IIT RESEARCH INSTITUTE

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Final Report

DEBRIS CLEARANCE STUDY

by

Edward B. Ahlers

September, 1963

Technology Center Chicago 16, Illinois

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FOREWORD

This is the Final Report on IIT Research Institute Project M264 "Debris Clearance Study" conducted for the Office of Civil Defense, Washington, D. C., under Contract OCD-OS-62-202. The report covers all work done since the inception of the contract.

Institute personnel contributing to this report include E. B. Ahlers, Project Engineer, R. L. Barnett, D. Feinstein, Dr. J. Haffner, A. Humphreys, C. A. Miller, and J. Wingfield. Individual block layouts in Chapter Four, are reproduced from Sanborn Maps and are included by permission of the copyright owners, Sanborn Map Company, Inc. of Pelham, New York.

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DEBRIS CLEARANCE STUDY

ABSTRACT

This initial study of problems involved in clearing structural debris in cities after nuclear weapon attack was directed toward identifying the major problems involved and performing limited technical studies in several of the problem areas. The investigation was performed as part of the continuing program of Post-Attack Research conducted by the Office of Civil Defense.

Procedures were developed for estimating gross debris accumulation in various types of urban areas, based on complete structural demolition and uniform distribution of the fragmented materials. Theoretical studies on the fragmentation process were initiated toward quantifying the fragment-size distribution of demolished structural elements. Analytical studies of the blast-wind-induced trajectories of structural fragments were performed. These latter two studies were directed toward providing inputs for estimating rubble contours for individual structures and groups of structures - - i.e., defining depths of rubble that may be expected to cover shelter entranceways and transportation arteries.

Estimating tables were prepared to indicate the capacities of excavating equipment in removing debris. Major problems involved in planning and scheduling debris removal operations and the essential elements of a clearance program are described. Associated problems resulting from radioactive contamination of the rubble are discussed.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

INDEX OF SYMBOLS

A	Attack overpressure level
C_1, C_2	Constants of integration
D	Total horizontal distance traversed by falling particle influenced by blast winds.
$D_1, D_2, --D_K$	Total horizontal distance traversed by falling particles of K sizes under influence of blast winds.
$\bar{D}_{debris}$	Average debris depth for complete destruction of all buildings.
$\bar{D}_{debris\ (A)}$	Average debris depth for an attack overpressure level A
DLF	Dynamic load factor
e	Base of natural logarithms
F_i	Probability of fracture in ith segment
$F(p)$	Fragment probability, or cumulative distribution function
$f(x)$	Load distribution function
g	Gravitational constant
$g(t)$	Pulse shape
h_o	Original height of particle above ground
$h(x, y, z)$	Arbitrary shape function
K_m	Ratio of solid volume of building material to total contained volume of structure
L_a, W_a	Dimensions of region in which debris is estimated (lot, city block, National Fallout Shelter Survey Standard Area, or an entire business district)
L_b, W_b, H_b	Dimensions of individual buildings
L_s, W_s	Dimensions of street lanes or streets
m	Material constant
n	Number of unit length segments in beam
P	Probability of fracture for a combination of segments
p	Overpressure
p_o	Peak overpressure

INDEX OF SYMBOLS (Cont'd)

p_f	Failure overpressure of building
R_o	Ground range
s	Unit length of segment
t_d	Positive phase duration
u	Air particle velocity
V	Volume of unit segment
v	Individual fragment volume
V_r	Void ratio in debris
V_s	Volume of solids in debris
V_v	Volume of voids in debris
$Vol_{material}$	Solid volume of building materials in structures
Vol_{debris}	Volume of debris, including voids
W	Weapon yield
x	Horizontal coordinate
x_i	Horizontal distance traversed in time Δt by falling particle influenced by blast winds
$x_i, x_z --- x_k$	Sizes of debris particles
y	Vertical coordinate
α	Aerodynamic coefficient, $\frac{\text{projected area x drag coefficient}}{\text{mass}}$
β	Substitution constant
ρ	Mass density of air
σ_i	Stress distribution in its segment of beam
σ_o, σ_u	Material constants
$(\dot{\ })$	Differentiation with respect to time

GLOSSARY OF TERMS

Central Business District	The major commercial region of a large Metropolis, characterized by a prevalence of tall, densely-packed buildings.
Cordon count	Record of motor vehicles entering and leaving a specific region of a city for a stated time period (e.g. fifteen minute intervals for twelve daylight hours)
Debris	The broken and misshapen building materials resulting from demolition or collapse of structures (building contents are not included in this report.) Vehicles are also considered a part of total debris.
Debri accumulation	Quantity of debris resulting from an attack, expressed either as volume of debris (i.e, as piled material with voids) or an average depth.
Debris clearance	Removal and disposal of debris to permit access within the city and its restoration and rebuilding.
Debris transport	Motion of structural fragments, following structural failure, induced by the blast winds.
Fragmentation pattern	Particle size-distribution of material from failed structural elements.
Particle trajectory	The path of an idealized object of known aerodynamic COEFFICIENT, acted upon by gravitational and blast-wind forces.
Rubble	Synonymous with debris.
Street clearance	Required volume of debris removal to permit resumption of transportation.
Void ratio	Ratio of volume of voids in piled debris to volume of solid debris material.

Chapter One

INTRODUCTION AND SUMMARY OF RESULTS

An unrestricted view of the potential magnitude of debris accumulation in major cities, resulting from nuclear attack, leads to the recognition that clearance problems transcend the considerations of clearance methods and procedures alone. With an over-all viewpoint, we quickly see the existence of numerous logistic problems in selecting a priority of clearance tasks, selecting optimum routes through the city for early clearance, and restoring housing for the homeless at a maximum rate. Debris clearance problems become closely associated with the requirements of programs for continuity of Government which require restoration of police and fire-fighting service, resumption of public transportation, and restoration of utilities and communications.

The possibility of nearly complete demolition of the business districts of great population centers by high-yield weapons brings to bear the realization that the magnitude of the debris accumulation will require massive removal effort--possibly requiring compulsory mobilization of excavating equipment and labor from regions beyond the cities. These measures introduce legal, administrative and planning problems.

While it is not within the scope of this program to consider all the problems involved in debris clearance, it is appropriate and wise to provide an initial identification of as many of the corollary problems as can be envisaged at this time. This will permit early recognition of many facets of the over-all problem, supplying local Civil Defense organizations with the opportunity to consider and introduce appropriate measures into their disaster plans.

Table 1.1 summarizes problems involved in debris clearance. This is an initial listing; further study would undoubtedly lead to the recognition of additional problems for consideration in pre-disaster planning. Not all the problems listed in Table 1.1 are considered in detail in ensuing chapters which are devoted to various technical aspects of debris clearance

Table 1.1

DEBRIS CLEARANCE PROBLEMS

Type of Problem	Outline of Problems Involved	Significance	Questions to be Resolved
Preparation of pre-disaster estimates of debris accumulation	A. Quantity of rubble under various attack conditions 1. Range of damage for various classes of buildings and yields 2. Degree of damage to various types of buildings 3. Likely attack patterns 4. Production of rubble a. Quantity of fragmented material b. Fragment-size distribution c. Void ratio in rubble B. Location of Rubble 1. Distances thrown by blast winds a. Conditions under which material is thrown across thoroughfares 2. Rubble contours for various classes of buildings under various target conditions	Enable Civil Defense planners to estimate magnitude of the debris removal task	1. What volume of rubble will be produced in target cities under various attack conditions? 2. What is the nature of the rubble--small, easily handled fragments or giant slabs requiring further demolition before removal? 3. Under what structural density and blast environment will streets become impassable? 4. What procedures can be developed to aid planners in estimating rubble accumulation to their cities?
Equipment, supplies, and manpower	A. Availability of equipment, manpower and supplies 1. Census of desirable resources (quantities and location) a. Excavating equipment Tractors Bulldozers Bull graders Scrapers Power shovels Draglines Front end loaders Farm tractors Road graders Back hoes Cranes b. Hauling equipment Trucks of all sizes Railroad Equipment Barges c. Acetylene-cutting equipment d. Supplies e. Manpower Skilled manpower Loss in target cities Training of unskilled Common labor pool Wrecking company personnel Demolition personnel 2. Capabilities of equipment and manpower a. Production rates with experienced operators b. Production rates with inexperienced operators c. Learning rates for inexperienced operators 3. Mobilization of equipment a. Establishment of mobilization regions about municipalities b. Provision for transferring equipment and experienced operators long distances if necessary 4. Potentialities for supplementation from military organizations (State Militia and Federal Forces) a. Excavating and hauling equipment b. Experienced operators c. Demolitions personnel	Enablement of Civil Defense planners to estimate debris removal capabilities of city areas Provide means for estimating expanded debris removal capabilities stemming from mobilization of facilities from outside the cities	1. What are the equipment, supplies and experienced personnel necessary for debris removal? 2. In what quantities are they available? 3. Where are they located relative to target cities? 4. What is their probability of loss in attack? 5. How effective are inexperienced personnel with this equipment? 6. How fast can unskilled men learn to be proficient with this equipment? 7. Under what rubble conditions are the various equipments effective? 8. Over how much of the city would it be necessary to utilize mechanical equipment? 9. How long would clearance take using only equipment available locally? 10. How much can clearance time be reduced by transferring equipment from regions beyond the cities? 11. To what extent can military facilities assist in operations?

Table 1.1 (Cont'd)

DEBRIS CLEARANCE PROBLEMS

Type of Problem	Outline of Problems Involved	Significance	Questions to be Resolved
Procedures	A. Equipment applicability for various regions of cities 1. Modes of failure for various types of structure and expected degrees of fragmentation a. Load bearing walls-masonry b. Structural steel frame with curtain walls c. Reinforced concrete d. Structural steel mill buildings e. Wood frame buildings B. Methods and equipment for handling various types of debris 1. Piled brick, blocks, lumber, etc a. Shallow layers b. Massive layers 2. Demolition of large-sized floor slabs, wall panels, and massive reinforced concrete boulders 3. Demolition of partially-felled buildings a. Explosives b. Military artillery 4. Clearance of demolished autos, buses, trucks, railroad cars 5. Clearance of twisted steel structures and steel frameworks a. Torch cutting b. Explosives C. Provisions for salvage of commodities and building materials 1. Recovery of vital resources from demolished stores and warehouses a. Food, clothing, bedding b. Medical supplies and drugs c. Utensils d. Valuable properties 2. Salvage of building materials for reuse a. Straightening of steel b. Chipping mortar from bricks c. Recovery of lumber 3. Locations for salvage function a. On site b. Dump areas	To foresee many of the operational problems involved in debris clearance and provide for more effectual methods	1. What equipments are adequate for handling various types of rubble? 2. What should be done about partially demolished buildings? 3. How can twisted steel members best be handled when intermixed with masonry debris? 4. How can autos, buses and trucks in the debris be handled? 5. What ways are most appropriate for breaking up massive slabs for clearance? 6. How should twisted steel frameworks be handled? 7. What measures should be provided for salvage of structural materials? 8. What provisions should be made for salvage of building contents?
Administrative and logistics	A. Establishment of Policy 1. Policy on mobilization of equipment manpower and supplies 2. Priority list of target cities whose early clearance is most vital in the national interest 3. Policy on complete abandonment of sites--or covering rather than incurring removal effort 4. Establish order of objectives for stages of debris clearance in a ranked order of preference - such as the following: a. Rescue: opening shelter entrance b. Rehabilitation of hospital facilities c. Minimal access--one 2-lane street in each of two directions through city d. Marginal access-one 2-lane street in each of two directions at stated intervals (say 1 mile) through city e. Access to all hospitals by connecting to cleared streets (for treatment if hospitals are standing, or merely for recovery of equipment) f. Access to commercial and warehousing centers for salvage of equipment and stores g. Restoration of intercity transportation--access to port facilities, railroad terminals and marshalling yards, airports h. Access to all utility plants i. Clearance of industrial districts j. Clearance of all main streets k. Restoration of intracity transit l. Clearance of all streets in multi-family housing areas m. Clearance of all streets n. Removal of all rubble 5. Translating objectives into removal tasks for computation of estimated time and effort for individual cities	Establishment of directed efforts in cities in accordance with well-considered objectives	1. With limited available equipment, which cities should be cleared first? 2. In what order should clearance tasks be performed in individual cities?

problems. Thus, while the logistic problems of selecting street routes through cities for early clearance may be appropriately studied by means of optimizing program techniques, they are merely mentioned here.

The first series of problems considered is the preparation of pre-disaster estimates of gross debris accumulation. Without data for estimating debris accumulation, local Civil Defense planners may have difficulty recognizing the potential quantity of structural debris that may accumulate in their municipalities, since their past experience includes no disasters of magnitudes comparable to high-yield weapon attack. It is most desirable to have methods whereby the depths of material likely under various attack conditions can be estimated. It is also desirable to realize the distances materials from buildings would be transported by blast winds to demonstrate the extent to which streets can be inundated under structural materials.

A second series of problems involves the actual equipment, supplies, and manpower required in debris clearance. The capabilities and capacities of facilities need to be determined to permit estimates of the removal task to be made. Local Civil Defense planners must certainly expect that an attack would likely produce very considerable losses of available excavating equipment. Likewise, the reduction of the skilled operators would have to be regarded as negligible. Regardless, it is still desirable to develop data for estimating removal time in terms of the quantities of equipment and operators that may be made available from beyond attack regions.

A third series of problems involves procedures for debris clearance. Structural debris is probably the most difficult material to handle. Structural steel members, piping, and other materials interspersed among debris will constantly slow down removal operations. Demolished autos, trucks, buses, and railroad cars pose special clearance problems which can only be handled with heavy removal equipment.

A fourth major series of problems involves planning, administration, and logistics. We have recognized earlier that, within the metropolitan area, loss of clearance equipment and operators may be extreme. Recourse to compulsory mobilization of equipment and trained operators outside the attack area can become necessary to accomplish clearance objectives. It has been estimated that men can actually be taught to operate a tractor in three to four days, but this implies merely manipulation of controls. New operators, after orientation, could be expected to be only about 25 percent as efficient as skilled men. Thus it might be preferable to obtain capable operators from outside attack zones, rather than penalize the output of the limited available equipment by using poorly-skilled operators.

1.1 Report Organization

This report contains six chapters dealing with major aspects of the debris problem. The first chapter, introductory in nature, defines the major problem areas involved in debris clearance.

Chapter Two provides general procedures for making first-order estimates of the magnitude of the debris clearance problem -- the depths and volumes of gross rubble accumulation. It is seen here that in central business districts of major cities, debris levels may reach levels of 20 feet or more, whereas in residential neighborhoods, average debris depths would be under three feet and even less than one foot in regions consisting solely of single family residences. The first-order estimating procedures assume complete structural fragmentation and uniform debris depths within regions of similar structural types and building spacing.

Development of second-order estimating procedures for making detailed estimates of gross debris accumulation is initiated in Chapter Three. This includes development of methods of estimating fragment-size distribution for structural elements which fail under blast loads, and computation of the ensuing fragment trajectories induced by the blast winds. The procedures are directed toward determination of debris contours for individual structures and groups of structures under various blast magnitudes.

Capabilities of major items of excavating equipment for debris clearance are discussed in Chapter Four. It is noted that the characteristics of structural debris are extremely variable. In some regions debris may consist solely of loose clumps of bricks. In central business districts the rubble may include many structural steel members which would delay the progress of excavators, and materially impede clearance operations. Extremely large boulders of reinforced concrete would also impede clearance operations while they are being reduced in size. Another impedence to clearance operations is the lack of trained operators for excavating and demolition operators.

Planning and scheduling of debris removal efforts are discussed in Chapter Five. The extreme potential magnitude of debris accumulation in major cities makes it necessary to seriously consider pre-disaster planning. While this chapter is essentially a brief discussion of planning problems which in themselves are of considerable breadth and consequence, it is felt that most of the essential elements of pre-disaster planning for debris removal are included. An initial outline for the delegation of essential planning functions is included.

Chapter Six reviews radioactive fallout considerations as they effect debris clearance efforts. It is seen that for surface and near-surface bursts, the extent of fallout exceeds that of blast and thermal effects -- and that where debris exists there will also be fallout. Decontamination of great amounts of debris would be an impossible task. Time alone would be the only solution to the contamination. Considering the rate of decay and the lengthy period required to accomplish removal, reasonable safe monitored operations can be expected if clearance is initiated in regions of least contamination.

A brife resume of pertinent nuclear weapon effects phenomena is included in Appendix A.

1.2 Conclusions and Recommendations

The following conclusions and recommendations result from this study:

- Severe debris accumulation is primarily a problem at city centers -- central business districts of tall, densely packed buildings.
    - Debris accumulation may reach depths of 20 feet or more in central business districts of major cities, with average levels in these regions reaching 12 feet.

  - In regions of two and three-story densely-packed apartment buildings, average debris depths would be under three feet.
  - In regions of single-story residences average debris depths are expected to be less than one foot.
- Major pre-disaster planning should be performed to provide direction to post-attack clearance efforts.
  - Debris clearance is a vast task requiring directed and coordinated activity in which Civil Defense operational organizations at all levels have significant functions to perform.
  - At the local level clearance equipment may be inadequate to accomplish vital tasks. Mobilization and allocation of equipment and trained operators on a national basis may be required after a multi-city attack.
  - Even complete structural failure in outlying residential areas would leave only moderate levels of debris, much of which can be cleared and salvaged by residents themselves.
  - Various policy decisions of national importance may be required, such as criteria for abandoning or covering over a city site or portion thereof, establishing an order of precedence among vital areas for early clearance, and setting a priority of objectives and tasks in clearance efforts.
- First-order estimates of debris accumulation in individual cities can be prepared by applying the methods developed in Chapter Two of this report.
  - Detailed estimates may be made with the aid of National Fallout Shelter Survey Data or Sanborn maps using the computational procedures described in Chapter Two.
  - Rough approximations of debris accumulation may be made for various regions of cities with the aid of debris computations for representative city blocks presented in Fig. 2.6 through 2.25. In this case the indicated debris depths would be adjusted to account for differences in average building height and the percentage of land surface actually occupied by buildings.

    - Estimates of gross debris accumumlation by first-order methods are probably most realistic when made for average depths in overall regions (e.g. central business districts, entire residential neighborhoods) than when made on a block-by-block, or more so, on a lot-by-lot basis.
- Transportation vehicles and industrial steel-frame (mill) buildings require separate consideration as debris problems.
    - Except in special cases (large parking areas) transportation vehicles constitute far less material than neighboring structures and would not account for a large increase in average debris depths.
    - Size and weight of vehicles is such that heavy machinery would be required to clear large numbers of vehicles from throughfares.
    - Industrial steel-frame (mill) buildings are not expected to move beyond the vicinity of their foundations. However; the presence of many destroyed mill buildings will require considerable effort in cutting steel members to size suitable for handling and hauling.
- Solutions to many debris problems (e.g. depths in vehicular arteries) can only be developed by considering the fragmentation characteristics of structural elements and the blast wind induced trajectories.
    - A suitable model for fragment trajectories is described in Chapter Three, conservative in the sense that it predicts maximum flight through assuming zero failure time and no shielding from blast winds.
    - Fragment trajectories are extremely sensitive to fragment size, as shown in Appendix D.
    - Current state-of-knowledge of fracture mechanics is insufficiently developed to define the fragment-size distribution of structural elements failing dynamic loads. Applying "weakest-link" hypotheses and probabilistic considerations, the methods initiated in Chapter Three of this report appear to be the most promising approach to this problem and warrant further study.
- Further analytical and experimental investigation into the fragmentation of structural elements is required to refine the second-order method of estimating structural debris distribution. Recommended research effort is outlined as follows:
    - Analytical investigation to date, limited to the case of uniform dynamic loading on a cantilever

beam, should be extended to the cases of simply-supported and fixed-end beams. Both uniform and other types of dynamic loading should be included in further investigations.

  - Experimental determinations should be made of the distribution parameters (e.g. Weibull constants) for various materials, these determinations are necessary for applying the results of fragmentation analyses to various building materials and structural elements.
  - Experimental studies of fragment-size distributions of model beams should accompany further analysis of fragmentation. Experiments should include fragment-size distribution counts for model beams of various end conditions and types of loading. Each case requires a large number of measurements to attain a statistically significant sample. This experimentation is needed to check the assumptions of stochastic independence and to support analytical studies.
  - Analysis of "in-house" data from past experimental studies of construction materials also appears warranted as a promising source of data on distribution parameters (Weibull constants).
  - Results of further fragmentation studies should be combined with the trajectory model described in Chapter Three of this report to define the expected distribution of debris (depth contours) for individual buildings or groups of structures. Ultimately this will lead to the development of debris depth contours for cities, and, consequently, the capability to make refined estimates of quantities of materials which must be cleared to render desireable traffic arteries passable. From this stage, it would be a relatively simple matter to program problems in optimum route selection.

- Preparation of a "Debris Clearance Handbook" for the education and guidance of local Civil Defense organizations is also recommended. Such a handbook should include:
  - Estimating data permitting local organizations to calculate the likely debris and clearance volumes they may expect after an attack.
  - Statements of objectives of clearance efforts and ranking of clearance tasks in terms of the objectives.

- Step-by-step planning directions to enable local organizations to plan their own clearance efforts.
- Operating instructions on clearance tasks and the use of clearance equipment. Rubble is a most difficult material to excavate. Instructional material should tell how to handle various types of materials, e.g., how to handle twisted steel structures, mammoth reinforced concrete boulders, vehicles, etc.

Chapter Two

ESTIMATING GROSS DEBRIS ACCUMULATION

Analysis of debris accumulation involves consideration of two mechanisms - - - the fragmentation of structural elements under blast loading and the transport of fragments by the blast winds. The state-of-knowledge of fracture mechanics is insufficiently developed to provide good estimates of the fragment-size distribution of structures at various overpressure levels. Based on probabilistic considerations, methods have been initiated for estimating fragment-size distributions for masonry-like materials, based on a "weakest-link" hypothesis. Only the initial steps have been accomplished in this study; considerable effort is still required to extend this analysis to real structural elements. The transport of fragments is more amenable to analysis, and trajectory analyses have been carried out for representative structural fragments. These two studies constitute the basis for a second-order estimating procedure for debris accumulation and are detailed in Chapter Three.

An alternate first-order estimating procedure is presented in this chapter, whereby debris accumulation is estimated by overall methods. This is a much simpler procedure which makes use of readily accessible data, and is believed to yield reasonable and meaningful results.

The problem of steel-frame industrial (mill) buildings is treated separately. Collapsed frameworks of these structures would be expected to remain near their foundations and would not contribute much to the general level of debris, especially in streets. Their removal however requires that the members be cut to sizes suitable for hauling and this can require extensive effort. Methods for estimating quantities of steel in mill buildings are therefore included in Section 2.4 of this chapter.

Similarly, transportation vehicles represent special problems in removal, though in general they are not expected to substantially increase average debris levels. Methods for estimating quantities of vehicles are outlined in Section 2.5.

2.1 First-Order Estimating Procedures for Debris Accumulation

The following factors are considered in the first-order estimate of debris accumulation:

- Collapse radii for various classes of buildings
- Quantity of material in structures
- Void ratio in the resulting rubble

Collapse radii for structures can be readily estimated using data contained in Effects of Nuclear Weapons (Ref. 1). Approximate methods for determining material quantities in structures are included in this chapter. Simple tests have been conducted on this program to estimate the void ratio in rubble. The overall estimating procedure consists of the following:

- Selecting collapse radii for various classes of structures and weapon yields
- Assuming complete destruction at or above the selected overpressures
- Estimating material volume for the failed structures as a percentage of the total contained structural volume
- Assuming a uniform distribution of rubble over lots, streets and alleys in the immediate neighborhood of the structures
- Using a measured estimate for the void ratio in the resulting rubble to determine the average depth of debris

Analytical expressions for estimating the average depth of debris over a region are derived below. Let

L_a, W_a = dimensions of studied region (lot, city block, or National Fallout Shelter Survey Standard Area)

L_b, W_b, H_b = dimension of individual buildings in region

K_m = ratio of solid material volume to total contained volume for individual buildings

V_R = void ratio in debris = $\frac{\text{volume of voids } (V_v)}{\text{volumes of solids } (V_s)}$

L_s, W_s = dimensions of streets through region (for emergency clearance W_s would be the desired width of traffic lanes rather than total street width)

$\bar{D}_{debris}$ = average debris depth in region

The total volume of solid material available as debris in a selected region is:

$$\mathrm{Vol}_{\mathrm{material}} = \sum K_m \,(L_b\, W_b\, H_b) \qquad \text{(Eq. 2.1)}$$

and the total volume of debris produced in the region is

$$\begin{aligned} \mathrm{Vol}_{\mathrm{debris}} &= \left(\frac{V_v}{V_s} + 1\right) \sum K_m \,(L_b\, W_b\, H_b) \\ &= (V_R + 1) \sum K_m \,(L_b\, W_b\, H_b) \end{aligned} \qquad \text{(Eq. 2.2)}$$

Values for K_m and V_R are discussed in Sections 2.2.2 and 2.2.3 respectively. The average debris depths in the region is

$$\bar{D}_{\mathrm{debris}} = \frac{(V_R + 1) \sum K_m \,(L_b\, W_b\, H_b)}{L_a\, W_a} \qquad \text{(Eq. 2.3)}$$

and where it is desired to clear the streets through the region, the amount of material to be removed is

$$\text{Street Clearance} = \bar{D}_{\mathrm{debris}}\; L_s\, (W_s + 2\, \bar{D}_{\mathrm{debris}} \cot 40^{\circ}) \qquad \text{(Eq. 2.4)}$$

where W_s is measured as the required width of cleared lanes and the angle of repose of rubble is estimated as 40 degrees.

This method of analysis has the following advantages:

- Application involves no mathematics other than simple arithmetic, nor any structural analysis, and can be used effectively at the local Civil Defense levels.
- All data needed as inputs can be made readily available to local Civil Defense personnel - -
  - Building dimensions can be obtained directly from the National Fallout Shelter Survey (N.F.S.S), which is considered 90 percent complete in regions of tall structures where debris problems are most serious.
  - The material ratio, K_m, has been estimated for various building types in Section 2.2.2 of this report.
  - Simple tests of random piling of rectangular

material, conducted on this program and described in Appendix A, indicate that a void ratio (V_v/V_s) of 1.0 is suitable. This value is used for rubble in several example problems presented here.

2.1.1 Debris Accumulation at Various Overpressure Levels

For target areas subjected to overpressures sufficient to collapse all structures in the area, e.g., 15-20 psi and up, all structures should be included in the computations of debris parameters in equations 2.1 through 2.4. For lesser overpressure levels, these equations should be modified to include only those classes of structures with failure overpressures below that of the attack condition. The plan area of the structures left standing should likewise be subtracted from the area of rubble dispersion. Thus, equation 2.1 becomes

$$\mathrm{Vol}_{\mathrm{material}} = \sum K_m \left[L_b W_b H_b \right] \quad ; \text{ for } p_f \leq A \qquad \text{(Eq. 2.5)}$$

where p_f = failure overpressure of building in psi

A = attack overpressure level in psi

Equation 2.2 becomes

$$\mathrm{Vol}_{\mathrm{total\ debris}} = (V_R + 1) \sum K_m \left[L_b W_b H_b \right] \; ; \text{ for } p_f \leq A \quad \text{(Eq. 2.6)}$$

and the average debris depth becomes

$$\bar{D}_{\mathrm{debris}(A)} = \frac{(V_R + 1) \sum K_m \left[L_b W_b H_b \right] ; \text{ for } p_f \leq A}{L_a W_a - \sum \left[L_b W_b \right] \quad ; \text{ for } p_f > A} \qquad \text{(Eq. 2.7)}$$

The street clearance for the attack overpressure is then

$$\text{Street Clearance } (A) = \bar{D}_{\mathrm{debris}\ (A)} L_s (W_s + 2 \bar{D}_{\mathrm{debris}\ (A)} \cot 40^{\circ}) \qquad \text{(Eq. 2.8)}$$

Data on failure overpressures and ground ranges for various types of structures, based on observations at Hiroshima, Nagasaki, and the Nevada tests are reported in Effects of Nuclear Weapons (Ref. 1); representative data are summarized in Fig. 2.1 through 2.3. PV code numbers in these figures refer to the equivalent N.F.S.S. classification (Ref. 2). This permits direct identification of buildings that would generally be expected to fail

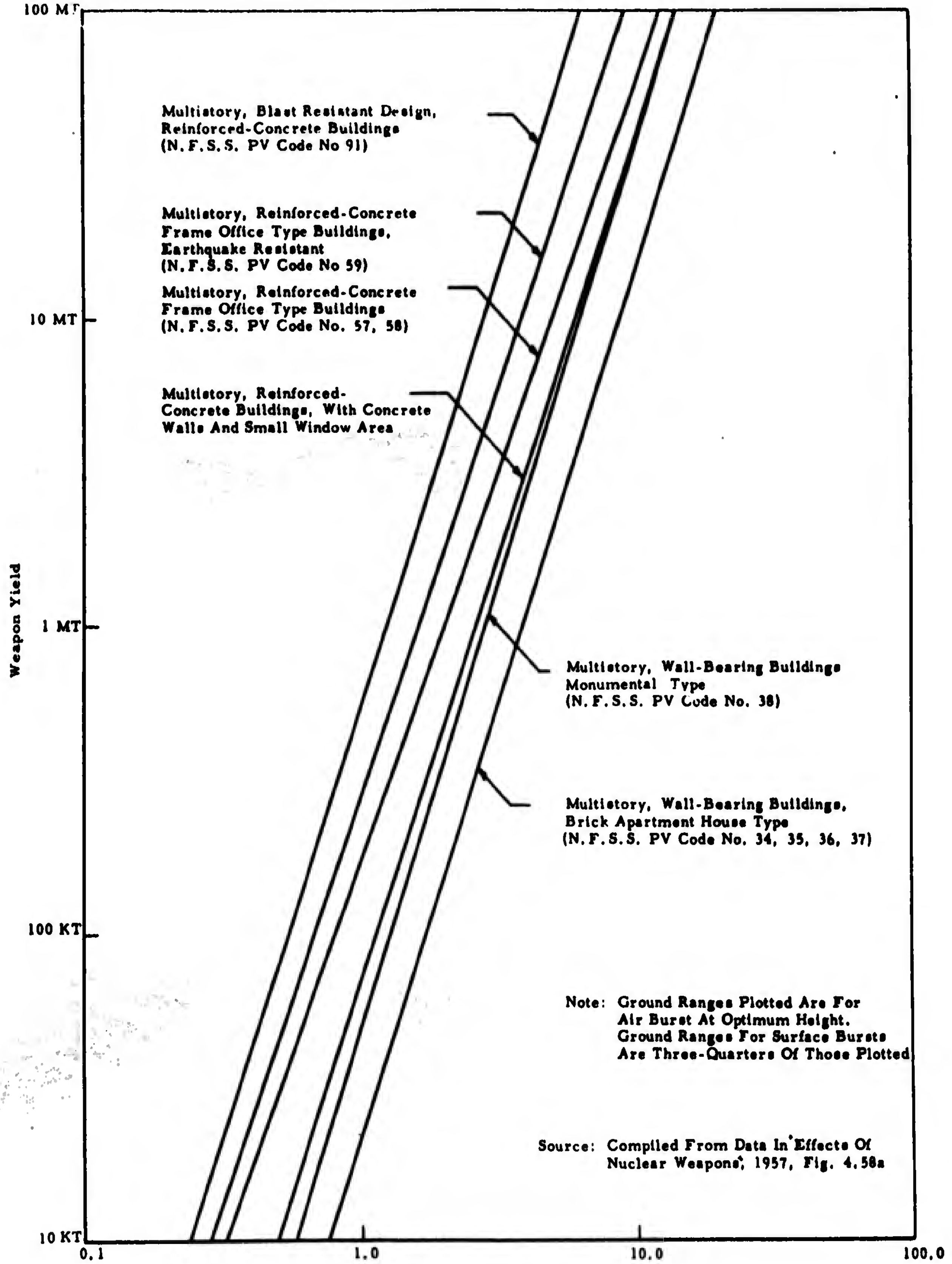
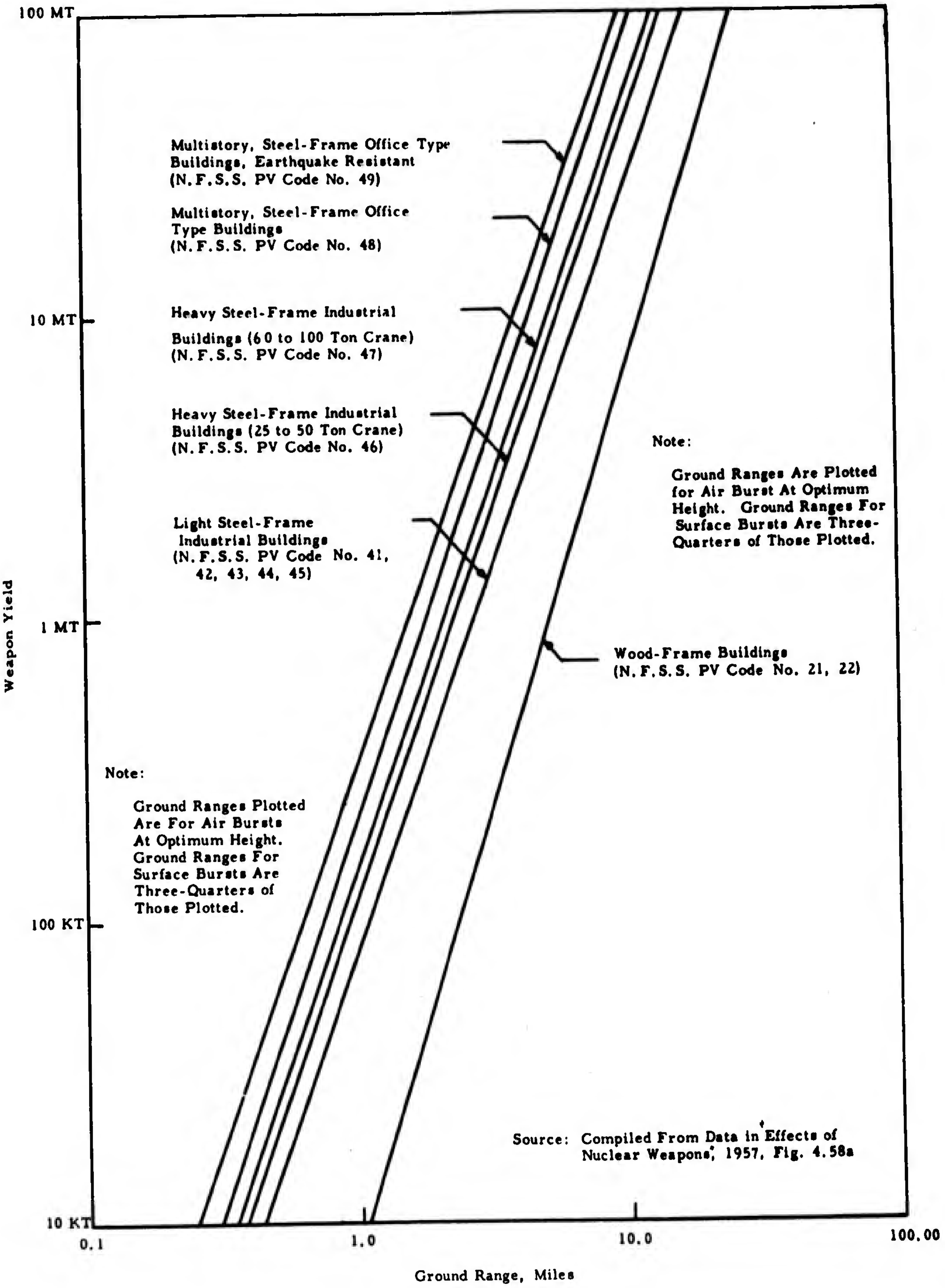


Fig. 2.1 COLLAPSE RADII FOR REINFORCED CONCRETE AND WALL-BEARING BUILDINGS



Note:

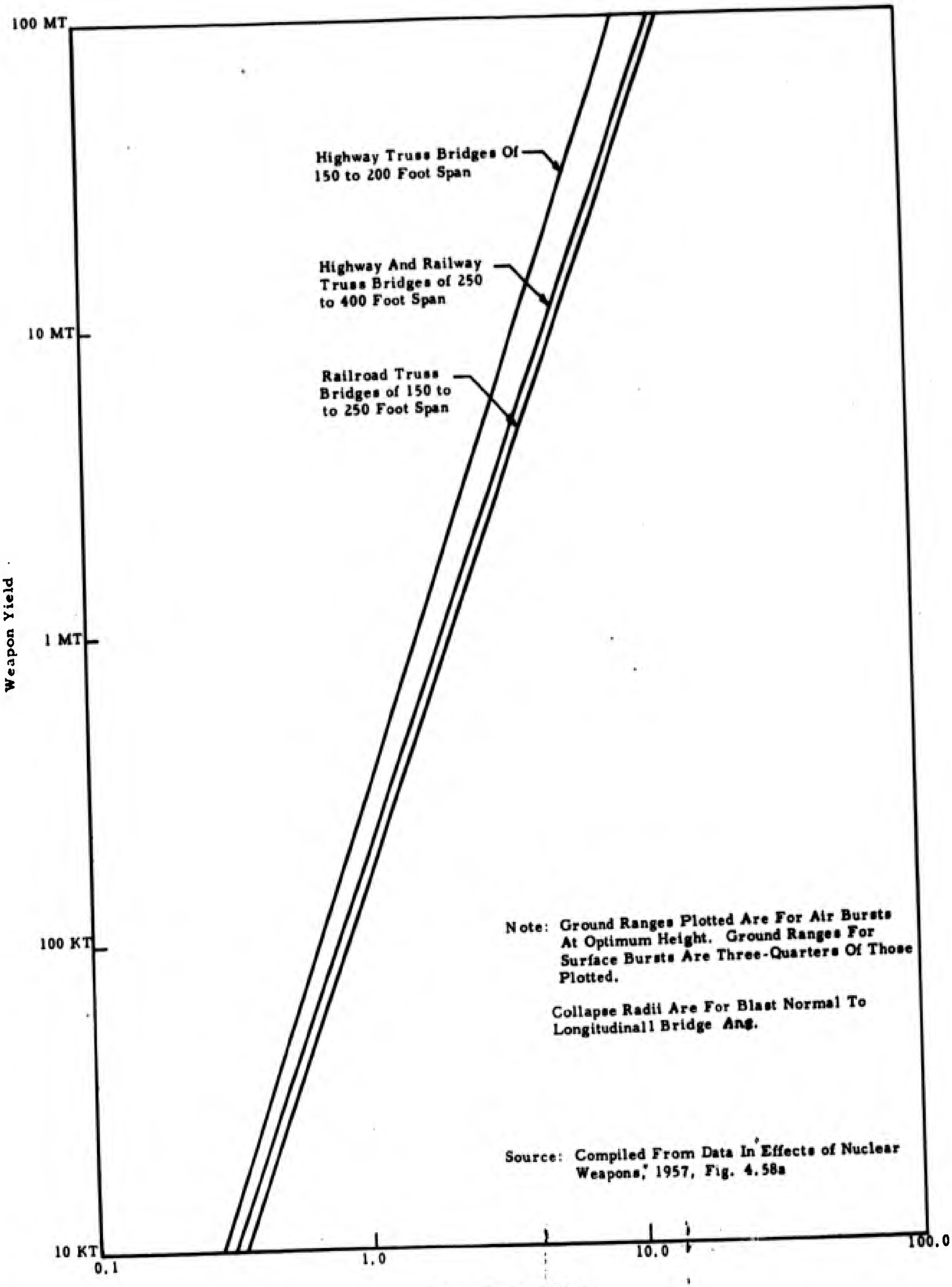
Ground Ranges Are Plotted for Air Burst At Optimum Height. Ground Ranges For Surface Bursts Are Three-Quarters of Those Plotted.

Note:

Ground Ranges Plotted Are For Air Bursts At Optimum Height. Ground Ranges For Surface Bursts Are Three-Quarters of Those Plotted.

Source: Compiled From Data in "Effects of Nuclear Weapons", 1957, Fig. 4.58a

Fig. 2.2 COLLAPSE RADII FOR WOOD-FRAME AND STEEL-FRAME BUILDINGS



Note: Ground Ranges Plotted Are For Air Bursts At Optimum Height. Ground Ranges For Surface Bursts Are Three-Quarters Of Those Plotted.

Collapse Radii Are For Blast Normal To Longitudinall Bridge Ang.

Source: Compiled From Data In "Effects of Nuclear Weapons," 1957, Fig. 4.58a

Fig. 2.3 COLLAPSE RADII FOR TRUSS BRIDGES within any ground range when the N. F. S. S. data are used in computing debris accumulation according to equations 2.5 through 2.8. When Sanborn maps or other sources of building data are used, the physical designation of building types can be used.

2.2 Sources of Input Data

2.2.1 Building Data Sources

Most building surveys or city plot plans should provide the building dimensions to be used as inputs to the computational procedures outlined. Chief among these sources are the N. F. S. S., the Sanborn maps, and city plot plans that may be available through municipal building departments and planning commissions.

Since the most severe problems exist in regions with a high structural density and primarily tall buildings, the N. F. S. S. is a prime data source. Building dimensions are specifically stated for each structure, as is the PV code number, - - an indicator of the ratio of material volume to total contained volume of the structure. The PV code number is also an indicator of the failure overpressure of the structure.

Because of the degree of coverage involved, caution must be exercised in applying N. F. S. S. data as inputs to computations of debris accumulation. The survey is a complete enumeration of all structures considered to fulfill certain requirements as fallout shelters. In general this means that it includes structures of three stories (or two stories plus a basement), or structures with the equivalent of 8 in. of concrete overhead, with a minimun of wall openings (under 20 percent), and walls equivalent to 8 in. of brick. In central business districts of large cities, this generally results in essentially complete coverage. In the central commercial district of Chicago, for example, the N. F. S. S. has been informally estimated to include over 90 per cent of all structures - - in which case estimates based on the survey probably account for 98 percent of the total contained structural material. In central business districts of large cities, input data from the N. F. S. S. alone are probably adequate for estimating total debris accumulation. Outside these areas, the structural enumeration should be checked against other data - - including Sanborn maps - - in computing debris accumulation.

The Sanborn maps serve as a second available source of building data in central business districts of large cities. They further serve as a prime source of input data on building characteristics outside the central business districts, - - where - - the N. F. S. S. is incomplete in its coverage. Sanborn maps are copyrighted products of the Sanborn Map Company, Inc. of Pelham, N. Y. Their primary usage is as fire insurance maps, and as such they are scaled visual depictions of street layouts, building location and construction, along with exposures, occupancies, fire hazards and fire protection factors of interest to underwriters. They picture buildings to scale in such a manner that users can recognize building characteristics and the nature of the surrounding neighborhood. Plan areas of buildings can be readily scaled but building heights are not always indicated. In the problems presented later in this chapter, the average story height for all buildings was assumed to be 10 ft. Since the Sanborn maps always give numbers of stories, this assumption allows estimates of structural volume to be made. More than 11,000 Sanborn publications are obtainable and the publishers state that, in general, their maps are available for every town with a population of 2,000 or more. Where local Civil Defense organizations do not already have access to Sanborn maps, their use may be relatively expensive, as compared with the cost of using the N. F. S. S. or other government data.

Other sources of input data on building sizes and types are frequently available locally as part of building department data in municipalities, transit surveys, regional planning data, and other sources. Though not uniform on a national scale, these data are of local applicability.

2.2.2 Material Ratios for Buildings

The material volume of structures can be computed in numerous ways. The most accurate manner would be to obtain these data directly from building plans; however, this is a long and tedious procedure, and a refinement that does not now appear warranted.

A second method involves multiplying the periphery of each structure by the wall thicknesses tabulated on the Sanborn maps, and adding a quantity estimated to account for the floor materials. This is the recommended procedure when Sanborn maps are available.

A third method is to estimate structural material volume on the basis of the total contained volume of the structure. Though less accurate, this is generally recommended since it makes effective use of the N. F. S. S. data and reduces computation effort substantially. This method assumes that for any type of structure there is a relatively fixed relationship between the volume of structural material and the total contained volume. On the basis of limited but representative calculations, the assumption appears warranted. The computations are summarized in Fig. 2. 4 and 2. 5, which give the material ratios for structures with load-bearing walls, and for reinforced concrete structures.

The slopes of these lines are nearly zero, and for computations of total debris accumulations K_m can be taken at 11 per cent for structures with load-bearing walls, and as 16 percent for reinforced-concrete structures.

2. 2. 3 Void Ratio in Debris

The depth of debris in a built-up urban area following a nuclear detonation will depend not only upon the total material quantity deposited in a unit area, but upon the void ratio of the piled material as well. The extent of voids in the debris will also influence the production rate (in terms of material quantities) of excavating and hauling equipment. In actual rubble accumulation, the voids ratio will vary with the extremes in fragmentation patterns of structural elements, the degree to which long boards or structural steel members exist in the rubble, and other effects. An approximate voids ratio for random-piled rectangular material has been developed from a series of simple experiments with blocks of various sizes as described in Appendix B. It was found that the test materials piled with a percent-of-solids of about 50 percent. Thus, in lieu of other information, it is recommended that the void ratio for rubble in equations 2. 2, 2. 3, 2. 6 and 2. 7 be taken as:

$$V_R = \frac{V_v}{V_s} = 1.00$$

This value is consistent with estimates obtained from several contracting firms.

2. 3 Debris Accumulation Estimates for Various Urban Areas

Estimates are presented here of the debris accumulation for a

$$K_m = \frac{\text{Volume of Structural Materials}}{\text{Total Contained Volume}}$$

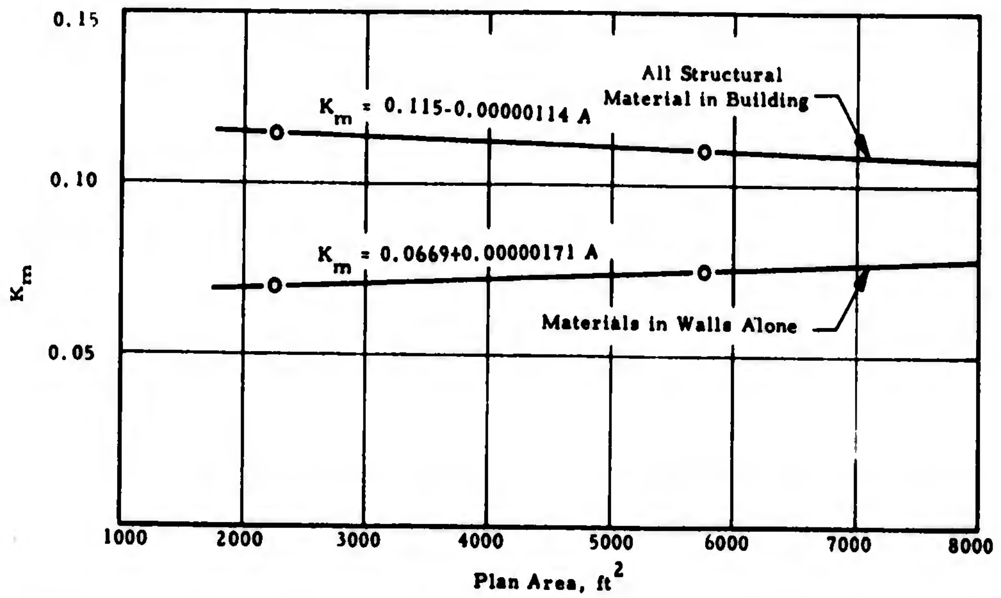


Fig. 2.4 VOLUME OF MATERIALS IN STRUCTURES WITH LOAD-BEARING WALLS (N.F.S.S. code numbers 31 through 38)

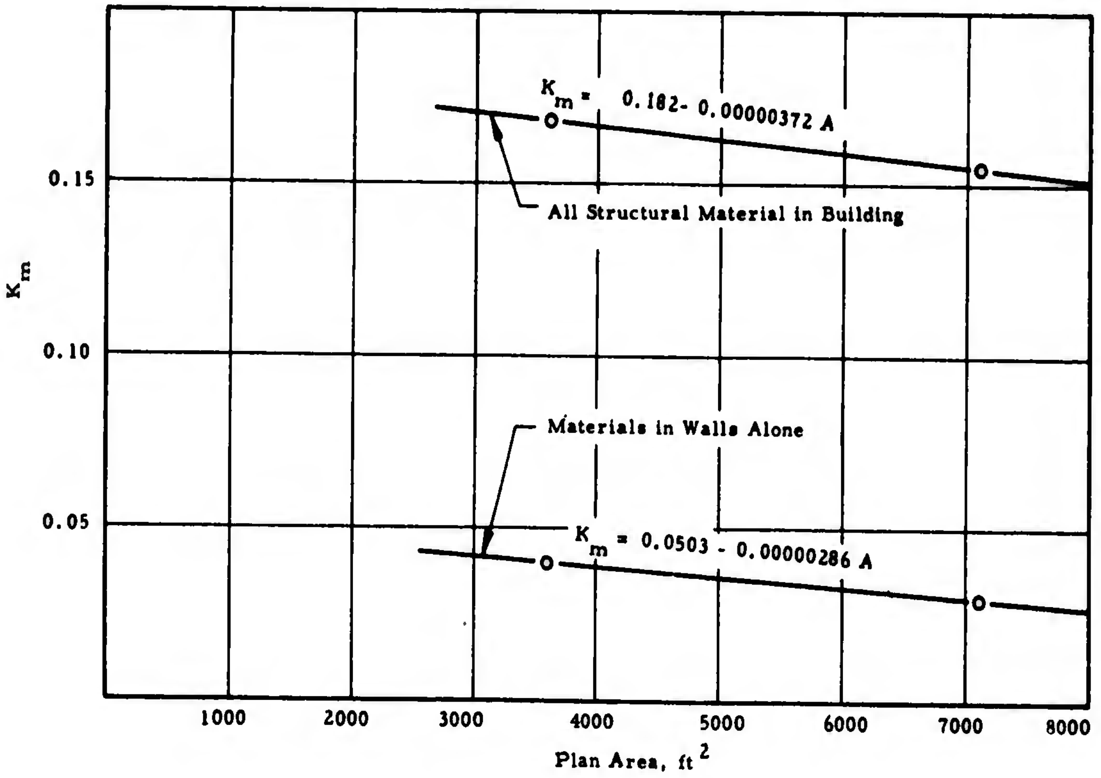


Fig. 2.5 VOLUME OF MATERIALS IN REINFORCED CONCRETE STRUCTURES (N.F.S.S. code numbers 51 through 59)

number of urban environments:

- The central business district of Chicago, a region of tall buildings with few vacant areas
- A secondary, or neighborhood commercial district in Chicago
- Region of high-rise apartments
- Modern suburban shopping center
- Several residential neighborhoods of various building heights and densities

General layouts, including building configurations and characteristics, building photographs, debris volumes, and debris depths are provided for each site selected. The method of calculation of debris depths, summarized in Appendix C, is based on estimating the contributions of structures to total debris accumulation on the basis of a fixed percentage of contained building volume. This mode of estimating was selected since layouts were readily available providing scaling floor area of structures, from which contained volume can be estimated on the basis of a fixed story height.

Omission of building contents from estimates tends to understate debris accumulation. The ommission can be justified in part on the basis that much of the contents (and some of the building materials) are combustible and may be consumed in accompanying fires. The volume of contents and the degree to which they are combustible will vary widely with building occupancy - - (e.g. warehouse, dwelling, store, or factory).

For each of the sites considered in Sections 2.3.1 through 2.3.5 the average debris levels have been computed on the following basis:

- All above-grade structural materials become debris, but contents are omitted
- An assumed story height of 10 ft, except where actual building heights are indicated on layouts
- A structural material volume equal to 15 per cent for the reinforced concrete structures in the high-rise apartment and shopping center, and 12 percent for all other structures
- A percent -of-solids in the rubble of 50 percent

The sites selected cover a wide range of urban environments and permit visualization of the potential debris depths in similar regions. As other urban regions vary from these patterns in average story height or the ground area covered by structures, rough estimates of debris accumulation can be made by taking ratios of the quantities indicated.

2.3.1 The Central Business District of Chicago

No central business district from any of the largest class of cities (population in millions) can really be called "typical". Many different factors influenced their development, resulting in considerable variations in average building heights, ground area covered by structures, street widths and space utilization. We thus observe that:

- Manhattan Island has concentrations of buildings with heights existing nowhere else in this country
- Los Angeles has few very tall structures

The central business district of Chicago was selected as an illustrative problem, to show the extent of debris accumulation in the highly built-up areas of very large cities, and to provide sample calculations of debris accumulation. It is a city intermediate between New York and Los Angeles in structural concentration. Characteristics of the region studied are as follows:

Total area = 16,120,000 sq ft

Total lot area = 9,120,000 sq ft (includes ground, buildings, and alleys)

Streets = 7,000,000 sq ft

Approximate land use = $\frac{\text{Total Lot Area}}{\text{Total Area}} = 56.6$ per cent

Total floor space = 79,050,000 sq ft

Approximate average building height = $\frac{\text{Total floor space}}{\text{Total lot area}} = 8.7$ stories

Average debris depths have been computed for the central business district as a whole, for each of the N.F.S.S. standard locations contained in the district, and for each block in the district. These computations are summarized in Appendix C. Computations are based on complete fragmentation of all structures and uniform distributions of the rubble throughout the area considered, according to the method of Section 2.1. For the entire district the average debris depth is estimated at 12.6 ft. Average debris depths for the contained N.F.S.S. standard locations, shown in Fig. 2.6, range from 11.3 to 15.3 ft. For individual blocks, average debris depths range from negligible quantities in the few relatively unoccupied blocks to a maximum of about 30.4 ft, as shown in Fig. 2.7.

Average debris levels were also computed for various main streets, based on the characteristics of adjacent buildings, and indicated in Fig. 2.7. For the North-South streets, average street levels were computed by averaging adjacent block levels along the west side of the streets, west being generally regarded as the likely direction of aiming points in attack situations since the east side of the city borders Lake Michigan. An unexpected result of this computation is that State Street, bounded by the major department stores appears to be one which would have one of the lower average debris levels. Average street debris levels for East-West streets in Fig. 2.7 were computed by averaging block levels for adjacent blocks along the south sides of the street - - the direction of the greater portion of the city's industry and housing. Where necessary, block levels were weighted according to their widths. It should be noted here that streets under railroad viaducts (Congress) or having elevated transit structures (Van Buren, Wabash, Lake and Wells) may pose special clearance problems beyond those represented by structural rubble from adjacent buildings alone.

2.3.2 A Neighborhood Business District in Chicago

Six blocks of a neighborhood business district were selected to depict the debris levels likely to exist in outlying commercial districts of major cities - - or in central commercial districts of smaller cities. Calculated debris levels in these blocks range from 1.6 to 7.2 ft as indicated in summary calculations of Fig. 2.8 through 2.15, which also show layouts and photographs of the blocks. The average debris level for the entire eight-block region is computed to be 3.8 ft while the average level for the four-block region at its center (Fig. 2.8 through 2.11) is 4.7 ft.

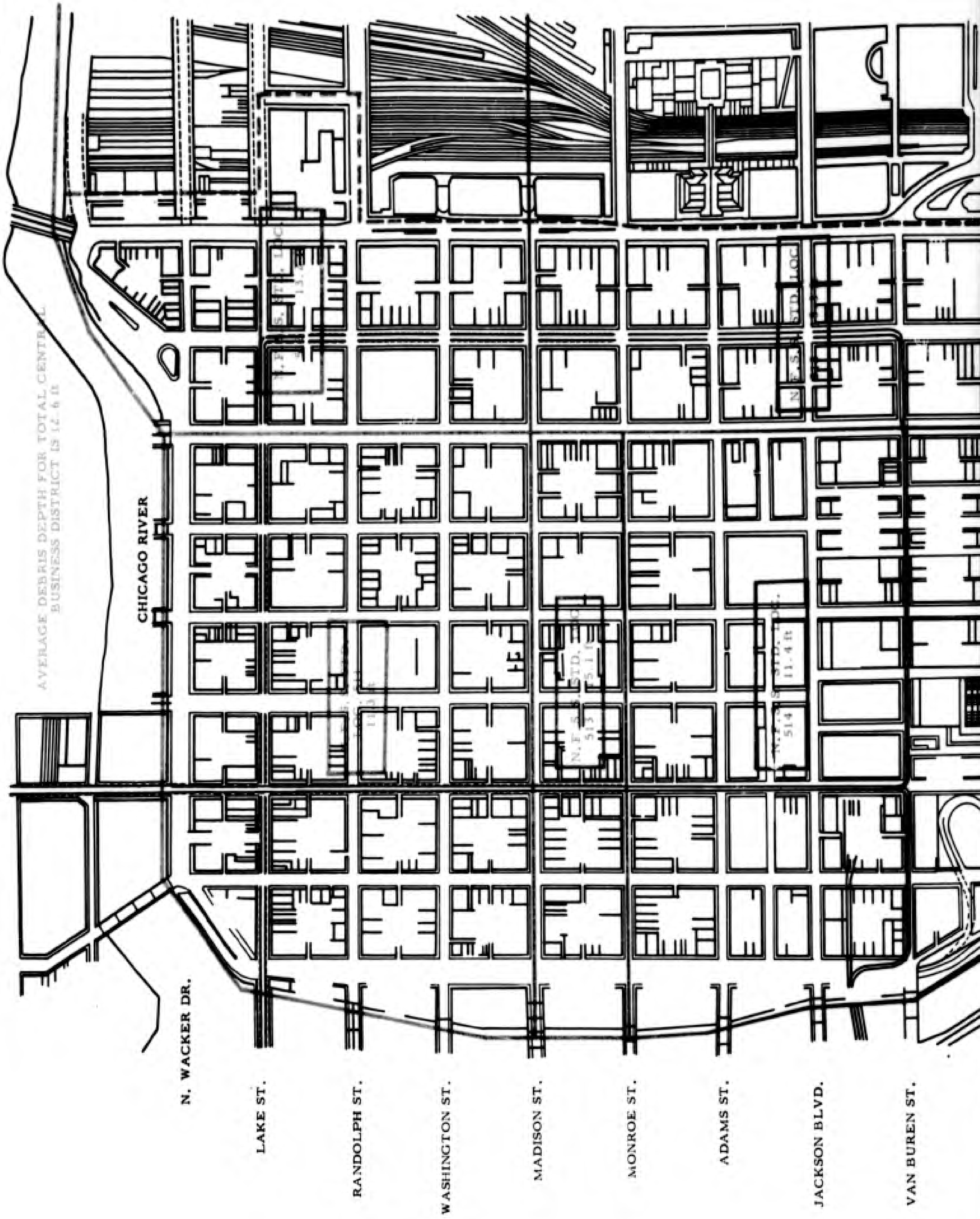


Fig. 2.6 DEBRIS DEPTHS FOR STANDARD LOCATIONS IN CENTRA

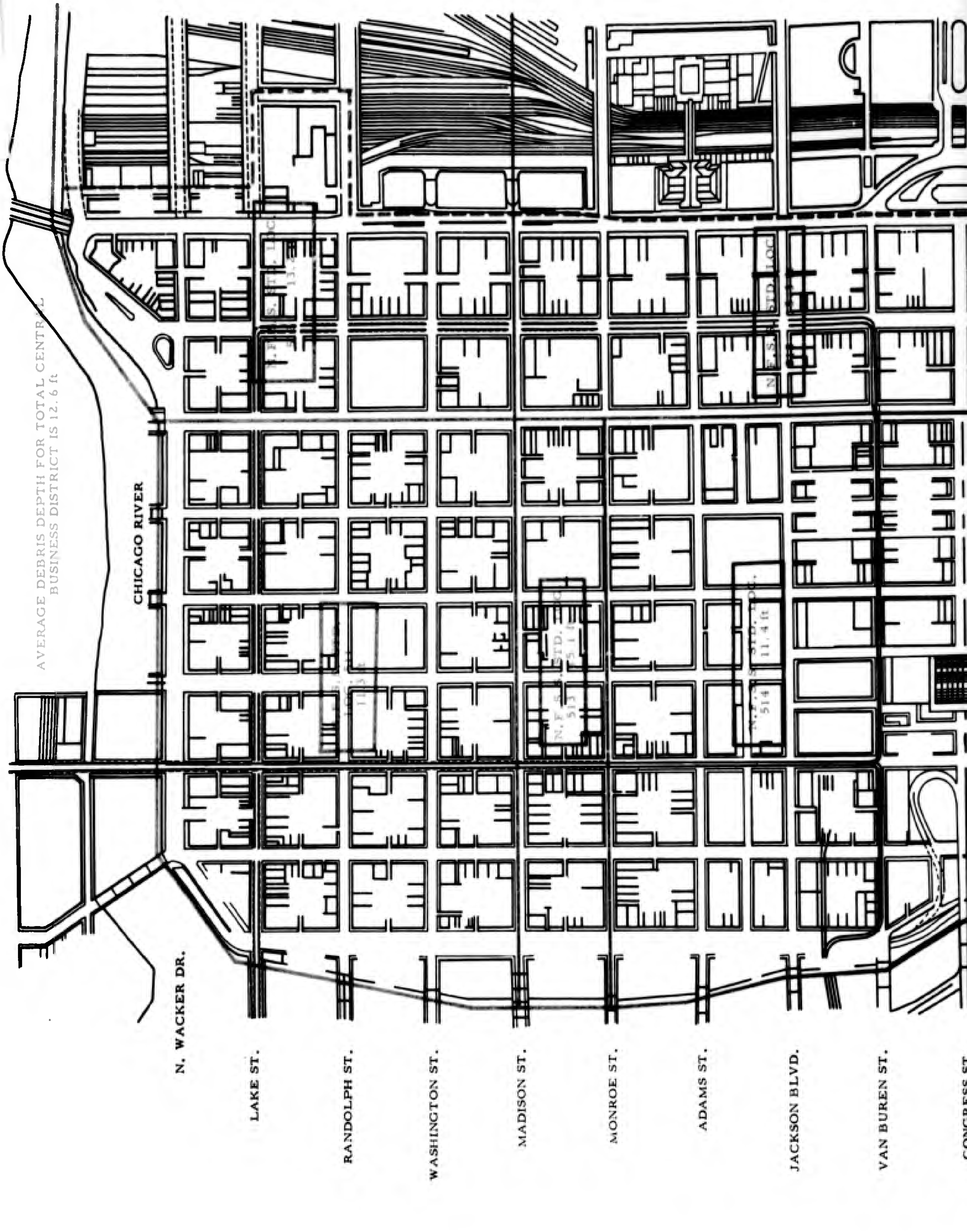
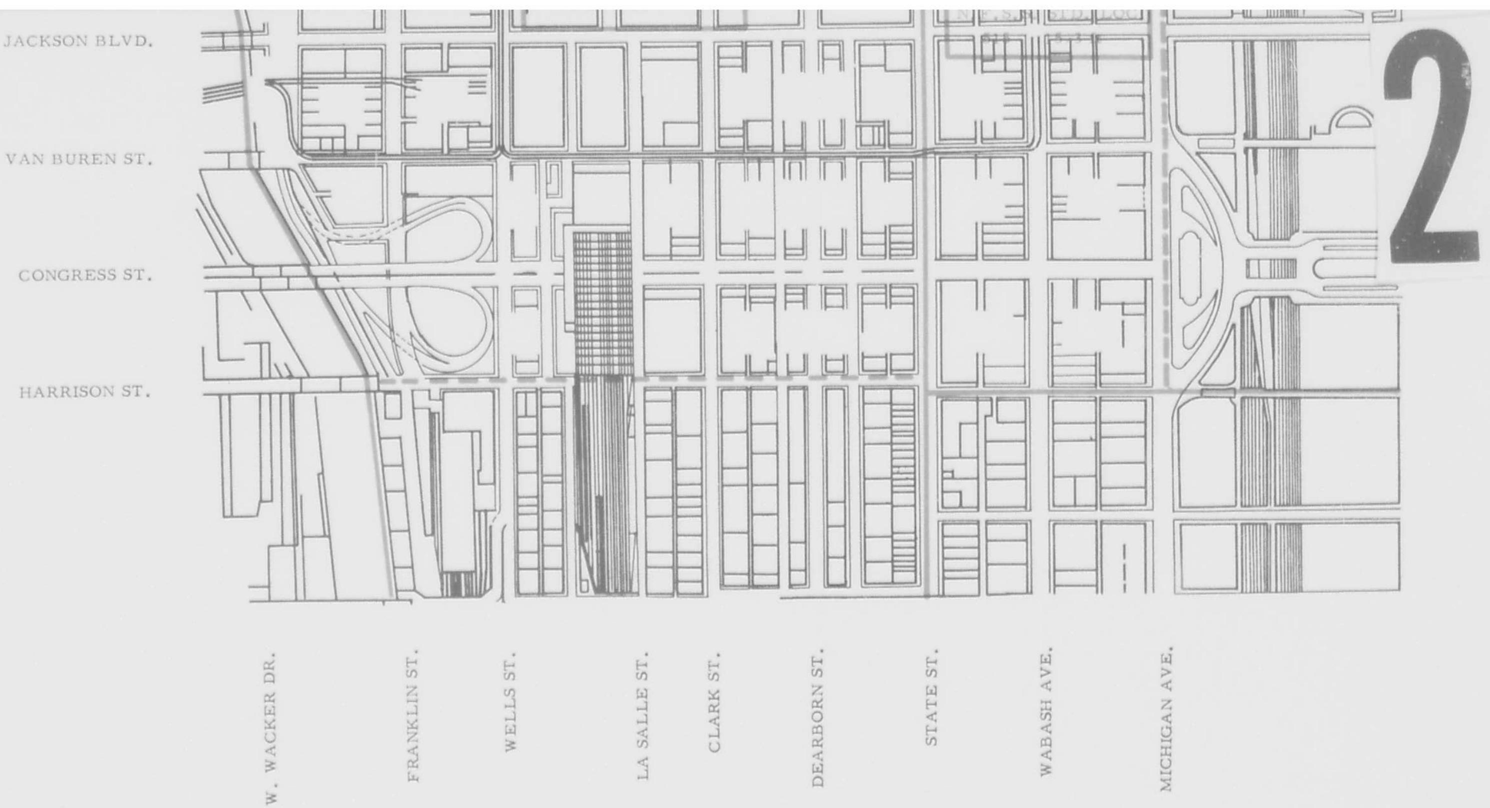


Fig. 2.6 DEBRIS DEPTHS FOR STANDARD LOCATIONS IN CENTRAL



DEBRIS DEPTHS ARE AVERAGES FOR COMPLETE FRAGMENTATION OF ALL BUILDINGS IN STANDARD LOCATION DEBRIS DEPTH FOR STANDARD LOCATION 514 IS ONLY FOR PORTION OF LOCATION NORTH OF HARRISON STREET, AS SHOWN BY DOTTED LINE. ONLY OCCUPIED BLOCKS OF STANDARD LOCATIONS 512 AND 515 ARE INCLUDED IN DEBRIS DEPTH CALCULATIONS, AS SHOWN BY DOTTED LINE

