equation can be reduced to a relationship among an independent set of dimensionless products. If n variables are functionally related by an unknown dimensionally homogeneous equation, then Buckingham's theorem states that the relationship can be expressed by n-r dimensionless products.[11] In most cases r is equal to the number of fundamental dimensions in the problem; in our case there are three dimensions - length, time, and force. Since Eq. (A1) is a dimensionally homogeneous relation among 11 variables, the form of the relationship can be reduced to an expression involving 8 dimensionless products.

*Conventional spallation criteria include a rate effect. A common relation between spall stress, σ_s, and stress rate, $\dot{\sigma}$, is

$$\sigma_s = A\dot{\sigma}^{\frac{1}{2}} + \sigma_o ,$$

where A and σ_o are experimentally determined constants for each material and other criteria are formulated in terms of the stress gradient. For a discussion of these and other criteria see Thurston and Mudd.[12]

in Fig. B1a. The sliding connection at the end of the spring limits the spring force to an amount R and represents the ultimate resistance of an elastic, perfectly plastic structure. Under static loading (P(t) varies slowly with time), the load deflection is shown in Fig. B1b and is seen to be identical with that of an elastic, perfectly plastic rod in a state of one-dimensional stress.

The parameters of a single-degree-of-freedom system such as the mass M and spring constant k were chosen to best simulate the response of the more complex structure. The determination of M is relatively straightforward; we then chose the value of the spring constant k so that the fundamental resonance of the reinforced concrete panel (which can be estimated by calculation or measured by experiment) was duplicated in the single-degree-of-freedom system. The value of viscous damping was included primarily for calculation.

The value of R, the ultimate resistance of the panel, was determined from yield-line theory for rectangular, rigid, perfectly plastic plates.

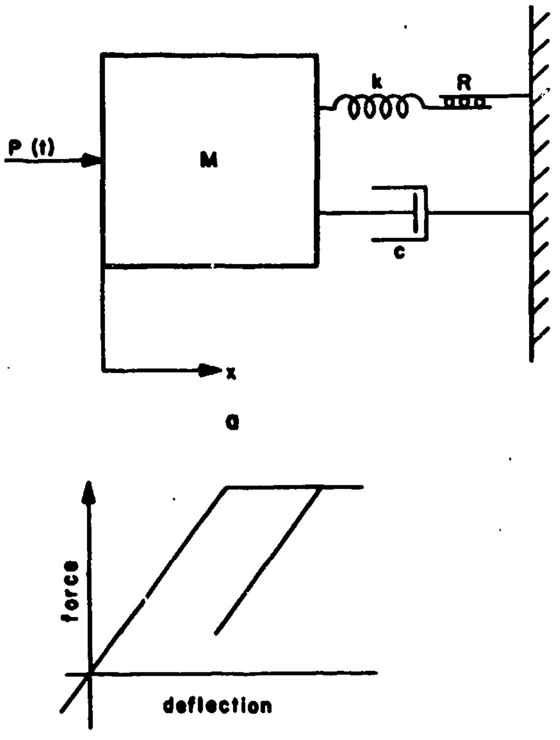

Fig. B1. Spring-mass model and load-deflection behavior under static loading.

According to the yield-line theory, a rectangular plate at collapse deforms at a constant load, with plastic deformation (characterized, in general, by points of maximum stress) confined to hinge lines of the plate, while the rest of the plate is rigid and rotates about these hinge lines. The hinge lines are called "yield lines" in the literature and are so arranged on the plate as to allow the deforming plate to operate as a mechanism. Methods for determining yield-line patterns for rectangular plates with various support conditions are discussed in References 13 and 14, and we give here only the yield-line pattern for an approximately square plate built-in on three sides and free on the fourth as shown in Fig. B2. The yield-line pattern agrees very well with the pattern developed on the roof panel during the scale-model structural tests as shown in Figs. 13 and 14.

The loading function, P(t), acting on the panel was determined from the explosively generated pressures and durations of positive pressure acting on it. Values of overpressure and duration of positive pressure were taken from the Explosive Effects Data Sheets[7] with a 60% increase in overpressure being allowed for the high explosive PBX 9404 in relation to TNT overpressures. The applied pressures were determined at the point on the panel nearest the explosive, and normal reflection of the pressure pulse was assumed. Preliminary calculations showed that the durations of positive reflected pressure were so short in

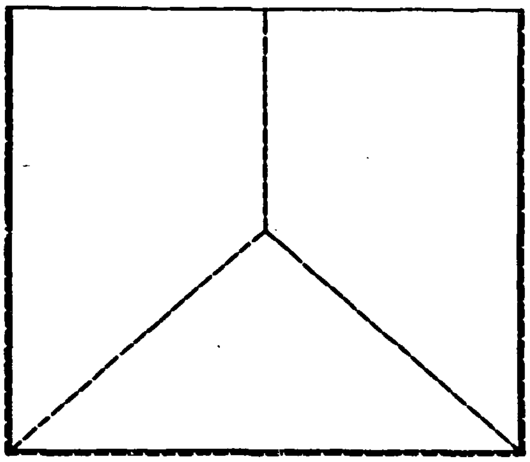

Fig. B2. Yield-line pattern for a plate built-in on three sides and free on the fourth.

relation to the natural period of the panel that impulse alone predicted the structural response with little loss in accuracy, and impulse was used in most response calculations. The reflected impulse was again determined by using the shortest straight-line distance of the panel from the explosive charge, and this value was assumed to act uniformly over the panel. Since we were neglecting multiple reflections of the blast pulse, we felt that this was an adequate approximation to the actual situation. Reference 6 provided a source of reflected impulse data for spherical Pentolite explosive charges, and a one-third increase in impulse was allowed for the high energy explosive PBX 9404. Since these data (adjusted for PBX 9404) were used often in calculations, we show the impulse data as a function of the scaled distance $R/W^{1/3}$ in Fig. B3; R is the distance between the panel and the explosive in feet, and W is the weight of PBX 9404 in pounds.

The differential equations describing the motion of the spring-mass system shown in Fig. B1a were integrated by Runge-Kutta numerical integration, with the structural parameters of the roof panel of the model processing bay as an example. The natural frequency of the panel was calculated to be approximately 250 cps. The response records at low charge levels in the scale-model tests showed a fundamental resonance at approximately 170 cps for the roof panel; this value was used to determine the value of k in the spring-mass system. The ultimate resistance of the model roof panel per unit area was computed from yield-line analysis and found to be 33 psi. Viscous damping of 20% of critical was assumed for the single-degree-of-freedom system. For initial conditions we took specified velocity computed from the appropriate impulse value and zero initial displacement.

Figure B4 shows the typical displacement, velocity, and spring-force response curves obtained in this fashion when an 88-gram test charge of PBX 9404 (equivalent to 100 lb in the actual structure) was detonated 12 in. from the center of the model roof panel. Finally, the solid curve of Fig. 19 summarizes the computations of maximum roof-panel displacement as a function of the eqivalent charge weight of PBX 9404 detonated in the full-scale structure. The computed values agree well with the deflection values obtained during the scale-model tests.

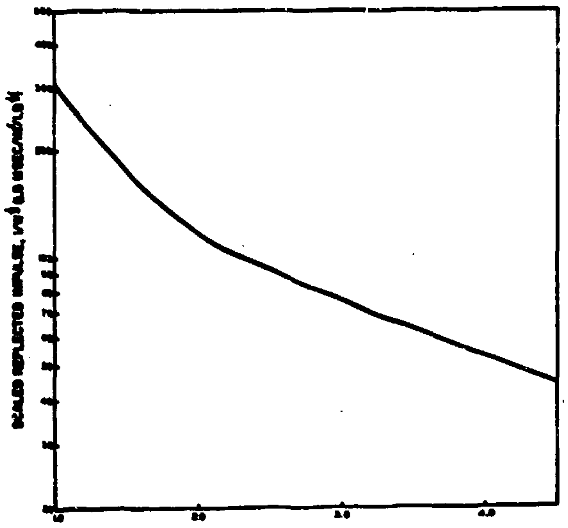

Fig. B3. Reflected scaled impulse vs scaled distance data taken from Reference 6 and adjusted for PBX 9404.

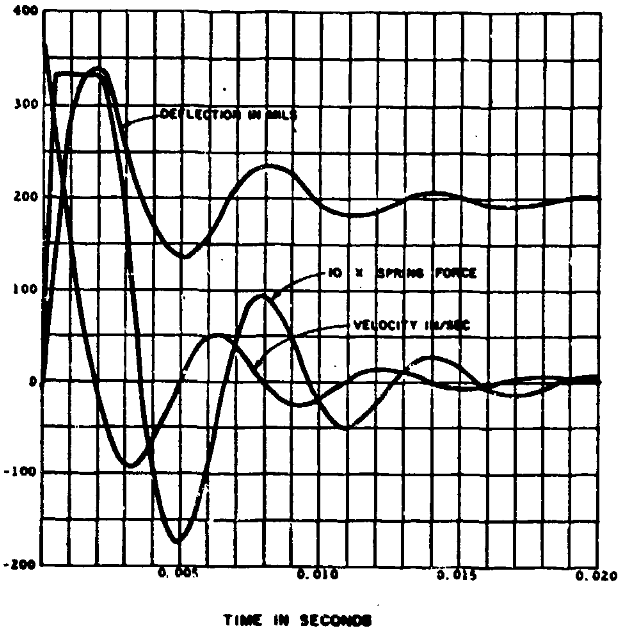

Fig. B4. Typical computed displacement, velocity, and spring-force response curves.

ACKNOWLEDGMENTS

The study reported here originated in 1960-61, and since then many people at GMX-3 have contributed their efforts to it. In particular, the author thanks G. S. Dow, Jr., N. K. Kernodle, R. W. Mathews, E. A. Pacheco, and B. W. Deitrick for their cooperation in ensuring that this study reached a successful conclusion.

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DESIGN OF A SMALL EXPLOSIVE LOADED STORAGE BUILDING

By: Bert F. Steves
Harry L. Callahan
William V. Hill

BLACK & VEATCH
consulting engineers

INTRODUCTION

The "Manual for Design of Protective Structures Used in Explosive Processing and Storage Facilities", has only recently been available to Architect-Engineers. The Manual provides the Engineer with a method of design to resist the effects of explosives. This paper provides a description of the method of design presented by the Manual for a small two-cell storage structure center wall. A simple structure was selected because the design method and the simpler reinforcing are easier to describe.* The paper has been limited to this one element since the design of one element will provide guidance to the design of other elements. Figure No. 1 is the original artist's view of the storage structure presented for the client's inspection of the design concept. The client was the Space and Missile Systems Organization, Air Force Systems Command.

TYPE OF STRUCTURE AND DESIGN CRITERIA

The structure consists of two 8'-0" X 8'-0" cells with reinforced concrete walls and floor, metal deck roof, and with 7'-0" X 8'-0" metal double doors. Figure No. 2 shows the front and side elevations of the structure. On Figures 3, 4 and 5, (floor plan and two sections), the location of a 26 pound explosive charge is indicated. The value of each piece of equipment to be stored in the structure requires a design which would permit the loss of the donor cell by an internal explosion without damage to the contents of the acceptor cell. The equipment in each cell is protected by a metal case which will permit small spalls of low velocity. Leakage of pressure

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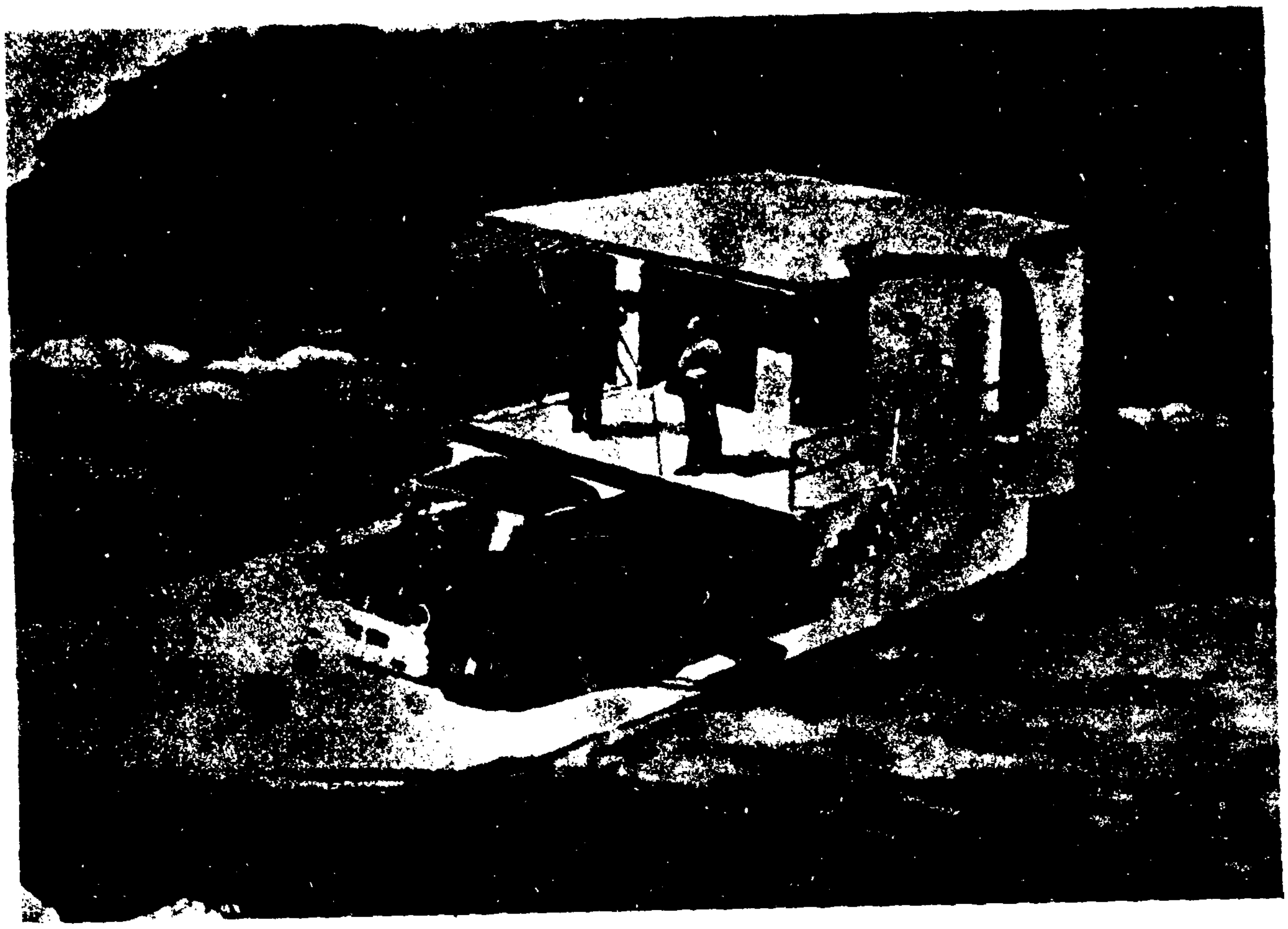
*For the description of a more complex structure see "Facility Design Features for Assembly, Surveillance and Inspection Building," same authors, Explosive Safety Seminar, August, 1968.



CONCEPT DRAWING

Figure 1

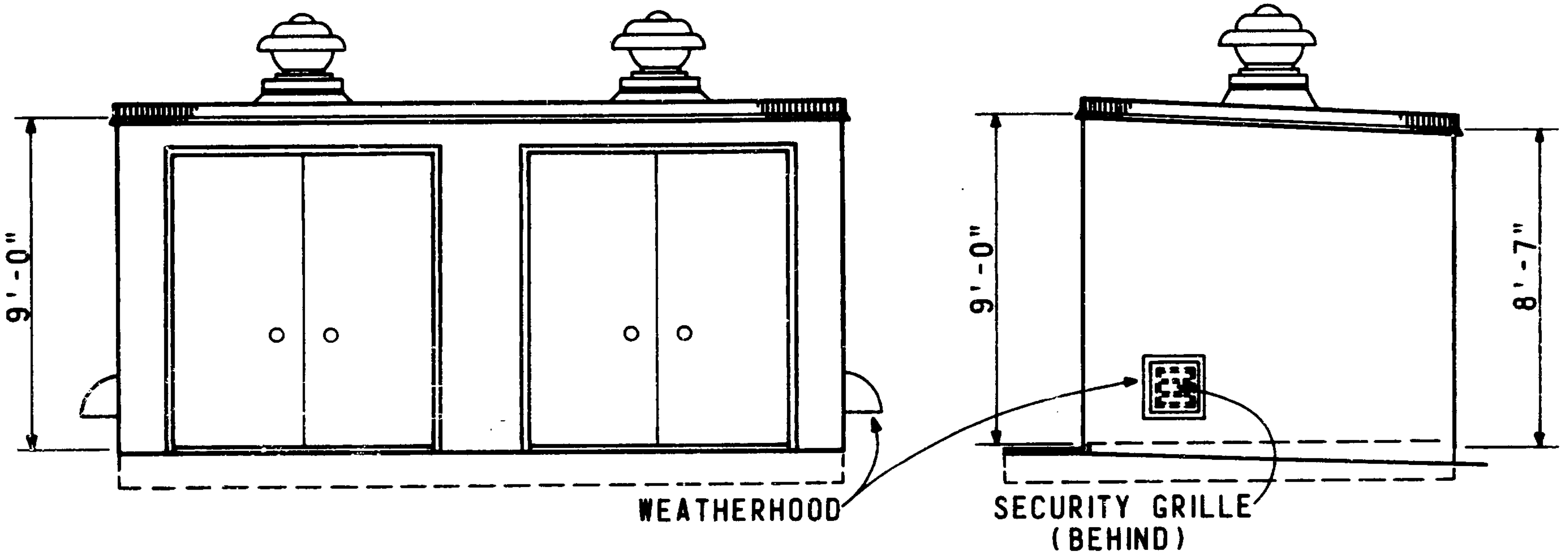
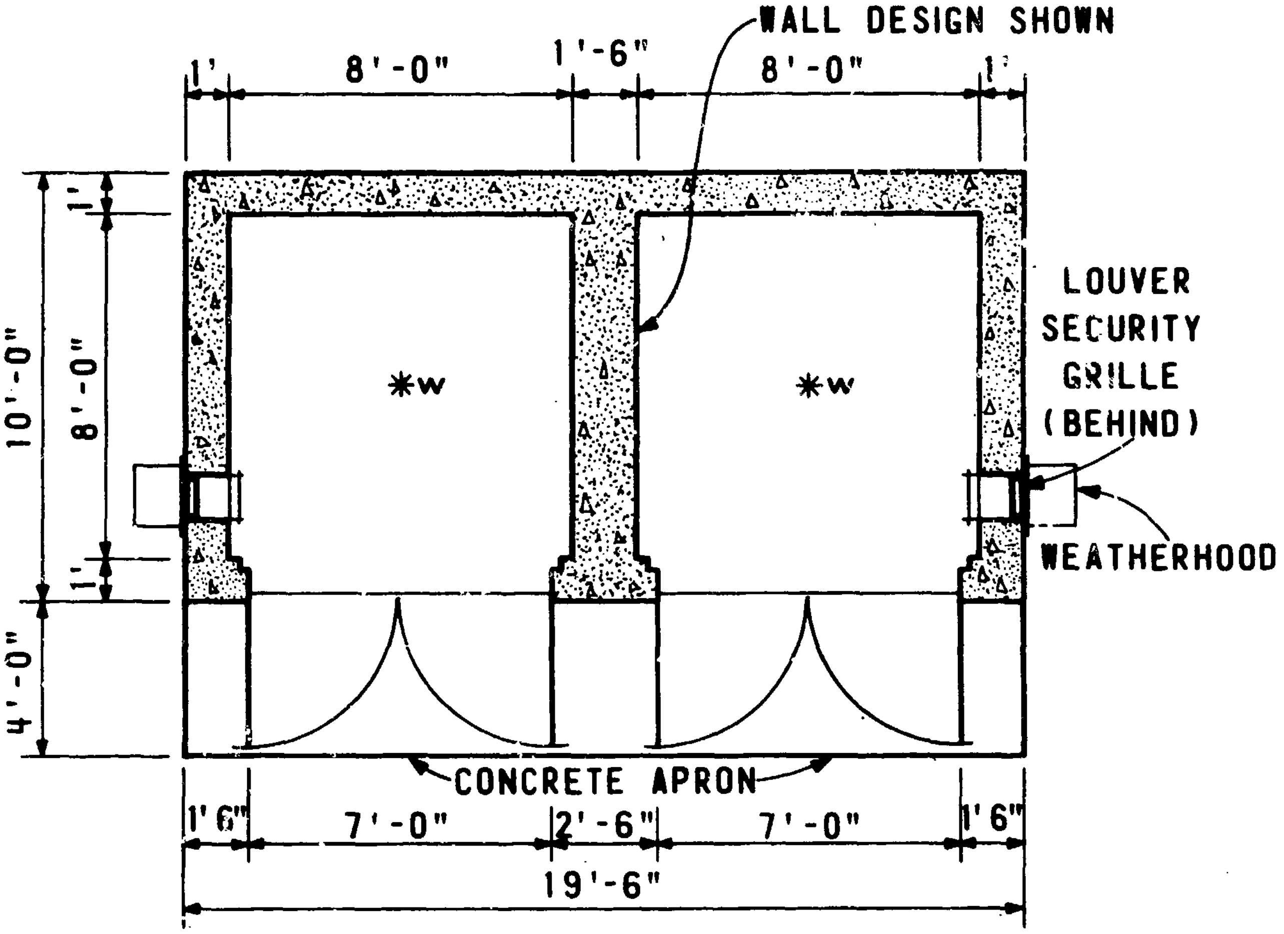


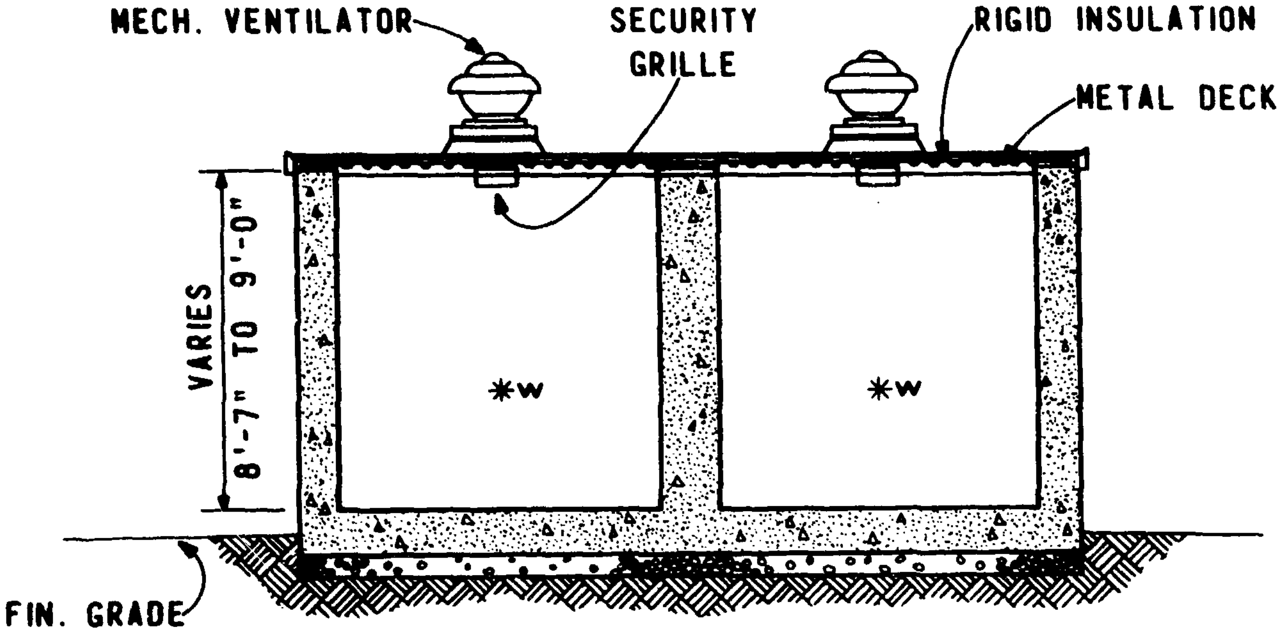
Figure 2

FRONT AND SIDE ELEVATIONS



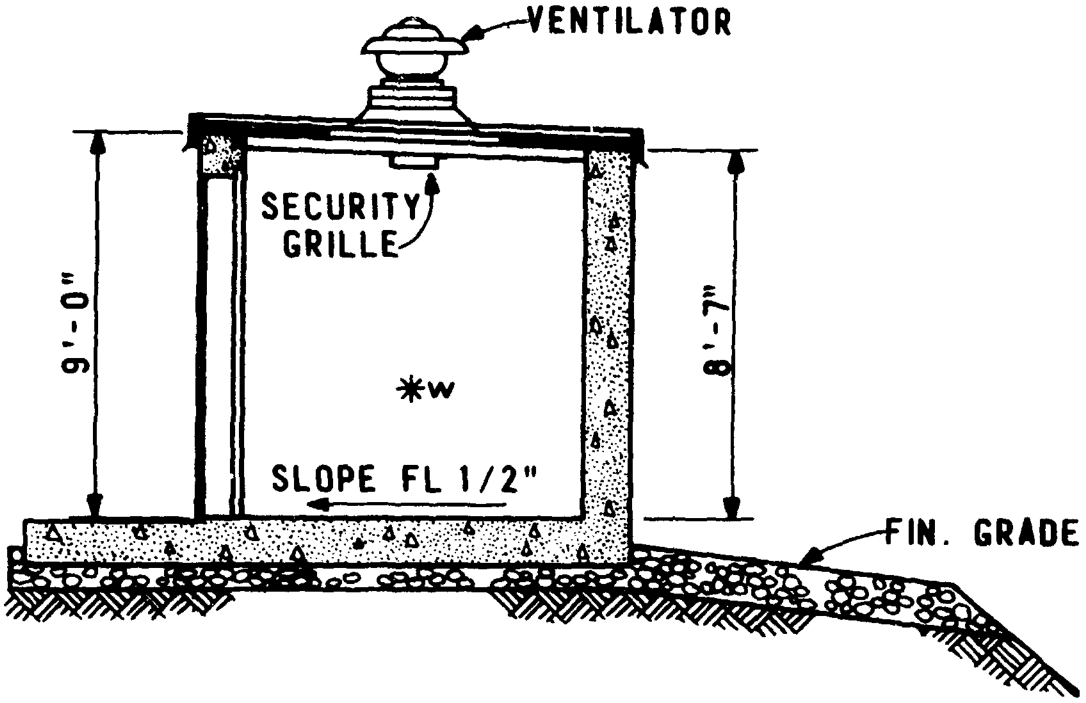
FLOOR PLAN

Figure 3



LONGITUDINAL SECTION

Figure 4



CROSS SECTION

Figure 5

through small openings was also permitted. The doors are designed to be blown out, so that gas pressure buildup need not be considered for an internal explosion but will resist the effects of an external explosion.

DESIGN PROCEDURE

The Manual is a comprehensive design document, but requires considerable study and a knowledge of dynamic design. This paper provides a step-by-step procedure for the convenience of persons not familiar with the Manual.

To illustrate this procedure, consider the design of the common wall of a two cell structure as previously described. The roof is not considered to be frangible. The metal deck, rigid insulation and built-up roofing weigh more than 10 pounds per square foot and will become a reflecting surface. The doors are assumed to blow out and vent the cubicle from the buildup of gas pressures. The structure falls into the category of a three wall cubicle with roof (See Figure 6 which is taken from page 4-59 of the Manual). The interior wall which is adjacent to the door openings is classified as a side wall with N = 3.

Required: Average scaled impulse on interior wall from an equivalent explosive charge of 26 pounds of TNT, located in center of cubicle and 3 feet above floor.

Given: h = 3'-0", Vertical distance to nearest reflecting surface.

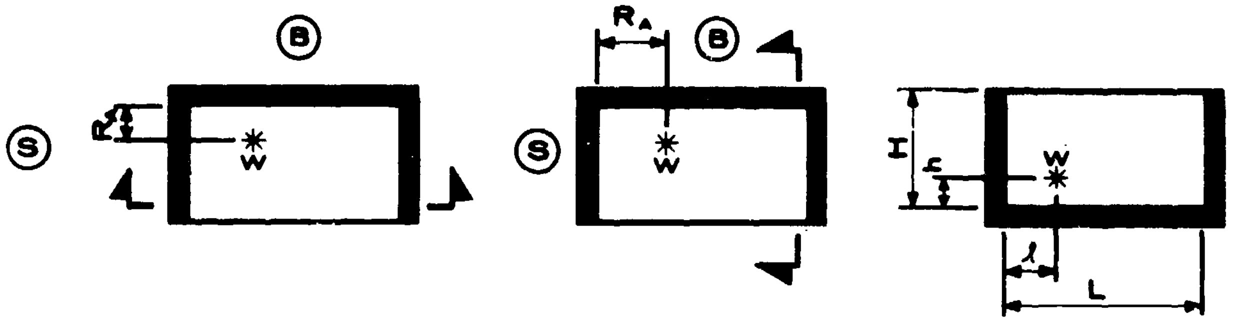
H = 8'-9-1/2", Vertical distance between reflecting surfaces.

L = 4'-0", Horizontal distance to nearest reflecting surface.

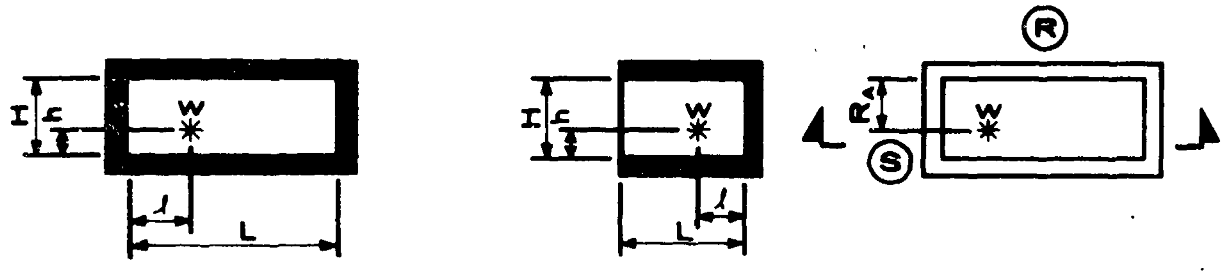
L = 8'-0", Horizontal distance between reflecting surface and free edge.

R_A = 4'-0", Normal distance.

W = 26 pounds, charge weight.



SECTIONAL PLAN SECTIONAL PLAN SECTION



SECTION SECTION ELEVATION

BACK WALL (N=4) SIDE WALL (N=3) ROOF (N=3)

THREE WALL CUBICLE WITH ROOF

Figure 6

Solution:

Step 1. Determine the following:

$\frac{h}{H} = \frac{3.0}{8.79} = 0.34$ $\qquad$ $\frac{\ell}{L} = \frac{4.0}{8.0} = 0.50$

$\frac{L}{H} = \frac{8.0}{8.79} = 0.91$ $\qquad$ $\frac{L}{R_A} = \frac{8.0}{4.0} = 2.0$

$Z_A = \frac{R_A}{W^{1/3}} \frac{4.0}{(26)^{1/3}} = 1.35$

Step 2. Determine the scaled unit blast impulse from the list of appropriate figures given in Table 1 taken directly from the Manual Figure 4-16. It will be seen that interpolation will be required for $\frac{h}{H}$. Interpolation will also be required for $\frac{L}{H}$ and Z_A.

Using Figures 4-45, 4-48, 4-51, and 4-53 of the Manual tabulate each unit blast impulse for the following values as shown in Table II:

$\frac{L}{R_A} = 2.0$, $\qquad$ $\frac{\ell}{L} = 0.50$, $\qquad$ $Z_A = 1.35$

$\frac{L}{H} = 0.75$, ~~150~~ 1.50, 3.00 and 6.00

$\frac{h}{H} = 0.15$, 0.25, 0.50 and 0.75

Figure 7, which is part of figure 4-45 of the Manual shows an example for obtaining the scaled unit blast impulse for the following ratios:

$\frac{L}{R_A} = 2.0$, $\qquad$ $\frac{\ell}{L} = 0.50$, $\qquad$ $Z_A = 1.35$

$\frac{L}{H} = 0.75$, $\qquad$ $\frac{h}{H} = 0.15$

Step 3. Draw four curves on log - log graph paper as shown in Figures 8, 9, 10 and 11, with $\frac{L}{H}$ as the abscissa and the scaled unit blast

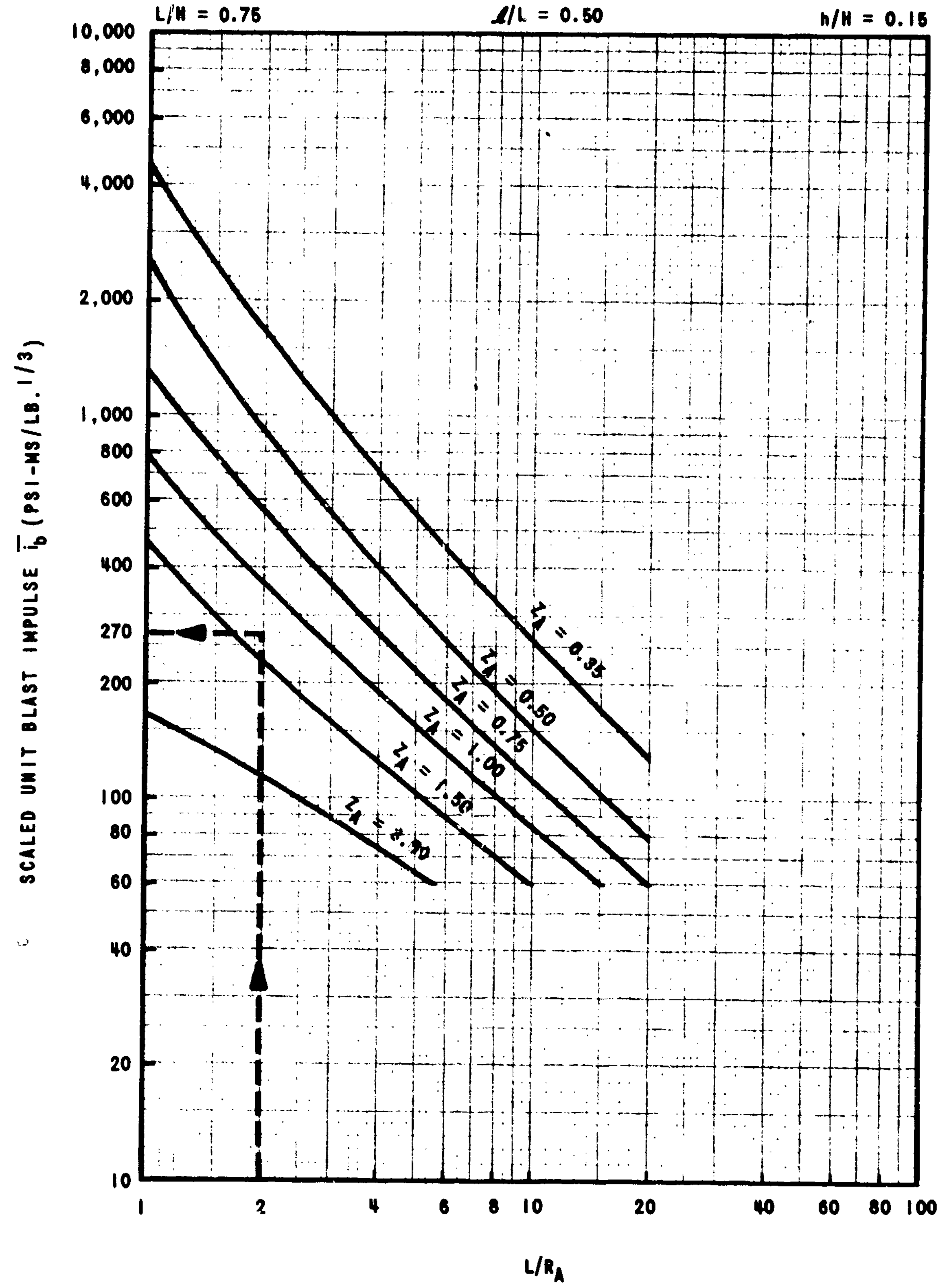


Figure 7 PARTIAL FIGURE 4-45 FROM MANUAL

TABLE I

LIST OF FIGURES
FOR SCALED AVERAGE UNIT IMPULSE LOADS

h/H	ℓ/L	NO. OF ADJACENT REFLECTING SURFACES			
		ONE	TWO	THREE	FOUR
0.15	0.10	4-17	4-28	4-43	4-54
	0.25	4-18	4-29	4-44	4-55
	0.50	4-19	4-30	4-45	4-56
	0.75		4-31		
0.25	0.10	4-20	4-32	4-46	4-57
	0.25	4-21	4-33	4-47	4-58
	0.50	4-22	4-34	4-48	4-59
	0.75		4-35		
0.50	0.10	4-23	4-36	4-49	4-60
	0.25	4-24	4-37	4-50	4-61
	0.50	4-25	4-38	4-51	4-62
	0.75		4-39		
0.75	0.25	4-26	4-40	4-52	
	0.50	4-27	4-41	4-53	
	0.75		4-42		

TABLE II

UNIT BLAST IMPULSES ($\bar{i}_b$)

TABULATION OF $\bar{i}_b$ FOR $\frac{L}{R_A} = 2.0$, $\frac{\ell}{L} = 0.50$, $Z_A = 1.35$

AND VARIOUS $\frac{h}{H}$ AND $\frac{L}{H}$ RATIOS

$\frac{L}{H}$ \ $\frac{h}{H}$	0.15	0.25	0.50	0.75
0.75	270	300	270	230
1.50	390	390	370	320
3.00	400	440	440	430
6.00		440	470	490
FIGURE	4-45	4-48	4-51	4-53

impulse as the ordinate - one curve for each value of $\frac{h}{H}$. From the curves determine the four scaled unit blast impulses for $\frac{L}{H} = 0.91$.

Step 4. Draw a curve on log - log graph paper as shown in Figure 12 from the values obtained in Step 3 with $\frac{h}{H}$ as the abscissa and the scaled unit blast impulse as the ordinate. For the value of $\frac{h}{H} = 0.34$, the scaled unit blast impulse, $\bar{i}_b = 320$ psi - ms/lb $^{1/3}$.

Step 5. Using the following materials, determine their dynamic strength from Table 5-3 of the Manual:

Concrete, $f_c' = 4{,}000$ psi

$f'_{dc} = 1.25 \times 4{,}000 = 5{,}000$ psi

Reinforcement, $f_y = 40{,}000$ psi

$fdy = 1.2 \times 40{,}000 = 48{,}000$ psi.

Step 6. Try an 18" thick wall with #5 bars @ 12" each way, each face, and #5 lacing bars. For other walls, try 12" thick with #4 bars @ 6" each way, each face.

Determine the ultimate resisting moments:

M_{VN} negative moment capacity in vertical direction.

M_{VP} positive moment capacity in vertical direction.

M_{HN} negative moment capacity in horizontal direction.

M_{HP} Positive moment capacity in horizontal direction.

$$M_u = \frac{A_s f_{dy} d_c}{b} \qquad \text{Eq. 5-7 of Manual.}$$

Where:

M_u = ultimate resisting moment

A_s = Area of tension reinforcement

f_{dy} = dynamic yield stress of reinforcement

d_c = distance between the centroids of the compression and tension reinforcement

$$M_{VN} = M_{VP} = \frac{.31 \times 48{,}000 \times 13.38}{12} = 16{,}600 \text{ inch lbs}$$

$$M_{HP} = \frac{.31 \times 48{,}000 \times 14.63}{12} = 18{,}200 \text{ inch lbs}$$

$$M_{HN} = \frac{.40 \times 48{,}000 \times 9.0}{12} = 14{,}400 \text{ inch lbs}$$

Step 7. Determine the yield line location from Figure 5-9 of the Manual.

$$\frac{L}{H} \times \left(\frac{M_{VN} + M_{VP}}{M_{HN} \quad M_{HP}}\right)^{1/2} = \frac{8}{8.75} \times \left(\frac{16{,}600 + 16{,}600}{14{,}400 + 18{,}200}\right)^{1/2} = 0.92$$

$\frac{Y}{H}$ = .965 therefore:

$y = .965 \times 8.79 = 8.47'$ (See Figure 13)

Step 8. Determine r_u ultimate unit resistance from Table 5-6 of Manual:

$$r_u = \frac{(M_{HN} + M_{HP}) \quad (3\ HP \div 2y)}{L^2 \quad (3H - 2y)}$$

$$= \frac{(14{,}400 + 18{,}200) \quad (3 \times 12 \times 8.79 + 2 \times 8.47)}{(12 \times 8)^2 \quad (3 \times 12 \times 8.79 - 2 \times 12 \times 8.47)} = 16.3 \text{ psi}$$

Step 9. Determine m_u effective mass.

Weight of wall = $\frac{150}{144} \times 1.5 = 1.56$ psi

Mass = $\frac{1.56 \times 10^6}{386} = 4{,}050$ psi - ms^2 per in.

From Figure 6-5 of the Manual K_{LM} load-mass factor equal 0.508

$m_u = (K_{LM}) \times (\text{Mass})$

$m_u = .508 \times 4{,}050 = 2{,}060$ psi - ms^2 per in.

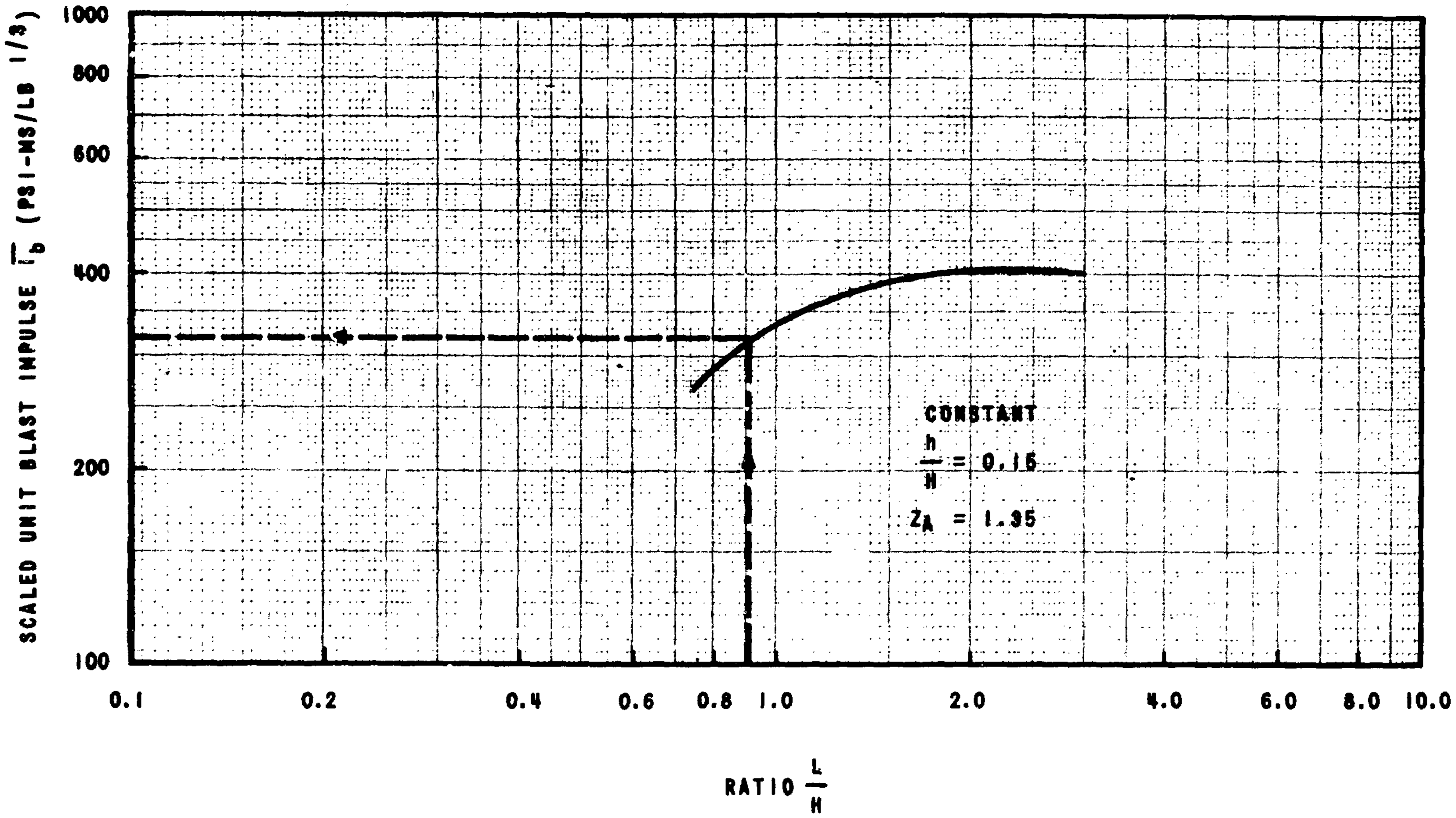


Figure 8 SCALED UNIT BLAST IMPULSE FOR CONSTANT $\frac{h}{H} = 0.15$

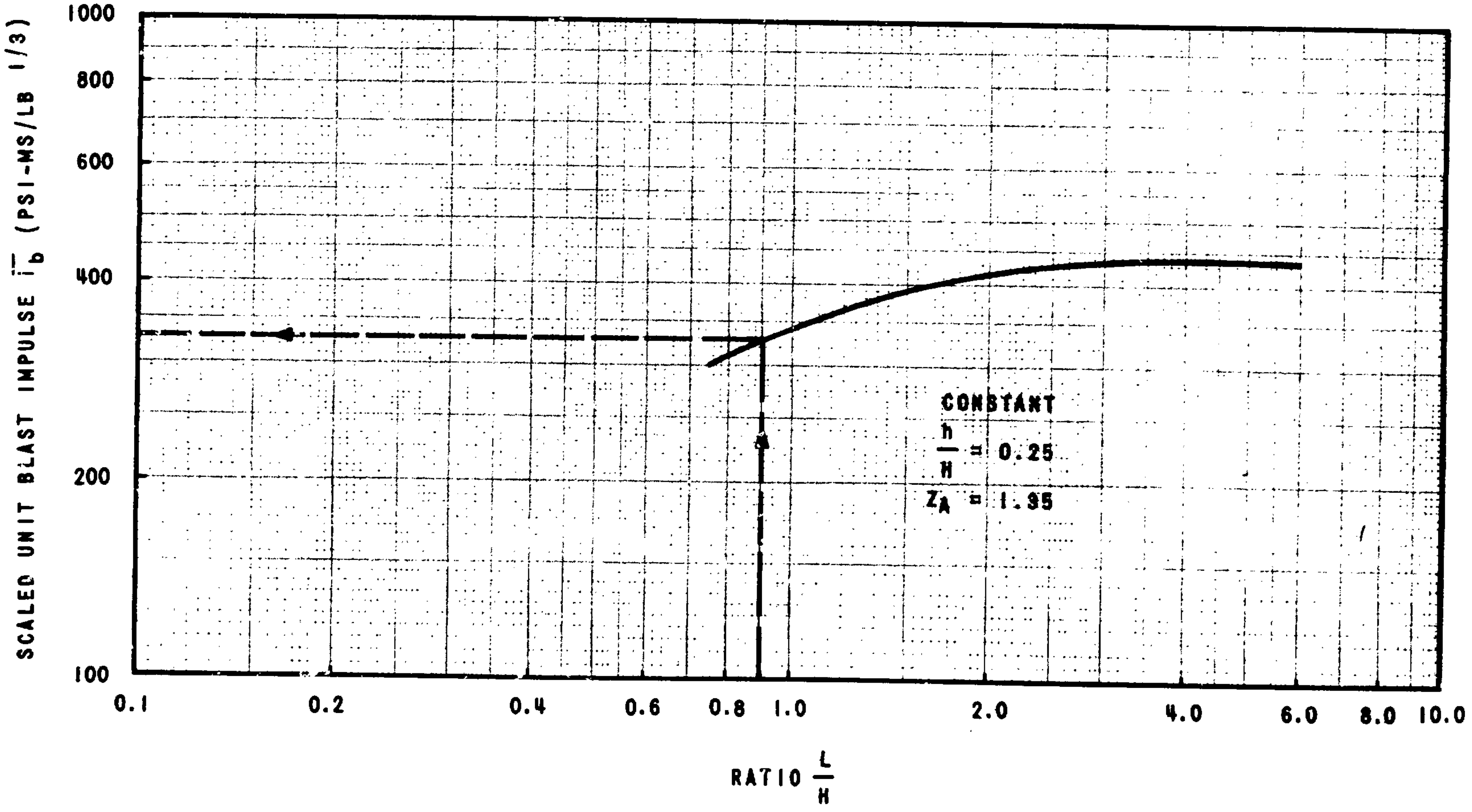


Figure 9 SCALED UNIT BLAST IMPULSE FOR CONSTANT $\frac{h}{H}$ = 0.25

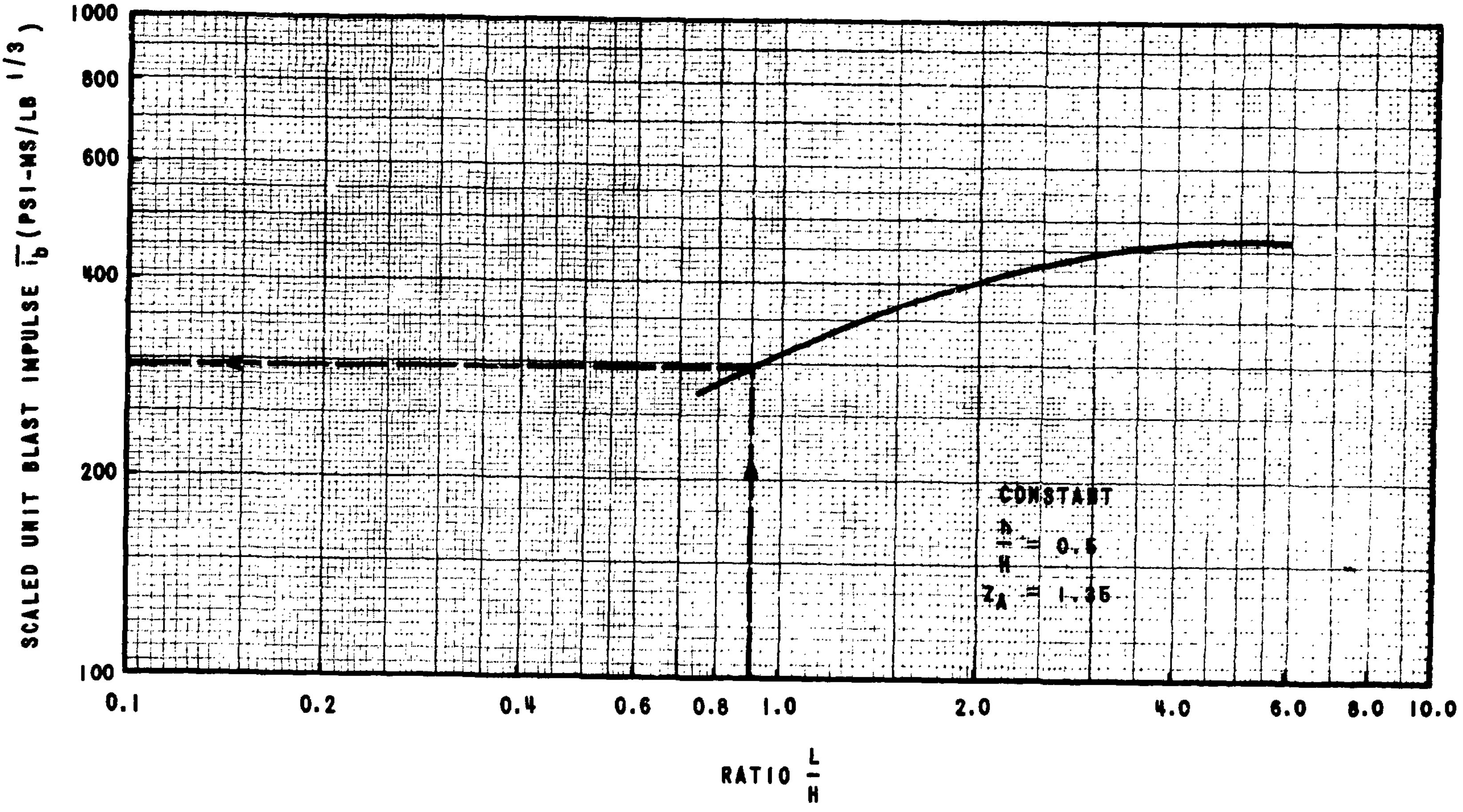


Figure 10 SCALED UNIT BLAST IMPULSE FOR CONSTANT $\frac{h}{H} = 0.50$

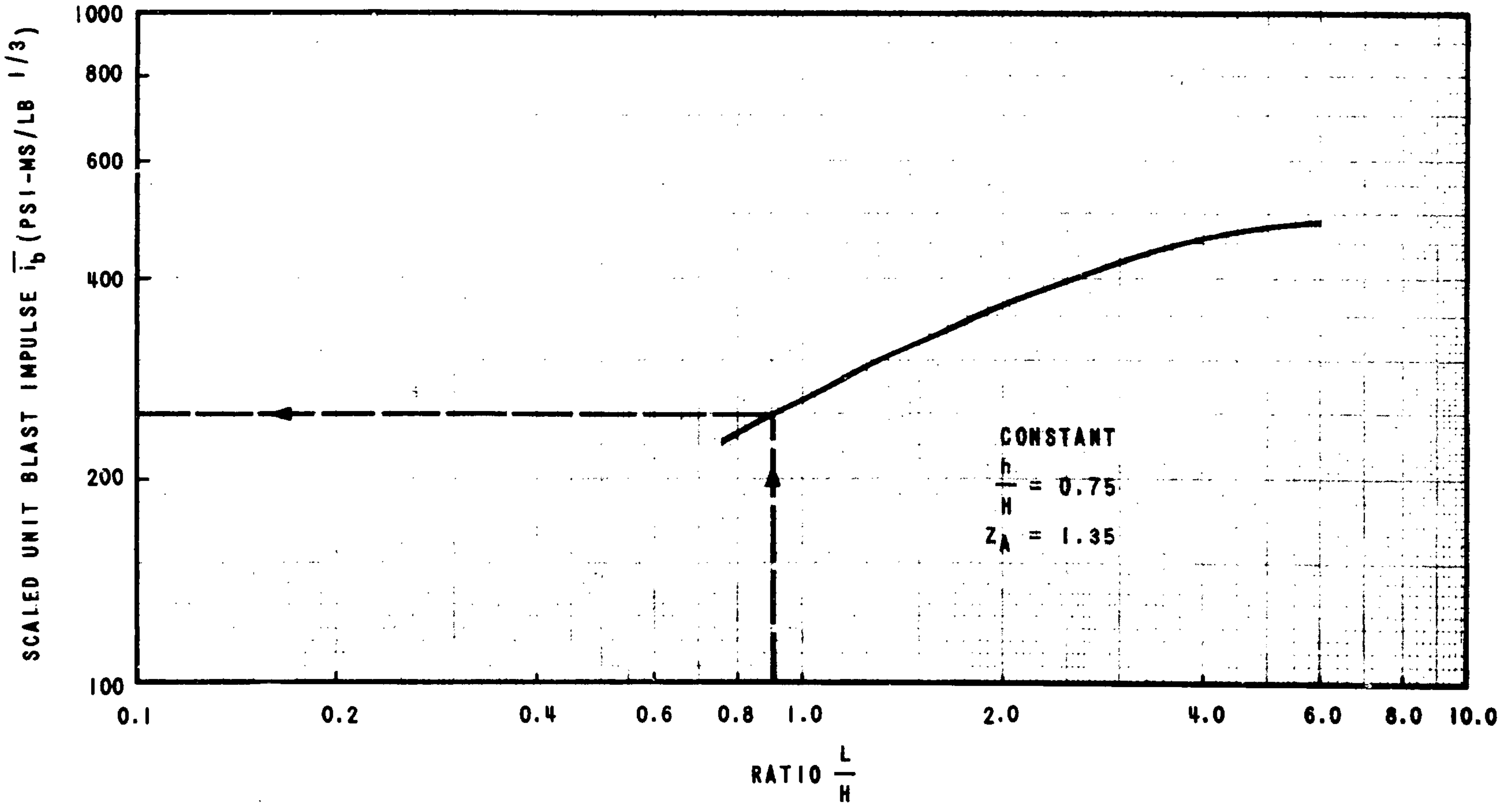


Figure 11 SCALED UNIT BLAST IMPULSE FOR CONSTANT $\frac{h}{H} = 0.75$

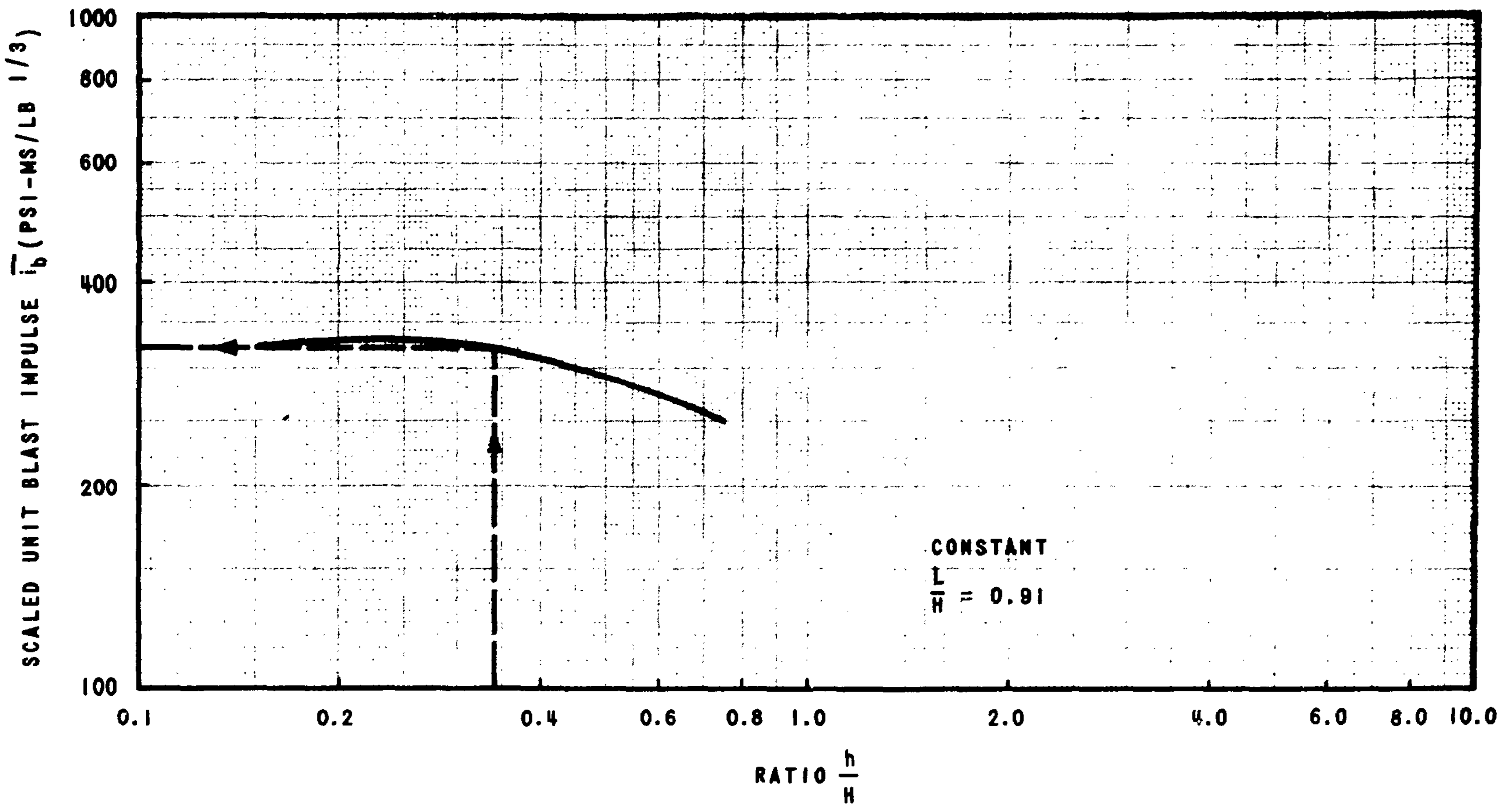
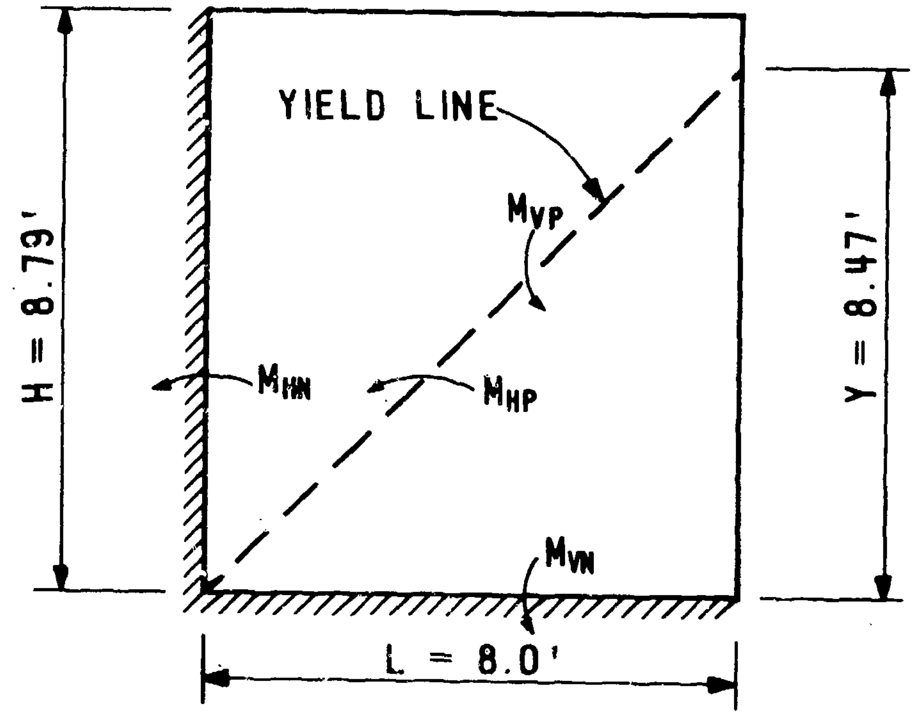


Figure 12 SCALED UNIT BLAST IMPULSE FOR CONSTANT $\frac{L}{H} = 0.91$



YIELD LINE LOCATION

Figure 13

Step 10. Determine X_m maximum deflection.

$$X_m = \frac{i_b^2}{2m_u \times r_u} \qquad \text{Eq. 6 - 22 Manual}$$

Find i_b unit blast impulse

$$i_b = \bar{i}_b \, W^{1/3} = 320\,(26)^{1/3} = 947 \text{ psi - m}_s$$

$$X_m = \frac{947^2}{2 \times 2{,}060 \times 16.3} = 13.4$$

Find θ deflection angle

$$\text{Tan}_\theta \quad \frac{X_m}{L} = \frac{13.4}{8 \times 12} = .1396$$

θ = 8° Less than 12°

Tests have shown that support rotations of laced elements can reach or exceed 12 degrees before failure occurs.

Step 11. Determine direct shear at wall support.

From Table 5-14 of the Manual find V_{SH} horizontal shear.

$$V_{SH} = \frac{3r_u \quad L \quad (2 - \frac{Y}{H})}{6 - \frac{Y}{H}}$$

$$= \frac{3 \times 16.3 \times 8 \times 12\ (2 - .965)}{6 - .965} = 966 \text{ lbs/in.}$$

$$v_{SH} = \frac{V_{SH}}{d_c} = \frac{966}{14.63} = 66 \text{ psi}$$

Find V_c allowable shear Eq. 5 - 10 of the Manual.

$$V_c = \Phi (1.9 \sqrt{f'_c} + 2500 p) \geq 2.28 \Phi \sqrt{f'_c}$$

$$V_c = .85 (1.9 \sqrt{4000} + 2500 \times \frac{.31}{12 \times 13.38}) = 106 \text{ psi} > 66 \text{ psi}$$

From the above, it can be seen that no stirrups are required at the wall support. If stirrups had been required, horizontal lacing would have been used above $\frac{Y}{2}$ to the top of the wall.

Step 12. Determine lacing requirements.

From Table 5-15 of the Manual find v_uV ultimate vertical shear stress at distance dc from the support.

$$v_uV = \frac{3r_u \left(1 - \frac{dc}{y}\right)^2}{\frac{dc}{y} \left(5 - 4 \frac{dc}{y}\right)}$$

$$= \frac{3 \times 16.3 \left(1 - \frac{13.38}{8.47 \times 12}\right)^2}{\frac{13.38}{8.47 \times 12} \left(5 - \frac{4 \times 13.38}{8.47 \times 12}\right)} = 63 \text{ psi}$$

By inspection use minimum lacing.

$A_v = .0015 bs = .0015 \times 12 \times 12 = 22$ sq. in.

Use #5 bars @ 12"

For convenience and ease of construction place all lacing in vertical direction.

Step 13. Check bond of horizontal bars.

$$u_u = \frac{Vu}{\phi \Sigma_o \ dc} = \frac{966 \times 12}{.85 \times 2 \times 14.63} = 466 \text{ psi}$$

Allowable bond stress for top bars, Table 5-2 of the Manual, shall not exceed

$$\frac{6.7 \sqrt{f'c}}{D} \quad \text{nor} \quad 560 \text{ psi}$$

$$\frac{6.7 \sqrt{4000}}{5/8} = 680 \text{ psi}$$

$466 \leq 560$, therefore bond is adequate.

DESIGN DRAWINGS

Figures 14 and 15 are reinforcing details taken directly from the construction plans. Figure No. 14 shows a sectional floor plan. The center wall is the element covered by the step by step design procedure. The center wall and the side wall reinforcing shown in Figure 15 is of particular interest in that the construction photographs, which are in the summary, reflect the same reinforcing in the process of installing and in place. The lacing bars in this structure are far easier to comprehend and place than in other structures of higher explosive loads and more complex construction. The center wall reinforcement must be in place prior to the pouring of the floor slab because dowelling of the vertical bars is prohibited. However, the exterior walls may be dowelled. The exterior walls may fail during an internal explosion but must resist the effect of an explosion from an adjacent cell.