State Street viewed North from Van Buren Street

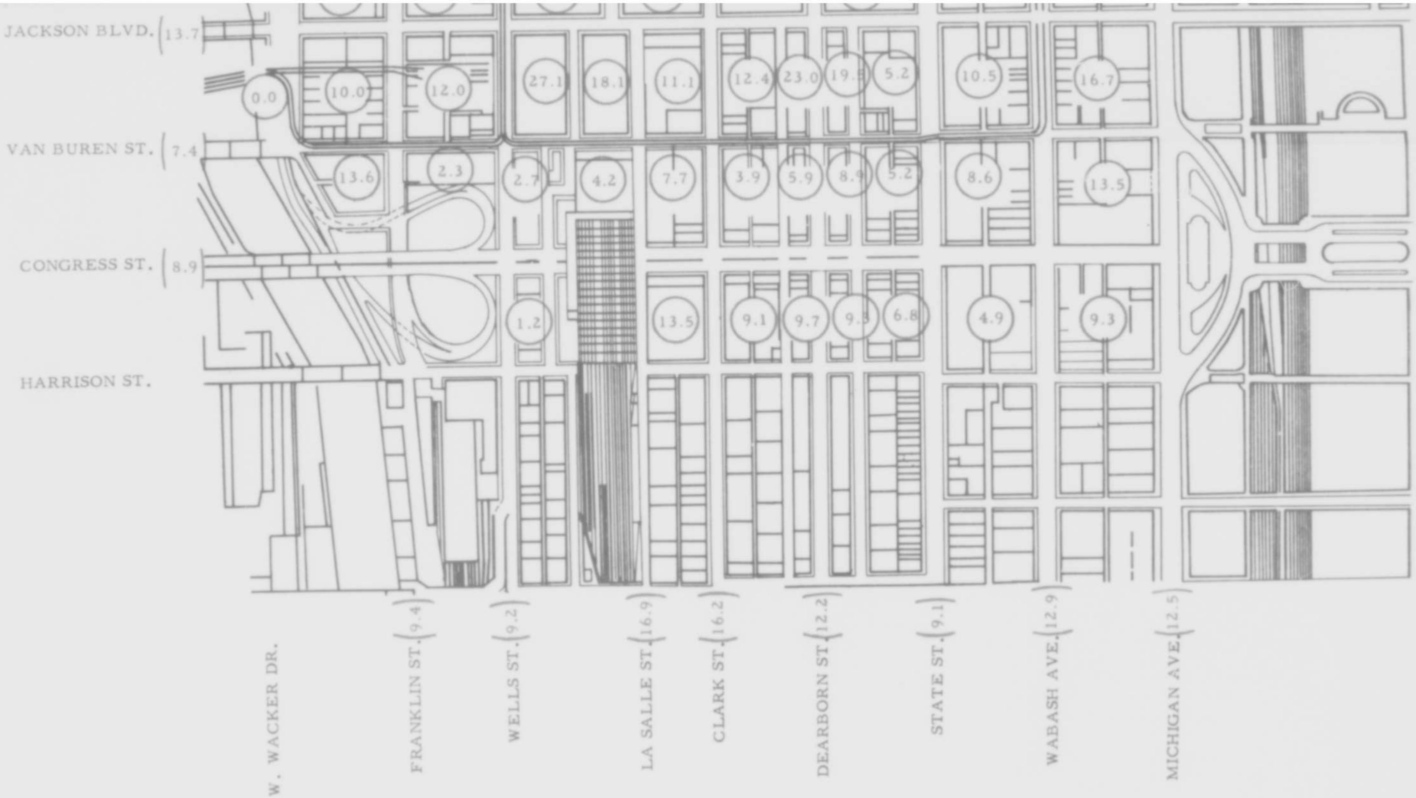
Michigan Avenue viewed from Lake Shore Drive at Chicago River

IONS IN CENTRAL BUSINESS DISTRICT OF CHICAGO

Fig. 2.7 DEBRIS DEPTHS FOR CITY BLOCKS AND STREETS IN CENTRAL BUSINESS

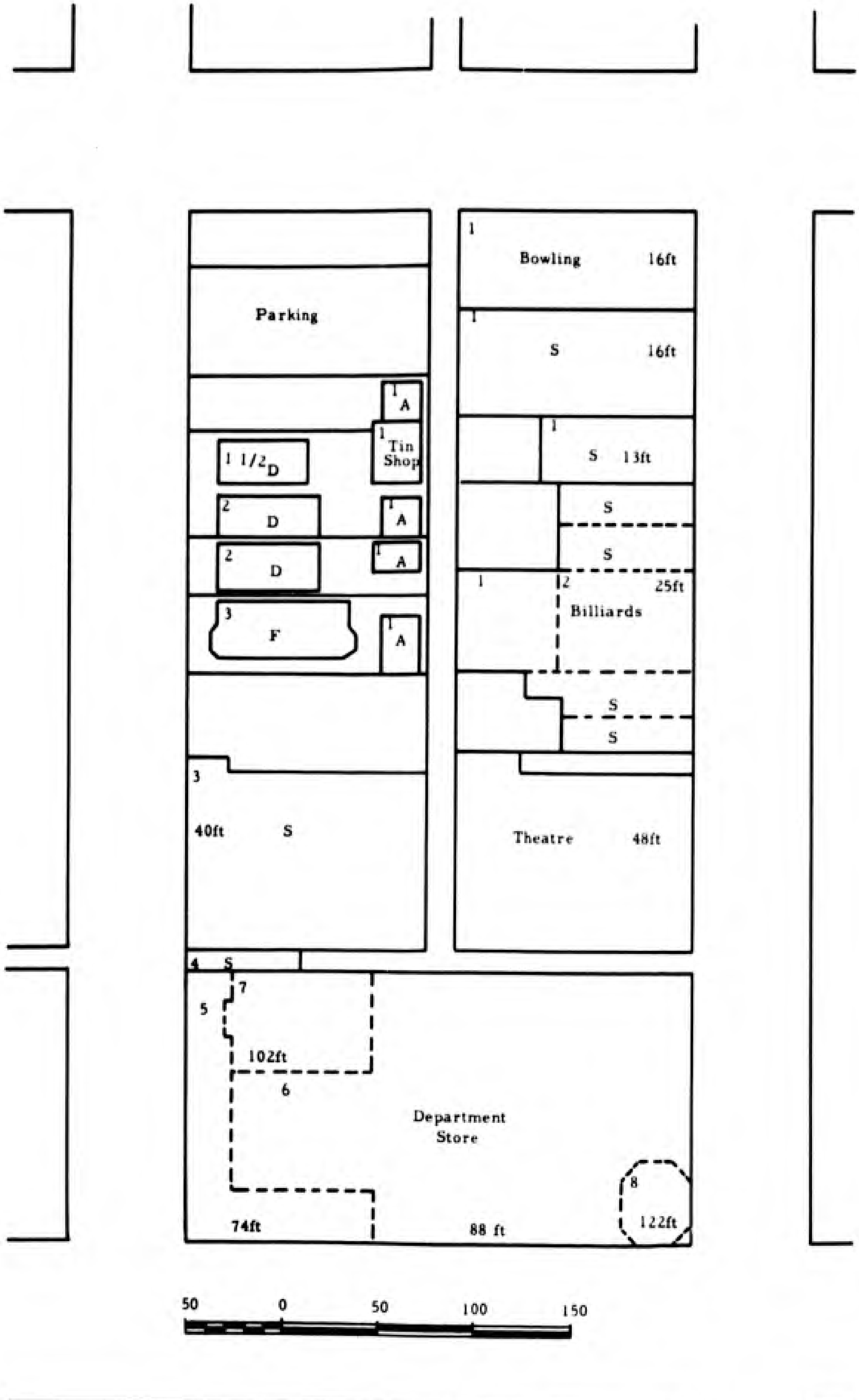
IN CENTRAL BUSINESS DISTRICT OF CHICAGO

2



Central business district viewed from
Lake Michigan at 12th Street

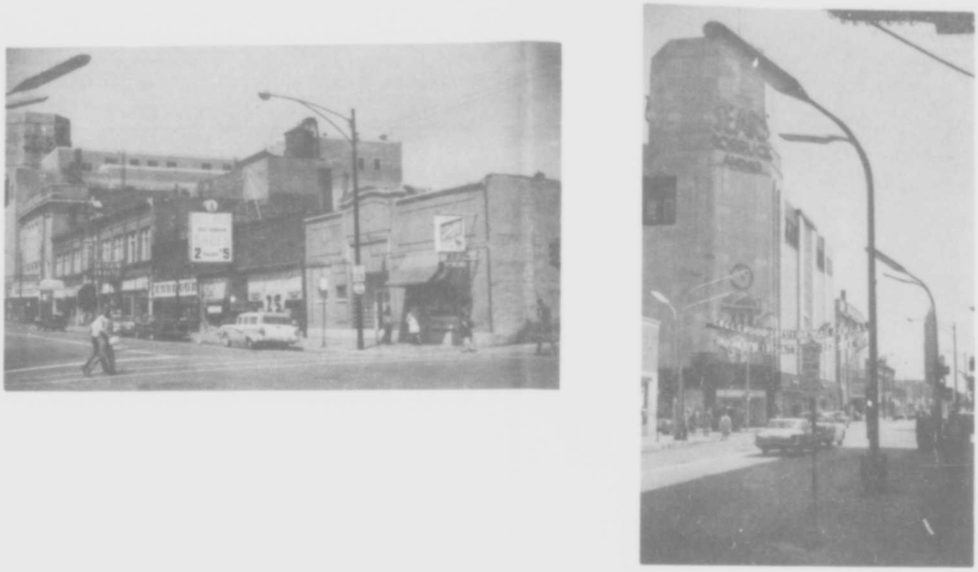
State Street viewed South from Lake Street



Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

Fig. 2.8

DEBRIS DEPTH FOR CITY BLOCK IN NEIGHBORHOOD BUSINESS DISTRICT



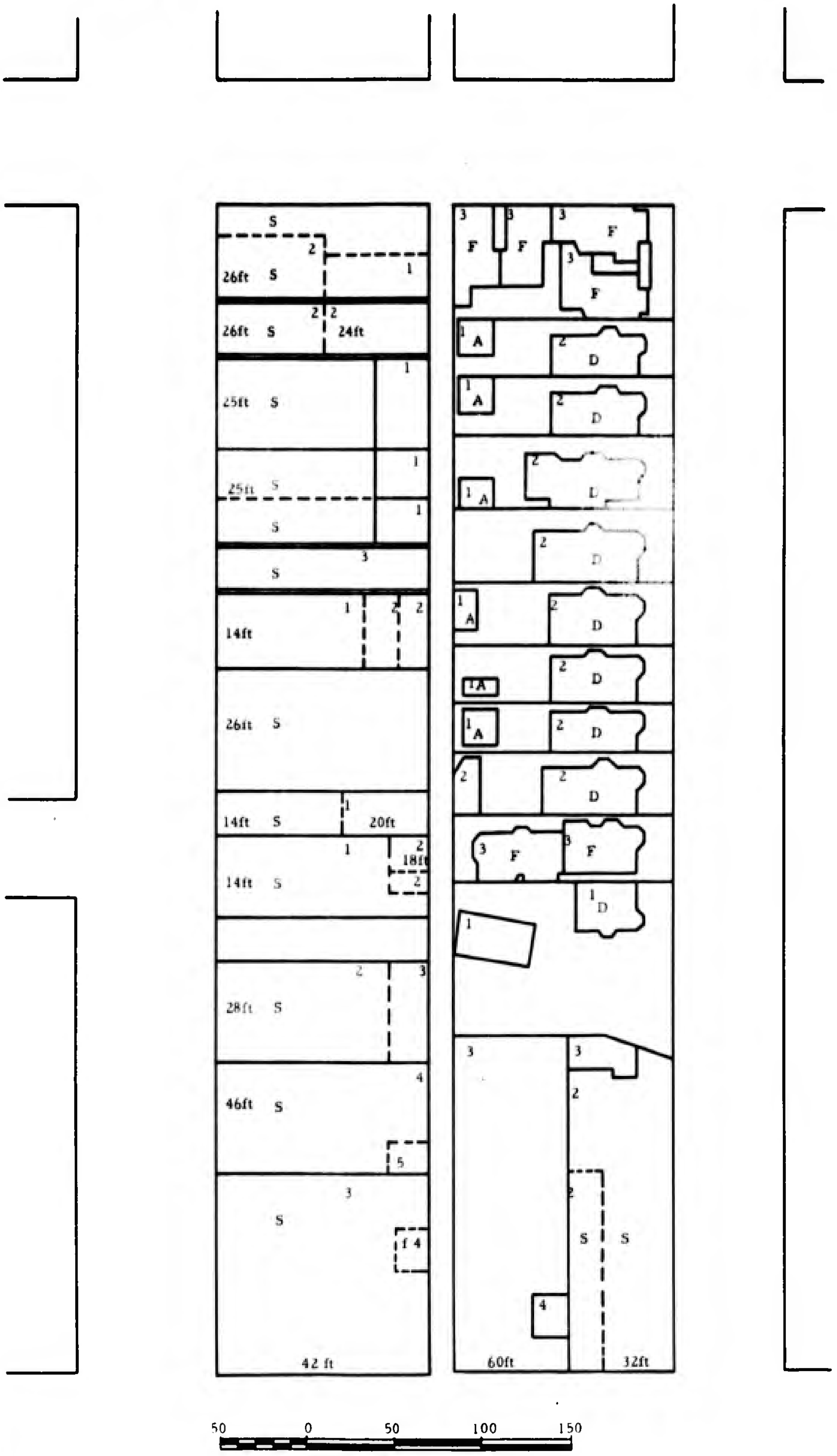
Floor Space:

Theatre, Shop, and Stores:	332,620	sq ft
Residences:	12,650	sq ft
Garages:	1,350	sq ft
Total:	346,620	sq ft

Contained Volume:	185,630	cu yd
Debris Volume:	44,800	cu yd
Area of Block, Including Streets and Alleys:	166,950	sq ft
Average Debris Depth:	7.2 ft	

2

S-store
A-auto garage
F-flat-building
D-dwelling



Note: Block layout reproduced through
courtesy of Sanborn Map Co., Inc.

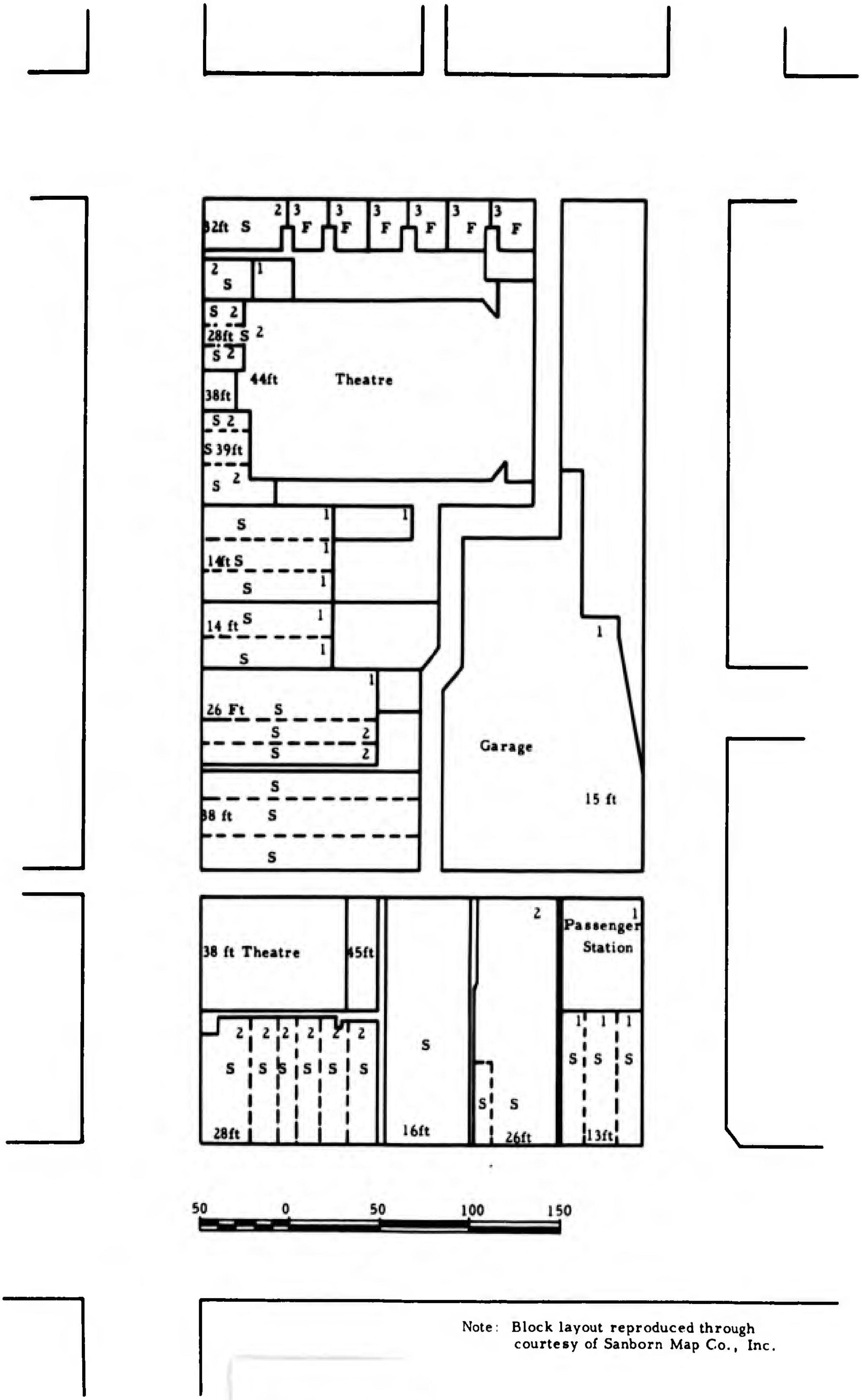
Fig. 2.9

DEBRIS DEPTH FOR CITY BLOCK IN NEIGHBORHOOD BUSINESS DISTRICT

Floor Spacing:		
Stores:	244,870	sq ft
Residences:	48,650	sq ft
Garages:	2,900	sq ft
Total	296,420	sq ft
Contained Volume:	142,784	cu yd
Debris Volume:	34,270	cu yd
Average Debris Depth:	4.5	ft
Area Of Block, Including Streets and Alleys:	207,050	sq ft

S- store
À-auto garage
F-flat-building
D-dwelling

2



Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

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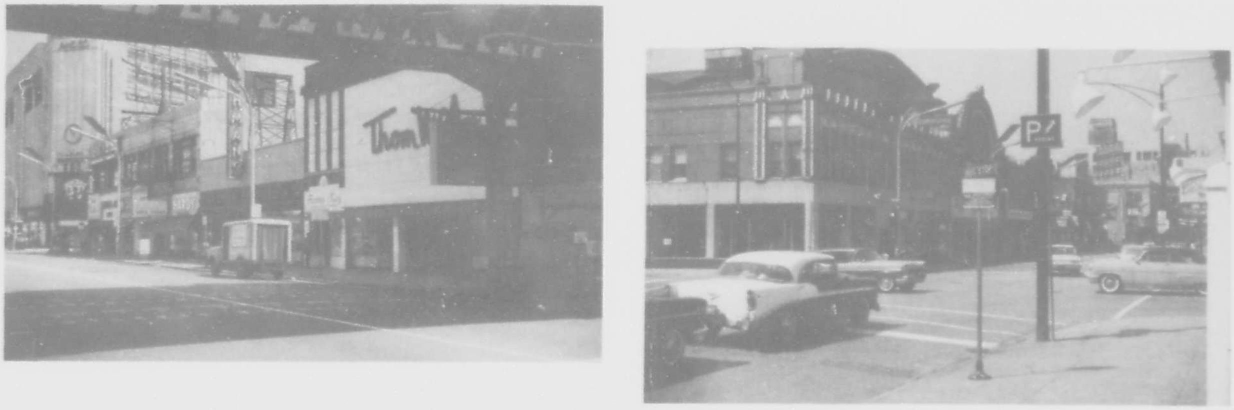
Fig. 2.10

DEBRIS DEPTH FOR CITY BLOCK IN NEIGHBORHOOD BUSINESS DISTRICT



Floor Space:

Theatre, Stores, Station, And Garage:	126,530	sq ft
Residences:	10,680	sq ft
Total	137,210	sq ft
Contained Volume:	103,630	cu yd
Debris Volume:	24,800	cu yd
Area Of Block, Including Streets And Alleys:	166,680	sq ft
Average Debris Depth:	4.0 ft	

S-store
A-auto garage
F-flat-building
D-dwelling

Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

[redacted]

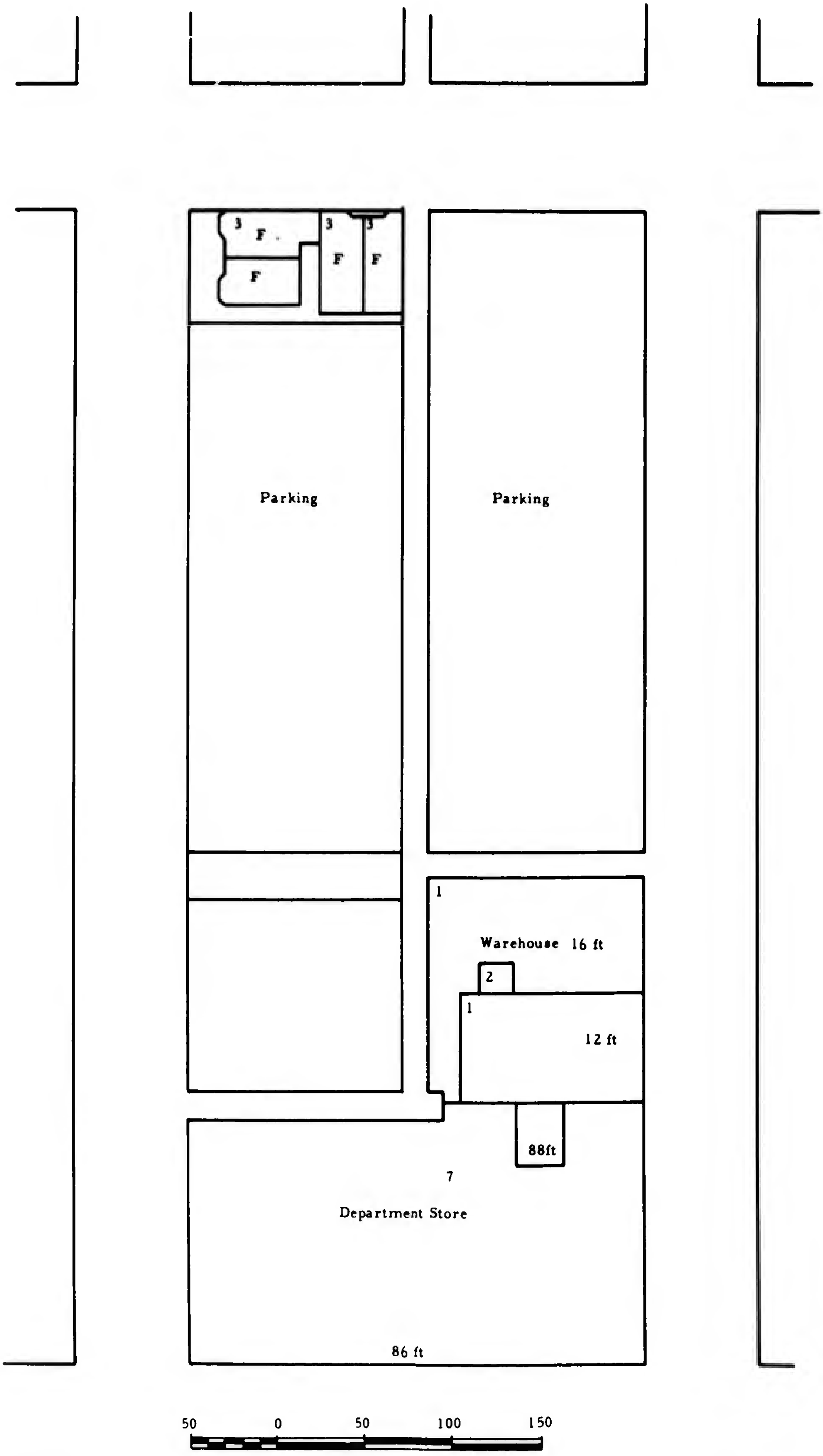
Fig. 2.11

DEBRIS DEPTH FOR BLOCK IN NEIGHBORHOOD BUSINESS DISTRICT

Floor Space:		
Theatre and Stores:	148,940	sq ft
Residences:	33,370	sq ft
Garages:	3,970	sq ft
Total	186,280	sq ft
Contained Volume:	110,270	cu yd
Debris Volume:	26,460	cu yd
Area of Block, Including Streets and Alleys:	202,240	sq ft
Average Debris Depth:	3.5	ft

S-store
A-auto-garage
F-flat-building
D-dwelling

2



Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

Fig. 2.12

DEBRIS DEPTH FOR CITY BLOCK IN NEIGHBORHOOD BUSINESS DISTRICT

Floor Space:

Store and Warehouse:	257,740	sq ft
Residences	16,310	sq ft
Total	274,050	sq ft

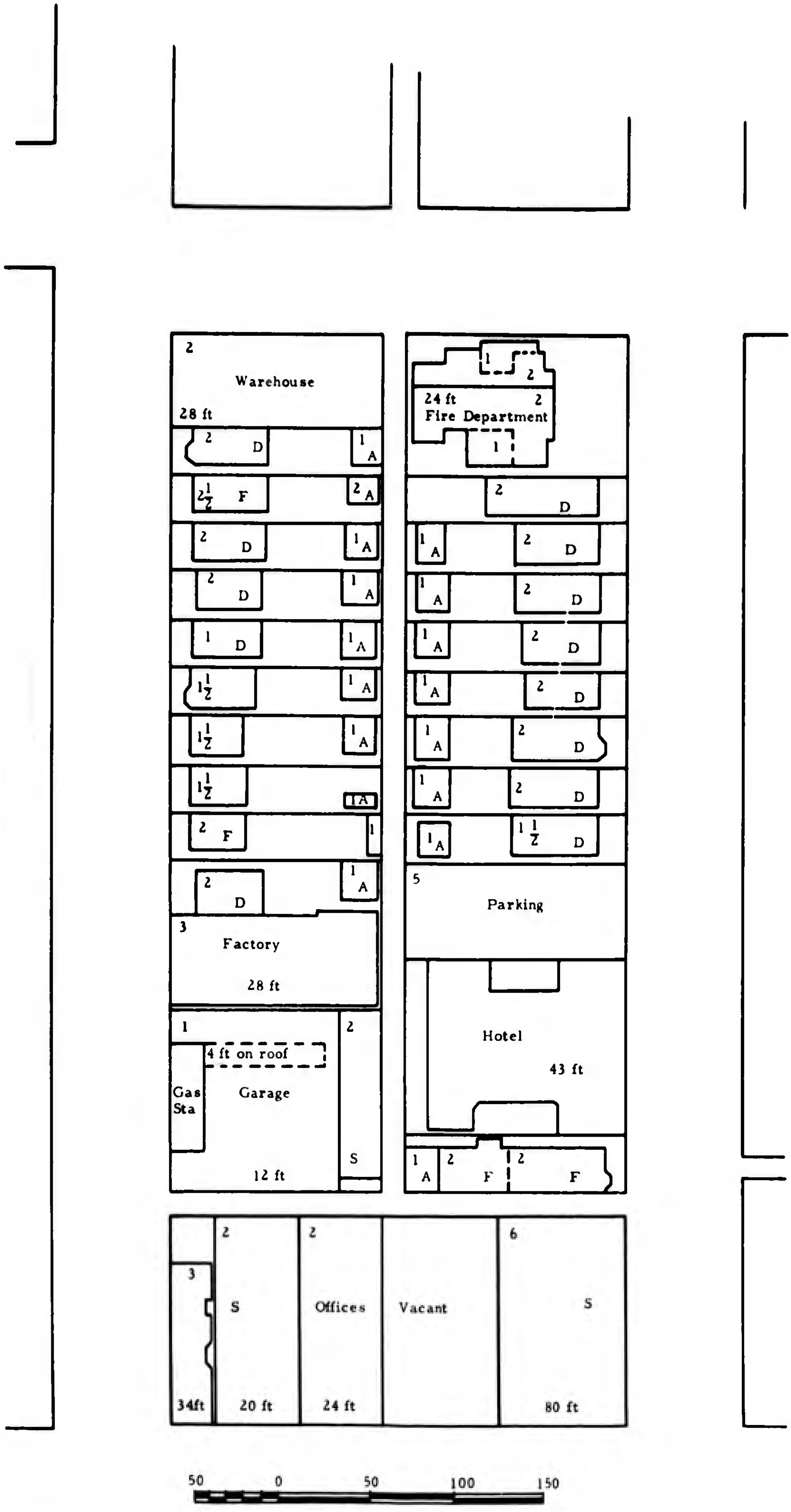
Contained Volume:	124,510	cu yd
Debris Volume:	29,880	cu yd
Area Of Block, Including Streets and Alleys:	184,000	sq ft
Average Debris Depth:	4.4	ft
One-Third Block Area, Excluding Parking Regions And Residences Above Alleys:	74,430	sq ft
Average Debris Depth Or Occupied Section Of Block, Below Alleys:	10.3	ft

2

S-store
A-auto garage
F-flat-building
D-dwelling

DE

1



Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

Fig. 2.13

DEBRIS DEPTH FOR CITY BLOCK IN NEIGHBORHOOD BUSINESS DISTRICT

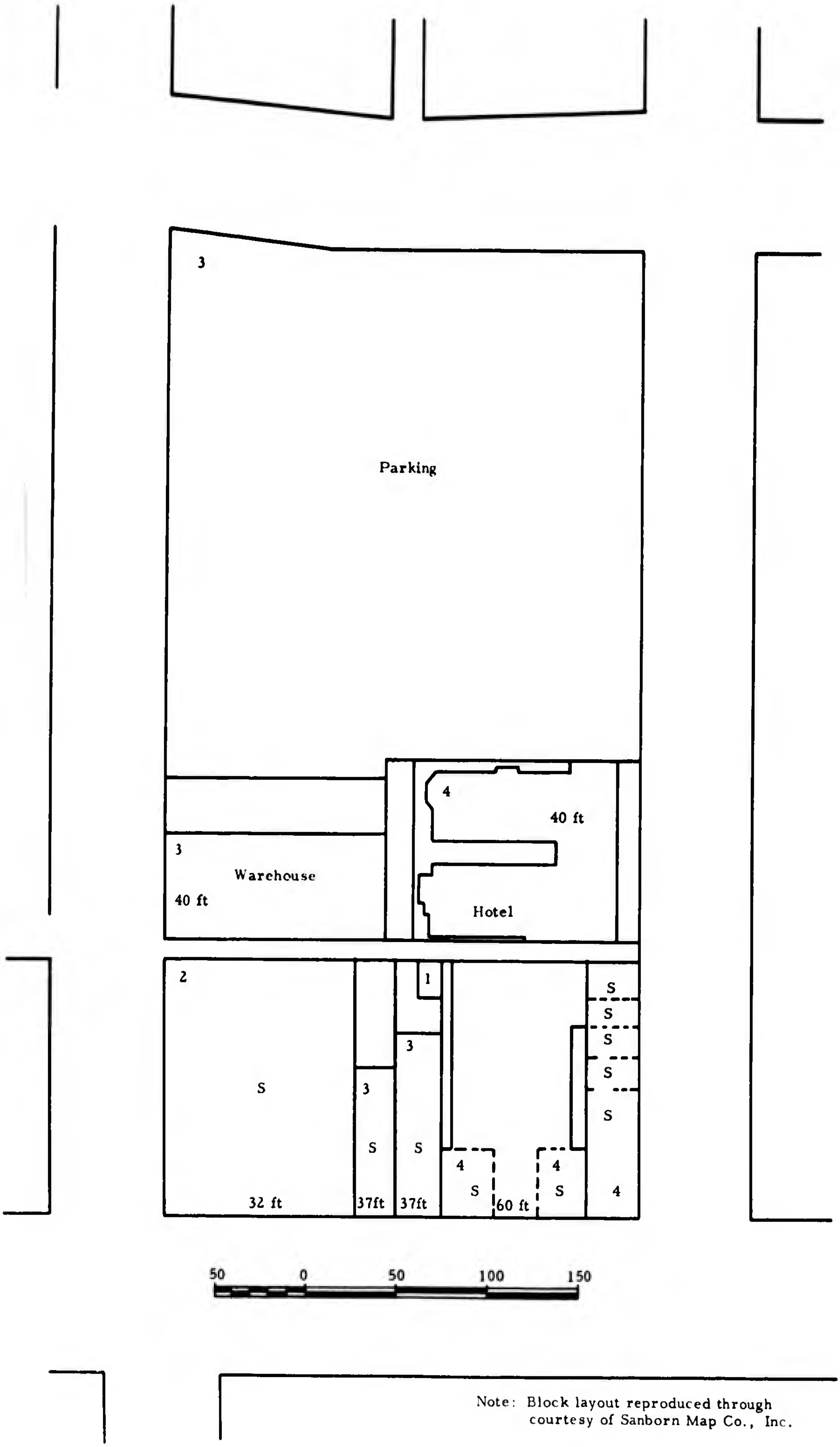
2

Floor Space:

Fire Department, Hotel, Stores, and Commercial Garage:	167,160	sq ft
Residences:	38,970	sq ft
Garages:	7,480	sq ft
Total	213,610	sq ft
Contained Volume:	91,490	cu yd
Debris Volume:	21,960	cu yd
Area of Block, Including Streets and Alleys:	192,000	sq ft
Average Debris Depth:	3.1 ft	

S-store
A-auto garage
F-flat-building
D-dwelling

1



Note: Block layout reproduced through
courtesy of Sanborn Map Co., Inc.

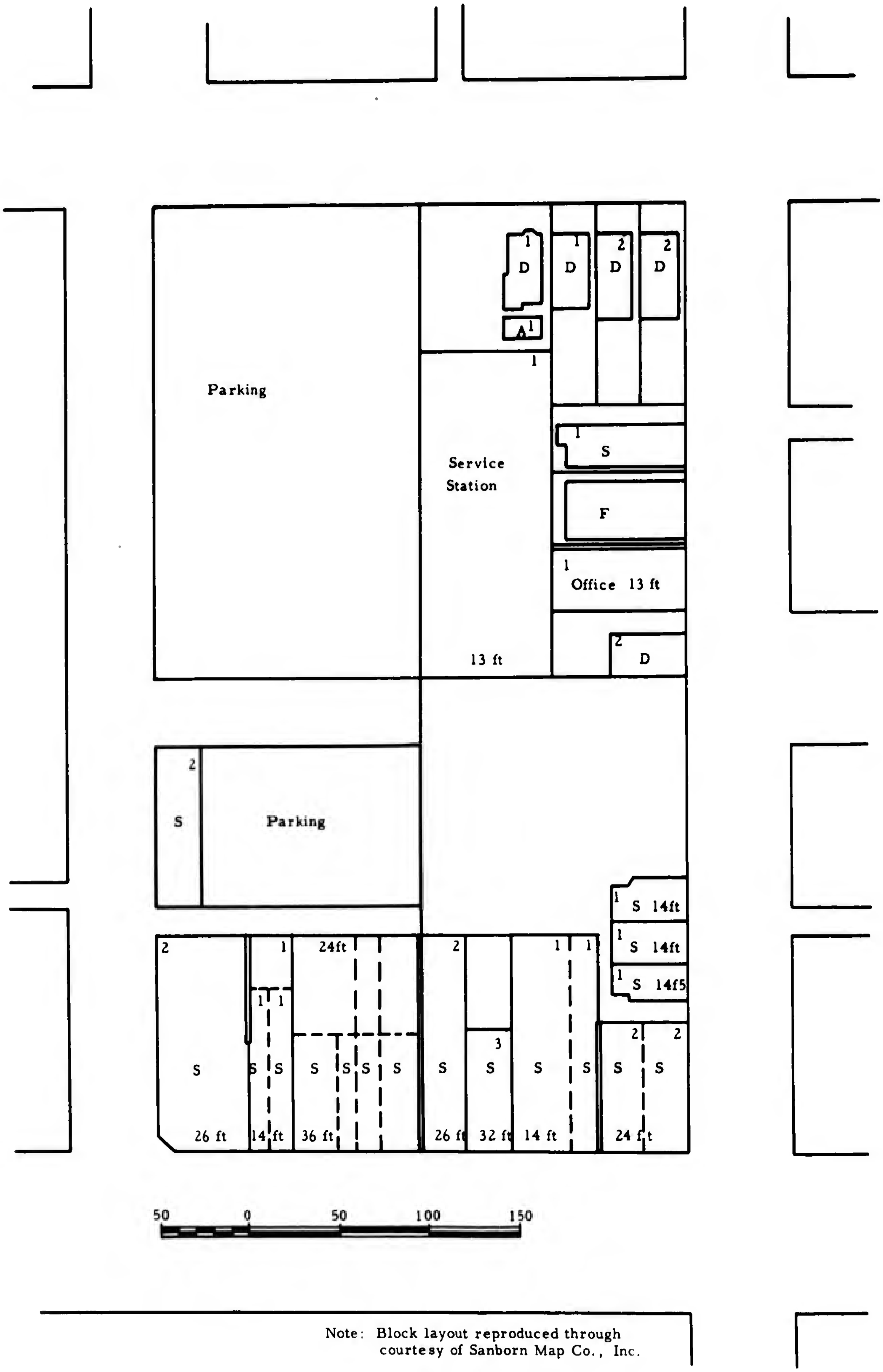
Fig. 2.14

DEBRIS DEPTH FOR CITY BLOCK IN NEIGHBORHOOD BUSINESS DISTRICT

2

Floor Space:		
Hotel and Stores:	147,750	sq ft
Garages:	240	sq ft
Total	147,990	sq ft
Contained Volume:	67,961	cu yd
Debris Volume:	16,310	cu yd
Area of Block, Including Streets and Alleys:	176,000	sq ft
Average Debris Depth for Entire Block:	2.5	ft
Area of Half-Block, Excluding Parking Lot Section:	71,500	sq ft
Average Debris Depth for Half-Block Excluding Parking Lot Section:	5.2	ft

S- store
A-auto garage
F-flat-building
D-dwelling



Note: Block layout reproduced through
courtesy of Sanborn Map Co., Inc.

Fig. 2.15

DEBRIS DEPTH FOR CITY BLOCK IN NEIGHBORHOOD BUSINESS DISTRICT

Floor Space:

Stores:	98,920	sq ft
Residences:	8,100	sq ft
Private Garage:	270	sq ft
Total	107,290	sq ft
Contained Volume:	49,500	cu yd
Debris Volume:	11,870	cu yd
Average Debris Depth:	1.6 ft	
Area Of Block, Including Streets And Alleys:	194,930	sq ft

S-store
A-auto garage
F-flat-building
D-dwelling

2.3.3 Debris Accumulation in Region of High-Rise Apartments

The Stateway Gardens Project of the Chicago Housing Authority, shown in Fig. 2.16, was selected as an example of debris levels which can be expected in regions of high-rise housing. Structural material in these buildings, computed from detailed building plans, is about 15 percent of total contained volume. On this basis the average debris depth for complete demolition of this region is 2.1 ft, as indicated in Fig. 2.16. It is to be noted that open spaces between buildings in this region are large. Similar structures, more densely packed, would yield greater debris depths.

2.3.4 Debris Accumulation in a Suburban Shopping Center

Use of suburban shopping centers as post-attack staging areas has been given consideration, since their large adjacent parking areas appear relatively easy to decontaminate. In view of this, it is appropriate to consider the depth of debris likely to be present in these areas, should the center be in an overpressure region sufficient to demolish the structure. An actual shopping center in a Chicago suburb, shown in Fig. 2.17 was selected for illustration purposes. Average debris depth for total destruction of structures is estimated to be about 1.3 ft. Structural materials were considered to be 15 percent of total contained building in this case, since considerable concrete construction is included, as well as covered sidewalks, outdoor columns, and other "non-building" walls. It should also be noted here that this debris estimate does not include automobile rubble. For a daytime attack on a busy shopping day, inoperable automobiles would add substantially to the clearance problem in this region. Parking lot capacity in this center is 7,400 vehicles, though it is seldom completely filled.

2.3.5 Debris Accumulation in Residential Areas

Even in the largest cities, much of the area destroyed by air blast will be residential. Regions of one-and two-family residences are found within two miles of central business districts in most cities. Average debris depths for selected residential blocks are summarized in the following figures:

Figure No.	Type of Neighborhood	Average Debris Depth
2.18	Three and four-story flat-buildings, stores, and garages	2.6 ft
2.19	Three-story flat-buildings, with garages	2.4 ft
2.20	Three-story flat-buildings, with garages	2.3 ft
2.21	Stores, residences, and garages	2.2 ft
2.22	Two and three-story flat-buildings and garages	1.9 ft
2.23	Two-story flat-buildings and garages	0.88 ft
2.24	One and two-story residences, and garages	0.66 ft
2.25	One and two-story residences, and garages	0.61 ft

2.4 Debris from Steel-Frame Mill Buildings

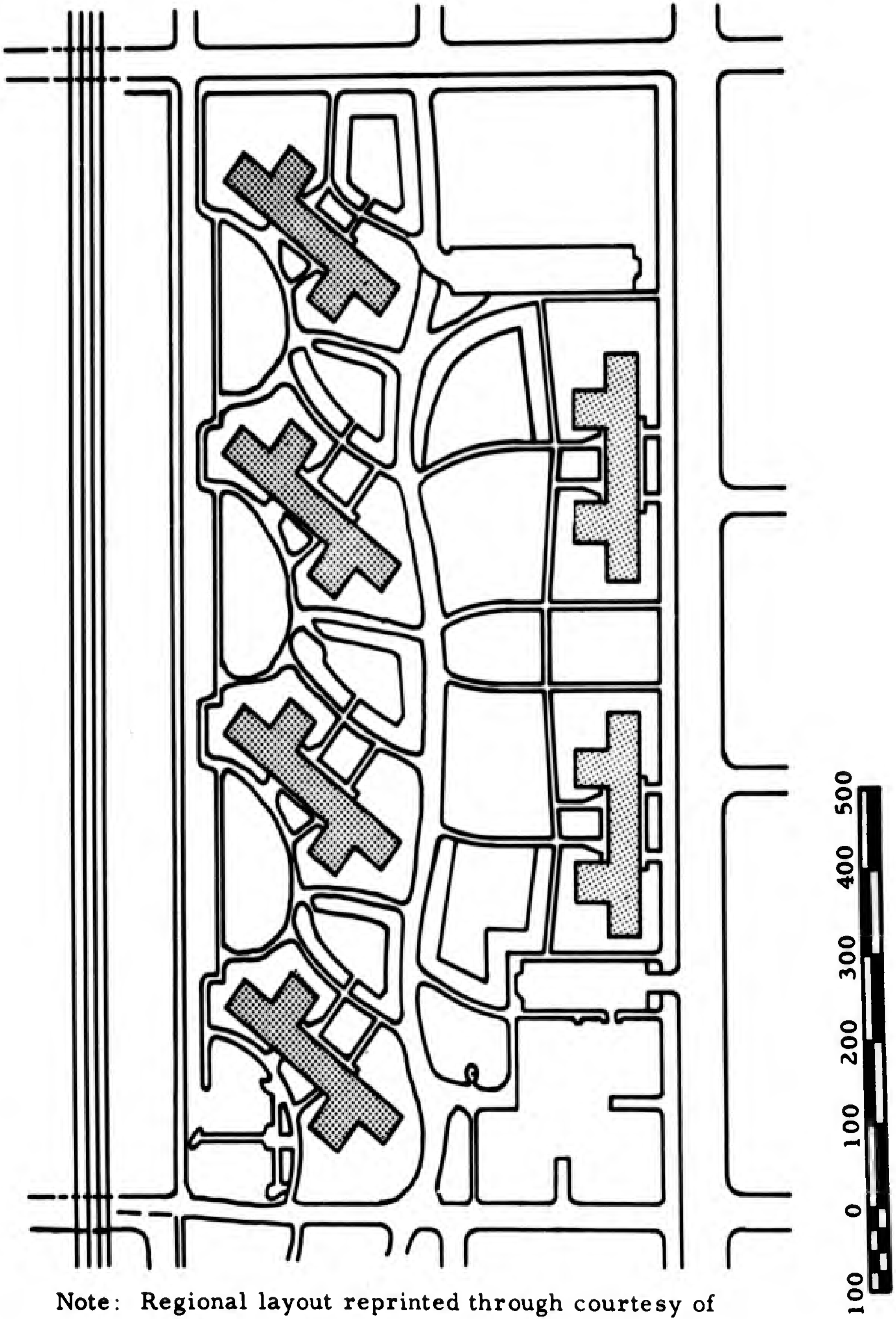
Failure of steel-frame buildings from blast wind loading would be characterized by

- stripping of roofing and siding which can be transported considerable distances by the blast winds
- severe distortion and collapse of the structural framework

The collapsed framework would be expected to remain in the immediate vicinity of the foundation. Blast effects on this type of structure at Nagasaki are shown in Fig. 2.26.

While destruction of these structures may contribute little to the general level of debris, especially in neighboring vehicular thoroughfares, the removal of these structures requires substantial effort. The steel members must be reduced to lengths suitable for handling and hauling. For a large number of industrial mill buildings, this will require a great deal of cutting - - either by torches, portable abrasive cutoff saws, or explosive charges.

The quantity of structural steel in frameworks of industrial steel-frame structures can be estimated, in terms of outside building dimensions, from Fig. 2.27. Results are in pounds of steel, an appropriate index for these collapsed and distorted frameworks since it is feasible to set work standards for cutting steel in terms of hours/ton, and since vehicular limits



Note: Regional layout reprinted through courtesy of Chicago Housing Authority

Fig. 2.16

DEBRIS DEPTH FOR REGION OF HIGH-RISE APARTMENTS

Floor Space:

10-story TT's: 2 at 81,500 sq ft = 163,000 sq ft

17-story Z's: 4 at 138,550 sq ft = 554,200 sq ft

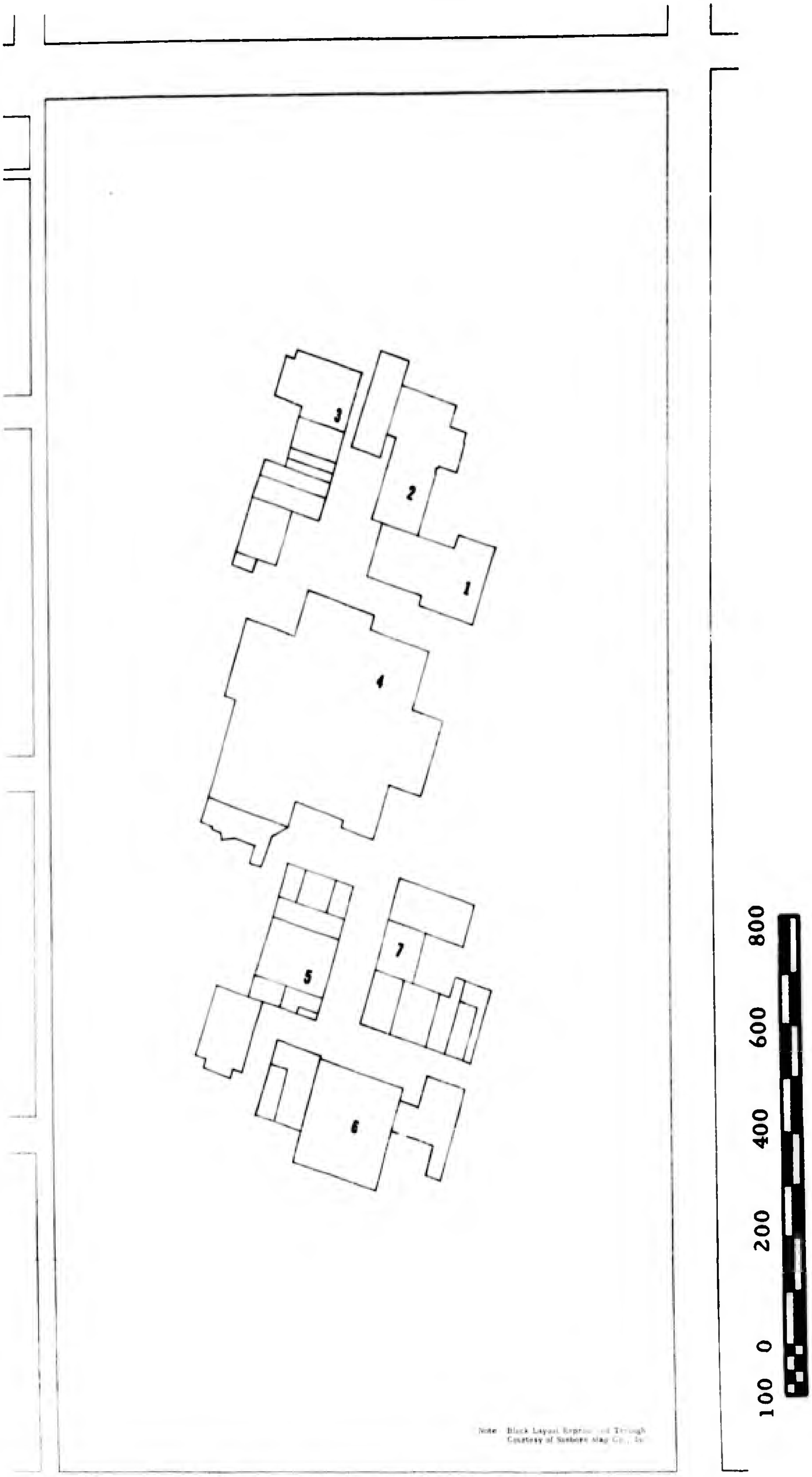
Total: 717,200 sq ft

Contained Volume: 265,630 cu yd

Debris Volume: 79,690 cu yd

Area of Region, Including Streets and Parking Areas: 1,026,000 sq ft

Average Debris Depth: 2.1 ft



Note: Block Layout Reproduced Through
Courtesy of Sanborn Map Co., Inc.

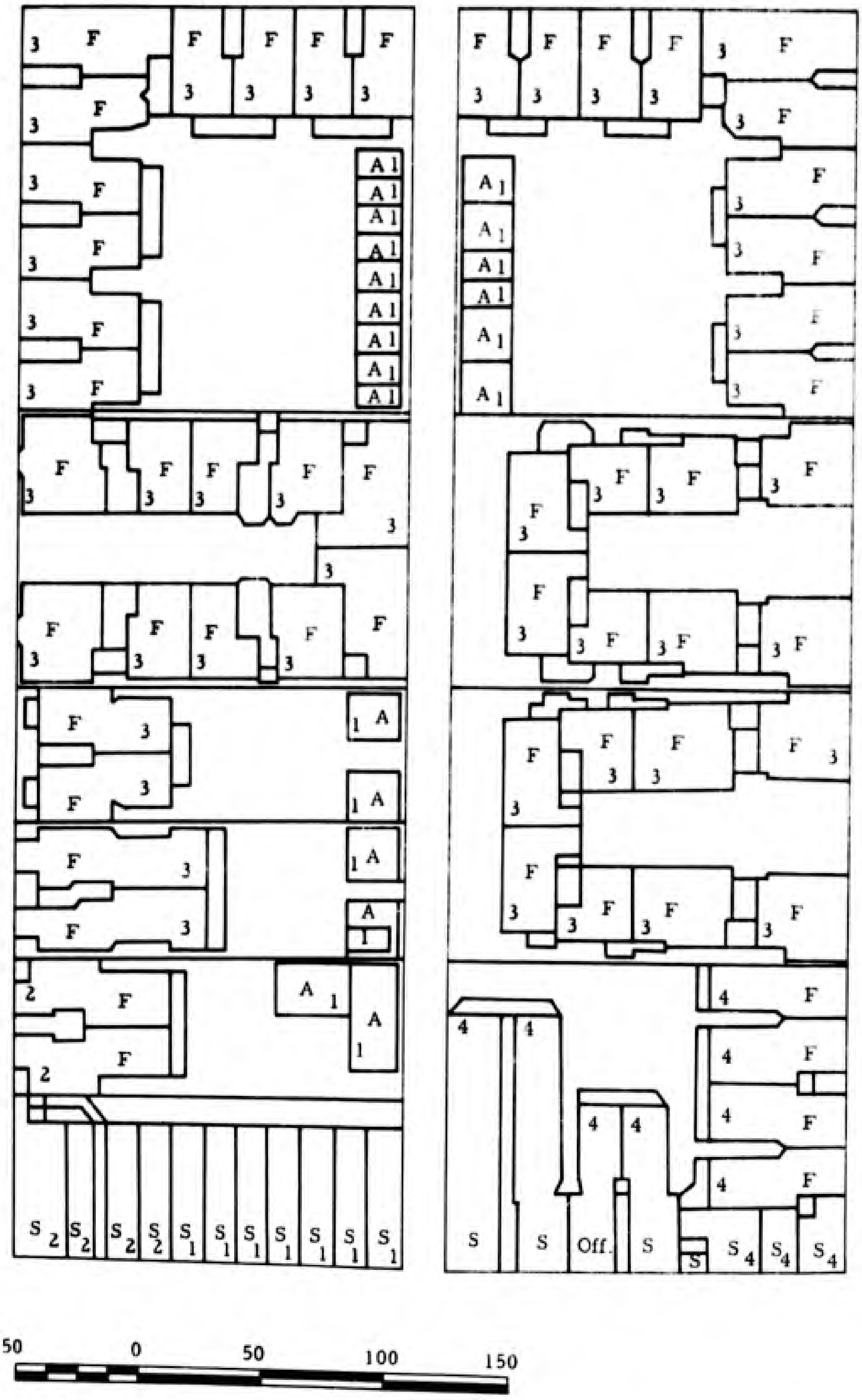
Fig. 2.17

DEBRIS DEPTH FOR SUBURBAN SHOPPING CENTER

Floor Space and Building Volumes:

Building Number	Floor Space sq ft	Contained Volume cu yd
1	73,590	40,390
2	85,290	40,580
3	46,900	27,790
4	232,440	155,890
5	51,560	36,570
6	101,390	59,160
7	46,760	27,710
Total	637,930	388,090

Debris Volume:	116,426 cu yd
Area of Lot, from South End of Building to Mid-Street at North End:	2,385,000 sq ft
Average Debris Depth:	1.3 ft



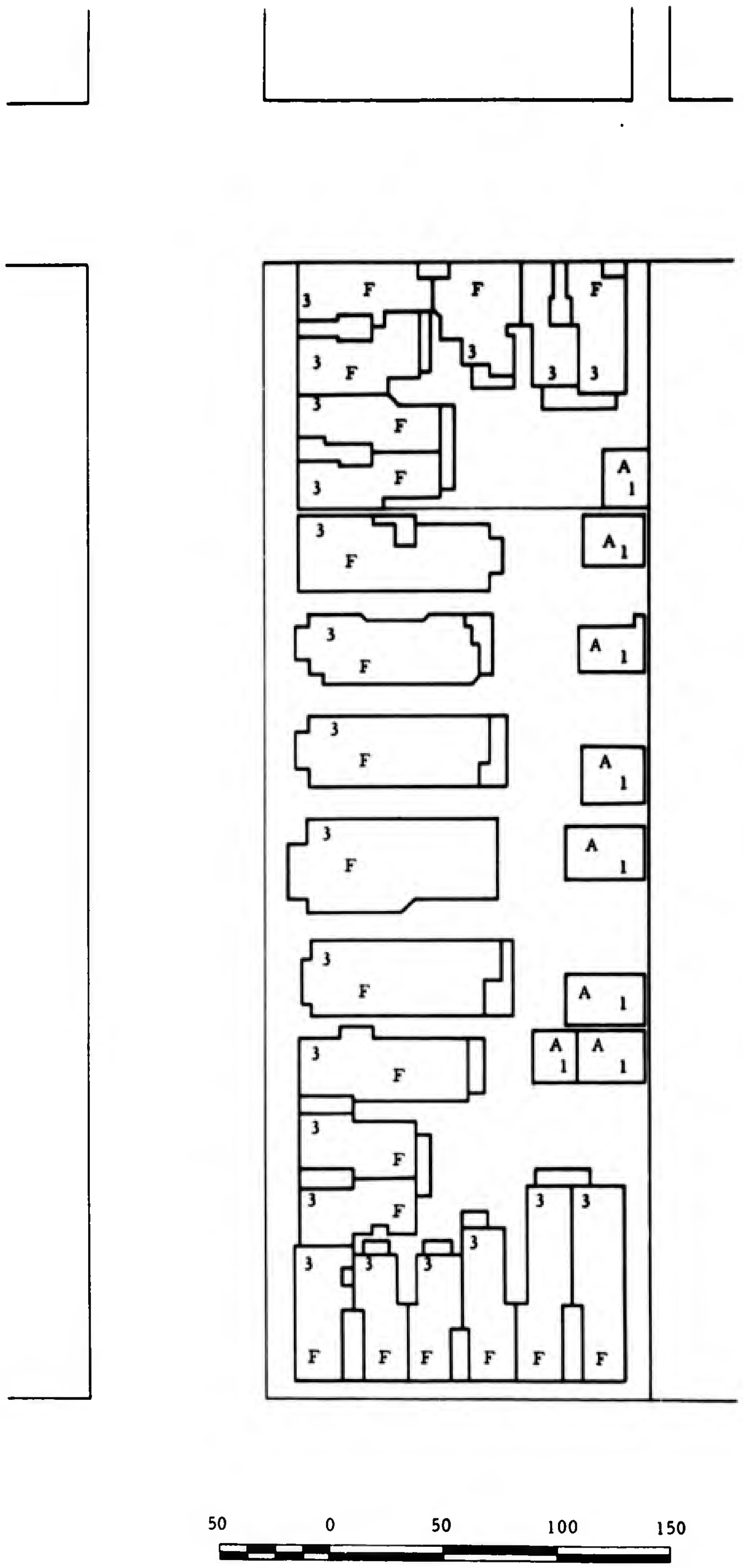
Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

Fig. 2.18

DEBRIS DEPTH FOR BLOCK OF THREE AND FOUR-STORY FLAT-BUILDINGS, STORES, AND GARAGES

Floor Space:	
Residences:	194, 310 sq ft
Stores and Offices:	43, 660 sq ft
Garages:	6, 830 sq ft
Total:	244, 800 sq ft
Contained Volume:	90, 670 cu yd
Debris Volume:	21, 760 cu yd
Area of Block, Including Streets and Alleys:	225, 500 sq ft
Average Debris Depth:	2.6 ft

S-store
A-auto garage
F-flat-building
D-dwelling



Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

Fig. 2.19

DEBRIS DEPTH FOR HALF-BLOCK OF THREE-STORY FLAT-BUILDINGS AND GARAGES

Floor Space:

Residences: 106,340 sq ft

Garages: 4,960 sq ft

Total: 111,300 sq ft

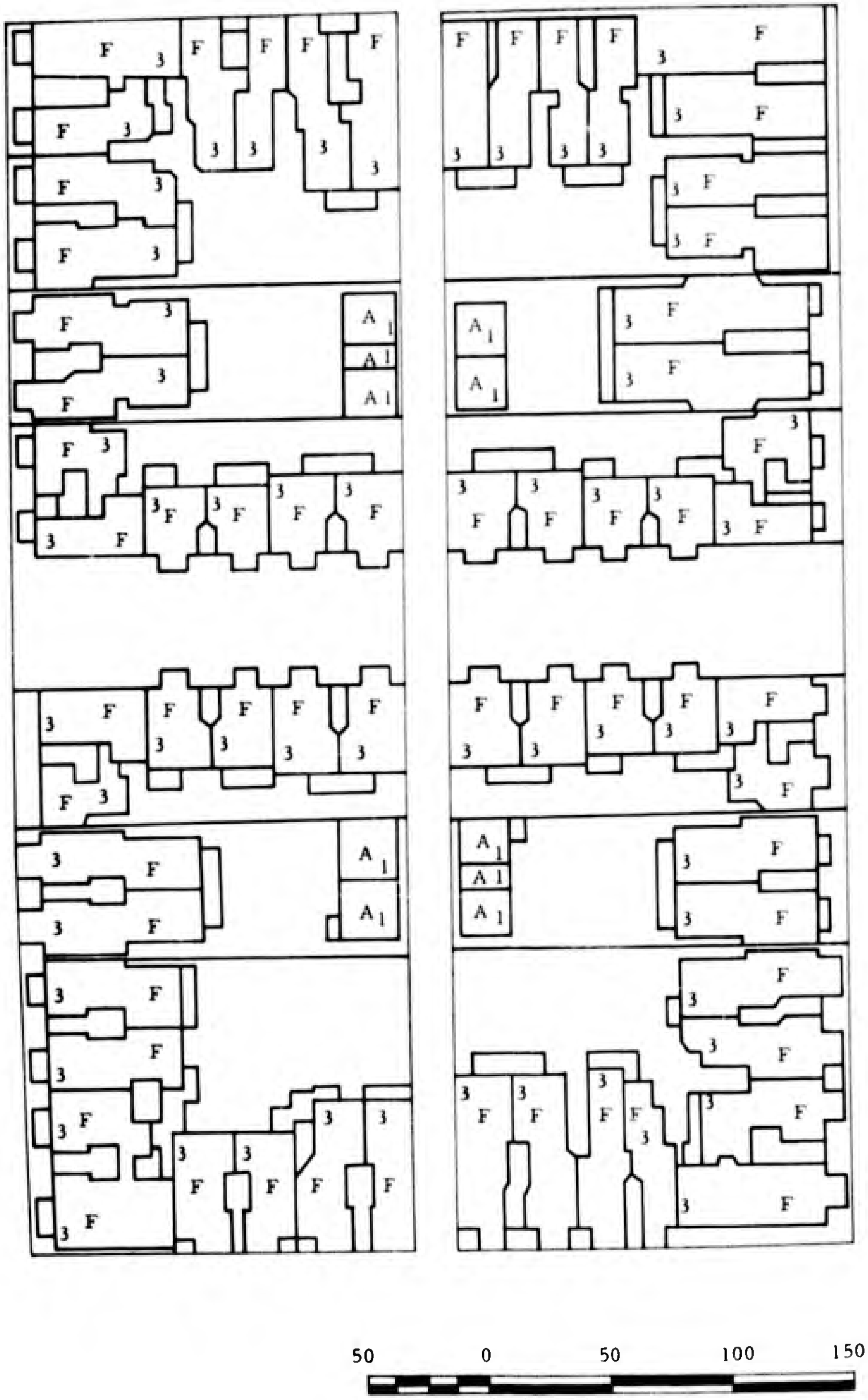
Contained Volume: 41,200 cu yd

Debris Volume: 9,890 cu yd

Area of Half-Block, Including Streets and Alleys: 112,800 sq ft

Average Debris Depth: 2.4 ft

S-store
A-auto garage
F-flat-building
D-dwelling



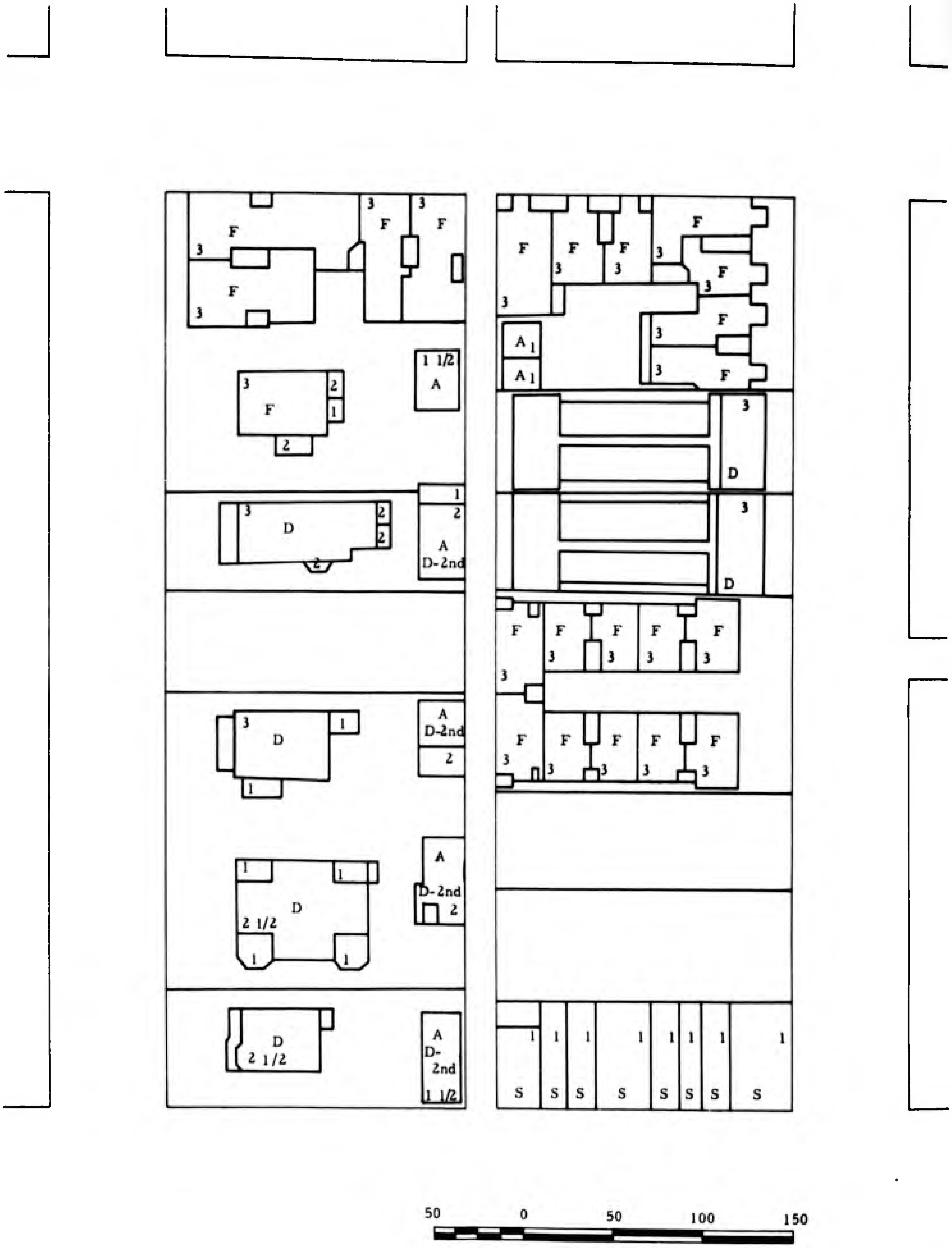
Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

Fig. 2.20

DEBRIS DEPTH FOR BLOCK OF THREE-STORY FLAT-BUILDINGS AND GARAGES

Floor Space:	
Residences:	212,750 sq ft
Garages:	3,770 sq ft
Total:	216,520 sq ft
Contained Volume:	80,190 cu yd
Debris Volume:	19,250 cu yd
Area of Block, Including Streets and Alleys:	227,400 sq ft
Average Debris Depth:	2.3 ft

S-store
A-auto garage
F-flat-building
D-dwelling



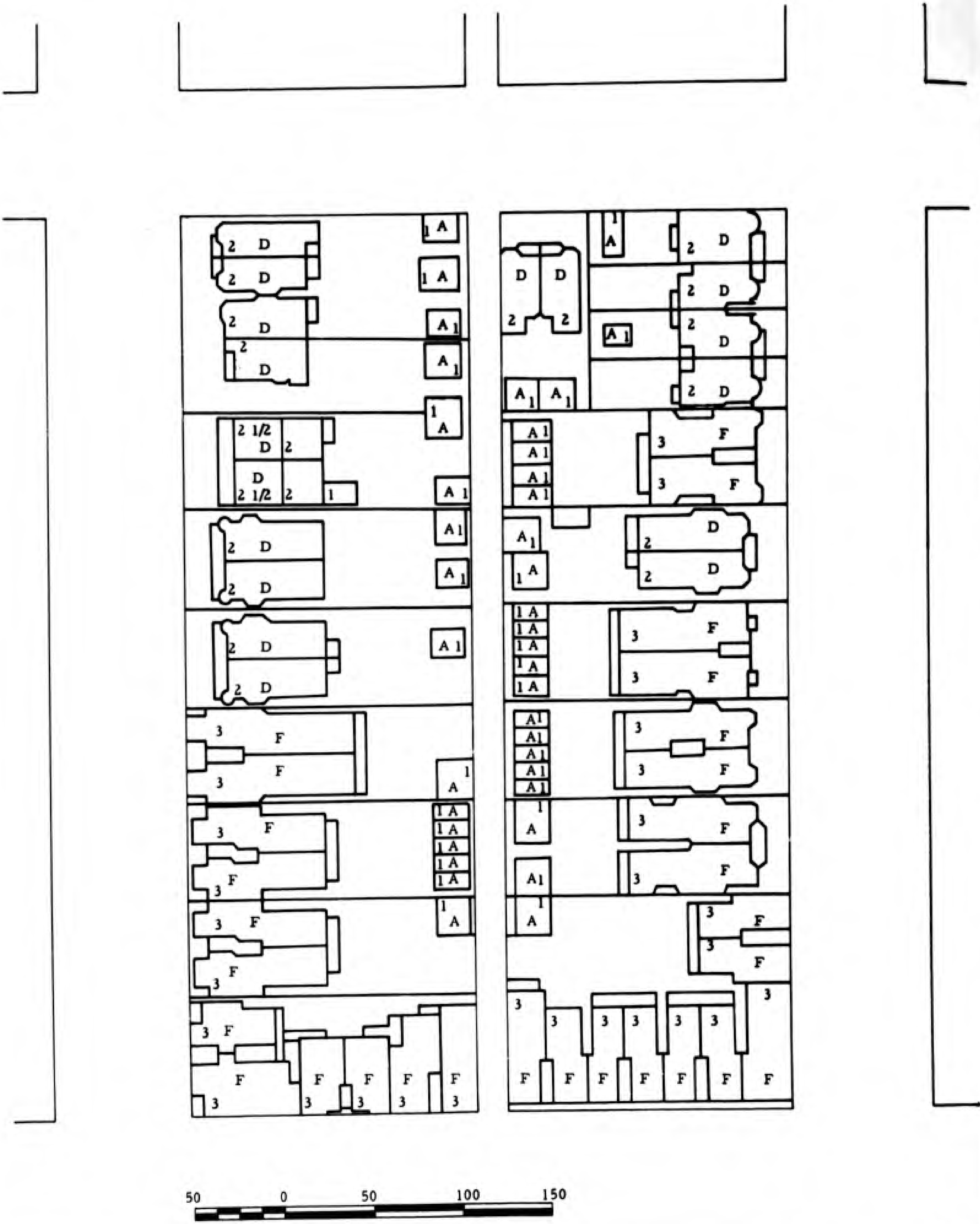
Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

Fig. 2.21

DEBRIS DEPTH FOR BLOCK OF STORES, RESIDENCES AND GARAGES

Floor Space:	
Residences:	157, 080 sq ft
Stores:	9, 790 sq ft
Garages:	5, 770 sq ft
Total:	172, 640 sq ft
Contained Volume:	63, 940 cu yd
Debris Volume:	15, 350 cu yd
Area of Block, Including Streets and Alleys:	188, 100 sq ft
Average Debris Depth:	2.2 ft

S-store
A-auto garage
F-flat-building
D-dwelling



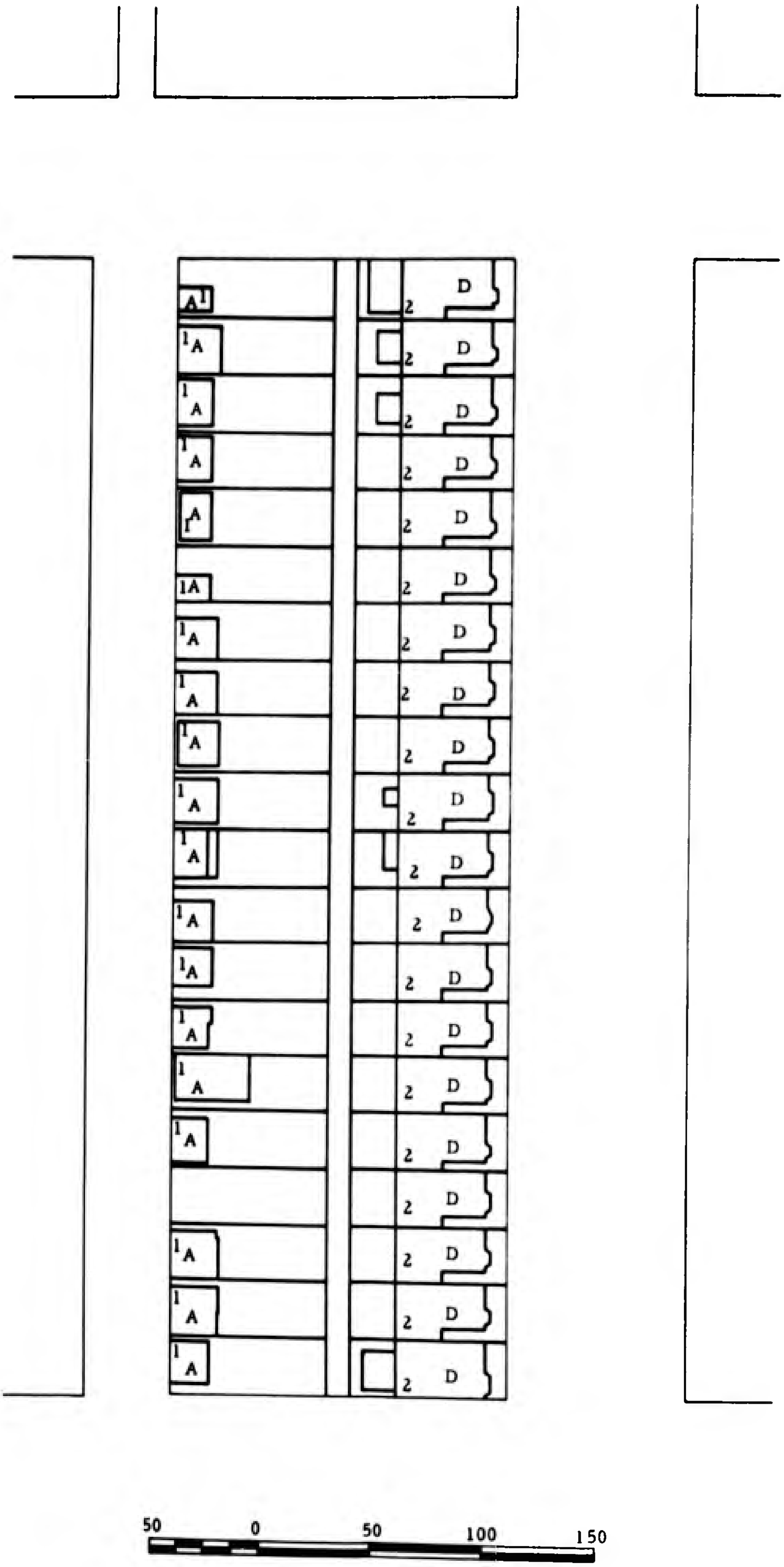
Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

Fig. 2.22

DEBRIS DEPTH FOR BLOCK OF TWO AND THREE-STORY FLAT-BUILDINGS, AND GARAGES

Floor Space:	
Residences:	151,770 sq ft
Garages:	10,190 sq ft
Total:	161,960 sq ft
Contained Volume:	59,990 cu yd
Debris Volume:	14,400 cu yd
Area of Block, Including Streets and Alleys:	201,800 sq ft
Average Debris Depth:	1.9 ft

S-store
A-auto garage
F-flat-building
D-dwelling



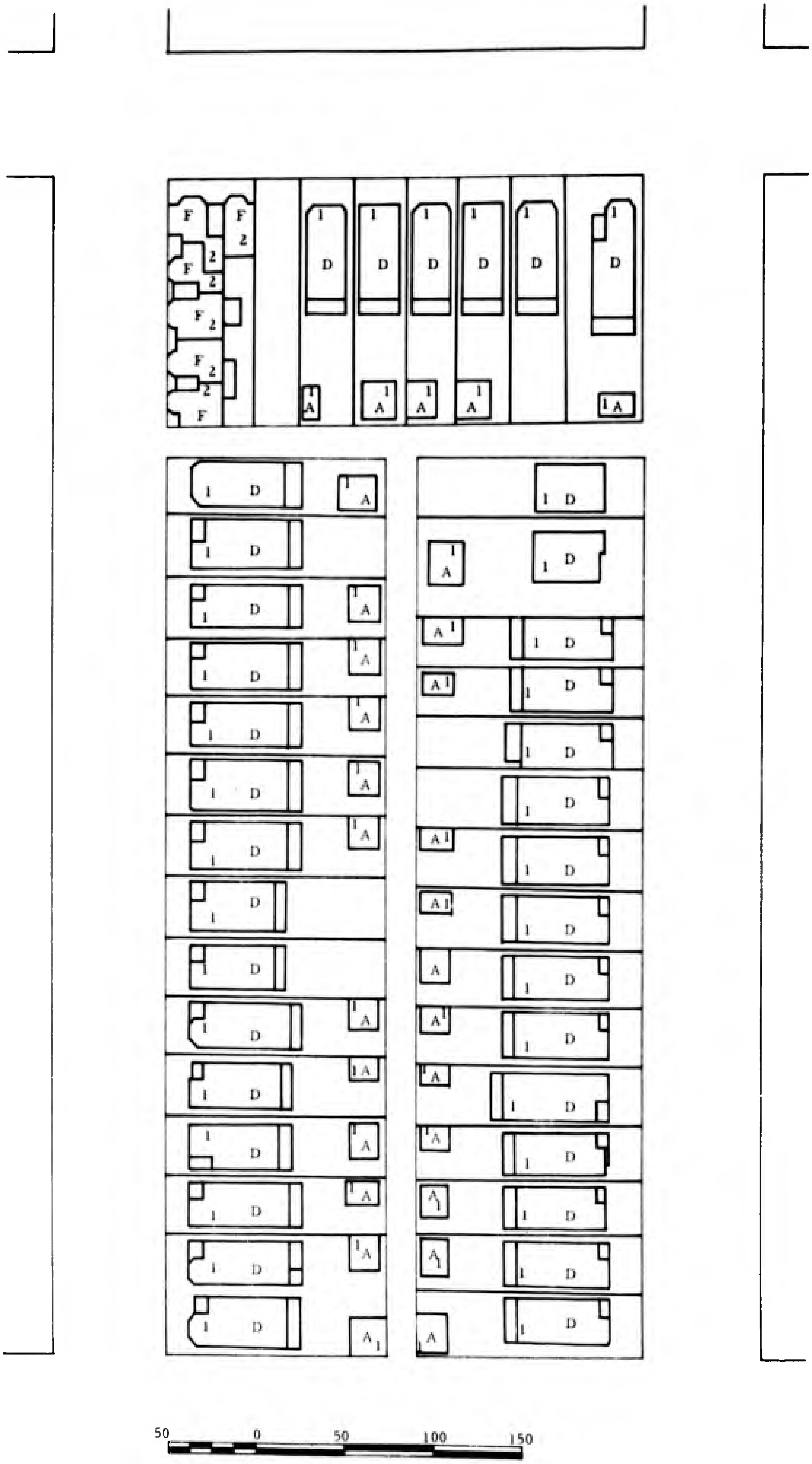
Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

Fig. 2.22

DEBRIS DEPTH FOR BLOCK OF TWO AND THREE-STORY FLAT-BUILDINGS, AND GARAGES

Floor Space:	
Residences:	151,770 sq ft
Garages:	10,190 sq ft
Total:	161,960 sq ft
Contained Volume:	59,990 cu yd
Debris Volume:	14,400 cu yd
Area of Block, Including Streets and Alleys:	201,800 sq ft
Average Debris Depth:	1.9 ft

S-store
A-auto garage
F-flat-building
D-dwelling



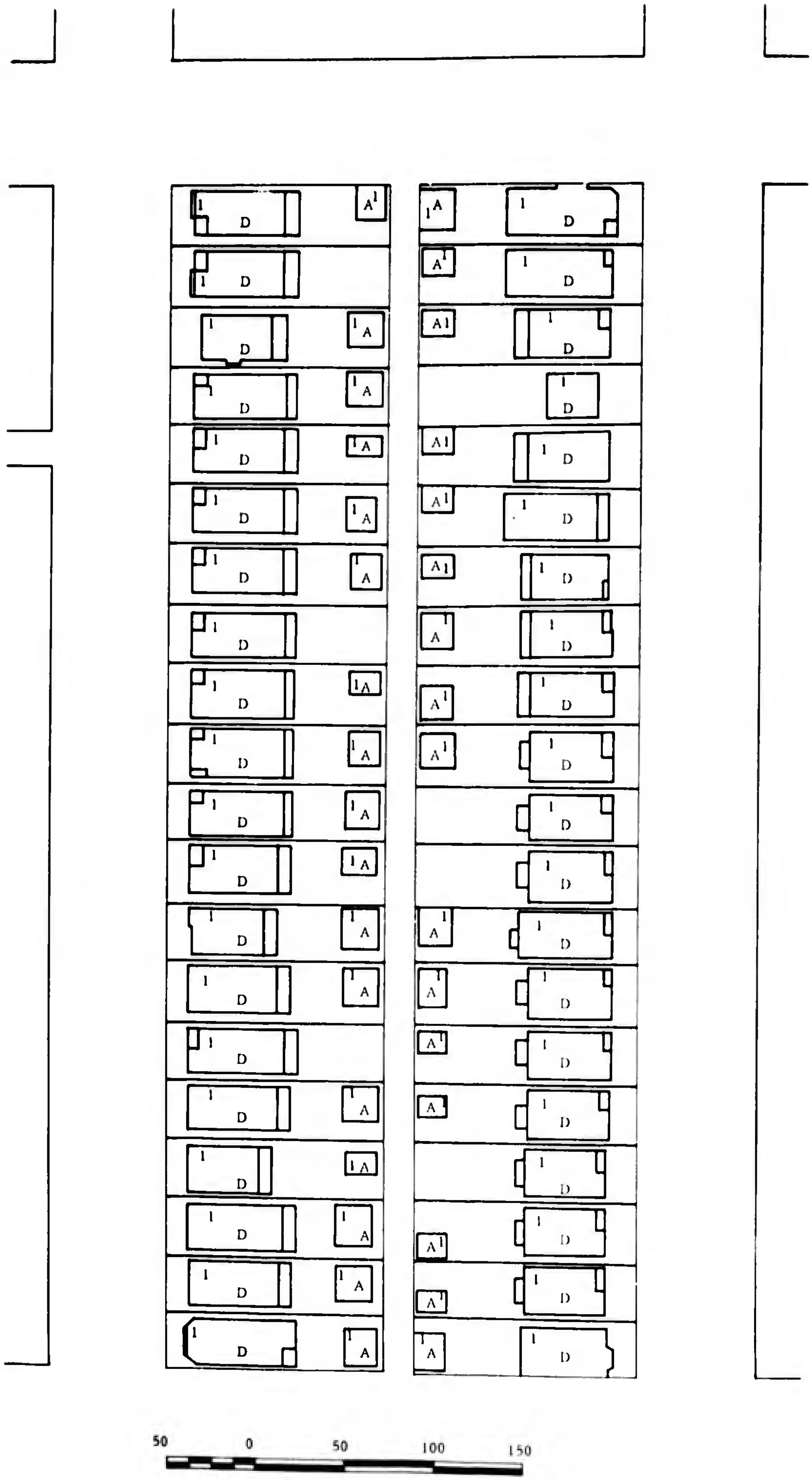
Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

Fig. 2.24

DEBRIS DEPTH FOR BLOCK OF ONE AND TWO-STORY DWELLINGS, AND GARAGES

Floor Space:	
Residences:	51,460 sq ft
Garages:	8,970 sq ft
Total:	60,430 sq ft
Contained Volume:	22,380 cu yd
Debris Volume:	5,370 cu yd
Area of Block, Including Streets and Alleys:	220,400 sq ft
Average Debris Depth:	0.66 ft

S-store
A-auto garage
F-flat-building
D-dwelling



Note: Block layout reproduced through courtesy of Sanborn Map Co., Inc.

Fig. 2.25

DEBRIS DEPTH FOR BLOCK OF ONE-STORY RESIDENCES, AND GARAGES

Floor Space:

Residences:	44,540 sq ft
Garages:	10,560 sq ft
Total:	55,100 sq ft
Contained Volume:	20,400 cu yd
Debris Volume:	4,900 cu yd
Area of Block, Including Streets and Alleys:	217,400 sq ft
Average Debris Depth:	0.61 ft

S-store
A-auto garage
F-flat-building
D-dwelling

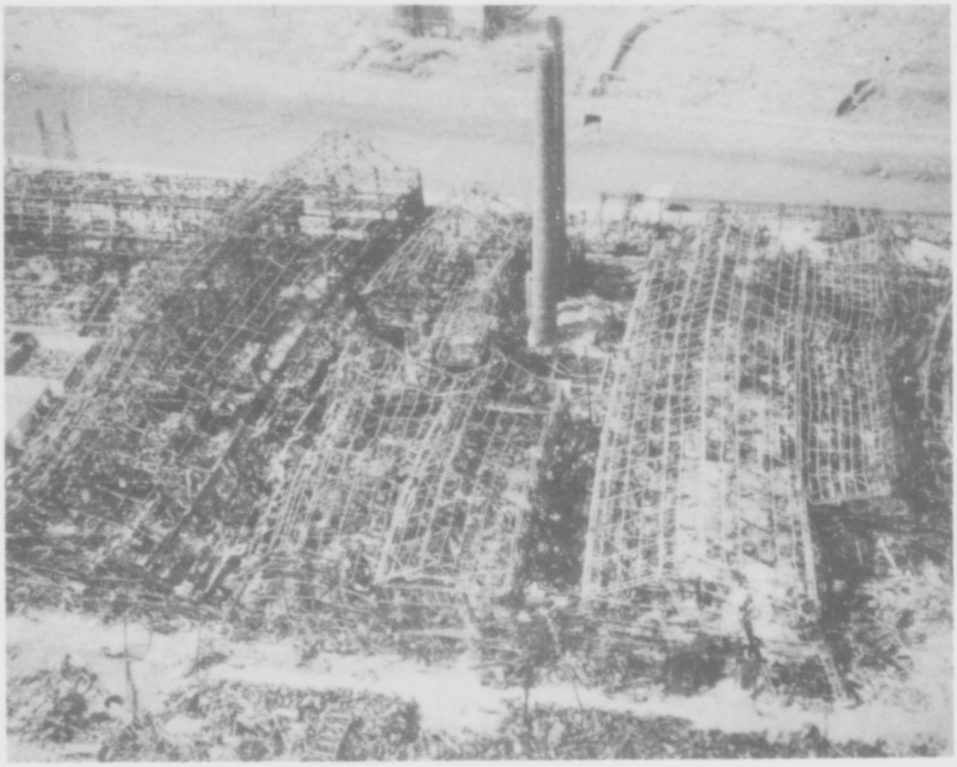


Fig. 2.26 DESTROYED INDUSTRIAL AREA AT NAGASAKI
Source: (Effects of Nuclear Weapons, 1957)

in hauling this material will be primarily a function of the load carried.

The data in Fig. 2.27 are based on quantities of structural steel in a series of heavy steel-frame mill buildings, computed on previous IIT Research Institute programs (Refs. 3 and 4). Separation between points for all PV classes of structures is not sufficiently well defined to establish distinctly separate curves for each class of structure. A single curve has therefore been drawn through the plotted points as an estimating value for the heavy steel-frame structures represented by PV codes 45 through 49 inclusive. Since no comparable data was available for light steel-frame buildings, an estimating line for these structures has been drawn as the lower envelope of extreme values of plotted points. This lower curve can be used to estimate structural steel in frameworks for light steel-frame buildings of PV codes 41 through 44 inconclusive.

The use of either of the three figures plotted is sufficient for estimating purposes, though Fig. 2.27a is preferred since both floor area and contained volume are considered independently. Fig. 2.27c is included for cases where building height or contained volume are not available.

When corrugated steel siding and roofing is used, the quantity of material used can be estimated as follows:

For Roofing

$$\text{Weight of Steel} = \left[\text{Net Area} + 15\% \text{ for side laps} + 6\% \text{ for end laps and flashing}\right]$$

$$\times \frac{1}{\cos 30^{\circ}} \text{ for roof slope } \times \text{ ave. unit weight}$$

$$= \left[L_b W_b \times 1.21 \right] \times 1.15 \times 1.8$$

$$= 2.5\, L_b W_b \text{ (lb)}$$

$$= 0.00125\, L_b W_b \text{ (tons)}$$

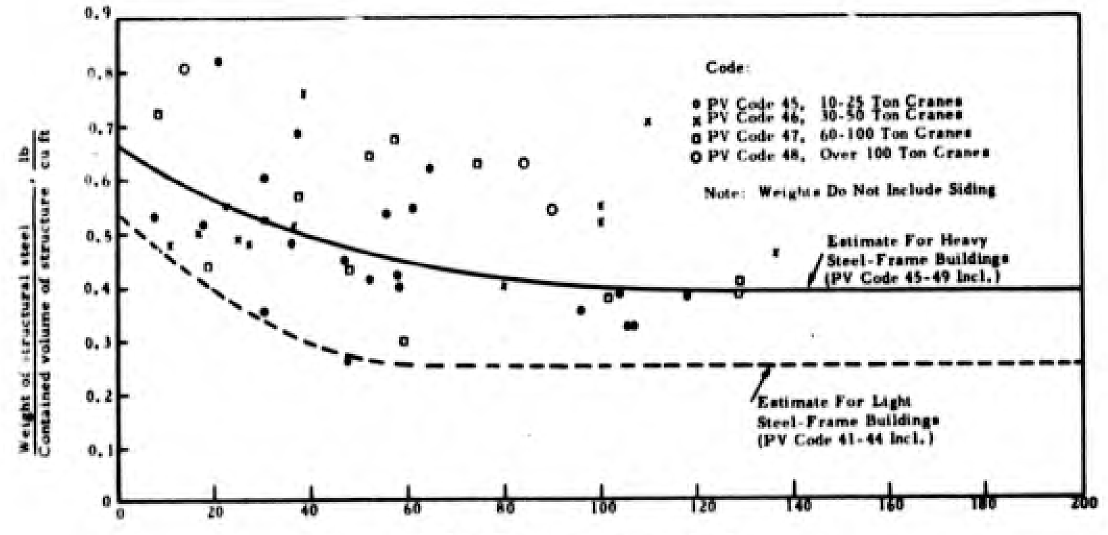
For Siding

$$\text{Weight of Steel} = \left[\text{Net Area} + 10\% \text{ for side laps} + 5\% \text{ for end laps}\right]$$

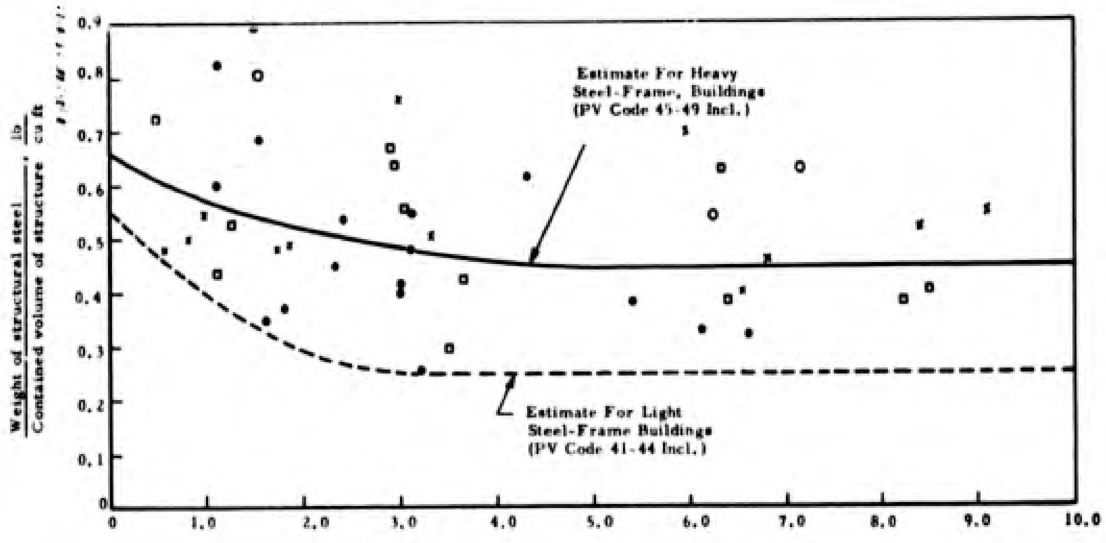
$$\times \text{ ave. unit weight}$$

$$= 2 \left[H_b (L_b + W_b) + .145\, W_b^2 \right] \times 1.8$$

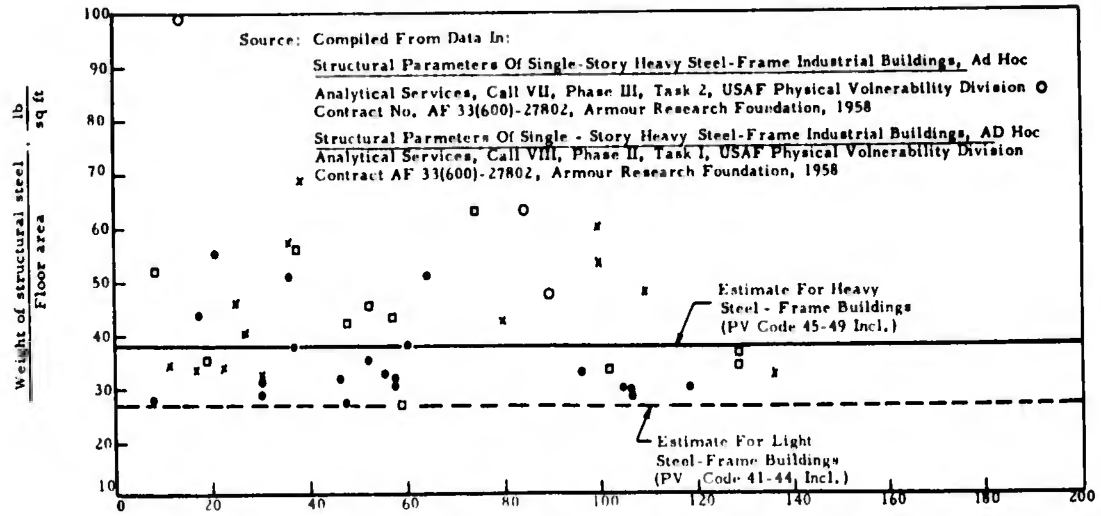
$$= 3.60\, H_b (L_b + W_b) + 0.52\, W_b^2$$



(A) Floor Area, thousands of sq ft



(B) Contained Volume Of Structure, millions of cu ft



Source: Compiled From Data In:
Structural Parameters Of Single-Story Heavy Steel-Frame Industrial Buildings, Ad Hoc Analytical Services, Call VII, Phase III, Task 2, USAF Physical Vulnerability Division Contract No. AF 33(600)-27802, Armour Research Foundation, 1958
Structural Parmeters Of Single - Story Heavy Steel-Frame Industrial Buildings, AD Hoc Analytical Services, Call VIII, Phase II, Task I, USAF Physical Volnerability Division Contract AF 33(600)-27802, Armour Research Foundation, 1958

(C) Floor Area, thousands of sq ft

Fig. 2.27 WEIGHT OF STRUCTURAL STEEL IN SINGLE STORY, INDUSTRIAL STEEL FRAME(MILL) BUILDINGS where

H_b = height of side wall

L_b = building length

W_b = building width

roof pitch = 30^o

ave. unit weight = 1.8 lb /ft^2; an estimated median weight since corrugated sheet actually varies from about 0.8 to 4.8 lb /ft^2.

2.5 Motor Vehicles as Debris

In comparison with the amount of structural materials available in buildings, motor vehicles will contribute relatively little to the total quantity of rubble. However, unlike structural material, they are not expected to fragment extensively and, hence, will require moving and hauling as complete units.

Damage radii for transporation vehicles are plotted in Fig. 2.28. It is seen that motor vehicles will probably be inoperable, as a result of blast damage alone, for distances measured in miles from the burst of a high-yield weapon. Falling debris will also contribute to rendering motor vehicles inoperable. Being in the streets prior to attack, they likely will become impediments to the clearance of streets and resumption of vehicular traffic. Removal of many vehicles from central business districts and heavily congested streets may well require special procedures, depending on their condition, such as

- initially towing out from the structural debris by means of tractors and cables
- ensuing removal to a dump site by means of tow trucks, flat-bed trailers, railroad flat cars, or railroad gondola cars

Daytime and nighttime distribution of motor vehicles within the city are different. However, the influx of motor vehicles into a central business district during working days does not account for the major percentage of motor vehicles in the city. For example, it is found that the total accumulation of motor vehicles in the central business district of Chicago (entering vehicles less departing vehicles) between 7 A.M. and 1 P.M. on week days is about

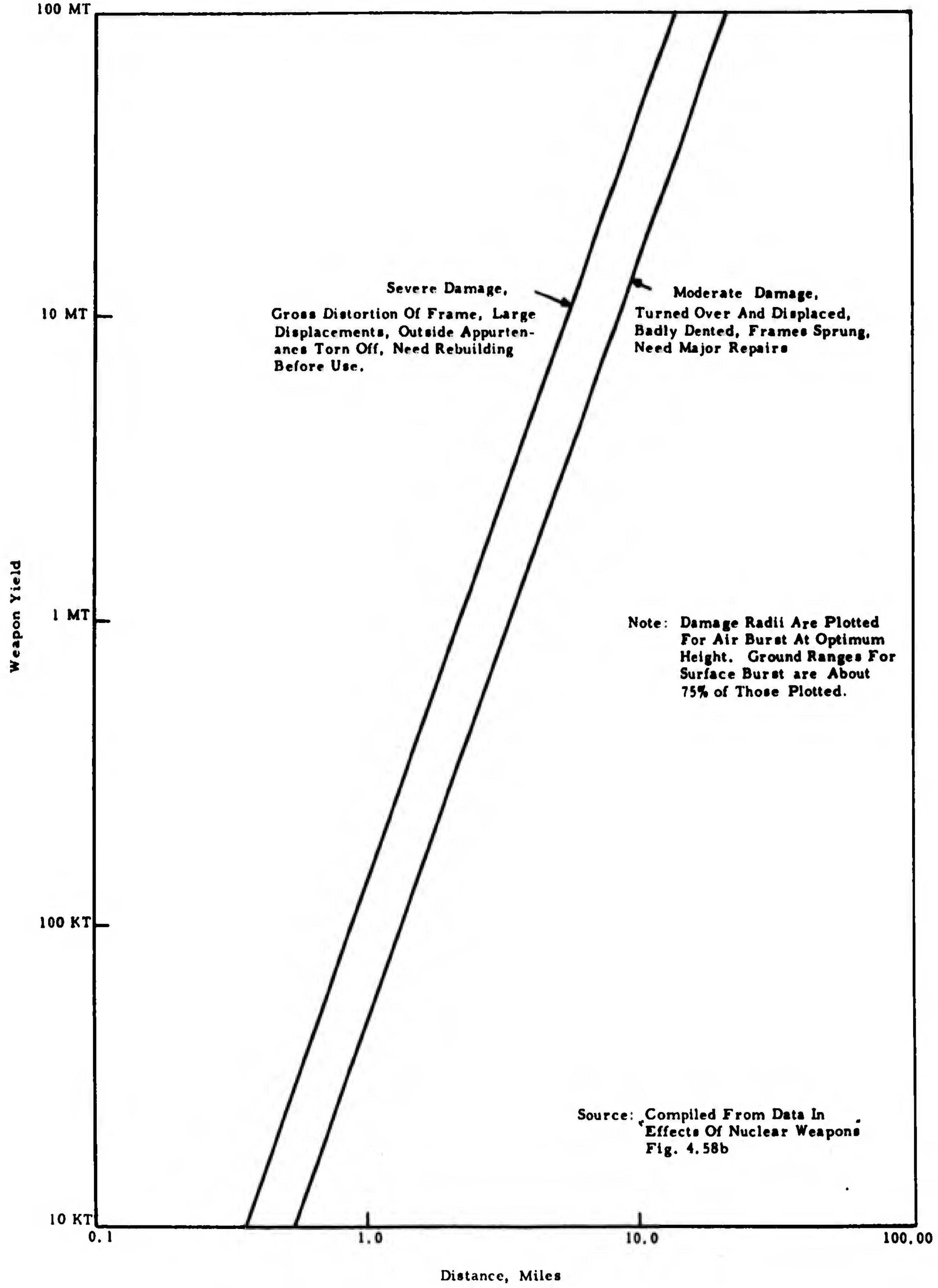


Fig. 2.28 DAMAGE RADII FOR TRANSPORTATION VEHICLES (automobiles and buses)

25,000 vehicles (see Fig. 2.29) whereas total vehicle registration in Chicago is over 900,000 (Ref. 5).

The main features of motor vehicle distribution appear to be:

- Substantial daytime concentrations of vehicles in commerical and industrial districts with much of it in off-the-street parking
- substantial numbers of vehicles on main thoroughfares in daytime
- most vehicles parked on residential streets at night

The vehicular debris problem will be most severe in central business districts following a daytime attack. Numbers of vehicles in central business districts can be computed from cordon counts, whereby stations are set up for counting entering and departing vehicles on all roads into the region. An example of this is the layout of cordon count stations for the City of Chicago, shown in Fig. 2.30. This figure shows the station locations for counting vehicles. Numbers alongside each station indicate the total number of entering and departing vehicles passing each station from 7 A.M. to 7 P.M. on a typical weekday in May, 1962.

One of the results of the cordon count is the reported accumulation of vehicles within the cordon. This is a cumulative figure computed as the difference between entering and departing vehicles from the time the count is started. The maximum accumulation of vehicles in the central business districts is estimated, by way of example, for the City of Chicago as follows. Similar estimates can be made for other cities from comparable data from street traffic bureaus or police department statistics.

Maximum cordon count accumulation		=	25,043 Vehicles at 1:15 P.M. from Fig. 2.28
Less: Parking			
Off-street in central business district:	15,960		
Grant Park Garage:	2,100		
Monroe St. Lot:	2,800		20,860 Vehicles at 100% occupancy

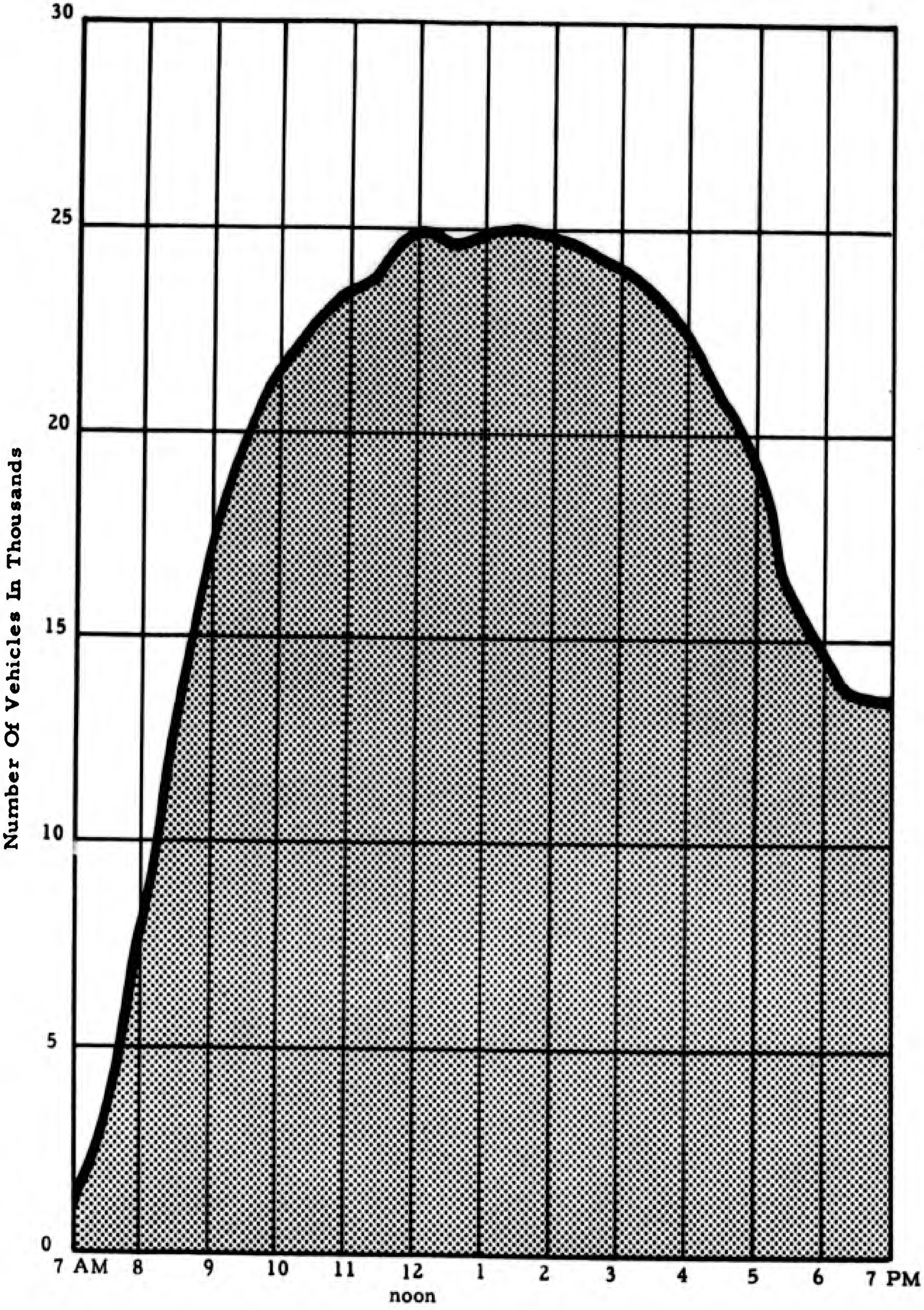


Fig. 2.29 ACCUMULATION OF VEHICLES BY FIFTEEN MINUTE PERIODS IN THE CENTRAL BUSINESS DISTRICT OF CHICAGO (Typical weekday in May, 1962)

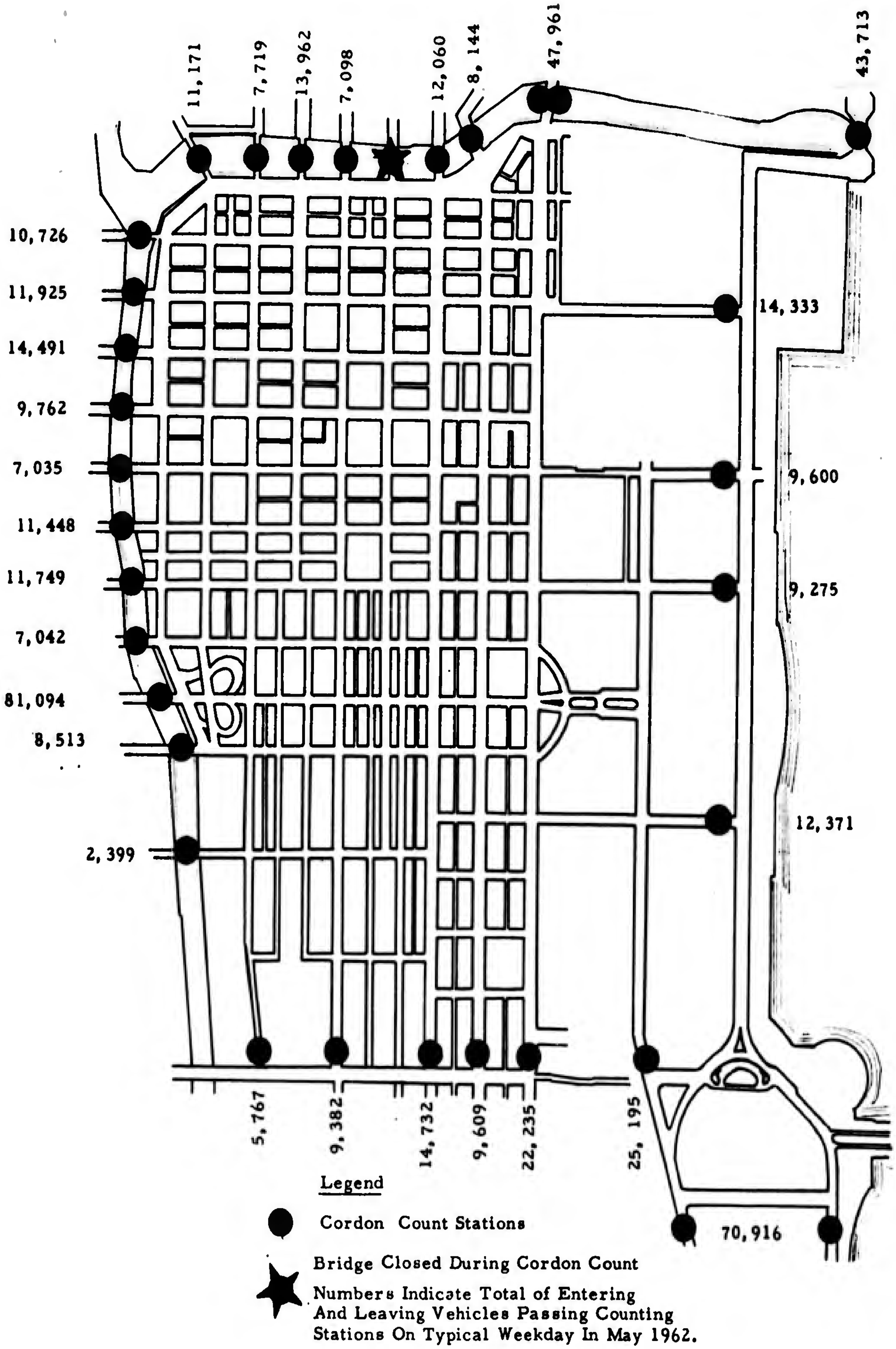
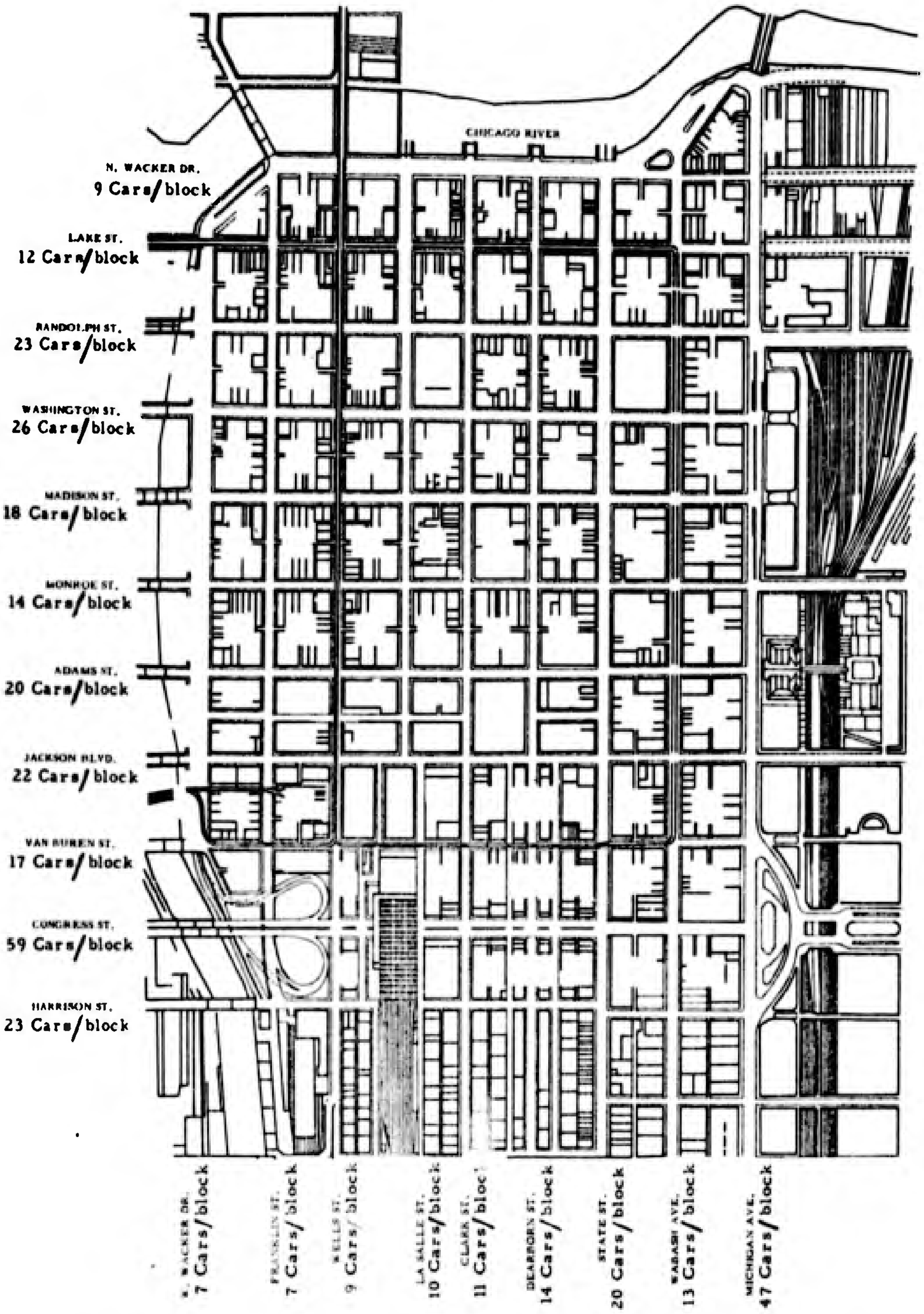


Fig. 2.30 CORDON COUNT STATIONS FOR CENTRAL BUSINESS DISTRICT IN CITY OF CHICAGO

Accumulation at start of cordon count		4,183
		843 Vehicles - assumed 20%
Estimated maximum on streets	=	5,026 Vehicles

Though there are probably about 26,000 vehicles in this district at the peak period, only about one-fifth of these are apparently on the streets, the remainder being in off-the-street parking. Cordon count data is used in Fig. 2.31 to estimate quantities of vehicles on individual thoroughfares in the central business in Chicago. The estimated number of vehicles on the streets in the business district are prorated among the thoroughfares approximately in proportion to the total entering and leaving counts at the two ends of the respective streets. This provides an approximate distribution, since all vehicular traffic in the district is certainly not straight-through traffic. This estimate, based on maximum accumulation provides an estimate of the most serious condition of vehicular debris.

For streets in residential areas within the ground range of vehicular destruction, the high limit estimate of vehicular debris can be obtained by assuming two full lanes of parked cars along the street at an estimated interval of twenty-five feet.



The central business district as defined in this plot is smaller than area included in Cordon Gount. Thus the accumulation of 5000 vehicles in the Cordon is estimated to be distributed as follows:

On East-West streets in central business district;	2020 vehicles
On North-South streets in central business district;	1380 vehicles
	3400
On streets in Cordoned region South of central business district;	780 vehicles
On Cordoned boulevards East of East of central business district;	850 vehicles
	5030

Fig. 2.31 ESTIMATED PEAK NUMBER OF VEHICLES ON STREETS IN DAYTIME IN CENTRAL BUSINESS DISTRICT OF CHICAGO

Chapter Three

STRUCTURAL FRAGMENTATION AND DEBRIS TRAJECTORIES

This chapter describes initial steps in the development of a model for predicting depth contours for structural debris arising from the detonation of a specified nuclear weapon at a known location. The prediction scheme is essentially a four-step procedure as follows:

- describing free field pressures resulting from a given set of attack parameters
- determining reflected and drag pressures on various structural elements
- determining fragment size-distributions for failed structural elements
- following the trajectories of the fragments during transport by the blast winds

This approach begins with the description of the free-field pressures resulting from a given set of attack parameters. The tools dealing with this phase of the procedure may be found in the Effects of Nuclear Weapons (unclassified) (Ref. 1) and Capabilities of Atomic Weapons (classified) (Ref. 6). Using the free-field pressures as input, the reflected and drag pressures on various structural elements can be determined by a number of theoretical and experimental results (Ref. 7).

At the third stage of the procedure we are faced with the problem of determining when and how a structural element will fail. This problem is much less complicated when the structural materials are ductile; however, for brittle materials, such as masonry, the state-of-the-art provides virtually no answers to the question of how an element will fail. This problem, called the fragmentation problem, is treated briefly in this chapter. Methods for estimating the fragment size-distribution, based on the "weakest-link" hypothesis and the use of statistics, are described in Section 3.1. Only initiation of methods was undertaken in this study however, and considerable effort is still needed to extend this analysis to real structural elements.

Before embarking upon a detailed study of fragmentation, assume that one is able to predict the sizes of the fractured pieces of a structural element. We then proceed with the final step in the debris prediction procedure; the trajectory problem. Here, using the classical approach to particle mechanics, the motion of an equivalent sphere is traced under the influence of gravitational and wind forces. It is evident that a one-to-one correspondence can be established between the materials in the target and their final disposition on the ground surface. Trajectory analyses conducted on this program are described in Section 3.2 and plotted in Appendix D.

3.1 Fragmentation of Masonry Structures

The ultimate strengths obtained from the repeated static testing of nominally identical brittle specimens will exhibit a characteristic scatter. Furthermore, the locations of the resulting fractures will vary from specimen to specimen. Because the dispersion of ultimate strengths is usually very large for brittle materials, it is generally not possible to predict the behavior of a single element with any useful accuracy regardless of the amount of accummulated experience with similar elements. It is possible, however, through the use of statistics, to predict the composite behavior of a large group of nominally identical brittle components from a knowledge of the characteristics of another large group of similar components.

The statistical nature of the brittle fracture problem has long been recognized (Ref. 8), and an extensive literature has developed to deal with the statistical description of the strength of brittle elements (Ref. 9). On the other hand, this literature is not even slightly concerned with the problem of describing the fracture modes.

3.1.1 Analysis of Fragment Size-Distribution

Adopting a statistical viewpoint, we shall consider the fragmentation of a brittle beam structure such as the cantilever shown in Fig. 3.1.

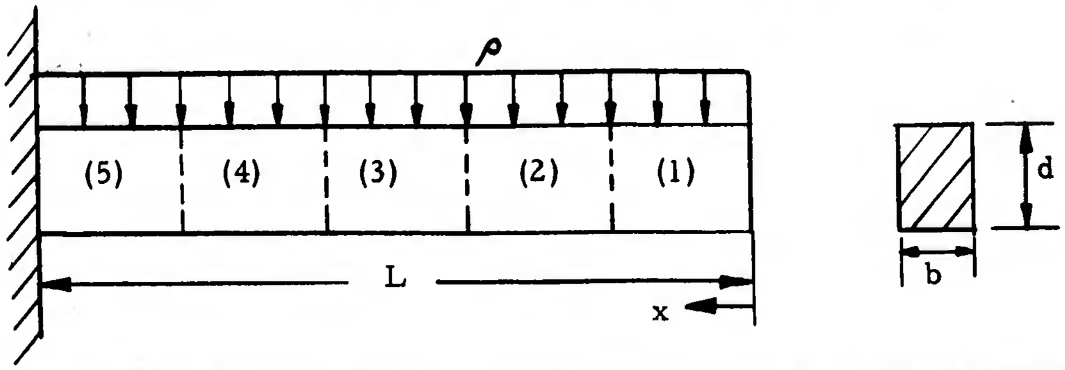


Fig. 3.1 BRITTLE CANTILEVER DIVIDED INTO FIVE IMAGINARY UNITS

Under a sufficiently high static loading, the statistical theory of fracture allows that fracture may occur anywhere in the span. Of course, the likelihood of fracture will be greatest at the fixed end where the stress level is the highest. We observe that the probability of fracture occurring at a specified station along the beam is zero. (Any finite probability of failure at the various beam stations would always result in the physical contradiction that the survival probability of the beam is zero.) Consequently, it is meaningless to seek fragments of a given size; and instead, one should try to find the number of fragments which occur within a given range of sizes. In this analysis, we shall predict the percent of the origianl beam mass or length which fractures into preselected size ranges.

To obtain a finite probability of fracture, we must consider a region along the beam rather than a specific station. Therefore, we shall imagine the beam to be divided into any arbitrary number of units. Having done this, we utilize a five step procedure for computing the fragment size-distribution. This involves computing the maximum dynamic stresses in each unit segment and relating them to the probability of fracturing the units. The unit fracture probabilities are used to compute the probability of getting a particular combination of broken and unbroken units. This probability of occurrence can be attributed to each of the various segment sizes associated with the combination. Finally, we must keep track of the segment probabilities from every possible combination.

3.1.2 Dynamic Stresses

We shall assume that the maximum dynamic stresses introduced into the various unit segments are independent of the fracture characteristics of these segments. This would be realized, for example, if the loading were sufficiently rapid to fully stress the units before any fracture occurred. This important assumption leads to the simplication that the units can be treated as stochastically independent. For static loading, the assumption is clearly invalid since fracture in a unit segment would immediately relieve the stresses in other segments. This implies that only one fracture can occur in a statically loaded, statically determinate beam. On the other hand, it is common experience that multiple fractures occur to statically determinate brittle beams under dynamic loading.

Taking the dynamic beam loading in the form pf(x)g(t) where the effects of magnitude, load distribution, and pulse shape are explicitly delineated, we can estimate the maximum dynamic stresses in a typical unit by multiplying the static stresses associated with pf(x) by the maximum dynamic load factor for the first mode of vibration, DLF. Thus, the stress distribution for a unit segment has the form ph(x, y, z) (DLF).

3.1.3 Statistical Strength of Unit Segments

The statistical strength characteristics of a typical unit segment are described by its cumulative distribution function, F(p). This function gives the probability of fracturing the unit at a load magnitude equal to or less than p. The distribution function may be determined by physically testing many unit segments or by appealing to one of the "weakest link" statistical fracture theories. Of these, Weibull's is the most popular theory and we shall write this in a form which is appropriate for the unit segment.

$$F(p) = 1 - \exp\left[- \int_V \left(\frac{\sigma_i - \sigma_u}{\sigma_o}\right)^m dV \right] \qquad \sigma_i \geq \sigma_u \qquad \text{(Eq. 3.1)}$$

$$= 0 \qquad \sigma_i < \sigma_u$$

where σ_i is the stress distribution in the i^{th} segment of the form ph(x, y, z) (DLF); σ_u, σ_o, and m are constants of the material; and where the integration is taken over the volume of the unit segment. The distribution parameters σ_u, σ_o, and m, are usually determined from simple bending or tension specimens.

The practical application of the Weibull function takes advantage of certain mechanical properties normally found in most brittle materials. For example, the linearity of the stress-strain relationship up to rupture greatly simplified the stress analysis. Also, the insensitivity of the strength of the brittle materials to wide variations in strain-rate enables one to determine a unique set of distribution parameters from static test results. Finally, since the tensile strength is generally much smaller than the compressive or shear strength, a consideration of tensile bending stresses alone is usually sufficient for the determination of the strength of normally proportioned beams.

3.1.4 Fracture Combinations

The distribution function for a typical unit segment enables us to attribute a fracture probability to each segment once the loading is prescribed. Now, assuming that any unit independently fractures or does not fracture, we can write down all possible combinations of these events. Consider, for example, a five-unit beam as shown in Fig. 3.1. If only the units numbered 1, 3, and 4 are fractured in a particular combination, we shall designate the combination by the index 134. There are 2^n possible combinations in an n-unit beam - - for the five unit beam, these combinations form the following sequence:

0
1
2
3
4
5
12
13
14
15
23
24
25
34
35
45
123
124
125
134
135
145
234
235
245
345
1234
1235
1245
1345
2345
12345

The first of these 32 combinations, 0, represents no fracture in any of the units.

We observe that the sequence of combinations has the following three properties:

1. The digits in each term are monotonically increasing.
2. No digit is greater than n.
3. The i + 1 term is the smallest integer exceeding the value of the i^{th} term and satisfying properties 1 and 2.

These properties may be generalized to generate the sequence for any size n; however, a digital computer must be employed for any useful number of unit segments. It is computationally significant that the method employed for generating the combinations requires little storage, i.e., the i + 1 combination may be found using only the i^{th} combination.

The probability that a given combination of independent events will occur is easily determined. Considering the five-unit cantilever, for example, the probability associated with the combination 235, representing fracture in units 2, 3, and 5 only, can be computed as the probability of the simultaneous fracture in 2, 3, and 5 with the simultaneous survival of units 1 and 4; thus,

$$P_{235} = (1 - F_1)\, F_2\, F_3\, (1 - F_4)\, F_5 \qquad \text{(Eq. 3.2)}$$

where $(1 - F_i)$ is the probability of survival and F_i is the probability of fracture in the i^{th} unit.

3.1.5 Fragment Sizes

Each combination of fractures gives rise to various size elemental fragments which we shall describe in terms of the unit size s - span length L divided by n. These sizes are related to the differences between the successive digits comprising the combination index. For example, if fracture is taken to occur at the midpoint of a unit segment, the combination 345 in the five-unit cantilever produces the elemental fragments shown in Table 3.1.

Table 3.1

ELEMENTAL FRAGMENT SIZES FOR COMBINATION 345 (n - 5)

Fragment Size-General	Variability	Separates/Remains	Fragment Size
$\left[n - (\text{last digit}) + 1/2\right] s$	± .5s	remains	(5 - 5 + 1/2)s = 0.5s
$\left[(\text{first digit} - 1/2\right] s$	± .5s	separates	(3 - 1/2)s = 2.5s
$\left\lvert \text{Difference between successive digits} \right\rvert s$	± s	separates	$\lvert 3 - 4 \rvert\ s = s$ $\lvert 4 - 5 \rvert\ s = s$

Because fracture may occur anywhere in the unit segment rather than at the center as assumed, any elemental fragment size indicated in Table 3.1 actually representes the midpoint of a range of sizes which may be as much as ± a greater than the indicated size. For the cantilever, the elemental fragment sizes or class marks form the sequence: 1/2s, 1s, 1 1/2s, 2s, ... (n - 1)s, (n - 1/2)s. The size ranges associated with these class marks are successively: (0 to 1s), (0 to 2s), (1s to 2s), (1s to 3s), ..., [(n - 2)s to ns], [(n - 1)s tons]. It is evident that these size ranges overlap considerably, and as a consequence, they cannot be used directly for classifying fragment sizes. Whereas we know the sizes associated with each class mark, a given fragment size may fit into several of the size ranges. To circumvent this problem, the elemental fragment sizes may be grouped into broad subdivisions in such a way that the effects of overlapping may be made as small we please.

Every application suggests a size interval which will adequately describe the distribution of fragment sizes, e.g., 0 to 2', 2' to 4', 4' to 6', etc. Clearly, as n is taken larger and larger the number of class marks or elemental sizes which will fall into these various intervals will increase. If the size interval is taken as L/5 and n = 20, each interval will contain eight class marks. The overlap between intervals will be no greater than s; consequently, the overlap will decrease linearly with increasing n. This situation is depicted in Fig. 3.2 where class marks are displayed for different values of n. Heavy diagonal lines are shown which divide the class marks into five predetermined size intervals. We observe that as n increases the number of elemental sizes in each interval increases and the relative overlap across contiguous boundaries decreases. Consequently, in principle our size description can be made as accurate as we desire.

3.1.6 Computation of Fragment Size-Distribution

In this section we shall determine the percent of the original beam length which fractures into every preselected size interval. We begin the computation by calculating the number of fragments contributed by each elemental size interval. These numbers will be expressed as a percentage of the number of beams tested just as in the case of combination probabilities. To illustrate the computational procedure, we again consider the elemental fragment sizes shown in Table 3.1 for the 345 combination. We observe that the percentage of 1/2 unit pieces which remain on the wall is equal to the probability that the 345 combination will occur, p_{345}. Similarly, the total percentage of one unit fragments which separate from the cantilever is 2 x p_{345}; for the 2 1/2 unit piece, p_{345}. If this computation is repeated for each of the possible combinations and if the percentages are accumulated for each elemental fragment size, we obtain the total number of pieces associated with each class mark expressed as a percentage of the number of beams tested.

Now, taking the class marks to represent the average length of the fragments in their corresponding intervals, we can describe the total per cent of the original beam length associated with each class mark by

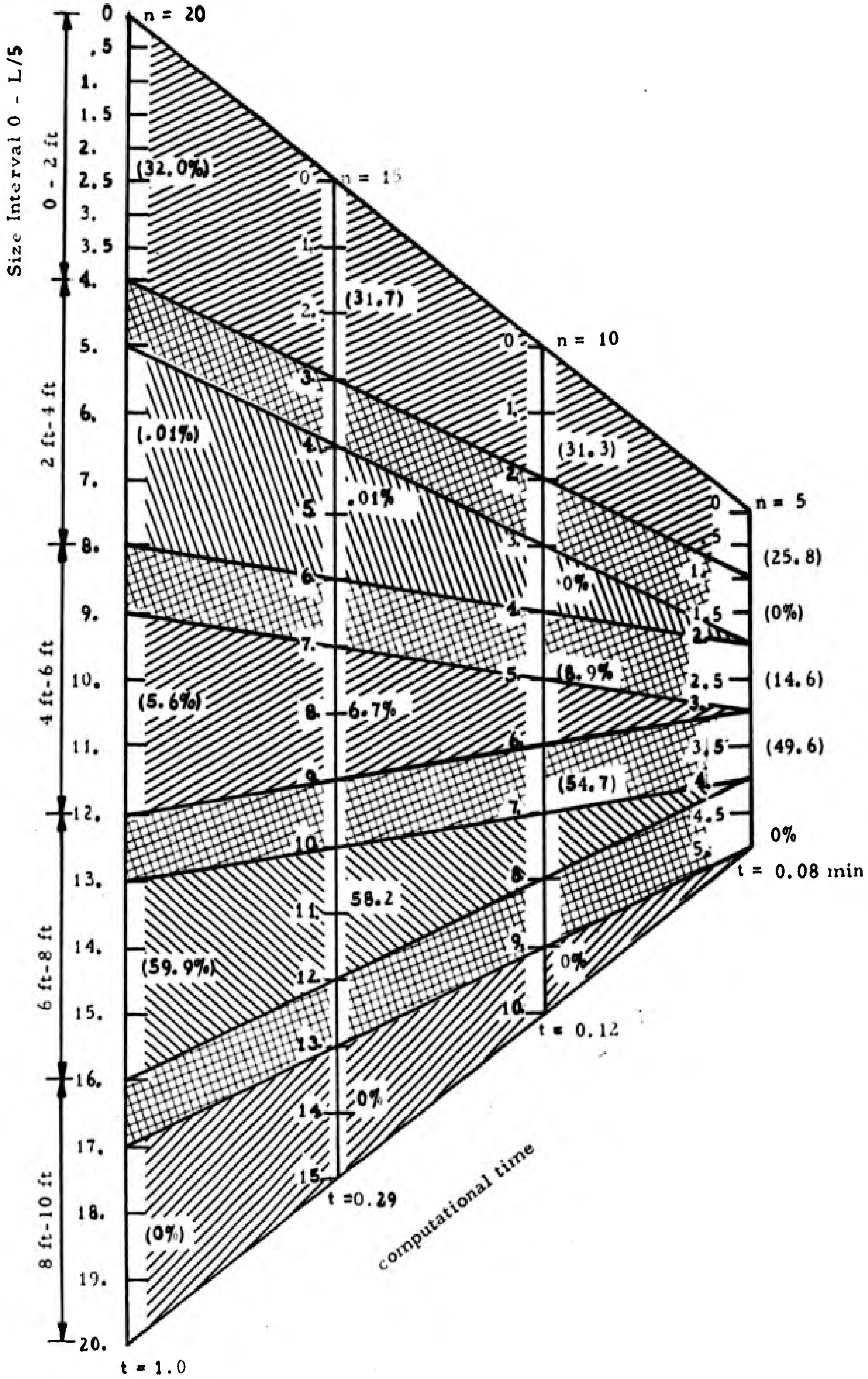


Fig. 3.2 ELEMENTAL AND PHYSICAL SIZE INTERVALS

forming the product of the class mark, the total percentage of fragments in the interval, and (100/L). The sum of these percentages for all the class marks, both "separated" and "remains", will equal 100%. This expression of the conservation of mass is useful as a computational check. Having found the percentage of the original beam length associated with each class mark, it is a simple matter to group these elemental fragment sizes into physically significant size intervals. The total percentage of the original beam length contained in an interval is simply the sum of the percentages associated with the class marks included in the interval.

The number of operations involved in the fragmentation computations is roughly proportional to $n. 2^n$. For the sake of economy, one usually tries to use the smallest n consistant with desired accuracy. Computations were carried out on an IBM 7090 for the cantilever in Fig. 3.1 under a 20 psi step pulse. The resulting percentages for the separated fragments are depicted in Fig. 3.2 by the numbers in parenthesis. The computation time is indicated for each n considered.

Two problems arise in conjunction with the measurement of physical data. First, we must adopt a method of measuring the length of a segment. This may be done by considering the length along the centroidal axis or by weighing the fragments and relating their weight to size. The second problem develops when multiple fractures occur in a single unit segment.

Here, we obtain more segments in the size range 0 to s than can be accounted for in the theory. It may be practical to exclude this interval from both the theory and the collected data. In any event, the problem may be studied by considering this interval for different values of n.

3.1.7 Example Case

Using the dimensions shown in Fig. 3.1, the fragmentation of this cantilever is computed for a step pulse of magnitude p. Taking a dynamic load factor of 2, the maximum effective bending moment in the i^{th} segment of an n-unit beam is

$$M_i = pbL^2 (i/n)^2 \qquad \text{(Eq. 3.3)}$$

It is convenient to take this moment to be uniform over the entire segment, an approximation which improves with increasing n. For this case, the

Weibull function for the fragment probability is given by (9).

$$F(p) = i - e^{-\left[\frac{V}{2(m+1)}\left(1 - \frac{\sigma_u}{\sigma_i}\right)\left(\frac{\sigma_i - \sigma_u}{\sigma_o}\right)^m\right]} \qquad \text{(Eq. 3.4)}$$

Assuming a 10 ft long fifteen unit beam, the following Weibull constants were used to study the fragmentation of the cantilever for a wide range of pressures:

$m = 9$

$\sigma_u = 50$ psi

$\sigma_o = 1500$ psi

Fragmentation characteristics for this beam are shown in Fig. 3.3. The amount of material fragmenting into the various size classes is expressed as a percentage of the total original beam length. It should be noted that these results are statistical in nature and provide overall expectations based on a large number of failed beams rather than a single beam. All beams of a single type are not expected to fragment in identical manners under the same dynamic loading. This explains the seemingly contradictory result that at 18 psi dynamic pressure 10 percent of total beam length fragments into a size range of 8 to 10 ft, which is impossible in a single beam. The proper interpretation of Fig. 3.3, consistent with observations of the statistical nature of the behavior of brittle materials, is that the indicated size-distributions would be the overall result of failures of a large (statisically significant) number of beams.

It should also be noted that the curves in Fig. 3.3 represent material that fragments and comes off the wall. Stub ends that remain on the wall are not included. This accounts for the situation at 6 psi dynamic pressure, where about 5 percent of the material fragments into 8-10 ft pieces and no other fragments are produced. The remaining material is accounted for by stub ends remaining fixed to the wall, and non-failures of most of the beams.

Results plotted in Fig. 3.3 indicate that cantilever beam failures at low dynamic pressures characteristically occurs at the fixed end. Beyond this, increased pressure results in smaller fragments. Certain fragment

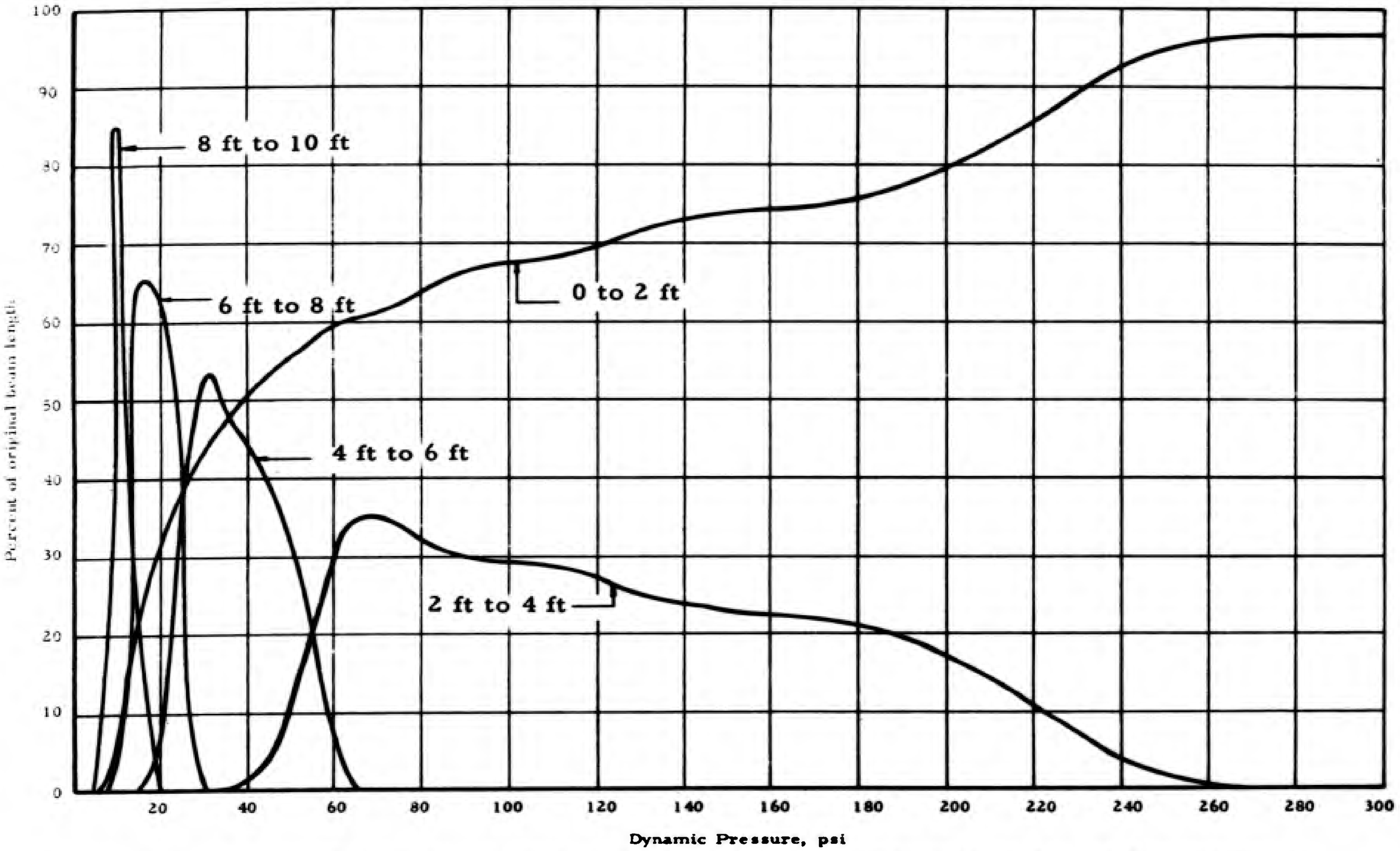


Fig. 3.3 VARIATION OF FRAGMENT-SIZE DISTRIBUTION WITH OVERPRESSURE FOR A 10-FT CANTILEVER BEAM

sizes predominate at various dynamic pressure ranges, the predominate size decreasing with increased pressure. At some finite dynamic pressure the fragment size becomes equal to the unit size exclusively and, if the unit size is made sufficiently small, a pulverizing pressure may theoretically be found.