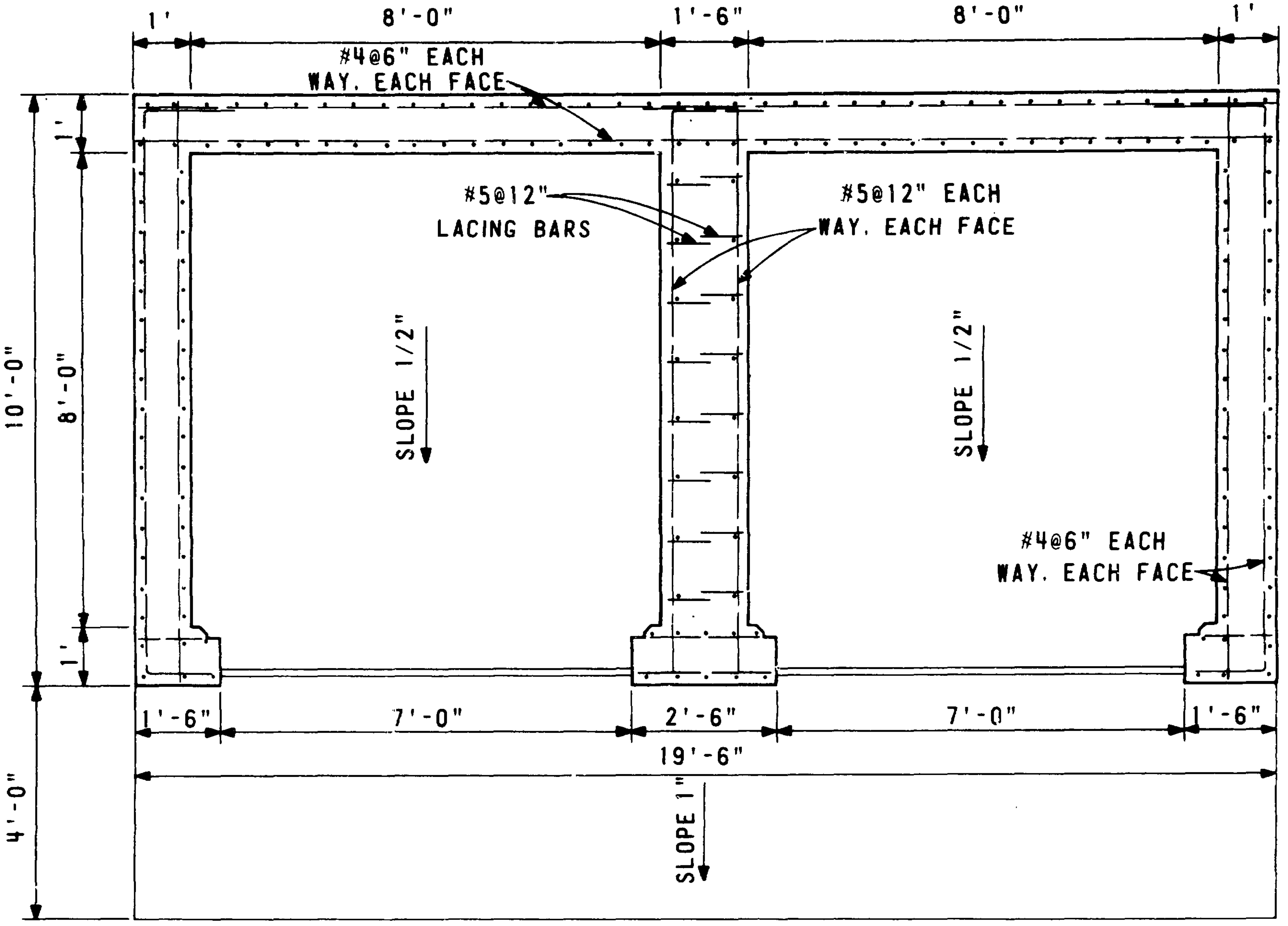


Figure 14 SECTIONAL PLAN – REINFORCING DETAILS

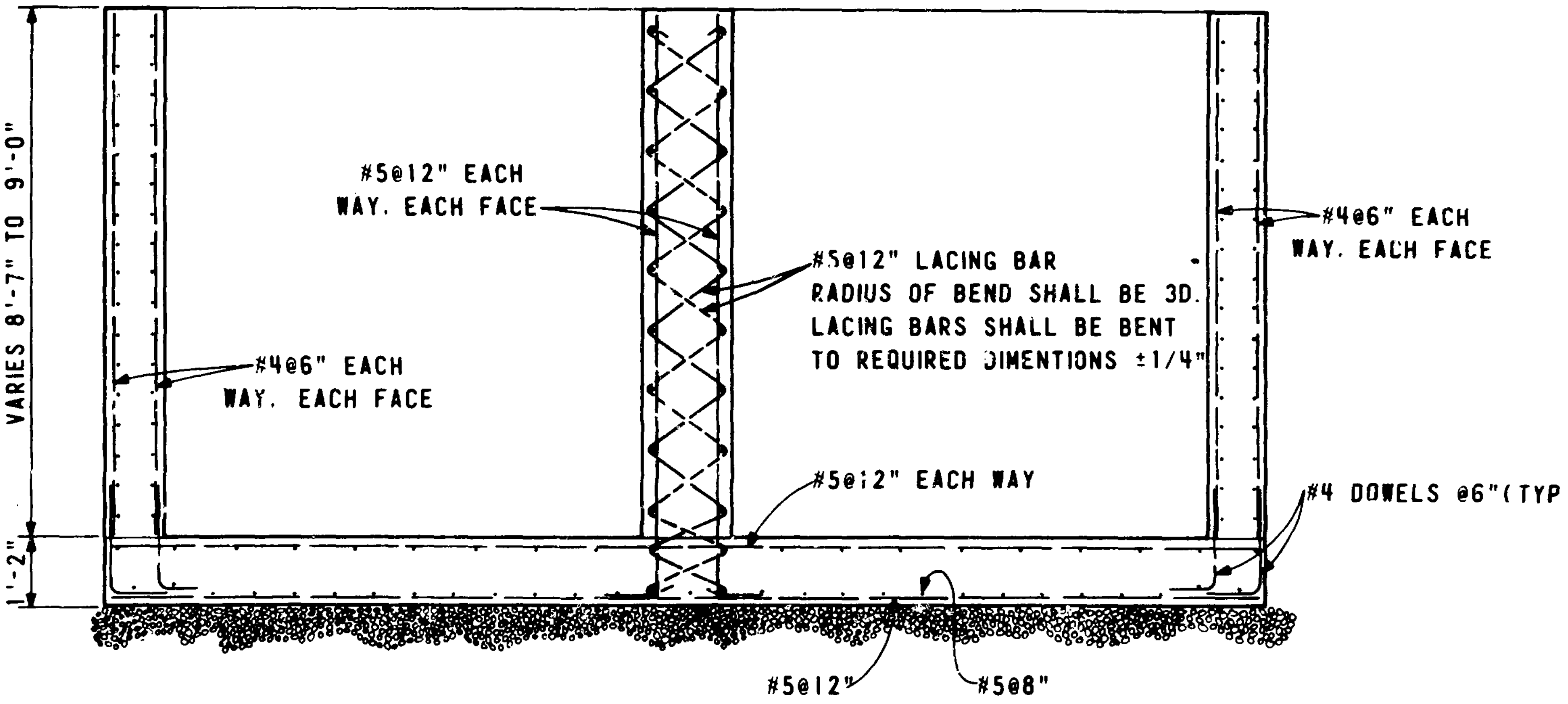


Figure 15 LONGITUDINAL SECTION — REINFORCING DETAILS

CONSTRUCTION PHOTOGRAPHS AND SUMMARY

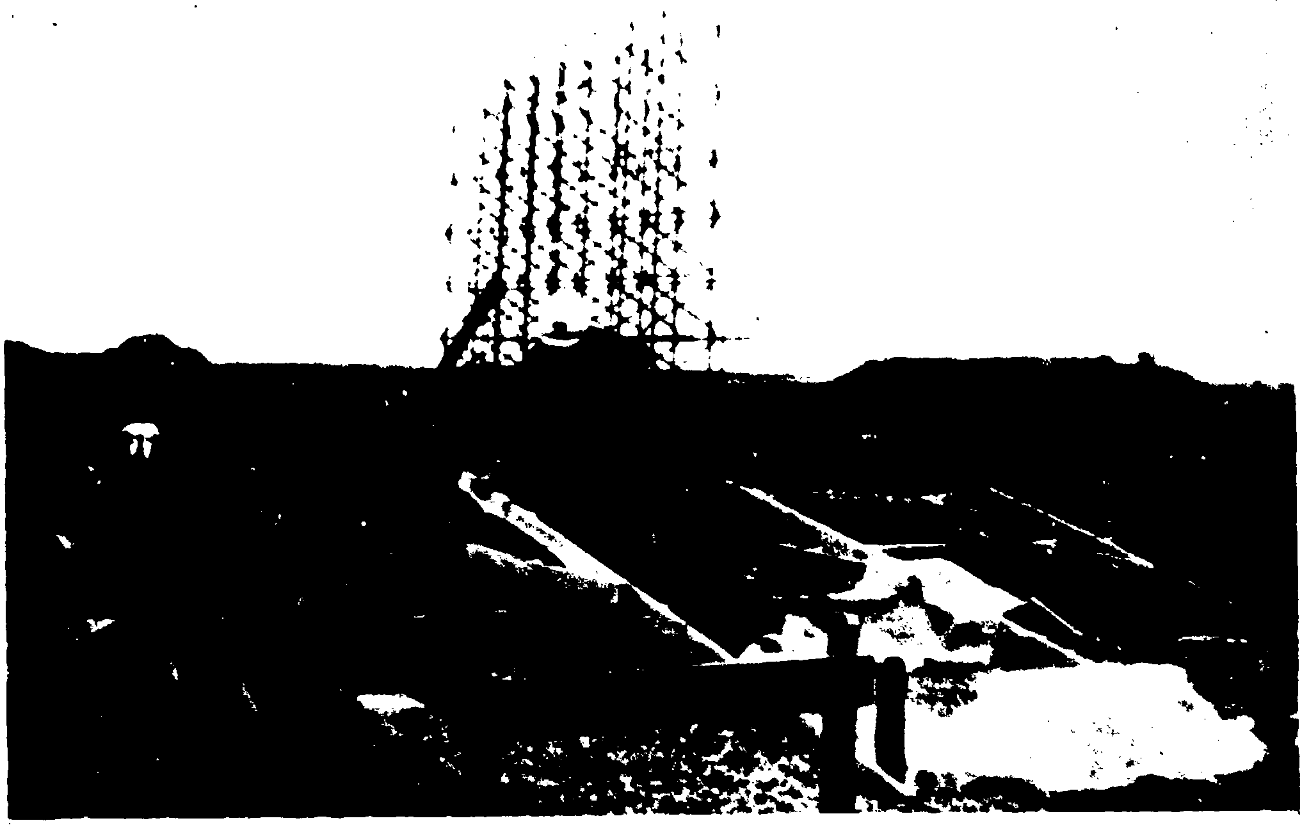
Construction photographs have been taken for a record of the construction. Most, but not all, of the photographs were taken with a Polaroid camera. Figure 16 was taken during installation of the floor slab and center wall reinforcing. The most interesting features are the lacing bars and the installation of the wall reinforcing prior to pouring the floor slab.

In Figure 17, the exterior wall dowels have been installed, and Figure 18 is a close-up of the center wall.

In Figure 19, the floor slab has been poured and the exterior walls are being placed. Figure 20 shows the structure after the walls have been poured and the forms removed. Electrical rough-in has been completed in the side elevation shown on Figure 21.

Figure 22 shows the details of the metal roof deck with a connection to the grounding system. Metal deck is welded to a 1/4 inch by 4 inch steel plate anchored flush with the top of the walls.

Figures 23 and 24 show the nearly completed structure with doors open and closed.



PLACING FLOOR SLAB REINFORCING

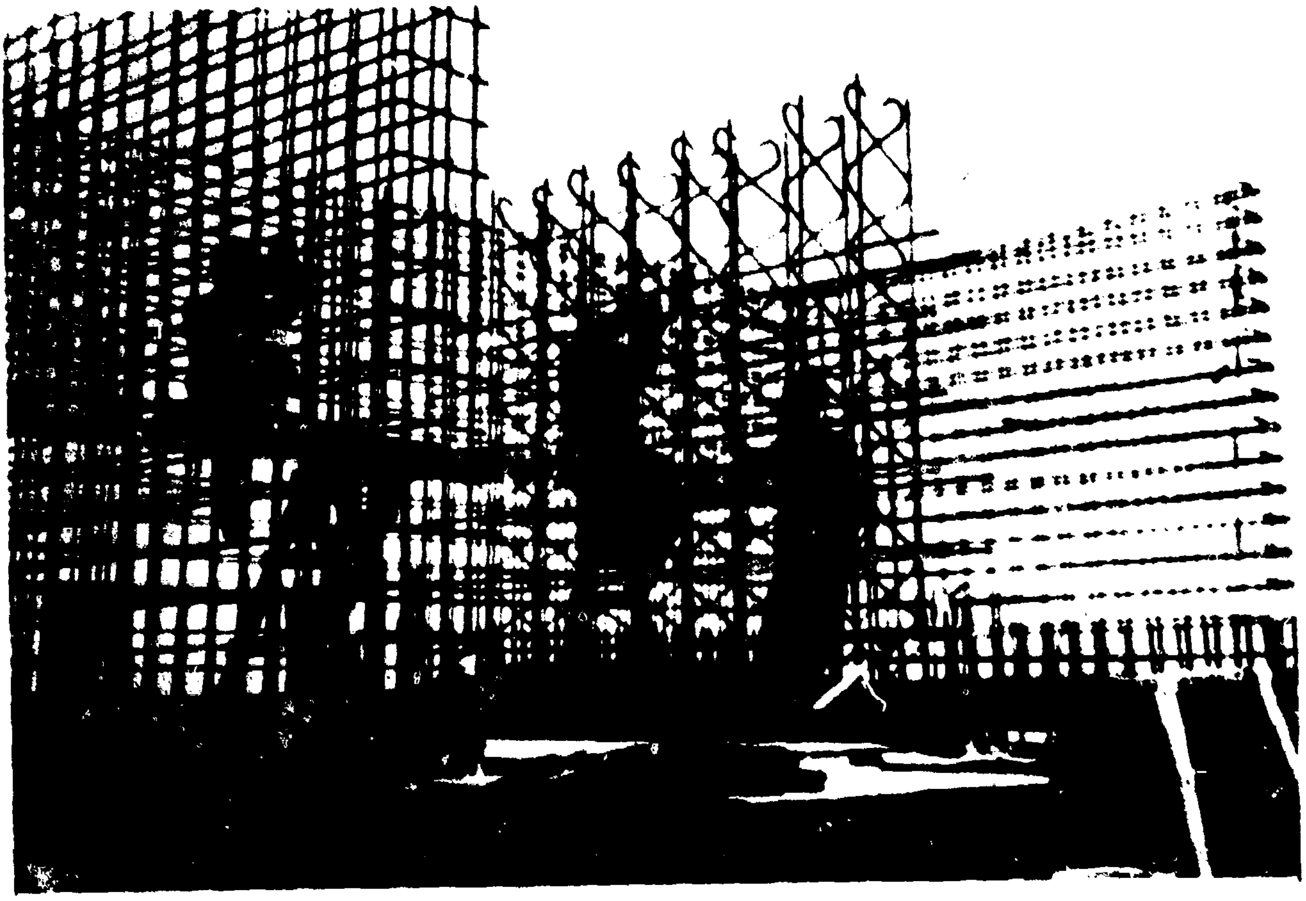
Figure 16

PLACING EXTERIOR WALL DOWELS

Figure 17

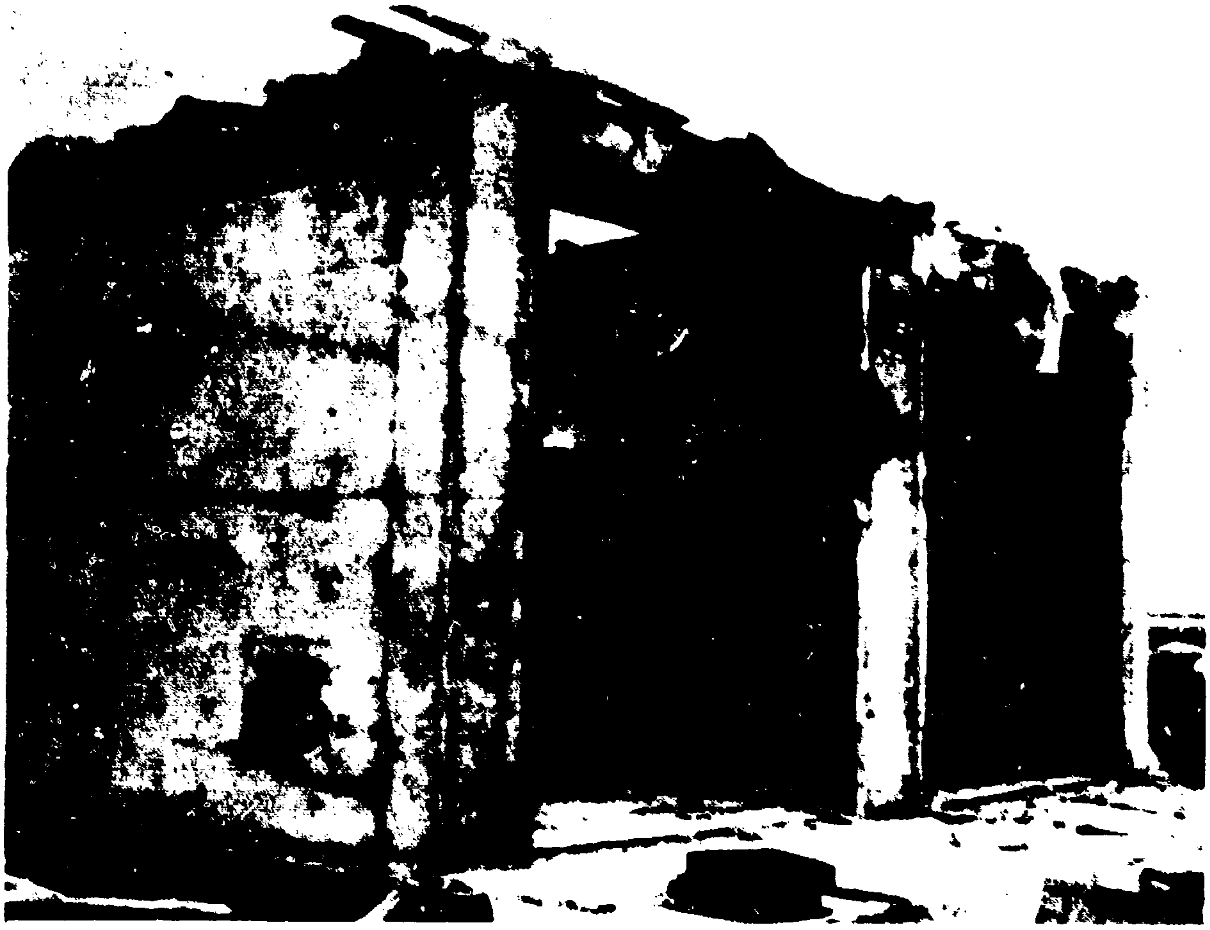
CENTER WALL REINFORCING

Figure 18



EXTERIOR WALL REINFORCING

Figure 19



CONCRETE POUR COMPLETE

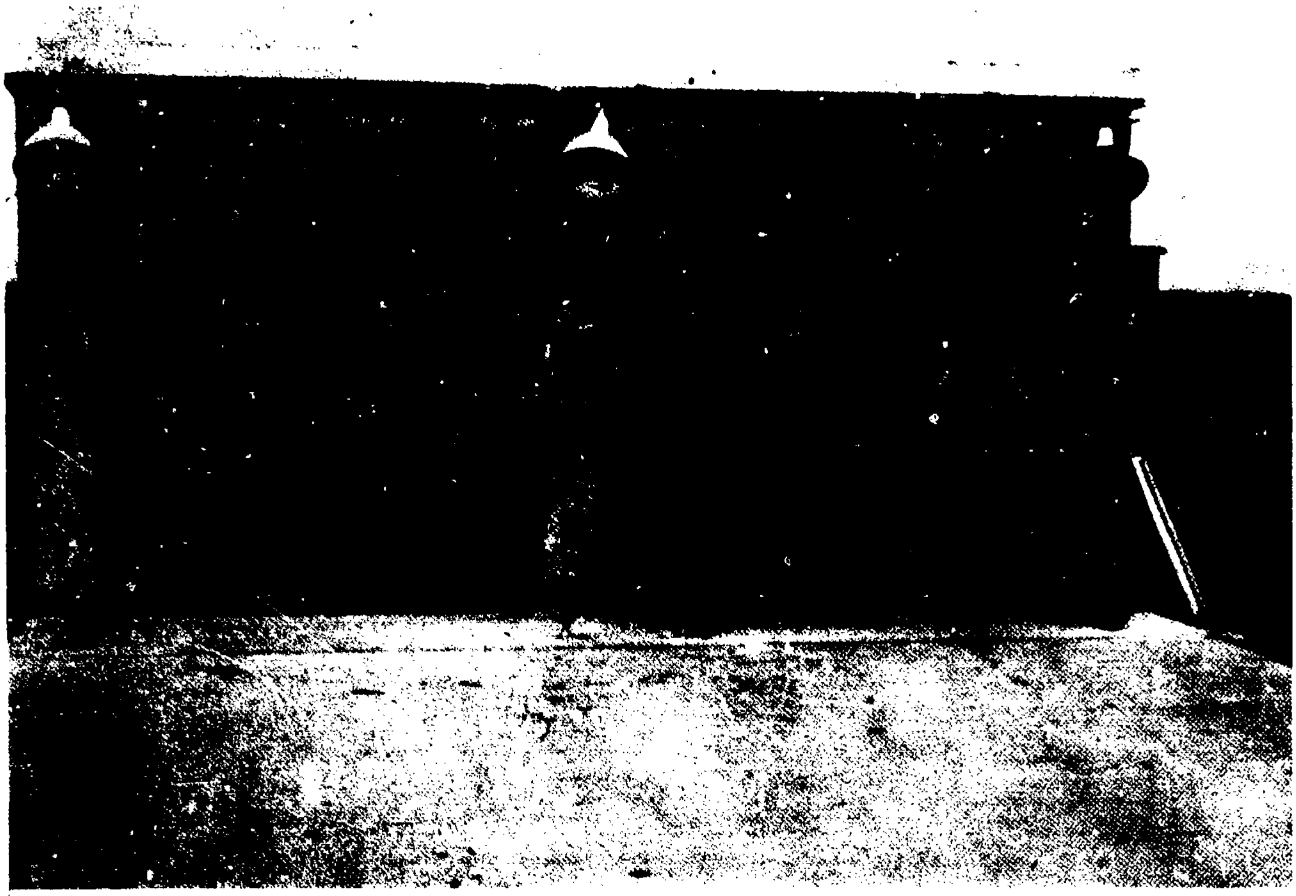
Figure 20

ELECTRICAL ROUGH-IN

Figure 21

ROOF GROUND CONNECTION

Figure 22



FRONT ELEVATION

Figure 23

COMPLETED STRUCTURE

Figure 24

BOARD POLICY WITH RESPECT TO PROTECTIVE CONSTRUCTION

R. G. Perkins
Armed Services Explosives Safety Board

The policy of the ASESB with respect to the application of protective construction techniques in the layout and design of explosive plants is as follows:

> The present "state of the art" in protective construction is such as to permit any calculated level of protection from explosion communication between adjacent bays or buildings, for personnel against death or serious injury from incidents in adjacent bays or buildings, and of vital and expensive equipment installations. Therefore, the major consideration in facility planning should be:
>
> 1. To provide protection against explosions communicating between adjacent bays or buildings and protection of personnel against death or serious injury from incidents in adjacent bays or buildings. In situations where the protection of personnel and facilities would be greatly enhanced or costs significantly reduced by having separate buildings to limit explosion propagation rather than using protective construction and separation of explosive units within one building, planning should so reflect this fact.
>
> 2. To provide protection to vital and expensive equipment installations, if the required additional cost is warranted.

This policy is intended to provide appropriate flexibility in the choice of either protective construction, distance separation or some combination of the two to promote economy. It is not intended to require absolute prevention of any injuries when to do so would be excessively costly. Judgment will be required in any particular design case.

LIQUID PROPELLANT EXPLOSIVES EQUIVALENCIES

Moderator:

Frank E. Belles
National Aeronautics & Space Administration
Lewis Research Center
Cleveland, Ohio

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Resume

The session began with the following formal presentations:

(1) Project Pyro: NASA-USAF Program on Liquid Propellant Explosive Hazards, Mr. W. A. Riehl, NASA/Marshall Space Flight Center

(2) Prediction of Explosive Yield and Other Characteristics of Liquid Propellant Rocket Explosions, Professor E. A. Farber, University of Florida.

Subsequent discussion centered around three questions:

(1) Is there a need for still more work?

In order to exploit more fully and confidently the work that has already been done, it appears that further studies are needed. These should probably concentrate on ignition probability, with considerable attention to possible self-limiting phenomena like electrostatic discharges that may occur when critical amounts of fuel and oxidizer are mixed; and on failure-mode probabilities in various systems.

(2) How valid and applicable are the Pyro results and conclusions?

A statistical analysis of the Pyro data carried out by Bellcomm, Incorporated, questions some of the Pyro results. The philosophical basis of this analysis is quite different from that adopted by Pyro, and differences in the results of the two studies are unresolved.

Meanwhile, the Pyro prediction method, which is based on failure-mode analysis plus the Pyro results, is being applied. It has been used in siting Titan III at Vandenberg Air Force Base and in assessing the survivability of a SNAP-27 package aboard a Saturn V.

Applicability under conditions markedly different from the failure modes studied in Pyro is questionable. For example, it would not be appropriate to apply the Pyro prediction method to estimate the hazard of a missile being tested inside a vacuum chamber.

(3) Should DOD Instruction 4145.21 be changed as a result of the work accomplished?

There should be changes in the explosive equivalencies assigned to various propellant combinations but there is no unanimity on what the changes should be. For the purposes of 4145.21, it would probably be best to retain the idea of equivalencies rather than switch over completely to the failure-mode-analysis approach.

Considerable study of this question has been carried out under the auspices of the ICRPG Working Group on Hazards and Mr. E. E. Harton, Chairman, made the following statement of their findings: (See Attachment).

Statement by E. E. Harton
Department of Transportation

Last December "Bob" Herman called a meeting of the ASESB Liquid Propellant Work Group for the day following a presentation at the ASESB by those associated with conducting Project PYRO.

During the course of the Work Group meeting, the PYRO report draft, the BellComm Review of PYRO and the work conducted by Dr. Farber at the University of Florida were discussed with respect to revising DoD Instruction 4145.21. Mr. Riehl also mentioned that the PYRO Steering Committee had some other points they would want to bring out with respect to the PYRO final report and would make this a separate document.

The members of the work group concluded that they would have to get copies of the PYRO report and others to study before they could recommend regarding possible revision of 4145.21.

Yours truly, attending as an advisor to the Army work group member, remarked that the Safety Criteria Committee of the ICRPG Working Group on Hazards would be reviewing all the documents mentioned, along with other information, to extract suitable portions for the chemical rocket propellant hazards manual under preparation by the Working Group on Hazards. I volunteered to task the Safety Criteria Committee to simultaneously do what it reasonably could in the way of a comparative review and recommendations which might be of help to Bob Herman and his work group.

Bob accepted the offer.

As Chairman of the ICRPG Working Group on Hazards and its Technical Steering Committee, I asked Paul King, the Chairman of the Safety Criteria Committee, if he felt the Committee could undertake the task and he answered affirmatively.

Paul lined up a select group from his Committee plus some outside experts and has, in spite of many obstacles, including the loss of his home during Hurricane Camille and all the troubles associated therewith, completed the assignment. Before proceeding with the brief summation of the review team's findings and recommendations, I would like to express to Paul and all those who contributed to the effort, the sincere thanks of the Technical Steering Committee for their time, effort and a job well done.

The essence of the review team's analysis and recommendations are set forth in three viewgraphs. The first contains general comments, Figure 1.

The second one contains the factors that should be borne in mind in applying the conclusions and recommendations of these studies to specific instances, Figure 2.

Recommendations appear in Figure 3.

Although much of the data presented has indicated that the yield factors for "static" conditions may be conservative, the range of data obtained in extreme cases does not permit the use of lesser values in the opinion of the Safety Criteria Committee (review team).

Dr. Marjorie Evans, in her letter to Mr. King, went into somewhat more detail than his letter to me and recommends that the reviewer prepare a draft report containing an analysis of the validity and applicability of the data and interpretations and a set of recommendations for modification (if any) to the Q-D tables. The format of the report should be established in advance by the ASESB or a Technical Review Committee set up by it, in concert with the technical reviewer. The reviewer should not have been associated with the project work and should probably, preferably be on the staff of one of the Government laboratories which has had extensive experience in basic research on explosives. She added the Bureau of Mines to the other two suggested organizations.

I concur in these recommendations as being very sound. The one practical problem in accomplishing it is how to get the individual and his organization to agree to 5-6 months of uninterrupted work to do the task.

I shall formally submit the report to Mr. Herman formally. He is receiving, this date, a copy of Mr. King's letter to me without attachments.

Blast Hazard Programs Review Team ---

General Comments

From studies, gained insight on how to predict with greater confidence potential severity of liquid and solid propellant explosions.

Studies include methods for identifying and estimating contributions from "incident" parameters (e.g., failure mode, fuel, degree of confinement, ignition delay) and suggest methods for minimizing "yield".

Programs have added considerable empirical and theoretical data to our knowledge of propellant reactions.

Figure 1

Blast Hazard Programs Review Team ---

Words of Caution

No detailed correlation and analysis of data for all three programs done yet.

In absence of such analysis, a number of apparently divergent points of view exist.

Variation in treatment of data may preclude direct comparison with significant accuracy.

Instrumentation technique differences may enhance difficulty of correlation.

Range of yields within similar failure modes is relatively large even to modest confidence level(9/10).

Variation in ranges of target response approach yield extremes postulated for specific cases.

Figure 2

Blast Hazard Programs Review Team ---

Recommendations

No changes in DoD publication 4145.21 be effected at this time.

The rationale, test methods and data obtained from the programs (PYRO, BellComm, University of Florida and SOPHY) be reviewed by a competent scientist in the field of explosives phenomena assisted as necessary by specialists in statistical techniques and mathematical modeling.

That the Ballistics Research Laboratories (Aberdeen Proving Ground) or the Naval Ordnance Laboratories be requested (contracted) to conduct this study -- estimated five man months effort.

Figure 3

PROJECT PYRO: NASA-USAF PROGRAM ON LIQUID PROPELLANT EXPLOSIVE HAZARDS

W. A. Riehl
NASA/Marshall Space Flight Center

Project PYRO consisted of a comprehensive program to determine the blast and thermal characteristics of the three liquid propellant combinations in most common use in military missiles and space vehicles; liquid oxygen-RP-1 (LO_2/RP-1), liquid oxygen-liquid hydrogen (LO_2/LH_2), and nitrogen tetroxide/50% unsymmetrical dimethylhydrazine-50% hydrazine (N_2O_4/50% UDMH-50% N_2H_4). During the course of the program some 270 tests were conducted with these propellant combinations on weight scales ranging from 200 lb to 100,000 lb. This basic explosive test program was supplemented by analytical and statistical studies, laboratory-scale experimental studies, simulation tests with inert propellant combinations and a series of high explosive tests for calibration and evaluation purposes.

The basic test program was designed to investigate the explosive characteristics of the three propellant combinations for the most credible ways that the propellants might accidentally come into contact with each other and result in a significant explosion.

The results of the basic test program in conjunction with the analytical studies and prior information regarding liquid propellant explosive behavior were used as the basis for developing methods for predicting the blast and thermal environment that would be expected for any given missile or space vehicle system and any specified failure mode.

In the prediction method the thermal environment is given only as a function of propellant type, while the blast environment is given as a function of a number of controlling parameters. A failure mode analysis is required to select the appropriate values of the parameters needed to predict the blast environment for a specific system.

PREDICTION OF EXPLOSIVE YIELD AND OTHER CHARACTERISTICS OF LIQUID PROPELLANT ROCKET EXPLOSIONS

By

Dr. E. A. Farber*

Abstract

This paper describes the work carried out by Dr. Farber and his group at the University of Florida on the characteristics of liquid propellants.

Three independent methods were developed describing the phenomena and are useful in the prediction of explosive yield.

- I. THE MATHEMATICAL MODEL[1,2,3,4]
- II. THE SEVEN CHART APPROACH[4,5,6,7,8,9]
- III. THE CRITICAL MASS METHOD[4]

These methods will be described briefly in this paper and references given where the detail can be found.

In addition to the above work, original in nature, giving much insight into the time sequenced phenomena from the mode of failure of a particular missile, through mixing of the propellants, ignition, formation of the shock and reaction fronts, their propagation and separation, their interaction with missile tankage, their emergence into the atmosphere, formation of the fireball, the fireball growth and cooling with finally the resulting combustion products cloud with its composition. These phenomena will be described in

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*Professor and Research Professor, University of Florida

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IV. Fireball Hypothesis and Experimental Verification, Describing the Reaction Front and Shockwave Behavior of Liquid Propellant Explosions.[4,10,11,12,13]

V. Fireball and Post-Fireball Combustion[4,14] Products Cloud History and Composition.

The measurements taken inside the exploding tank configurations are believed to be the first of their kind furnishing new information.

The methods described above, which were developed with regard to liquid propellants, are now being used in the analysis of the Saturn V destruct system, making predictions as to the expected explosive yield from our largest liquid propellant rocket. This work or the early phases of it are briefly discussed in

VI. Saturn V Destruct System Analysis

A great wealth of information is condensed into this paper and for further information a number of reports and papers are listed as references for those who wish to delve deeper into this subject.

Introduction

In the early days of the liquid rocket development the hazards could be reduced to negligible values through distance from the rockets. This was possible because the rockets were small and the quantities of liquid rocket propellants involved were not large.

With the increased size of today's liquid propellant rockets, now in the range of several hundred of thousands of pounds to millions of pounds in the case of our moon rocket the Saturn V, the hazards take on major proportions.

For this reason it becomes of utmost importance to be able to predict the explosive behavior of such large quantities of liquid propellants so that adequate measures can be taken to protect the astronauts, the launch and support personnel, the neighboring communities, and in some measure the launch and support facilities.

This paper presents three independent methods

I. <u>THE MATHEMATICAL MODEL</u>

II. <u>THE SEVEN CHART APPROACH</u>

III. <u>THE CRITICAL MASS METHOD</u>

which can be used in predicting the explosive yield of liquid propellant rockets.

The three independent methods, requiring different input information, lead to essentially the same results.

The second method mentioned above requires more input information than the other two, but in return it gives more detail about the processes involved. This becomes especially valuable when the processes are to be controlled to give minimum explosive yield.

In connection with this work, as the various natural phenomena were studied, a Fireball Hypothesis was developed, describing in detail the time sequenced phenomena leading to the explosion. After the explosion it gives information about the shock and reaction fronts and their behavior, the generation of the fireball, the combustion products cloud and its composition. This is described in

IV. <u>Fireball Hypothesis and Experimental Verification, Describing the Reaction Front and Shockwave Behavior of Liquid Propellent Explosions</u>.

V. <u>Fireball and Post-Fireball Combustion Products Cloud History and Composition</u>.

Through the above work, methods were developed by which the explosive yield of liquid rocket propellant explosions can be described and predicted. The methods were applied to field experiments for comparison of predictions with actual measurements, then with a minimum number of assumptions to actual rocket explosions for which yield estimates were available, and finally to the destruct system of the Saturn V, our largest liquid propellant rocket.

The analysis of the Saturn V will be briefly described and some preliminary results given in

VI. Saturn V Destruct System Analysis

I. THE MATHEMATICAL MODEL

In the early stages of the investigation to describe the physical phenomena in liquid propellant explosions it was assumed that a relationship exists between the mixing characteristics of the liquid propellants and the explosive yield obtained.

The very sparse data available indicated the possible functional relationship and so a MATHEMATICAL MODEL was developed. It had to satisfy the data, available at the time, and be flexible enough to incorporate future data if modification of the functional relationship seemed desirable. In addition the model had to satisfy requirements for statistical analysis so that probability averages, confidence limits and confidence regions can be determined.

The MATHEMATICAL MODEL developed was a rather complicated function forming a probability surface controlled by four parameters. Three of these parameters were needed to describe the data of possibly considerable range. The fourth parameter allowed the description of an average characteristic of all the data or, if the data was grouped, the characteristic of the grouping criteria.

In this work it was used to express the effect of quantity of propellants upon explosive yield.

The expected explosive yield can be obtained from the MATHEMATICAL MODEL, a bivariate function, carrying out the indicated mathematical operation

$$E(y/x) = \int_0^1 y \frac{f(x,y)}{\left[\int_0^{x^d} f(x,y)dy\right]} dy$$

where the function is

$$f(x,y) = \frac{d\Gamma(a+b+c)}{\Gamma(a)\Gamma(b)\Gamma(c)} x^{d-1}(1-x^d)^{a-1} y^{b-1} (x^d-y)^{c-1}$$

The probability of a certain yield to occur can be found from

$$P_y(y) = \int_{y^{\frac{1}{d}}}^{1} f(x,y)\, dx$$

The probability of a certain degree of mixing to occur can be found from

$$P_x(x) = \int_0^{x^d} f(x,y)\, dy$$

If the confidence regions into which a certain percentage of all values fall is desired it can be found from

$$V_{x,y} = \int_0^1 \int_0^{x^d} f(x,y)\, dy\, dx$$

Even though the MATHEMATICAL MODEL was originally developed for the purpose of describing the overall behavior of liquid propellant explosions it has since been employed to predict explosive yields.

The results from the analysis of the MATHEMATICAL MODEL with parameters $b = 4.0$, $c = 1.1$, $d = 1.5$, which satisfy the available information and parameter $a = 70$, a value which satisfies all the information, are presented in Figure 1.

Figure I-1A presents the probability with which each of the various explosive yields can be expected to occur.

Figure I-1B presents the probability with which each of the various degrees of mixing can be expected to occur.

Figure I-1C presents the probability regions which contain the explosive yield and the spill (mixing) values. The triangular area slightly smaller than half of the square contains all yield and spill values. The small oval area contains 80 percent of all yield spill values.

If the data is grouped as to quantity of propellants involved the parameter a becomes a function. Figure I-2 presents the functional relationship, an "S" curve. The last data point available is for about 282,000 lbs of propellants and [illegible] the value for the Saturn V is shown, bracketed by the two limiting values.

Figure I-3 indicates that the yield is not sensitive with respect to the parameter a at large values of a. So rather large variations or uncertainties in a, for large liquid propellant rockets has very little effect on the predicted explosive yield value.

Figure I-4 presents the final results, the average explosive yield as predicted by the MATHEMATICAL MODEL, the upper bound (95% Confidence limit) and experimental results.

The behavior of the small quantities of liquid propellants is quite different from the large ones, observed as a step in the value of parameter a.