3.2 Fragment Trajectory Analysis

Trajectory analysis for structural fragments starts with the equation-of-motion of a particle acted upon by drag forces. This is a second-order nonlinear differential equation, which can be solved in a series of steps as the fragment is followed through its horizontal translation. The flight time of the particle is determined by its initial height, depending on its location in the structure under consideration. Families of trajectories can be found for a range of particle sizes, each set corresponding to some combination of weapon yield and ground range. An indication of debris distribution can then be made by combining all the sets of trajectories corresponding to a specific weapon yield.

The initial conditions required for the use of this transport model are characterized by three results of the fragmentation solution, namely: time of failure, size of fragment, and initial fragment velocity. Since the fragmentation model is not sufficiently developed to give these results, solutions are obtained for a range of particle sizes and with the conservative assumption that time of failure and failure velocity are zero. We now discuss the transport model in some detail.

3.2.1 Trajectory of a Particle

Consider the motion of a particle through air such that the drag force acting on the particle is proportional to the square of the relative velocity between the particle and the medium. It is assumed that the vertical and horizontal motion of the debris particle are uncoupled. This is true if the center of pressure of the particle coincides with its centroid for all orientations so that no rotation occurs, and further that the horizontal component of relative velocity between the air and particle be significantly greater than the vertical component.

The horizontal equation of motion is then

$$\ddot{x} = \frac{k\alpha\rho}{2} (\dot{x} - u)^2 \qquad \text{(Eq. 3.5)}$$

where

x = horizontal coordinate
y = vertical coordinate, positive downward
$(\dot{\ })$ = differentiation with respect to time
α = aerodynamic coefficient, $\dfrac{\text{(projected area x drag coefficient)}}{\text{mass}}$
ρ = mass density of air
u = air particle velocity
g = gravitational constant

$$k = \begin{cases} -1 \; ; & u \geq \dot{x} \\ +1 \; ; & u < \dot{x} \end{cases}$$

$$k = \begin{cases} +1 \; ; & \dot{y} \leq 0 \\ -1 \; ; & \dot{y} > 0 \end{cases}$$

This is a Riccati type non-linear differential equation, and can be linearized by a simple transformation of coordinates.

Let $$\dot{x} = \beta \frac{\dot{s}}{s} \qquad \text{(Eq. 3.6)}$$

Then $$\ddot{x} = \beta \frac{\ddot{s}}{s} - \beta \left(\frac{\dot{s}}{s}\right)^2 \qquad \text{(Eq. 3.7)}$$

Making the substitution into Eq. 3.5

$$\beta \frac{\ddot{s}}{s} - \beta \left(\frac{\dot{s}}{s}\right)^2 = \frac{k}{2}\alpha\rho \left[u^2 - 2u\beta\frac{\dot{s}}{s} + \beta^2 \left(\frac{\dot{s}}{s}\right)^2\right] \qquad \text{(Eq. 3.8)}$$

The value of β can be determined to make the $\left(\frac{\dot{s}}{s}\right)^2$ term vanish.

Thus

$$\beta = - \frac{2}{k\alpha\rho} \qquad \text{(Eq. 3.9)}$$

and then

$$\beta \frac{\ddot{s}}{s} - \beta \left(\frac{\dot{s}}{s}\right)^2 = -\beta^{-1} u^2 + 2u \frac{\dot{s}}{s} - \beta \left(\frac{\dot{s}}{s}\right)^2$$

$$\beta \frac{\ddot{s}}{s} = -\beta^{-1} u^2 + 2u \frac{\dot{s}}{s} \qquad \text{(Eq. 3.10)}$$

$$\beta^2 \ddot{s} = -u^2 s + 2 \beta u \dot{s}$$

$$\beta^2 \ddot{s} - 2 \beta u \dot{s} + u^2 s = 0$$

Treating u as a constant, a closed form solution to Eq. 3.10 can be obtained in the form

$$s = (C_1 + C_2 t)\, e^{\frac{u}{\beta} t} \qquad \text{(Eq. 3.11)}$$

and

$$\dot{s} = \frac{u}{\beta} (C_1 + C_2 t)\, e^{\frac{u}{\beta} t} + C_2 e^{\frac{u}{\beta} t} \qquad \text{(Eq. 3.12)}$$

where C_1 and C_2 are constants of integration.

From the substitution

$$\dot{x} = \beta \frac{\dot{s}}{s}$$

It can be shown that

$$\dot{x} = u + \frac{C_2 \beta}{C_1 + C_2 t} \qquad \text{(Eq. 3.13)}$$

and

$$x = \beta \log_e s \qquad \text{(Eq. 3.14)}$$

Solving Eqs. 3.13 and 3.14 in terms of the constants C_1 and C_2 gives

$$C_1 (u - \dot{x}) + C_2 (\beta + tu - t\dot{x}) = 0 \qquad \text{(Eq. 3.15)}$$

$$C_1 + C_2 t = e^{\frac{x - ut}{\beta}} \qquad \text{(Eq. 3.16)}$$

Whose simultaneous solution is

$$C_2 = -\frac{u - \dot{x}}{\beta} e^{-\frac{x - ut}{\beta}} \qquad \text{(Eq. 3.17)}$$

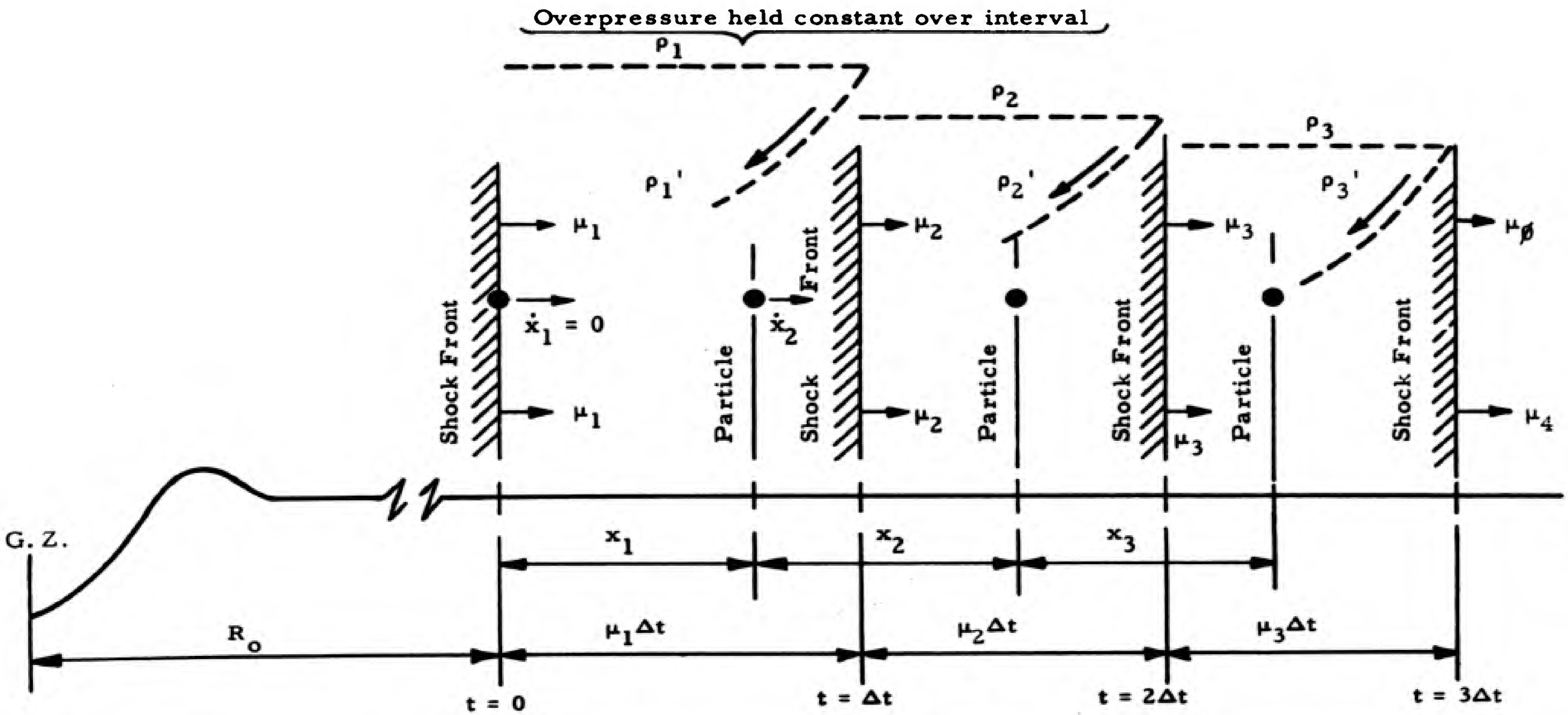
$$C_1 = e^{\frac{x - ut}{\beta}} - C_2 t \qquad \text{(Eq. 3.18)}$$

It will be noted that a constant wind velocity u is assumed in

$$m \ddot{x} = \frac{k}{2} \rho A C_d (\dot{x} - u)^2 \qquad \text{(Eq. 3.19)}$$

This is not true for the induced motion of the particle as a result of blast winds. The wind velocity, u, is a function of overpressure, which is dependent on yield, ground range, and time. Hence, trajectories must be determined by computing the horizontal motion for a series of short time intervals, Δt, over each of which a constant wind velocity can be assumed. Consideration must also be given to the increasing lag of the particle behind the shock front during flight, as shown in Fig. 3.4.

A description of the physical situation is as follows. Consider the instant at which the building is fragmented. The blast parameters are now inspected. Denote the weapon yield as W, ground range as R_o. Under these conditions we can evaluate the shock wave velocity, u, the air mass density ρ, the positive phase duration t_d, and the overpressure p at the instant the initial shock wave is R_o distance from ground zero; or in other words, just as the shock wave is exerting its influence on the particle. Now we can allow the action to continue until some small duration of time has lapsed, Δt. The shock front has moved a distance $u \Delta t$. From Eq. 3.14 we can find the particle movement, x_1. Furthermore, the particle has fallen behind the shock front because it has not been able to accelerate fast enough to keep up with it. At this point we can evaluate a new u, ρ , t, and p. However, this must be done for the blast wave which is now acting on the particle. This requires taking into account an additional decay in



ρ is the overpressure computed at shock fronts
ρ' is the overpressure computed at particle position
Total distance particle is transported is

$$\sum_{i=1}^{\mu} x_i$$

R_o is initial ground range
μ is shock front velocity
$\dot{x}$ is particle velocity

Fig. 3.4 LAG OF PARTICLE BEHIND SHOCK FRONT overpressure. After these new "constants" are evaluated, we can again solve Eq. 3.14 for some time increment, Δt, and obtain the new distance the particle travels, x_2. So far the particle has traveled a total distance of $x_1 + x_2$, if we do not change Δt, the number of times we can increment is $n = \sqrt{\frac{2h_o}{g}} \Big/ \Delta t$. Where $\sqrt{\frac{2h_o}{g}}$ is the fall time of a particle from height h_o, using the considerations outlined for each increment or solution of Eq. 3.14, the total distance the particle travels is:

$$D = \sum_{i=1}^{n} x_i$$

If we index the size of the particles to show that they are of different sizes, we have the total distance each particle travels by repeating the solution of Eq. 3.10 under these conditions, but for different sizes of particles. We obtain:

$$D_1 = \sum_{i=1}^{n} x_{1_i}$$

$$D_2 = \sum_{i=1}^{n} x_{2_i}$$

If we select k sizes:

$$D_k = \sum_{i=1}^{n} x_{k_i}$$

It is then possible to incorporate all this information into graphical form valid for the W_o, R_o in question, as depicted in Fig. 3.5.

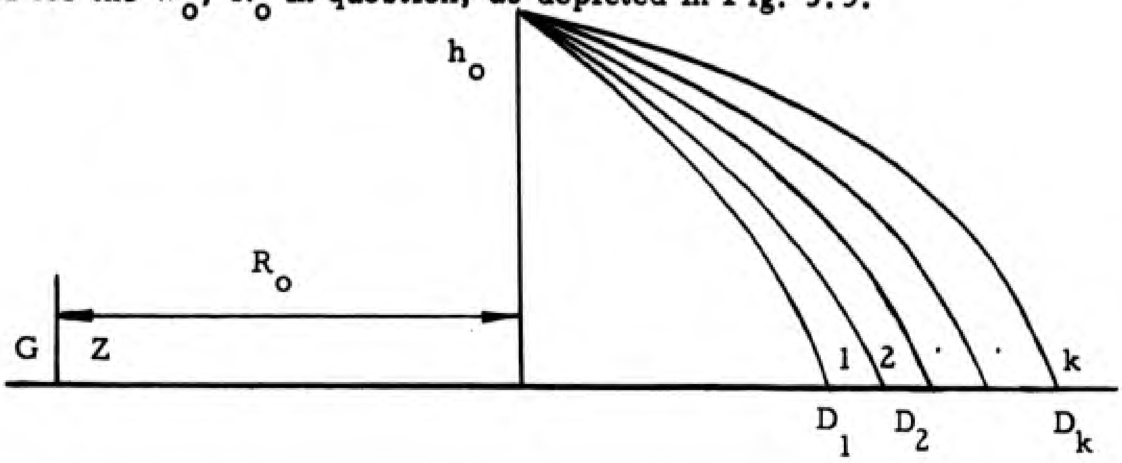


Fig. 3.5 TRAJECTORIES OF VARIOUS SIZED DEBRIS PARTICLES

3.2.2 Numerical Results

The solution to Eq. 3.10 was carried out on the IMB 7090/1401 digital computer. The computer program, diagrammed in Fig. 3.6, consists of the following steps for each time interval Δt:

- compute position of particle at start of time interval Δt
- compute position of shock front at start of time interval Δt
- compute shock velocity and peak overpressure at shock front
- compute time elapsed since shock front passed current position of particle
- compute new peak overpressure at particle location
- compute wind velocity at particle
- compute new constants of integration

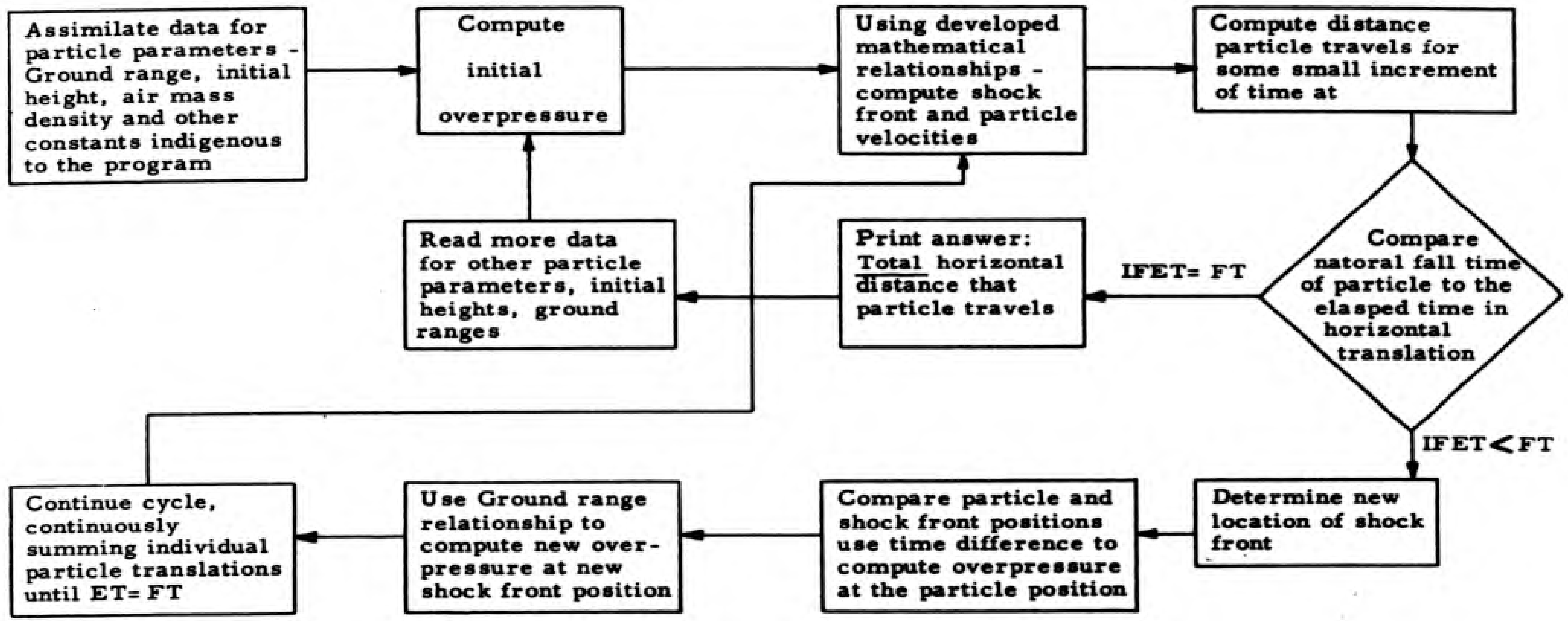
Trajectories have been computed, plotted, and included in Appendix D for the following cases:

- equivalent particle diameters of 2", 4", 6", 8", 10", 12", 16", and 24"
- initial fragment heights from 0 to 280 ft.
- surface bursts of 100 KT, 500 KT, 1 MT, 20 MT and 50 MT
- selected initial ground ranges corresponding to overpressure levels varying from about 200 psi to about 4 psi

By way of example, trajectory plots for the 100 KT surface burst and ground ranges from 1000 to 6000 ft are shown in Fig. 3.7.

3.2.3 Applications of Fragmentation and Trajectory Analysis

Results of trajectory analyses included in this report provides the nucleus of the second-order method of estimating debris distribution. Combining the trajectory results with appropriate fragment size-distributions for structural elements will permit estimates to be made of the debris contour for a single structure as indicated schematically in Fig. 3.8. Combining these contours for groups of structures then leads to the synthesis of



Note:
ET = Horizontal elapsed time
FT = Fall time

Fig. 3.6 COMPUTER FLOW CHART FOR PARTICLE TRAJECTORY CALCULATIONS

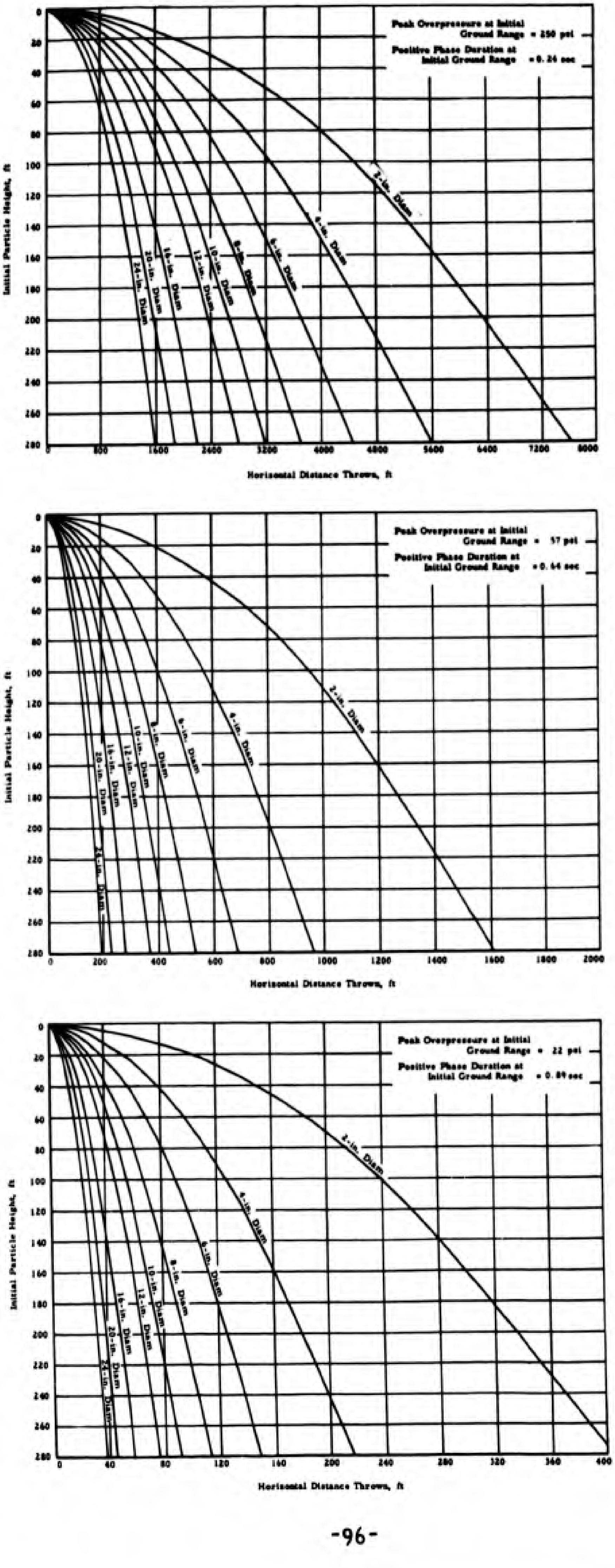


Fig. 3.7 PARTICLE TRAJECTORIES FOR 100 KT SURFACE BURST

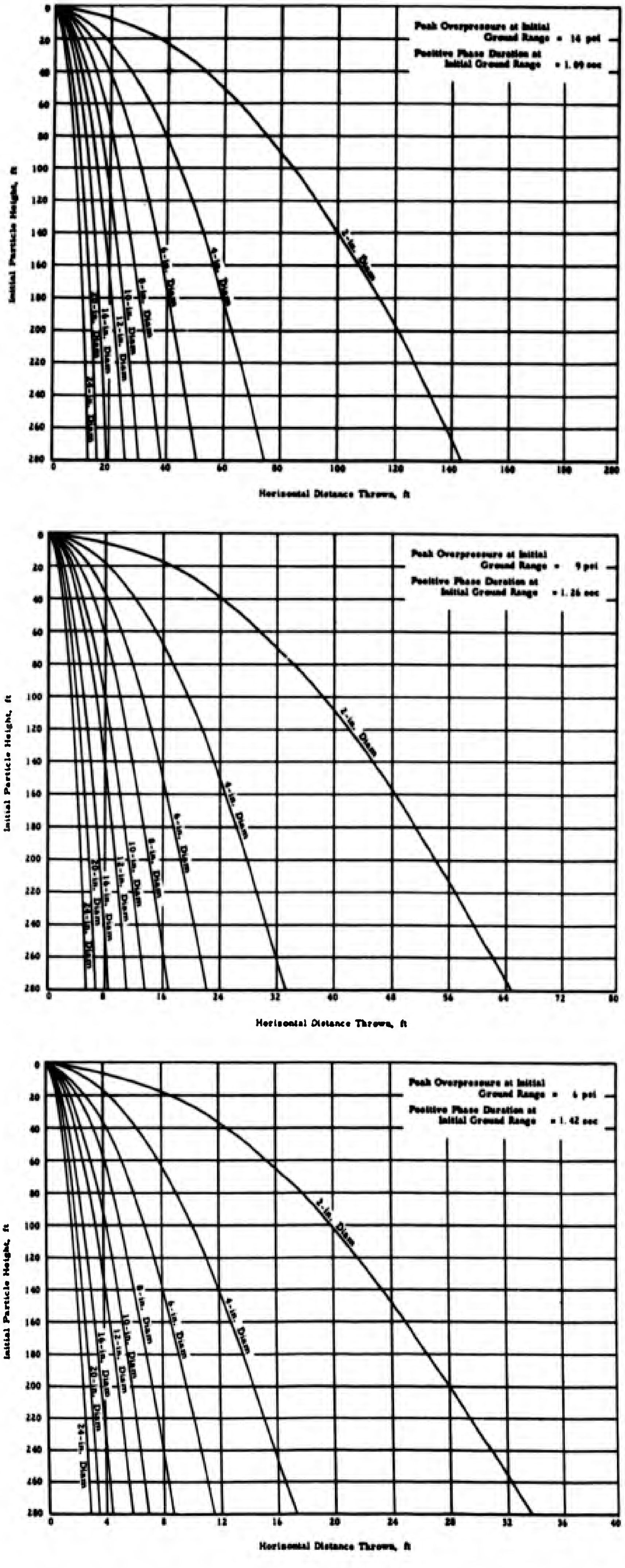
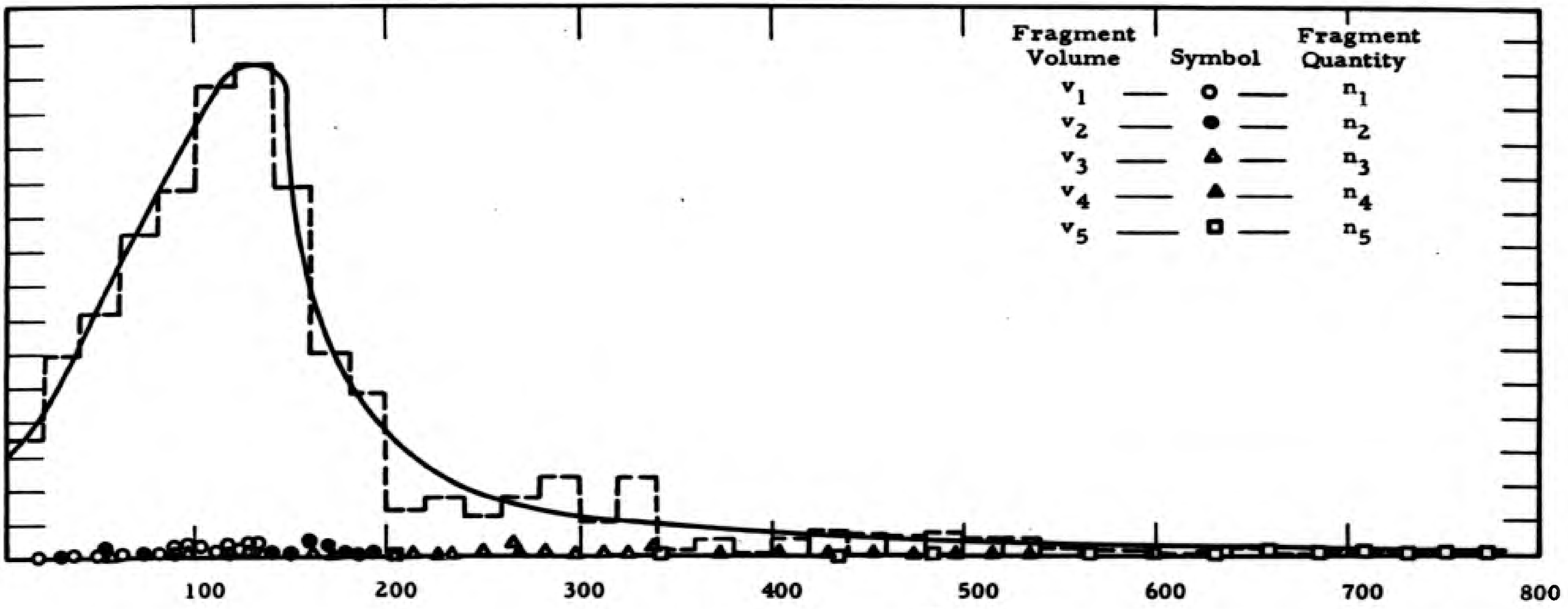


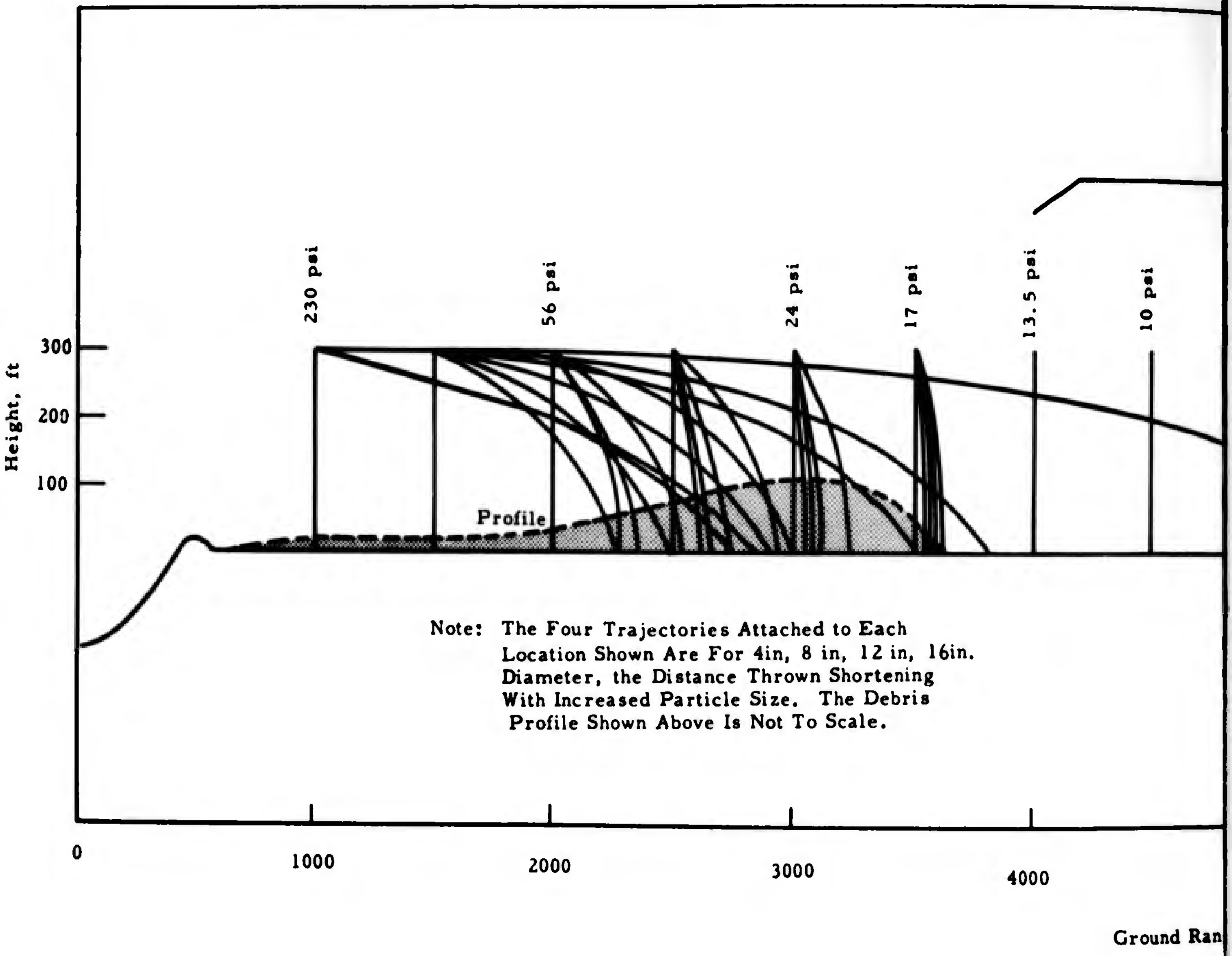
Fig. 3.7 (Cont'd) PARTICLE TRAJECTORIES FOR 100 KT SURFACE BURST



$$\text{Debris Depth at any distance} = \frac{\sum v_i \; n_i}{\text{Percent of solids in debris x area of distribution}}$$

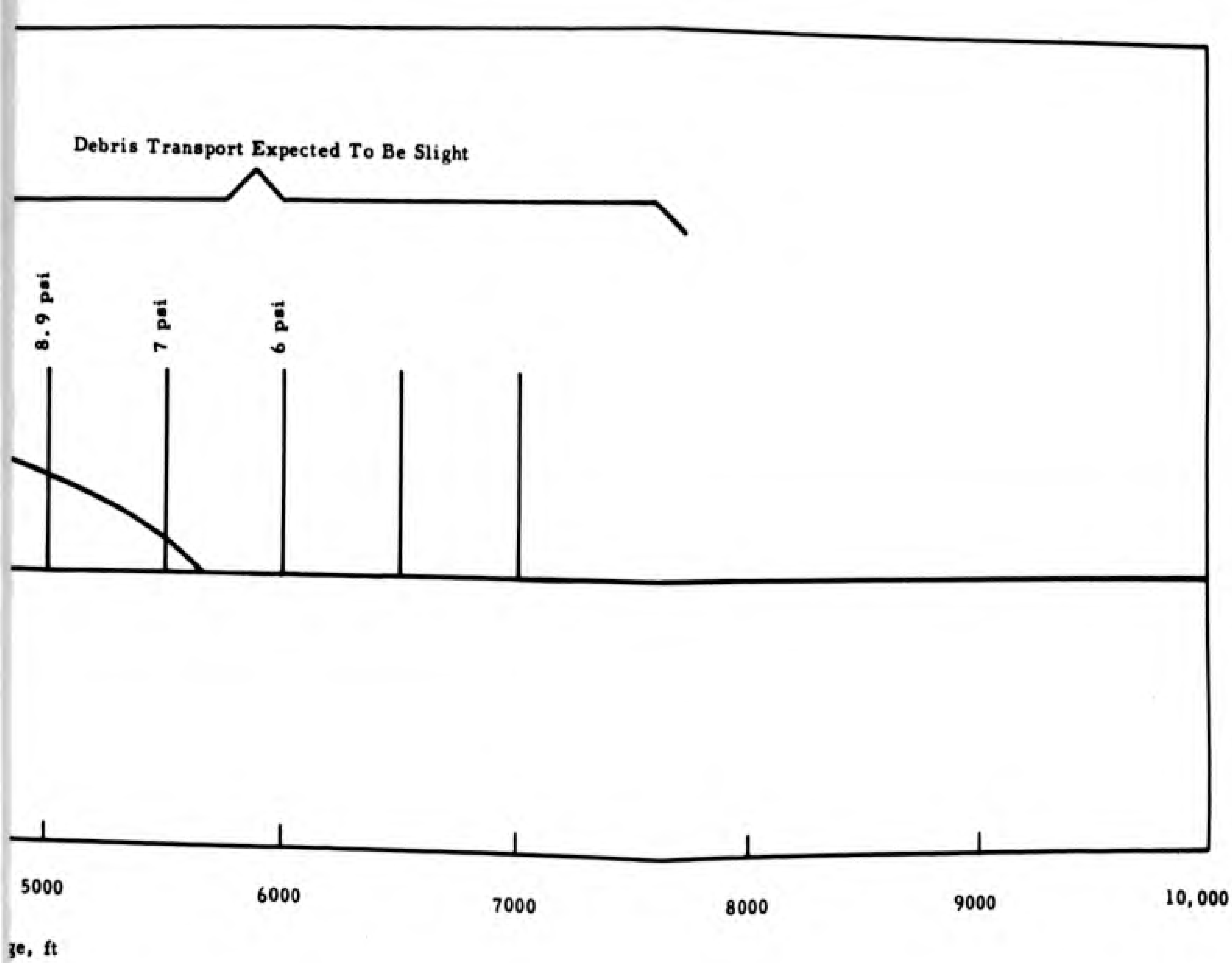
Fig. 3.8 SCHEMATIC DEVELOPMENT OF DEBRIS CONTOUR FOR A SINGLE STRUCTURE debris contours for various regions.

One interesting observation concerning particle trajectories is the fact of substantial overlap of trajectories originating at widely separated ground ranges, as can be seen in Fig. 3.7. This introduces the possibility of the debris tending to concentrate at certain ground ranges as illustrated pictorially in Fig. 3.9. This consideration is based on uni-directional transport consistent with a plane blast wave rather than on radial dispersion of the material. Quantitative estimates of contours by these methods, however, requires that the fragmentation study, begun on this program, be sufficiently refined to permit application to real structural elements.



Note: The Four Trajectories Attached to Each Location Shown Are For 4in, 8 in, 12 in, 16in. Diameter, the Distance Thrown Shortening With Increased Particle Size. The Debris Profile Shown Above Is Not To Scale.

Fig. 3.9 DEBRIS DISPERSION CHARACTERISTICS (100 KT)


Debris Transport Expected To Be Slight
8.9 psi
7 psi
6 psi
5000
6000
7000
8000
9000
10,000
ge, ft

Chapter Four

DEBRIS CLEARANCE EQUIPMENT AND MANPOWER

4.1 Capabilities of Removal Equipment

Estimating procedures, as performed for bid preparation on excavating work, customarily involve consideration of numerous factors affecting the required machine time; these include:

- Total quantity of material to be moved
- Type of material to be excavated
- Haul distance
- Travel conditions
- Grades on which equipment will operate
- Power and capacity of machines
- Altitudes, which affect machine capabilities
- Efficiency factors--waiting time, operator and supervisory skill, machine down time, and personal delays
- Job layout

With a knowledge of these factors a machine cycle time consisting of a fixed time (loading, dumping, turning, accelerating and decelerating) and a variable time which is a function of the haul distance can be synthesized.

A total debris removal task for a metropolitan area cannot be defined in sufficiently precise terms to make this type of estimating meaningful. Total quantities of material can be estimated in general terms, but the type of material poses other problems. Although certain analytical studies can be made to provide estimates of the fragment size-distribution, the prevalence and effect on operation time of quantities of structural steel and piping mixed randomly in the rubble cannot be predicted. It is likely that in many cases the work of bulldozers and power shovels will be frequently delayed by the necessity for torch cutting of structural steel, or by the need to blast fallen panels into sizes more suitable for loading. Highly detailed studies of rubble removal times are thus not entirely appropriate without refined definition of the nature of the operations.

Current needs are more appropriately represented by the provision of general estimates of the capabilities of excavating equipment operating in rubble. Such estimates of machine capability are first approximations of the production which can be expected of the machines in structrual debris when not hampered by the presence of twisted steel, limited by lack of operator skill, or penalized by unusual servicing requirements. As such, they represent the high limit of output for massive debris removal efforts.

Production rates included in this chapter are based on a rubble material resembling poorly blasted rock, and attainment of 45 minutes of machine time per hour. Hourly production rates for major classes of equipment are detailed in the following exhibits:

- Bulldozers -- Fig. 4.1
- Angledozers -- Fig. 4.2
- Tractor Scrapers -- Fig. 4.3
- Self-Propelled Scrapers -- Fig. 4.4
- Motor Graders -- Fig. 4.5

Production capabilities are summarized in Fig. 4.6, wherein the hourly production rates of the equipments are normalized in terms of the load capacity of the equipment. It should be noted here that equipments are not being compared for similar operations. Rates for power shovels are based on loading the rubble onto an embankment or into trucks for hauling, whereas the other estimates are based on the excavator doing the hauling, or pushing.

As stated, actual production rates would be less than the standards presented in Fig. 4.1 through 4.6, because of the following factors:

- Presence in the debris of steel work which must be cut away
- Unusually large clumps of reinforced concrete which may require special handling
- Need for further blasting of large panels
- Radiation monitoring and periodic decontamination of equipment, if required.
- Interruptions in fuel supply

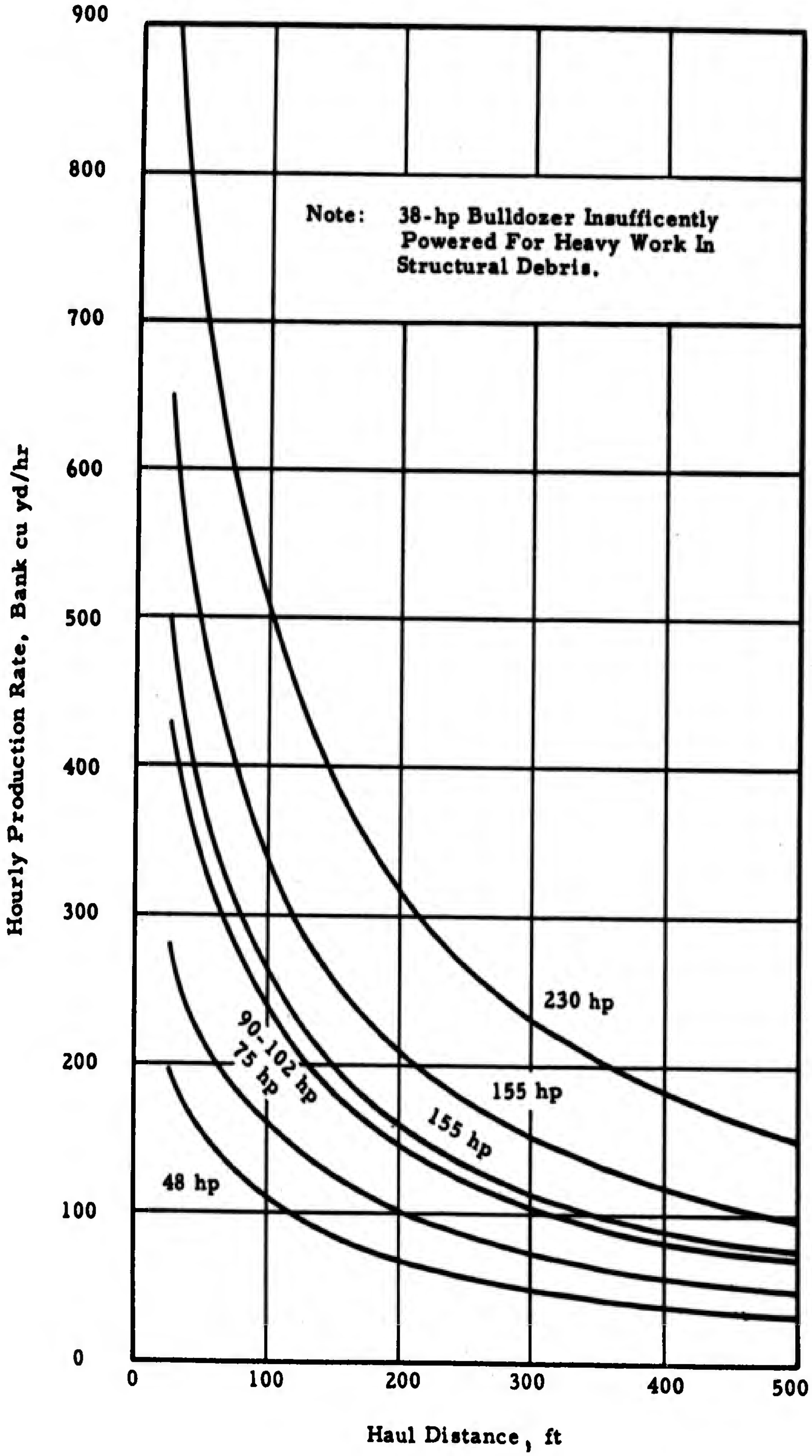


Fig. 4.1 ESTIMATED PRODUCTION RATE IN STRUCTURAL DEBRIS, CRAWLER-TYPE BULLDOZERS

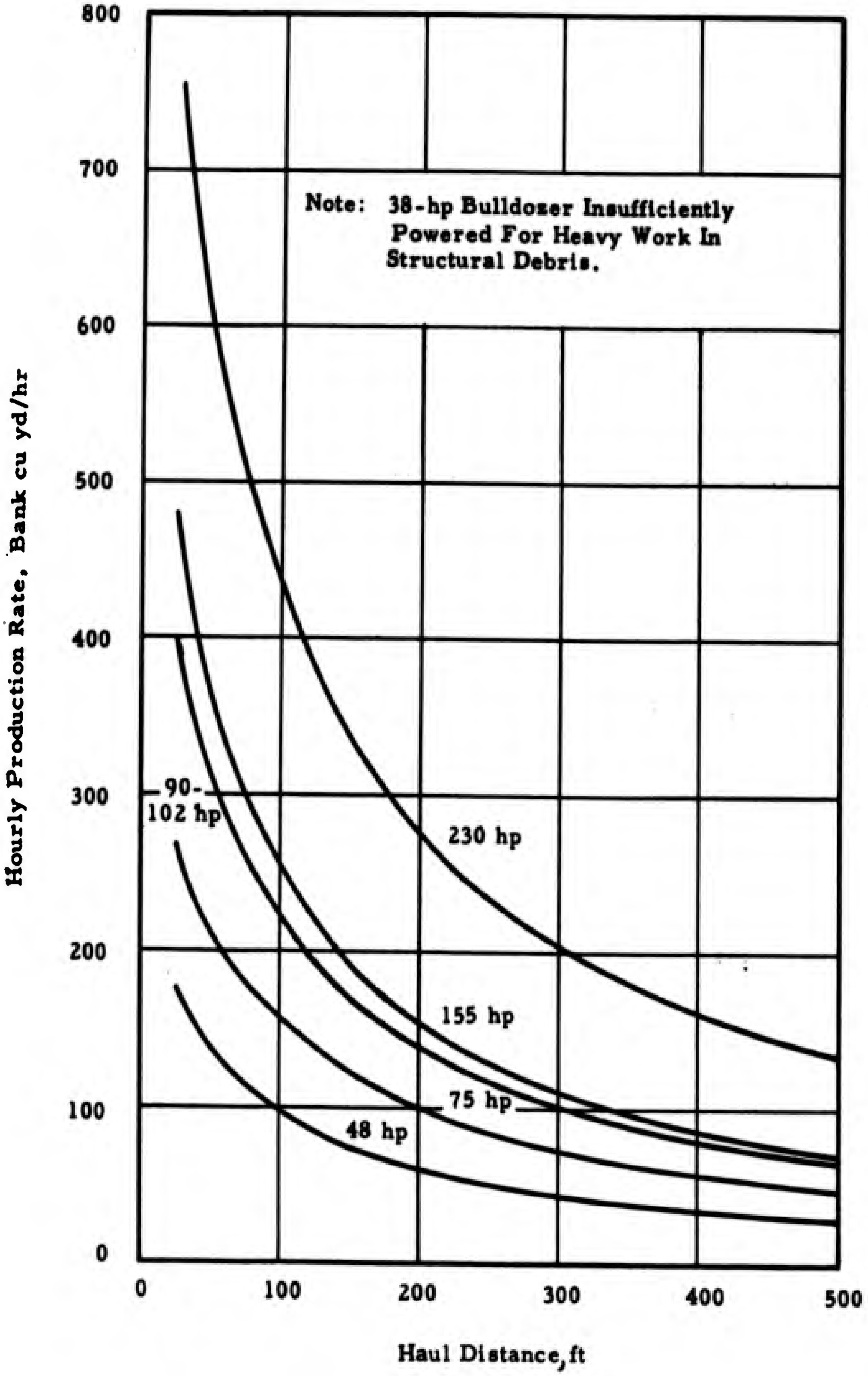


Fig. 4.2 ESTIMATED PRODUCTION RATE IN STRUCTURAL DEBRIS, CRAWLER-TYPE ANGLEDOZERS

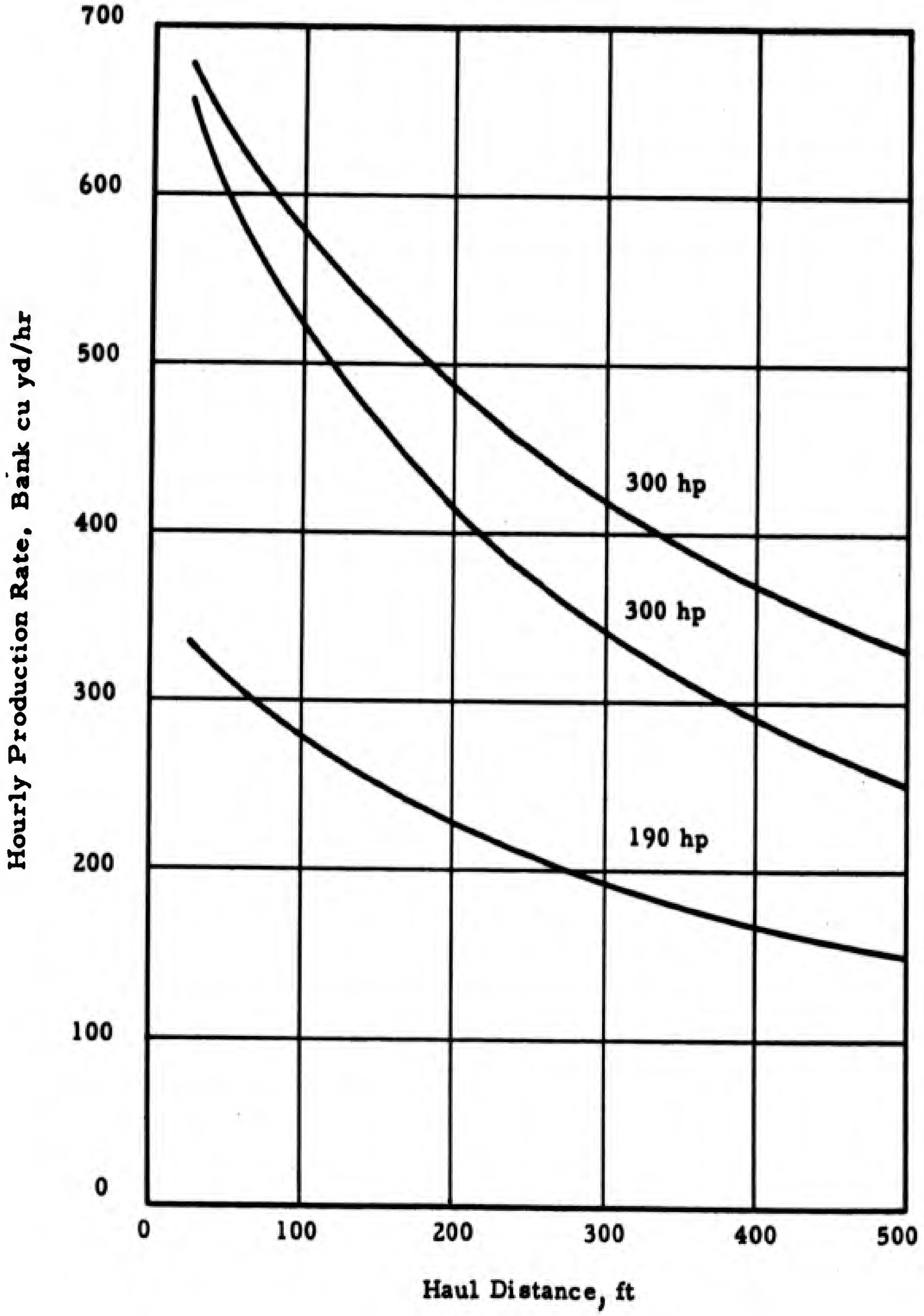


Fig. 4.3 ESTIMATED PRODUCTION RATE IN STRUCTURAL DEBRIS, TRACTOR SCRAPERS

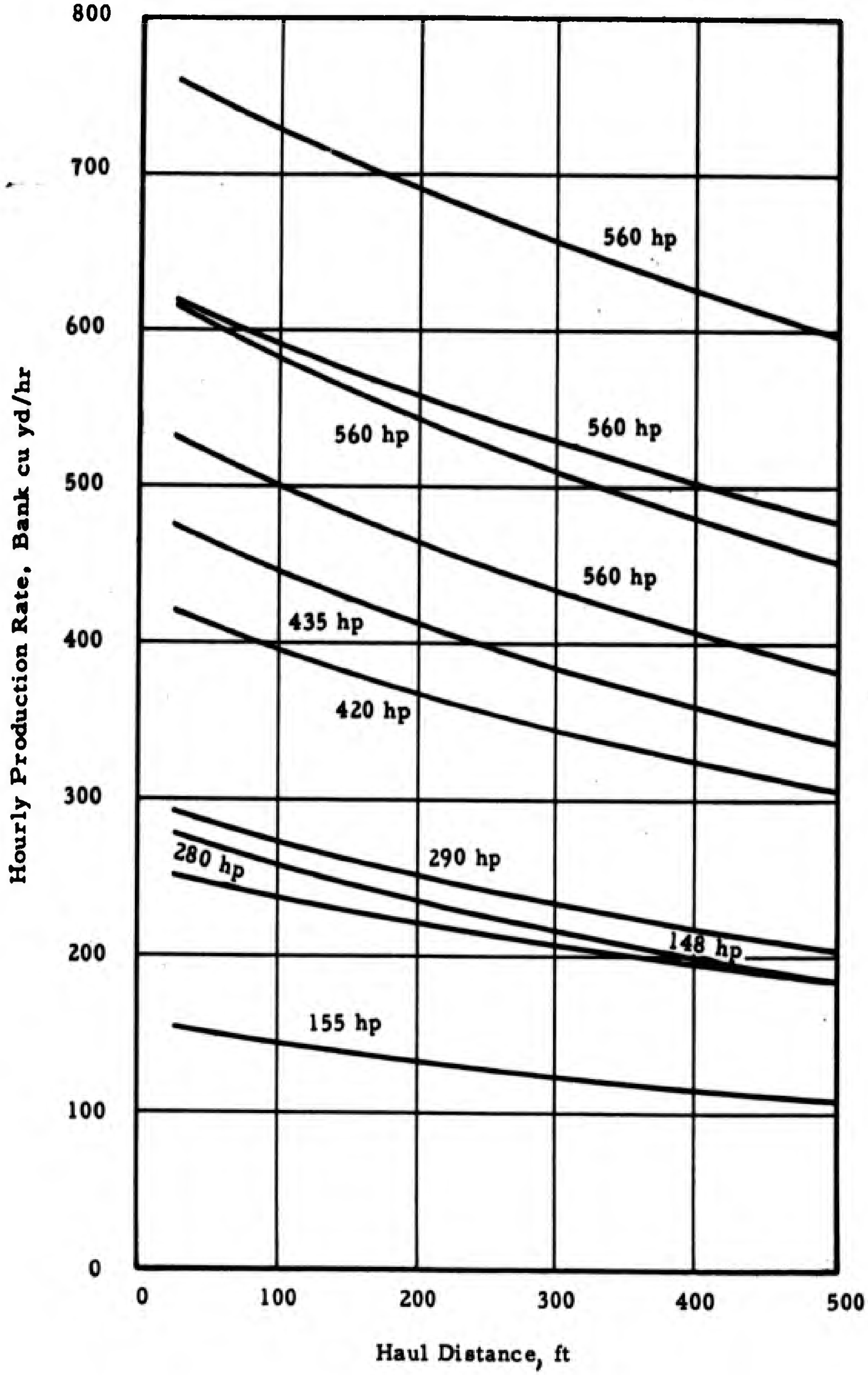


Fig. 4.4 ESTIMATED PRODUCTION RATE IN STRUCTURAL DEBRIS, SELF-PROPELLED SCRAPERS

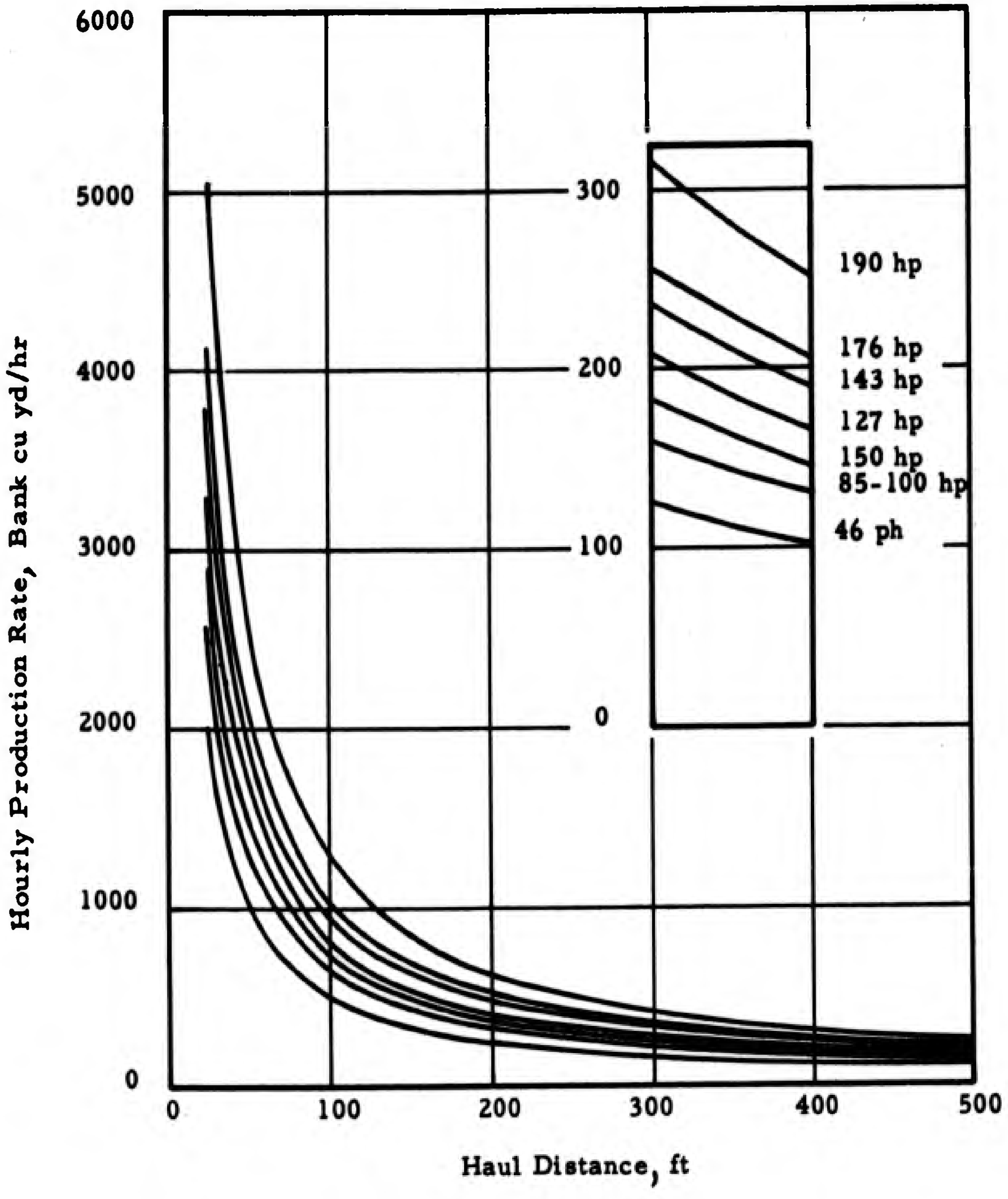


Fig. 4.5 ESTIMATED PRODUCTION RATE IN STRUCTURAL DEBRIS, MOTOR GRADERS

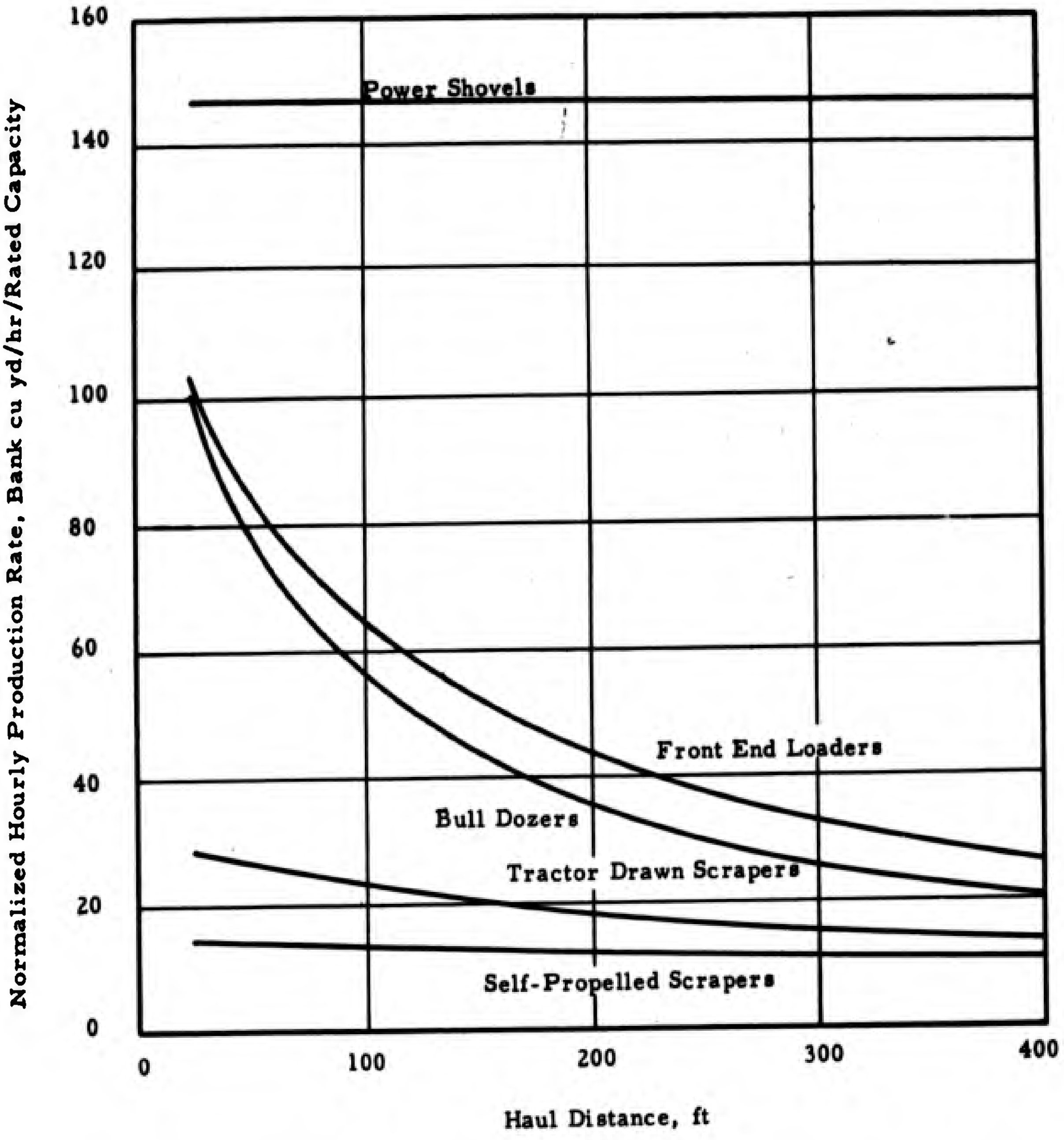


Fig. 4.6 ESTIMATED PRODUCTION RATES FOR DEBRIS REMOVAL

- Possible use of unskilled operators

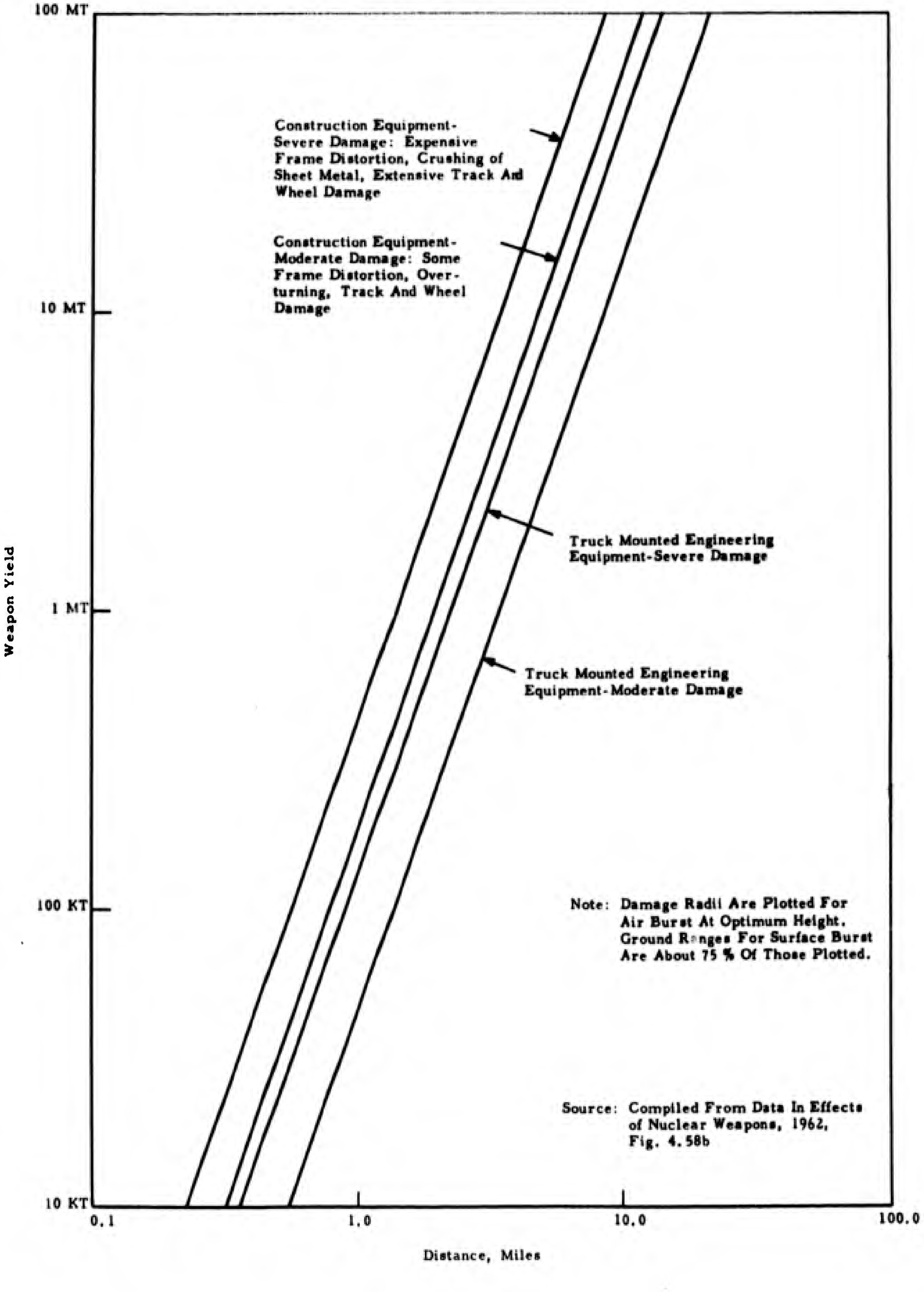
It is difficult to state the degree to which machine output would be reduced by these factors. Structures in the center of the city would contain more steel and piping than structures in the suburbs and hence be more difficult to handle. As far as operator skill is concerned, we have been advised that a tractor operator can be trained in three to four days. This training implies little more than physical manipulation of controls -- at an efficiency of about 25 percent than that of a skilled operator. In view of these factors it does not appear inappropriate to expect actual production rates from 50 to 75 percent of the standards in residential areas, and from 25 to 50 percent in commercial and industrial districts of major cities.

Equipment located within cities will be subject to blast damage -- and a likely reduction in numbers available. Regions within which equipment will be destroyed or damaged can be estimated from data in Fig. 4.7 and 4.8. In general, equipment within the range of moderate damage will require extensive repairs and not be immediately available. Equipment within the range of severe damage in Fig. 4.7 and 4.8 will require major overhaul, rebuilding, or be of value only for salvage of parts.

4.2 Availability of Labor Skills

The United States Census of Population, Series D, is a prime source of data on the availability of labor skills (Ref. 10, 11, 12). Available data include detailed occupation statistics on the employed and the experienced labor force - - - for the entire nation, regions, individual states, urban and rural divisions, and for the more populous counties (of over 250,000 population) and standard metropolitan statistical areas (of over 100,000 population). Civil defense planners can use these statistics in estimating the availability of manpower skills in regions of their concern. Volumes and tables from the 1960 Census of Population which contain occupational statistics are listed in Table 4.1.