The Mathematical Model, $a = 70$, $b = 4.0$, $c = 1.1$, $d = 1.5$

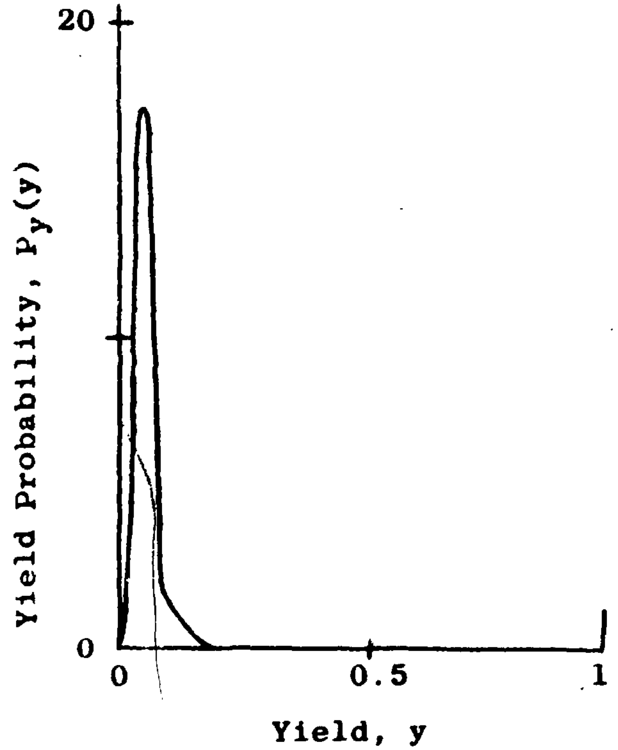


Figure I-1A Probability Distribution for the Yield Function (Missile Failures)

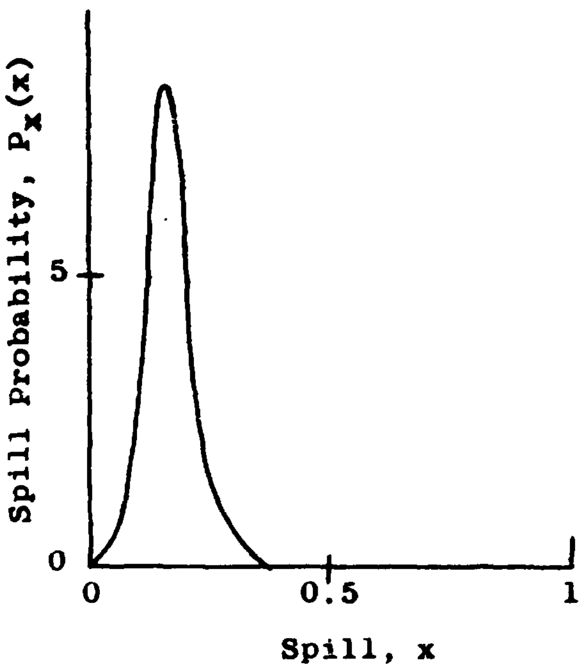


Figure I-1B Probability Distribution for the Spill Function (Missile Failures)

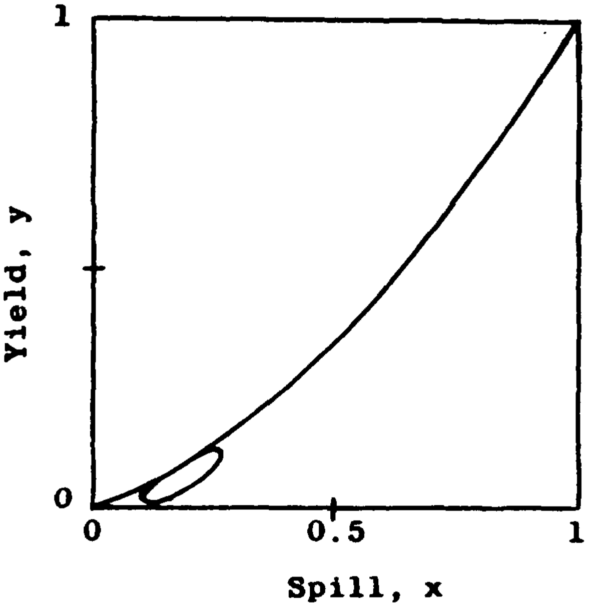


Figure I-1C Yield-Spill Probability Regions (Missile Failures)

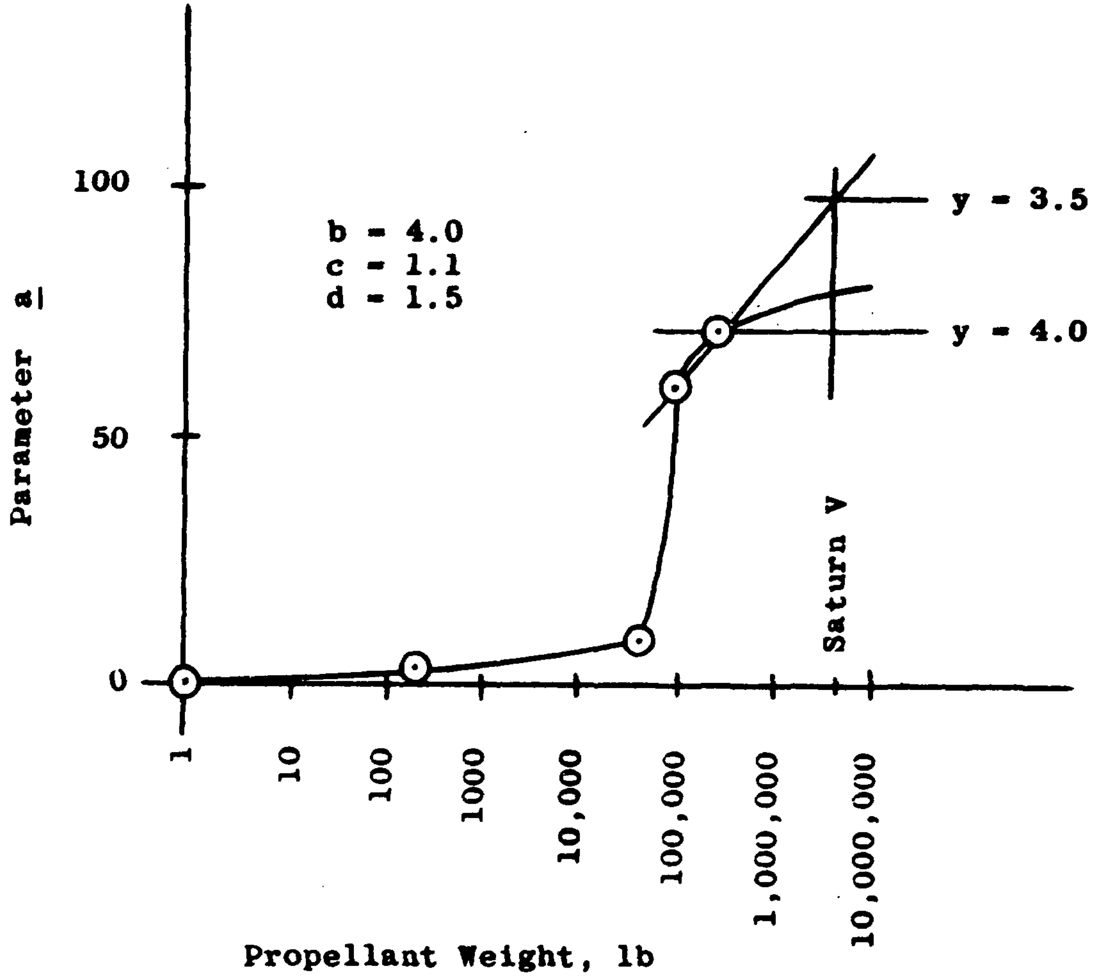


Figure I-2 Scaling Parameter a as a Function of Propellant Weight

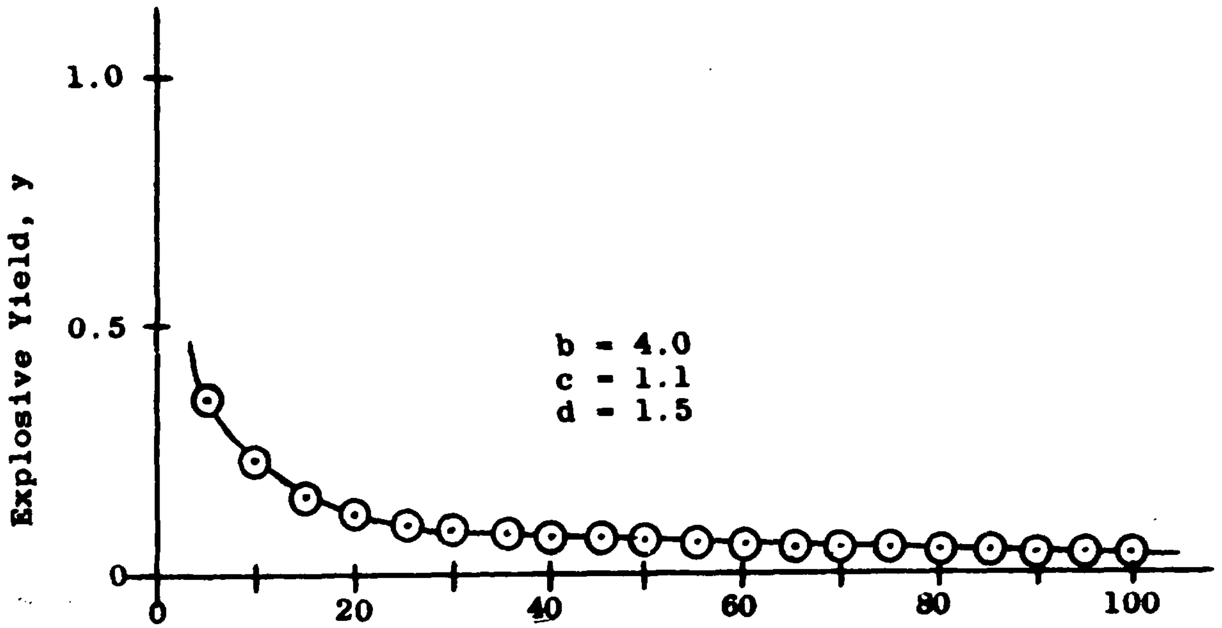


Figure I-3 Effect of Scaling Parameter a on Explosive Yield

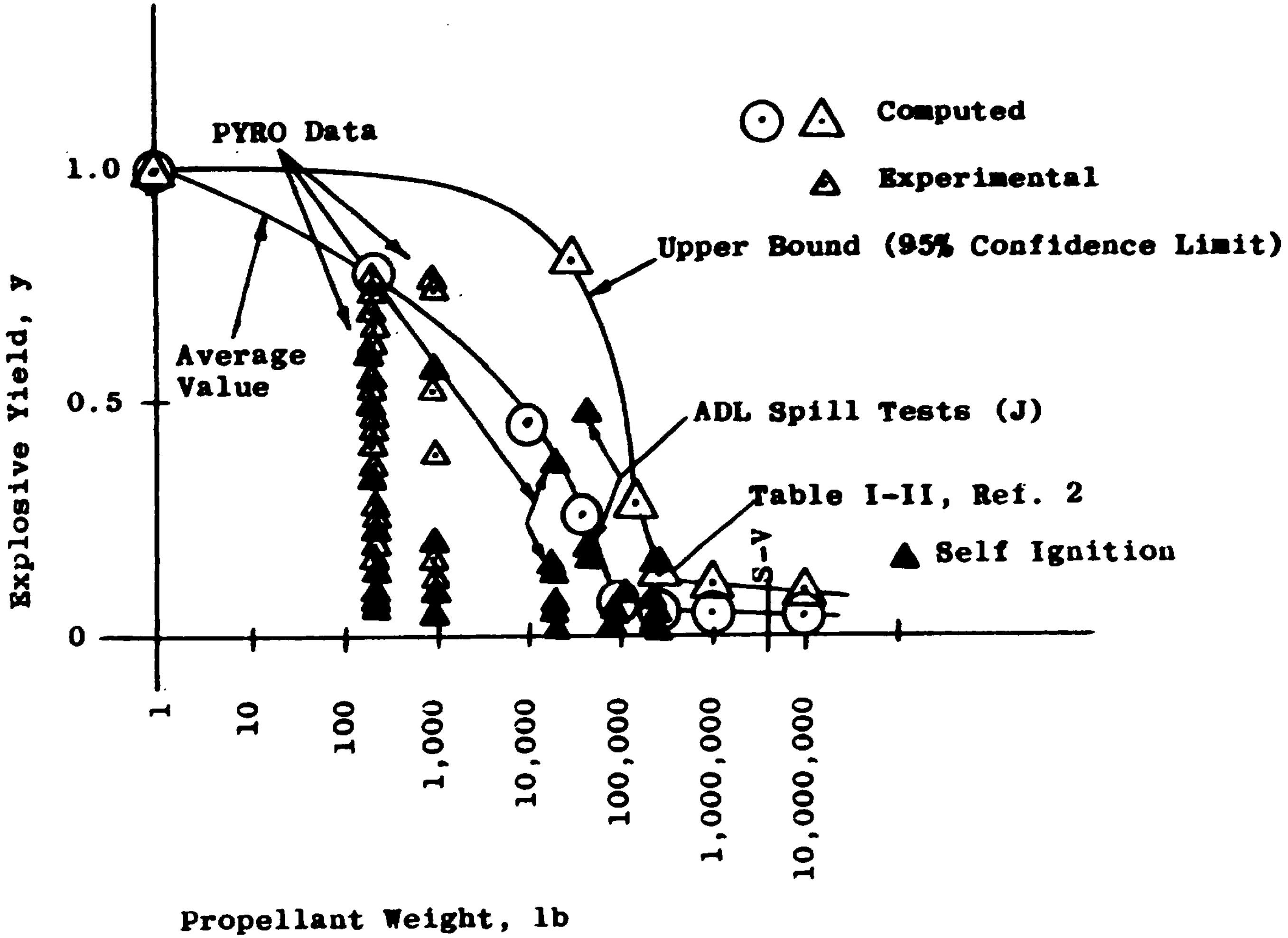


Figure I-4 Estimated Explosive Yield as a Function of Propellant Weight

Large explosive yields could be obtained by the small liquid propellant quantities since they could be ignited at will at a pre-selected time. This was not possible with the large quantities of liquid propellants since they auto-ignited relatively early during the mixing process.

The large circles and triangles represent computed values the small triangles experimental results and actual missile failures.

From Figure I-4 it can be seen that the predicted explosive yield values are high for small quantities of propellants and relatively small for the large liquid propellant quantities.

It might again be mentioned that the values presented here as predicted by the MATHEMATICAL MODEL are fractions of the theoretical maximum so as not to bring in the very questionable relationships of different propellants. If however a comparison is desired such as a TNT equivalent one of the references allows, with reservation, this process.

II. THE SEVEN CHART APPROACH

The SEVEN CHART APPROACH is a systematic procedure to arrive at a prediction of the explosive yield from liquid propellants.

This method essentially divides the problem of determination of the explosive yield from liquid propellant explosions into three basic phenomena.

1. The Yield Potential Function
2. The Mixing Function
3. The Ignition and Detonation Time

Each of these three basic phenomena can be studied separately and then the results of each study combined for the explosive yield prediction.

Yield Potential Function. The Yield Potential Function can be calculated from the knowledge of the propellants involved and the knowledge of the mode of failure.

In this manner, by the principles of chemical kinetics and heat transfer, the maximum yield which can be obtained theoretically at any time after failure can be calculated. This value is naturally greatest at time zero when all the propellants are still present.

Figure II-1 and Figure II-2 give this relationship for a three propellant, LOX/LH_2/RP-1, mixture, when dumped into a splash area.

Mixing Function. Even though the explosive yield potential, as defined above, is greatest at time zero, none of the propellants have come together or are mixed so that an explosion is impossible. At any time later if ignition should occur, only the propellants which are mixed at that time can take part in producing the explosive yield.

The fraction of the total propellants available at any time and actually mixed is referred to as the Mixing Function. The Mixing Function for the above case is shown in Figure II-3. This function is typical of mixing functions since they start at zero at some time after failure, reach a maximum and decrease again.

The Mixing Function can be determined from hydrodynamic calculations including heat transfer or from experiments both full scale and modeling. Four methods

a. The Vibration Mixing Analysis
b. The Wax Cast Analysis
c. The High Speed Photographic Analysis
d. The Thermocouple Grid Analysis

were developed by Dr. Farber's group to do this and after checking them against each other were employed.

Figure II-4 presents the Mixing Function for the S-IVB experiment carried out under project PYRO.

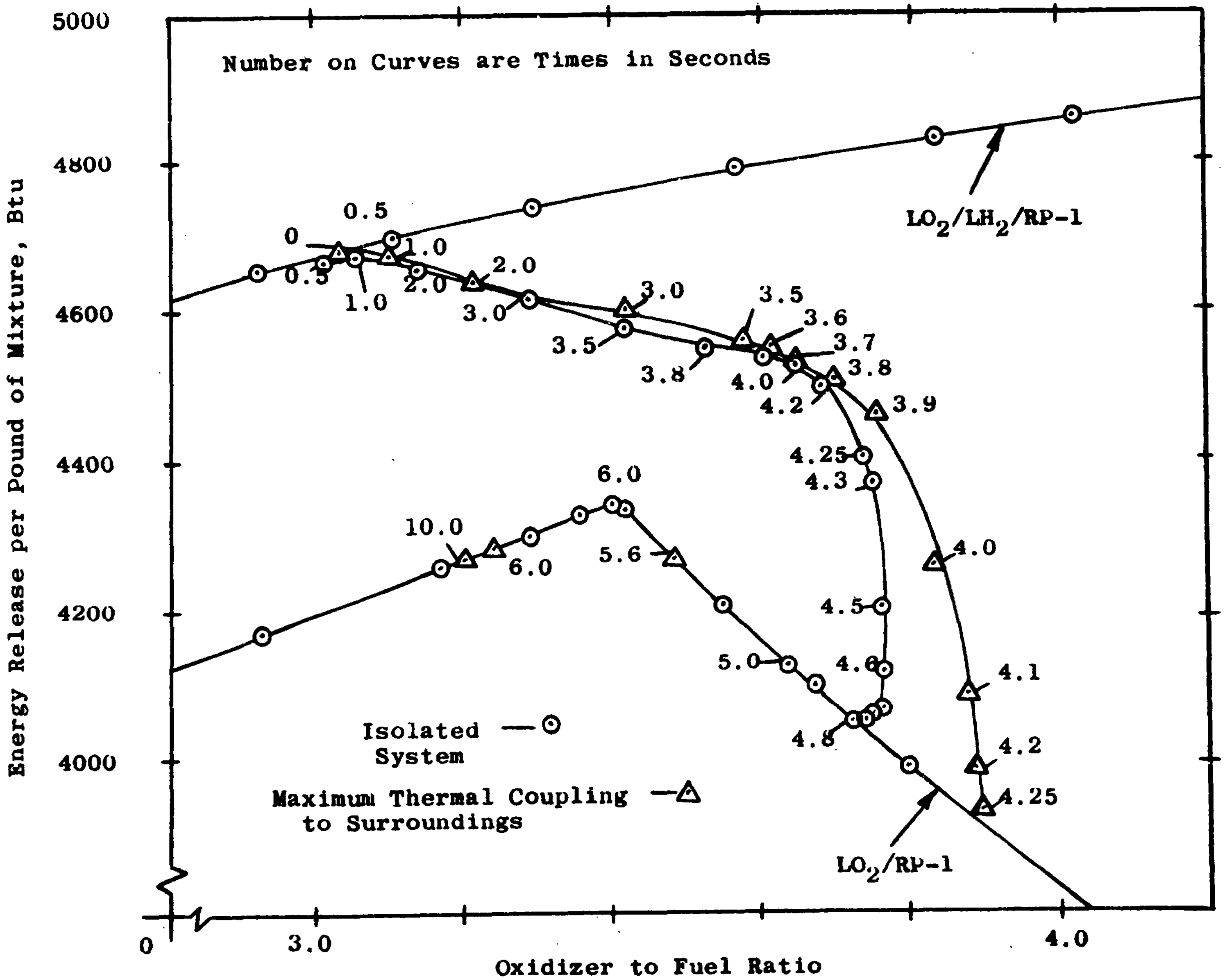


Figure II-1 Maximum Amount of Energy Release for a Three Component Liquid Propellant Mixture

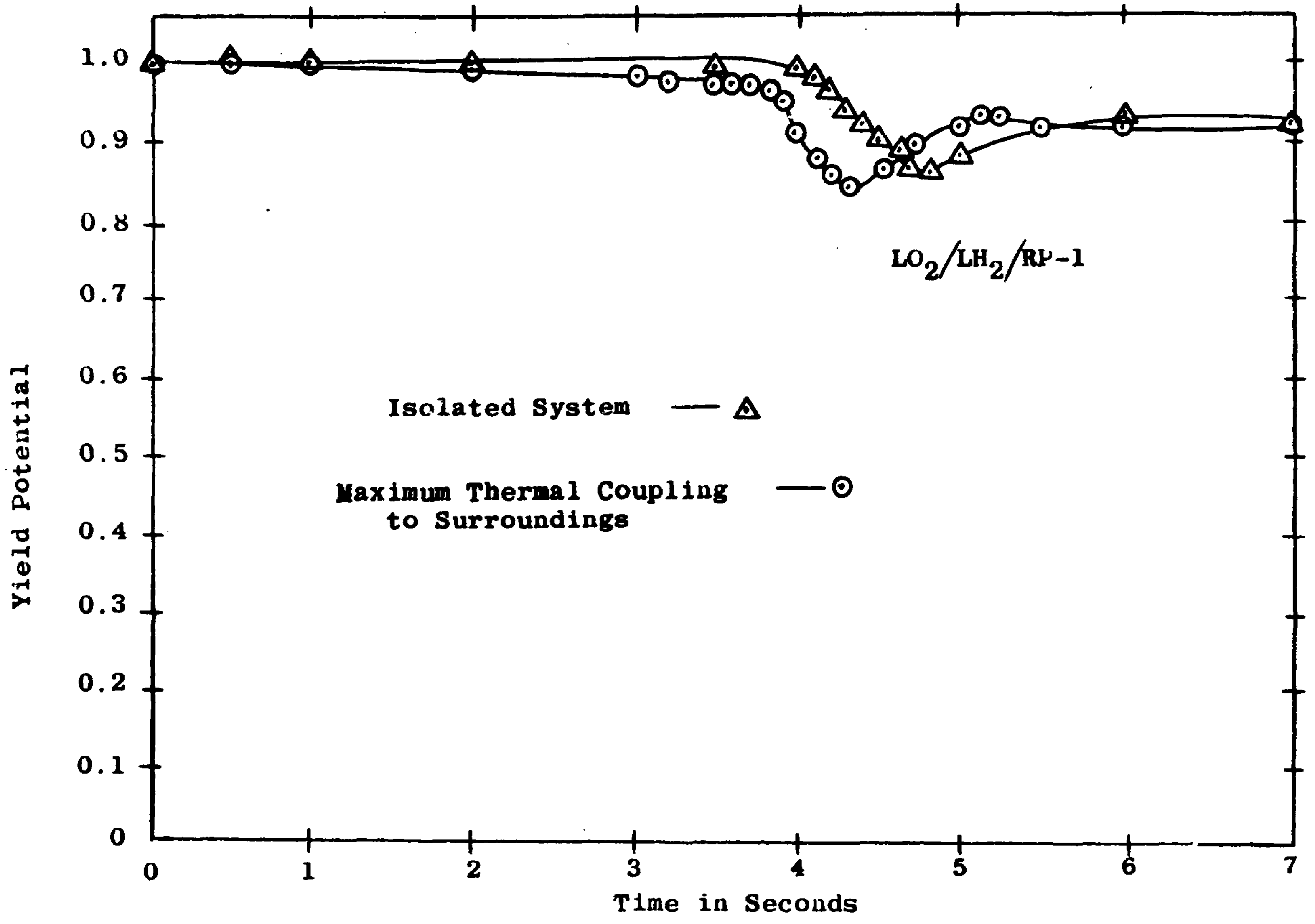
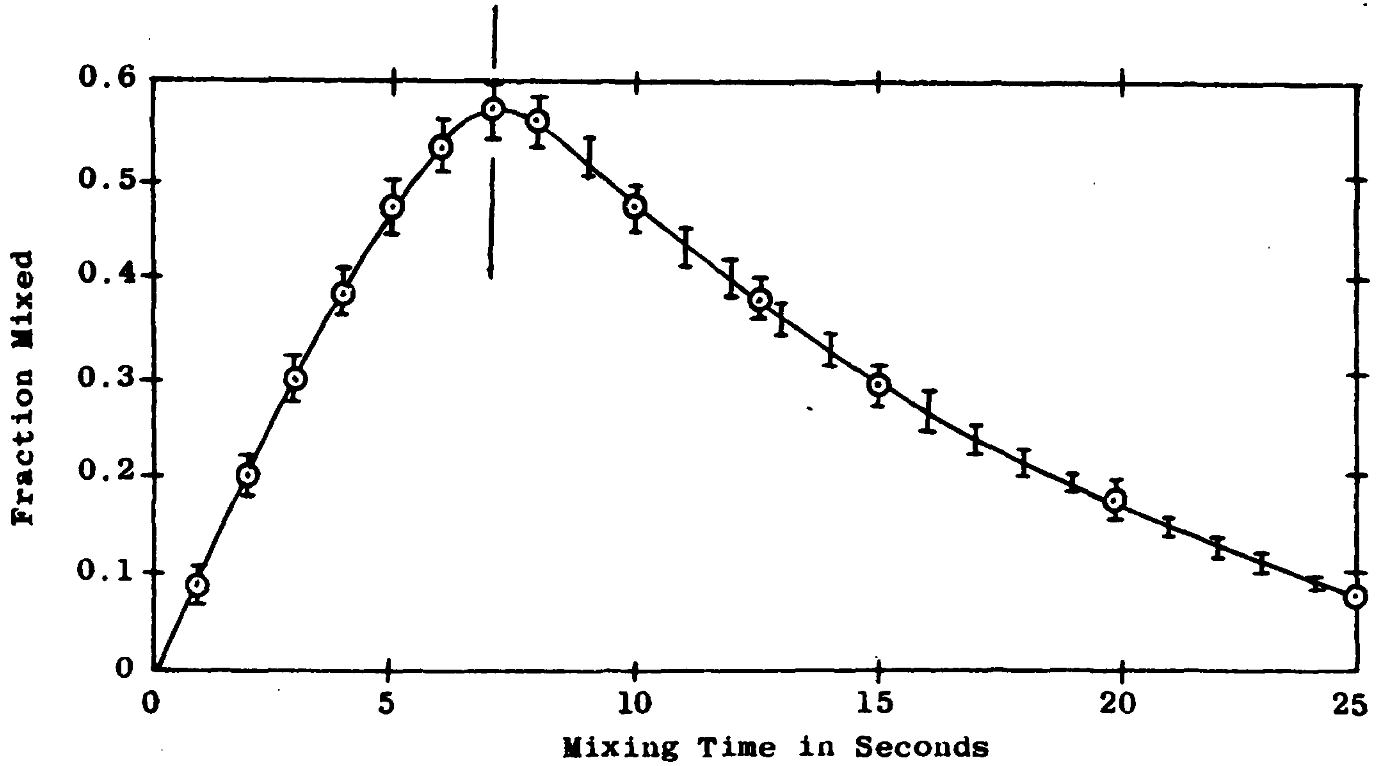


Figure II-2 Yield Potential as Time Function



<u>Figure II-3</u> Mixing Function or Spill Function for Three Component Liquid Propellant Spill Tests

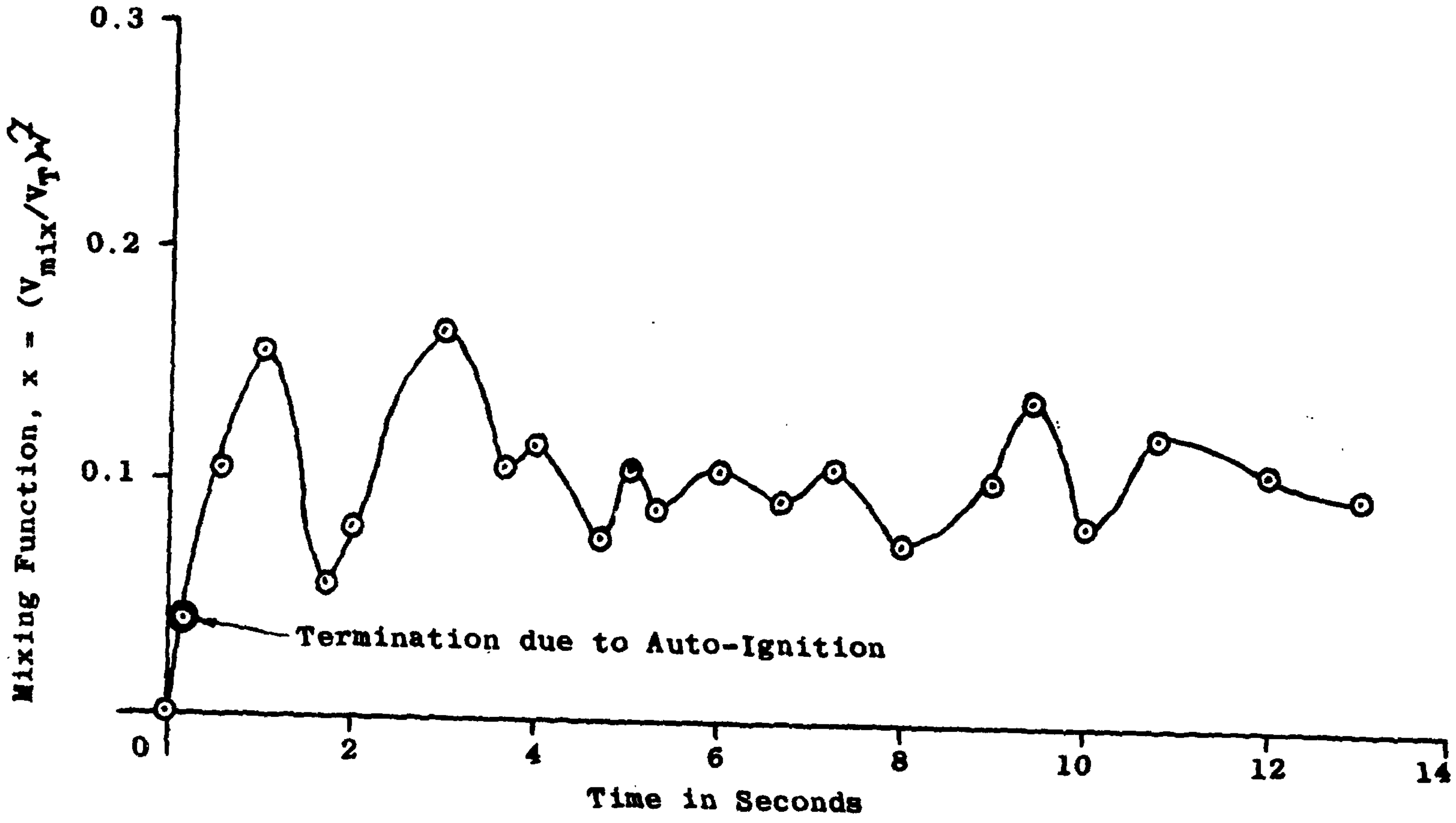


Figure II-4 Mixing Function, S-IV LO_2/LH_2 (Based upon 3" Diameter Simulated Experiment)

Figure II-5 presents the Mixing Function for the 25,000 lbs LOX/RP bulk head type failure mode experiments.

Figure II-6 presents the Mixing Function for the 200 lb Cold Flow and Explosive Experiment.

Expected Explosive Yield. Multiplying the explosive yield potential at any time t by the Mixing Function at the same time t, the Expected Explosive Yield is obtained at that time. Doing this for all t the Expected Explosive Yield, as a function of time, is obtained. In other words if ignition occurs at any time t the Explosive Yield Expected is the value of the expected yield curve at that time t.

Figure II-7 and Figure II-8 present explosive yield prediction curves corresponding to the Mixing Function curves Figure II-3 and Figure II-6. The experimental results are marked on the first curve as J_1, J_2 and J_3 involving approximately 44,000 lb of propellants and the second curve marks the point of ignition and yield value for the 200 lb Cold Flow and Explosive Experiment. The agreement between the measured explosive yield values and the predicted values was in all cases excellent.

Ignition and Detonation Time. The ignition time for prediction purposes, can be a controlled value, a known value based upon the characteristics of the propellants, a statistical value with confidence limits, or it can be a value determined by the CRITICAL MASS METHOD as described in the next section.

It was shown that if the propellant characteristics, the mode of failure, and the ignition time are known, the explosive yield can be predicted for liquid propellants by the SEVEN CHART APPROACH.

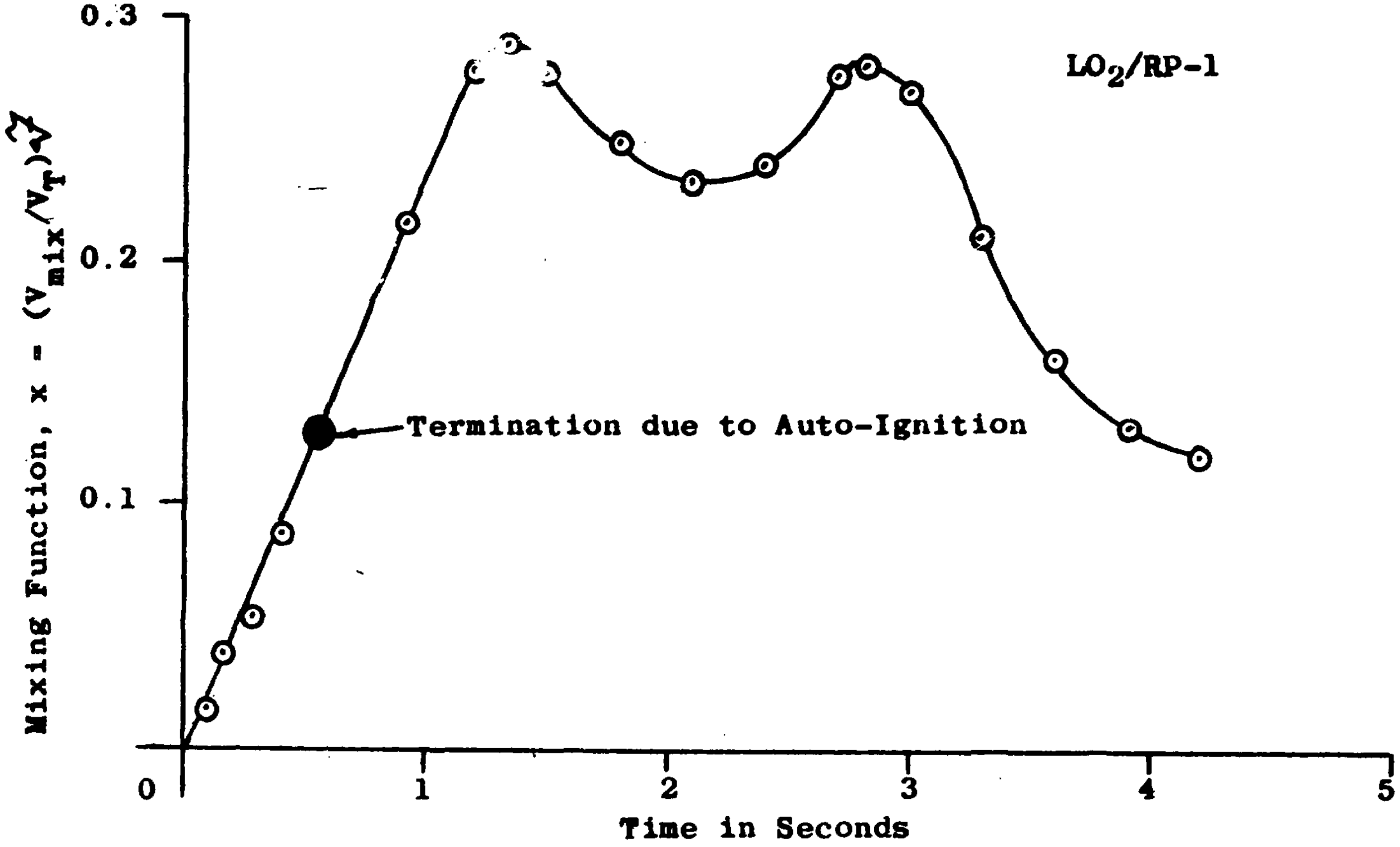


Figure II-5 Mixing Function, 25,000 lb Explosion Experiment
(Based Upon 3" Diameter Simulated Experiment)

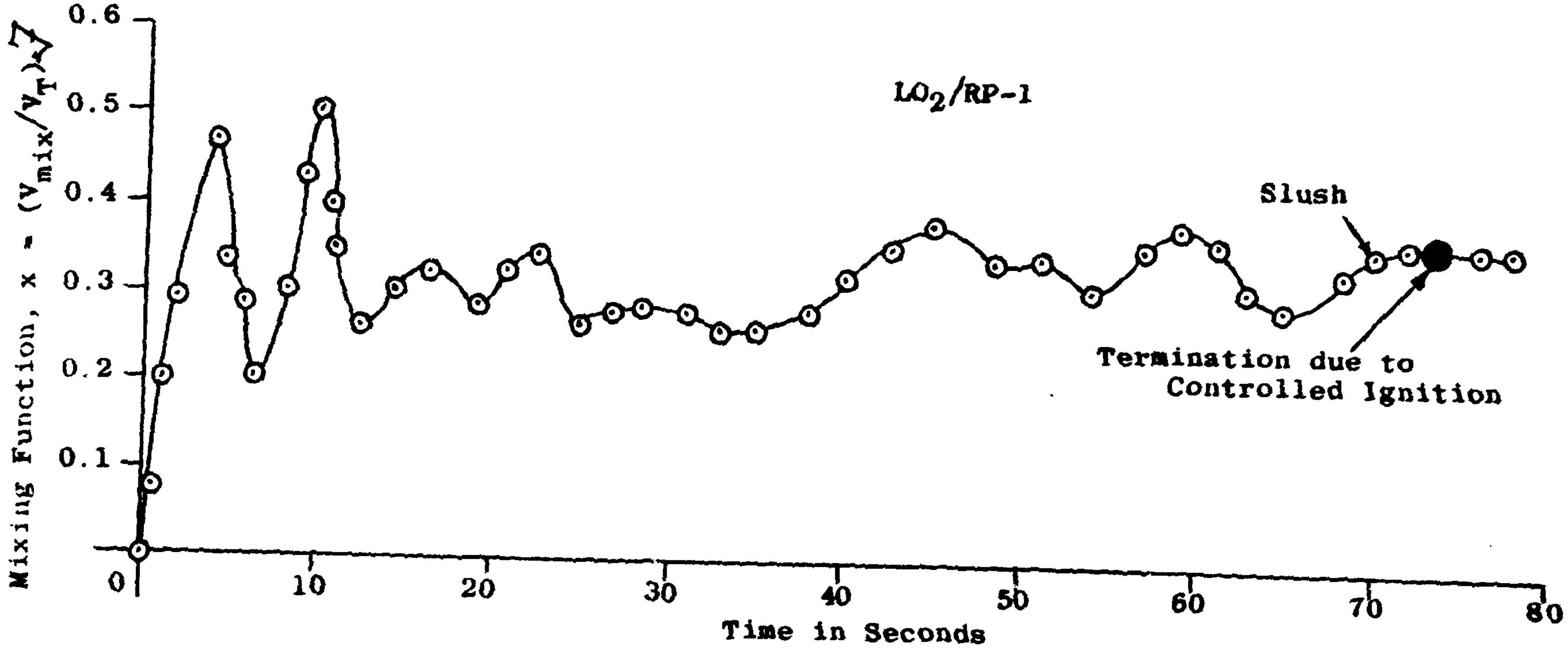


Figure II-6 Mixing Function, 200 lb Cold Flow Experiment (Based Upon 3" Diameter Simulated Experiment)

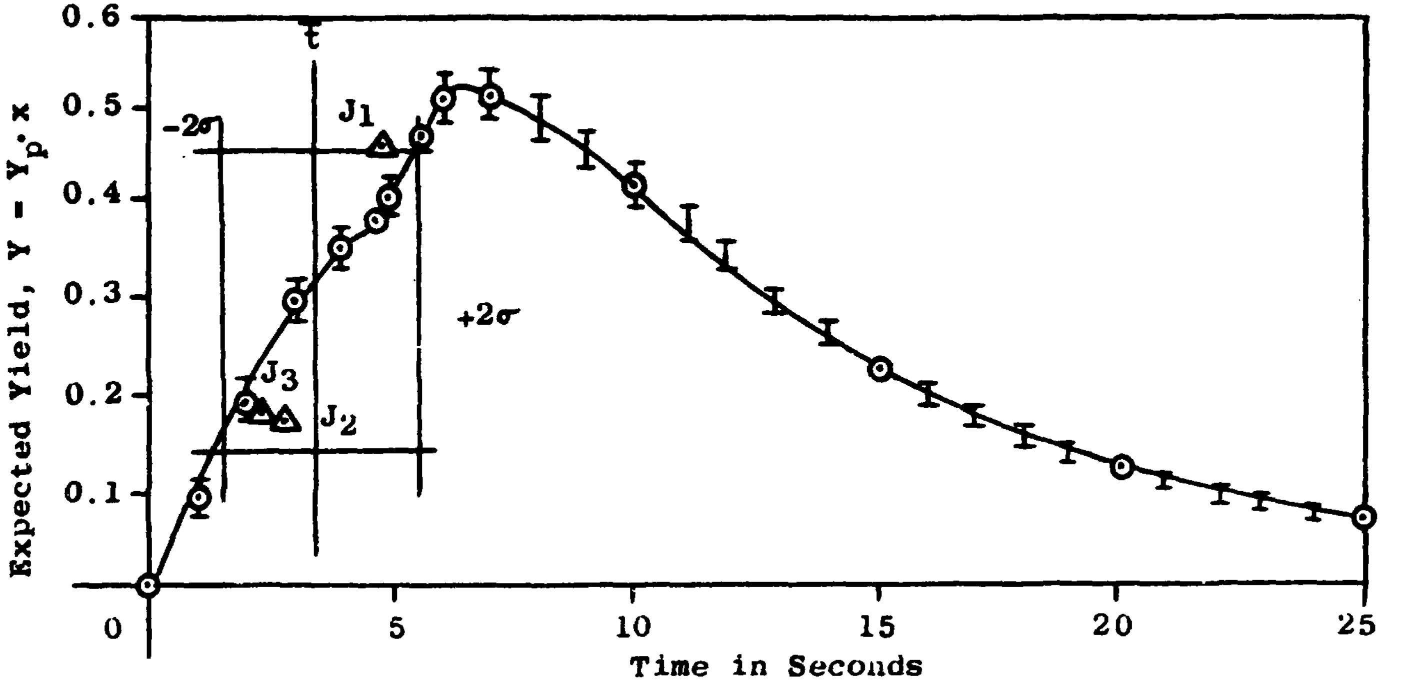


Figure II-7 Actual Yield for Random Ignition and Detonation Showing the Upper and Lower Limits of the Statistical Confidence Regions for Liquid Propellant Spill Tests

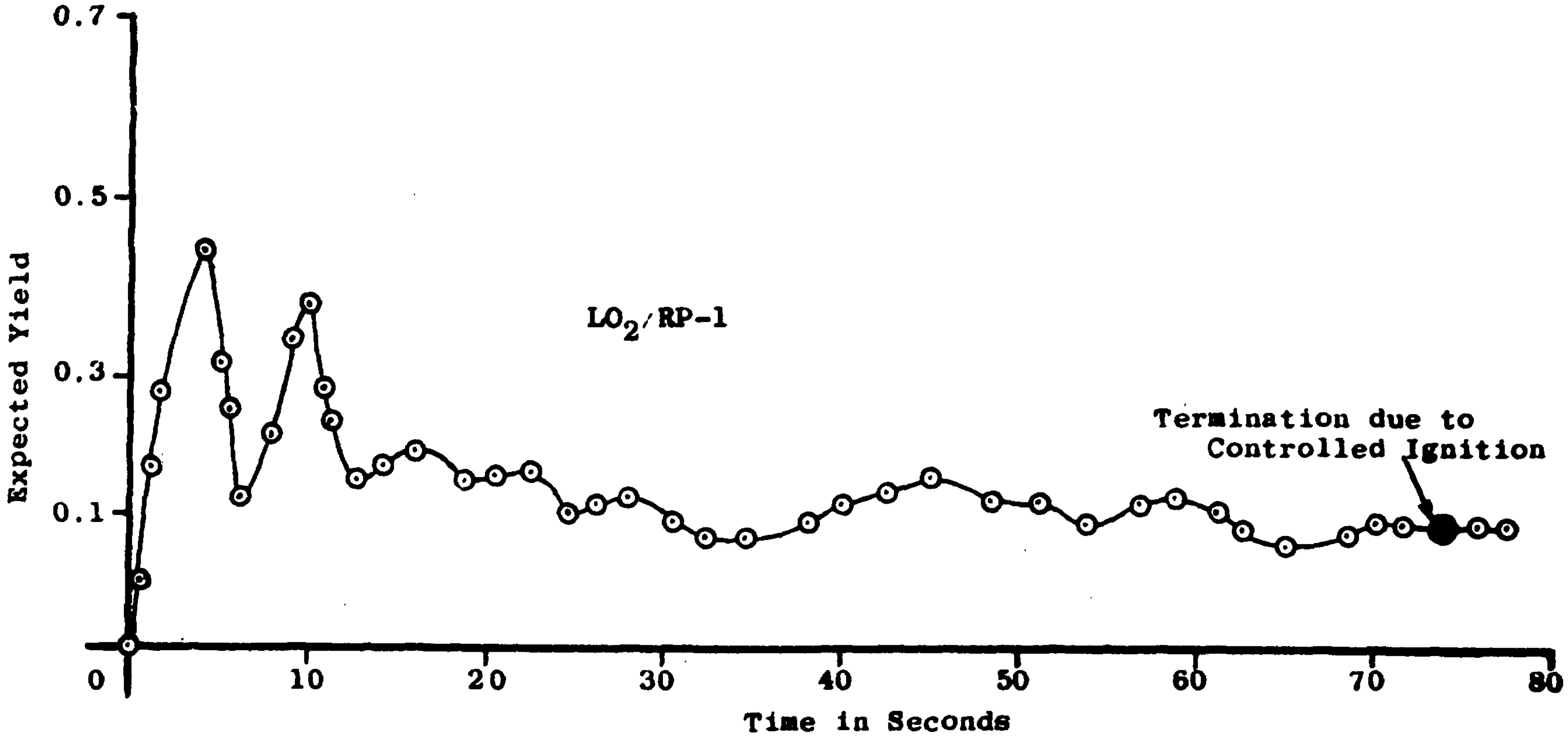


Figure II-8 Expected Yield as a Time Function
(200 lb Cold Flow and Explosion Experiment)

III. THE CRITICAL MASS METHOD

It was observed that auto-ignition occurred with large liquid propellant quantities. Many sources of ignition are available during a missile failure, such things as hot surfaces, flames or fires, the energy of falling structural members, striking of sparks, crystal fracture, silent glow, phase change mixing, electrostatic charge generation, etc.

In this work it was assumed that if no external ignition sources are available, the mixing processes themselves produce the ignition through electrostatic charge generation and discharge across one of the vapor bubbles.

For the purpose of studying these phenomena many combinations, including LN_2 and RP were mixed and their electrostatic charge and voltage buildup determined. The experiments showed that an average voltage of 4 volts was produced for every 200 ml of LN_2. Projecting this to mixtures of LOX and RP and LOX and LH_2, corresponding values not much different were obtained.

Using the observation that the smallest most prevalent bubbles were 1/4 inch in diameter and combining it with the literature information that it takes an electric field strength of 76,000 volts/inch before sparking can occur a CRITICAL MASS of about 2300 lb LOX/LH_2 and about 2800 lb for LOX/RP are obtained.

Ignition can occur earlier and especially with LOX/LH_2, masses of as small as 13 lb have on occasion been observed to auto-ignite.

Figure III-1 presents the voltage buildup for LN_2/RP and Figure III-2 the charge buildup.

When the CRITICAL MASS METHOD is applied to the field experiment it would indicate that at values below the critical auto-ignition may occur but is not normally expected. Above the critical value it is statistically a certainty that auto-ignition will occur.

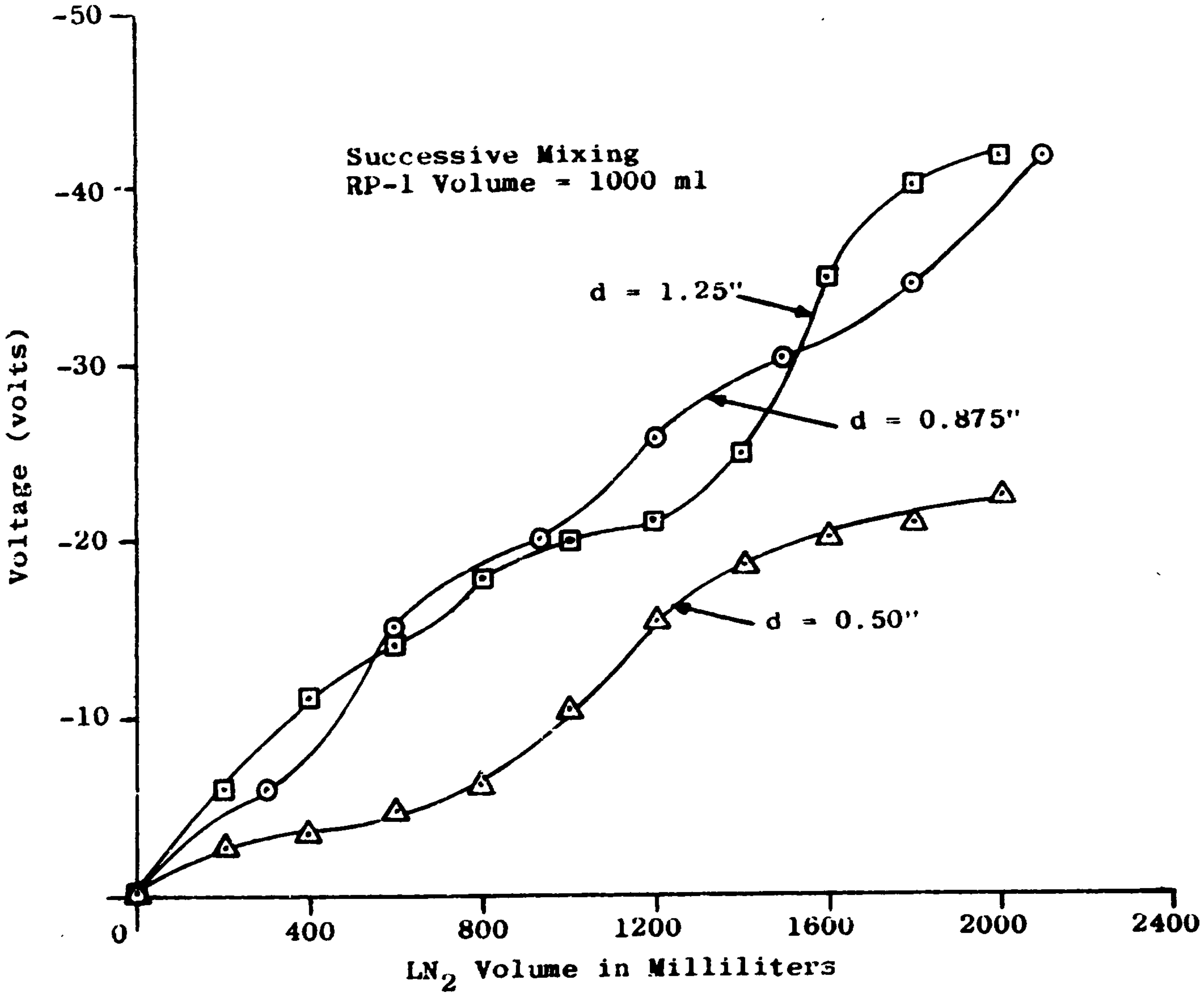


Figure III-1 Typical Voltage-Volume Relationship as a Function of Electrode Spacing

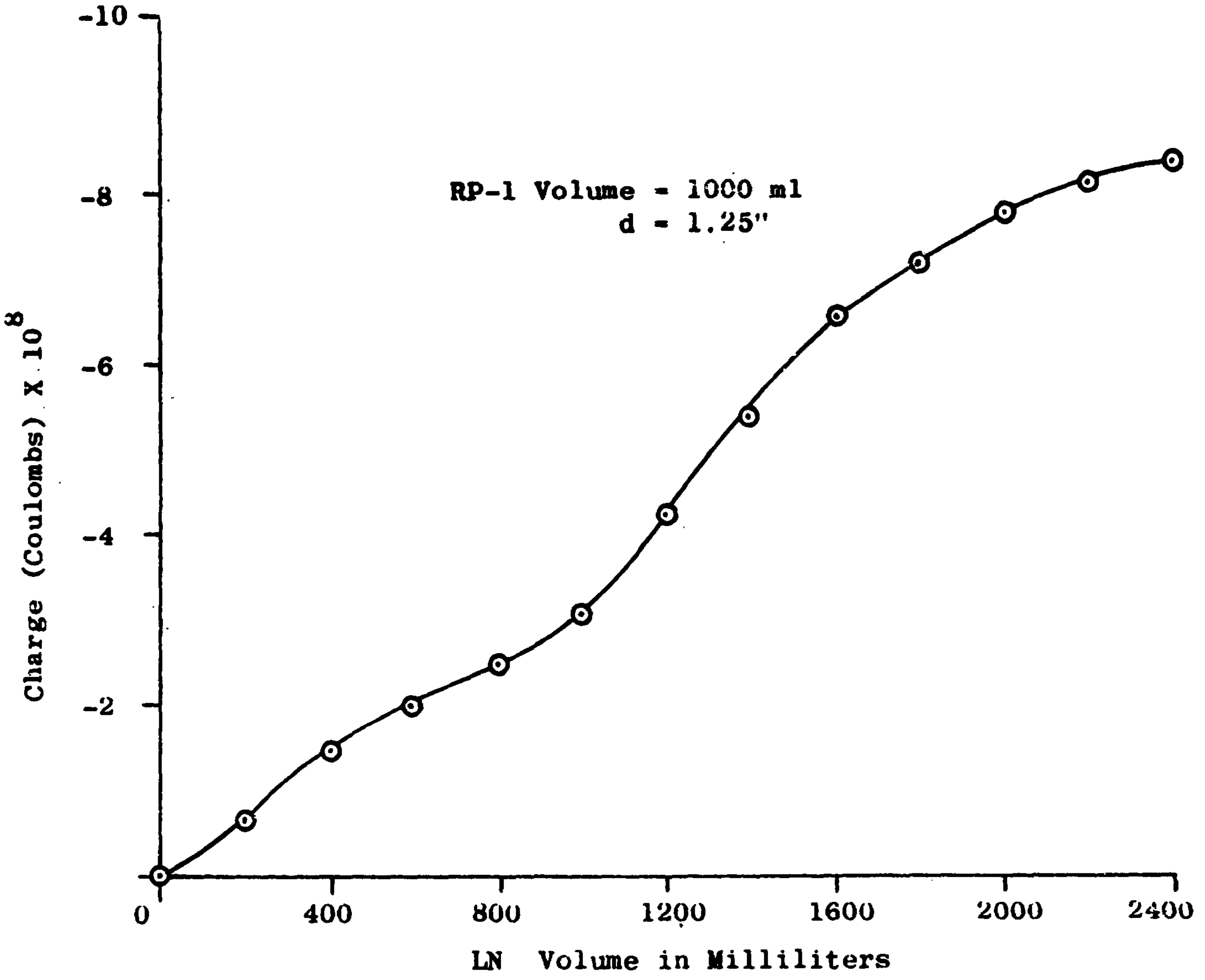


Figure III-2 Typical Charge-Volume Relationship

For the 25,000 lb experiments the CRITICAL MASS METHOD predicts an explosive yield value of 2800/25,000 = 0.113 while the actual measurements were 0.12 and 0.12.

For the S-IVB the predicted value is 2300/92,400 = 0.025 and observed values were 0.036, 0.01, 0.01.

The CRITICAL MASS as determined here was due to mixing primarily through boiling of the propellants. If they are brought together more violently, since it takes a definite but small time to build up the voltage, more of the propellants can be mixed before detonation is induced thus increasing the CRITICAL MASS value. The same is true if liquids at the same temperature are mixed very gently, greater quantities can be mixed than those quoted here. The above values are however typical if the boiling process is the primary factor in the mixing.

From the CRITICAL MASS an ignition time can also be obtained when the mixing function is taken and the time determined at which the CRITICAL MASS is reached. This ignition time can be used as the input to the previous section.

IV. Fireball Hypothesis and Experimental Verification, Describing the Reaction Front and Shock Wave Behavior of Liquid Propellant Explosions.

The Fireball Hypothesis was developed to describe the phenomena which take place from the time of ignition through the formation of the fireball. Since no information was available about the happenings inside an exploding missile, the hypothesis had to be formulated and mathematical relationships developed to express the quantitative behavior. For this purpose the Fireball Hypothesis was divided into four regions. They are

A. The region where ignition produces phenomena which develop into the detonation phenomenon.

B. The region where the reaction front and the shock front travel together through the propellants.

C. The region where the shock front and the reaction front separate, interact, and travel from one medium into others.

D. The region in which the shock wave travels through the atmosphere as an air shock and where the fireball grows and develops separately and behind the shock wave.

These four regions are graphically presented in Figure IV-1 with the regions distorted since they are of widely different dimensions.

To verify the Fireball Hypothesis, two 25,000 lb LOX/RP Explosive Experiments and one 200 lb Cold Flow and Explosive Experiment were completely instrumented with a thermocouple grid, a method developed by Dr. Farber and his group, in the hope to be able to measure phenomena inside the exploding missile. High speed camera coverage was to measure the phenomena on the outside. With the internal and external events tied to a common absolute time basis, the phenomena could be followed from the start of the failure to the formation of the combustion products cloud.

It was hoped, through this procedure, to:

1. Correlate the mixing phenomena of true propellants with laboratory experiments employing inert fluids for simulation.

2. Substantiate experimentally part or all of the Fireball Hypothesis proposed.

Some of the specific objectives were to determine by this experimental procedure part or all of the following:

After failure but before ignition:

a. The three dimensional mixing front or boundary of the mixing region.

b. The degree of mixing at a particular point.

c. The degree of turbulence at a particular point.

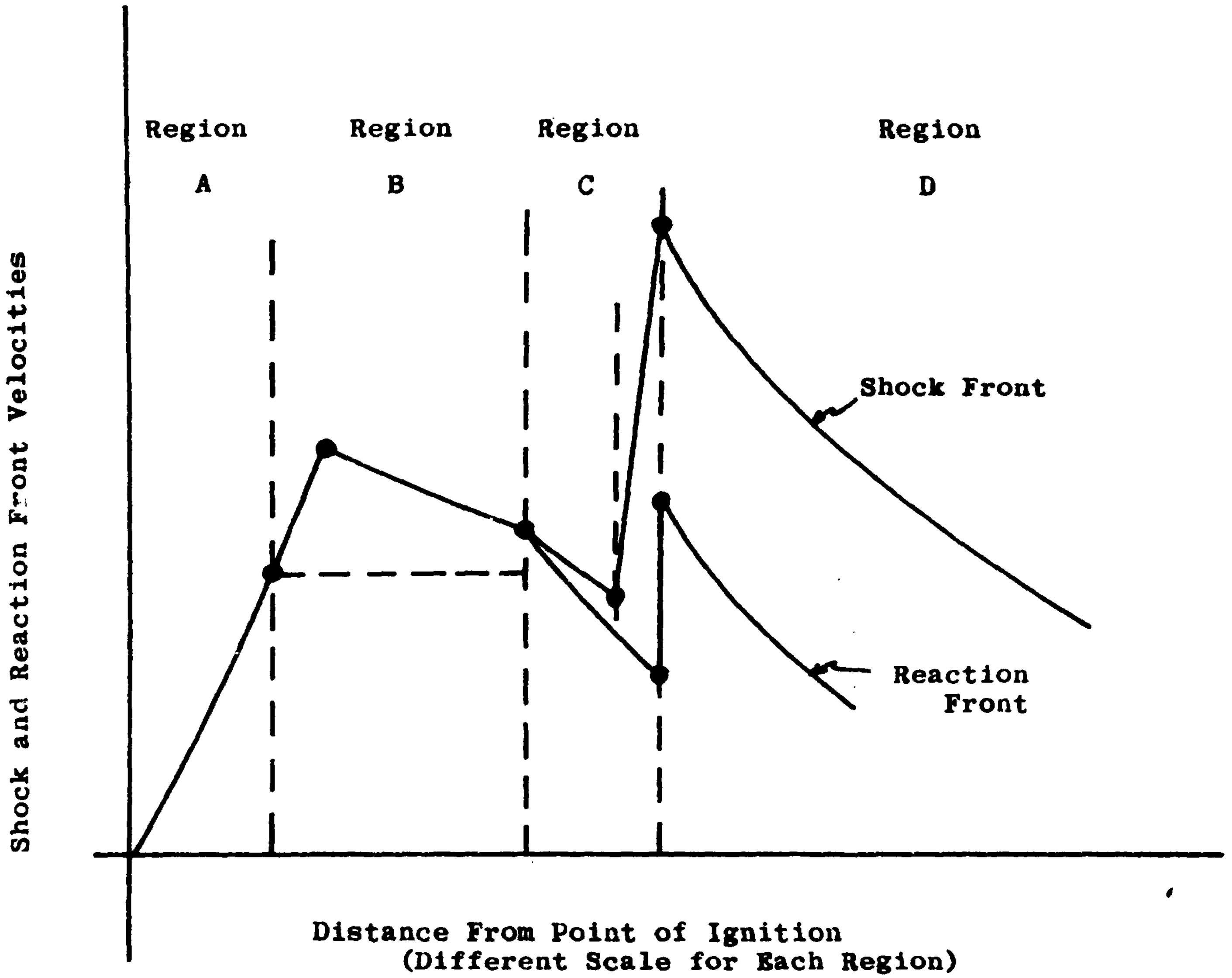


Figure IV-1 Fireball Hypothesis, Describing the Shock Wave And Reaction Front Behavior in Liquid Propellant Explosions.

After ignition:

d. The location of the point or points of ignition.

e. The time delays from initiation of failure to start of mixing, to ignition.

f. The propagation of the reaction front.

g. The propagation of the shock front.

h. The separation of the shock front and reaction front.

i. The interaction, if any between the two fronts.

j. The emergence of the fronts into the atmosphere.

k. Other phenomena and events obtainable by detailed analysis.

Figure IV-2 presents the experimentally obtained velocities as a function of distance from the point of ignition. There was only one point of ignition.

In region A a velocity of about 7500 fps is reached in the 25,000 lb experiments. In region B the shock and reaction fronts separate, with the shock front reaching the tank walls first and then bouncing back and forth while the tank walls are beginning to burst, and emerge almost simultaneously with the shock front reaching a peak velocity of almost 28,000 fps quickly attenuated and the reaction front a peak velocity of over 18,000 fps.

With smaller propellant quantities the extreme values are slightly smaller.

Figure IV-3 shows the velocity as a function of time, indicating that the whole process takes only a few milliseconds.

Figure IV-2 can be compared with the Fireball Hypothesis and it can be seen that the hypothesis is in remarkable agreement with the observed and measured facts.

Much more detail about this work and the results can be found in the references.

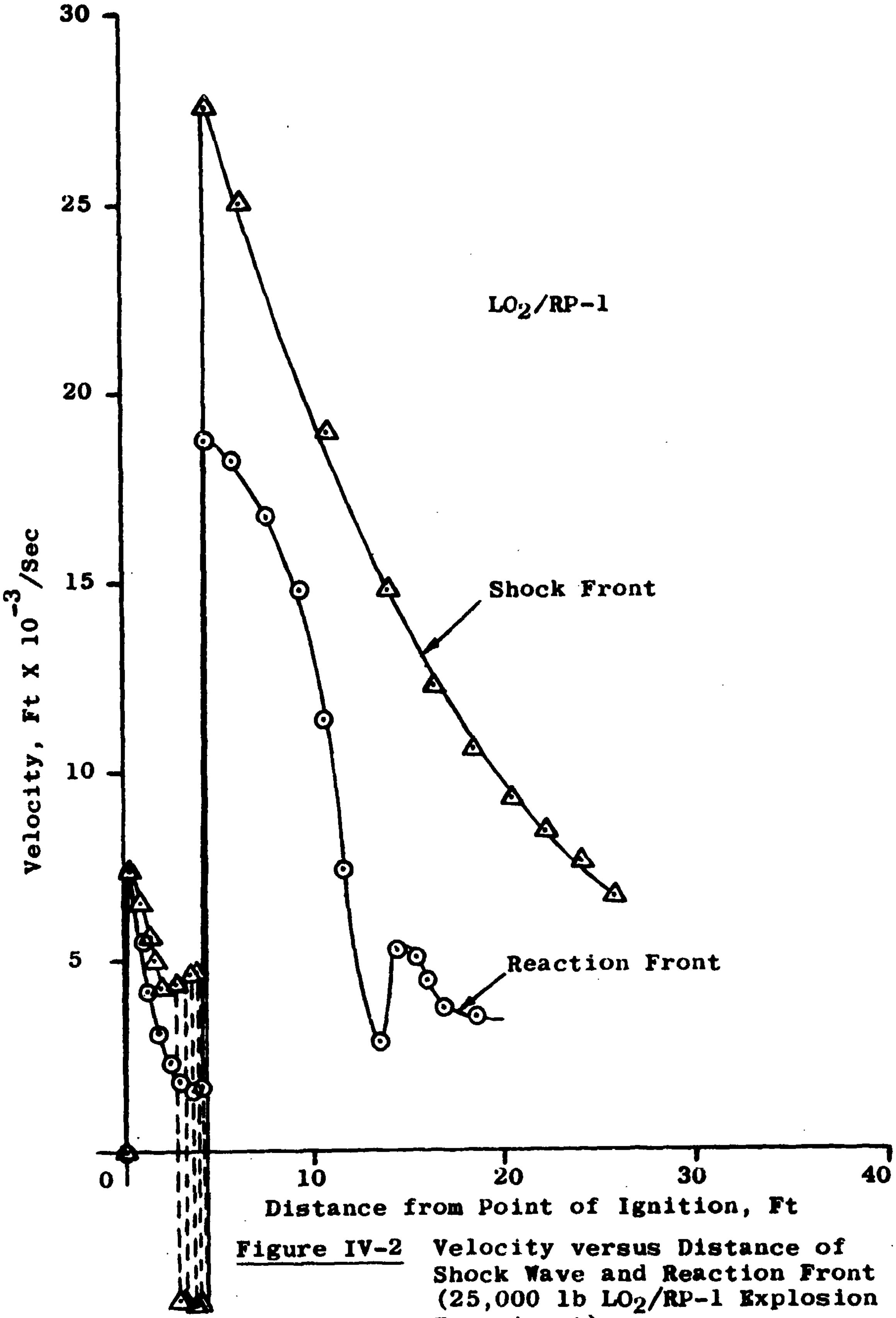


Figure IV-2 Velocity versus Distance of Shock Wave and Reaction Front (25,000 lb LO_2/RP-1 Explosion Experiment)

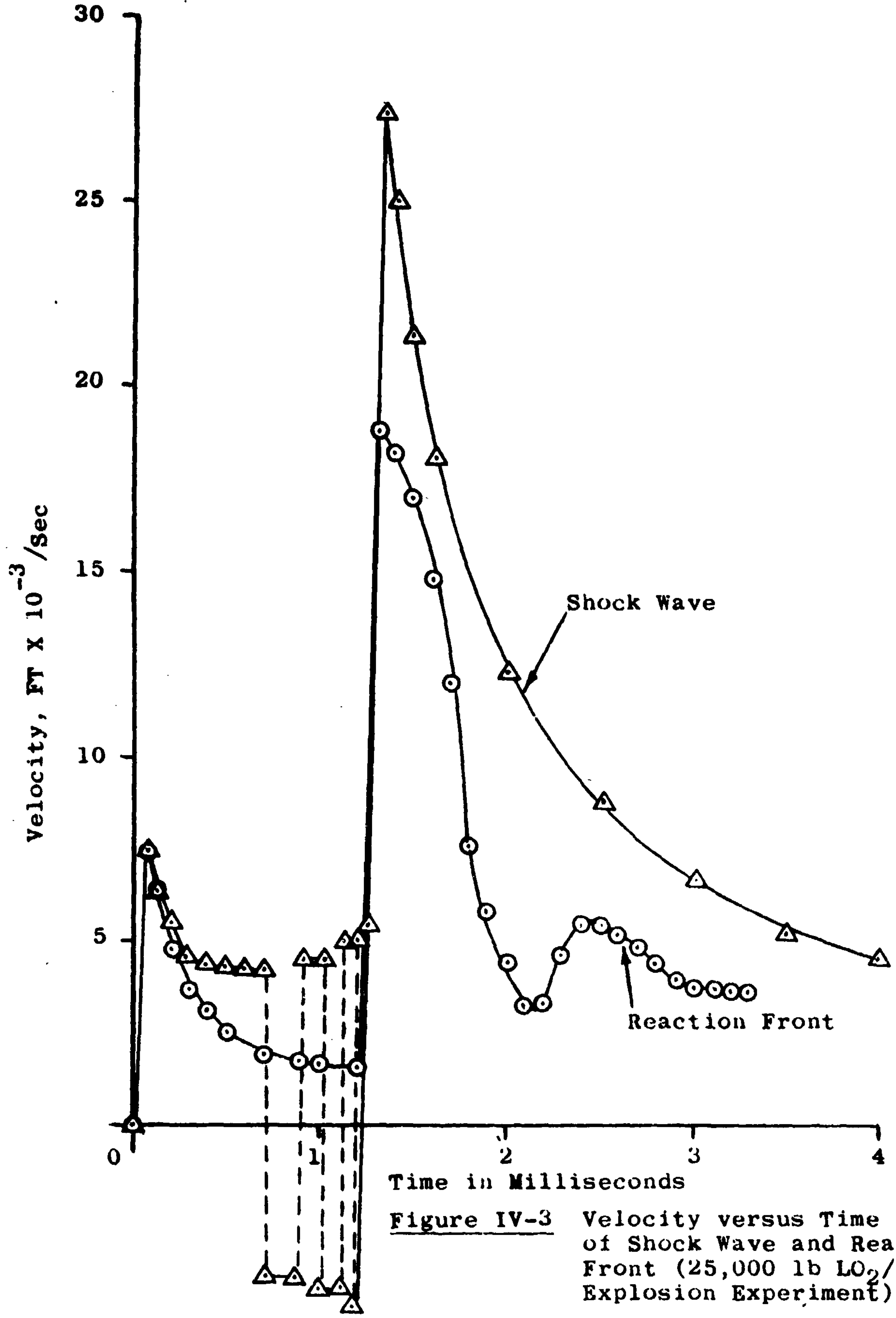


Figure IV-3 Velocity versus Time of Shock Wave and Reaction Front (25,000 lb LO_2/RP-1 Explosion Experiment)

V. Fireball and Post Fireball Combustion Products Cloud History and Composition.

In the previous sections the phenomena have been traced from the initiation of the failure, through the mixing, ignition, shock front and reaction front propagation, inside and outside the exploding missile.

To complete the picture the reaction front is looked at in more detail in its later stages, first forming the fireball and then the combustion products cloud.

The previous work and that by others has given information on the

a. Volume of the fireball and combustion products cloud.
b. The pressure pushing the reaction front.
c. The temperature of the fireball and combustion products cloud.

The three above estimates have been taken as input for a rather elaborate computer program to calculate the composition of the fireball and combustion products cloud as a function of time. To be able to do this, thermal equilibrium was assumed throughout the fireball, which due to the high turbulence is believed to be reasonable.

The above input information of volume, pressure and temperature, since experimental verification is possible, is believed to be better than such things as fuel burning rates, etc. used by others.

Figure V-1 gives the volume time function for the combustion products of a 100,000 lb LH_2/RP-1/LOX/10% F liquid propellant explosion with an explosive yield of 4.5 percent.

Figure V-2 presents the pressure time function for the same liquid propellant explosion.

Figure V-3 presents the temperature time relationship for the above liquid propellant explosion, approximated by linear segments indicating the late burning of some of the propellants during the expansion of the fireball.