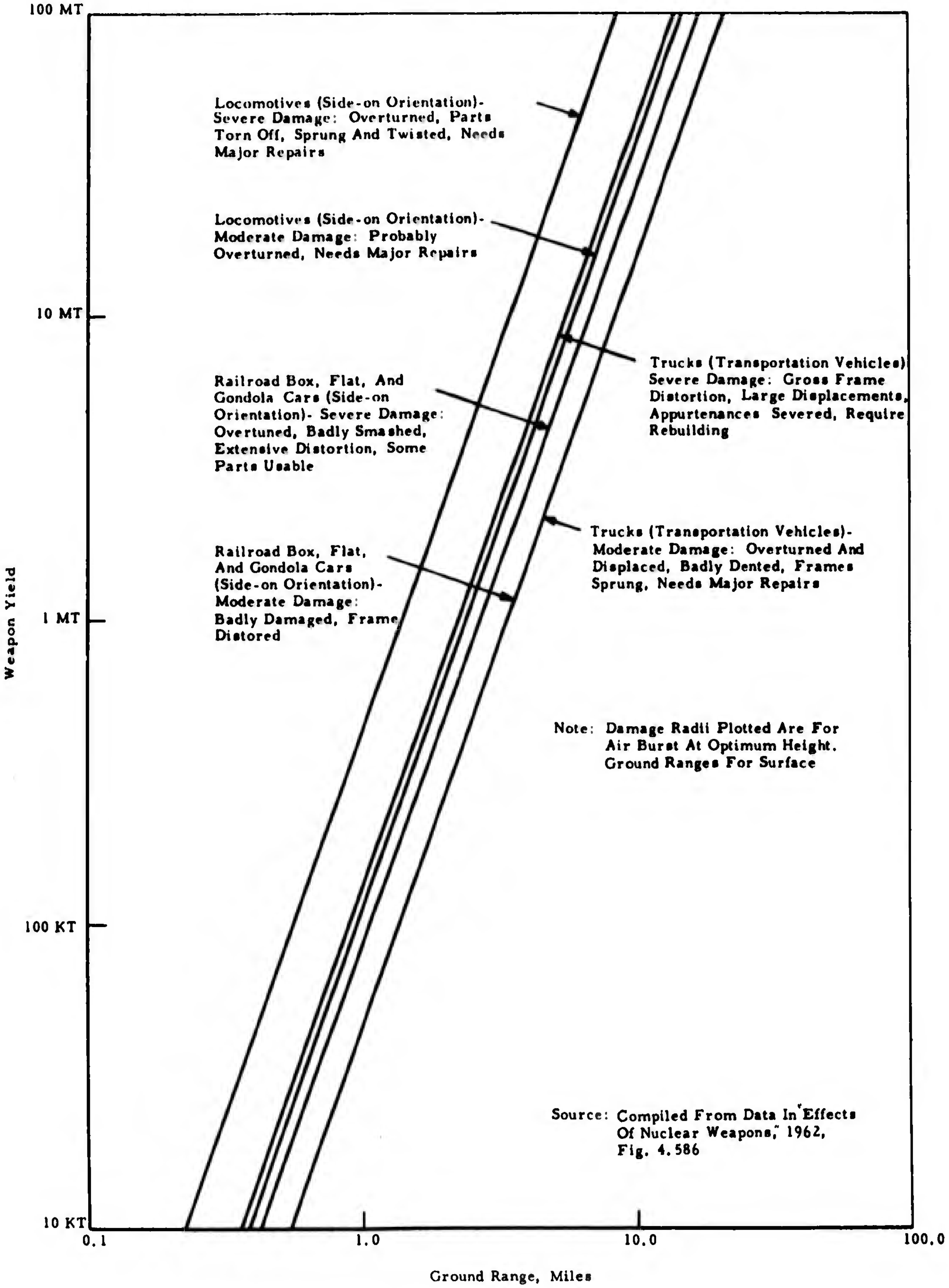
Selected statistics from the population census are reproduced in Table 4.2 to demonstrate the experienced manpower picture about one center, the City of Chicago. The number of people employed and/or experienced in selected occupations needed in debris clearance are tabulated for the City of Chicago, the Chicago-Northwest Indiana Area, the State of



Note: Damage Radii Are Plotted For Air Burst At Optimum Height. Ground Ranges For Surface Burst Are About 75 % Of Those Plotted.

Source: Compiled From Data In Effects of Nuclear Weapons, 1962, Fig. 4.58b

Fig. 4.7 DAMAGE RADII FOR ENGINEERING EQUIPMENT



Note: Damage Radii Plotted Are For Air Burst At Optimum Height. Ground Ranges For Surface

Source: Compiled From Data In "Effects Of Nuclear Weapons," 1962, Fig. 4.586

Fig. 4.8 DAMAGE RADII FOR HAULING EQUIPMENT

Table 4.1
OCCUPATIONAL STATISTICS IN THE U.S. POPULATION CENSUS OF 1960

Volume Number	Title of Volume	Tables on Occupations	
		Table Number	Title of Table
PC (1) ID U.S.	U. S. Census of Population, 1960 United States Summary, Detailed Characteristics	201	**Detailed Occupation of the Experienced Civilian Labor Force, by Sex, for the U.S. 1960 and 1950**
		202	**Detailed Occupation of the Employed, by Sex, for the U.S., 1960 and 1950**
		203	**Detailed Occupation of the Employed, by Sex, for the U.S. , Urban and Rural, 1960**
		256	**Detailed Occupation of the Experienced Civilian Labor Force and of the Employed, by Sex, for Regions, U.S.**
PC (2) 7C	U. S. Census of Population, 1960 Occupation by Industry	2	**Detailed Occupation of Employed Persons, by Detailsd Industry and Sex for the U.S., 1960**
PC (1) 2D Alabama through	U. S. Census of Population, 1960 (name of state, Detailed Characteristics	120	**Detailed Occupation of the Experienced Civilian Labor Force and of the Employed, by Sex, for the State, 1960 and 1950**
PC (1) 52 D Wyoming		121	**Detailed Occupation of the Employed, by Sex, for the State, Urban and Rural, for Standard Metropolitan Statistical Areas of 100,000 or more, Countries of 250,000 or more, 1960**

Table 4.2

NUMBER OF PERSONS EMPLOYED AND EXPERIENCED IN SELECTED OCCUPATIONS

Region and Item	Source	Occupation				
		Excavating, Grading, and Road Machinery Operations	Blasters and Powdermen	Welders and Flame Cutters	Truck and Tractor Drivers	Bus Drivers
United States:						
Experienced Civilian Labor Force	1	225,617	7,319	386,622	1,662,723	184,905
Total Employed	2	196,356	5,936	363,373	1,555,793	184,040
North Central Region: (Ohio, Indiana, Michigan, Wisconsin, Illinois, Missouri, Kansas, Nebraska, Iowa, Minnesota, North and South Dakota)						
Experienced Civilian Labor Force	3	58,823	1,260	151,265	481,438	47,917
Total Employed	3	49,292	1,079	141,788	449,572	47,191
Illinois:						
Experienced Civilian Labor Force	4	6,779	264	27,380	87,680	11,856
Total Employed	4	5,822	228	25,874	83,234	11,665
Total Employed -Urban	5	3,216	89	20,037	64,787	9,744
Total Employed-Rural	5	2,606	139	5,837	18,447	1,921
Chicago:						
Total Employed	5	2,210	32	14,627	48,499	8,840
Chicago-Nortwestern/Indiana Standard Consolidated Area:						
Total Employed	5	2,693	36	17,751	53,580	9,221

Sources:

1. Table 201 from U.S. Census of Population 1960, United States Summary, Detailed Characteristics, Final Report PC (1) ID U.S.
2. Table 202 from U.S. Census of Population 1960, United States Summary, Detailed Characteristics, Final Report PC (1) ID U.S.
3. Table 256 from U.S. Census of Population 1960, United States Summary, Detailed Characteristics, Final Report PC (1) ID U.S.
4. Table 120 from U. S. Census of Population 1960, Illinois, Detailed Characteristics, Final Report PC (1) 15 D Ill.
5. Table 121 from U.S. Census of Population 1960, Illinois, Detailed Characteristics, Final Report PC (1) 15D Ill.

Illinois, the North Central region of states, and the nation. It is seen that the larger geographical areas surrounding a major city, (i.e., the state and region) provide a substantial pool of available skills. This could be utilized if experienced manpower in the necessary skills in the city is inadequate due to casualties, or if certain skills are available only in limited numbers. The statistics on blasters and powermen, whose skills are applicable in felling partially demolished structures, provide an interesting observation. Though only 32 people of these skills are enumerated as employed in Chicago, we see that 228 of them are employed in the State of Illinois and that 60 percent of them are in rural areas -- where casualties could be expected to be less.

The occupational census thus provides data for use in estimating the available manpower skills normally available in the urban area, and in larger geographical regions about the major cities. They further delineate the portion of the labor force which is located in rural areas where casualties among them may be lower. Census reports also indicate numbers of persons in occupations similar to those desired in debris clearance -- such as bus drivers, many of whom could probably learn to drive trucks in a short time period. Foremen, superintendents, and other construction tradesman and laborers also possess useful skills.

4.3 Estimates of Available Debris Clearance Equipment

The number of machines operating in construction is estimated and reported periodically by the McGraw Hill Publication, Construction Methods and Equipment (Ref. 13). The 1960 estimate is reproduced in Table 4.3 . This estimate is based primarily on production records and expected service life of equipments. This equipment list includes many of the machines needed in debris clearance -- tractors, dozers, shovels, graders, and heavy trucks. Other construction equipment in this list, though not having a direct relation to debris clearance operations, but which may be useful in post-attack restorative construction, are also included here.

The equipment quantities given in Table 4.3 are totals for the entire nation. Reference 13 does not reduce this estimate to quantities for smaller geographical regions. Reasonable estimates of equipment quantities for local regions may be made by prorating these total quantities according

Table 4.3

ESTIMATED EQUIPMENT IN USE IN CONSTRUCTION, UNITED STATES 1960

Type of Equipment in Use	Estimated Number in use 1960
Asphalt Plants	4,000
Automobiles, Company Owned	250,000
Batching Plants, concrete	13,500
Bituminous distributors	10,000
Compressors, air, portable	50,000
Conveyors	20,000
Cranes (see Shovels)	
Crushers, stone (stationary)	5,500
Crushers, stone (portable)	6,500
Crushing Screening Plants	5,000
Draglines (see Shovels)	
Dozers, bull and angle (not including tractor)	165,000
Dredges, floating	750
Earth augers and post hole diggers	20,000
Earth borers and pipe pushers	7,500
Front-and loaders (see Tractor Loaders, Shovels)	
Finishing machines and spreaders, pavement	10,000
Generators, electric, including light plants (stationary)	17,500
Generators, electric (mobile)	14,000
Graders, motor	81,000
Graders, pull	10,500
Hoists	17,500
Locomotives, industrial and tunnel	1,100
Mixers, concrete and mortar	100,000
pavers	15,000
Mixers, trucks, ready-mix (see Truck mixers)	
Mixers, soil stabilization and bituminous	15,000
Pumps, portable (total)	160,000
Pumps, portable (with tires)	80,000
Rollers, pneumatic	8,000
Rollers, tamping, sheepsfoot (compaction)	15,000
Rollers, road, self-propelled	29,000
3 wheel	(6,000)
Portable	(5,000)
Tandem	(18,000)
Saws, circular, band, chain (power hand saws not included)	75,000
Scrapers, carrying	43,500
Screens, rotary or shaker	9,000
Shovels, including cranes and draglines on truck chassis	30,000
Shovels, including cranes and draglines	50,000
Trailers, wagon	5,800
Tractors, crawler	340,000
Tractors, wheel	35,000
Tractor Shovels, complete	60,000
Crawler, mounted	(29,000)
Wheel, mounted	(31,000)
Tractor Attachments, Crane	5,000
Front and Loader	100,000
Trench machines	9,500
Ladder	(6,000)
Wheel	(3,500)
Truck mixers and agitators	32,000
Trucks, off-the-highway	16,000
Trucks, over-the-road	1,650,000
Wagons (see Trailers, wagon)	
Welders, electric	55,000

Source: Market and Media Facts from Contruction Methods and Equipment,
McGraw-Hill Publishing Company, New York

to suitable indices. Several indicies may be used to estimate local equipment quantities -- total dollar volume of construction, miles of new road building, or numbers of people in associated occupations. An example of a local estimate is presented in Table 4.4, in which selected items of earthmoving equipment are estimated for various geographical regions around the City of Chicago. In this estimate the machinery is prorated according to the numbers of persons employed as excavating, grading and road machinery operators according to United States Census Data.

Comparisons indicate that many more items of equipment (Table 4.4) are available than operators (Table 4.2). This is not unusual since contractors would be expected to make greater time utilization of men than equipment, and would be expected to retain old equipment for peak load usage.

Table 4.4

ESTIMATED AVAILABILITY OF EARTHMOVING MACHINERY-CHICAGO AND SURROUNDING REGIONS

Type of Equipment	United States Total	Illinois			Chicago	Chicago - Northwest Indiana Standard Consolidated Area	North Central Region
		Total	Urban	Rural			
Tractors, Crawler	340,000	10,000	5,600	4,500	3,820	4,660	83,600
Tractors, Wheel	35,000	1,040	580	460	390	480	8,600
Tractor Shovels, Complete	60,000	1,780	980	800	670	820	1,480
Dozers, Bull and Angle (not including tractor)	165,000	4,890	2,700	2,190	1,850	2,260	40,600
Tractor Attachments, Crane	5,000	148	82	66	56	68	1,230
Tractor Attachments Front End Loader	100,000	2,960	1,630	1,330	1,120	1,370	24,600
Shovels, Including Cranes and Draglines	50,000	1,480	820	660	560	680	12,300
Shovels, Including Cranes and Draglines; on Truck Chassis	30,000	890	490	400	340	410	7,400
Scrapers, Carrying	43,500	1,290	710	580	490	600	10,700
Graders, Motor	81,000	2,390	1,320	1,070	910	1,110	19,900
Graders, Pull	10,500	310	170	140	120	144	2,580
Trucks, Off-the-Highway	16,000	470	260	210	180	220	3,940
Trucks, Over-the-Road	1,650,000	48,800	27,000	21,800	18,500	22,600	406,000
Trailers, Wagon	5,800	172	95	77	65	79	1,430

Chapter Five

PLANNING AND SCHEDULING DEBRIS REMOVAL EFFORT

5.1 Needs for Pre-Disaster Planning of Debris Clearance Measures

As earlier chapters show, debris accumulation in large cities can reach extensive proportions. The clearance effort can reach magnitudes requiring mobilization of equipment and manpower from regions beyond the city itself. In the event of multi-city attacks the effort can even require the mobilization and allocation of resources on a national basis.

It is possible that cities could be so devastated as to appear economically unfeasible to restore. A situation whereby all structures in a community are destroyed would justifiably pose questions relative to the wisdom of rebuilding on the same site. However, certain site-selection factors tend to favor rebuilding, such as

- natural advantages of certain harbor areas
- present locations at hubs of transportation networks
- economic value of existing underground utility systems
- economic value of repairable structures and facilities.

For these reasons, current city sites may be favorable rebuilding sites even if the level of damage dictated vast reconstruction efforts.

Multiple attacks on urban areas with high-yield weapons would render many miles of streets immediately impassable to all but tracked vehicles. Clearance may involve the removal of millions of cubic yards of rubble, a task requiring large quantities of equipment and manpower. Within the disaster area excessive casualties among excavating equipment and skilled operators can be expected; however, possibilities exist for mobilization of equipment and manpower from beyond disaster areas to accomplish the immediately requisite tasks.

Effective accomplishment of debris clearance in major municipalities will require effective pre-disaster planning. Even if hundreds of thousands of urban dwellers remain uninjured in an attack, and many began clearance through enthusiastic voluntary manual effort, the undirected and uncoordinated application of this vast labor pool would be likely to produce, at best, a multiplicity of cleared islands in an expanse of rubble. Ultimately these islands would expand and enlarge. The effectiveness of the effort in achieving vital missions first would be partially a matter of chance.

If timely clearance of urban regions is to be accomplished with expediency, pre-disaster planning for this operation is necessary. Such pre-disaster planning should include

- Preparation of debris estimates to fully inform local Civil Defense administrators of the magnitude of their task
- Preparation of a census of excavation equipment and operators, together with an allocation plan for their mobilization
- Preparation of step-by-step clearance programs for individual cities
- Provision for implementing clearance programs upon post-attack observations
- Provisions for life-support services to workers during clearance operations

The effectiveness of debris clearance measures often to be directly related to the extent of pre-disaster preparation. An initial outline of the elements of debris clearance measures is presented here for consideration as part of disaster planning.

National, regional, state, and local Civil Defense organizations all have a role in planning for debris clearance operations. The role of the national group would be primarily that of establishing policy, administration, resource allocation, and instructing local Civil Defense administrators on preparation of local programs.

It will be assured that responsibility for actual clearance operations rests with local agencies. Operations may be centrally coordinated, but not centrally directed.

5.2 Delegation of Functions Under a Pre-Disaster Debris Clearance Plan

One school of thought hypothesizes that retaliatory weapons systems, rather than major cities, would be the prime targets in an attack. If this were the case, debris problems in the major cities would be less serious. Major airport facilities capable of becoming bases for Strategic Air Command bombers are generally considered likely targets. Because these facilities generally are at considerable distances from central business districts, hits on them would demolish suburban homes, but perhaps leave the congested region of tall buildings relatively intact.

In Civil Defense planning, we can not disregard the possibility that an attacking force would regard the financial, industrial, transportation, and administrative centers of the nation to be prime targets, -- nor the possibility that reduction of the nation's urban populations would actually be an attack objective. With the increasing stock piles of nuclear armaments, the existence of sufficient weapons for both military and civilian objectives must be assumed.

For these reasons, pre-disaster planning for debris clearance has been outlined with a view to the possibility of a broad-based attack on the major population centers. Devastation from such an attack would be such as to require active participation of Civil Defense groups at all levels (local, state, regional and national) to accomplish a directed and coordinated program of restoration.

Functional responsibilities for debris clearance measures are outlined in Table 5.1. This initial outline delineates some of the major tasks involved -- other considerations are involved in integrating these functions into the over-all Civil Defense disaster plans of the nation.

As projected in Table 5.1 the function of the national OCD headquarters is one of policy making, planning, instruction, and over-all administration. A massive attack on all major cities would cause equipment losses in target areas without damaging equipment in most rural areas. The national organization would assume responsibility for such

Table 5.1

FUNCTIONAL RESPONSIBILITIES IN DEBRIS CLEARANCE PLANNING

Civil Defense Organizational Level	Functional Responsibility.	Tasks
NATIONAL	Policy Making, Planning, Administration, and Education	• Establishment of mobilization and allocation policies for equipment. and manpower. • Assignment of responsibilities to lower organizations. • Coordination of the National effort. • Preparation of expected attack patterns. • Preparation of priority lists of cities to be cleared in event of massive multi-city attack. • Preparation of enabling legislation for mobilization of manpower and equipment. • Inter-regional transfers or equipment and manpower. • Preparation of handbook on debris clearance problems and other instructional materials. • Decisions of extreme national importance (i.e., complete abandonment of a city site). • Establishment of policy on selection of dump sites. • Coordination of debris removal plans with national military objectives.
REGIONAL	Coordinative and Directive	• Integration of local debris clearance plans into coordinated regional efforts. • Implementation of mobilization plans for manpower and equipment. • Intra-regional transfers of equipment and manpower • Selection of dump sites.
STATE	Facilitation and Supplementation	• Assignment of state-owned equipment and personnel • Mobilization and utilization of militia and militia equipment. • Participation in regional preparations and post-disaster operations. • Assistance to local organizations in directing and conducting clearance operations. • Supplementation of personnel. • Preparation of census of equipment and manpower resources.
LOCAL	Operational	• Pre-disaster estimating of magnitude of local problem. • Pre-disaster planning of clearance operations. • Pre-disaster estimations of equipment and manpower requirements. • Post-disaster implementation of clearance operations.

Table 5.2

NATIONAL-LEVEL TASKS IN DEBRIS CLEARANCE PROGRAMS

PRE-DISASTER

Policy Making

Mobilization

Designate equipment, skills, and supplies subject to mobilization

- Excavating equipment
- Portable acetylene cutting equipment
- Demolition explosives
- Protective clothing
- Hauling equipment
- Fuels, tires, etc.
- Skilled operations

Establish conditions for exemption from mobilization

Allocation

Establish regions of mobilization about cities for various attack patterns.

Operational

Select standards for permissible dump sites for rubble.

Establish procedures for selecting transportation arteries for clearance in various stages of the over-all clearance program.

Planning

Preparation of alternate attack patterns.

Keep expected attack patterns current.

Review regional and local disaster plans
- Integrate with national interests
- Assure compliance with standards.

Establishment of mechanisms for interregional transfer of mobilized resources.

Administration

Assign authority and responsibilities to regional and local organizations
- Establish regions
- Man regional commands

Coordinate regional and local plans with the national effort

Prepare enabling legislation for enforcement of mobilization measures

Advise local organizations of magnitude of debris clearance tasks

Instruct regional and local organizations in clearance measures and methods.

Instruct regional and local organizations in procedures for pre-disaster planning.

Instruct regional and local organizations in post-disaster control of operations.

Prepare Debris Clearance Handbook and other instructional material.

POST-DISASTER

Policy Making

Allocation

Revise equipment allocation scheme depending on variance in expected needs.

Operational

Decisions regarding complete abandonment of a city with an extreme level of damage.

Decisions regarding covering of rubble rather than removal.

Rescue - clearance of shelter entranceways
Restoration of minimum transportation
Access to all remaining hospitals
Restoration of utilities
Restoration of communications
Clearance of all main streets
Restoration of public transportation
Clearance of all streets
Industrial recuperation
Commercial recuperation
Rehabitation of residences
Ultimate removal of all rubble

Coordination with National Military Objectives

Assistance of military services in clearing cities

Clearance of vital military facilities
- Ports
- Airfields

Planning

Review losses of available equipment and operators for excavating, hauling, and demolition work, as input to revising allocation plan.

Administration

Facilitate compliance with clearance objectives in post-attack period
- Review progress
- Introduce corrective measures where objectives are not being met.

excavating equipment and operatiors. Mobilization and transfer of surriving equipment with operators would likely be required. Our preliminary study suggests that in such regions as the great industrial belts, orderly mobilization and allocation reflecting in the national interest should be performed in accordance with national policy and under Federal directive. This is based on the surmized that whereas two neighboring cities cannot simultaneously commandeer the same equipment, it is likely that all state and local organizations would consider their own regions the most demanding of immediate assistance. Situations can also be expected where a selection between sites scheduled for earliest clearance must be made; this would best reflect the national interest only if done in accordance with federal policy.

General coordination and direction of clearnce is delegated to regional Civil Defense groups. It is envisaged that this would facilitate clearance in accordance with the over-all national interest without placing an undue burden on the limited Federal staff.

Actual removal operations are assigned to the local Civil Defense organizations. It appears that recuperation from massive multi-city attack can be accomplished in no other way. State Civil Defense organizations are stated here to be facilitative and supplementary. If this role appears minor, such seeming unimportance is illusory. A major attack on metropolitan areas would result in casualities among local officials designated to organize and conduct debris clearance. The remaining skeleton staff would need to be filled out and expanded, and state officials well versed with local plans, would constitute the only real availabe supplementation.

5.3 Task Assignments in Debris Clearance

A tentative schedule of debris removal task assignments consistent with the functional responsibilities outlined has been prepared. This schedule is presented in Tables 5.2 and through 5.5. While not all-inclusive in nature, this schedule represents an initial step in delineating the pre-attack preparations that can be taken to upgrade the post-disaster effort, to introduce some order into the chaotic post-attack environment, and to strive for a directed effort consistent with the national interest.

Table 5.3

REGIONAL LEVEL TASKS IN DEBRIS CLEARANCE PROGRAMS

PRE-DISASTER

Coordinative

Assist local organizations in preparation of debris removal programs.

Review local plan for conformance to the national interest.

Integration of local plans into a unified regional effort.

POST-DISASTER

Directive

Implement mobilization of manpower and equipment.

Perform intraregional transfers of equipment, manpower, and supplies to obtain timely performance of removal objectives.

Select dump sites.

Review and evaluate areas of extreme devastation, considering advisability of complete abandonment.

Reallocate resources as objectives fall behind schedule locally.

Review local performance per schedule, and introduce corrective measures.

Table 5.4

STATE LEVEL TASKS IN DEBRIS CLEARANCE PROGRAMS

PRE-DISASTER

Facilitative and Supplementary

Participate in integrating local clearance plans into regional programs.

Maintain full cognizance of local plans.

Prepare census of equipment and manpower resources.

POST-DISASTER

Facilitative and Supplementary

Assist local organizations in directing and conducting clearance operations.

Supplement personnel
  Building inspectors
  Street and highway personnel
  Political leadership and administrative personnel.

Mobilize and direct utilization of state equipment
  Militia and militia equipment and supplies
  Fuel, tires, etc.
  Highway department facilities.

Table 5.5

LOCAL LEVEL TASKS IN DEBRIS CLEARANCE PROGRAMS

PRE-DISASTER

Operational

- Prepare estimates of debris accumulation in own areas, using N.F.S.S. tabulation and other data.
- Prepare complete local debris clearance plans
    - Prepare den[illegible] indicating likely depths of debris
    - Note vital re[illegible] early clearance
    - Locate permissible dump sites and note capacities.
    - Draw primary access routes through cities preferred for early clearance.
    - Map out clearance program by stages according to major objectives noting quantities and movement required. (as per Table 1.1)
    - Set up time schedule for program by stages, considering the amount of mobilized and allocated equipment available.
    - Prepare task assignments for clearance operators.
    - Select personnel to lead debris clearance program.
    - Integrate major excavating contractors, wrecking companies, truckers into disaster plans, and assign roles under mobilization procedures.
    - Introduce appropriate city and state technical employees into the clearance effort -- i.e., building inspectors, utility personnel, political leaders.
    - Organize secondary level of leadership outside disaster area (state organization) to organize clearance if losses among primary personnel are excessive.
- Submit local plans to regional organization for integration into the over-all plan.
- Revise plans to comply with regional and national objectives.
- Disseminate standing instructions to personnel.
- For post-attack survey of disaster area and implementation of pre-attack plans.

POST-DISASTER

Operational

- Conduct survey determining actual rubble accumulation.
    - Denote areas of heaviest rubble
    - Denote conditions of major transportation arteries
    - Note areas that cannot be worked because of radioactivity.
- Revise debris clearance plans to fit actual debris patterns
- Select thoroughfares for resumption of traffic, in accordance with major objectives.
- Set up control points, supply points (fuel, tires, explosives, etc.), and some form of communications with operators.
- Mobilize equipment and manpower, within local allocation zone.
- Advise regional command of needs for additional equipment, supplies, and operators.
- Advise regional command of areas of extreme devastation which may not be worth clearing.
- Establish and police hauling routes.
- Issue task orders to equipment crews and common labor pool.
- Set up life-support services (monitoring of radiation, food, water, etc.).
- Set up salvage provisions for recovering materials of value.

Chapter Six

FALLOUT AND ITS EFFECT UPON THE PROBLEM OF DEBRIS CLEARANCE

In considering the radiation problems connected with the rubble left after a nuclear attack on a metropolitan area, the following questions are raised:

> How much radioactivity is present in the rubble?
> How can it be predicted?
> How can it be measured?
> What problems does the radioactivity of the rubble cause in disposing of the rubble?

Several studies have been carried out dealing with the predicted fallout from a nuclear attack on the United States. These studies range from evaluation of large scale aspects for the entire nation (Ref. 14) to the detailed variations expected in the vicinity of one detonation (Ref. 15, 16, 17). Since the area contaminated by fallout from a surface burst is generally much larger than the area in which blast and thermal effects are important, it is obvious that under most (if not all) conditions the rubble produced by blast and thermal effects will be contaminated by fallout as well.

The general characteristics of fallout are reasonably well understood. For large (1MT and up) surface nuclear bursts, the level of radioactivity at ground zero will be on the order of 10,000 R/hr at 1 hour after detonation. At the maximum radius of structural failure (2-3 psi overpressure) the level of radioactivity will be approximately 100 R/hour at 1 hour after detonation. The radioactivity decreases with time approximately as $t^{-1.2}$ for the first 6 months and more slowly thereafter. This fallout contamination consists largely of radioactive dust which begins to settle on the rubble almost immediately and is essentially complete within 24 hours after detonation. While a fair amount of the fallout will probably sift down into the rubble, most of it is expected to remain on top if left undisturbed.

Weather effects will modify the fallout distribution both before and after it has reached the surface of the earth. Ambient winds, if present during the time the fallout is in the air will carry the fallout downwind. The larger fallout particles ($>$1000 microns in diameter) will reach the earth within a few minutes after a surface nuclear detonation, and will therefore not be transported horizontally to any appreciable extent unless a strong wind ($>$ 30 mph) is blowing. The smaller particles, especially those less than 100 microns in diameter, will take hours to fall and will be transported several miles downwind by even a moderate ($\sim$ 15 mph) wind.

The occurrence of precipitation while the fallout is still in the air will accelerate the deposition of the fallout. The level of radioactivity at the ground surface may be increased by a factor of 2 within the rubble area, and by a factor of 20 or more downwind, due to this effect.

Once the fallout has reached the surface of the earth, the wind and rain still may exert further influence upon it. Wind may blow the fallout about, tending to sweep open areas clean, and piling the fallout up against structures which cause the wind to change velocity or direction suddenly, much as snow is piled in drifts. The surface flow of rain and melting snow will tend to carry the fallout along with it; sewers, rivers, and depressions in the earth will then become more radioactive than before (Ref. 18).

The number of variable weather effects is sufficiently large that predicting the fallout in any specific situation is difficult. Added to this are the uncertainties as to the yield, type, placement, and timing of the nuclear weapon so that a sophisticated analysis of a metropolitan area will produce only probable radioactivity distributions for given initial conditions. Actual post-attack situations will require a fallout survey of the damaged area to accurately assess its distribution.

Any survey of radioactivity present in and around the rubble must be considered in the larger context of the overall situation. Rescue and treatment of survivors of the nuclear attack by specially trained teams will be, perhaps, the first order of business. These teams will require radiation meters (such as V-700 unit Defense Instruments) but at this stage they will be used primarily to assess the local dangers rather than to survey the entire rubble-covered area.

Once the most immediate needs of survivors (water, food, shelter, clothing) are met and effective governmental controls established at the local level, the problem of the radioactive rubble can be considered.

The first phase of the problem of radioactive rubble will probably be to survey the situation. While this survey will likely include an inventory of available facilities and equipment, here we are concerned only with the contamination of the debris.

Various methods of carrying out the survey may be considered, with aerial survey by airplane, helicopter, captive balloon, or radio controlled drones appearing feasible if they can be made available (Ref. 19). Equipment and techniques used in uranium prospecting could be used here. The use of shielded tracked vehicles (e.g., tanks) is another possibility, though their availability for this purpose is questionable. Trained animals might also be considered if no other means existed.

Once the contamination survey has been completed, the problem of disposing of the radioactive rubble remains. Three alternative courses of action can be considered:

a) Decontaminate it without removal.
b) Remove it either to be decontaminated or abandoned.
c) Reuse it without either decontamination or removal.

Contamination of the rubble will present difficulies in any case. No matter what action is taken with regard to rubble, the accumulated fallout will produce radiation levels which will limit the amount of time unshielded personnel can work in the region of severe blast damage. Endurance times will be approximately inversely proportional to the existent radiation levels. While peacetime radiation limits for civilians are currently set at 5 R/year (Ref. 20) much higher exposure limits will undoubtedly be used under post-attack conditions. For the purposes of this study exposure limits of 100R have been assumed, since at this level healthy humans do not exhibit external effects which prevent their functioning normally (Ref. 21). Endurance times at various distances from ground zero following the detonation of a 50 percent fission 1.0 MT weapon are shown in Fig. 6.1 for a total dose of 100R.

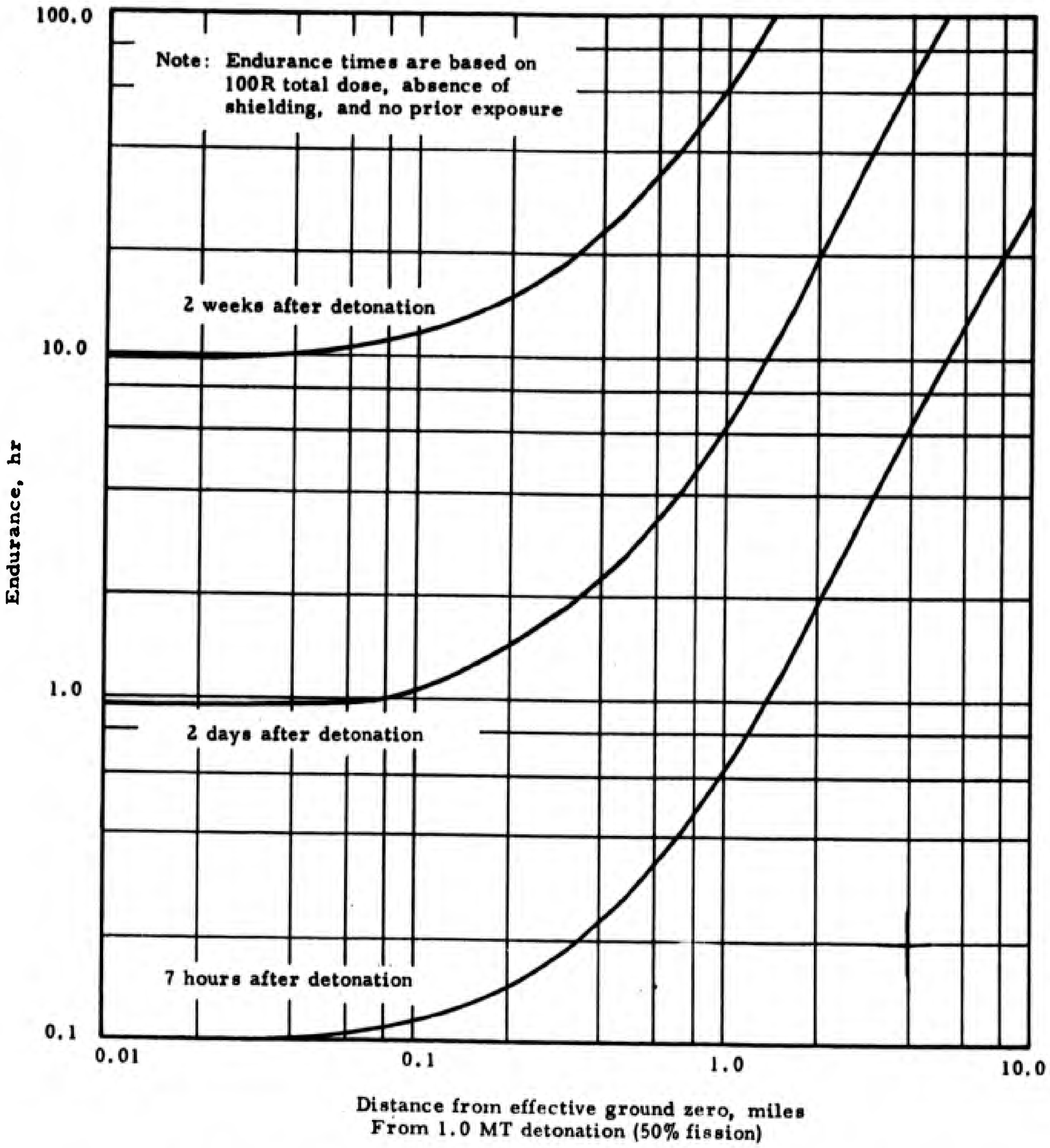


Fig. 6.1 ENDURANCE TIMES IN POST-ATTACK PERIOD

It is possible to increase these endurance times by gamma ray shielding. While the energy of the gamma rays from fallout changes with time, average attenuation coefficients can be used to obtain an approximate evaluation of the effectiveness of a given thickness of many materials (Ref. 22, 23). The required thickness of material to attenuate fallout radiation by a factor of 10 are shown in Table 6.1 for several materials (Ref. 22).

Table.6.1

SHIELDING THICKNESS REQUIRED TO ATTENUATE FALLOUT RADIATION BY FACTOR OF 10

Material	Thickness
water	9.4 inches
earth	6.9 inches
concrete	4.5 inches
iron	1.3 inches
lead	0.5 inches

Source: Reference 22

With the above shielding thicknesses, the endurance times shown in Fig. 6.1 would be increased by about a factor of 10.

A note of caution should be mentioned here. While most of the radiation due to fallout will be coming directly from the surface of the earth at times greater than 24 hours after detonation, a small fraction (1-10 percent) of the radiation will be scattered by standing structures and even the air. Therefore, shields much thicker than the dimensions given in Table 6.1 will not be as effective as expected unless some shielding is provided all around (i.e., on top as well as on the sides and bottom of vehicles). As long as the thickness of the top shielding is on the order of 10 percent of that of the side and bottom shielding, this scattered component will be negligible.

The biological recovery of humans from nuclear radiation is also relevant to exposure limits. While there is disagreement on the rate of biological recovery and the degree of irreparable damage, it is acknowledged that some recovery from non-lethal radiation does does take place. A reasonable assumption is that about 70 percent of the radiation damage received by a healthy adult will be overcome within 30 days (Ref. 24). Assuming 70 percent recovery in 30 days and a 100R effective dose limit, a worker accumulating an initial dose rate of 100R (e.g., 0.1 hour exposure at 0.05 miles from ground zero 7 hours after detonation) could probably perform a mission 30 days later in which he would receive 70R without exceeding the limit, provided he received no additional exposure during the month.

In addition to exposure to the nuclear radiation from fallout, problems of possible ingestion of radioactive material must be considered by personnel performing missions in the region of structural demolition. Breathing masks should be worn whenever the possibility of stirring up radioactive dust exists. Missions of sufficient duration to require food will require special precautions to prevent dust from being eaten, and after every mission into a contaminated area the individuals should be checked to make certain they have not accumulated radioactive dust on their bodies and clothing. A bath and a change of clothing would probably be standard procedure for personnel after such missions.

The feasibility of decontamination under various circumstances has received a great deal of attention (Ref. 25, 26, 27). For objects and facilities which have not been damaged by the blast and thermal effects of a nuclear detonation, decontamination is an obvious solution. This is especially true for those objects and facilities which can be decontaminated more easily than they can be replaced and for which it is not feasible or desirable to wait until the radioactivity has decayed to tolerable levels.

However, decontamination of the rubble itself does not appear to be feasible. Plowing the rubble under is one method which has the same effect as decontamination. Hosing down an area that has been cleared of rubble with water has been shown to be one of the most effective means of decontamination (Ref. 27). However, rubble will probably contain a sufficiently large number of inaccessable regions, (e.g., voids), in which water bearing radioactivity can collect that decontamination of rubble will probably not prove satisfactory.

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APPENDIX A

WEAPONS EFFECT PHENOMENA

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WEAPONS EFFECTS PHENOMENA

Detonation of a nuclear weapon in the atmosphere produces aerodynamic blast waves, thermal radiation, and radioactivity. For a sea level detonation, the energy of the blast is distributed approximately as follows: 50 percent in shock waves, 35 percent in thermal radiation, and 15 percent in radioactivity. For altitudes above sea level the fraction of energy in shock waves decreases, that in radioactivity remains approximately constant, while that in thermal energy increases.

Concerning the effects of nuclear weapons on structures, the blast waves act to fail and fragment structures, the thermal radiation acts to ignite combustibles and melt noncombustibles, while the radioactivity acts to contaminate the area, adding to the difficulties of repair and rebuilding. Specific effects of each portion of the energy released by the detonation of a nuclear weapon depend upon the point of detonation, the type and yield of weapon, meteorological conditions, time of day, and other factors. Obviously, it is impossible to consider all of these variables simultaneously; however, it is possible to discuss the effects of each variable independently and then consider a reasonably probeble over-all effect. It is recognized that wide variations from this reasonably probable picture may exist.

Aerodynamic Shock

Aerodynamic shock waves resulting from the detonation of a nuclear weapon travel at velocities from 3000 fps (at 100 psi overpressure) to sonic speed of about 1100 fps (at $<$ 1 psi overpressure). The peak overpressure at a given distance varies with the cube root of the weapon yield, being 10 psi at 1,000 ft from a 1-KT detonation. Thus the peak overpressure would be 10 psi at 10,000 ft from a 1-MT yield. The relation between distance and overpressure for a 1-KT weapon is shown in Fig. A-1. Using this graph and the cube root scaling rule, the overpressure-distance-yield relation can be obtained for any detonation at any distance.

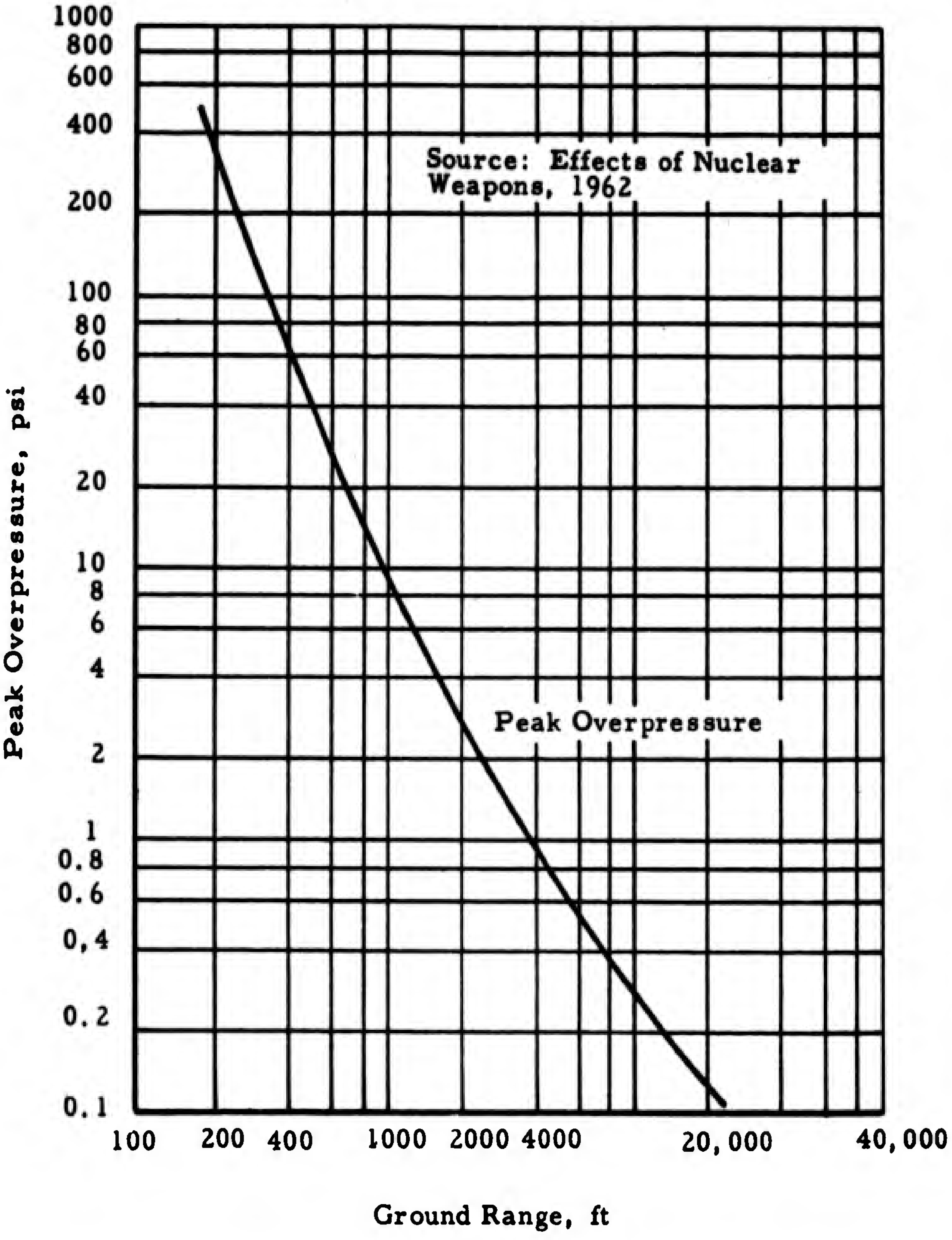


Fig. A-1 PEAK OVERPRESSURE FOR 1-KT SURFACE BURST

The effects of overpressure on buildings and structure vary considerably. Steel-reinforced concrete structures may withstand over 10 psi, while frame houses may collapse at 2 psi. Steel girder bridges apparently will withstand 10 psi, while motor vehicles can withstand about 5 psi. On the other hand, aircraft may not be operable after exposure to 2 psi. While humans standing upright will be knocked down and possibly injured at 1 psi, humans lying in trenches may survive 10 psi. On this basis, the detonation of a nuclear weapon at altitudes from a few hundred to a few thousand feet above a city will almost certainly reduce all structures exposed to about 15 or 20 psi to rubble. Other structures may be reduced to rubble out to 2 psi.

Thermal Radiation

Thermal radiation resulting from the nuclear detonation travels with the speed of light and will transport energy varying approximately linearly with the yield and inversely as the square of the distance. For a 10-KT detonation at a slant range of 1 mile, the thermal radiation is 10 cal/cm^2. Thus a 1-MT weapon at 20 miles slant range will produce thermal radiation of 2.5 cal/cm^2. Actually the thermal energy radiated increases a little faster than the yield, as shown in Fig. A-2 and its attenuation with distance decreases somewhat faster than $1/4\pi r^2$ on a cloudy day.

Thermal radiation heats exposed objects, and possibly ignites them. Radiant exposures required for ignition of various fabrics and other household materials are duration-dependent, as shown in Table A-1. On the basis of the listed exposures, most combustibles would be expected to ignite if exposed to 100 cal/cm^2 from nuclear weapons. Since combustible materials are customarily found in homes which could be ignited at less than 3-5 cal/cm^2 (for 20 KT) or 6-11 cal/cm^2 (for 10 MT), fires may be a problem in these regions.

Radioactive Fallout

Detonation of a nuclear weapon produces both prompt (initial) and delayed nuclear radiation. The prompt radiation consists of neutrons and gamma rays emitted essentially at the instant of detonation. Gamma rays produce no radioactivity and the neutrons usually produce relatively little. A nuclear weapon detonated at the surface of earth would activate a fair

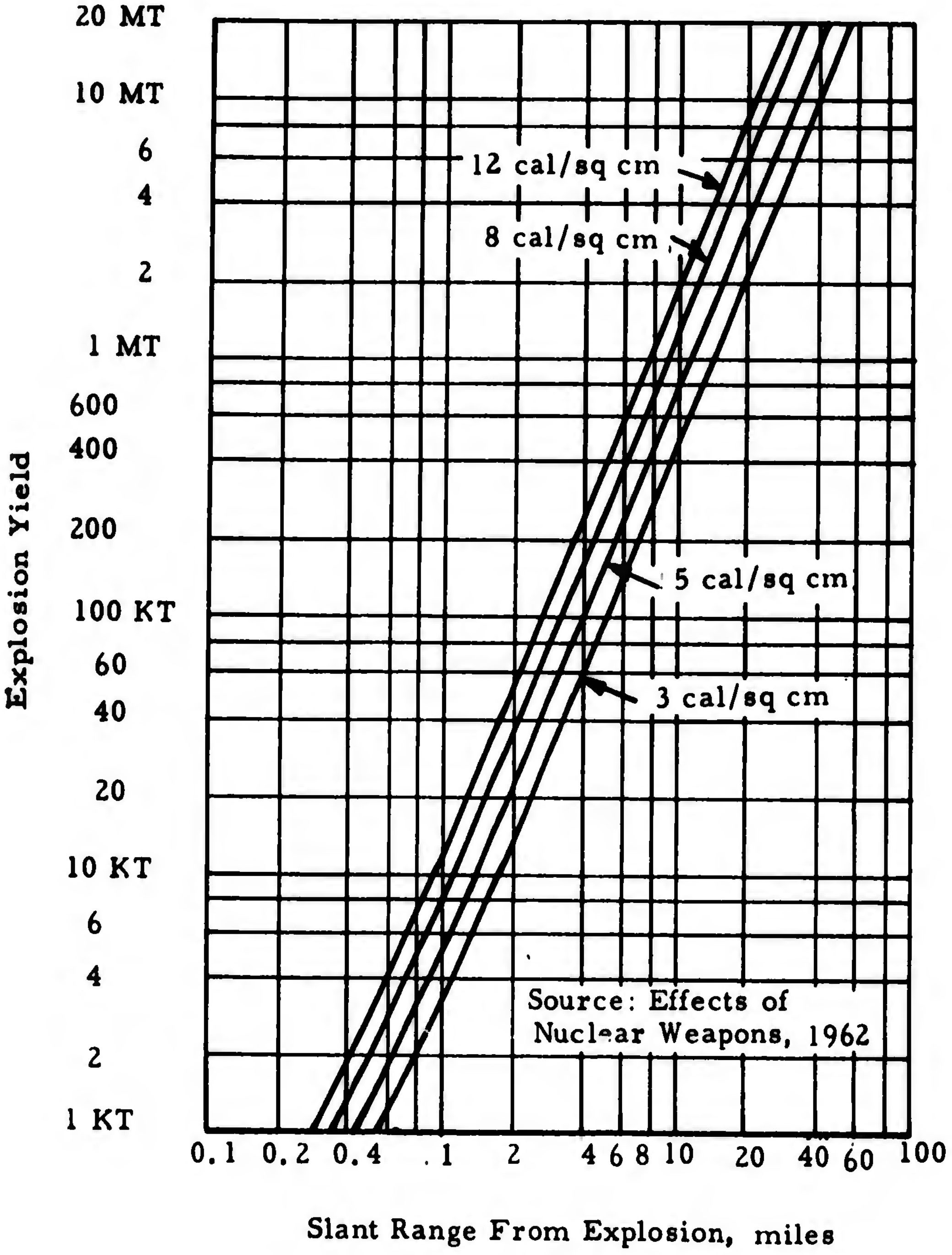


Fig. A-2 THERMAL RADIATION EXPOSURE LEVELS

Table A-1

APPROXIMATE RADIANT EXPOSURES FOR IGNITION OF SELECTED FABRICS AND HOUSEHOLD MATERIALS

Material	Weight	Ignition Exposure (Cal/Sq Cm.)	
	02/Sq Yd	20 KT	10 MT
Rayon-acetate Taffeta (wine)	3	2	3
Cotton Chenille Bedspread (light blue)		4	8
Cotton Muslin, Oiled Window Shade (green)	8	5	11
Cotton Awning Canvas (green)	12	5	9
Cotton Sheeting, Unbleached, Washed (cream)	3	15	30
Cotton Shirting (tan)	5	7	13
Cotton and Rayon Auto Seat Cover (dark blue)	9	8	13
Rayon-Acetate Drapery (wine)	5	9	16
Cotton Auto Seat Upholstery (green, brown, white)	10	9 *	16 *
Wool Broadloom Rug (gray)	7	16 *	35 *
Wool Pile Chair Upholstery (wine)	16	16	35
Cotton Mattress Stuffing (gray)		8	16
Burlap, Heavy Woven (brown)	18	8 *	16 *
Rubberized Canvas Auto Top (gray)	20	16 *	28 *
Vinyl Plastic Auto Seat Cover	10	16	27
Newspaper Piled Flat, Surface Exposed		3	6
Cotton Waste (oily gray)		5	8
Paper Bristol Board, 3 Ply (white)	10	12	25
Kraft Paper Carton, Flat Side, Used (brown)	16	8	15
Excelsior, Ponderosa Pine (light yellow)	2 lb/cu ft	5 *	12 *
Leather, Thin (brown)	6	15	30

* Not ignited to sustained burning at indicated temperatures.

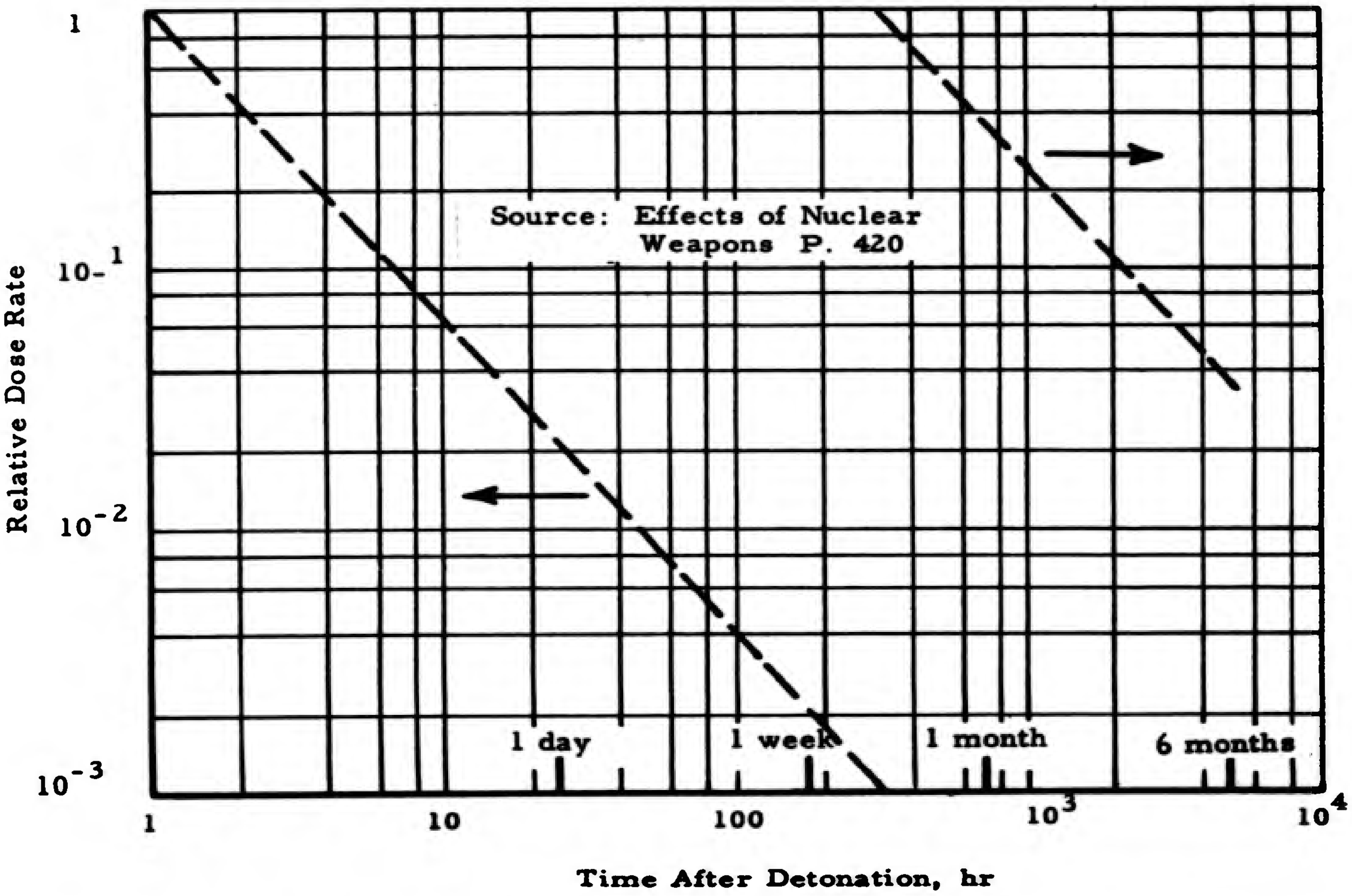
Source: Effects of Nuclear Weapons, 1962 amount of soil (Ref. 16); however, the radioactivity produced would almost certainly be less than 10 percent of that inherent in the weapon. For the purposes of this discussion it can be neglected.

The major source of radioactivity resulting from the detonation of a nuclear weapon is the fission products of the weapon itself. It is essentially only the fission portion of the yield which contributes here. Detonation of a 1-KT weapon produces about 3×10^{11} Curies of activity at one minute. This activity decreases approximately according to the $t^{-1/2}$ rule for times up to six months, as shown in Fig. A-3. Thus one month after the detonation, the activity is down by a factor of about 40,000 compared with the activity one hour after detonation. "Dirty" nuclear weapons would provide activity falling off more slowly. The fallout begins falling a few minutes after the detonation and is essentially complete within 24 hours.

Of more interest here than the total activity is the way it is distributed on the ground. Experimental evidence indicates that a maximum dose rate of 10^4 R/hr at one hour after the detonation will be found in the vicinity of ground zero, falling off with increasing radius. Presence of winds will act to distort the circular isodose rate contours into long cigar-shaped patterns. Anything which affects the wind pattern or the time the radioactive material is airborne will further modify the fallout pattern.

From the standpoint of the debris problem, the primary interest is in fallout over the area within which the aerodynamic shock wave is strong enough to produce rubble. This is about 2 psi. For a 1-MT weapon this corresponds to a radius of about 5 miles. The effects of wind will be appreciably less within this radius than outside it. A dose rate of about 100 R/hr will be found one hour after the detonation at the edge of the debris, increasing to about 10,000 R/hr at ground zero as shown in Fig. A-4. This is the initial net effect of the radioactivity upon the debris problem.

For surface or near-surface bursts there will be radioactive fallout wherever there is rubble. The dimensions of the fallout pattern are much larger by about an order of magnitude than the dimensions of blast and thermal damage. The fallout pattern will depend greatly upon the wind and weather during the first 24 hours after the detonation but only in very unusual conditions (e.g., a very high wind) will any significant portion of the blast damage area be free from dangerous radioactivity levels for the first few days.



Source: Effects of Nuclear Weapons P. 420

Fig. A-3 TIME DECAY OF FALLOUT (Proportional to $t^{-1.2}$ for times up to six months)

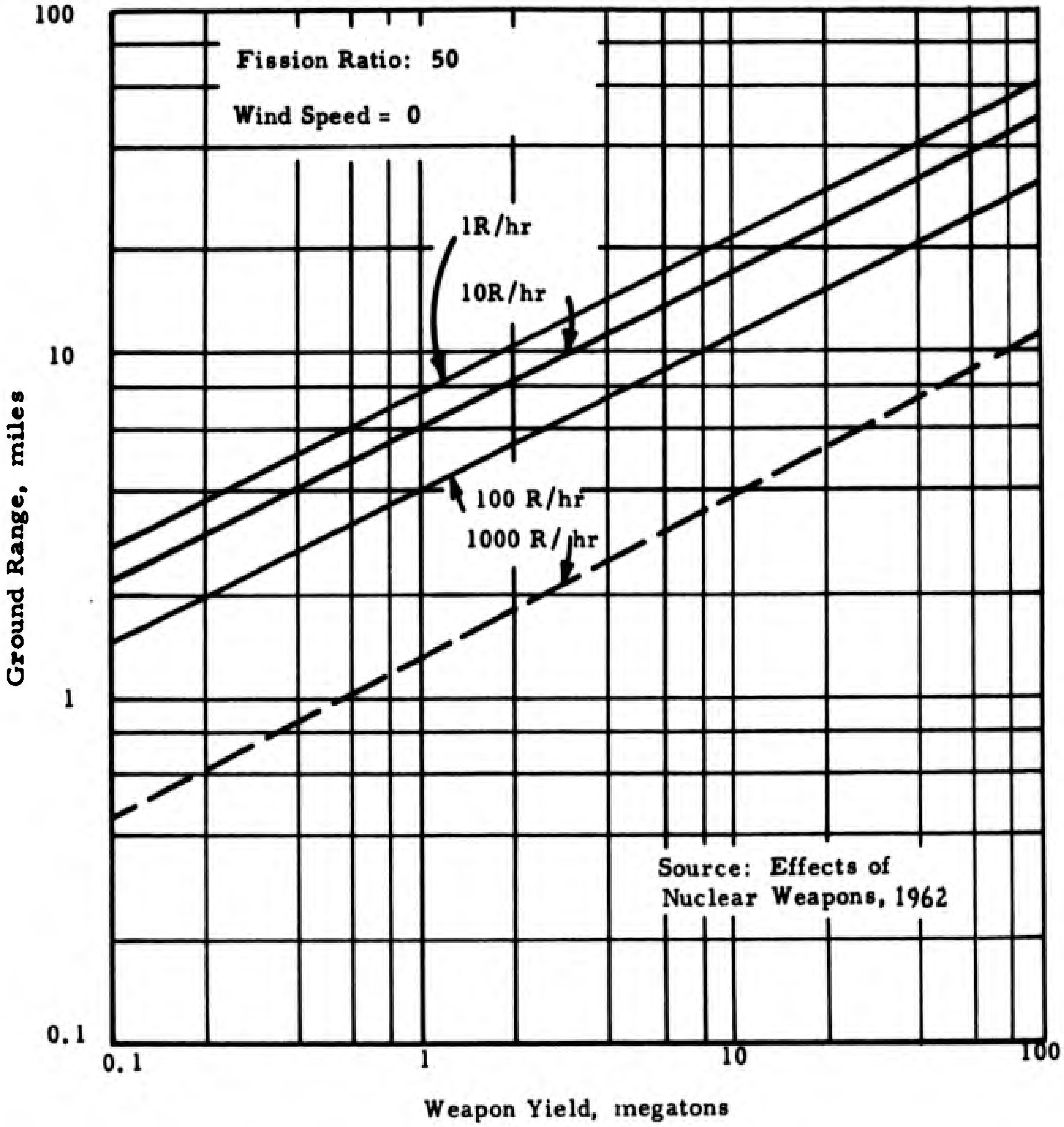


Fig. A-4 FALLOUT DOSE RATES ONE HOUR AFTER DETONATION

APPENDIX B

PERCENT-OF-SOLIDS IN RANDOM-PILED RECTANGULAR MATERIAL

APPENDIX B

PERCENT-OF-SOLIDS IN RANDOM-PILED RECTANGULAR MATERIAL

Test Procedure

Three types of children's building blocks were used to obtain approximate measurements of the void ratio of random-piled rectangular material; their characteristics and sizes are shown in Fig. B-1 and B-2 The Halsam* and Lego* blocks are plastic blocks, undercut on the underside, with appendages on top. The Plaskool* blocks are solid wood with slightly rounded edges. Departures from prismatic shapes in the cases of the Halsam and Lego series were not considered undesirable since broken masonry, though basically rectangular in nature, would have such irregularities as adhering mortar.

Container selection was aimed toward obtaining a pile whose dimensions would be several multiples of the individual block dimensions and a column height substantially greater than its diamter. Solid volumes for the blocks were based on actual dimensions of the blocks, excluding appendages. Total heights of random-piles materials were determined from column heights in the selected containers, making visual estimates of the average column height at its irregular top surface.

To approximate random piling, blocks were dropped into the containers in handfuls or greater quantities at mixed orientations, assuring that the first quantity dropped into the container would be sufficient to preculde regular or patterned orientation in the bottom of the container.

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*Manufacturer's trade names.

Results

Twenty measurements of percent–of-solids were made in each test. Maximum, minimum, and mean values are tabulated for each test in

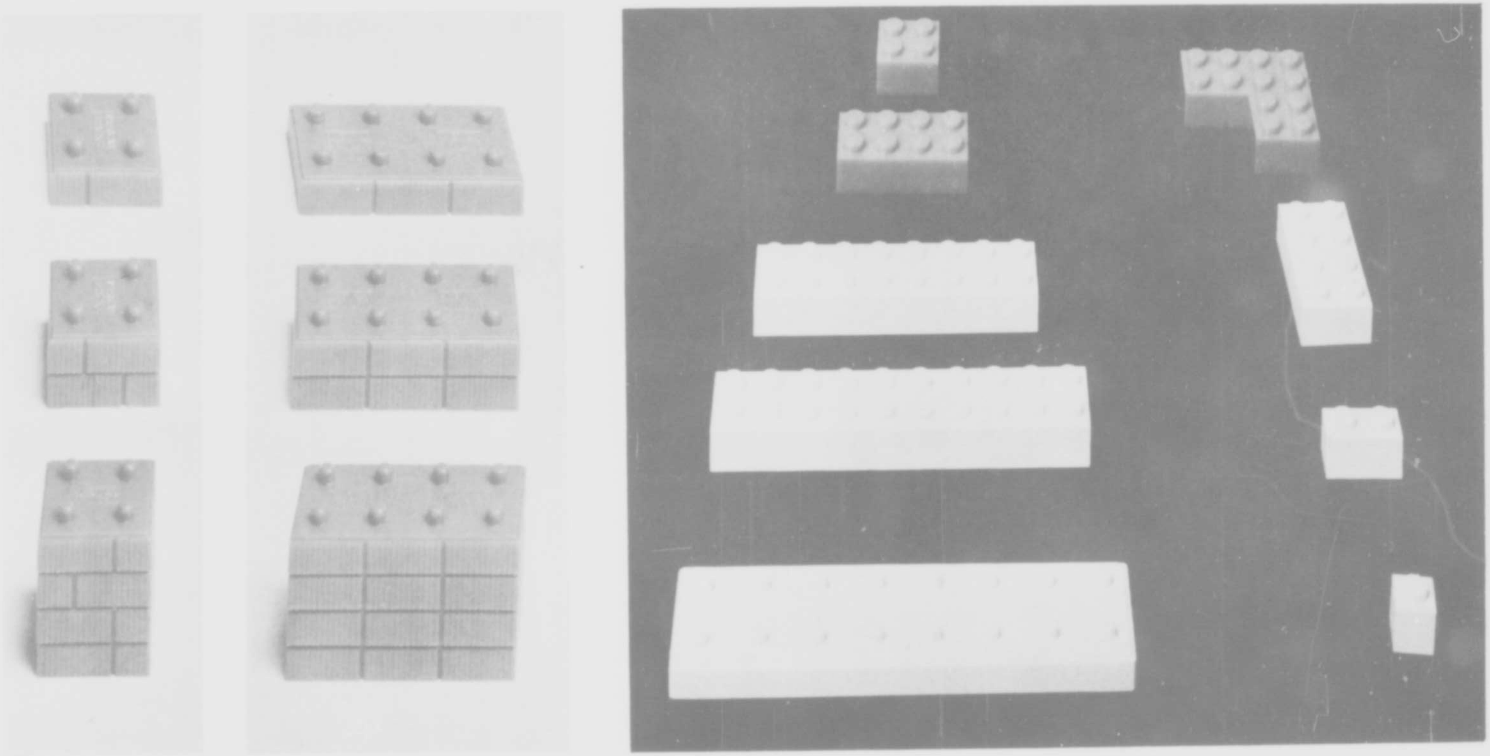

Fig. B-1 CHILDREN'S BUILDING BLOCKS USED IN VOID RATIO APPROXIMATIONS

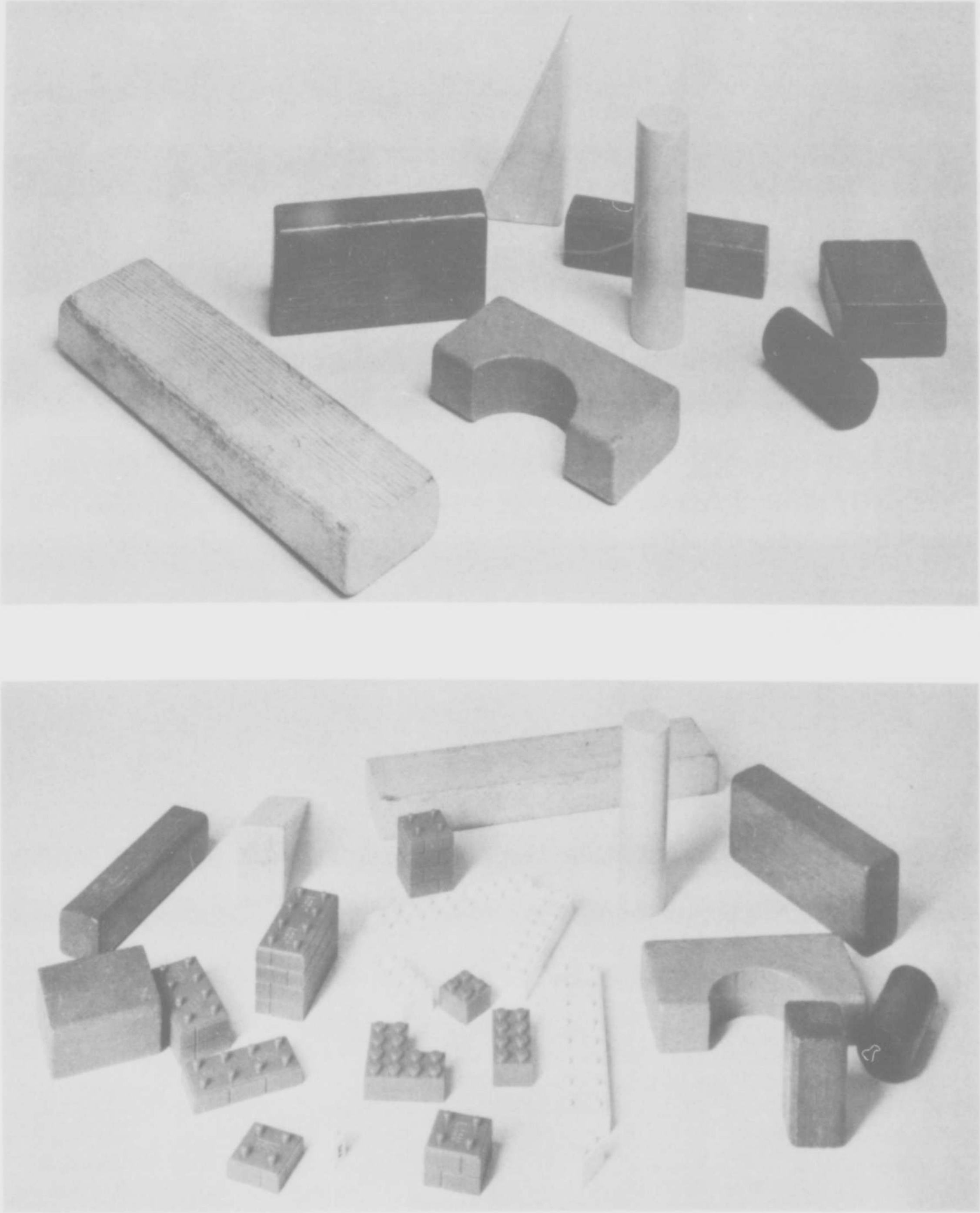

Fig. B-2 CHILDREN'S BUILDING BLOCKS USED IN VOID RATIO APPROXIMATIONS in Table B-1. From this series of tests it appears that 50 percent is an appropriate estimate of the percent-solids for random-piled rectangular blocks. This is considered appropriate for estimating debris depths in urban areas.