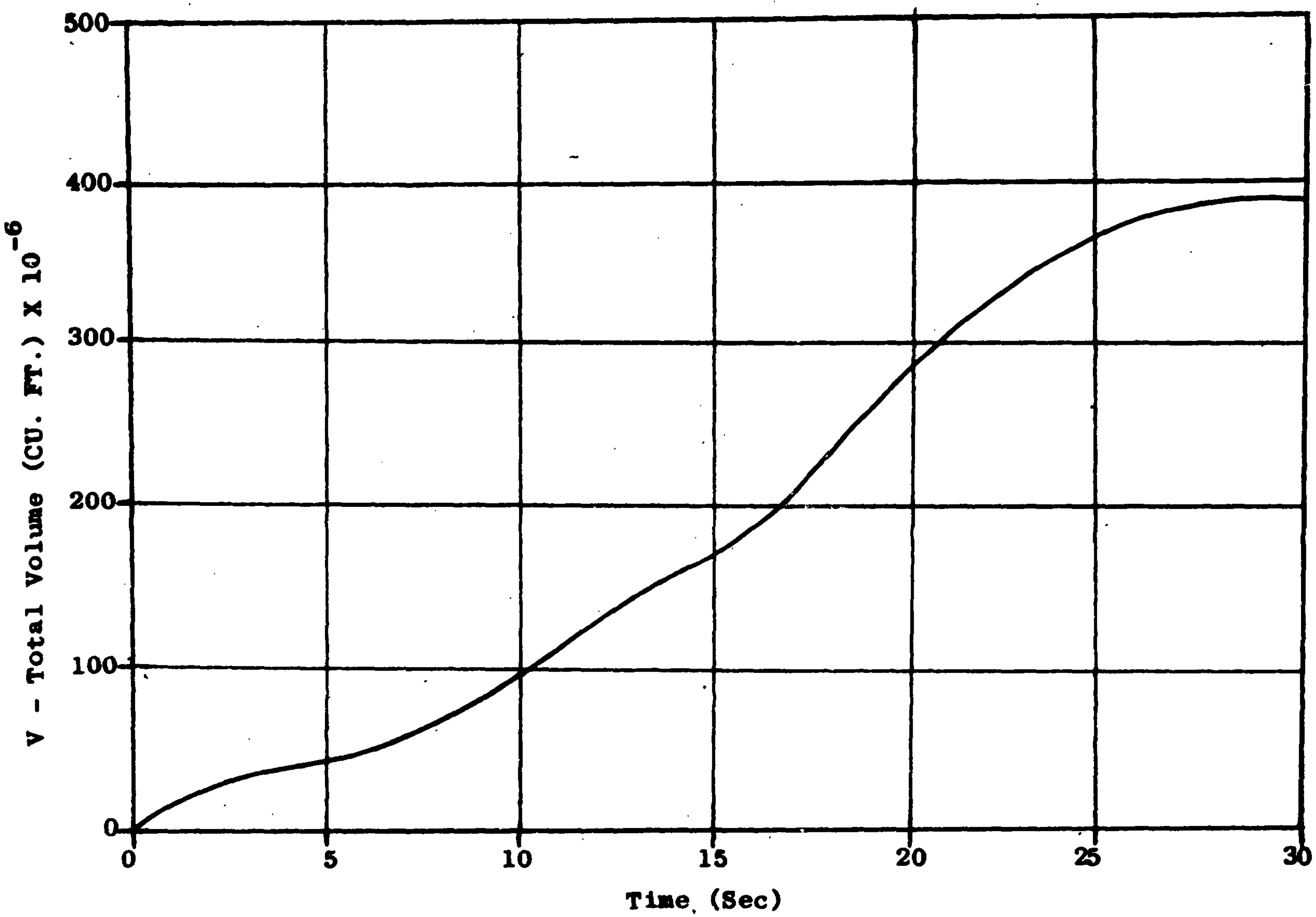


Figure V-1 Volume-Time Function for LH_2/RP-1/LO_2 + 10% F Liquid Propellant Explosion Products (Yield = 4.5 Percent)

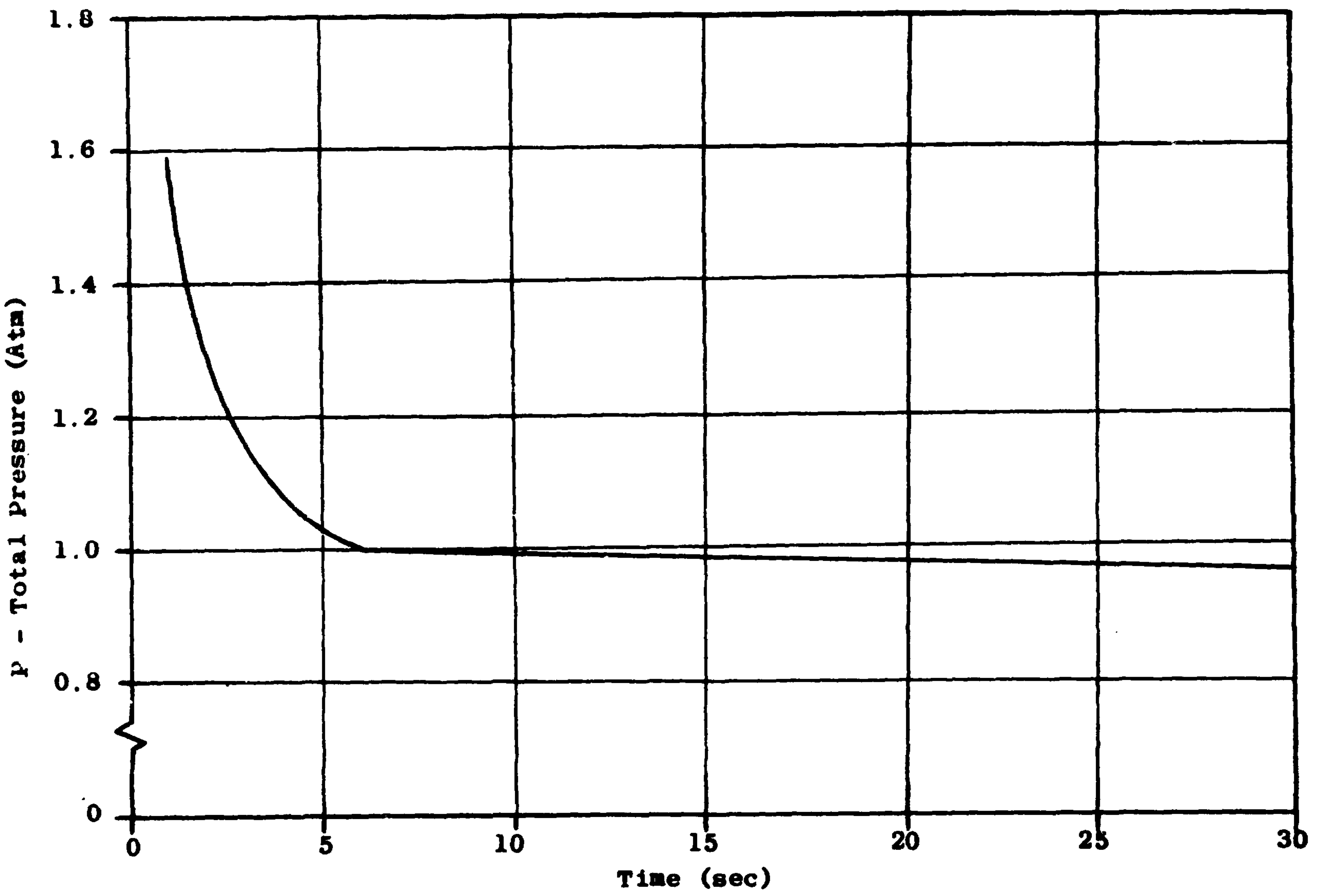


Figure V-2 Typical Pressure-Time Function for Liquid Propellant Explosion Products (Yield - 4.5 percent)

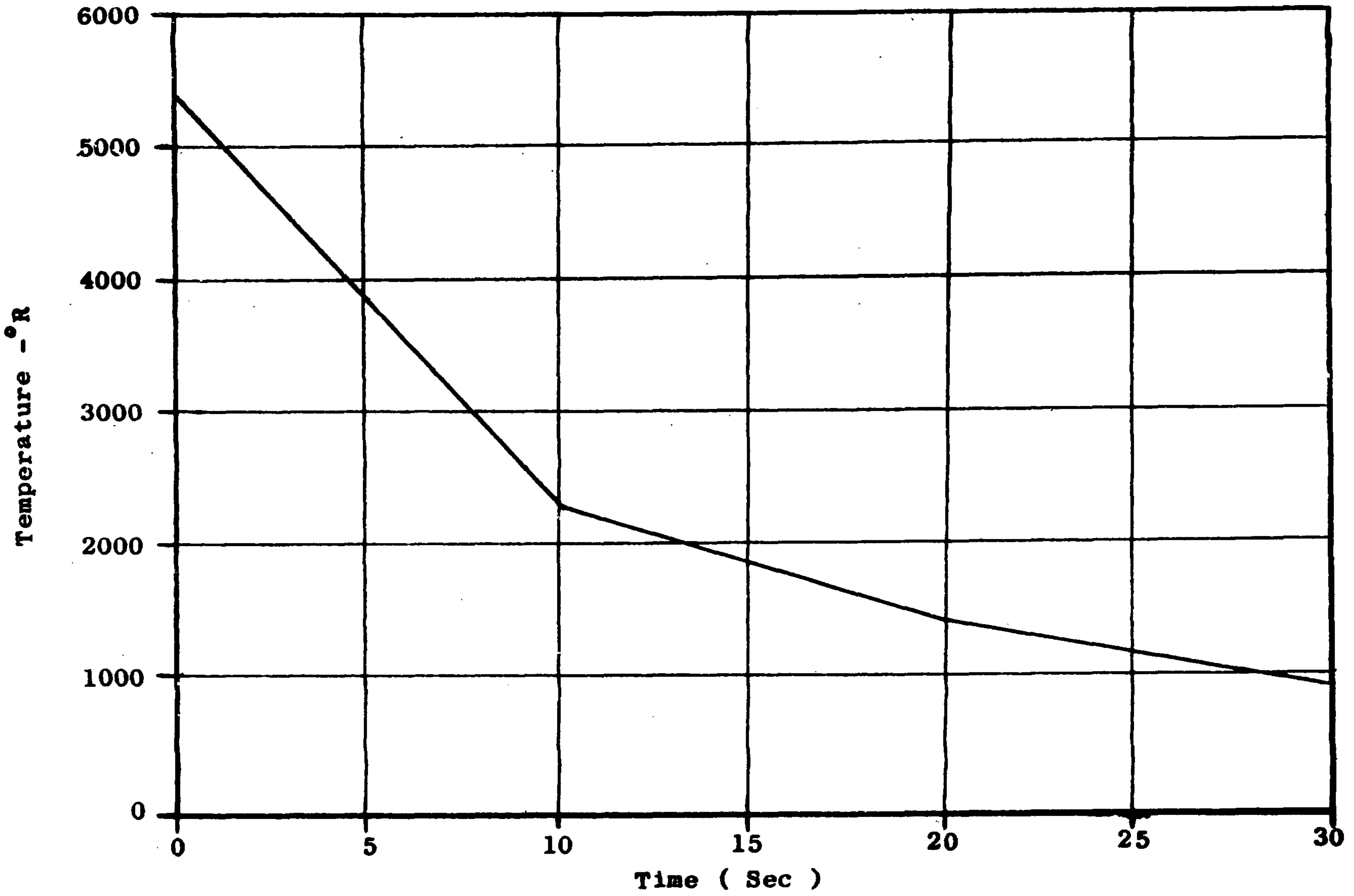


Figure V-3 Typical Temperature-Time Function for Liquid Propellant Explosion Products (Yield = 4.5 percent)

Using the above three curves as input the composition at any time, for equilibrium conditions, can be calculated. The results from such calculations are presented here in Figure V-4.

The complete work up to this point allows the tracing of the phenomena of liquid propellant explosions from the initiation time of the failure through ignition till a cool combustion products cloud is produced. Thus, this work encompasses the complete processes of liquid propellant explosions from beginning to the end.

VI. Saturn V Destruct System Analysis

Having methods, developed by Dr. Farber and his group, which make it possible to systematically analyze liquid propellant rocket explosion from the initiation of failure through the combustion products cloud, the University of Florida was asked to apply the above methods to the evaluation of the Saturn V destruct system.

This request came as a result of the suggestion by the above group that it may be better, in case of forced abort, to destroy the rocket in a known manner with a predictable explosive yield, rather than letting nature takes its course.

This work is now in progress but some preliminary results are available.

The Saturn V destruct system was designed to be propellant dispersal system with the fuel being emptied on one side and the oxidizer on the opposite side through explosively cut openings. This forms splash puddles on the launch pad which will mix both as liquid puddles and as vapor clouds above.

The result of explosive yield versus time obtained from the SEVEN CHART APPROACH for this case is presented in Figure VI-1. It is indicated by the results that a yield of about 14 percent could be attained theoretically

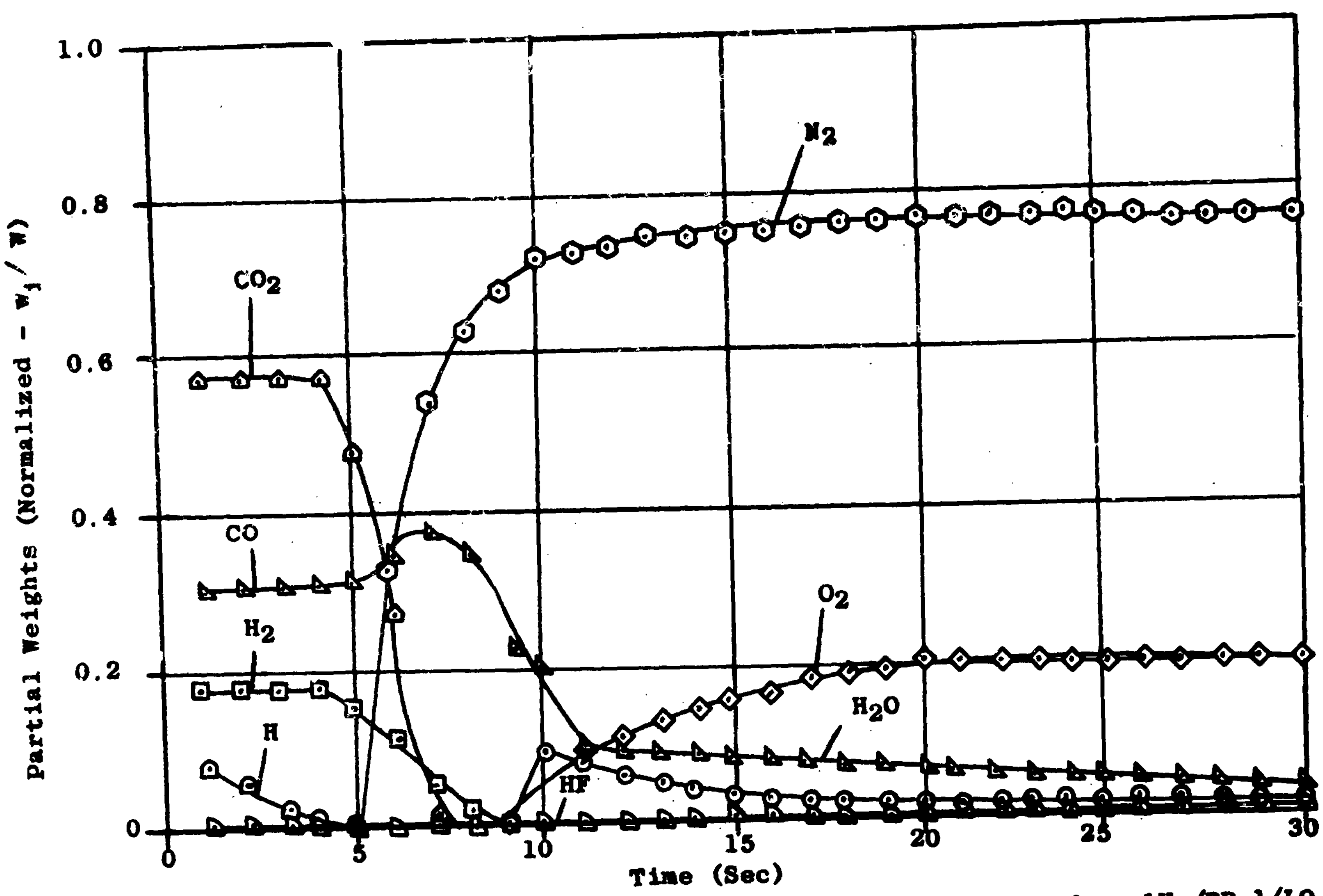


Figure V-4 Weight Composition of the Combustion Products from LH_2/RP-1/LO_2 + 10%F Liquid Propellant Explosion (Yield = 4.5 percent)

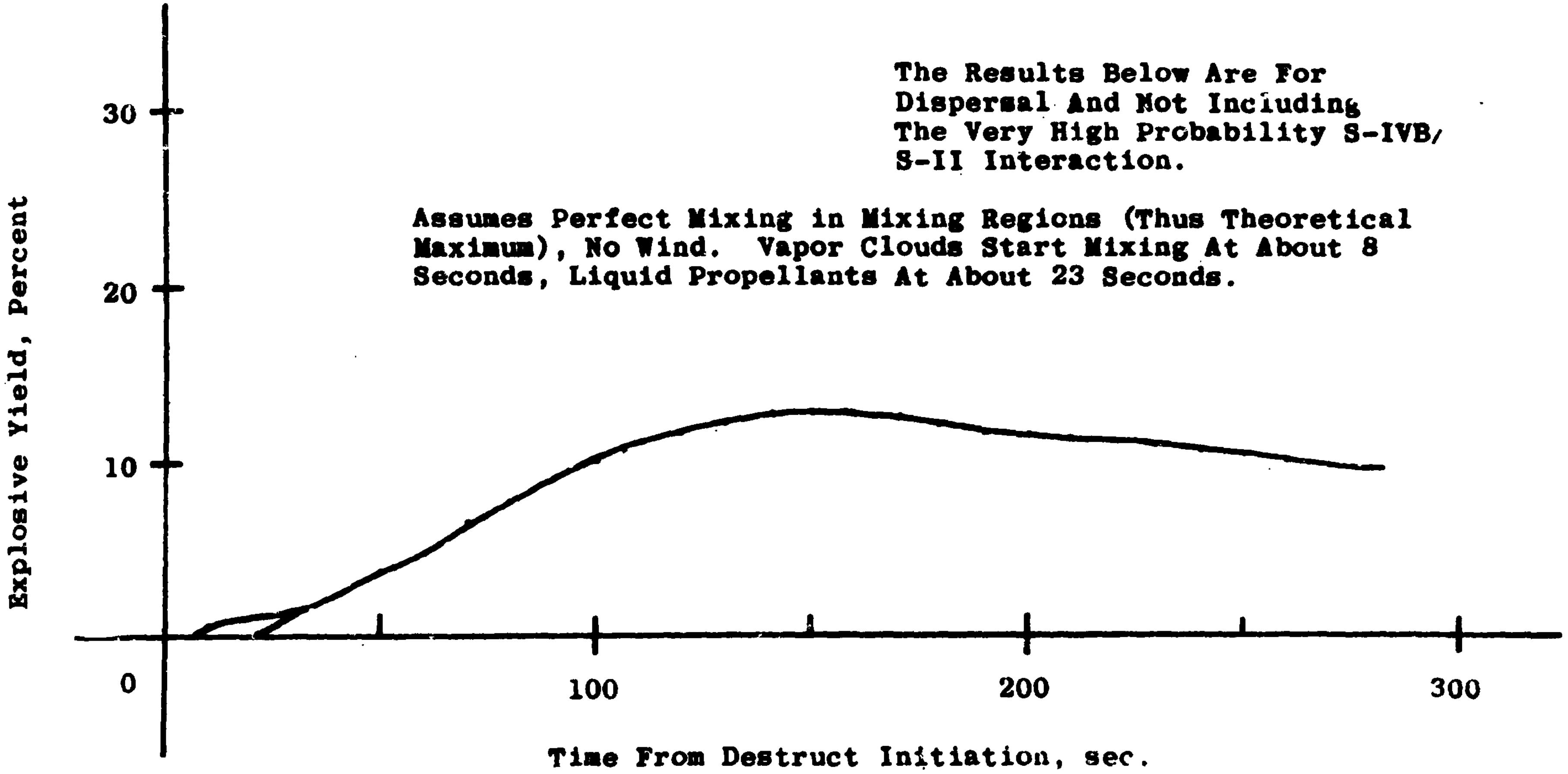


Figure VI-1 Theoretical Explosive Yield Prediction - Saturn V (Destruct Spill) if it were possible to delay ignition for almost 3 minutes after the tankage is opened by the linear charges.

A time delay of almost 3 minutes has extremely low probability of occurring with all the potential ignition sources present. So it is expected that actual ignition will occur very early in the process and therefore the yield will be low as also predicted by the other methods.

This analysis is based upon information furnished by NASA as to the effects of the destruct system on the Saturn V tankage, namely opening slots 2 and 3 feet wide and the length of the charges. There exists some uncertainty about this.

The analysis by the University of Florida further uncovered the very high probability that the destruct system will not act as a dispersal system but that the cutting of a 47 inch diameter hole into the bottom of the LOX tank of the S-IVB will drop the engine and thrust cone of that stage which in turn will cut a hole into the LH_2 tank of the S-II. This will allow LOX to pour on top of LH_2 producing a primary explosion which may propel the engine and thrust cone upward through the S-IVB, producing a larger secondary explosion, and through the service module and payload.

This last and much more serious effect is being investigated now, as well as alternatives to the present destruct method, such as pancake charges, etc.

Again the value of the analysis methods developed is demonstrated, and hopefully will be used in the future in evaluating proposed designs so that undesirable features are prevented from reaching the final stages.

This paper had to be necessarily brief since a great amount of material was covered. The details, however, can be found in the references cited.

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2. Farber, E. A., "A Mathematical Model for Defining Explosive Yield and Mixing Probabilities of Liquid Propellants," Third Space Congress Proceedings, March, 1966.

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14. Farber, E. A., et al., "Fireball and Post-Fireball Composition and Atmospheric Chemistry of Fuel/Oxygen-Fluorine Propellants," NASA report, Contract NAS10-1255, July, 1967.

*Many more references are cited in the above references to complete the picture on the studies in this field.

NEW MANUFACTURING PROCESSES IDP, PNEUMATIC MIX, CONTINUOUS TNT

Moderator:

David H. Carstater
U. S. Naval Ordnance Station
Indian Head, Md.

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NEW MANUFACTURING PROCESSES

GENERAL FORUM COMMENTS

A discussion of risk classification and hazard potential had been ably introduced earlier in this seminar meeting by Mr. Watson of the U.K. Discussion in this Specialist Session related to that topic of evaluating both the consequences and the likelihood of an explosive incident. Insofar as the dynamics of explosive processing rates it high in the explosive likelihood category, it was widely conceded that all possible and realistic measures should then be taken to limit the consequence risk. This was accomplished, to varying degrees, by the three processes discussed here. To have a realistic quantity-distance relationship, while still affording personnel a high degree of protection, these three processes,

1. Limited the quantity of explosive under process and
2. Reduced or eliminated the number of personnel exposed to explosive operations.

The foresight in establishing these process capabilities is therefore, obvious.

The next foresight to be exercised should begin now, and it should be directed at how these systems should be applied in the future. Most of those present agreed that the application of erstwhile propellant processing technology would well be employed in explosive loading applications.

A discussion ensued on the recent demands for installations and loading facilities to be more versatile in their capabilities. Should there be more emphasis on plant modernization for conventional explosive casting facilities? It was mentioned that processes, such as those discussed, had elements of greater flexibility in them. A need to be practical was noted, however. Cost effectiveness is becoming more and more a must requirement when establishing facilities.

It was postulated that establishing processes such as these was an attempt to improve safety through:

1. Reduction of quantity in process
2. Reduction of sensitivity of materials
3. Reduction of severity of processing, and/or
4. Total or partial remote operation.

Before deciding how much of the total safety postulate he will buy in a design, to be realistic one must weigh questions such as:

1. How long should one go between maintenance checks with a highly automated system?
2. How many procedures should be dictated by safety in an automated system?
3. Although personnel exposure is minimized by remote and automated control, how many new hazards come into view (dependability)?
4. How many and which of the process safety postulates can be traded off to attain a reasonably safe, cost effective operation? Can any be traded off?

It was concluded that although there is no happy medium, that meetings such as this help to maintain a proper prospective through a continuing interplay and communication among people in the industry with an interest in safety.

PNEUMATIC MIX RESUME

Presented by: Albert J. Colli
Continuous Processes
Naval Ordnance Station
Indian Head, Maryland

Abstract:

The Pneumatic Mix Process continuously mixes explosive ingredients as they flow dispersed in an inert gas. This allows the mixture of small quantities of material at a rapid rate while averting the use of large, close-toleranced, mechanical devices as used in conventional mixing. The Pneumatic Mix Process has been used to process several composite type propellants and is currently being used to process a castable PBX formulation containing RDX. A test series to determine the extent of hazards which could be encountered in dry nitrogen atmosphere was described. A description of process equipment was given, including solids feeders and control, mixing units, propellant-gas separators, nitrogen gas generation and compressor and overall plant design considerations.

This included exploitation of the process safety advantages; small quantities in process, ingredients maintained in an "inert" gas which may be scrubbed, filtered and recycled; and in-line turbulent mixing without mechanical moving parts. Other safety features of the plant include below grade casting with cure in place capability and remote control of complete operations.

Comments:

Discussion of the ignitability of solids when suspended in an "inert" gas stream led to a discussion of Hartman machine test results. In these tests a 1.6 ounce RDX suspension in a cubic foot of nitrogen (very close to process conditions) could not be ignited by a spark of one joule. (This is similar to dust and flour initiation levels in air.)

In the cases of aluminum or ammonium perchlorate a problem of ignitability in nitrogen was not found to exist.

A 0.2% oxygen contamination of nitrogen gas was discussed as a monitoring point accepted as procedurally sufficient to shut down processing.

Reference was made to some separate studies made on the impaction of a particular double-base propellant on a steel plate to question the speed of particles from Pneumatic Mix on reaching the separation operation and consideration of initiation at this point. It was pointed out that the separate tests were not applicable since not only the test conditions but the material under test were markedly different from those found in Pneumatic Mix.

COMPARISON OF CONTINUOUS & BATCH TNT MANUFACTURING

Charles C. Gardner
Hercules Incorporated
Radford Army Ammunition Plant
Radford, Virginia

TNT has been produced on a large scale for approximately 60 years. All production of this material in the United States during this time has been by a batch process which was developed for use on an industrial scale by the Griesheim Chemical Factory in Germany in 1891.

In practice, the production of crude TNT by the batch nitration process is carried out in separate distinct phases.

The first phase involves the nitration and subsequent separation of approximately 1,600 pounds of toluene to mononitrotoluene (MNT) with weak nitric and sulfuric acids. Next the product MNT is nitrated to dinitrotoluene (DNT) with stronger nitric and sulfuric acids. The DNT is subsequently separated and nitrated to trinitrotoluene (TNT) with strong nitric acid and oleum. Separation of the acids from the TNT takes place and the batch of approximately 3,500 pounds of crude TNT is sent to be purified.

The purification phase of the crude TNT also takes place using the batch technique. Washing to remove entrapped acid, Selliting to remove unwanted isomers and the finishing phase to acquire the desired flake or grain of TNT are all done with large batches of TNT product in process.

In all phases of batch manufacture, personnel are intiminately involved. The makeup of the various acid mixes, the control of product flow and agitation, the assurance of proper temperature and separation, the monitoring of adequate residence times, all involve the visuals and manual capability of the human. He must be exposed to the various steps of the operation to assure that the product is manufactured properly and safely.

Recently, various systems were developed for the continuous nitration and purification of TNT, all of which offered many outstanding advantages of manufacture over the older batch methods.

The first plant using this type of process in North America was developed jointly by Canadian Industries, Limited (CIL) and AB Chematur, a Swedish Engineering firm, and began production at Beloeil, Quebec, Canada, in December 1962. A second plant was built by CIL at Valleyfield, Quebec in 1965. The capacity of these plants were 15 and 25 ton/day respectively. The two firms jointly designed a continuous TNT process, utilizing counter-current flows for the acid and nitrobody.

During 1965 and 1966, the United States Government conducted negotiations with CIL for use of this plant design in construction of continuous TNT facilities in the United States. The Office of Bombs and Related Components prepared the project, and the plant was assigned to the Ammunition Procurement and Supply Agency for installation at one of its active manufacturing complexes. On 23 June 1967, authorization was granted for the construction of a continuous TNT facility at Radford Army Ammunition Plant, Radford, Virginia.

The knowledge and experience gained in building and operating the CIL plants was used in designing the larger 50 ton/day Radford units. Although the basic process concept remains unchanged, further improvements have been made especially in the design which makes the TNT facilities at Radford the most modern available today.

Production of TNT by the continuous method involves three distinct operations contained in two buildings. First, in the Nitration and Purification Building toluene feed stock is reacted with mixtures of nitric and sulfuric acids to yield a crude trinitrotoluene. Then the crude TNT is washed and purified by chemical treatment. Finally, the purified TNT is sent to a Finishing Building to be dried, solidified and packaged.

The nitration section of the process is divided into six nitrator/separator stages with two of the stages having two nitrating vessels to a single separator, while the other four stages are single nitrator/separator units.

Toluene and weak nitric acid (WNA) are metered by a metering pump and controlled flow valves into nitrators No. 1A and 1B where it is nitrated to mononitrotoluene (MNT). Two nitrators are used without separation to provide assurance of process control. The product from 1A nitrator flows to 1B nitrator for further conversion of the toluene to MNT. The nitrobody (MNT) phase is separated in No. 1 separator by a difference in density from the mixed acid and flows on to nitrator No. 2.

The nitrobody (MNT), approximately 60% weak nitric acid, and the effluent water from the first stage of the purification process referred to as yellow water flows into Nitrator No. 2. In this nitrator, the major portion of the MNT is converted to dinitrotoluene (DNT) with some material being converted to trinitrotoluene (TNT). The nitrobody, MNT, DNT, and TNT, is separated in No. 2 separator by its density from the mixed acid, and flows forward in the system.

The nitrobody emulsion and strong nitric acid (SNA) flows into Nitrator No. 3A. Here the conversion of DNT to TNT begins to take place on a large scale. The emulsion, acid mix, and nitrobody from 3A travels directly to Nitrator No. 3B without separation to give a more complete nitration at this stage. This is needed here to lessen the chance of materials being oxidized or impurities being formed which are difficult to remove later in the process. The acid emulsion mix is separated, by density, in No. 3 separator and the nitrobody phase travels forward for further nitration.

The remaining DNT continues to be converted to TNT in Nitrators 4 and 5. Strong nitric acid is added to these nitrators to promote the reaction. Separation occurs after each nitrator with countercurrent flow taking place.

The nitrobody emulsion from No. 5 separator, SNA, and oleum flow into Nitrator No. 6. In this vessel, nitration of the remaining materials is carried to its completion. The acid-emulsion mix is separated by density in Separator No. 6. The crude TNT, consisting of approximately 99.8% TNT and 0.2% DNT, flows forward to the purification section of the Nitration and Purification Buildings.

While the nitrobody phase if flowing forward through the process, all acids are flowing backward.

The acid flow is a continual process by means of what is called a recycle line from the separators back to the nitrators, and then flow lines from the separator decanters back to the next lower nitrator.

The recycle lines are placed in the bottom of the separators and thus cause acid to be syphoned back into the nitrator connected to the separator. The decanter, which controls the level of split or separation of the acid and nitrobody in the separator, is placed just below the nitrobody level; therefore, controlling the flow and residence times within the vessels.

Throughout the nitration phase of the process, the analysis of nitric acid in the various nitrators is used to control the quality of the product TNT. The titration of samples from each nitrator indicates the quality of the reaction taking place. If a titration should come out high or low, adjustments to the metering pump controlling the flow of the acids and toluene into the building wier boxes and thence into the process are accomplished.

The heat produced during the nitration reaction is removed by passing cold water through the cooling coils in each nitrator. The quantity of cooling water used is automatically controlled to maintain the temperature of each nitrator at a present value.

The driving force for the countercurrent flow of nitrobody and acid in the nitration vessels is supplied by agitation and densities of the materials.

The design of the equipment allows for nitrating acid to be recycled from the separator to the nitrator in the same stage, which has the effect of displacing nitrobody to the next nitrator and thereby greatly reducing the quantity of explosive in process.

Crude TNT, containing three types of the TNT (alpha, beta, and gamma), DNT, and dissolved and entrained acid flow from Separator No. 6 to the acid washer of the purification process.

The first operation in the purification process, the acid washer, is to remove as much of the dissolved and entrained acid as possible by simple water wash.

The acid washer is a five stage mixer/settler unit which provides the crude TNT with five water washes to remove the entrained and dissolved acid.

The almost acid free crude TNT leaves the last mixer/settler stage and is fed via a decanter into the first Selliting unit. The TNT is mixed with fresh sellite solution from the sellite dissolver and spent sellite solution from the second selliting stage in No. 1 Sellite Washer. Soda ash and sulfur dioxide are also added in this vessel to maintain the desired reaction. The sellite reacts with the beta and gamma isomers of TNT and other impurities to form the waste product Red Water.

The TNT and Red Water waste product are separated by density in No. 1 Sellite Separator. TNT flows from No. 1 Sellite Separator into No. 2 Sellite Washer where a second sellite reaction takes place to more completely remove unwanted isomers. The spent sellite solution, usually referred to as Red Water, overflows the weir in the separator and is carried by means of pipes and gutters to the Red Water Destruction Area.

TNT from No. 2 Sellite Washer, after washing and subsequent separation, flows into the post Sellite Washer.

The post Sellite Washer is a vessel similar in design to the acid washer. In it, the TNT is given five separate water washes to remove any entrained or dissolved sellite solution and/or Red Water.

The now purified TNT passes into the pump tank where it is mixed with approximately three times its weight of water. A submerged centrifugal pump, pumps the TNT/water mixture up to an interrupted funnel located above the building roof. From here the TNT water mix flows by gravity through a 3-inch SS traced and insulated line to the Finishing Building, a distance of approximately 220 feet.

In the Finishing Building, the water and TNT are allowed to separate and the water is returned to the Nitration/Purification Building. The TNT flows out of the bottom of the separator into the hold tank and then into the drier.

The drier is equipped with a series of crosswise baffles which force the TNT to take a serpentine course of approximately 30 feet before exiting the unit. In each channel formed by the baffles is a horizontal pipe containing numerous holes. Air is supplied to these pipes, thus creating agitation. Steam to the jackets of the drier supplies heating to bring the TNT to the required 0.1% moisture by evaporation.

From the drier, the TNT passes into the flaker pan. The rotating drum of the flaker dips into the molten material and picks up a thin layer of TNT on the surface. As the drum rotates, the TNT solidifies. A beryllium/copper doctor blade on the back side of the flaker scrapes the TNT off the surface of the drum, shattering it into small irregular pieces. The flaked material drops into a hopper from where it is packed into 50-pound fiberboard cases.

As can be seen from the previous descriptions, the continuous process for the manufacture of TNT exposes less personnel. Security systems designed into the operating equipment monitor and automatically react to add cooling water should temperatures increase within the nitrators; should this not be adequate to control the reaction, automatic controls will take over and stop feeding all ingredients into the nitration process. If temperatures continue to increase and reach 15° above the nitrator operating temperature, the automatic controls will open a "drowning" valve dumping the reaction products into large water filled tanks under the nitrator/separator couple stopping the reaction. Throughout the nitration steps, the molten nitrobody is emulsified with the acid phase. This technique allows the nitration to take place at a high rate, yet in relatively small separate quantities within each nitrator. The combined effect of the relatively small quantity of reactants and the high cooling capability within the nitrating vessels insures an ability to control the reaction closely and stop it, at will, by closing off ingredient feeds or quickly drowning the charge.

The basic design of this process permits a higher production rate capability for a given space, reduced personnel exposure to explosive hazards, smaller in-process quantities of TNT, automatic control of process parameters, and improved industrial hygiene conditions.

The operation of continuous TNT plants in the Northern Hemisphere for the past seven years has demonstrated that there is knowledge, equipment, and technique available to automate large-scale explosive processes.

Planned and future modernization through continuous processes will require smaller quantities in each operation thus allowing siting of facilities on existing manufacturing complexes at appropriate distances without further expense for real estate. This will reduce personnel requirements and exposure, and increase the quality and safety in each process.

Does it not behoove the industry to continue in modernization of this type so that we can attain the realization of the basic safety rule of explosive manufacture? "Minimum exposure for minimum personnel for a minimum time."

Comments:

A discussion of the enhanced safety characteristics in TNT processing as a result of the continuous method of operations revealed the following:

a. Personnel exposure in processing has been reduced from approximately 18 (by batch) to 2 personnel, based on comparable output.

b. Smaller separate quantities in process and total accumulation is smaller in continuous processing than in batch.

c. Automatic drowning operation if a portion of the nitrating operation should exceed the specified operating temperature by 15°C or more.

d. Quality of product is maintained by sample analysis for set point (solidification temperature) of 80.2°C or higher. Slugs of reject material are diverted at the Finishing Building and reworked.

e. Toxicity and personal hygiene conditions are improved through reduced personnel exposure, essentially closed system, and destruction of "red water" (by evaporation and incineration).

f. The SO_2 used in the selliting and purification operations is used in a closed system and is otherwise controlled by a capability for total containment.

A discussion of technical aspects of the continuous TNT processing revealed:

a. No data have been gathered, to date, on a comparison of the exudation product from the continuously processed TNT as compared to the batch material. This situation exists simply because of lack of age and availability of the newer product.

b. All yellow water is recycled in the continuous process.

c. Throughout the process all of the mixed acids (strong to weak) are more dense than the nitrobody (MNT, DNT, TNT, and mixtures).

d. The dip pan for the flaking drum accumulates only about 150 pounds of finished melt material, although a larger separate storage capacity exists in case an accumulation should be required.

e. A safety-maintenance requirement called for weekly dismantle, inspection and reassembly of a great number of automated process valves. This has the potential to drive up operating costs, but costs are within reason since this requirement is occasionally waived. It was agreed that reexamination of the original inspection requirement is probably in order.

f. The process could be more cost effective if melt casting capability were allowed "on line" as well as flake pack-out. Another cost savings measure contemplated is the sale of fly ash, from the red water destruction, as building material.

TRANSPORTATION PROBLEMS -
REGULATIONS, BLOCKING, AND BRACING, ETC.

Moderator:

John Byrd
Savanna Army Depot
Savanna, Illinois

RECENT CHANGES TO DOT REGULATIONS

Discussion Leader: Erskine Harton
Office of Hazardous Materials
Department of Transportation

The first viewgraph indicates recent regulatory and related activities which should be of interest. I shall cover these items in more detail, but not necessarily in the order shown.

DOT REGULATORY AND RELATED ACTIVITIES OF PARTICULAR INTEREST TO DOD

HM-3, AMENDMENT 173-6 PUBLISHED IN F.R. VOL. 34, NO. 83, MAY 1, 1969 -- HAZARD TESTING
HM-7, NOTICE NO. 68-5 PUBLISHED IN F.R. VOL. 33, NO. 163, AUG. 21, 1968 -- CLASSIFICATION AND LABELS, HANDLING AND STOWING, PLACARDS AND EMERGENCY PROCEDURES, PACKAGES, UNIFORMITY, COST-BENEFIT
HM-8, PUBLISHED IN F.R. VOL. 33, NO. 202, OCT. 16, 1968 -- REQUESTS ADVICE ON U.N. LABELS AND CLASSIFICATION SYSTEM

SEC'Y'S TASK FORCE ON RAILROAD SAFETY

RAILROAD SAFETY BILL

AIRLIE HOUSE CONFERENCE

Amendment 173-6 to HM-3 permits shipment of new explosives by DOD, without going to the Bureau of Explosives. It was originally intended to reference the document which contains the hazard classification test procedures. However, since this has not been done for the Bureau of Explosives test methods, the idea was dropped. Had the reference been cited, it would have been made to the joint regulations which implement DOD Instruction 4145.24. The current version, of course, is that shown in the next viewgraph.

EXPLOSIVES HAZARD CLASSIFICATION PROCEDURES

TB 700-2
NAVORD INST 8020.3
TO 11A-1-47
DSAR 8220.1

19 MAY 1967

This is referred to frequently as the "Minimum Test Criteria" by those of us who struggled with its development. It might be of interest to point out that we had a query the other day by someone wanting to know what the sample temperature should be for the detonation test. We assumed it was ambient room temperature, but probably should have said so. We were very specific for other tests.

DOD is in fact testing according to these procedures and DOT receives a copy of the classification report. Unless we take exception, the classification is concurred in automatically.

Another area which has been getting a lot of attention is railroad safety. DOT is very much interested in preventing derailments, accidents at grade crossing, etc. There has been a rash of railroad accidents of a serious nature, as you are aware.

On April 18, 1969 Secretary Volpe established a Task Force on Railroad Safety to examine railroad safety and to advise him. This group was chaired by the FRA Administrator and included representatives of the railroad industry, railroad labor organizations and State regulatory commissions. The Task Force reported to the Secretary on June 30. The areas listed in the next viewgraph illustrate the lack of Federal regulatory control.

RAILROAD ASPECTS NOT FEDERALLY REGULATED

DESIGN, CONSTRUCTION AND MAINTENANCE OF: RAILROAD
  CAR TRUCKS, WHEELS AND AXLES
  BRIDGES AND TUNNELS
  TRACK AND ROADBED

PROMULGATION OF STANDARDS FOR EMPLOYEE:
  QUALIFICATIONS
  PHYSICAL REQUIREMENTS
  TRAINING

PRESCRIBING UNIFORM RAILROAD OPERATING RULES

The next chart lists some, but not all, of the conclusions reached by the Task Force.

SECRETARY'S TASK FORCE CONCLUSIONS (IN PART)

RAILROAD SAFETY PROBLEM IS NATIONAL IN SCOPE

TRANSPORT OF HAZ. MTLS. IS ECONOMIC NECESSITY

TRAIN ACCIDENT CAUSES EQUALLY DIVIDED:
  TRACK AND ROADBED DEFECTS OR FAILURE
  EQUIPMENT DEFECTS OR FAILURE
  HUMAN ERROR

STATE AND FEDERAL STANDARDS MISSING

ACCIDENT REPORTING AND INVEST. INADEQUATE

RESEARCH RE RAILROAD SAFETY INADEQUATE

Some recommendations appear next.

SECRETARY'S TASK FORCE RECOMMENDATIONS (IN PART)

SEC'Y. OF TRANSPORTATION THRU FRA HAVE AUTHORITY TO PROMULGATE STANDARDS IN ALL AREAS OF RAILROAD SAFETY

SEC'Y. SHOULD FORM NATIONAL RAILROAD SAFETY ADVISORY COMMITTEE CONSTITUTED LIKE THE TASK FORCE TO REVIEW PROPOSED SAFETY STANDARDS AND AMENDMENTS

FRA SHOULD REVIEW RULES FOR REPORTING ACCIDENTS

SEC'Y., IN CONJUNCTION WITH AND ASSISTANCE OF THE TASK FORCE AND APPROPRIATE CONGRESSIONAL COMMITTEES, SHOULD DRAFT PROPOSED LEGISLATION TO IMPLEMENT THE RECOMMENDATIONS

It should be mentioned that an effort was made to get a railroad safety bill passed in the 90th Congress, but this did not come to pass. It would have given the Government control by law over track, equipment, etc.

Perhaps some people present may have attended the Airlie House Meeting. However, most were not and I think it would be of interest to touch briefly upon the meeting, because it is bound to have a significant impact upon future hazardous materials transportation regulations.

Recognizing the value of an outside appraisal, the office of Hazardous materials contracted with the National Academy of Science to convene a meeting of technical authorities in the fields related to hazards and hazardous materials transportation.

The NAS-NRC Highway Research Board and the Committee on Hazardous Materials convened such a conference this past May at the Airlie House, near Warrenton, Virginia. Following an opening General Session, the five panels, listed in the next viewgraph, met and evaluated the hazardous materials transportation situation.

AIRLIE HOUSE CONFERENCE PANELS

THE TRANSPORTATION ENVIRONMENT

HAZARD CLASSIFICATION

CONTAINMENT

HAZARDOUS CARGO IDENTIFICATION

REPORTING

A report, entitled "A Study of Transportation of Hazardous Materials", was submitted to the Office of Hazardous Materials by the NAS-NRC on July 31, 1969. The findings and recommendations appear in the next three charts. The first deals with general aspects.

AIRLIE HOUSE CONFERENCE
FINDINGS AND RECOMMENDATIONS -- GENERAL

THE PROCESS IS COMPLEX

UNIFIED STANDARDS-BASED SYSTEM IS ACHIEVABLE

RESEARCH SUPPORT IS REQUIRED

TIME AND MONEY ARE REQUIRED

SYSTEM MANAGEMENT IS RECOMMENDED

The next lists technical items.

AIRLIE HOUSE CONFERENCE
FINDINGS AND RECOMMENDATIONS -- TECHNICAL

ENVIRONMENTAL STDS. CAN BE ESTABLISHED

INTERIM STDS. SHOULD BE ESTABLISHED

ENVIRONMENTAL RES. MUST BE CONDUCTED

CLASSIFICATION OF HAZARDS IS FEASIBLE

CLASSIFICATION CONCEPT IS RECOMMENDED

CLASSIF. RES. AND TESTS MUST BE DONE

CONTAINMENT PERF. STDS. ARE ATTAINABLE

CONTAIN. TESTING REQUIRES RESEARCH AND DEVELOPMENT

The third encompasses the management area.

AIRLIE HOUSE CONFERENCE

FINDINGS AND RECOMMENDATIONS -- MANAGEMENT

UNIFIED INFORMATION FACILITY IS NEEDED

REPORTING SYSTEM SHOULD BE DEVELOPED

ALL-MODE HAZARDOUS MATERIALS IDENTIFICATION SYSTEM IS NEEDED

RAPID-RESPONSE INFORMATION SYSTEM FOR EMERGENCIES IS RECOMMENDED

ADMINISTRATIVE IMPLEMENTATION REQUIRES SPECIALIZED ADVICE

OHM overall plans emphasize the items mentioned in the next chart.

PLANNED OHM AREAS OF EMPHASIS

GENERAL CONSOLIDATION AND REVISION OF DOT HAZARDOUS MATERIALS REGULATIONS

CONVERT REGS. TO PERFORMANCE STANDARDS

DEFINE HAZARDS --- CLASSES AND DEGREES

PREPARE A SET OF PERFORMANCE STDS.

DEVEL. A SYSTEM OF MEANINGFUL TESTS AND CRITERIA

DETERMINE THE HAZARDS OF MATERIALS

DEVEL. PACKAGE-QUANTITY RELATIONSHIPS RE DIFFERENT TRANSPORTATION MODES

And specific FY 1970 goals include such items as are shown in the next viewgraph.

CONTEMPLATED OHM RESEARCH AREAS
FY 1970-71

ENVIRONMENTAL CONDITIONS RELATING TO TRANSPORTATION OF HAZARDOUS MATERIALS

CLASSIFICATION OF HAZARDS

ACCIDENT PARAMETERS

PACKAGING STANDARDS

ACCIDENT DATA ANALYSIS

HAZARDS FROM ENVIRONMENTAL POLLUTION

SPECIAL SAFETY STUDIES

SYSTEMS ANALYSIS

OHM contemplates research in those areas shown in the next chart.

OHM FY 1970 GOALS

REDEFINE ENTIRE SPECTRUM OF HAZARDS AND MAKE CONSISTENT WITH OTHER GOV'T. STDS. AND INDUSTRY OPERATIONS

START SURVEY PROGRAM OF EMPIRICAL HAZ-CLASSIFICATION TEST METHODS

COMPLETE STUDY PROGRAM ON SHIPMENT OF POISONS

INITIAL STUDIES ON PHYSICAL PARAMETERS OF TRANSPORTATION ACCIDENTS (SHOCK, IMPACT, FIRE, ETC., ON DIFFERENT TYPES OF PACKAGING)

Examples of the type of information we will be seeking to develop good hazardous materials transportation regulations are shown in the final viewgraph.

DOT HAZARDS INFORMATION REQUIREMENTS

INHERENT CHARACTERISTICS OF MATERIALS

MATERIALS AND ITEMS BEHAVIOR IN THE TRANSPORTATION ENVIRONMENT

HAZARD ATTENUATION EFFECTIVENESS OF PACKAGING AND CONTAINERS

CREDIBLE ACCIDENT AND FAILURE MODES

ACCIDENT AND FAILURE PROBABILITIES DERIVED FROM ACTUAL DATA

APPROVED LOADING PROCEDURE PROBLEMS

Discussion Leader: A. F. Grassmuck
Bureau of Explosives
Assn. of American Railroads
Chicago, Illinois

The first rail impact test to develop safe carloading methods for the transportation of explosives was conducted early in the 1900's by Colonel Dunn, the first Chief Inspector of the Bureau of Explosives, in conjunction with the Pennsylvania Railroad. This test was to provide an answer whether commercial explosives could be safely transported and of course the success of the test has been the basis and has led to the safe shipment of thousands of tons of explosives and ammunition in the ensuing years.

This test also led to the creation of a container and loading section within the Bureau who were to be responsible for aiding in the development and testing of new packages for explosives and other dangerous articles and carloading methods to ensure their safe transportation. These carloading methods were distributed in the form of Bureau of Explosive Pamphlets and Bureau Field Inspectors, in turn, were assigned the task of educating both shipper and rail carrier employees in their proper use. From these pioneering days, until the present day, our mission has remained much the same and while packages have become more sophisticated, the basic principles of carloading have remained constant and are still recognized by inclusion [illegible] the D.O.T. Regulations as recommended procedures.

During World War I, these carloading methods were adequate for the needs of the Military in that most ammunition items were packaged in heavy wooden boxes, handled and loaded individually.

With the development of more and improved military weapons and accompanying munition items of varying configurations, plus a move to palletization, particularly by the Navy, it was apparent that the Military would have to test and develop individual drawings to cover these items individually to insure that proper guidance was available for their personnel. Completed drawings were to be reviewed and approved by the Bureau of Explosives prior to being distributed thru military channels.

About this same time, in the interest of car conservation, the Military was asked to consider heavier loads in cars in an effort to prevent or minimize car shortages in the event of a national emergency.

This program was undertaken in the late 30's and early 40's and prior to World War II, by the Navy at the Naval Depot, Hingham, Massachusetts, and now at the Naval Weapons Handling Laboratory, NAD-Earle, New Jersey, and by the Army at Savanna

Army Depot, Savanna, Illinois. Carloading methods for Air Force items were prepared by the Army, for the most part, inasmuch as they were usually stored in Army depots.

Recognizing the importance of this cooperative undertaking, the Bureau assigned Mr. T. C. George, our present Chief Inspector, who was then headquartered in Boston, to work with the Navy, and my predecessor in Chicago, Mr. E. J. League, to work with the Army at Savanna. While I have performed this service with the Army for the last 15 years, for about the last 10 years I have worked with all branches of the military, having been given the title of Military Assistant to the Chief Inspector and a job to which I devote approximately 60% of my time. It can therefore be seen that our Bureau has not taken this important phase of our work lightly, only 3 men having been involved so that continuity could be maintained and to provide our best attention to this continuing program.

Fortunately, I was assigned to this position just prior to the advent of missile items and was thus available to participate in the first test of flatcar loading, a test which involved the original NIKE. Although the then I.C.C. Regulations prohibited the loading of explosive items on flatcars, large missile items presented such a need and due to the time and effort expended and the many tests conducted, open top loading was and has proven feasible and many, many, such shipments have since moved in this manner with complete safety. In the meantime, the Regulations have been amended to provide for the open top loading of large explosive items.

Our involvement in military carloading methods includes the participation in and the witnessing of impact tests, when considered to be required, and the review for comment, rejection and/or approval of submitted covering drawings, as well as advising the Military of new rail equipment, procedures or practices which might affect their shipments. As both we and the armed services are striving for the same end result, that is safety in the movement of ammunition, a very close relationship has resulted, with mutual exchange of ideas and discussions as to areas where improvement may be required or desirable.

This same close relationship between packaging people and those charged with the responsibility of developing carloading methods, unfortunately does not seem to have been achieved to the same degree. All too often, not enough thought is given to the fact that an item must eventually be handled and transported. Development of carloading methods for a given item can be most difficult at times and to be suddenly confronted with a package not lending itself to conventional bracing methods only serves to compound this difficulty and often leads to the need for more costly and exotic shipping methods. To be faced with this problem as a crash program shortly before an item is to be procured, produced and shipped, does not contribute to safety in transportation.

It would appear that the breakdown takes place somewhere between development of an item, its packaging and its handling and shipping. New items do not appear overnight, but are the result of considerable advance planning while in the research and development stage. We surmise that sufficient lead time is usually available and only requires correlation of effort between research and development and packaging and carloading personnel, and in sufficient time to permit those responsible for outloading procedures to develop adequate and safe methods. Development of an item is only the first step. Safe handling and transportation and the ability to place it in the hands of the user in an undamaged condition is the second and probably the most important step.

Our Bureau is specifically named in certain paragraphs of the D.O.T. Regulations to approve loading methods before an item can technically be offered for transportation. Of late we have been called upon to give such approval by telephone or by an "on the job" visit to an installation where a new item is being shipped for the first time. As realistic and safe outloading methods often involve the integrity of the package or unit load and often require transportation evaluation or testing prior to being offered for shipment, we do not feel that safety in transportation is being served to the extent it should be by our continuing to honor such requests on the basis of combat necessity.

While we are on record with the Military regarding this situation and have suggested a joint meeting to explore corrective measures to insure a better flow of advance information between development and shipping people, we appreciate this opportunity to present and let it be known that a problem exists, and particularly to those in research and development who may be in attendance. Defining the problem often is the first step and sometime the most difficult whereas the solution usually is proven to be much less difficult.

Discussion ensued as to the relationship of the Bureau of Explosives and the Department of Transportation. It was pointed out that the Bureau of Explosives is not a federal agency but an element of the Association of American Railroads.

NEW DEVELOPMENTS IN TRANSPORTATION

Discussion Leader: Lyle Donaldson
Military Airlift Command
22nd Air Force
Travis AFB, California

The Military Airlift Command has developed a system for the palletization of materials being shipped by air and the materials handling equipment required to support the system. The total package has been identified as the 463L System and includes a special pallet along with a specially designed truck for handling the pallet while off-loading cargo aircraft.

The basic pallet is made of aluminum, square shaped, and equipped with tie-down fittings. It is designed to be used as an integral part of the aircraft during shipment.

Individual items are placed on the pallet in a manner to gain optimum utilization of the space available. After the initial loading is complete, plastic sheeting is placed over the unit load to provide protection from the elements. The load is rigidly held in place by nets with adjustable tie points for proper tension. Once the unitized load is complete, it can be handled by standard forklift for movement to loading points.

Since cargo loading doors are at a variety of heights from the ground level, a vehicle with an adjustable platform has been designed. The unit has the capability of tilting both laterally and longitudinally for flexibility in handling the specially designed pallet. In addition, the platform can be adjusted vertically to conform to a variety of cargo door heights.

A proposed site plan was presented showing requirements to be considered in the design of future airports involved in shipping explosives and other hazardous materials. With the coming of such large aircraft as the C5A, it will necessitate the collection of significant quantities of explosives for each aircraft shipment. Quantity distance requirements to assure safe separation of these explosives will become a major consideration in the location and design of airport facilities. Safe separation distances will be required between individual cargo airplanes and between temporary storage sites for explosives awaiting shipment.

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DOD TRANSPORTABILITY PROGRAM

Discussion Leader: Harold Murphy
U. S. Army Transportation
Engineering Agency
Fort Eustis, Virginia

This is an informational briefing on transportability. First, I will review the background leading to the current alignment before presenting to you current activities in progress. The initial program dates back to 1959. The DOD Instruction, "DOD Engineering for Transportability Program," dated April 27, 1964, was implemented by joint regulation, AR 705-8, which designated the Director of Transportation, DCSLOG, as the Army Transportability Agent. At that time, transportation engineering services were provided by DCSLOG for the Army. As a result of its broad application, a joint study on transportation engineering was conducted in 1965 to investigate the application of transportation engineering DOD-wide. The joint study proposed the realignment of Army transportation engineering resources.

It was recommended that the transportation engineering resources, then resting in the Directorate of Transportation, DCSLOG, be transferred to MTMTS. This was accomplished 1 July 1966. At that time, six spaces were retained by DCSLOG in the Director of Transportation's office to provide staff direction for the Army program. A DA, TAG letter dated 5 May 1967, subject: Transportation Engineering, was issued defining general responsibilities and general working relationships. It cited that MTMTS was to prepare and publish transportability criteria for the land modes and AMC was to conduct transportability field analysis which was to be used by MTMTS in the preparation and publication of transportability guidance. Last year, DOD Directive entitled "Engineering for Transportability" dated 1 Aug 1968, was issued to implement the realignment. Following this, a TAG letter was issued on 9 October 1968 which directed that MTMTS, as the operating transportability agency for Army, was to prepare and coordinate a joint regulation. MTMTS has met with the other services and has prepared a proposed draft which is now with the Director of Transportation, DCSLOG, for comment prior to further coordination with the other services.

Another TAG letter was issued on 4 November 1968 to clarify the MTMTS responsibility for preparation and issue of transportability guidance. The scope was to include the technical and physical characteristics necessary to delineate effective transportation procedures.

I think it is well to point out that the transportability program requires joint services activation for its effective accomplishment. It involves Army, Navy, Air Force, Marine Corps and the Defense Supply Agency. The primary objectives are to provide for transportability review of items under development. This will be done through the concept stage and the research and development stage. It will involve the preparation and publication of criteria on critical transportation environments encountered worldwide. Transportability field testing will be accomplished to insure that military materiel may be transported safely and efficiently by the required modes of transportation. The results of these tests will be documented and published as transportability guidance for the use of transportation personnel connected with the movement of materiel. This guidance will then be coordinated with appropriate elements of the transportation industry.

In order to provide effective transportability guidance, the end product of our transportability program, it was found essential that transportability testing be accomplished by the Army, Navy and the Air Force. Certain steps have been taken by these services in the development of resources essential to the conduct of effective transportability testing.

At this point, I will emphasize the Army activation taking place. Director of Transportation, DCSLOG, will provide the staff supervision for the Army portion of this program. MTMTS, as the Army transportability operating agency, will operate the Army program. Transportation Engineering Agency, located at Fort Eustis, will execute this program. CDC will insure that transportability is keyed in their activities. MTMTS will prepare the transportability criteria and transportability guidance in close coordination with AMC-conducted transportability field tests. From this guidance, CONARC will prepare the training literature necessary for troop transportation.

We see transportability conducted in five essential parts: criteria; integration in CDC; transportability field tests; transportability guidance; and the liaison of transportation industry and the other services. I will give a general summary of what we are doing in each of these five parts at this time.

In the criteria area we are preparing for publication test standards for the land modes - rail, highway and terminal operations. We are preparing and publishing transportability criteria on the limiting characteristics of transportation systems worldwide. We are studying those critical environments which will be incurred in the movement of the transportation systems worldwide. We will prepare and publish criteria for the RDT&E people to use in the development of items. Current CDC input involves TEA's review of current QMRs, SDRs, and QMDOs with transportability considerations being included at appropriate stages during the CDC activation.

Transportability field tests are the responsibility of AMC. TEA will document and validate the characteristics of those items under Army development. We will document a loading, blocking and bracing, and slinging procedure necessary for the movement in the land environments.

Currently we are developing a program for transportability guidance for the coming year. We are breaking this down into three basic parts - those in the supply line requiring transportability guidance; those items in the RDT&E cycle requiring guidance; and those items to be procured off-the-shelf which will require such guidance.

The current transportability guidance publications can be divided into two basic parts - one, the preparation of a basic document, TB 55-46, which validates the dimensions and weights of all items in the TOEs. This was originally concerned with critical items only. The second is the preparation of transportability guidance for the movement of specific items by the required modes of transportation. This consists of evaluation of the criteria for the transportation system against the characteristics of the particular item. It will include a tested procedure for movement of the required modes of transport. The third phase, will be the coordination of these tested procedures with the elements of transportation industry by which the item must move.

Current industry liaison by the land modes includes the Association of American Railroads, American Trucking Association, and elements of terminal industry.

AMC ESCORT VEHICLE

Discussion Leader: John L. Byrd
AMC Ammunition Center
Savanna Army Depot
Savanna, Illinois

A requirement for a special fire truck for the escort of classified explosive shipments was identified by AMC in August 1967. The basic parameters of the vehicle were identified as follows:

a. A roadable vehicle with a high fire-kill capability.

b. Assembled from standard commercially available components.

c. No external features identifying the vehicle as a fire truck.

A project was assigned to the Commanding Officer, Savanna Army Depot, and subsequently to the AMC Ammunition Center, to develop a prototype vehicle. The basic concept developed was approved in January 1968. Detailed specifications were developed resulting in the procurement of a prototype vehicle.

The basic vehicle is a 4 x 4 Dodge Powerwagon, four-wheel drive with lock-out front hubs, powered by a 212 horsepower V-8 engine. The primary fire extinguishing unit utilizes 450 pounds of "Purple K" dry chemical complemented with 50 gallons of "light water". The unit is self-contained, utilizing compressed gas to expell the fire extinguishing agents. The primary unit is housed in an insulated body heated by a thermostatically controlled gasoline heater. Four compartments house additional equipment, such as insulated bolt cutters, an insulated pike pole, an asbestos blanket for tire fires, voice projection units, etc.

The primary unit has 100 feet of hose that can be electrically rewound. In addition, the entire primary unit can be extended full length from the body for maintenance.

The vehicle was delivered to Savanna Army Depot in late 1968 and has been undergoing a series of tests and trial runs and an engineering evaluation. The performance of the vehicle and its fire-fighting capability has been rated by the users as excellent.

At the present time, the main unit has been exercised 20 times during demonstrations and has been driven approximately 13,000 miles over all types of primary and secondary roads.

The twinned unit has proven its capability to extinguish a 1600 square foot fuel fire in 30 seconds under normal conditions. In addition, dual tires, having been allowed to burn until the rubber melts and drips, are extinguished in an average of 3 seconds.

General discussions in each session were concentrated in the areas of the commercial availability of similar equipment and the method of extinguishment using the two chemicals. It was pointed out that several companies manufacture equipment of this type. The ability of the extinguishing agents to stop fuel fires is attributed to the knockdown and smothering effect of the dry chemical and the ability of light water to attach to hydrocarbon molecules forming a film over the fuel. The possibility of flash back fires is significantly reduced using this system.

AMMUNITION BLOCKING AND BRACING FILMS

Discussion Leader: Leonard Pawski
Evaluation Division
Savanna Army Depot
Savanna, Illinois 61074

A motion picture on "Railroad Carloading and Bracing of Ammunition" was produced by the Army Pictorial Center. The movie is an orientation and training film directed to carloading crews and their chiefs in proper car blocking and bracing procedures and how it should properly be done. Emphasis is placed on using Army and Navy procedural drawings. This was a joint effort of the Navy Ordnance Command and the Army Materiel Command to reduce the number of damaged shipments and the possibility of catastrophe happenings due to improper blocking and bracing.

The contents of the movie, with live shots and schematics, include an introduction covering damaged shipments, forces imposed on a railcar, testing, and preparation of outloading procedures. The movie shows the procedures for blocking and bracing of unitized loads of ammunition in boxcars and missile containers on flat and gondola cars. Outloading procedures covered conventional boxcar, conventional boxcar - plugged door; DODX boxcar, equipped with mechanical dunnage systems; commercial boxcar equipped with mechanical dunnage systems; flatcar and gondola car.

The filming of the movie was done at Savanna Army Depot during July and August of 1968. The Naval Weapons Handling Laboratory, USNAD Earle and the AMC Ammunition Center, Savanna Army Depot, served as responsible offices for the Navy and Army respectively.

Copies of the movie have been distributed to Naval Libraries, Army Audio Visual Centers, Schools, Commodity Commands, the Naval Weapons Handling Laboratory, and the AMC Ammunition Center.

In addition to the film for "Railroad Carloading and Bracing of Ammunition", a second film covering truckloading of ammunition is being developed. The truckloading film will portray the same depth of detail as the railroad carloading film and should be distributed in the Third Quarter of FY 1970.

For those wishing to stay, the film will be shown.

General questions were concentrated around the availability of the film to be shown to interested agencies. It was pointed out that this film has been distributed to Army and Navy Agencies. The AMC Ammunition Center, Savanna Army Depot, Savanna, Illinois, has a limited number of films that are available for loan on a short term basis.

DEMILITARIZATION OF AMMUNITION

(UNLOADING, WASHOUT, DETONATION)

Moderator:

Robert M. Enz
Savanna Army Depot
Savanna, Illinois

Summary

1. The Ammunition Peculiar Equipment (APE) program is under the direction of the Army Materiel Command. It is a clearing house for equipment and facility problems that involve surveillance, maintenance and demilitarization of ammunition.

2. This program dates back to the early 1950's. Two Army Depots are assigned missions for design, development, fabrication and procurement of equipment. The main objective being to develop conformity in ammunition depot procedures for improved quality and safe economical operations.

3. The broad scope of this program has resulted in 375 line items of standard equipment. This equipment is made available to CONUS and OCONUS Army Depots. Supply can also be arranged for Army Ammunition Plants, Navy, Air Force and Military Assistance Pact countries.

4. The type equipment ranges from a complete explosive washout facility to a tool for cleaning fuze cavity threads.

5. One of the major objectives in this program is to avoid duplication of design and development for new items of equipment. A concerted effort is made to obtain designs, ideas, suggestions for review and analysis, prior to assigning an engineering project.

6. To provide a close look at this program specifically on demilitarization of ammunition, three topics have been selected for discussion.

7. Demilitarization of ammunition is accomplished by the following methods: Washout, Burning, Demolition and Sea Dump. The most popular is washout, due to the recovery value of explosives and metal parts when adequate quantities provide an economical operation. Burning and the use of a deactivation furnace for certain items has its limitations. Demolition is quite restrictive. Sea dump is normally used as a last resort.

8. The first topic covers the standard washout system, presented by Mr. J. Palmer of Tooele Army Depot. Specific discussion on the demilitarization of Minol 2 and M15HE mines is encouraged.

9. Mr. R. Green, Savanna Army Depot, will make a presentation on fluidics. Its potential use on demilitarization and maintenance equipment will be discussed.

10. To provide background data on air and water polution problems, Mr. R. Yardley, Savanna Army Depot, will provide past experience in the disposal of toxic material.

EXPLOSIVES DEMILITARIZATION

Joseph L. Palmer
Tooele Army Depot
Tooele, Utah

1. Methods for the washout and reclamation of explosives have been developed and standardized to enable the operator to position most types and configurations of explosive items on a washout tank and by the application of hot water under pressure, remove the explosive from the item thus facilitating the recovery and reuse of the basic components.

2. The standard system includes washout, pelleting and water reclamation systems. The application of various accessory configurations to accommodate the differences in the items to be washed out. This plant has the capability of recovering 12,000 to 16,000 lbs of explosives per shift.

3. The closed system requires very little water after tanks are initially charged. The water is heated to approximately 205°F and pressurized to 110 PSI. The explosives, being heavier than water, settle to the bottom of the tanks and are withdrawn by a water jet eductor and transferred to the pelleting section.

4. The pelleting process permits the forming of spherical pellets and dried to less than 5% moisture content. The end product is adaptable to commercial mining as well as reuse.

5. Today the majority of bombs loaded utilize Minol 2 explosive. The standard washout system will remove the explosive filler; however, the recovery of the explosives is not feasible. Preliminary engineering studies indicate it is not economically feasible to develop the necessary equipment required to extract the amonium nitrate from solution and reconstitute the explosive into some usable form.

As an alternate method of removing and reclaiming Minol 2 explosives, several concepts are being explored. Project Hydr-Knife uses the concept for removal of explosives by low volume high-pressure water. The system would deliver 6 GPM water at 3-4000 PSI. The system would be used in conjunction with a steam heated tube explosive melt unit that would produce usable reclaimed explosives.

6. The question left unresolved is the response by Navy personnel to our statement that "Should Minol-2 Loaded Bombs require demilitarization, the explosive could be removed from the bomb casing using standard washout facility." They indicated that the Navy was in possession of certain directives that prohibited the application of

steam or hot water to the Minol-2 Filler to effect the explosives removal. They indicated these documents resulted from certain British and Canadian tests that indicated a potential hazard but those Naval personnel in attendance at the seminar were not fully conversant with the documents or the specific hazards involved.

As this information is in conflict with research data on washout of Minol-2 explosives accumulated by this office, an effort is being made to resolve the differences. The Bureau of Naval Ordnance, Washington, D.C., has been contacted and is supplying us with all available data on demilitarization of Minol-2. Upon receipt of this information a formal study should be made to compromise the problem. Results should then be disseminated to all interested agencies.

APPLICATION OF FLUIDICS ON DEMILITARIZATION EQUIPMENT

Richard A. Green
Savanna Army Depot
Savanna, Illinois

1. The definition of fluidics was presented. Illustrations were used to explain the various phenomena and the evolution of the fluidics device. Examples were provided to explain the turbulance amplifier and the sensors. Several examples were discussed on the application of the sensors.

2. Advantages of fluidic devices presented are: resistant to vibration, radiation, temperature, moisture. The ability to perform logic functions which were made possible only electronically and limited the design engineer in developing automatic equipment.

3. Some of the limiting factors are:

a. The low air pressure and air flow associated with fluidic device requiring some type of interface device to function power components.

b. Circuit design requires more attention than conventional pneumatic circuits to insure reliability.

c. Fluidic components will be used on designing logic circuits for multiple operation and remote control automatic equipment. This type of equipment requiring logic control circuit of the machine to perform function normally performed by a human operator using manually operated device, i.e., observe that the machine elements and work piece are in the proper locations at the proper times and take corrective action when this condition does not exist, start and stop machine operations on the proper sequence, provide emergency shut down in the event of abnormal conditions at any station or phase of the operation, etc. Fluidic devices readily lend themselves to this type of application.

AIR POLLUTION

Roger D. Yardley
Savanna Army Depot
Savanna, Illinois

1. As earlier presentations pertained to washout, burnout and detonation of HE, this presentation will be oriented toward disposal of toxic wastes (war gas).

2. A brief introductory portion defined why demilitarization is necessary and very general guidelines/criteria common to good practice, i.e., site condition, atmospheric conditions, personnel protection, etc. This was followed by movies and slides of two demilitarization operations which were conducted at an Army Ammunition Depot in early 60's, with emphasis placed on surface and atmospheric control and pollution standards then, in contrast to present criteria/attitudes. The most notable operational impact would be a refined scrubber system for the exhaust products.

3. The munitions demilitarized were 115 lb M70 mustard filled bombs, and 500 and 1000 lb cyanogen chloride filled M78 and M79 bombs. Phosgene in M78 and M79 bombs was also demilitarized experimentally in the same plant as the cyanogen chloride.