These tests were conducted with minimal equipment and to a defree of accuracy for estimating purposes only. No effort has been made to evaluate side effects in the container, or to measure the effects of different methods of dropping material in the container. Only limited effort was made to check the effect of variations in size distributions in mixtures.

Through individual values of percent-solids varied over a considerable range over all tests (422 to 567 percent), there is a significant central tendency at about 50 percent or slightly lower.

Table B-1

PERCENT-SOLIDS FOR RANDOM-PILED RECTANGULAR MATERIALS

Item	Dimensions, (in.)	Quantity	Container	Solid Volume/Total Volume*			Standard Deviation** (%)	Range (%)	*** Total Volume / Solid Volume +
				Minimum	Maximum	Mean			
Halsam Square Blocks	7/8 x 7/8 x 0.2875	(194)	6 in. Plastic Tube, 5-9/16-in. ID	0.5093	0.5491	0.5282	1.7	7.5	1.893
	7/8 x 7/8 x 0.575	(97)	6 in. Plastic Tube, 5-9/16-in. ID	0.5214	0.5668	0.5496	2.2	8.3	1.819
	7/8 x 7/8 x 1.150	(48)	6-in. Plastic Tube, 5-9/16-in. ID	0.5115	0.5521	0.5270	2.4	7.7	1.897
Halsam Rectangular Blocks	7/8 x 1-3/4 x 0.2875	(433)	6-in. Plastic Tube, 5-9/16-in. ID	0.4478	0.4859	0.4678	2.5	8.2	2.137
	7/8 x 1-3/4 x 0.575	(216)	6-in. Plastic Tube, 5-9/16-in. ID	0.4969	0.5324	0.5178	2.2	6.9	1.931
	7/8 x 1-3/4 x 1.150	(108)	6-in. Plastic Tube, 5-9/16-in. ID	0.4876	0.5360	0.5093	2.7	9.5	1.963
Halsam Mixed Square and Rectangular Blocks	7/8 x 7/8 x 0.2875 7/8 x 1-3/4 x 0.2875 7/8 x 3-1/2 x 0.2875	(194) (433) (16)	6-in. Plastic Tube, 5-9/16-in. ID	0.4646	0.4809	0.4724	0.9	3.5	2.117
	7/8 x 7/8 x 0.2875 7/8 x 1-3/4 x 0.2875	(194) (433)	6-in. Plastic Tube, 5-9/16-in. ID	0.4743	0.4851	0.4802	0.8	2.3	2.083
Lego Rectangular Blocks	5/16 x 5/16 x 3/8	(28)	250 ml Graduate	0.4420	0.4799	0.4533	2.5	8.4	2.206
	5/16 x 5/8 x 3/8	(38)	250 ml Graduate	0.4223	0.4801	0.4458	3.0	13.0	2.243
	5/8 x 5/8 x 3/8	(75)	1000 ml Graduate	0.4640	0.5072	0.4770	2.1	9.1	2.096
	8/8 x 15/16 x 3/8	(35)	1000 ml Graduate	0.4346	0.4792	0.4541	3.0	9.8	2.202
Lego Mixed Rectangular Blocks	5/16 x 5/16 x 3/8 5/16 x 5/8 x 3/8 5/8 x 5/8 x 3/8 5/8 x 15/16 x 3/8	(28) (39) (75) (35)	1000 ml Beaker 1000 ml Graduate	0.4770 0.4752	0.5064 0.4936	0.4936 0.4866	2.2 0.9	6.0 3.8	2.026 2.055
	5/16 x 5/16 x 3/8 5/16 x 5/8 x 3/8 5/8 x 5/8 x 3/8 5/8 x 15/16 x 3/8 5/8 x 1-1/4 x 3/8 1/2 x 1-1/4 x 1-7/8 x 3/8 L-Shaped Block 5/8 x 3-1/8 x 3/8 5/8 x 3-1/2 x 3/8	(40) (57) (118) (55) (255) (12) (11) (1)	6-in. Plastic Tube, 5-9/16-in. ID	0.4786	0.5180	0.5007	1.9	7.9	1.997
Summary for Five Tests of Mixtures				0.4646	0.5180	0.4867		11.0	1.845
Summary for all Measurements				0.4223	0.5668	0.4909		29.4	2.037
Estimates of a Major Wrecking Company	Bricks Concrete					0.60 0.45-0.50			1.67 2.00 - 2.22
Random Mixture of Plaskool Blocks						0.506			1.976

* Twenty measures were taken for each test.

** Standard Deviation is computed from total volume measurements and expressed as a percent of the mean value. It is approximately equal to the standard error of the percent-of-solids.

*** Total range is expressed as a percentage of mean value.

\+ Based on mean value of percent-of-solids.

APPENDIX C

COMPUTATION OF DEBRIS ACCUMULATION IN CENTRAL BUSINESS DISTRICT OF CHICAGO

APPENDIX C

COMPUTATION OF DEBRIS ACCUMULATION IN CENTRAL BUSINESS DISTRICT IN CHICAGO

Total debris accumulation and average debris depths are computed in this appendix for the central business district of Chicago. Computations are based on the following assumptions.

- All above-grade structural material becomes debris (i.e., overpressure levels about 15 psi are assumed).
- Above-grade structural material accounts for 12 percent of total contained volume.
- Void volume in the rubble is 50 percent of total volume.
- Building contents are not included as a contribution to debris, and vehicles are neglected. This tends to underestimate debris levels.
- Average story height is 10 ft. Many department stores on State street have some ceiling heights of 20 or 30 ft, but much of the area consists of office buildings. This may tend to underestimate debris depths in certain locales.
- Area of streets and alleys is taken as 77 percent of gross lot area throughout the district. This is a satisfactory average, though the ratio varies somewhat throughout the region.

Contributions of structures to total debris volume was computed on this basis since a complete tabulation of floor areas and story-heights, virtually building by building, was available for the entire district. Thus, the total contained structural volume for any block becomes

$$\text{Contained Volume (cu yd)} = \frac{\text{Floor Area (sq ft)} \times 10}{27}$$

The total debris volume becomes

$$\text{Debris Volume (cu yd)} = \frac{\text{Contained Volume (cu yd)} \times 0.12}{0.50}$$

and the average debris depth becomes:

$$\text{Debris Depth} = \frac{\text{Debris Volume (cu yd)} \times 27}{1.77 \text{ gross lot area (sq ft)}}$$

The layout of the central business district is shown in Fig. C-1, and the debris computations are summarized in Table C-1. It will be noted that the layout used is not up-to-date, that redevelopment has taken place in certain sections of the district since the date of building compilation used as the basis of this estimate. Though this would change debris estimates for certain blocks the over all estimate is still considered appropriate, since only a small percentage of the total number of structures has been demolished or replaced.

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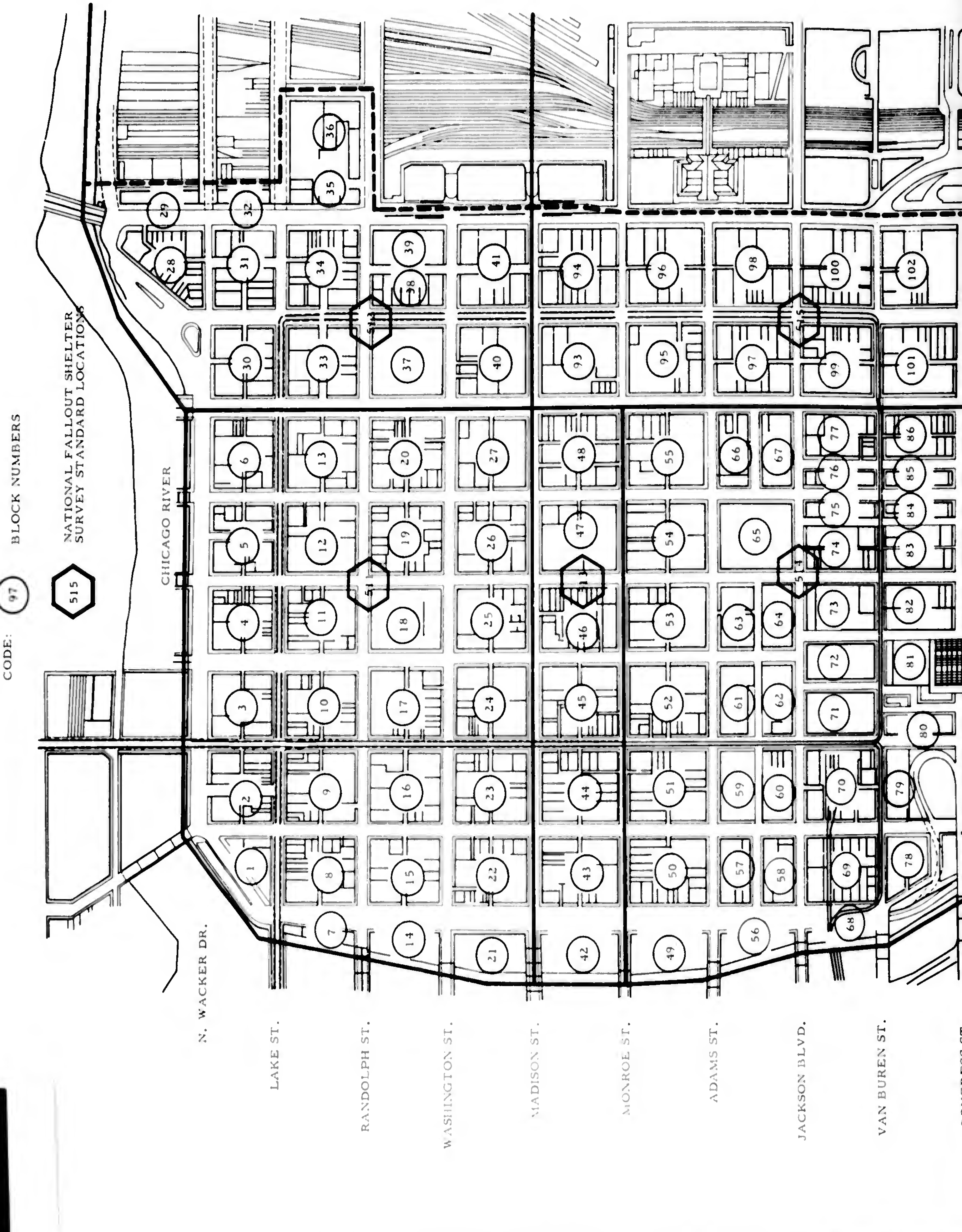
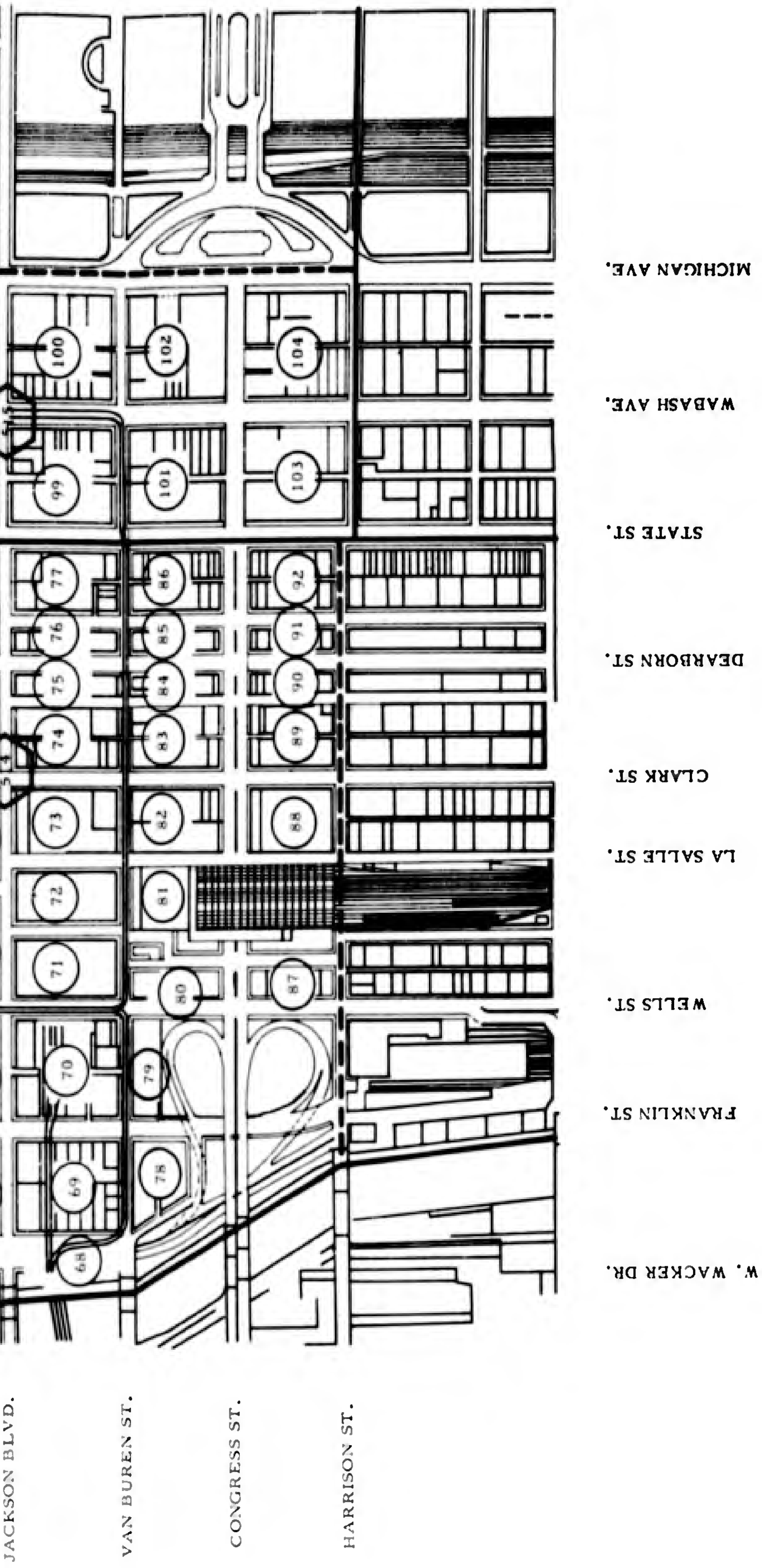


Fig. C-1 BLOCK NUMBERS AND N. F. S. S. STANDARD LOCAT



2 LOCATIONS IN CENTRAL BUSINESS DISTRICT OF CHICAGO

Table C-1

SUMMARY OF DEBRIS CALCULATIONS FOR CENTRAL BUSINESS DISTRICT OF CHICAGO

N.F.S.S.Std. Location Code	Block Number	Gross Lot Area w/o Alley, (sq ft)	Area of Streets, (sq ft) (Take 77%)	Total Gross Area, (sq ft)	Total Floor Area, (sq ft)	Total Contained Volume (cu yd)	Total Expanded Material Volume (cu yd)	Debris Depth (ft)
	1	37,500	28,900	66,400	20,800	7,700	1,848	0.75
	2	78,290	60,300	138,590	699,100	258,900	62,150	12.09
	3	90,000	69,300	159,300	990,000	366,500	88,000	14.90
	4	90,000	69,300	159,300	812,000	300,700	72,200	12.22
	5	72,500	55,800	128,300	215,900	80,000	19,200	4.04
	6	96,000	73,900	169,900	319,600	118,300	28,400	4.51
	7	25,470	19,600	45,070	140,220	51,900	12,440	7.45
	8	117,375	90,400	207,775	904,600	335,000	80,400	11.43
	9	112,000	86,200	198,200	189,000	70,000	16,800	2.74
	10	105,900	81,500	187,400	1,096,800	406,200	97,500	14.03
	11	104,550	80,500	185,050	1,156,300	428,300	102,800	15.00
	12	116.200	89,500	205,700	646,400	239,400	57,500	7.55
	13	110,880	85,300	196,180	1,039,100	384,900	92,400	12.71
	14	48,000	36,960	84,960	0	0	0	0
	15	113,000	87,000	200,000	754,000	279,200	67,000	9.05
	16	113,000	87,000	200,000	1,137,000	421,100	111,000	14.99
	17	105,000	80,900	185,900	1,126,000	416,600	100,000	14.53
	18	115,000	88,500	203,500	1,100,000	407,000	97,600	12.96
	19	113,000	87,000	200,000	700,000	259,000	62,200	8.40
	20	108,000	83,100	191,100	945,000	349,600	83,900	11.86
	21	76,000	58,500	134,500	1,300,000	481,000	115,500	23.18
	22	112,000	86,250	198,250	1,040,000	384,800	92,400	12.58
	23	108,500	83,500	192,000	440,000	162,800	39,040	5.49
	24	112,000	86,200	198,200	1,030,000	381,000	91,400	12.44
	25	106,000	81,600	187,600	1,890,000	699,300	167,800	24.15
	26	118,000	90,900	208,900	900,000	333,000	79,900	10.31
	27	102,000	78,500	180,500	1,100,000	407,000	97,600	14.58
511	Total	2,606,165	2,005,000	4,611,165	2,697,800	8,029,300	1,927,000	11.27
	28	99,375	76,500	175,875	721,650	267,000	64,000	9.81
	29	28,000	21,560	49,560	629,300	232,800	55,800	30.36
	30	93,550	72,000	165,550	720,850	266,600	64,000	10.42
	31	94,200	72,500	166,700	1,058,900	391,793	94,000	15.21
	32	18,900	14,550	33,450	121,800	45,100	10,820	8.73
	33	114,050	87,800	201,850	462,600	171,200	41,050	5.39
	34	118,000	90,800	208,800	979,300	263,400	63,100	8.15
	35	24,100	18,560	42,660	147,000	54,400	13,050	8.25
	36	145,000	111,650	256,650	1,600,000	592,000	142,200	14.96
	37	125,000	96,200	221,200	1,625,000	601,300	144,300	17.61
	38	60,000	46,200	106,200	614,000	227,200	54,500	13.84
	39	60,000	46,200	106,200	250,000	92,500	22,200	5.64
	40	105,600	81,300	186,900	1,770,000	654,900	157,000	22.68
	41	53,000	40,800	93,800	658,000	243,500	58,400	16.80
512	Total	1,138,775	875,650	2,014,425	11,358,400	4,103,693	985,000	13.20
	42	51,800	39,880	91,700	640,000	236,800	56,800	16.71
	43	124,800	96,100	220,900	755,900	280,000	67,200	8.22
	44	108,000	83,100	191,100	540,000	199,800	47,950	6.77
	45	118,000	90,800	208,800	1,285,300	475,600	114,200	14.78
	46	121,600	93,500	215,100	1,840,000	680,800	163,200	20.48
	47	123,000	94,600	217,600	2,668,000	987,200	237,000	29.40
	48	120,000	92,400	212,400	822,000	304,100	72,950	9.26
513	Total	767,200	590,380	1,357,600	8,551,200	3,164,300	759,300	15.10
	49	60,000	46,200	106,200	0	0	0	0
	50	122,000	93,900	215,900	1,025,000	379,200	91,000	11.38
	51	122,000	93,900	215,900	1,960,000	725,200	174,000	21.76
	52	111,600	85,900	197,500	1,520,400	562,500	135,000	18.44
	53	118,400	91,100	209,500	1,705,000	630,800	152,300	19.63
	54	118,400	91,100	209,500	1,355,000	501,400	120,200	15.50

513	Total	767,200	590,380	1,357,600	8,551,200	3,164,300	759,300	15.10
	49	60,000	46,200	106,200	0	0	0	0
	50	122,000	93,900	215,900	1,025,000	379,200	91,000	11.38
	51	122,000	93,900	215,900	1,960,000	725,200	174,000	21.76
	52	111,600	85,900	197,500	1,520,400	562,500	135,000	18.44
	53	118,400	91,100	209,500	1,705,000	630,800	152,300	19.63
	54	118,400	91,100	209,500	1,355,000	501,400	120,200	15.50
	55	123,000	94,600	217,600	820,000	303,400	72,700	9.03
	56	58,000	44,600	102,600	0	0	0	0
	57	50,000	38,500	88,500	350,000	129,500	31,070	9.48
	58	51,000	39,280	90,280	300,000	111,000	25,640	7.66
	59	50,000	38,500	88,500	0	0	0	0
	60	50,000	38,500	88,500	525,000	194,300	46,600	14.22
	61	54,000	41,550	95,550	1,000,000	370.000	88,700	25.04
	62	51,000	39,280	90,280	740,000	273,800	65,650	19.63
	63	54,000	41,550	95,550	897,200	332,000	79,700	22.50
	64	56,000	43,100	99,100	800,000	296,100	71,000	19.32
	65	125,000	96,300	221,300	730,000	270,100	64,900	7.91
	66	56,000	43,100	99,100	506,000	187,200	44,950	12.23
	67	57,500	44,300	101,800	384,000	142,100	34,100	9.04
	68	40,000	30,800	70,800	0	0	0	0
	69	115,000	88,500	203,500	850,000	314,500	75,500	10.02
	70	120,000	92,400	212,400	1,063,000	393,300	94,300	11.98
	71	80,000	61,600	141,600	1,600,000	592,000	142,100	27.10
	72	72,000	55,450	127,450	964,000	356,700	85,500	18.12
	73	84,000	64,700	148,700	686,000	253,800	60,950	11.05
	74	79,000	60,900	139,900	720,000	266,400	64,000	12.35
	75	27,000	20,800	47,800	460,000	170,200	40,800	23.03
	76	27,000	20,800	47,800	388,000	143,600	34,440	19.45
	77	78,000	60,050	138,050	301,000	111,400	26,720	5.22
	78	50,000	38,500	88,500	500,000	185,000	44,450	13.55
	79	60,000	46,200	106,200	100,000	37,000	8,870	2.25
	80	40,000	30,800	70,800	80,000	29,600	7,100	2.70
	81	160,000	123,200	283,200	500,000	185,000	44,400	4.23
	82	70,000	53,900	123,900	400,000	148,000	35,480	7.73
	83	70,000	53,900	123,900	200,000	74,000	17,750	3.87
	84	25,000	19,425	44,425	110,000	40,700	9,760	5.93
	85	25,000	19,425	44,425	350,000	129,500	31,070	18.88
	86	65,000	50,050	115,050	250,000	92,500	22,200	5.21
	87	57,000	43,900	100,900	50,000	18,500	4,440	1.19
	88	60,000	46,200	106,200	600,000	222,000	53,250	13.52
	89	60,000	46,200	106,200	402,000	148,700	35,650	9.05
	90	21,000	16,180	37,180	150,000	55,500	13,300	9.65
	91	21,000	16,180	37,180	144,000	53,300	12,790	9.29
	92	60,000	46,200	106,200	300,000	111,000	26,640	6.76
514	Total	3,053,400	2,350,000	5,403,400	25,785,600	9,549,800	2,292,000	11.45
	93	118,000	90,900	208,900	1,538,600	569,300	136,500	13.91
	94	130,000	100,100	230,100	1,590,000	588,300	141,100	16.54
	95	128,000	98,500	226,500	1,961,000	725,600	174,200	20.77
	96	133,200	112,600	245,800	1,425,000	527,300	126,500	13.90
	97	118,000	90,900	208,900	1,275,000	471,800	113,200	14.62
	98	130,000	100,100	230,100	1,146,000	424,000	101,700	11.92
	99	121,000	93,200	214,200	935,000	346,000	83,000	10.45
	100	131,000	100,900	231,900	1,612,000	596,400	143,200	16.66
	101	125,000	96,200	221,200	790,000	292,300	70,100	8.55
	102	132,000	101,600	233,600	1,315,000	486,600	116,700	13.49
	103	124,000	95,500	219.500	445,000	164,600	39,500	4.86
	104	132,000	101,700	233,700	900,000	333,300	80,000	9.25
515	Total	1,526,200	1,175,000	2,701,200	14,932,600	5,525,500	1,533,000	15.33

SUMMARY FOR NATIONAL FALLOUT SHELTER SURVEY STANDARD LOCATIONS:

511		2,606,165	2,005,000	4,611,165	2,697,800	8,029,300	1,927,000	11.27
		1,138,775	875,650	2,014,425	11,358,400	4,103,693	985,000	13.20
		767,200	590,380	1,357,600	8,551,200	3,164,300	759,300	15.10
		3,053,400	2,350,000	5,403,400	25,785,600	9,549,800	2,292,000	11.45
		1,526,200	1,175,000	2,701,200	14,932,600	5,525,500	1,533,000	15.33
	Total	9,091,740	6,996,030	16,087,790	63,325,600	30,372,593	7,496,300	12.58

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* Based on materials equalling 12 percent of total contained volume, and voids amounting to 50 percent of total volume of rubble.

APPENDIX D

PARTICLE TRAJECTORIES

APPENDIX D

PARTICLE TRAJECTORIES

Trajectory calculations were carried out, according to the methods described in Section 3.2, for spherical fragments of various sizes from 2in. to 24in. in diameter. Shperical fragments were selected for this analysis since drag effects are identical for all orientations of the sphere -- whereas little is known of drag effects of rectangular material at random orientations or during rotation. The effect of this assumption is considered conservative in the sense that longer trajectories are predicted.

A value of 1.0 was used for the drag coefficient, C_d. The selected value of the material density is 135 lb/ft^3, which is in the range of most masonry building materials.

Results of the calculations, performed on the IBM 7090/1401 digital computer are plotted in the following figures:

Figure Number	Yield	Initial Ground Range, ft	Peak Overpressure At Initial Ground Range, psi	Positive Phase Duration at Initial Ground Range, Sec.
D-1.1	100KT	1,000	250	0.24
D-1.2	100KT	1,500	130	0.46
D-1.3	100KT	2,000	57	0.64
D-1.4	100KT	2,500	32	0.78
D-1.5	100KT	3,000	22	0.89
D-1.6	100KT	3,500	18	0.99
D-1.7	100KT	4,000	14	1.09
D-1.8	100KT	4,500	10	1.18
D-1.9	100KT	5,000	9	1.26
D-1.10	100KT	5,500	7	1.34
D-1.11	100KT	6,000	6	1.42
D-2.1	500KT	1,800	258	0.53
D-2.2	500 KT	2,800	100	0.80
D-2.3	500KT	3,800	53	1.03
D-2.4	500KT	4,800	30	1.25
D-2.5	500KT	5,800	19	1.45
D-2.6	500KT	6,800	14	1.62
D-2.7	500KT	7,800	12	1.80
D-2.8	500KT	8,800	10	1.95
D-2.9	500KT	9,800	8	2.10
D-2.10	500KT	10,800	7	2.28

Figure Number	Yield	Initial Ground Range, ft	Peak Overpressure At Initial Ground Range, psi	Positive Phase Duration at Initial Ground Range, Sec.
D-3.1	1MT	2,460	224	0.73
D-3.2	1MT	3,460	106	1.03
D-3.3	1MT	4,460	61	1.29
D-3.4	1MT	5,460	38	1.52
D-3.5	1MT	6,400	26	1.73
D-3.6	1MT	7,400	18	1.92
D-3.7	1MT	8,400	14	2.10
D-3.8	1MT	9,400	11	2.26
D-3.9	1MT	10,400	9	2.42
D-3.10	1MT	11,400	8	2.58
D-3.11	1MT	12,400	7	2.74
D-3.12	1MT	13,400	6	2.89
D-3.13	1MT	14,400	5	3.03
D-4.1	20MT	6,400	240	1.90
D-4.2	20MT	8,400	129	2.48
D-4.3	20MT	10,400	82	3.00
D-4.4	20MT	12,400	57	3.48
D-4.5	20MT	14,400	42	3.91
D-4.6	20MT	16,400	31	4.32
D-4.7	20MT	18,400	24	4.71
D-4.8	20MT	20,400	19	5.10
D-4.9	20MT	22,400	15	5.50
D-4.10	20MT	24,400	12	5.86
D-4.11	20MT	26,400	10	6.22
D-4.12	20MT	28,400	8	6.58
D-4.13	20MT	30,400	7.5	6.82
D-4.14	20 MT	32,400	7	7.22
D-5.1	50MT	8,500	250	2.30
D-5.2	50MT	10,500	150	3.06
D-5.3	50 MT	12,500	128	3.70
D-5.4	50MT	14,500	78	4.23
D-5.5	50MT	16,500	56	4.74
D-5.6	50MT	18,500	42	5.20
D-5.7	50MT	20,500	34	5.63
D-5.8	50MT	22,500	28	6.05
D-5.9	50MT	24,500	23	6.45
D-5.10	50MT	26,500	19	6.82
D-5.11	50MT	28,500	16	7.20
D-5.12	50MT	30,500	14	7.54
D-5.13	50MT	32,500	13	7.90
D-5.14	50MT	34,500	11	8.22
D-5.15	50MT	36,500	10	8.53
D-5.16	50MT	38,500	9	8.86
D-5.17	50MT	40,500	8	9.18

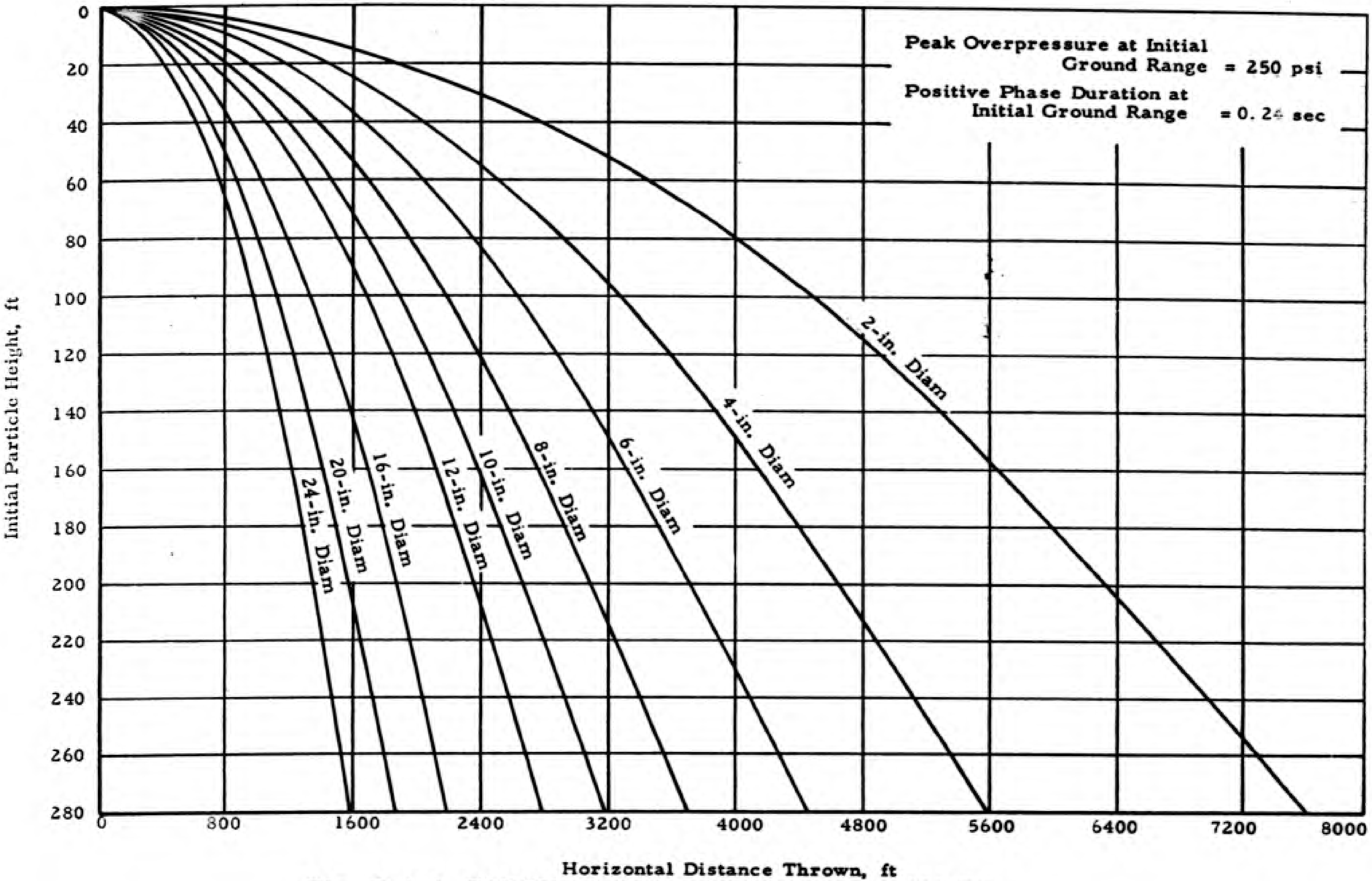

Fig. D-1.1 PARTICLE TRAJECTORIES AT 1,000 FT. FROM 100 KT SURFACE BURST

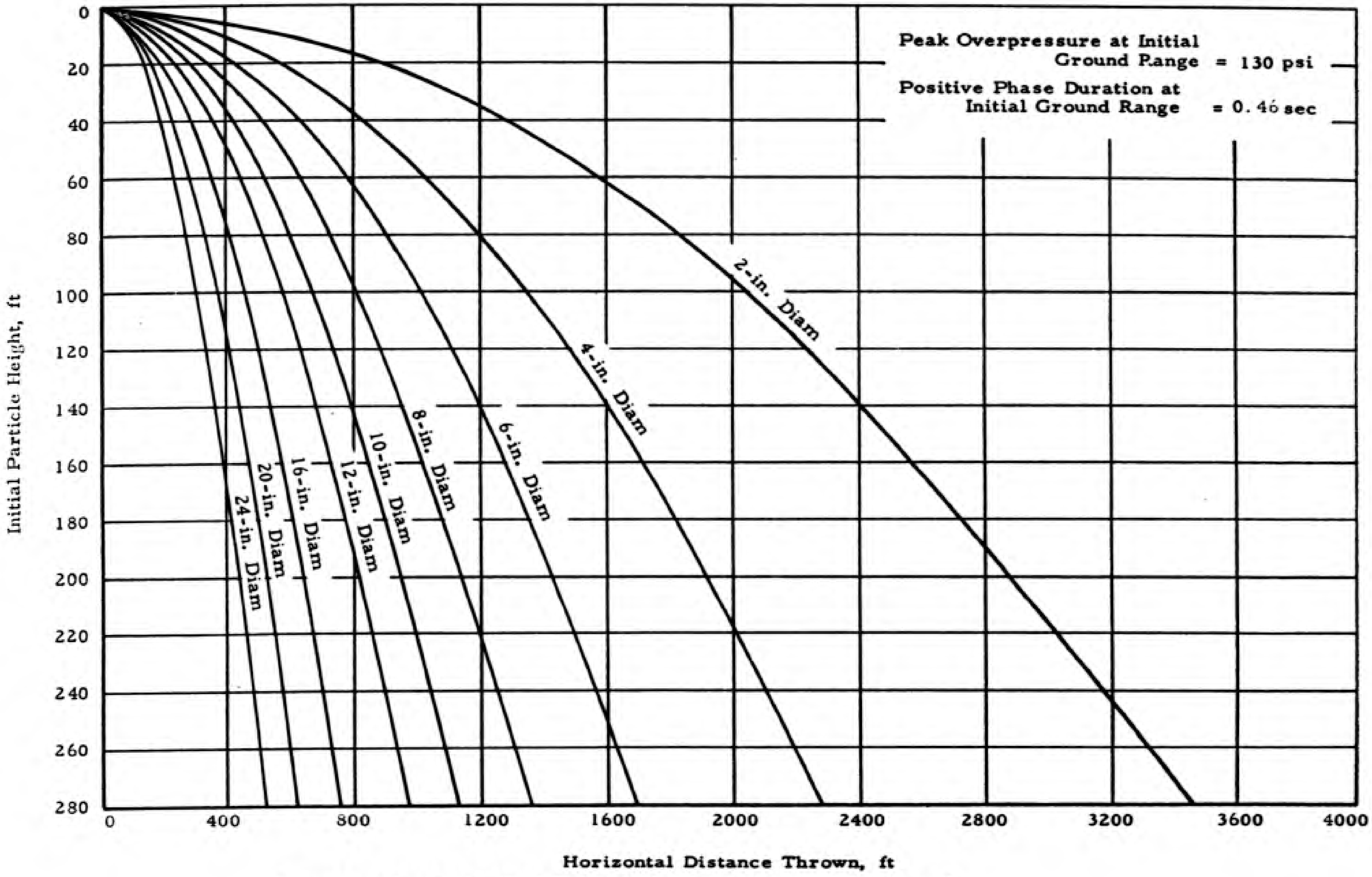

Fig. D-1.2 PARTICLE TRAJECTORIES AT 1,500 FT. FROM 100 KT SURFACE BURST

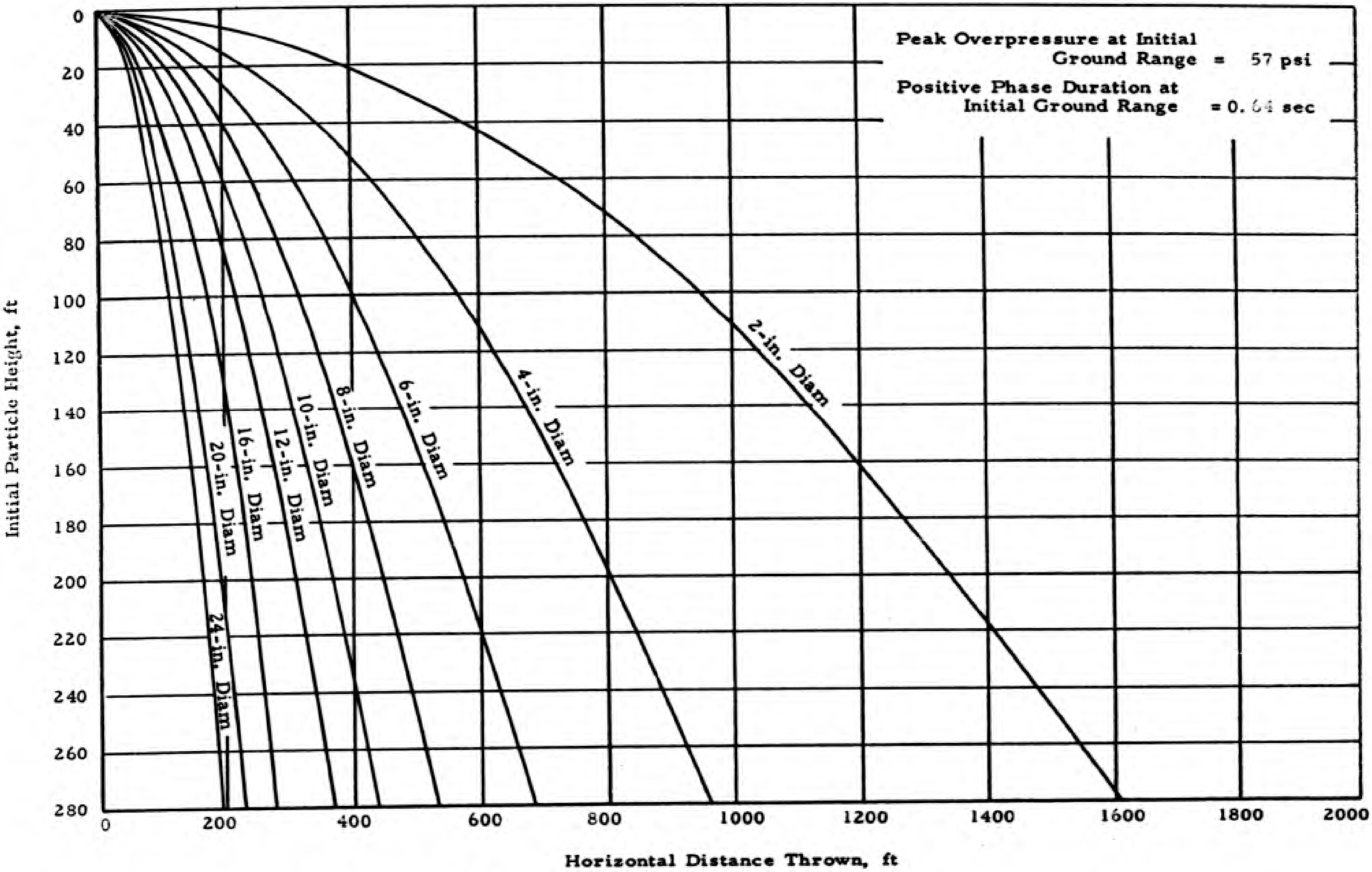

Fig. D-1.3 PARTICLE TRAJECTORIES AT 2,000 FT. FROM 100 KT SURFACE BURST

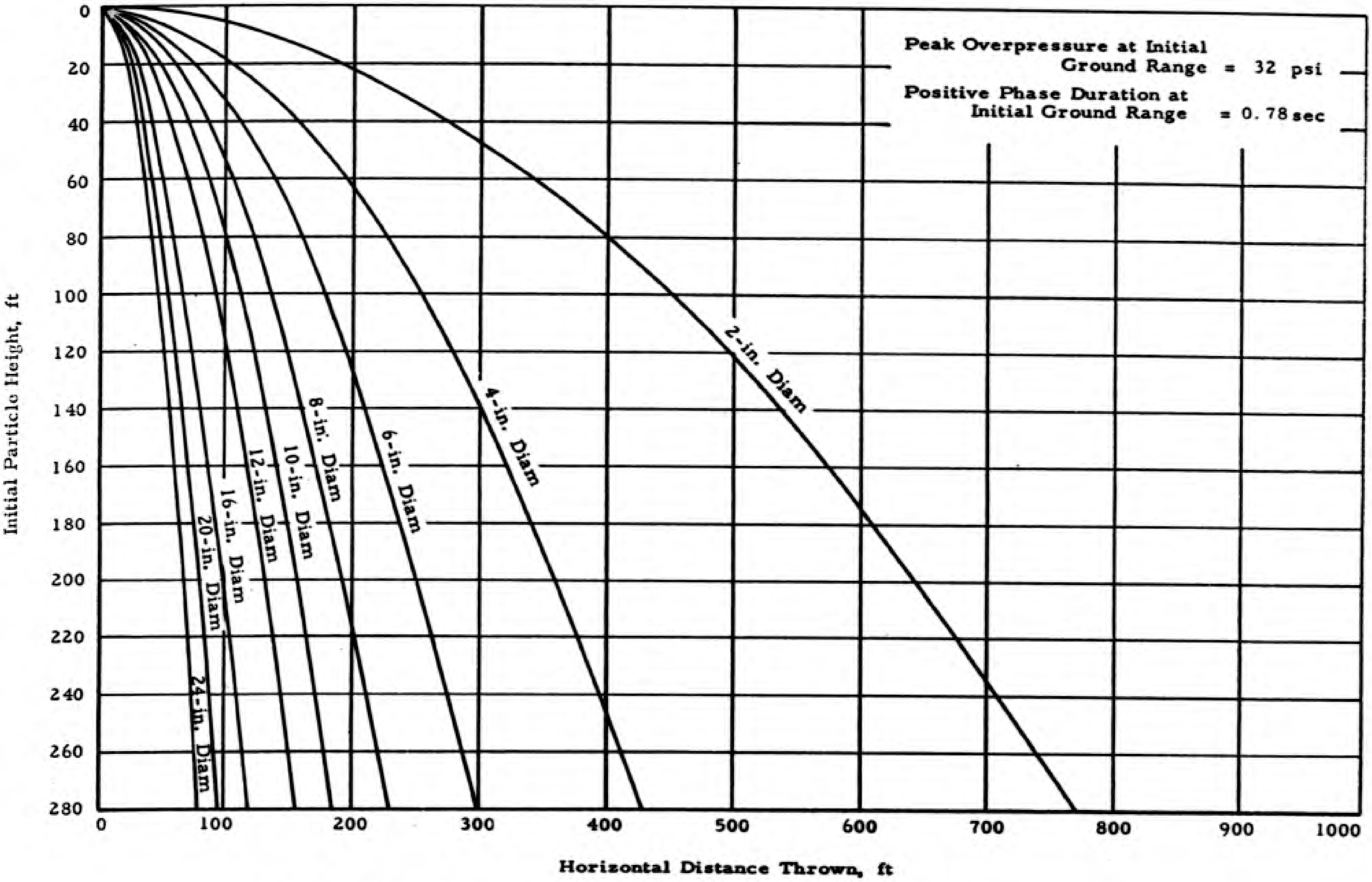

Fig. D-1.4 PARTICLE TRAJECTORIES AT 2,500 FT. FROM 100 KT SURFACE BURST

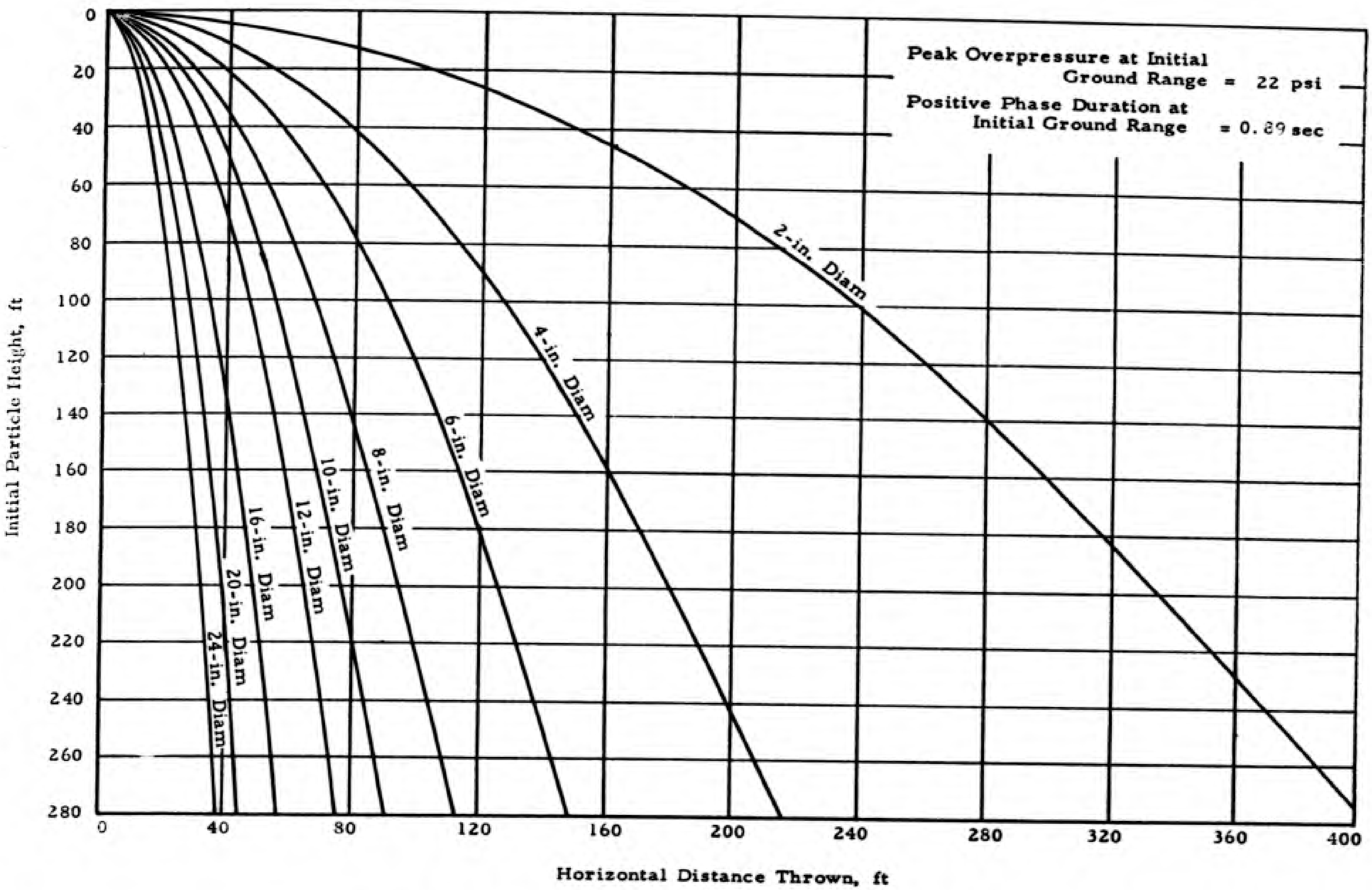

Fig. D-1.5 PARTICLE TRAJECTORIES AT 3,000 FT. FROM 100 KT SURFACE BURST

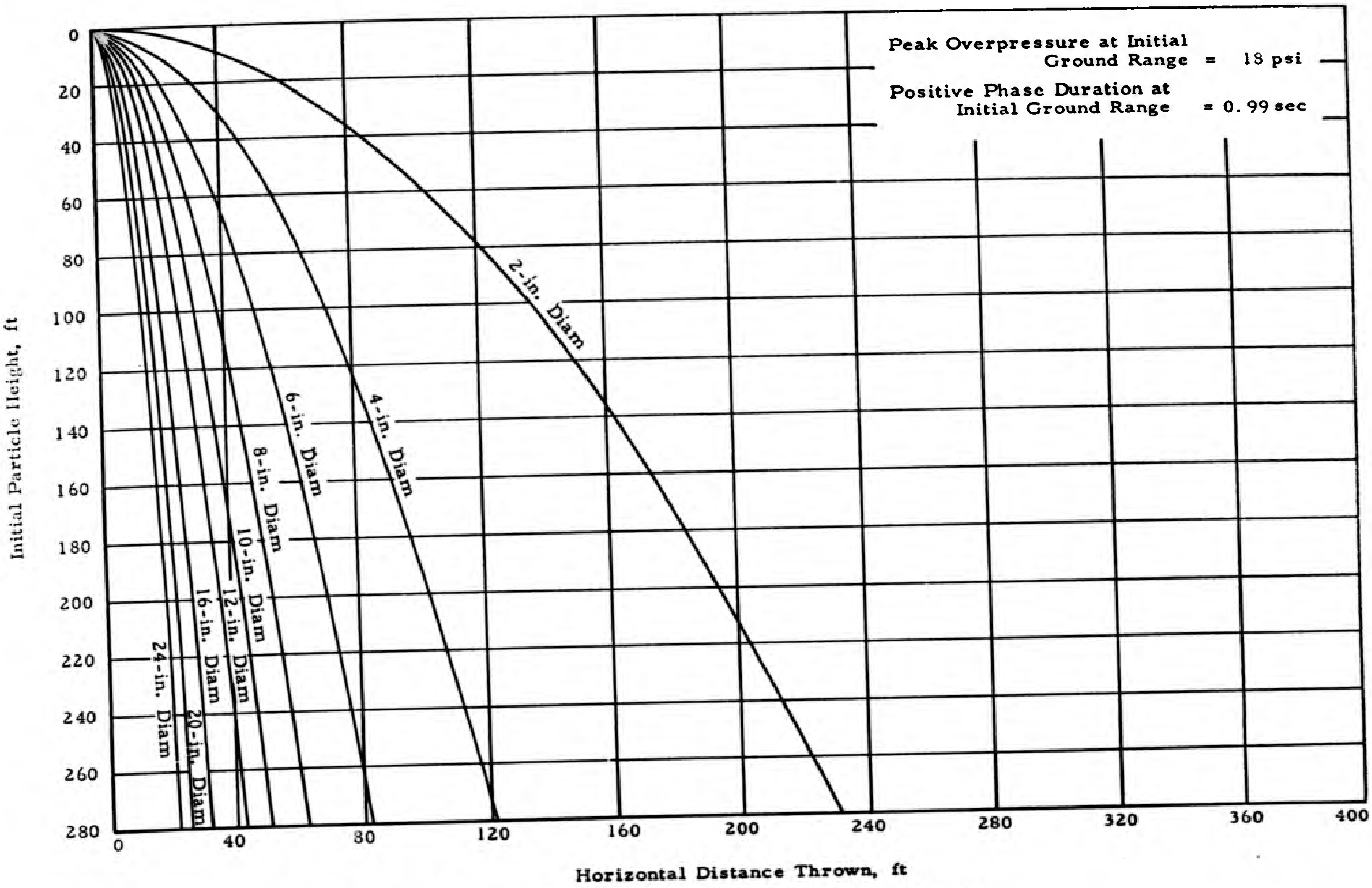

Fig. D-1.6 PARTICLE TRAJECTORIES AT 3,500 FT. FROM 100 KT SURFACE BURST

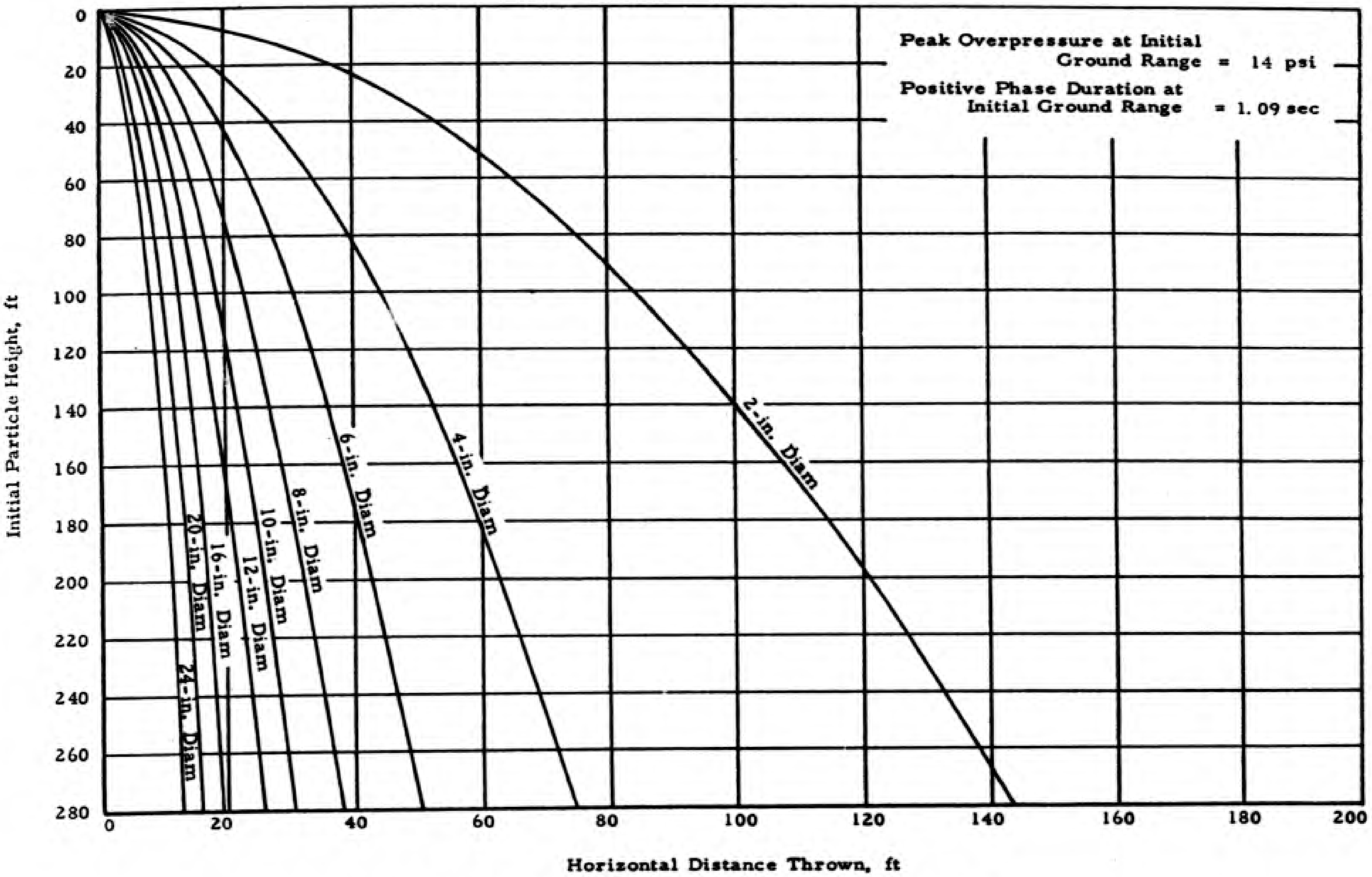

Fig. D-1.7 PARTICLE TRAJECTORIES AT 4,000 FT. FROM 100 KT SURFACE BURST

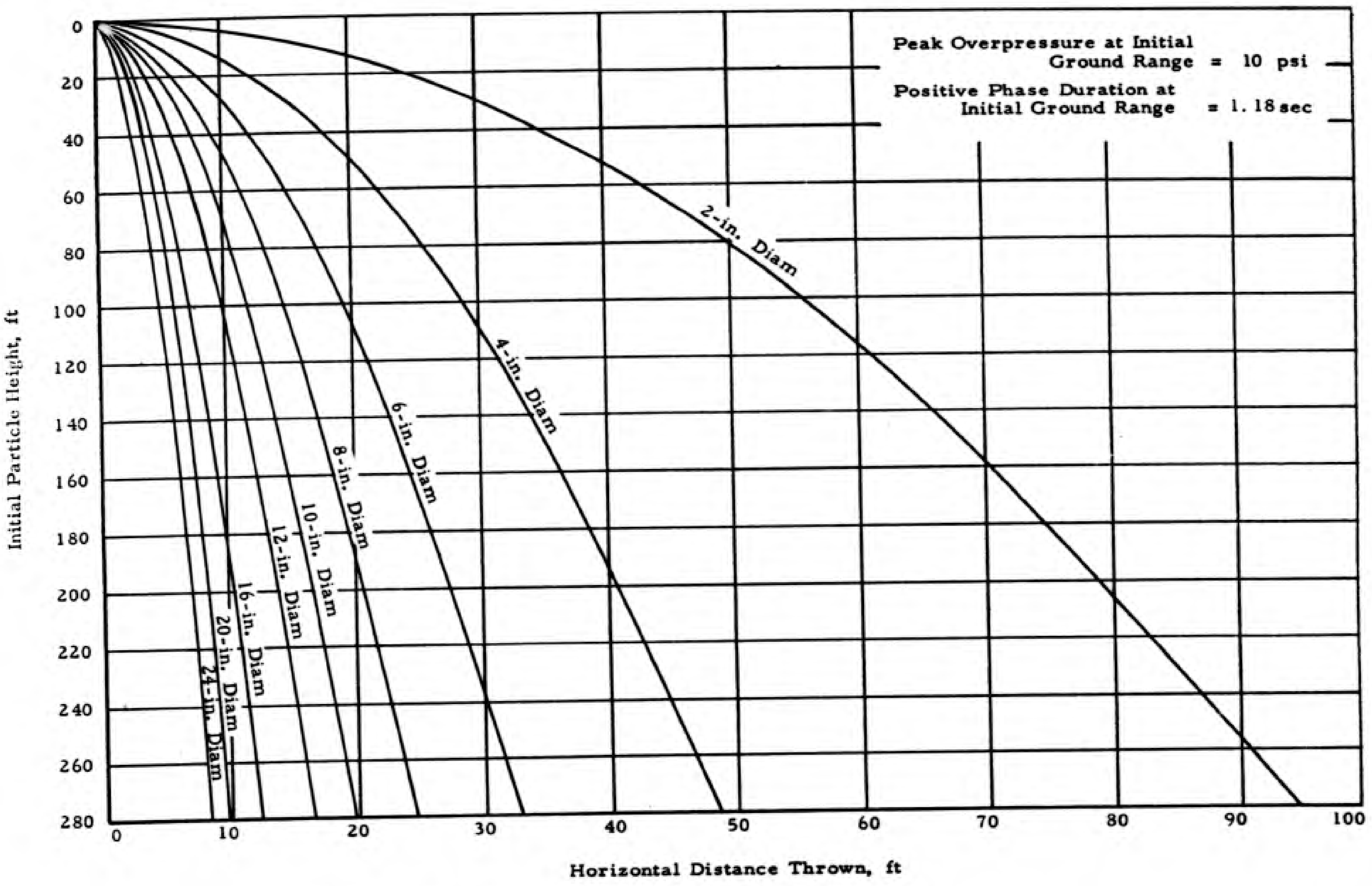

Fig. D-1.8 PARTICLE TRAJECTORIES AT 4,500 FT. FROM 100 KT SURFACE BURST

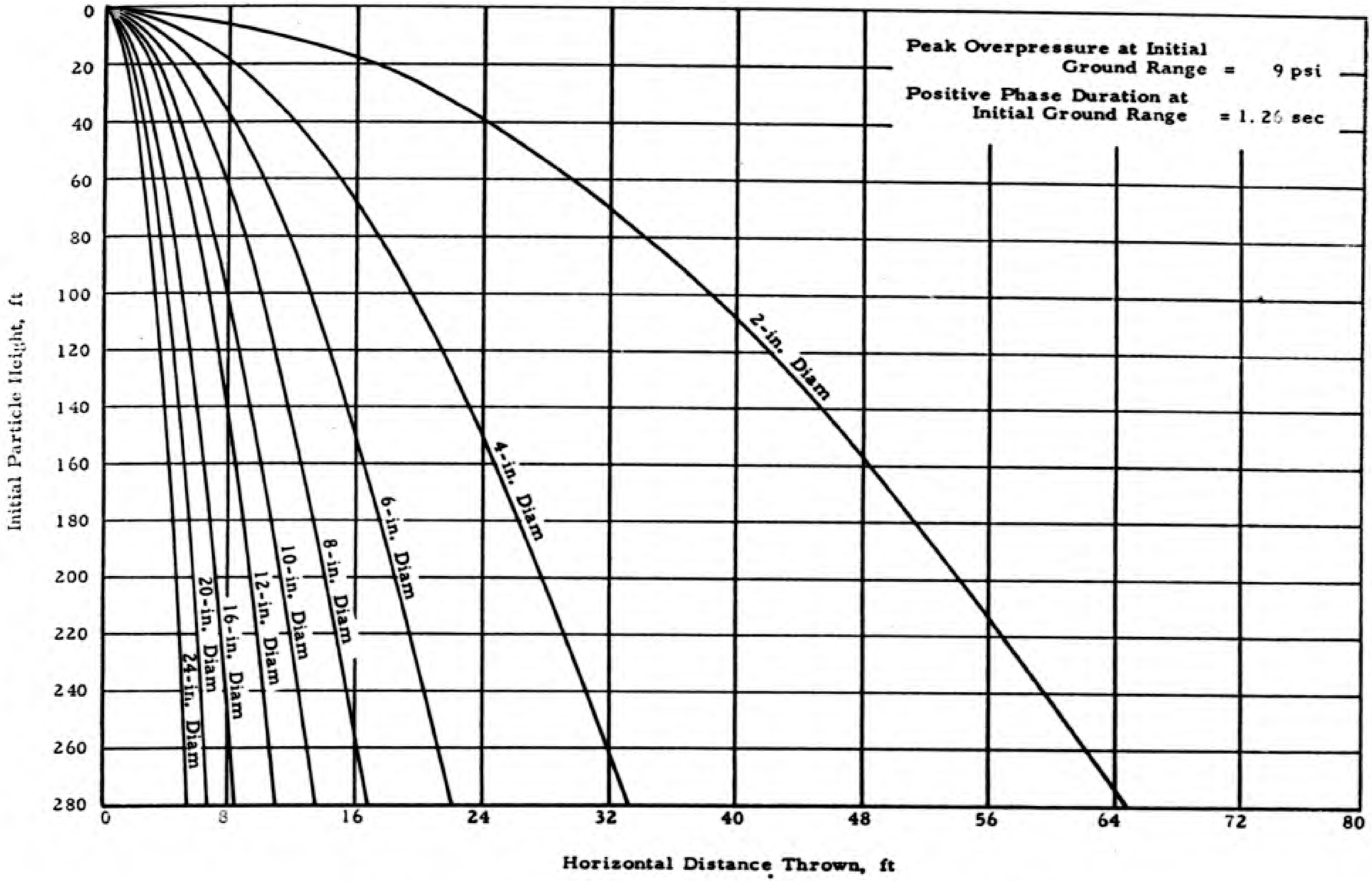

Fig. D-1.9 PARTICLE TRAJECTORIES AT 5,000 FT. FROM 100 KT SURFACE BURST

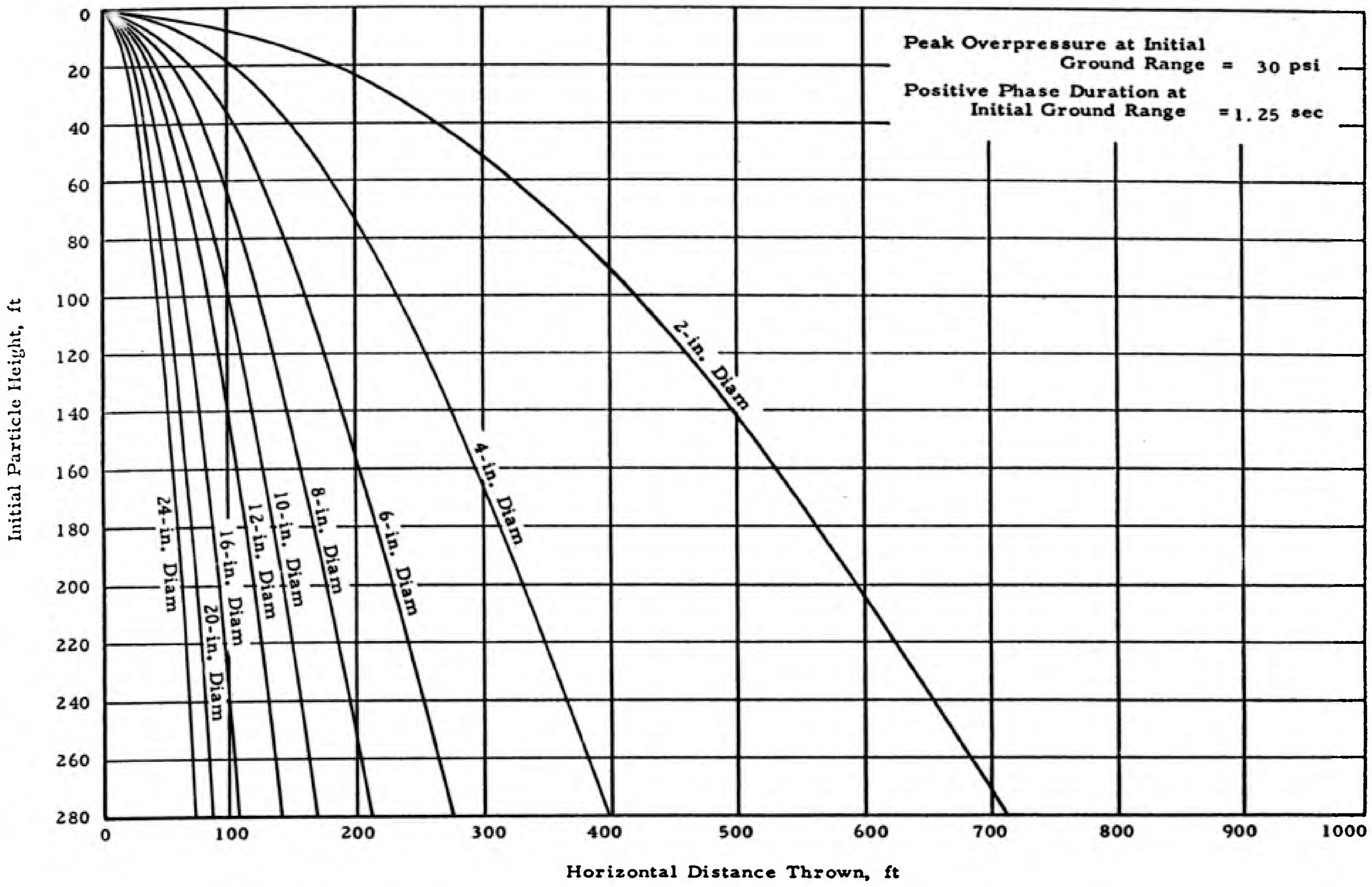

Fig. D-1.10 PARTICLE TRAJECTORIES AT 5,500 FT. FROM 100 KT SURFACE BURST

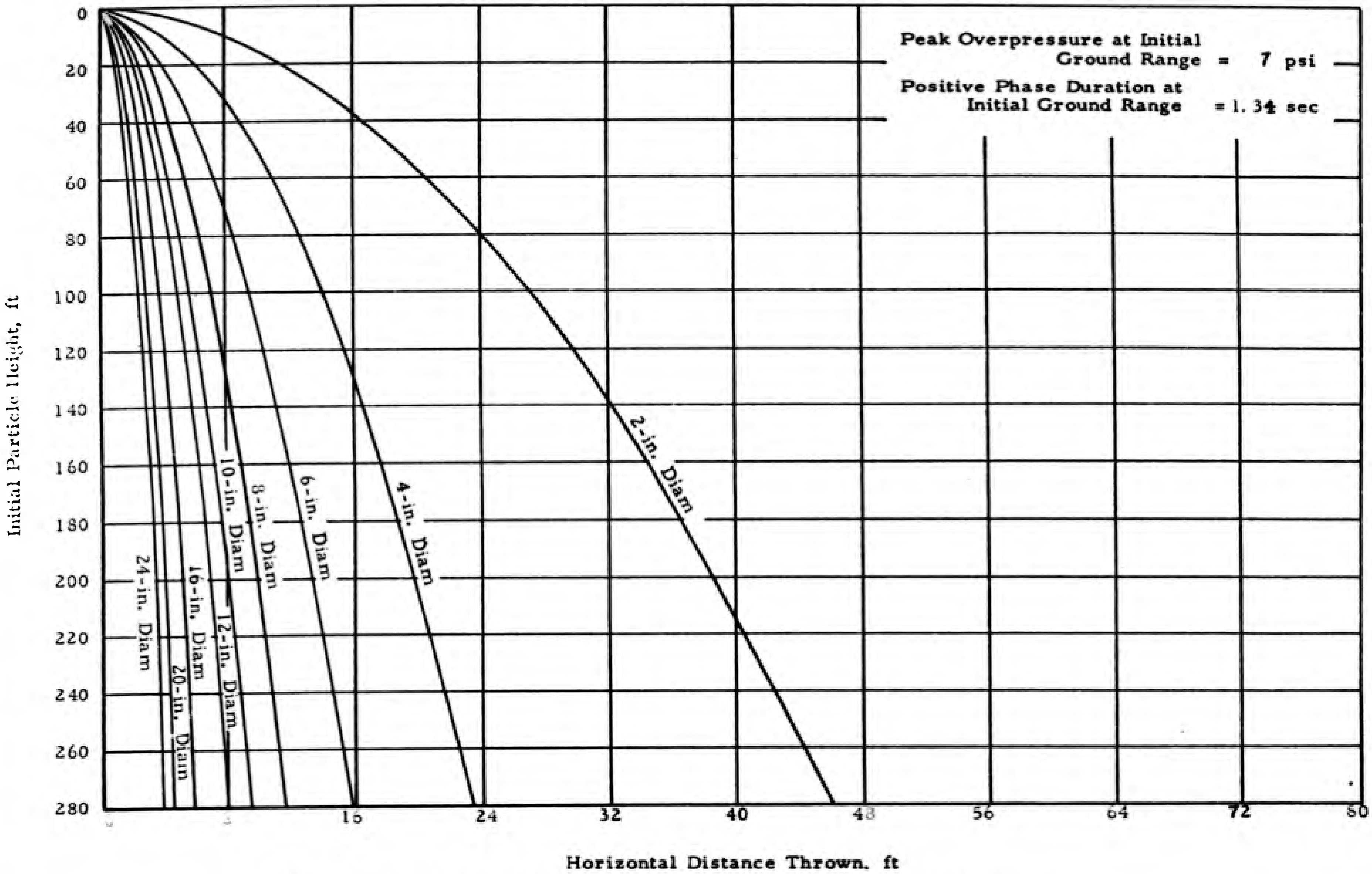

Fig. D-1.11 PARTICLE TRAJECTORIES AT 6,000 FT. FROM 100 KT SURFACE BURST

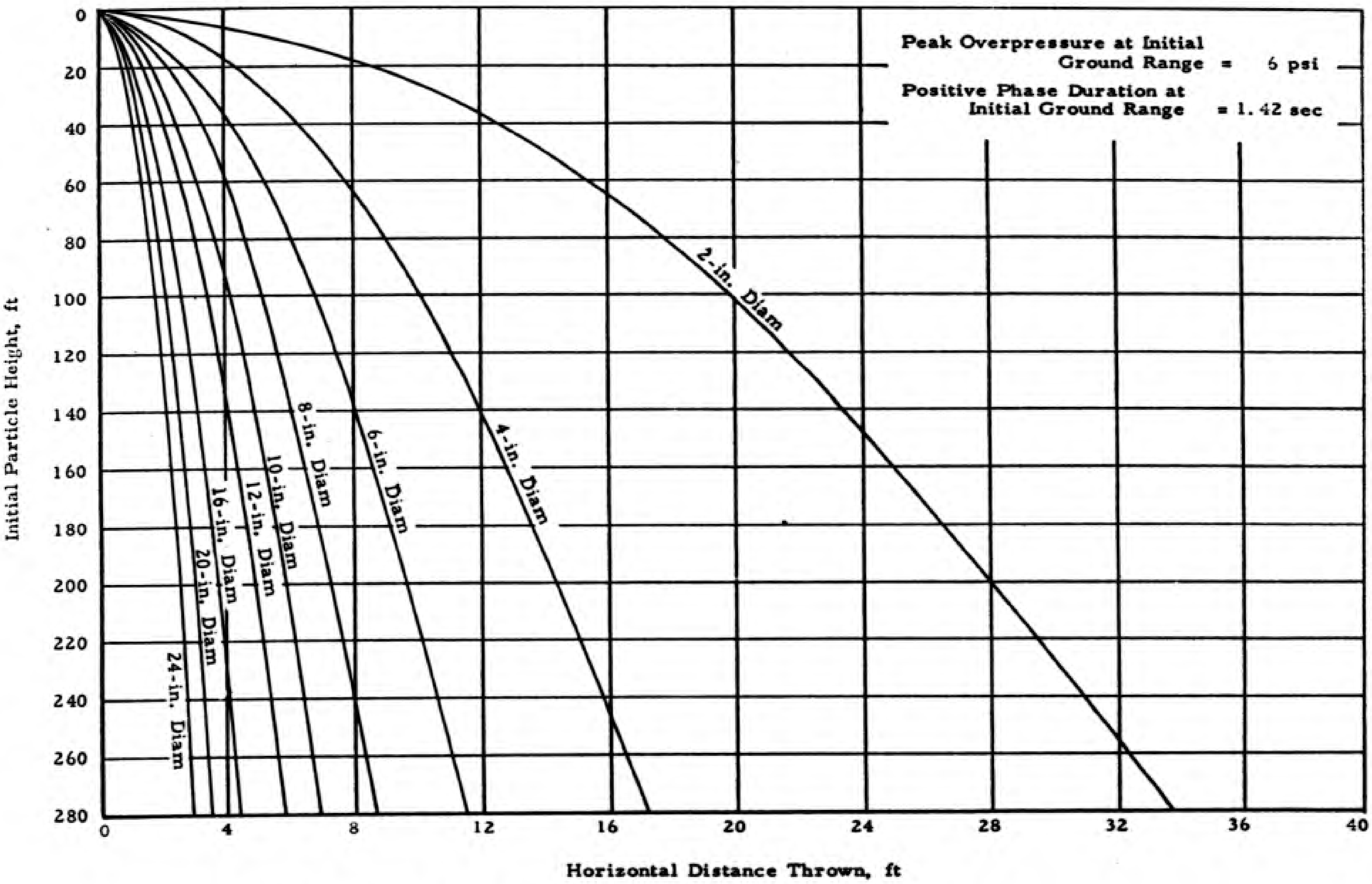

Fig. D-2.1 PARTICLE TRAJECTORIES AT 1,800 FT. FROM 500 KT SURFACE BURST

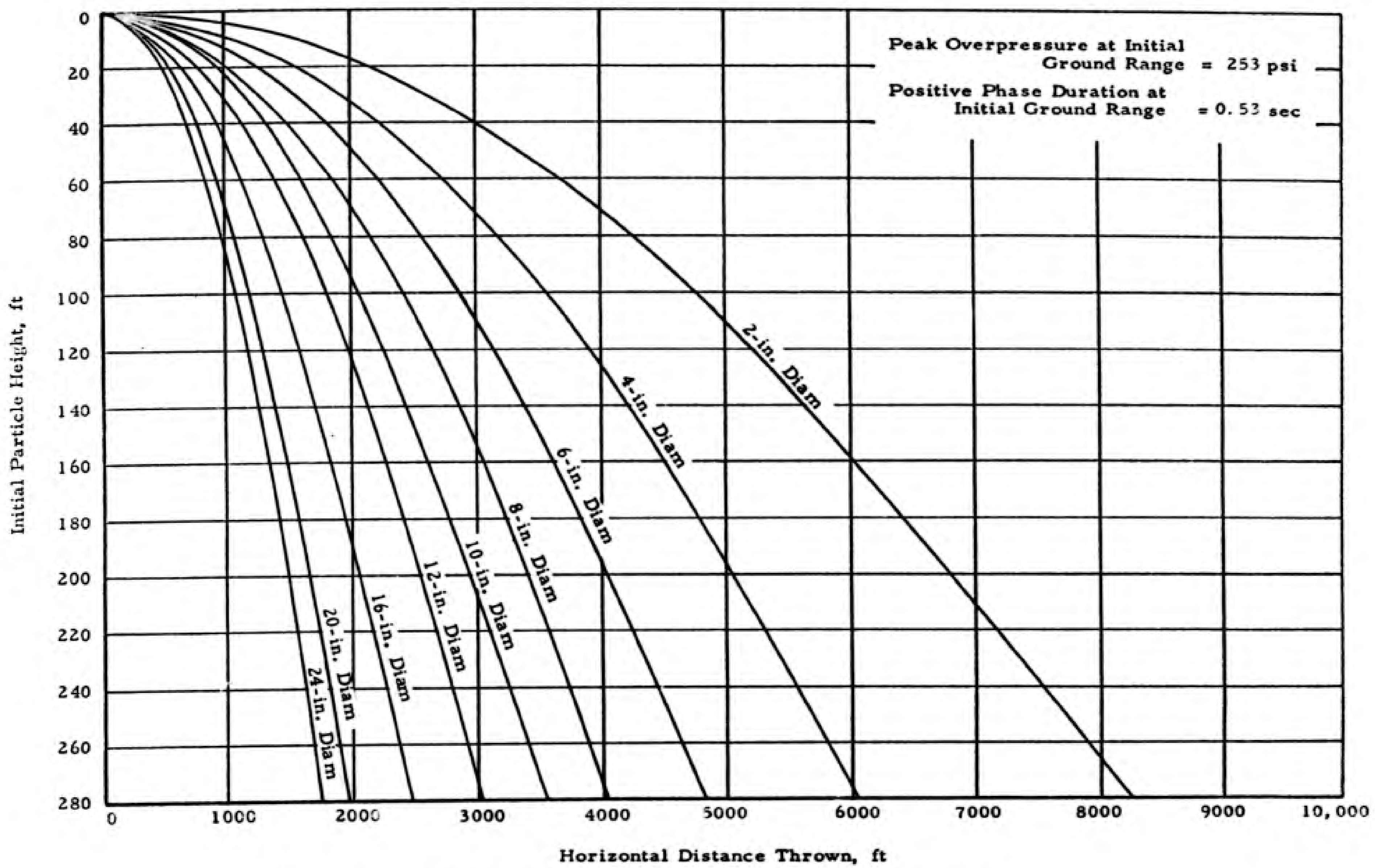

Fig. D-2.2 PARTICLE TRAJECTORIES AT 2,800 FT. FROM 500 KT SURFACE BURST

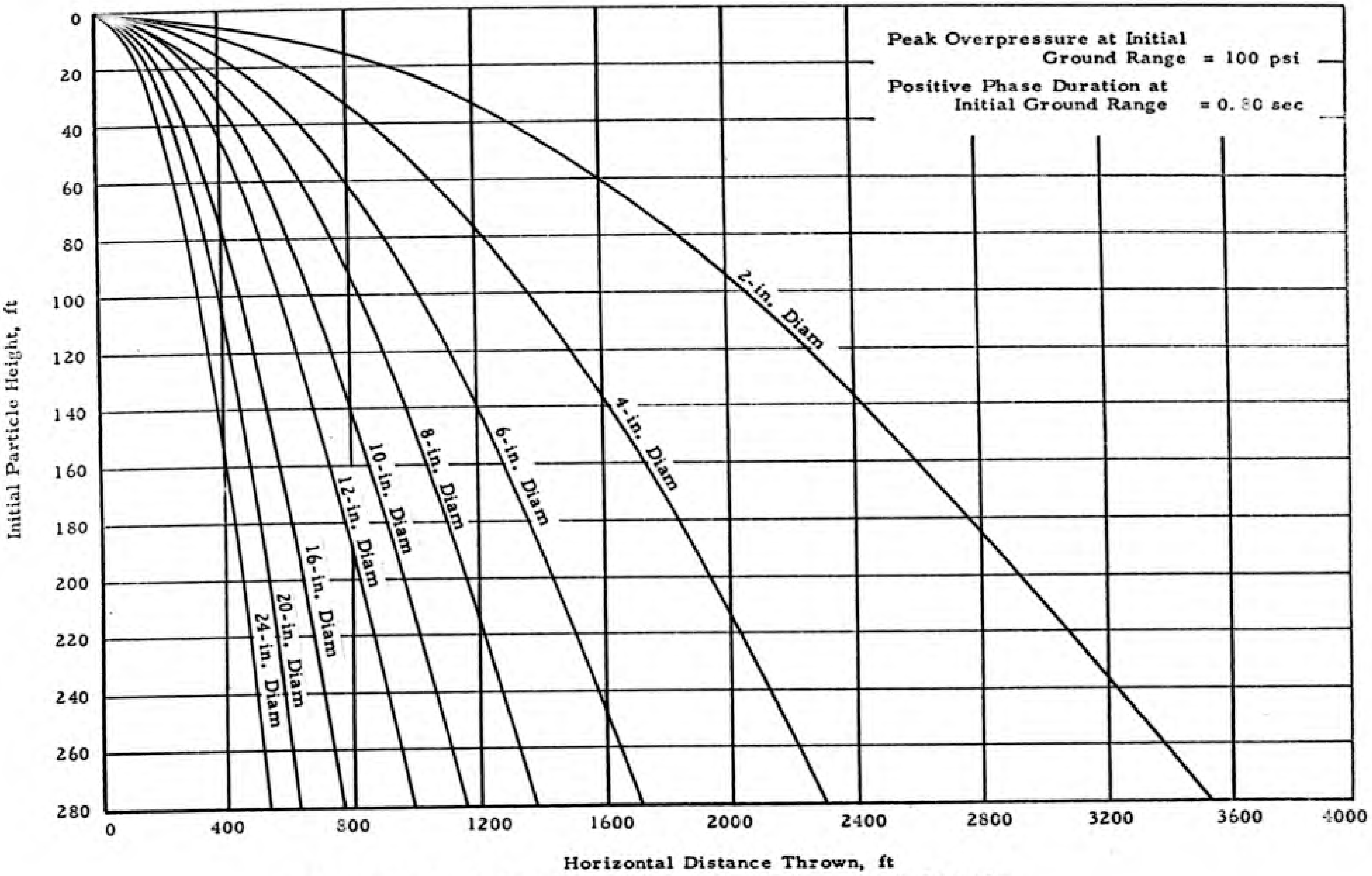

Fig. D-2.3 PARTICLE TRAJECTORIES AT 3,800 FT. FROM 500 KT SURFACE BURST

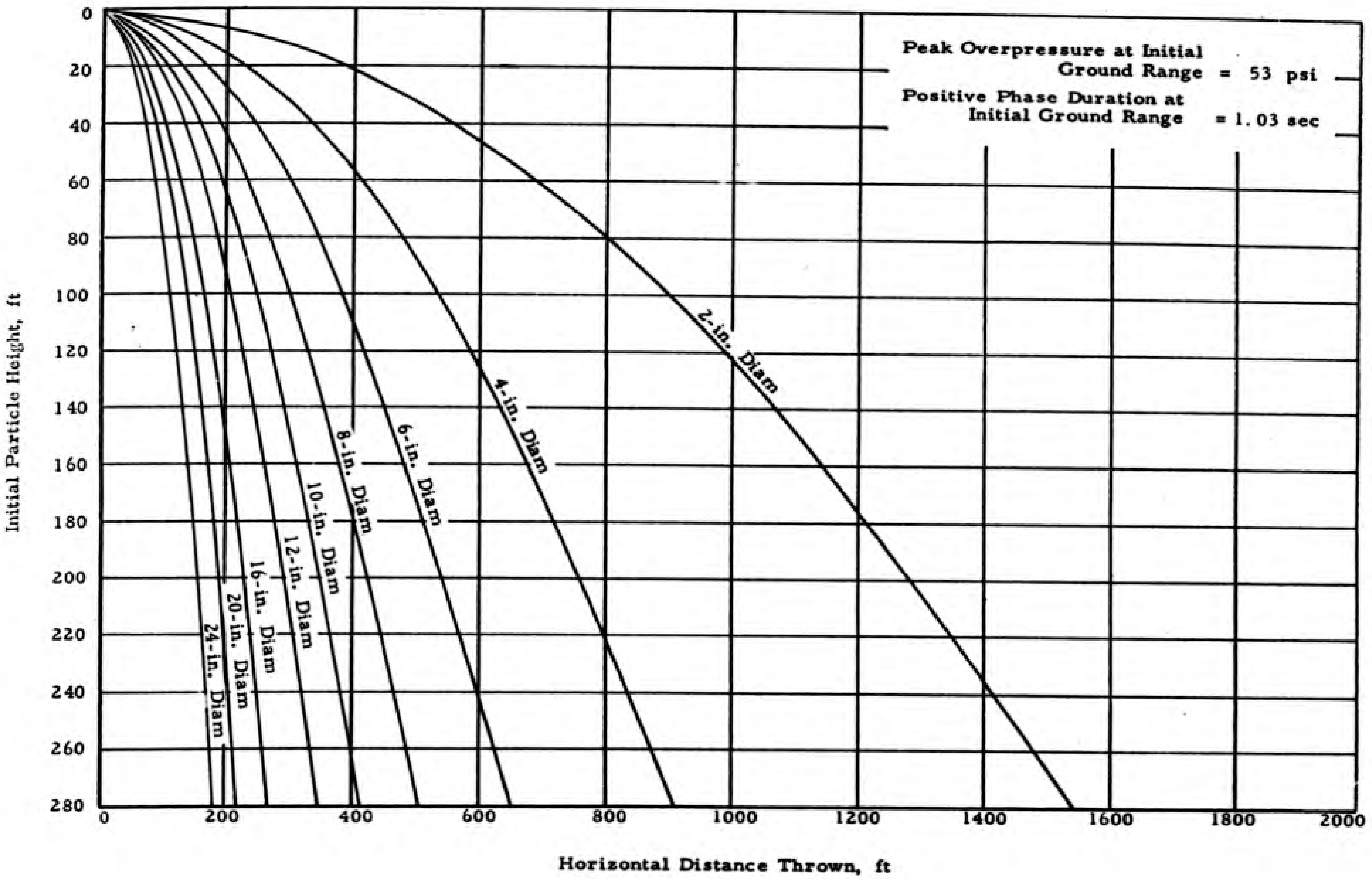

Fig. D-2.4 PARTICLE TRAJECTORIES AT 4,800 FT. FROM 500 KT SURFACE BURST

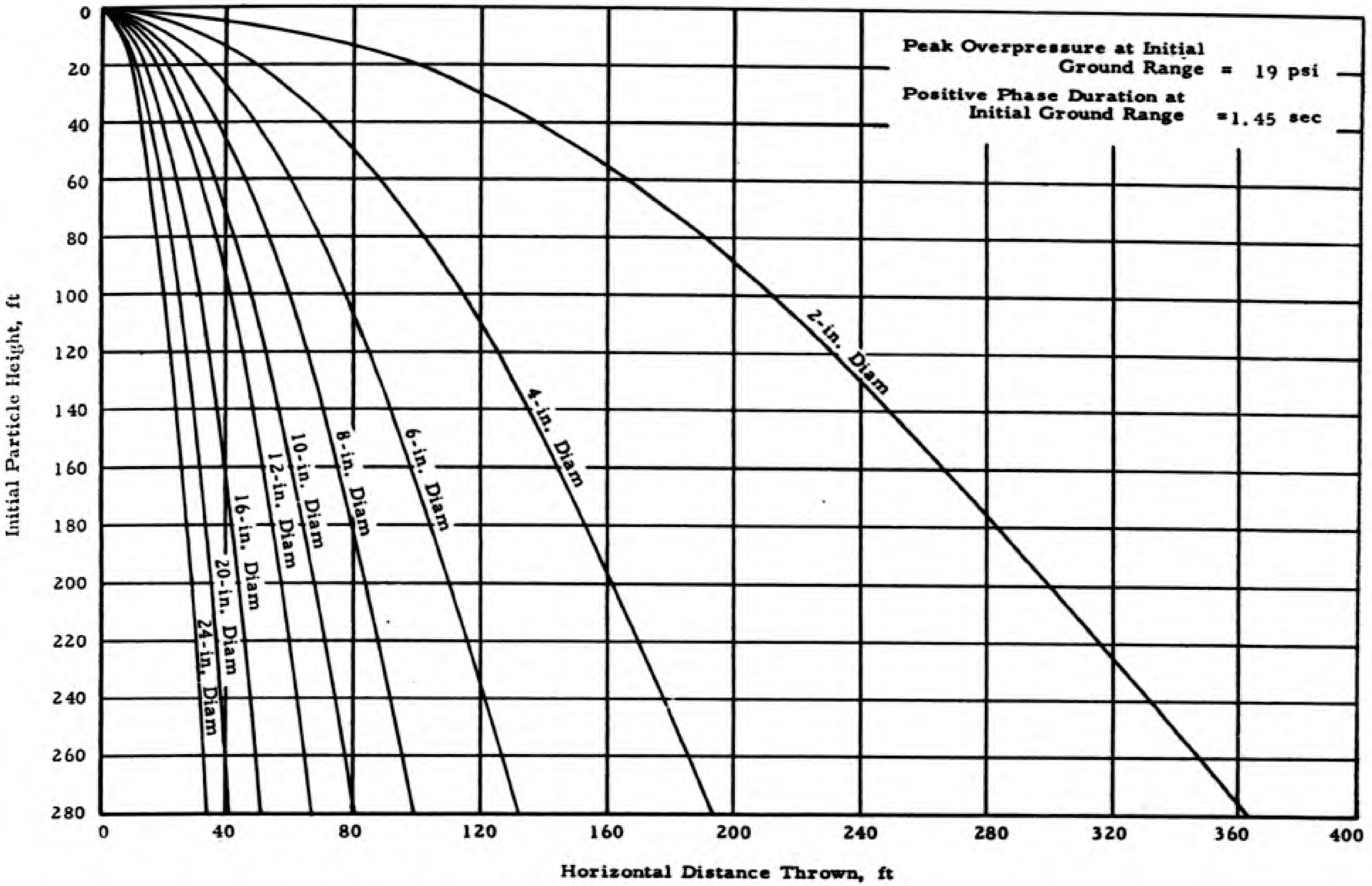

Fig. D-2.5 PARTICLE TRAJECTORIES AT 6,800 FT. FROM 500 KT SURFACE BURST

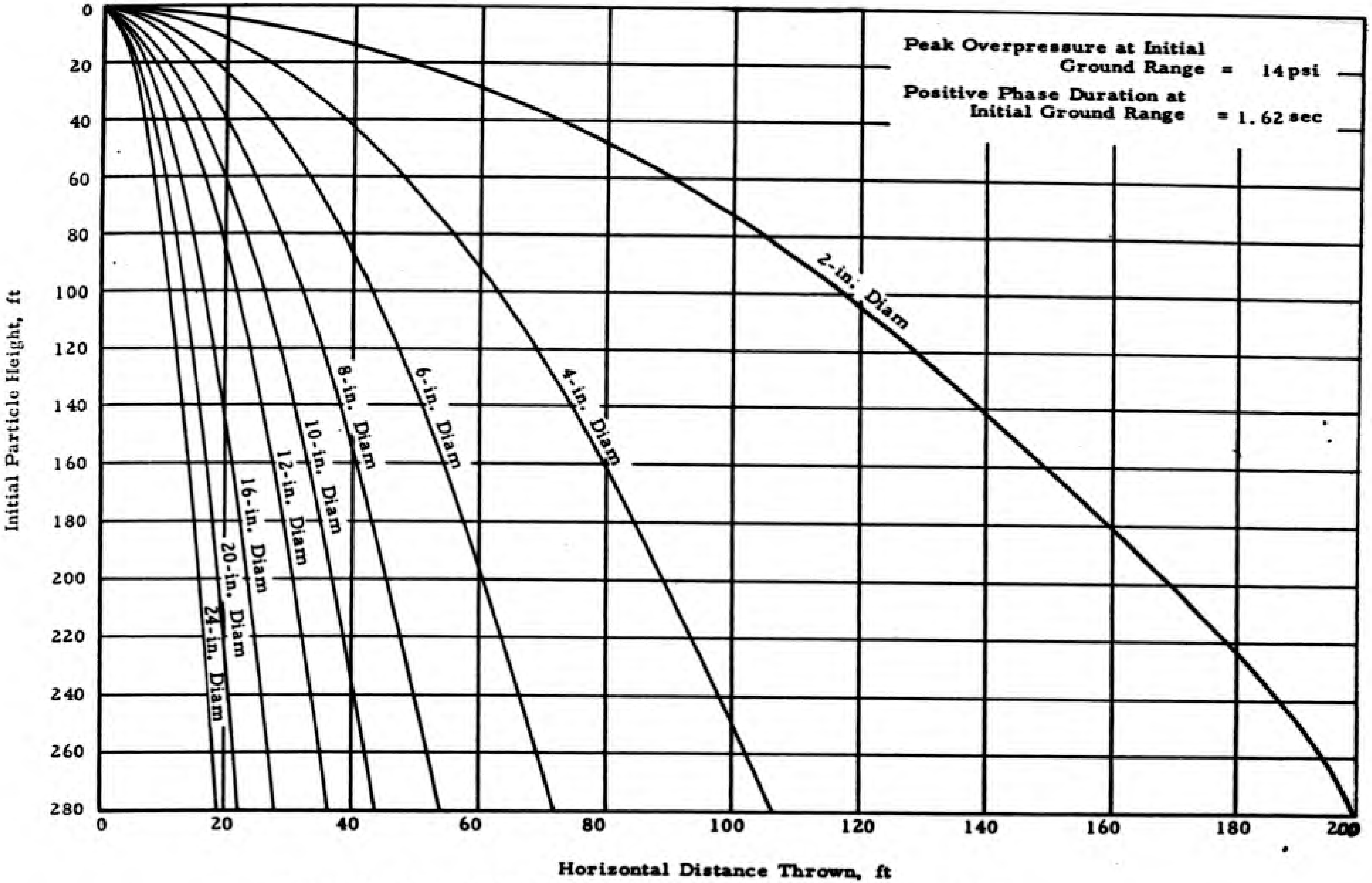

Fig. D-2.6 PARTICLE TRAJECTORIES AT 7,800 FT. FROM 500 KT SURFACE BURST

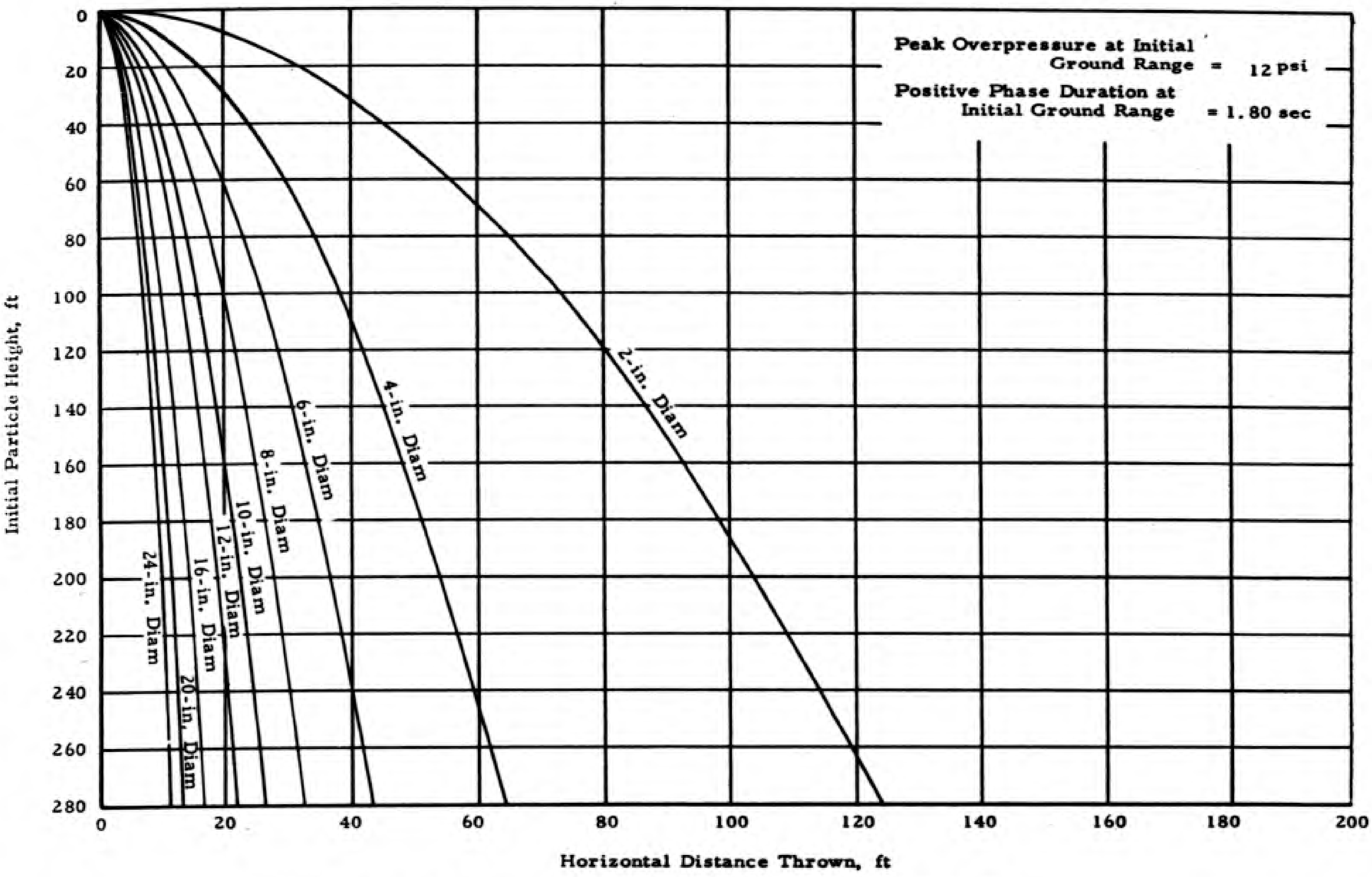

Fig. D-2.7 PARTICLE TRAJECTORIES AT 7,800 FT. FROM 500 KT SURFACE BURST

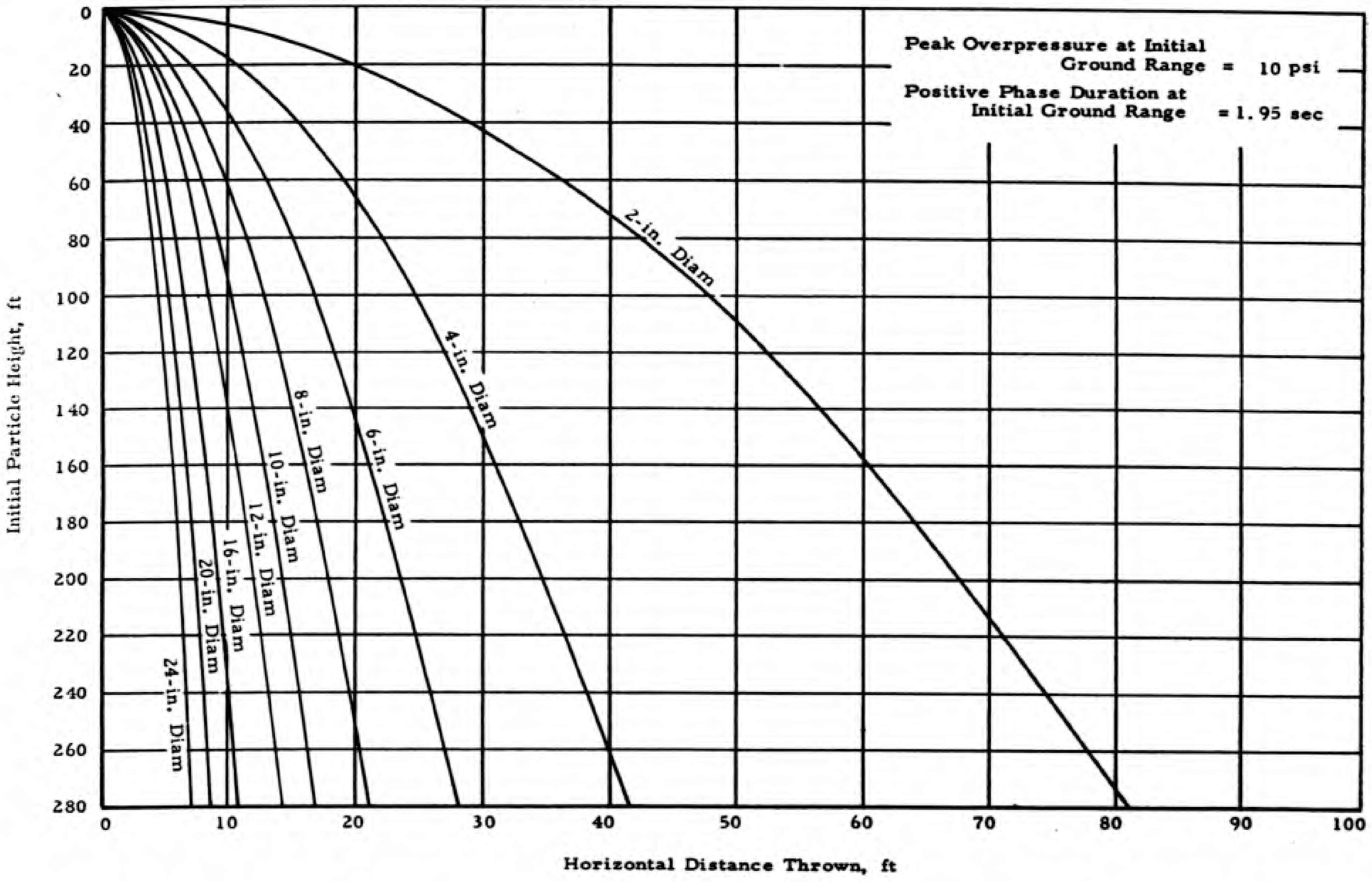

Fig. D-2.8 PARTICLE TRAJECTORIES AT 8,800 FT. FROM 500 KT SURFACE BURST

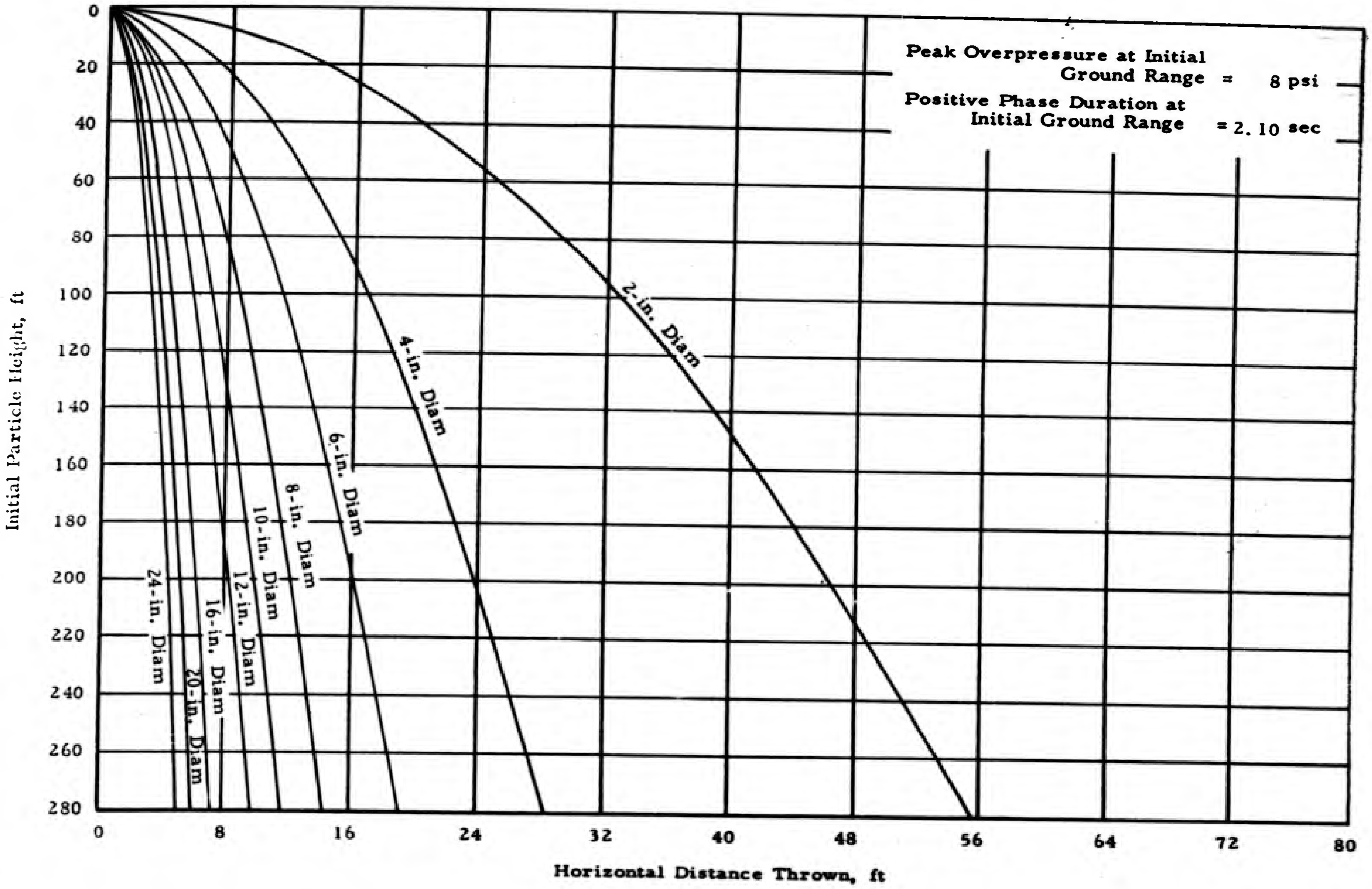

Fig. D-2.9 PARTICLE TRAJECTORIES AT 9,800 FT. FROM 500 KT SURFACE BURST

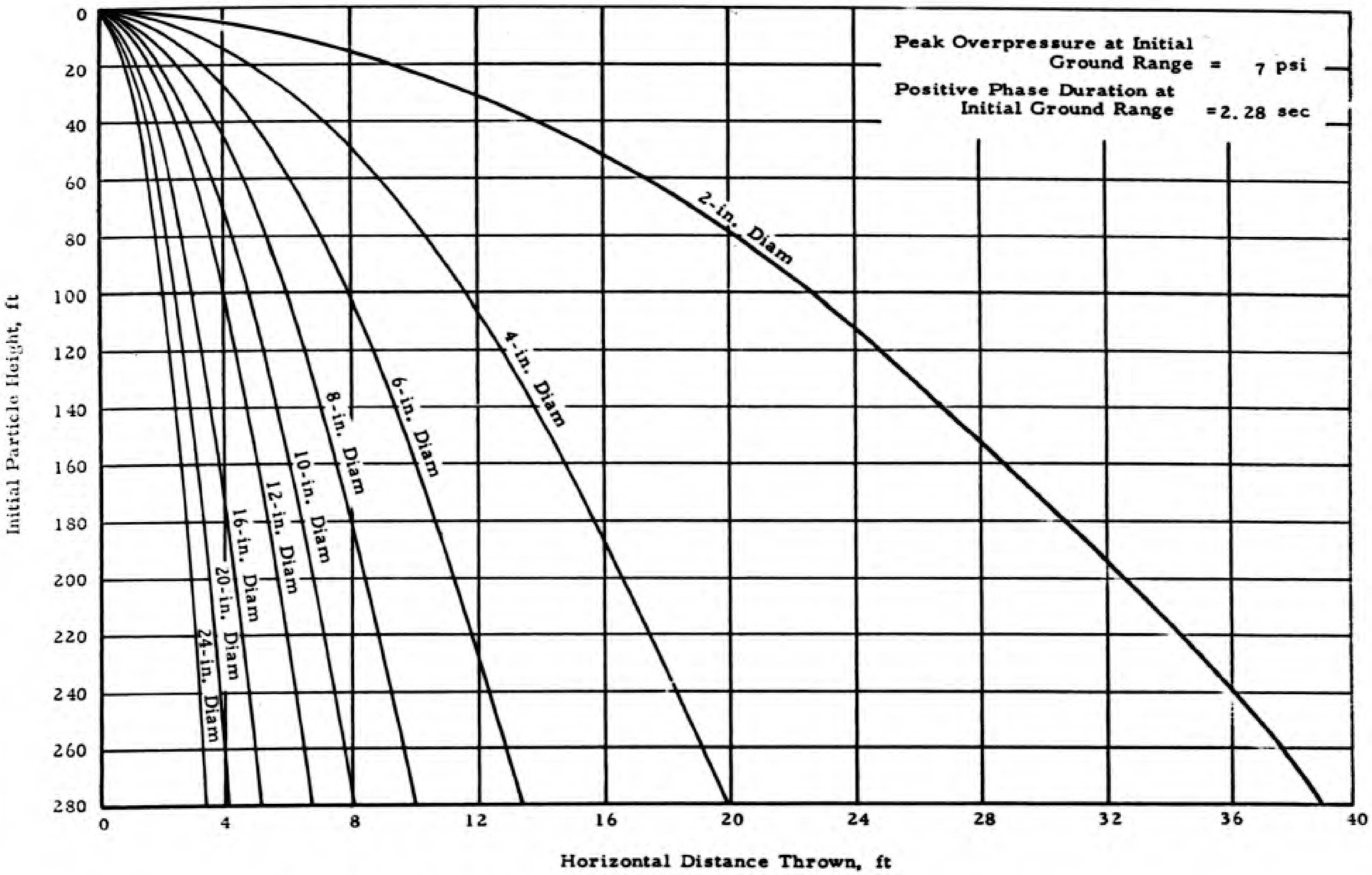

Fig. D-2.10 PARTICLE TRAJECTORIES AT 10,800 FT. FROM 500 KT SURFACE BURST

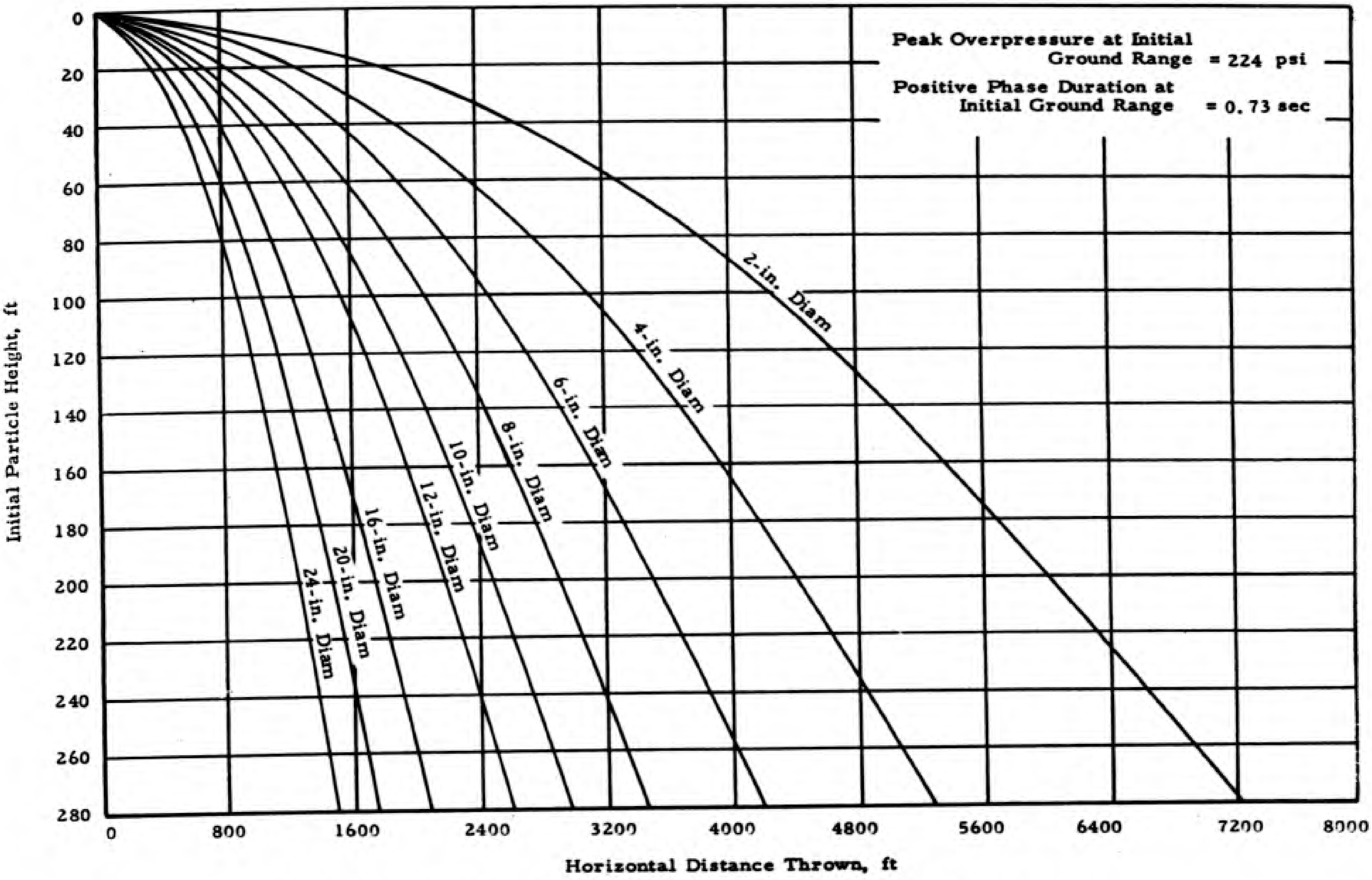

Fig. D-3.1 PARTICLE TRAJECTORIES AT 2,460 FT. FROM 1 MT SURFACE BURST

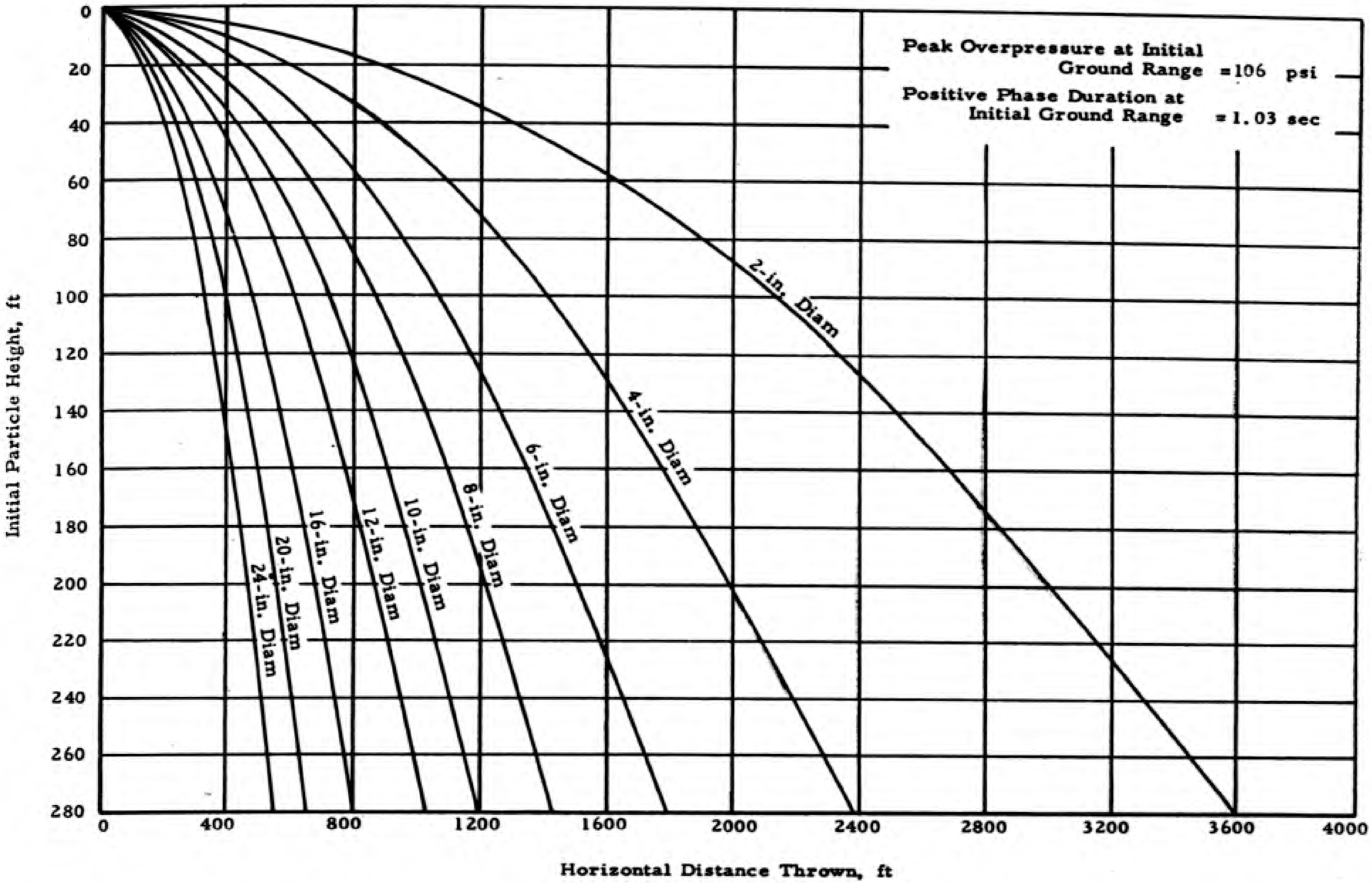