4. The mechanical plant methods were contracted to the conventional field disposal methods as well as chemical decomposition, sea dump, land burial and deep well disposal. The latter three are no longer considered satisfactory and chemical decomposition suggests problems associated with disposal of effluents. Hi-temp incineration under controlled, mechanized conditions was advocated.

5. Discussion resulted in the following areas:

Disposal facilities for scrap HE, compatible with current anti polution policies. The feasibility of recovering and processing for resale was considered worthy of study. As an example, Iowa AAP burns approximately 12,000 lbs of HE that is generated daily from loading activities. State air pollution controls will effect current burning operations after 31 Dec 1969.

6. The APE deactivation furnace for Small Arms Ammunition violates pollution control policies.

7. Positive action must be taken to develop an approved incinerator to process contaminated material (packing boxes, etc.) generated daily in Army Ammunition Plants and Depots. Disposal facilities for propellant and HE scrap are also required.

ATTENDEES

Abernethy, D. F.	Defense Supply Agency, Alex., Va.
Abrams, COL B. B., USA	Chairman, Armed Services Explosives Safety Bd
Adams, A.	Hq, Naval Air Systems Command, Wash, DC
Adams, D. C.	USA Limited War Laboratory, Aberdeen, Md.
Ahlers, E. B.	IIT Research Institute, Chicago, Ill.
Akst, I. B.	Mason & Hanger-Silas Mason Co., Amarillo, Tex.
Allan, D. S.	Arthur D. Little, Inc., Cambridge, Mass.
Anderson, C. A.	Los Alamos Scientific Lab, UnivCal, N. M.
Ashcraft, F. M.	Hq, MAC, Scott AFB, Ill.
Athens, P.	Arthur D. Little, Inc., Cambridge, Mass.
Bachtell, N. D.	Armed Services Explosives Safety Board
Bagnall, L. J.	Kentron-Hawaii Ltd., Huntsville, Ala.
Bailey, M. R.	USAMC Field Safety Agency, Charlestown, Ind.
Baker, Dr. W. E.	Southwest Research Institute, San Antonio, Tex.
Baker, CAPT R. W., USN	Armed Services Explosives Safety Board
Baldwin, W. J.	DSA, DCAS, Alex., Va.
Baran, C.	MAC, 21AF, McGuire AFB, N. J.
Barron, E. R.	USA Natick Laboratories, Natick, Mass.
Bauer, B. J.	Aerojet-General Corp., Fullerton, Calif.
Beauregard, R. L.	Hq, Naval Ordnance Systems Command, Wash, DC
Bedenbaugh, B. A.	North American Rockwell Corp., McGregor, Tex.
Belles, F. E.	NASA Lewis Research Center, Cleveland, Ohio
Bergan, J. D.	USARPAC Materiel Management Agency, APO SF
Biretta, COL A. A.	Hq USAF, Norton AFB, Calif.
Blackburn, Harvey	USA Safeguard System Command, Huntsville, Ala.
Blee, CAPT Ronald	USA Claims Service, Fort Holabird, Md.
Borchelt, H. C.	McDonnell Douglas Corp., St. Louis, Mo.
Borgstrom, LTC T. J.	AFWTR, Vandenberg AFB, Calif.
Borum, Dr. O. H.	Hq USA Materiel Command, Wash, DC
Bosley, H. C.	Navajo Army Depot, Flagstaff, Ariz.
Boutwell, Dr. F. K.	AC Electronics Def Res Labs, GM Corp, Goleta, CA
Boyars, C.	USN Ord Lab, Silver Spring, Md.
Brameier, H. A.	Aberdeen Proving Ground, Md.
Breckenridge, J. H.	NOTU, Patrick AFB, Fla.
Breeding, C. A.	Armed Services Explosives Safety Board
Breneman, B.	Lockheed Propulsion Co., Redlands, Calif.
Breuer, R. D.	Iowa AAP, Burlington, Iowa
Breuer, W. F.	Mo. River Div, Corps of Engr., Omaha, Neb.
Brill, W. C.	Atlas Chemical Industries, Wilmington, Del.
Brown, A. B.	NASA Mississippi Test Support Dept, Bay St L, Miss.
Brown, Dr. Billings	Hercules Inc., Magna, Utah
Brown, Dr. J. A.	Esso Res & Eng Co., Linden, N. J.
Brown, Meyor	DCAS, O'Hare Int Airport, Chicago, Ill.
Brown, S. F.	Milan AAP, Milan, Tenn.

Browne, T. P.	USA Missile Command, Redstone Arsenal, Ala.
Browning, J. L.	USN Ordnance Station, Indian Head, Md.
Braswell, A. T.	Red River Army Depot, Texarkana, Tex.
Buchanan, H. G.	USA R&D Center, Aberdeen PG, Md.
Buckner, A. K.	Kansas AAP, Parsons, Kan.
Burnett, LTC G. H.	DCS Logistics, DA, Wash, DC
Burns, W. J.	Tri-State Motor Transit Co., Arlington, Va.
Buschman, E. H.	USN Ordnance Station, Indian Head, Md.
Butas, J. A.	USA Safeguard Command, Huntsville, Ala.
Buxton, W. W.	Aerojet-General Corp., Sacramento, Calif.
Byrd, J. L.	USAMC Ammunition Center, Savanna AD, Ill.
Cain, G. E.	Hercules Inc., Wilmington, Del.
Call, R.	Olin Mathieson Chemical Corp., Marion, Ill.
Callahan, H. L.	Black & Veatch, Kansas City, Kan.
Campbell, C. J.	USA Weapons Command, Rock Island, Ill.
Campbell, E. E.	Lake City AAP, Independence, Mo.
Carew, D. L.	Hq 10th AF, Richards-Gebaur AFB, Kan. City, Mo.
Carney, R.	Hq MAC, Scott AFB, Ill.
Carpenter, V. L.	Picatinny Arsenal, Dover, N. J.
Carstater, D. H.	USN Ordnance Station, Indian Head, Md.
Childress, W. L.	Thiokol Chemical Corp., Brigham City, Utah
Clark, E. G.	Deseret Test Center, Fort Douglas, Utah
Clay, R. B.	IRECO Chemicals, Salt Lake City, Utah
Clayton, W. N.	Badger AAP, Baraboo, Wisc.
Colbath, L. E.	Tooele Army Depot, Tooele, Utah
Colli, A. J.	USN Ordnance Station, Indian Head, Md.
Collinsworth, F. P.	Hq USAF, Norton AFB, Calif.
Conley, J. H.	Aberdeen Proving Ground, Md.
Connolly, E. J.	E. I. du Pont de Nemours & Co., Newport AAP
Cormack, C. M.	Hq, Naval Air Systems Command, Wash, DC
Cormier, P. M.	NavUnderwaterWpnsR&E Stn, Newport, R. I.
Corso, P.	Mason & Hanger-Silas Mason Co., Jacksonville, Fla.
Courtright, C. W.	Los Alamos Scientific Lab., UnivCal, N. M.
Crismon, W.	Los Alamos Scientific Lab., UnivCal, N. M.
Crook, A. M.	Joliet AAP, Joliet, Ill.
Crowley, W. J.	Susquehanna Corp., Alex., Va.
Cruse, C. S.	R&D Center, Aberdeen PG, Md.
Custard, G. H.	Falcon R&D Co., Denver, Colo.
Dale, Dr. C. B.	USN Ordnance Station, Indian Head, Md.
Dail, P. V.	USN Ammunition Depot, St. Juliens Creek, Va.
D'Asto, V. D.	Thiokol Chemical Corp., Longhorn AAP, Tex.
Daugherty, J. H.	Aberdeen PG, Md.
Davis, CAPT G. J.	Office, Chief of Naval Operations, Wash, DC
Davis, W. O.	AAI Corp., Baltimore, Md.
Dayable, A. F.	Australian Embassy, Wash, DC
Deans, H. L.	USA Materiel Command, Wash, DC
Deese, J. H.	NASA JFK Space Center, Fla.

DeLorge, A. A.	USA Missile Command, Redstone Arsenal, Ala.
Del Regno, L.	DSA, DCAS, Dallas, Texas
DeRose, C. E.	NASA Ames Research Center, Moffett Fld, CA
Dickerson, C. L.	NOSSOLANT, Norfolk NavShipyard, Portsmouth, Va.
Dickinson, L. A.	USN Ordnance Station, Indian Head, Md.
Dobbs, N. G.	Ammann & Whitney, New York, N. Y.
Docherty, B. M.	Assistant General Counsel, OSA, Wash, DC
Dodgen, J. E.	Olin Mathieson Chemical Corp., Baraboo, Wisc.
Donaldson, L.	MAC, 22AF, Travis AFB, Calif.
Donovan, J. C.	Hq NASA, Wash, DC
Driscoll, T. W.	DSA, DCASR, Atlanta, Ga.
Duffy, LT M. J.	USA Missile Command, Redstone Arsenal, Ala.
Duncan, L. R.	Twin Cities AAP, Minneapolis, Minn.
Dunn, D. J.	USA R&D Center, Aberdeen PG, Md.
Dunn, J. S.	Hercules Inc., Sunflower AAP, Kansas
Dunwoody, C.	MAC, 62 MAWG, McChord AFB, Wash.
Durham, T. H.	USA Munitions Command, Dover, N. J.

Eavenson, CAPT T. J.	Hq USAF, Norton AFB, Calif.
Eddy, 1/LT W. C.	AFFDL, Wright-Patterson AFB, Ohio
Egly, Dr. R. S.	Commercial Solvents Corp., Terre Haute, Ind.
Ehringer, A. G.	Savanna Army Depot, Ill.
Elsasser, F.	MAC, 60 MAWG, Travis AFB, Calif.
Enz, R. M.	Savanna Army Depot, Ill.
Erkman, J. O.	USN Ordnance Laboratory, Silver Spring, Md.
Euglow, C. M.	Lowry Tech Training Ctr, Lowry AFB, Colo.
Evans, W. H.	Hq, Naval Ordnance Systems Command, Wash, DC
Ewing, L. C.	Atlas Chemical Industries, Chattanooga, Tenn.

Fairchild, J. M.	Aerojet-General Corp., Sacramento, Calif.
Falck, G. C.	Olin Mathieson Chemical Corp., Baraboo, Wisc.
Farber, Dr. E. A.	University of Florida, Gainesville, Fla.
Farmer, A. A.	Polaris Missile Facility, Pacific, Bremerton, Wash.
Farmer, M. D.	Lexington-Blue Grass Army Depot, Lexington, Ky.
Feazell, G. L.	Hq USA Materiel Command, Wash, DC
Fidell, F. J.	Frankford Arsenal, Phila., Pa.
Filler, W. S.	USN Ordnance Laboratory, Silver Spring, Md.
Fine, W. T.	USN Ordnance Laboratory, Silver Spring, Md.
Finger, M.	Lawrence Radiation Lab., UC, Livermore, Calif.
Fitzgerald, J. A.	Honeywell Inc., New Brighton, Minn.
Fletcher, Dr. E. R.	Lovelace Foundation, Albuquerque, N. M.
Fountain, L. K.	USN Ordnance Laboratory, Silver Spring, Md.
Fowler, W. T.	Radford AAP, Blacksburg, Va.
Froehling, S. C.	Brunswick Corp., Sugar Grove, Va.
Foltz, Fred	Newport AAP, Ind.
Frazier, J. D.	McDonnell-Douglas Corp., St. Louis, Mo.
Fristrom, Dr. R. M.	APL, Johns Hopkins Univ., Silver Spring, Md.

Gallagher, E. V.	IITRI, Chicago, Ill.
Galles, F. P.	USN Torpedo Station, Keyport, Wash.
Gandy, M. P.	Defense Depot Memphis, Tenn.
Gandy, 1/LT M. P., Jr.	Hq SAC, Offutt AFB, Neb.
Gardner, A. B.	DCS Personnel, DA, Wash, DC
Gardner, C. C.	Hercules Inc.
Garvin, L.	Olin Mathieson Chemical Corp., E. Alton, Ill.
Gegg, L. R.	USA Mobility Equipment Com, St. Louis, Mo.
Gilmore, A. E.	USN Ammunition Depot, Crane, Ind.
Gilmore, C. A.	Anniston Army Depot, Anniston, Ala.
Glenzer, W. K.	USN Ammunition Depot, Hawthorne, Nev.
Goff, C. R.	Day & Zimmermann, Inc., Texarkana, Tex.
Gott, R. W.	Hercules Inc., Wilmington, Del.
Gougler, G. M.	AFPRO, Hill AFB, Utah
Grady, T. G.	Hercules Inc., Radford AAP, Va.
Grassmuck, A. F.	Bur of Explosives, AssocAmRR, Chicago, Ill.
Graves, J. W.	Lone Star AAP, Tex.
Gray, N. C.	NASA JFK Space Center, Fla.
Green, J.	NOSSOPACIFIC, San Diego, Calif.
Green, L. G.	UnivCal, Lawrence Radiation Lab., Livermore, CA
Green, R. A.	Savanna Army Depot, Ill.
Greenwall, W.	Defense Depot Memphis, Tenn.
Gregg, F. P.	DCS Logistics, DA, Wash, DC
Gregg, MAJ J. L.	Office, Surgeon General, DA, Wash, DC
Griffin, K. T.	ARO, Inc., Arnold AFS, Tenn.
Grimes, LTC C. K.	AFFDL, Wright-Patterson AFB, Ohio
Gross, L. J.	Fairfield Scientific Corp., Granville, Ohio
Haite, W. F.	Aerospace Corp., San Bernardino, Calif.
Hall, G. W.	Pan American World Airways, Patrick AFB, Fla.
Hall, P. H.	MAC, 437 MAWG, Charleston AFB, S. C.
Hamilton, C. R.	NASA Goddard SFC, Greenbelt, Md.
Hamilton, E. H.	USN Air Station, Memphis, Tenn.
Hamlett, R. G.	USA Missile Command, Redstone Arsenal, Ala.
Hand, J. V.	USN Ammunition Depot, Crane, Ind.
Hannah, M.	MAC, 63 MAWG, Norton AFB, Calif.
Harper, B. R.	Pace Corp., Memphis, Tenn.
Hart, F. E.	USA Missile Command, Redstone Arsenal, Ala.
Harton, E. E.	Dept of Transportation, Wash, DC
Hartman, F. X.	NASA JFK Space Center, Fla.
Head, L. E.	Remington Arms Co., Bridgeport, Conn.
Heaney, MSGT D. O.	ATC, Randolph AFB, Texas
Helle, C. J.	Companhia Brasileira de Cartuchos, Sao Paulo, Brazil
Henderson, LCDR K. A.	USN Ammunition Depot, Crane, Ind.
Henderson, L. D.	USN Ordnance Station, Indian Head, Md.
Henderson, W. P.	Edgewood Arsenal, Md.
Henning, J. C.	Western Electric Co., Greensboro, N. C.
Henry, Dr. M. C.	Natick Laboratories, USA, Natick, Mass.
Henry, R. E.	Lawrence Radiation Lab., Livermore, Calif.

Herman, R. C.	Armed Services Explosives Safety Board
Herron, R. A.	USA R&D Center, Aberdeen PG, Md.
Hewes, W. J.	Atlantic Research Corp., Gainesville, Va.
Hikel, T. R.	Boeing Co., Seattle, Wash.
Hill, T. P.	Day & Zimmermann, Inc., Texarkana, Tex.
Hillyer, LTC W. K.	Hq USAF, Wash, DC
Hindman, K. H.	Fort Detrick, Md.
Holley, H. Q.	Thiokol Chemical Corp., Marshall, Texas
Hough, F. Z.	Hq, Naval Air Systems Command, Wash, DC
Hughes, G. F.	USN Weapons Station, Yorktown, Va.
Hunt, Miss P. N.	Research Triangle Institute, Durham, N. C.
Hunter, B. H.	AFCMD, Los Angeles AFS, Calif.

James, W. B.	USN Ammunition Depot, Bangor, Wash.
Jamison, J. E.	Mason & Hanger-Silas Mason Co., Burlington, Iowa
Jarboe, E. A.	USN Ammunition Depot, Bangor, Wash.
Jeffers, S. L.	Sandia Corp., Albuquerque, N. M.
Jennings, W. G.	Aberdeen Proving Ground, Md.
Jezek, Louis	Hq USA Materiel Command, Wash, DC
Johnson, H. J.	Aberdeen Proving Ground, Md.
Johnson, L. L.	NASA Langley Research Center, Hampton, Va.
Johnson, R. E.	Olin Mathieson Chemical Corp., Badger AAP, Wisc.
Jones, D. J.	Talley Industries, Mesa, Arizona
Just, P. W.	Seneca Army Depot, Romulus, N. Y.

Kahler, R. J.	Mason & Hanger-Silas Mason Co., Grand Is., Neb.
Kamm, H. E.	North American Rockwell Corp., McGregor, Tex.
Kane, E. M.	US Naval Missile Center, Point Mugu, Calif.
Karl, F. P.	Atlantic Research Corp., Saugus, Calif.
Kasdorf, F. W.	US Naval Weapons Laboratory, Dahlgren, Va.
Katz, H.	Hq, Naval Air Systems Command, Wash, DC
Keller, L.	Sandia Corp., Albuquerque, N. M.
Kelley, H. L.	SMW, Los Angeles AFS, Calif.
Kelso, J. R.	Defense Atomic Support Agency, Wash, DC
Kempf, L. M.	DSA, DCAS, Cameron Station, Alex., Va.
Kendall, S. S.	NASA Manned Space Center, Houston, Texas
Kennedy, P. E.	Aerospace Corp., Vandenberg AFB, Calif.
Kerns, A. J.	Picatinny Arsenal, Dover, N. J.
Kervin, T. L.	White Sands Missile Range, N. M.
Kesselman, A. C.	AFSWC, Kirtland AFB, N. M.
Kieke, R. H.	Armed Services Explosives Safety Board
King, L. C.	General Dynamics, Convair Div., Cocoa Beach, Fla.
King, P. V.	General Electric Co., Bay St. Louis, Miss.
Kinney, Dr. G. F.	Naval Postgraduate School, Monterey, Calif.
Koger, D. M.	General Electric Co., Bay St. Louis, Miss.
Kohout, W.	Aberdeen Proving Ground, Md.
Kontovich, F. T.	Volunteer AAP, Chattanooga, Tenn.
Kopatch, L. M.	Aberdeen R&D Center, Aberdeen PG, Md.
Kordalski, J. S.	MERDC, USA, Fort Belvoir, Va.
Kriechbaum, C. B.	Letterkenny Army Depot, Chambersburg, Pa.
Krikorian, M.	Brunswick Corp., Sugar Grove, Va.

Lagamma, V. E.	DSA, DCASR, New York, N. Y.
Lampe, L.	Sierra Army Depot, Herlong, Calif.
Lane, J. L.	USN Ammunition Depot, Portsmouth, Va.
Lee, Paul	Holston Defense Corp., Kingsport, Tenn.
Leigh, C. S.	Northrop Carolina Inc., Asheville, N. C.
Levens, Ernest	McDonnell Douglas Corp., Santa Monica, Calif.
Lewis, Hal	NOSSOPAC, San Diego, Calif.
Lewis, Hamilton	E.I. du Pont de Nemours & Co., Carney's Pt, N.J.
Livsey, R. H.	Fairfield Scientific Corp., Rockaway, N. J.
Lofton, L. B.	Louisiana AAP, Shreveport, La.
Lowell, J. W.	Armed Services Explosives Safety Board
Lussier, R. M.	USN Base, Newport, R. I.
McBride, Wm.	USN Weapons Station, Yorktown, Va.
McCay, W. C.	Longhorn AAP, Marshall, Texas
McGee, 2/LT J. L.	Pine Bluff Arsenal, Ark.
McGowan, J. R.	McDonnell Douglas Corp., Titusville, Fla.
McKeen, W. R.	USN Ammunition Depot, Crane, Ind.
McLaughlin, D.	USA Missile Command, Redstone Arsenal, Ala.
McLeod, J.	Sunflower AAP, Lawrence, Kansas
McNally, T. J.	Frankford Arsenal, Phila., Pa.
McSmith, Duane	NASA Langley Research Center, Hampton, Va.
MacDonald, J. L.	IIT Research Institute, Chicago, Ill.
Mallory, Dr. H. D.	USN Weapons Center, China Lake, Calif.
Marsischky, G. W.	USN Ammunition Depot, Crane, Ind.
Martens, L. C.	Honeywell Inc., New Brighton, Minn.
Mathis, J. M.	Martin Marietta Corp., Vandenberg AFB, Calif.
Maxwell, L. V.	USN Ammunition Depot, McAlester, Okla.
Mayes, F. D.	Deseret Test Center, Fort Douglas, Utah
Merrill, F. C.	Red River Army Depot, Texas
Meyers, R. H.	USN Evaluation Facility, Kirtland AFB, N.M.
Miller, CAPT L. G.	ADTC, Eglin AFB, Fla.
Mills, J. L.	Pace Corp., Memphis, Tenn.
Milner, J. R.	Holston Defense Corp., Kingsport, Tenn.
Mitchell, J. H.	Hercules Inc., Wilmington, Del.
Molloy, J. J.	North American Rockwell Corp., El Segundo, Calif.
Moore, C. D.	Martin Marietta Corp., Vandenberg AFB, Calif.
Moorehead, R. M.	Aerojet-General Corp., Sacramento, Calif.
Morgan A. J.	AFFTC, Edwards AFB, Calif.
Morris, B. G.	NASA Manned Space Center, Houston, Texas
Mott, D. A.	Northrop, Electro-Mech Div, Anaheim, Calif.
Muller, MAJ A. F.	AFSC, Andrews AFB, Wash, DC
Muncy, C. R.	USN Ammunition Depot, Crane, Ind.
Murphy, H. J.	USA Transp Eng Agency, Fort Eustis, Va.
Murphy, J. L.	Thiokol Chemical Corp., Huntsville, Ala.
Myers, Ray L.	USAMC Field Safety Agency, Charlestown, Ind.

Nakashima, B. O.	AFFTC, Edwards AFB, Calif.
Napadensky, Mrs. Hyla	IITRI, Chicago, Ill.
Neal, R. D.	ARO, Inc., Arnold AFS, Tenn.
Nichols, Jack	ADTC, Eglin AFB, Fla.
Niemitz, J. J.	USN Ammunition Depot, APO SF
Nogle, K. E.	AFSC, Andrews AFB, Md.
Nolan, W. J.	USA Munitions Command, Dover, N. J.
Oakes, R. M.	Sierra Army Depot, Herlong, Calif.
O'Brien, E.	USA Munitions Command, Dover, N. J.
O'Dea, J. P.	Cornhusker AAP, Grand Island, Neb.
Odell, Dr. F. A.	Aberdeen R&D Center, Aberdeen PG, Md.
O'Driscoll, J. J.	Southern Railway System, Atlanta, Ga.
Osborne, B. A.	Atlantic Research Corp., West Hanover, Mass.
O'Toole, CDR W. D.	Office, Chief of Naval Operations, Wash, DC
Overbey, C. A.	NASA JFK Space Center, Fla.
Pagoria, Richard	Cornhusker AAP, Grand Island, Neb.
Palmer, J. L.	Tooele Army Depot, Tooele, Utah
Parks, D. K.	Falcon R&D Co., Denver, Colo.
Pawski, L.	Savanna Army Depot, Ill.
Pell, H. D.	Custom Materials, Inc., Chelmsford, Mass.
Perkins, Dr. J. N.	Research Triangle Institute, Durham, N. C.
Perkins, R. G.	Armed Services Explosives Safety Board
Peterson, F. H.	AFWL, Kirtland AFB, N. M.
Peterson, G. W.	USN Missile Center, Point Mugu, Calif.
Pitcher, D.	Explosive Devices, Inc., Picayune, Miss.
Pledger, D. B.	Hq, Naval Facilities Engr Command, Wash, DC
Pratt, T. H.	Rohm & Haas Co., Huntsville, Ala.
Prescott, S. N.	Jet Propulsion Lab., Pasadena, Calif.
Prior, L. C.	Jet Propulsion Lab., Pasadena, Calif.
Queen, W. G.	Hq, USA Materiel Command, Wash, DC
Rachel, C. K.	Hughes Aircraft Co., Tucson, Ariz.
Rafael, H. J.	ADC, Ent AFB, Colo.
Raiford, J. P.	Hq SAC, Offutt AFB, Neb.
Ranes, W. A.	USN Ammunition Depot, Hawthorne, Nev.
Redman, C. W.	Cornhusker AAP, Grand Island, Neb.
Reeves, 2/LT R. B.	ADTC, Eglin AFB, Fla.
Regan, L. F.	Hq, USA Materiel Command, Wash, DC
Regier, K. R.	TRW Systems, Redondo Beach, Calif.
Reynolds, M. J.	Uniroyal Inc., Joliet AAP, Ill.
Rezetka, W. L.	Pacific Missile Range, Point Mugu, Calif.
Rhoads, D. E.	E. I. du Pont de Nemours & Co., Newport, Ind.
Rhodes, COL C. W., USAF	Armed Services Explosives Safety Board
Richardson, J. M.	Sperry Rand Corp., Louisiana AAP, Shreveport, La.
Richardson, D.	Harvey Aluminum Sales Inc., Milan, Tenn.
Richmond, Dr. D. R.	Lovelace Foundation, Albuquerque, N. M.

Ricks, LTC A. C.	SAFSP, Vandenberg AFB, Calif.
Ridosko, J. F.	AFSWC, Kirtland AFB, N.M.
Riehl, W. A.	NASA Marshall Space Flight Center, Ala.
Riley, H. C.	AVCO Corp., Richmond, Ind.
Rindner, Richard	Picatinny Arsenal, Dover, N. J.
Roberts, L. L.	NASA Marshall Space Flight Center, Ala.
Roberts, W. L.	USN Weapons Station, Yorktown, Va.
Robbins, R. G.	ARADCOM, Ent AFB, Colo.
Ronkiewicz, T. D.	Volunteer AAP, Chattanooga, Tenn.
Rosser, T. B.	USA Eng Waterways Experiment Stn, Vicksburg, Miss.
Rost, D. L.	Sandia Laboratories, Albuquerque, N. M.
Royall, R. R.	Holston AAP, Kingsport, Tenn.
Roylance, H. M.	Hq, Naval Ordnance Systems Command, Wash, DC
Rouse, LTC J. H.	USA Claims Service, Fort Holabird, Md.
Rozas, C. J.	North Am Rockwell Corp, Canoga Park, Calif.
Ruda, P. T.	Letterkenny Army Depot, Chambersburg, Pa.
Rydlund, H. P.	Monsanto Co., St. Louis, Mo.
Sackewitz, R. A.	USA Engineer District, Kansas City, Mo.
Sadler, R. E.	KDI Precision Products Inc., Cincinnati, Ohio
Sahlin, R. A.	Remington Arms Co., Inc., Bridgeport, Conn.
Sampson, J. R.	USA Weapons Command, Rock Island, Ill.
Sams, J. J.	Bendix Corp., Kennedy Space Center, Fla.
Savage, E. G.	McDonnell Douglas Corp., St. Louis, Mo.
Savaiko, M. B.	USA Electronics Command, Fort Monmouth, N. J.
Scharf, R. W.	AVCO Corp., Richmond, Ind.
Schimmel, B. H.	Pace Corp., Memphis, Tenn.
Schleicher, A. R.	Research Triangle Institute, Durham, N. C.
Schlueter, D. S.	Aberdeen R&D Center, Aberdeen PG, Md.
Scott, H. T.	Atlantic Research Corp., Alexandria, Va.
Scott, Dr. R. A.	Armed Services Explosives Safety Board
Selders, R. J.	Omaha District, CofEngrs, USA, Omaha, Neb.
Shay, D. A.	US Dept of Labor, Wash, DC
Sheeline, R. D.	North American Rockwell Corp., Canoga Park, Calif.
Sheley, D. E.	OOAMA (OOYSI), Hill AFB, Utah
Sheriff, D. T.	S&MS Div, Norton AFB, Calif.
Shields, W.	USN Weapons Station, Seal Beach, Calif.
Shopher, K. R.	AFLC, Wright-Patterson AFB, Ohio
Sirlanne, R. A.	DCS Logistics, DA, Wash, DC
Skaar, K. S.	USN Weapons Station, China Lake, Calif.
Slade, D. C.	White Sands Missile Range, N. M.
Slemrod, S.	USA Munitions Command, Dover, N. J.
Slight, G. E.	USN Ammunition Depot, Crane, Ind.
Smith, Earle	MAC, 22AF, Travis AFB, Calif.
Smith, G. L.	Remington Arms Co., Inc., Bridgeport, Conn.
Stack, MAJ P. J.	S&MSO, Los Angeles AFS, Calif.
Stanckiewitz, W. P.	USA Ammo Procurement & Supply Agency, Joliet, Ill.
Stcherbinine, Y. A.	USN Weapons Station, Fallbrook, Calif.
Stevens, C. J.	Hq, Naval Facilities Eng Command, Wash, DC

Steves, B. F.	Black & Veatch, Kansas City, Mo.
Stine, R. E.	Fort Detrick, Md.
Stocki, A. T.	Miller Research Corp., Baltimore, Md.
Stonebraker, H. J.	Tooele Army Depot, Tooele, Utah
Stout, B. C.	USAFMDC, Holloman AFB, N. M.
Straw, C. A.	Atlas Chemical Industries, Inc., Chattanooga, Tenn.
Stull, T. W.	Iowa AAP, Burlington, Iowa
Sullivan, A. J.	USN Ordnance Station, Indian Head, Md.
Summers, G. E.	Hq NASA, Wash, DC
Swink, S. O.	Jet Propulsion Laboratory, Edwards, Calif.
Sydow, M. L.	Cornhusker AAP, Grand Island, Neb.

Taylor, Dr. F.	Picatinny Arsenal, Dover, N. J.
Terry, R. R.	ADTC, Eglin AFB, Fla.
Thayer, F. A.	Titan III Div, Patrick AFB, Fla.
Thomas, W. B.	USA Missile Command, Redstone Arsenal, Ala.
Thompson, J. D.	USN Weapons Laboratory, Dahlgren, Va.
Thompson, M. S.	AFETR, Patrick AFB, Fla.
Thornton, R. H.	Research Triangle Institute, Durham, N. C.
Thornton, W. C.	TAC, Langley AFB, Va.
Thorpe, H. L.	Aerojet-General Corp., Fullerton, Calif.
Thorpe, T. C.	USN Weapons Station, Concord, Calif.
Todsen, W. P.	Omaha District, CofEngrs, USA, Omaha, Neb.
Tolins, A. D.	Hq, Naval Facilities Engr Command, Wach, DC
Toran, J. M.	Hq USA Materiel Command, Wash, DC
Tracey, Lee	Explosive Devices, Inc., Picayune, Miss.
Tracy, H. L.	North American Rockwell Corp., Downey, Calif.
Turk, M. S.	Hercules Inc., Wilmington, Del.
Tweed, P. B.	Martin Marietta, Orlando, Fla.

Umlauf, J. L.	Boeing Co., Seattle, Wash.
Unangst, R. C.	Savanna Army Depot, Savanna, Ill.

Vann, J.	Harvey Aluminum Sales Inc., Milan, Tenn.
Vessels, C. C.	USA Safeguard System Command, Huntsville, Ala.
Vickery, J. F.	Australian Embassy, Wash, DC
Visnov, M.	Frankford Arsenal, Phila., Pa.
Voegelein, J.	Edgewood Arsenal, Md.

Waldrup, T. H.	Pine Bluff Arsenal, Ark.
Walker, M. S.	Umatilla Army Depot, Oregon
Watkins, C. R.	Hq USAF, Wash, DC
Watson, R. R.	Ministry of Defence, United Kingdom
Wehmhoener, E.	Remington Arms Co., Lake City AAP, Mo.
Weingarten, G.	Picatinny Arsenal, Dover, N. J.
Weller, J. F.	USN Ammunition Depot, Crane, Ind.
Wenzel, A. B.	Southwest Research Institute, San Antonio, Tex.
West, F. L.	AFAD&TC, Eglin AFB, Fla.
Wetherholt, J. R.	Uniroyal Inc., Joliet AAP, Ill.

Wheeler, R.	Explosive Technology, Fairfield, Calif.
Wigger, G. F.	Office, Chief of Engineers, Wash, DC
Williams, A. G.	Arnold AFS, Tenn.
Williams, F. A.	Lexington-Blue Grass Army Depot, Ky.
Willis, F. M.	E. I. du Pont de Nemours & Co., Gibbstown, N.J.
Wilson, F. W.	USN Weapons Station, Seal Beach, Calif.
Wilton, C.	URS Research Co., Burlingame, Calif.
Winer, H.	ARADCOM, Ent AFB, Colo.
Wirt, W. D.	Hq USAFE, APO New York
Witkowski, CDR J. A.	Hq, Naval Ordnance Systems Command, Wash, DC
Wiuff, Carl	Consultant, Memphis, Tenn.
Wojciak, J. A.	Western Electric Co., Greensboro, N. C.
Wood, J. F.	Goddard Space Flight Center, Greenbelt, Md.
Wood, R.	Indiana AAP, Charlestown, Ind.
Woolfolk, Dr. R. W.	Stanford Research Institute, Menlo Park, Calif.
Workum, A. D.	McDonnell Douglas Astronautics, Titusville, Fla.
Yardley, R. G.	Savanna Army Depot, Savanna, Ill.
Yonetz, G. C.	Fort Detrick, Md.
Young, R. E.	Picatinny Arsenal, Md.
Zaker, Dr. T. A.	IIT Research Institute, Chicago, Ill.
Zabra, S. J.	Picatinny Arsenal, Dover, N. J.
Zimmer, Dr. M. F.	USN Ordnance Station, Indian Head, Md.
Ziswarek, J. W.	USA Test & Evaluation Command, Aberdeen PG, Md.

DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD
2461 EISENHOWER AVENUE
ALEXANDRIA, VIRGINIA 22331-0600

DDESB-KMC

07 JUL 2000

MEMORANDUM FOR DDESB RECORDS

SUBJECT: Declassification of Explosives Safety Seminar Minutes

References: (a) Department of Defense 5200.1-R Information Security Program, 14 Jan 1997

(b) Executive Order 12958, 14 October 1995 Classified National Security Information

In accordance with reference (a) and (b) downgrading of information to a lower level of classification is appropriate when the information no longer requires protection at the originally level, therefore the following DoD Explosives Safety Seminar minutes are declassified:

a. AD#335188 Minutes from Seminar held 10-11 June 1959.
b. AD#332709 Minutes from Seminar held 12-14 July 1960.
c. AD#332711 Minutes from Seminar held 8-10 August 1961.
d. AD#332710 Minutes from Seminar held 7-9 August 1962.
e. AD#346196 Minutes from Seminar held 20-22 August 1963.
f. AD#456999 Minutes from Seminar held 18-20 August 1964.
g. AD#368108 Minutes from Seminar held 24-26 August 1965.
h. AD#801103 Minutes from Seminar held 9-11 August 1966.
i. AD#824044 Minutes from Seminar held 15-17 August 1967.
j. AD#846612 and AD#394775 Minutes from Seminar held 13-15 August 1968.
k. AD#862868 and AD#861893 Minutes from Seminar held 9-10 September 1969.

The DoD Explosives Safety Seminar minutes listed above are considered to be public release, distribution unlimited.

DANIEL T. TOMPKINS
Colonel, USAF
Chairman

Attachments:
1. Cover pages of minutes

cc:
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AD 862868

DEPARTMENT OF DEFENSE UNITED STATES OF AMERICA

MINUTES OF THE ELEVENTH EXPLOSIVES SAFETY SEMINAR

SHERATON-PEABODY HOTEL
MEMPHIS, TENNESSEE
9-10 SEPTEMBER 1969

VOLUME I

Conducted by
ARMED SERVICES EXPLOSIVES SAFETY BOARD
Washington, D. C. 20315

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