Fig. D-3.2 PARTICLE TRAJECTORIES AT 3,460 FT. FROM 1 MT SURFACE BURST

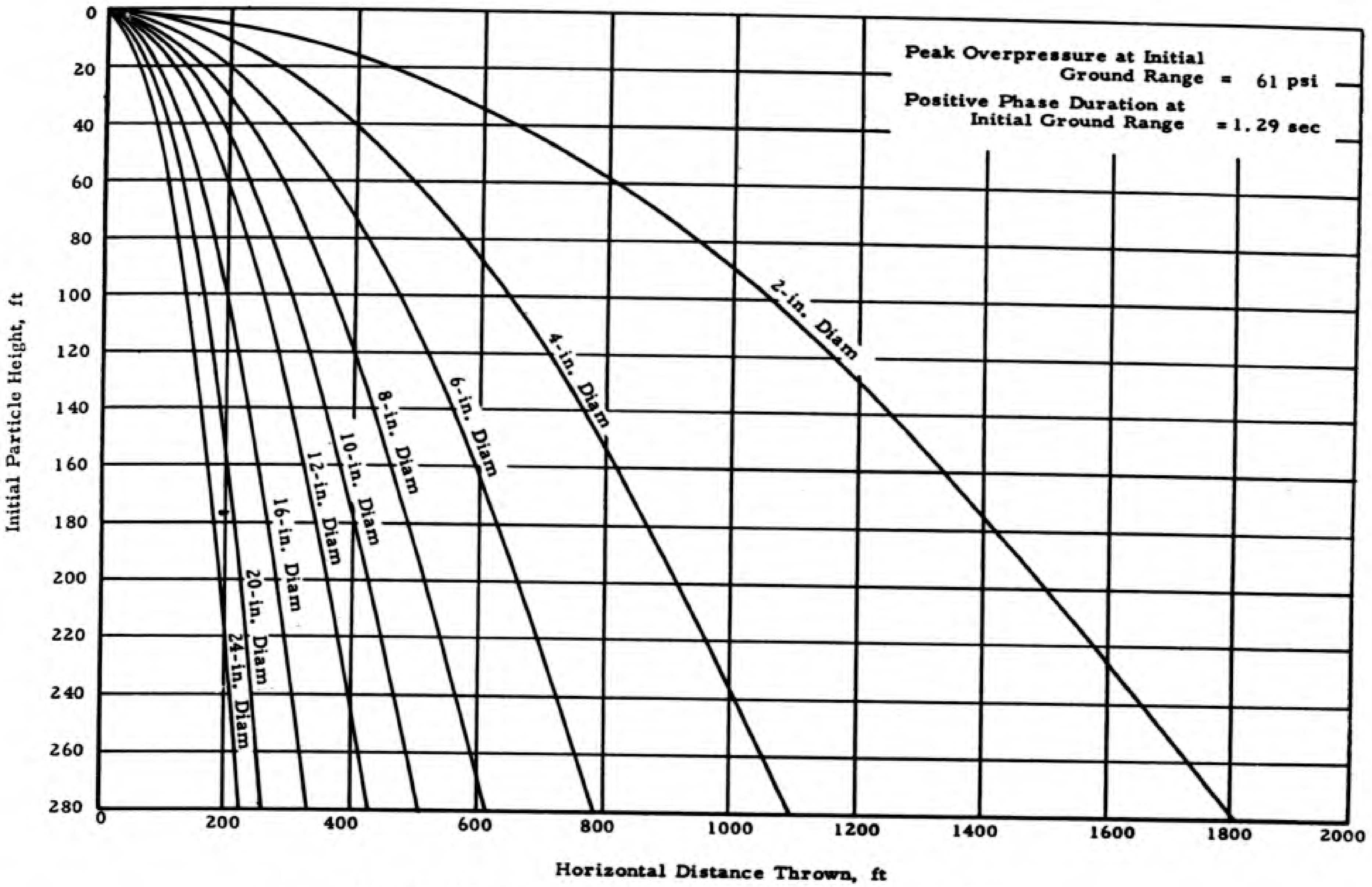

Fig. D-3.3 PARTICLE TRAJECTORIES AT 4,460 FT. FROM 1 MT SURFACE BURST

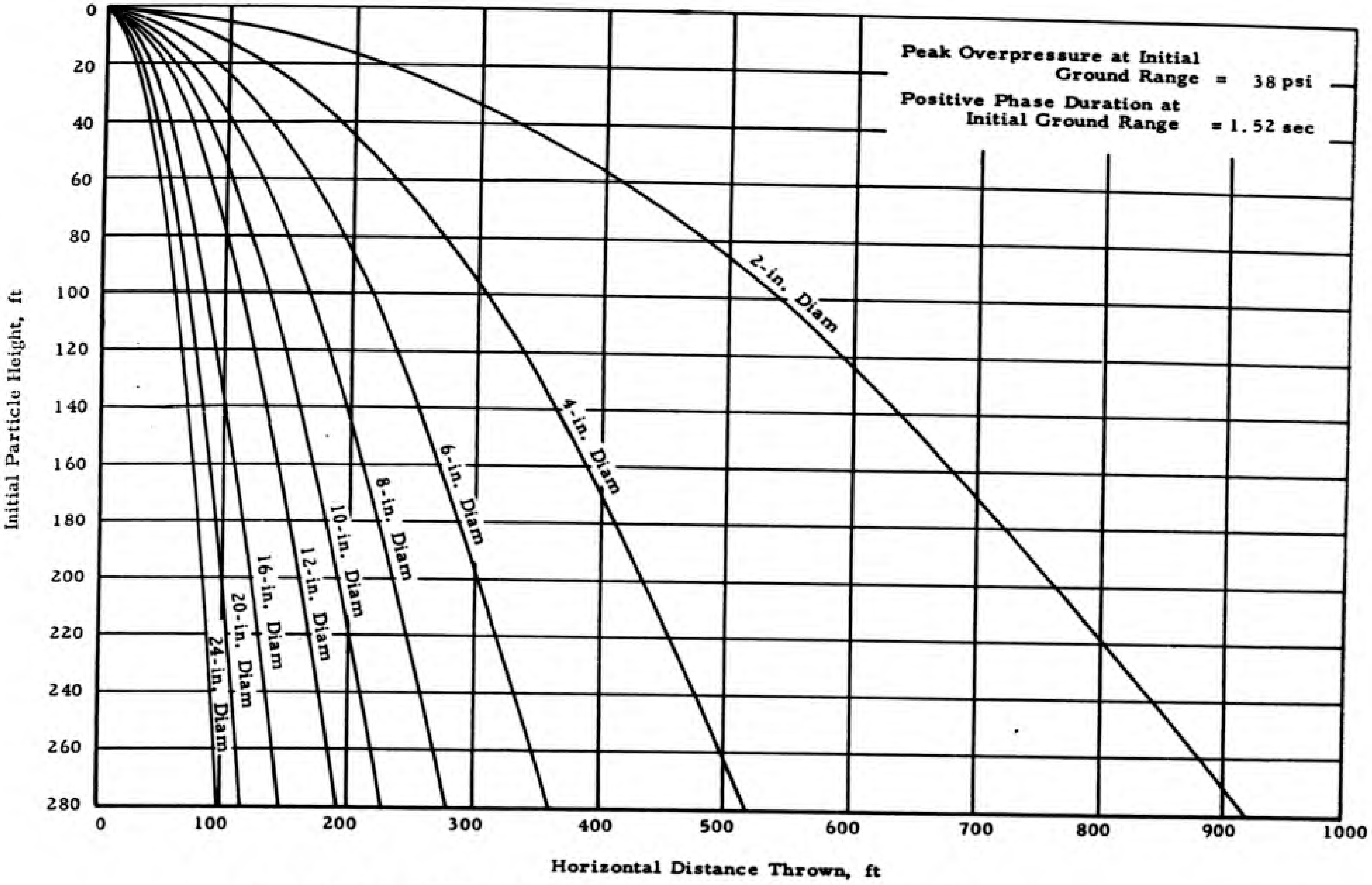

Fig. D-3.4 PARTICLE TRAJECTORIES AT 5,460 FT. FROM 1 MT SURFACE BURST

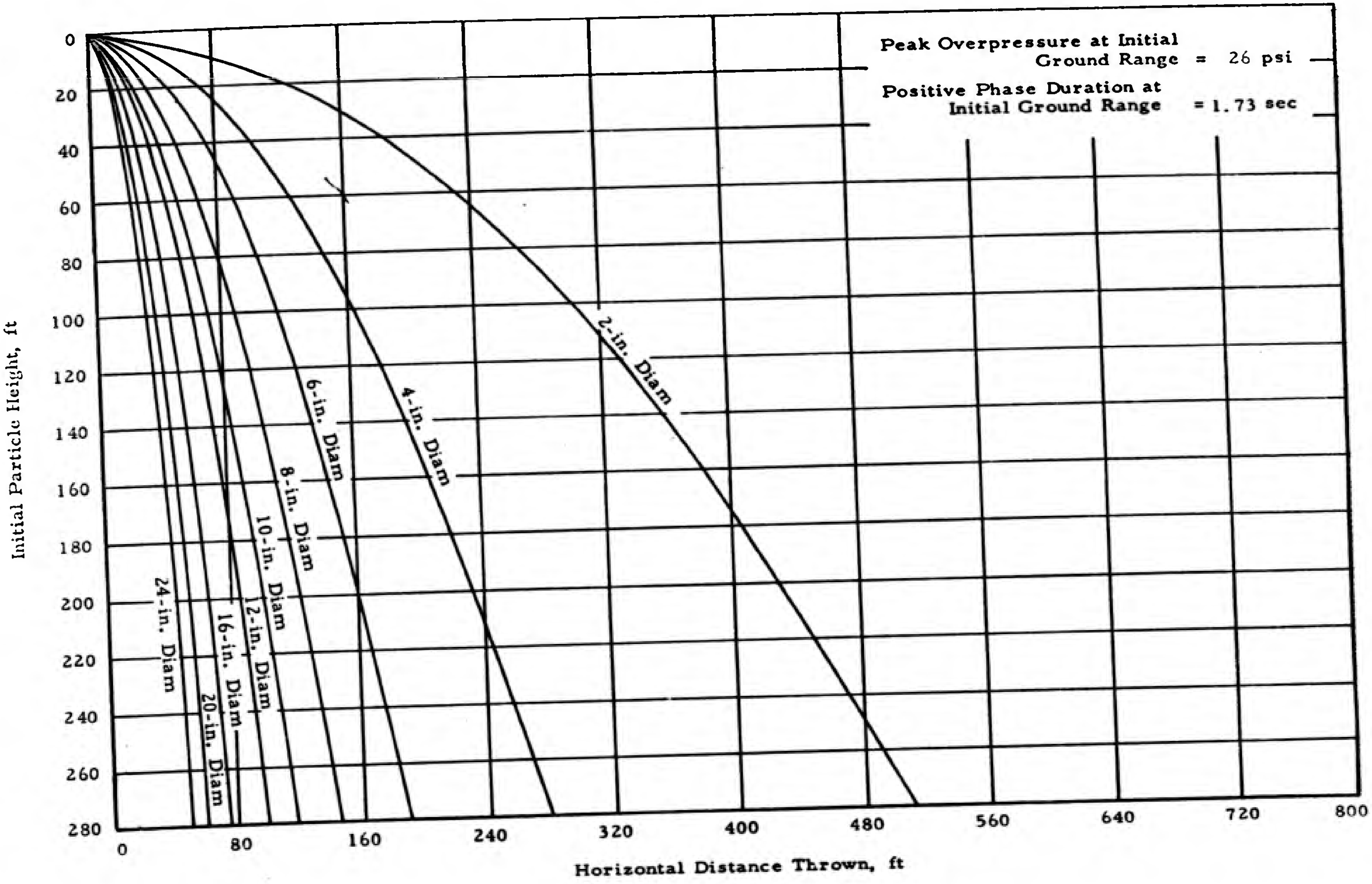

Fig. D-3.5 PARTICLE TRAJECTORIES AT 6,400 FT. FROM 1 MT SURFACE BURST

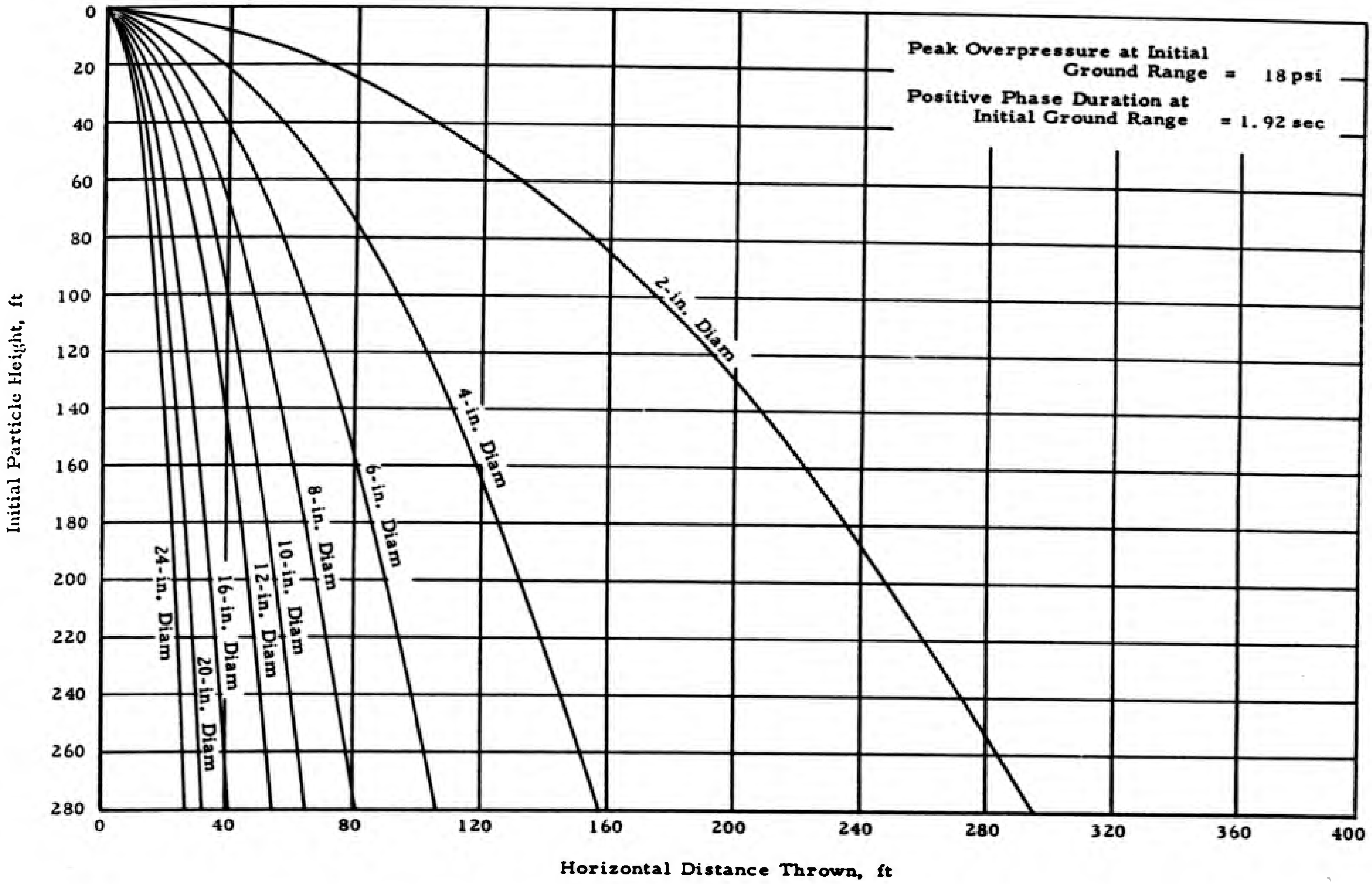

Fig. D-3.6 PARTICLE TRAJECTORIES AT 7,400 FT. FROM 1 MT SURFACE BURST

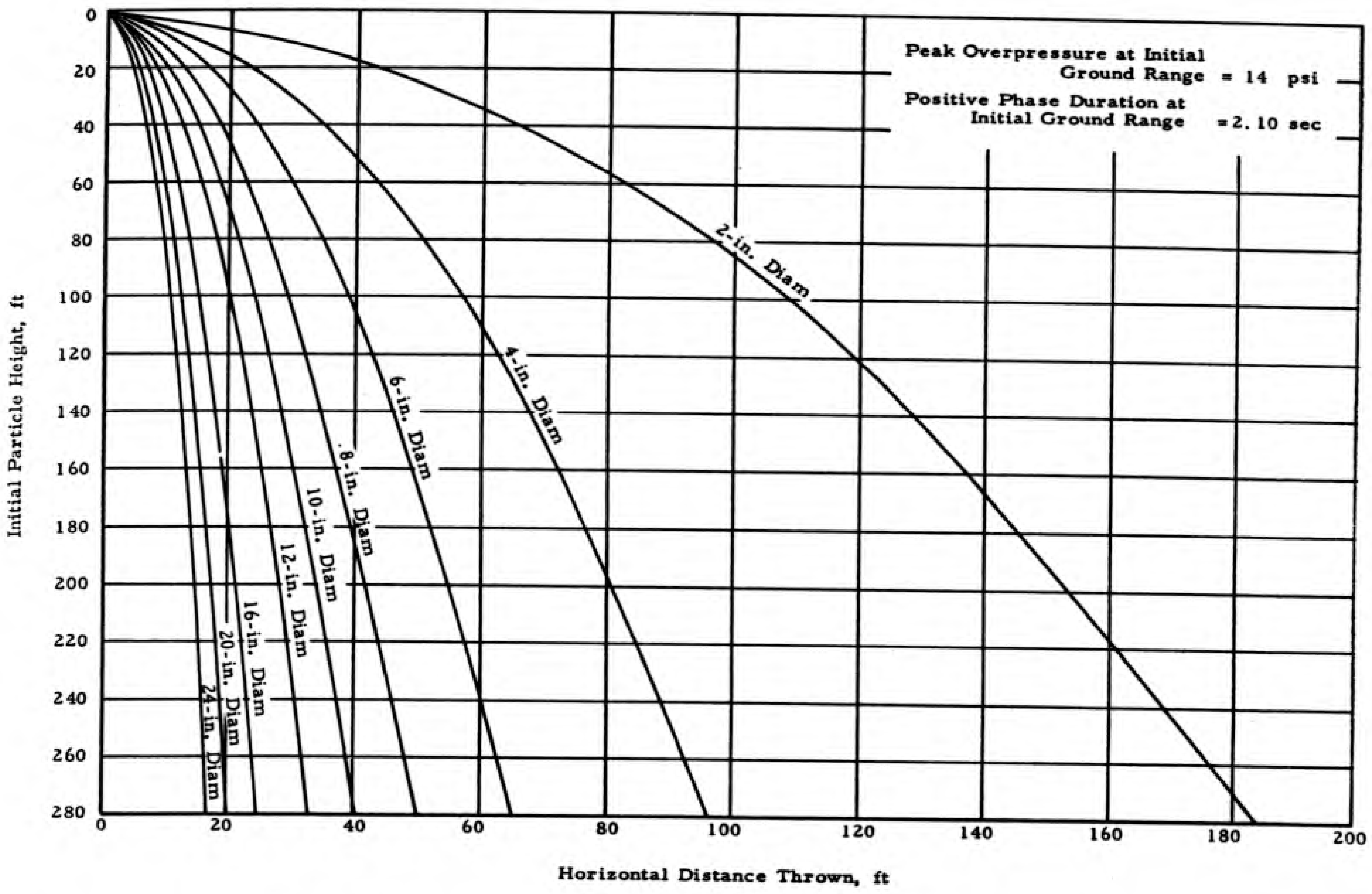

Fig. D-3.7 PARTICLE TRAJECTORIES AT 8,400 FT. FROM 1 MT SURFACE BURST

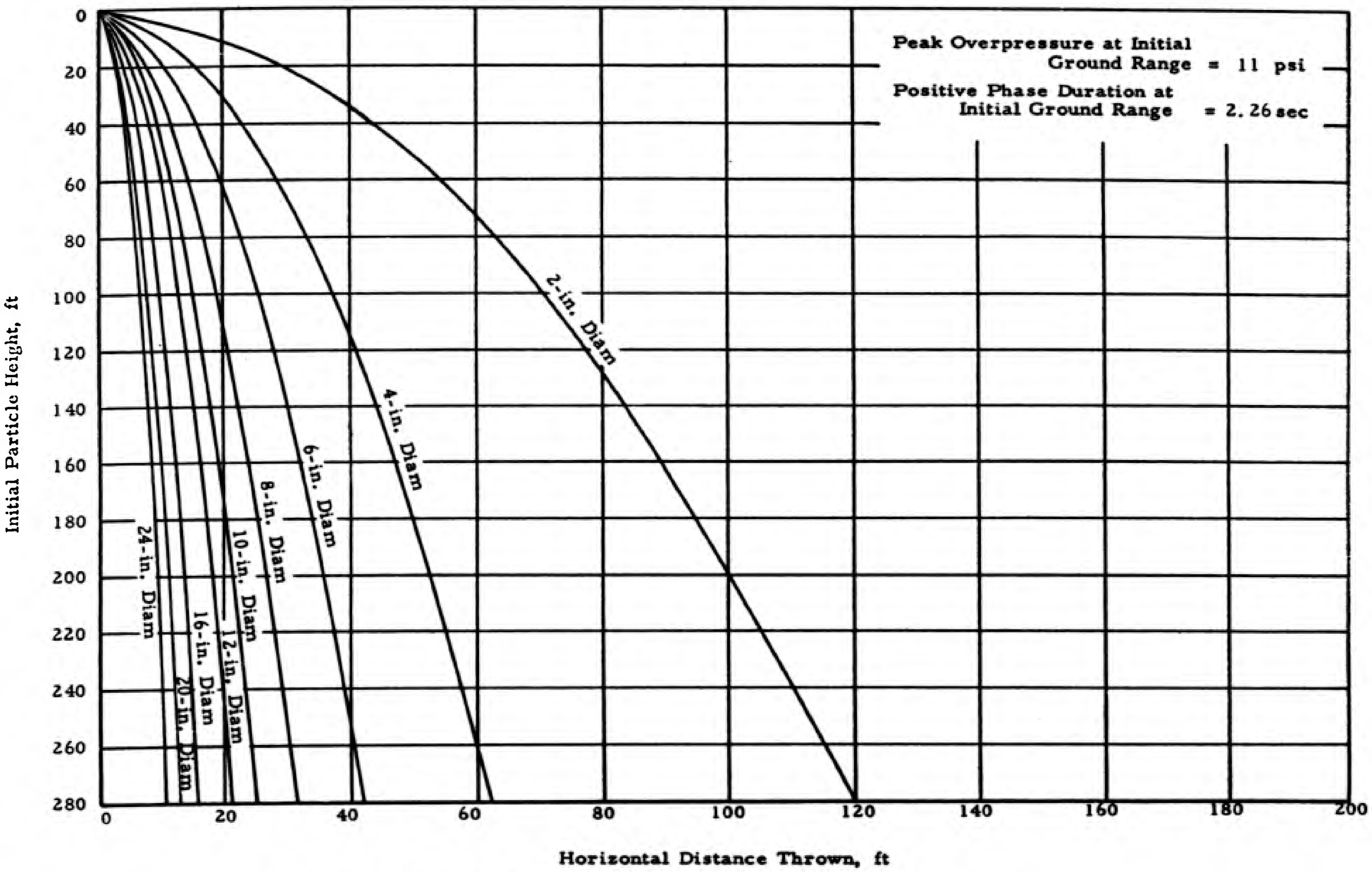

Fig. D-3.8 PARTICLE TRAJECTORIES AT 9,400 FT. FROM 1 MT SURFACE BURST

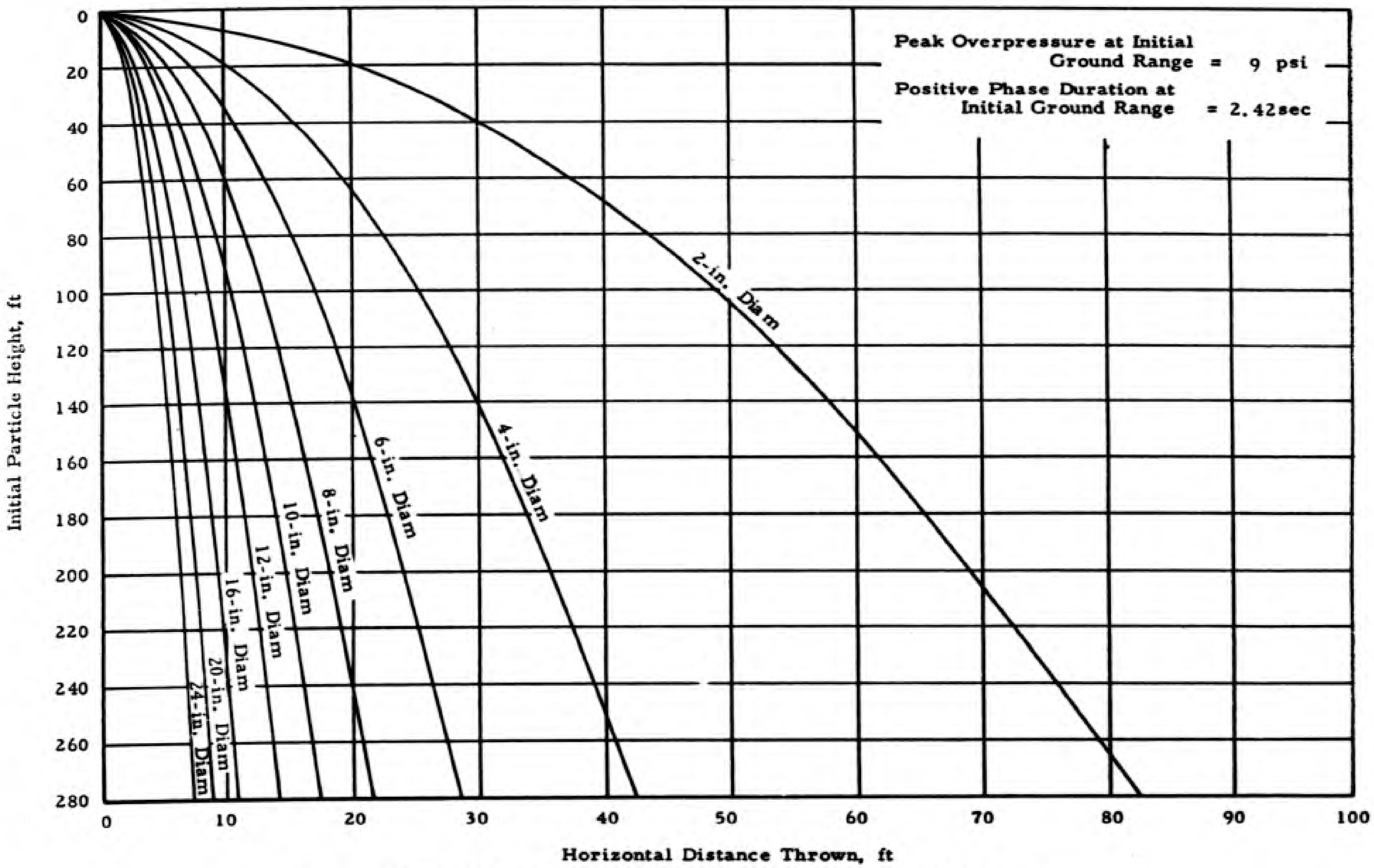

Fig. D-3.9 PARTICLE TRAJECTORIES AT 10,400 FT.
FROM 1 MT SURFACE BURST

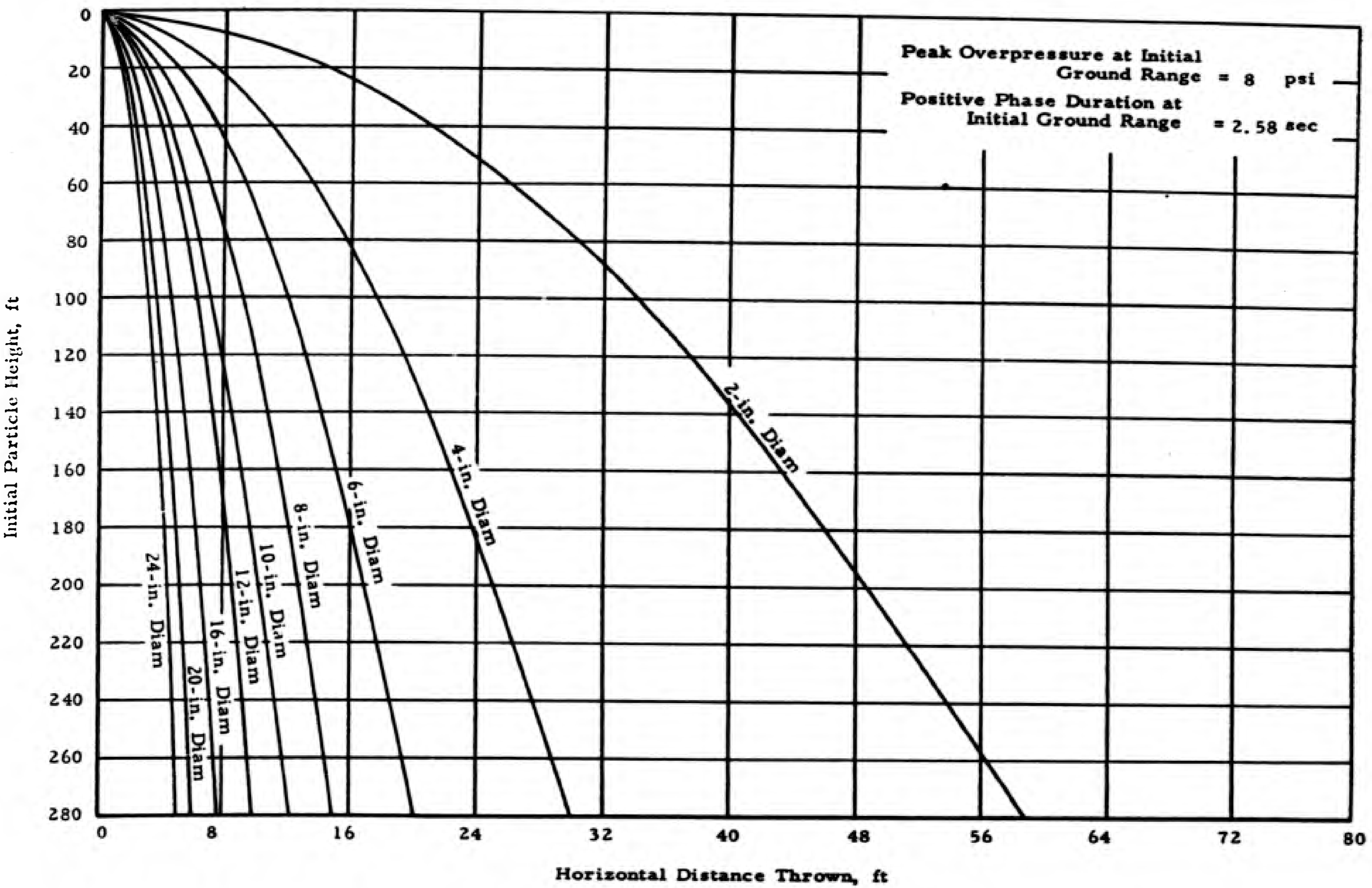

Fig. D-3.10 PARTICLE TRAJECTORIES AT 11,400 FT. FROM 1 MT SURFACE BURST

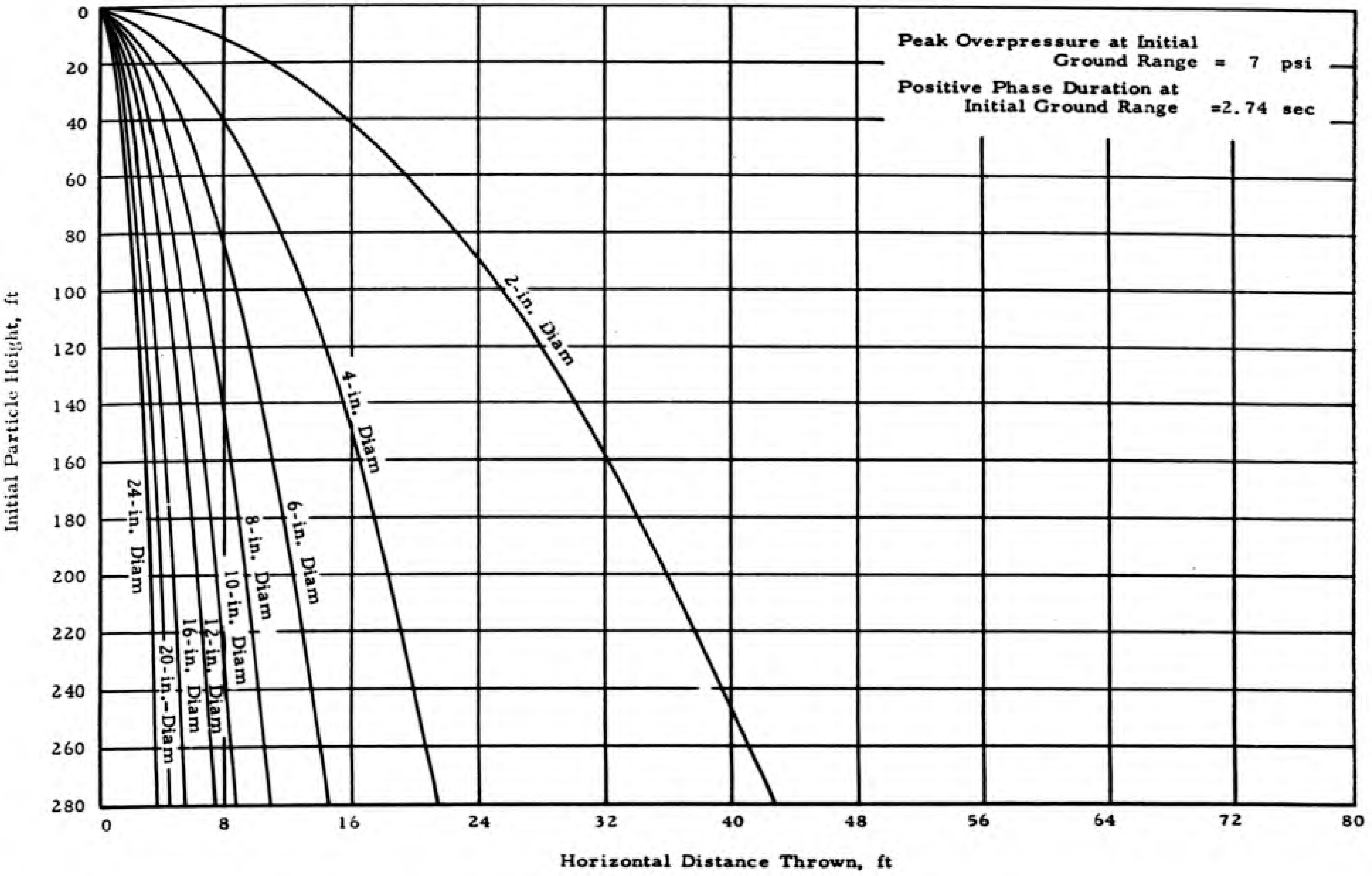

Fig. D-3.11 PARTICLE TRAJECTORIES AT 12,400 FT. FROM 1 MT SURFACE BURST

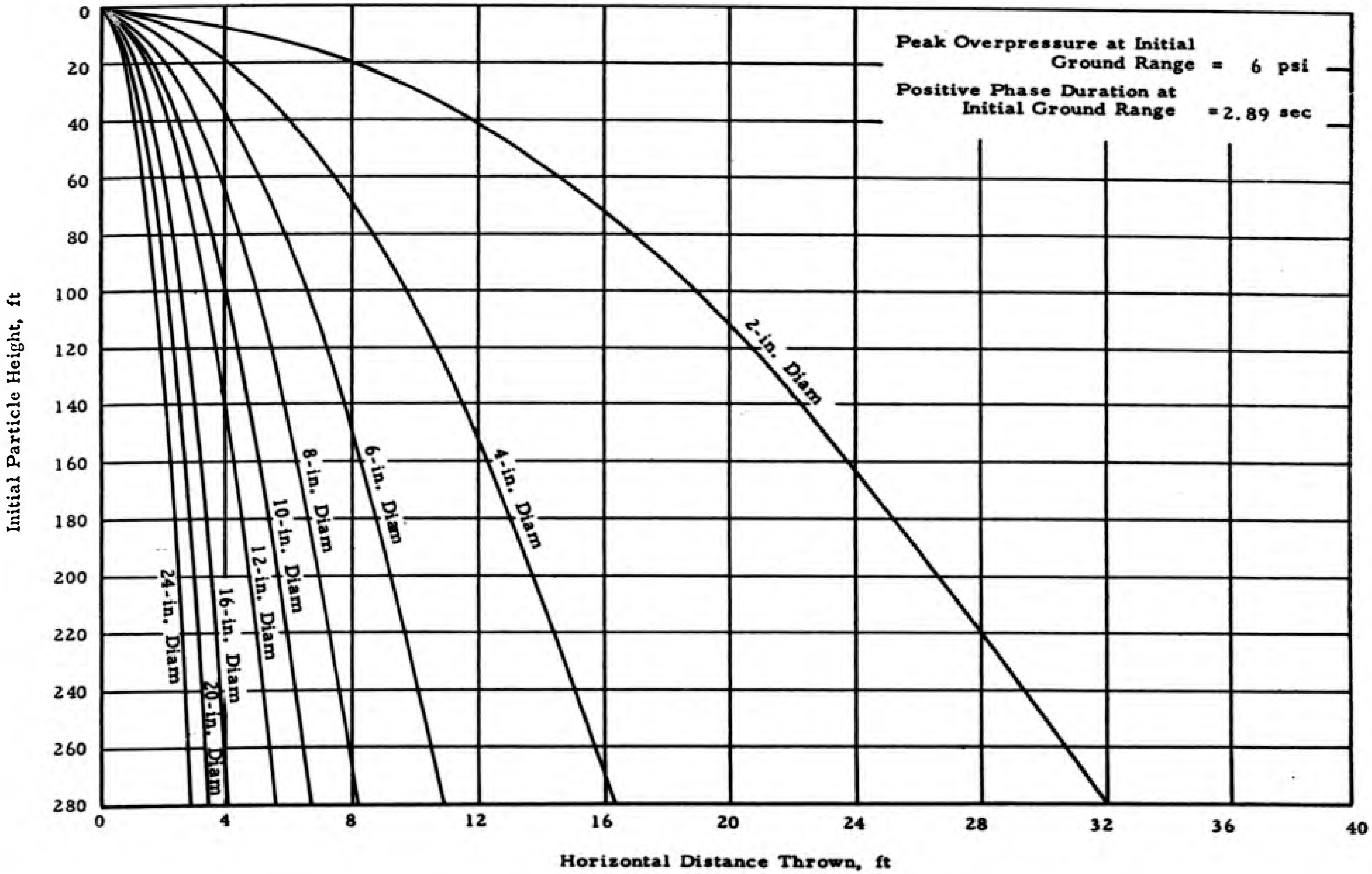

Fig. D-3.12 PARTICLE TRAJECTORIES AT 13,400 FT. FROM 1 MT SURFACE BURST

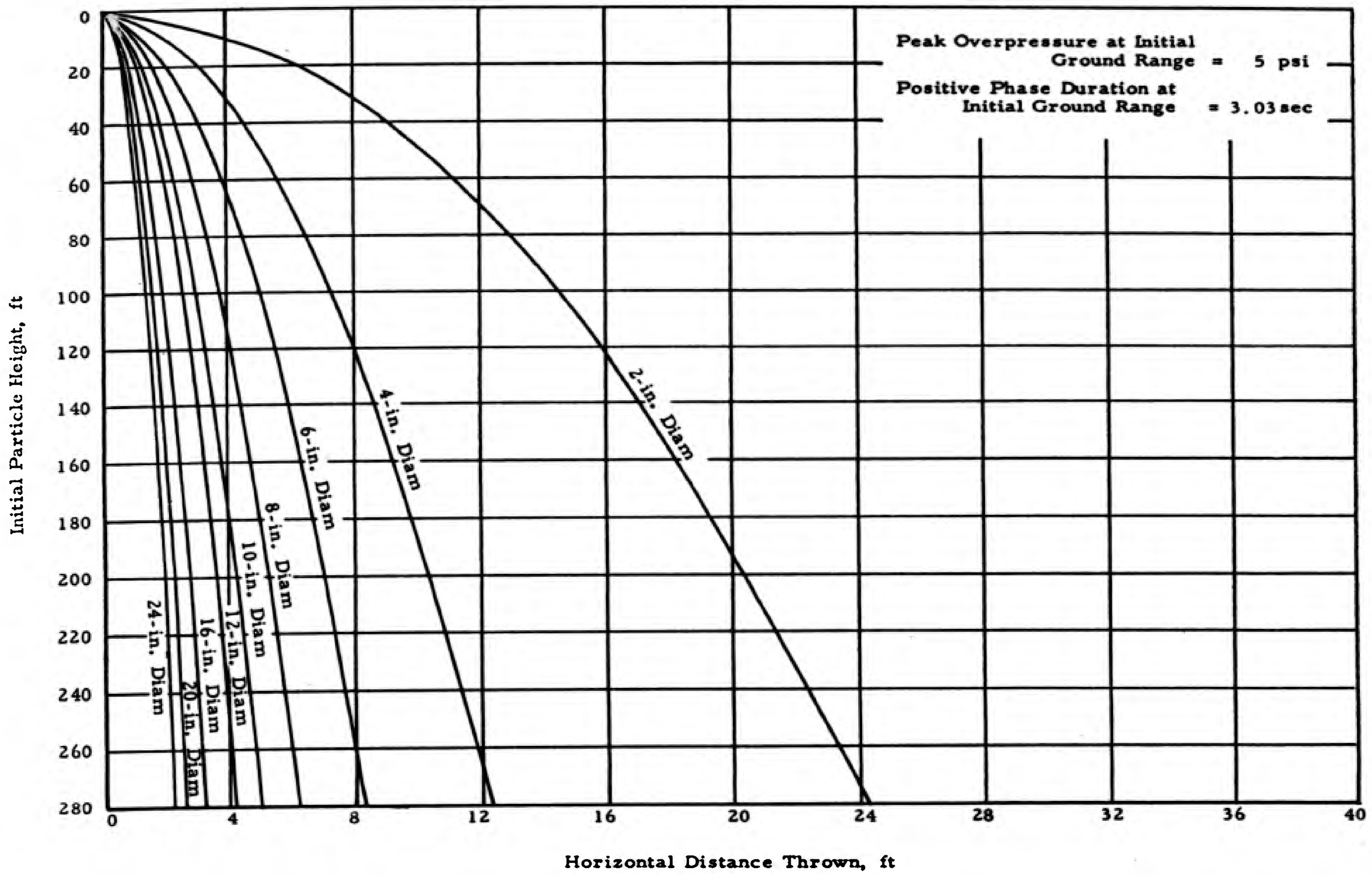

Fig. D-3.13 PARTICLE TRAJECTORIES AT 14,400 FT. FROM 1 MT SURFACE BURST

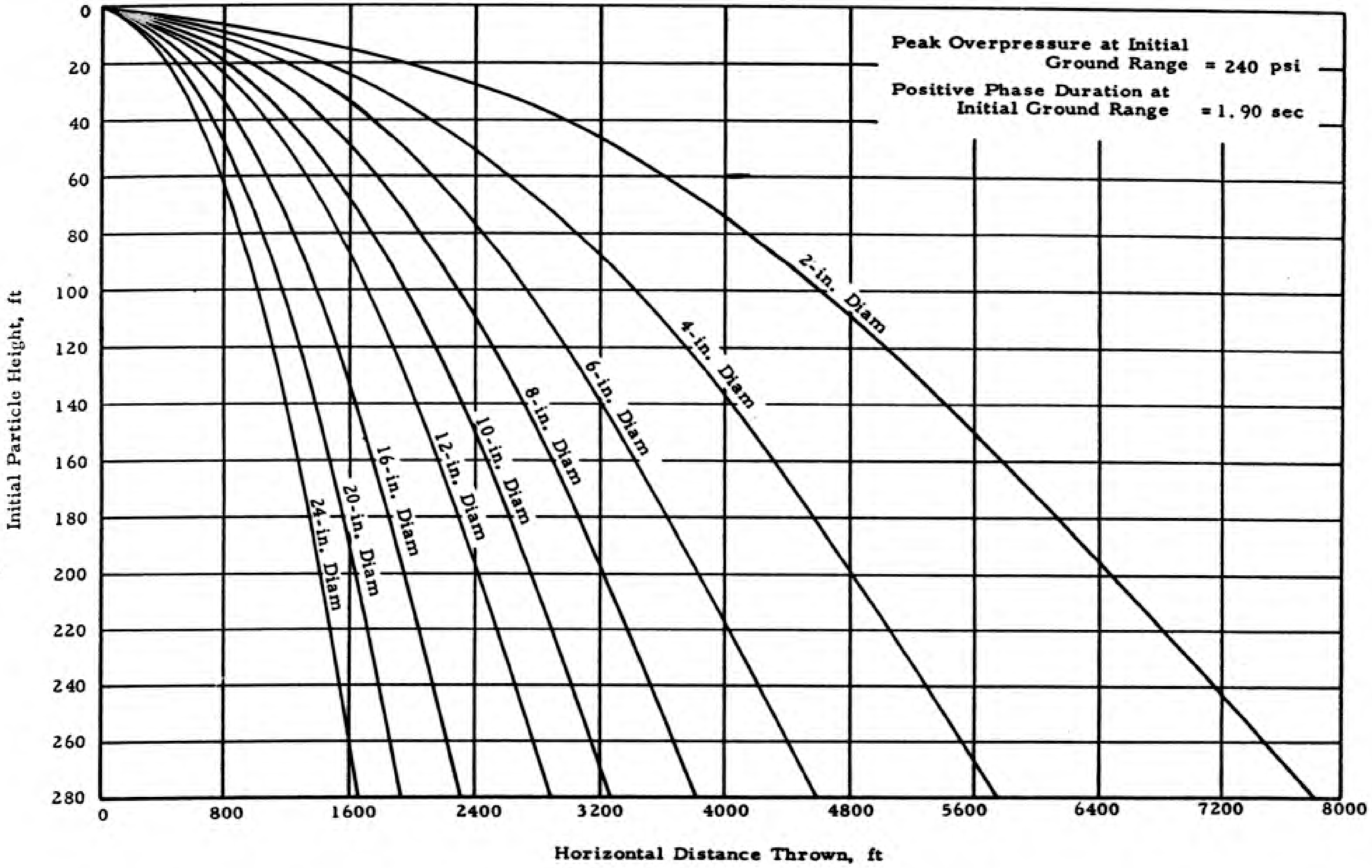

Fig. D-4.1 PARTICLE TRAJECTORIES AT 6,400 FT. FROM 20 MT SURFACE BURST

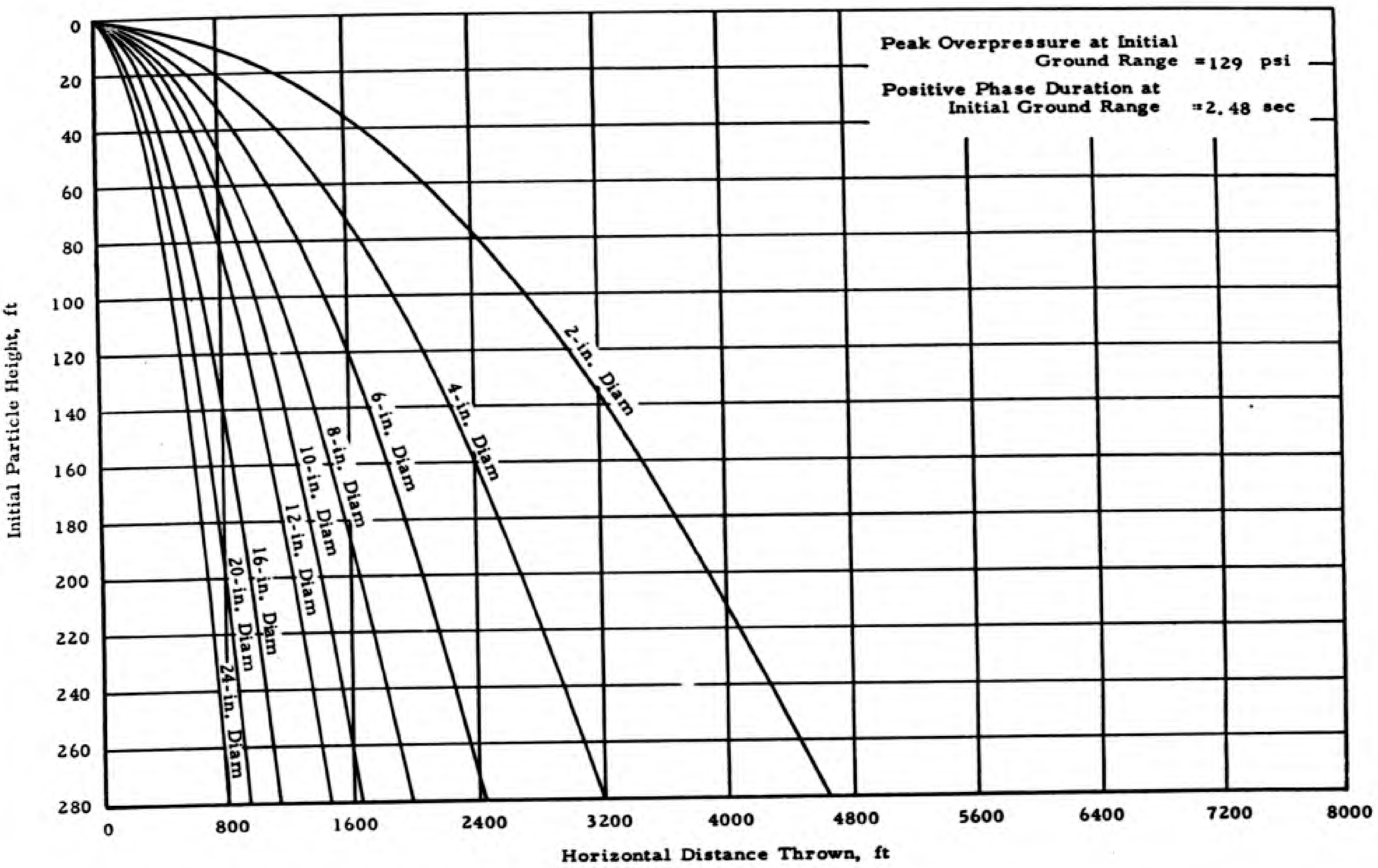

Fig. D-4.2 PARTICLE TRAJECTORIES AT 8,400 FT. FROM 20 MT SURFACE BURST

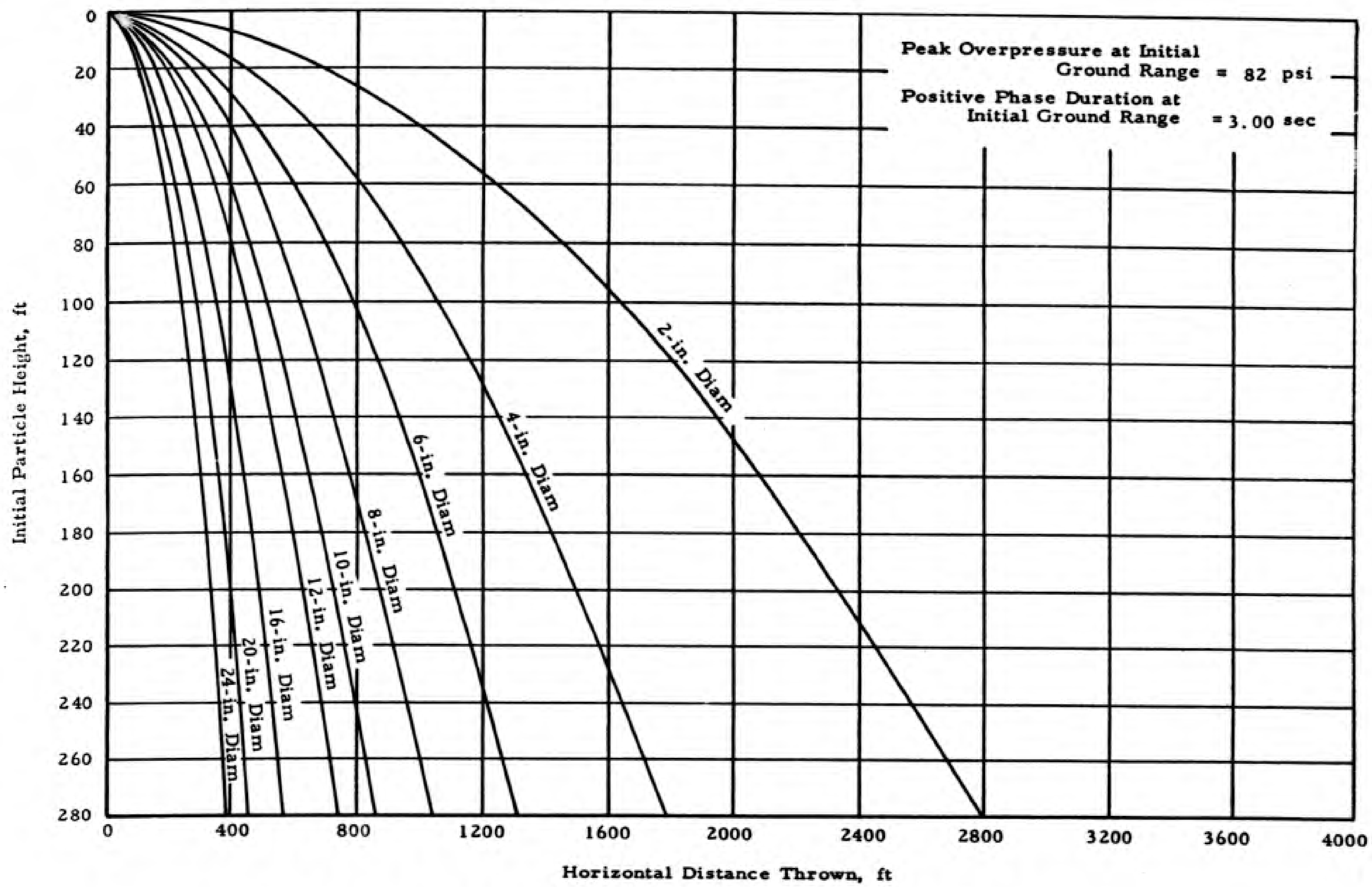

Fig. D-4.3 PARTICLE TRAJECTORIES AT 10,400 FT. FROM 20 MT SURFACE BURST

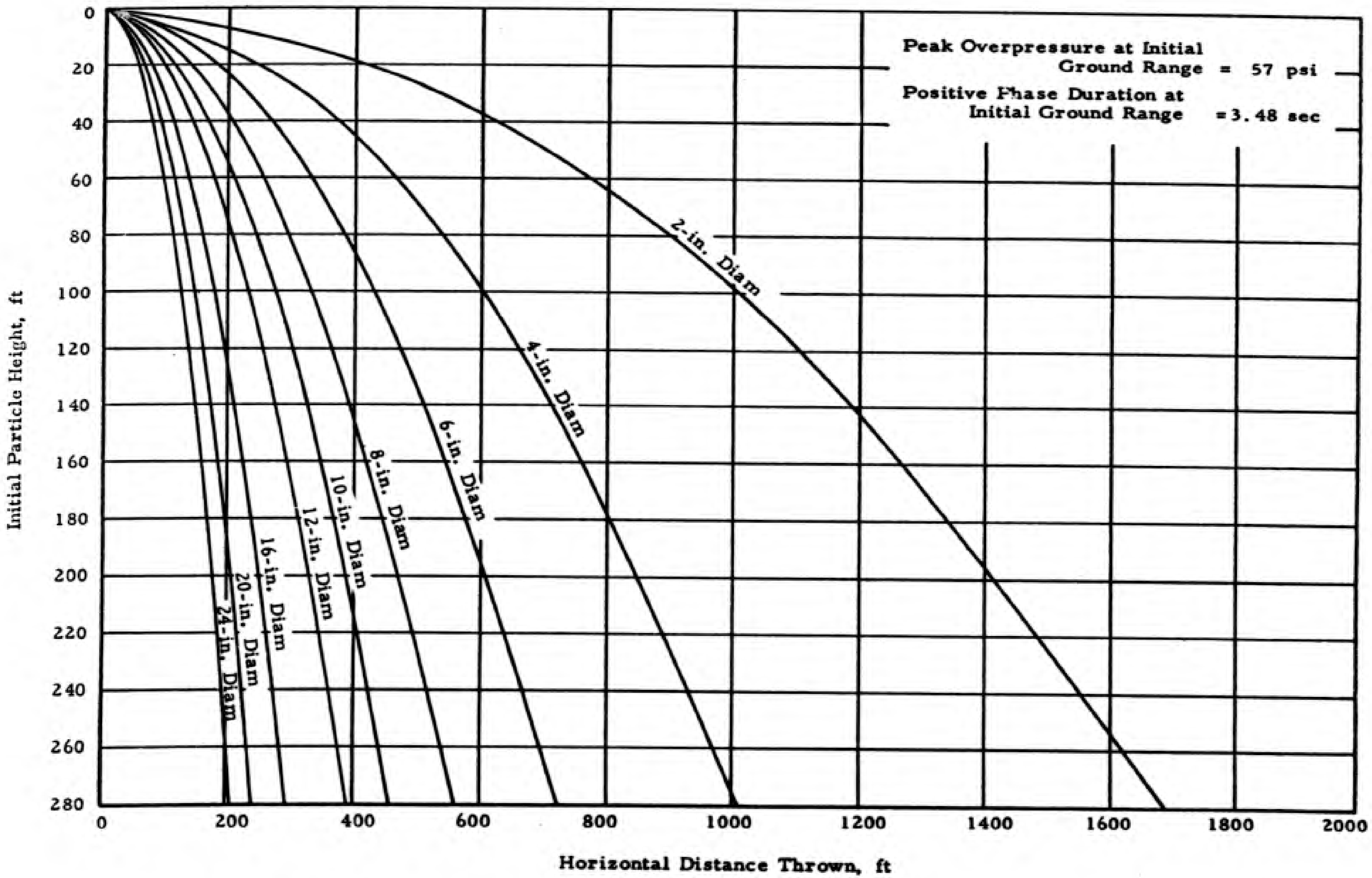

Fig. D-4.4 PARTICLE TRAJECTORIES AT 12,400 FT. FROM 20 MT SURFACE BURST

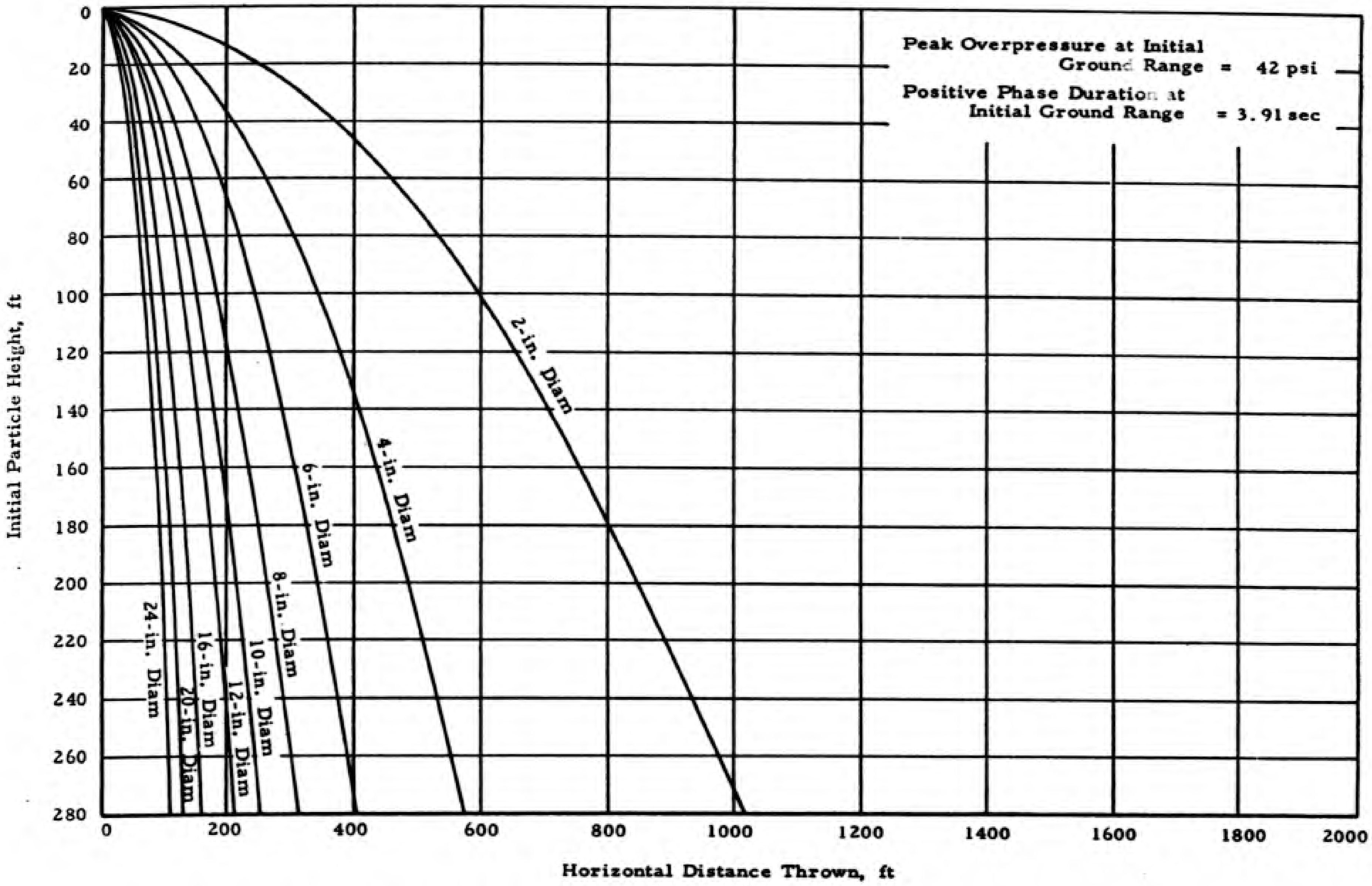

Fig. D-4.5 PARTICLE TRAJECTORIES AT 14,400 FT. FROM 20 MT SURFACE BURST

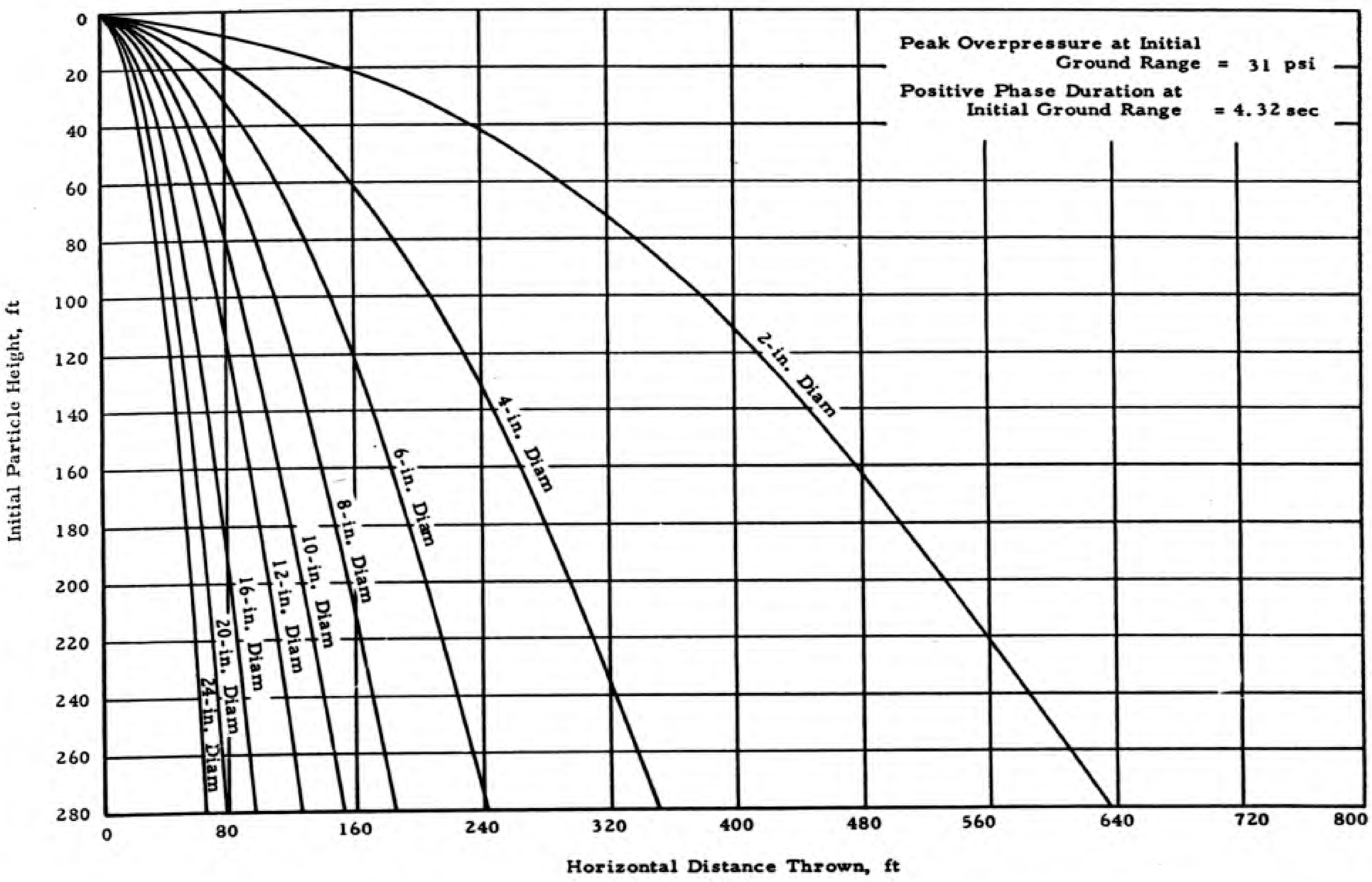

Fig. D-4.6 PARTICLE TRAJECTORIES AT 16,400 FT. FROM 20 MT SURFACE BURST

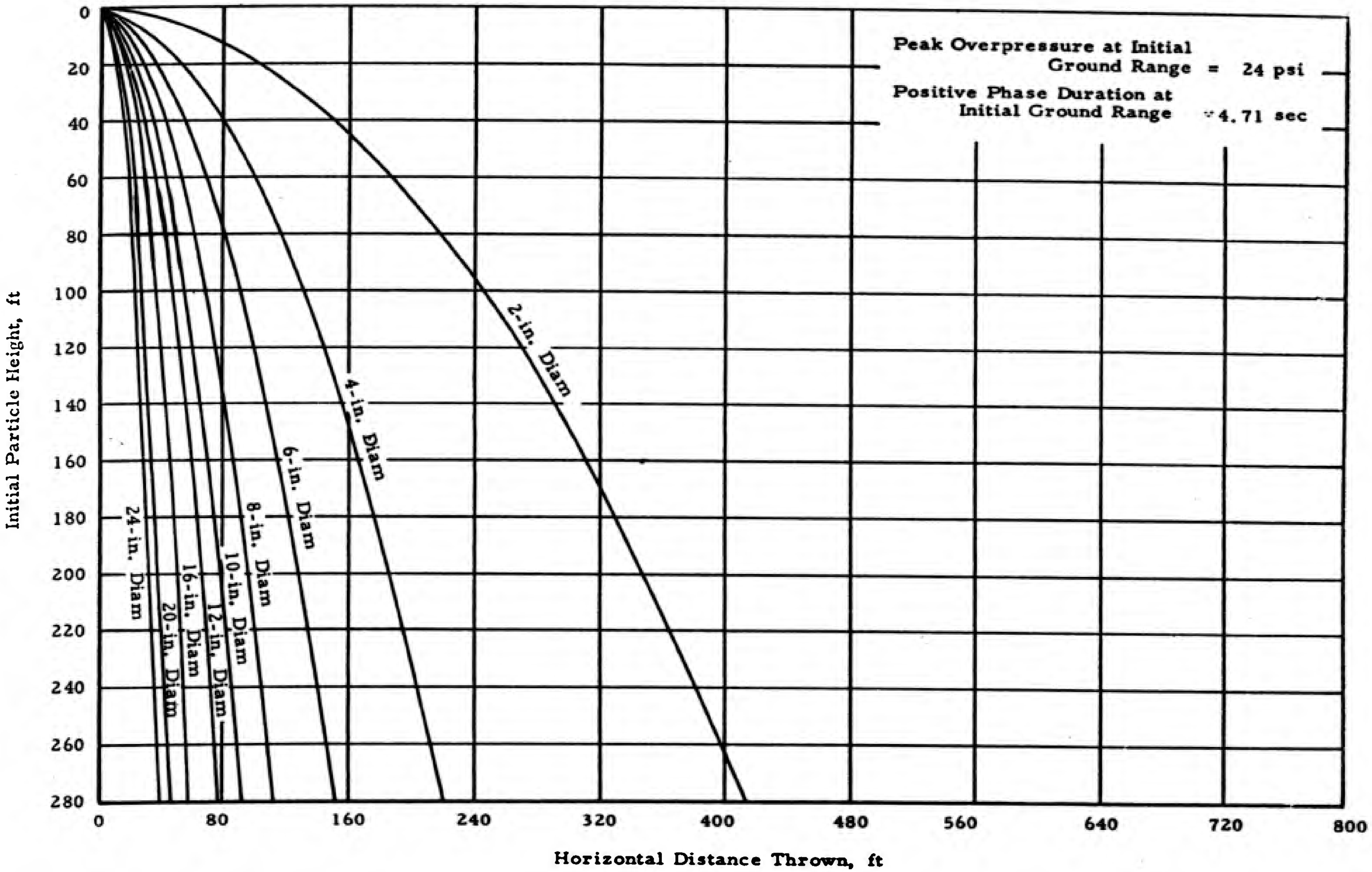

Fig. D-4.7 PARTICLE TRAJECTORIES AT 18,400 FT. FROM 20 MT SURFACE BURST

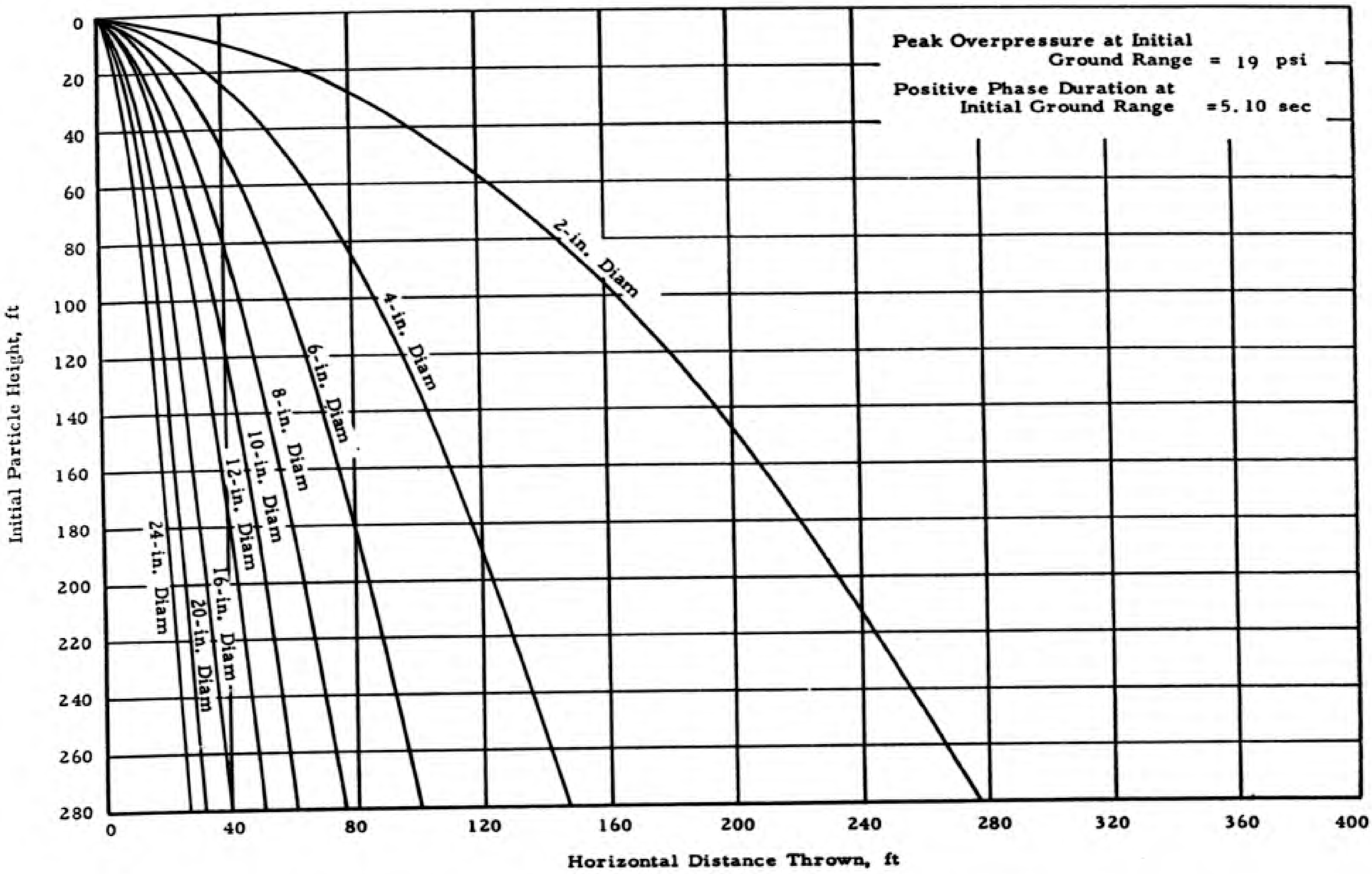

Fig. D-4.8 PARTICLE TRAJECTORIES AT 20,400 FT. FROM 20 MT SURFACE BURST

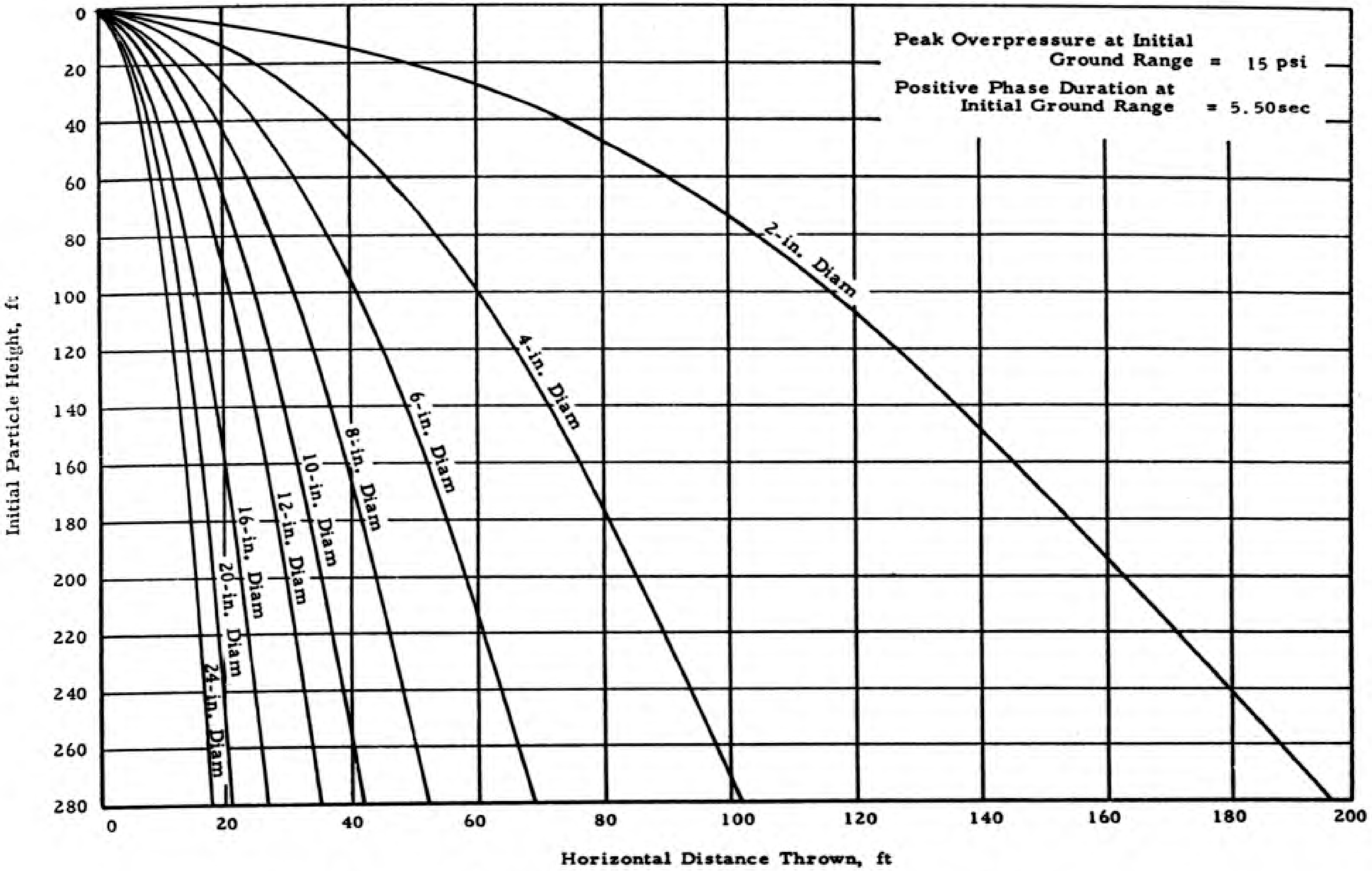

Fig. D-4.9 PARTICLE TRAJECTORIES AT 22,400 FT. FROM 20 MT SURFACE BURST

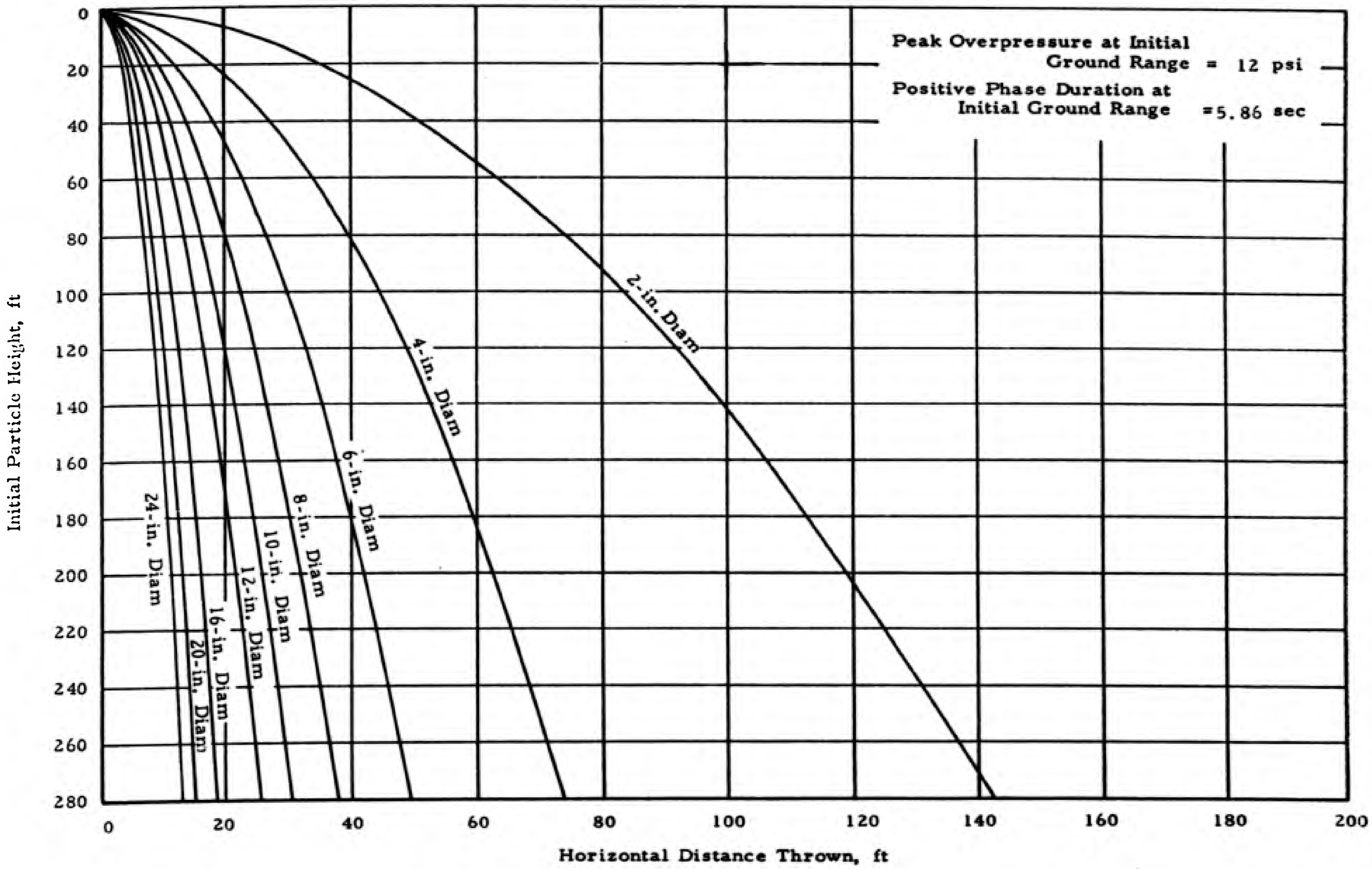

Fig. D-4.10 PARTICLE TRAJECTORIES AT 24,400 FT. FROM 20 MT SURFACE BURST

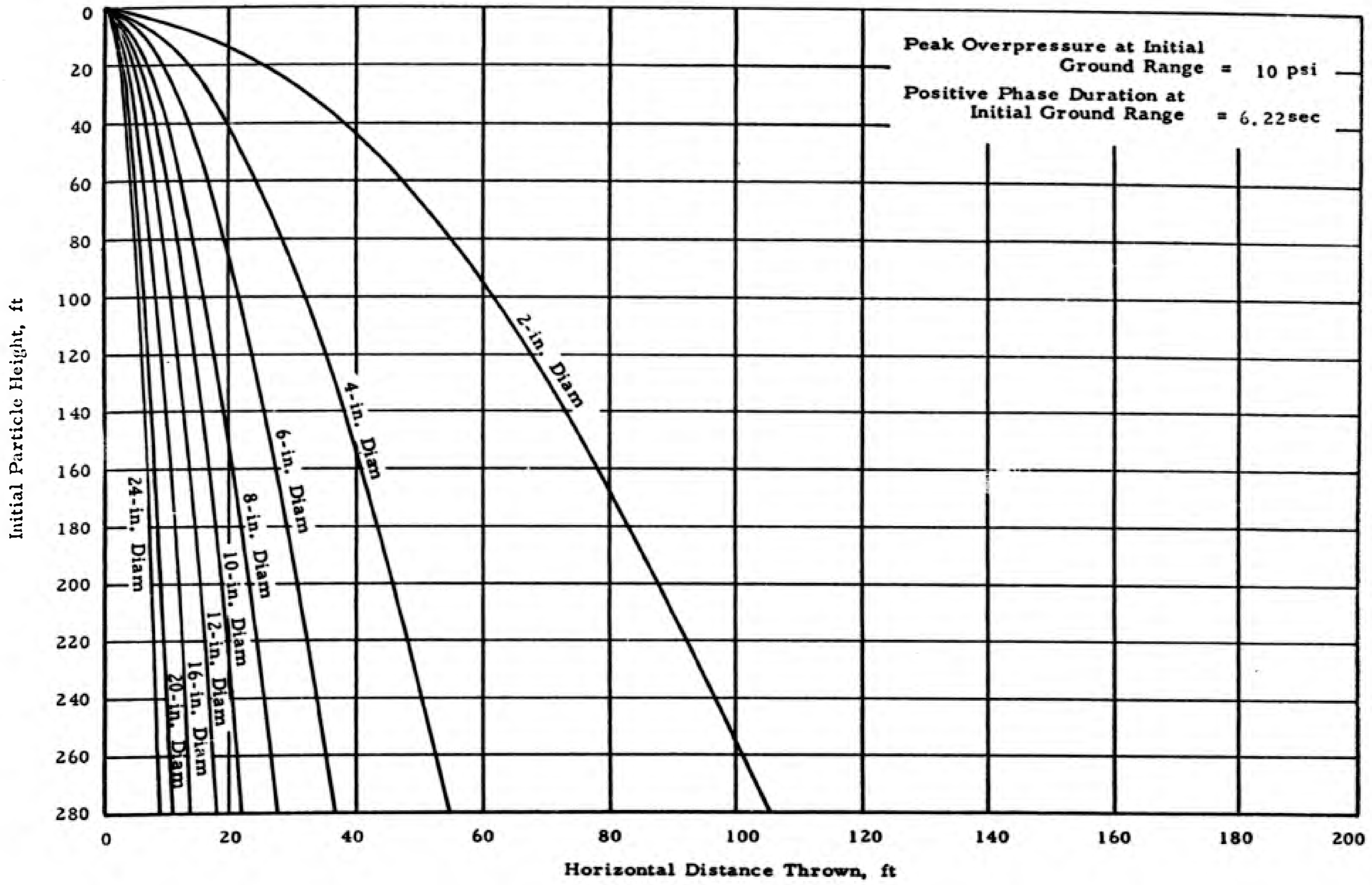

Fig. D-4.11 PARTICLE TRAJECTORIES AT 26,400 FT. FROM 20 MT SURFACE BURST

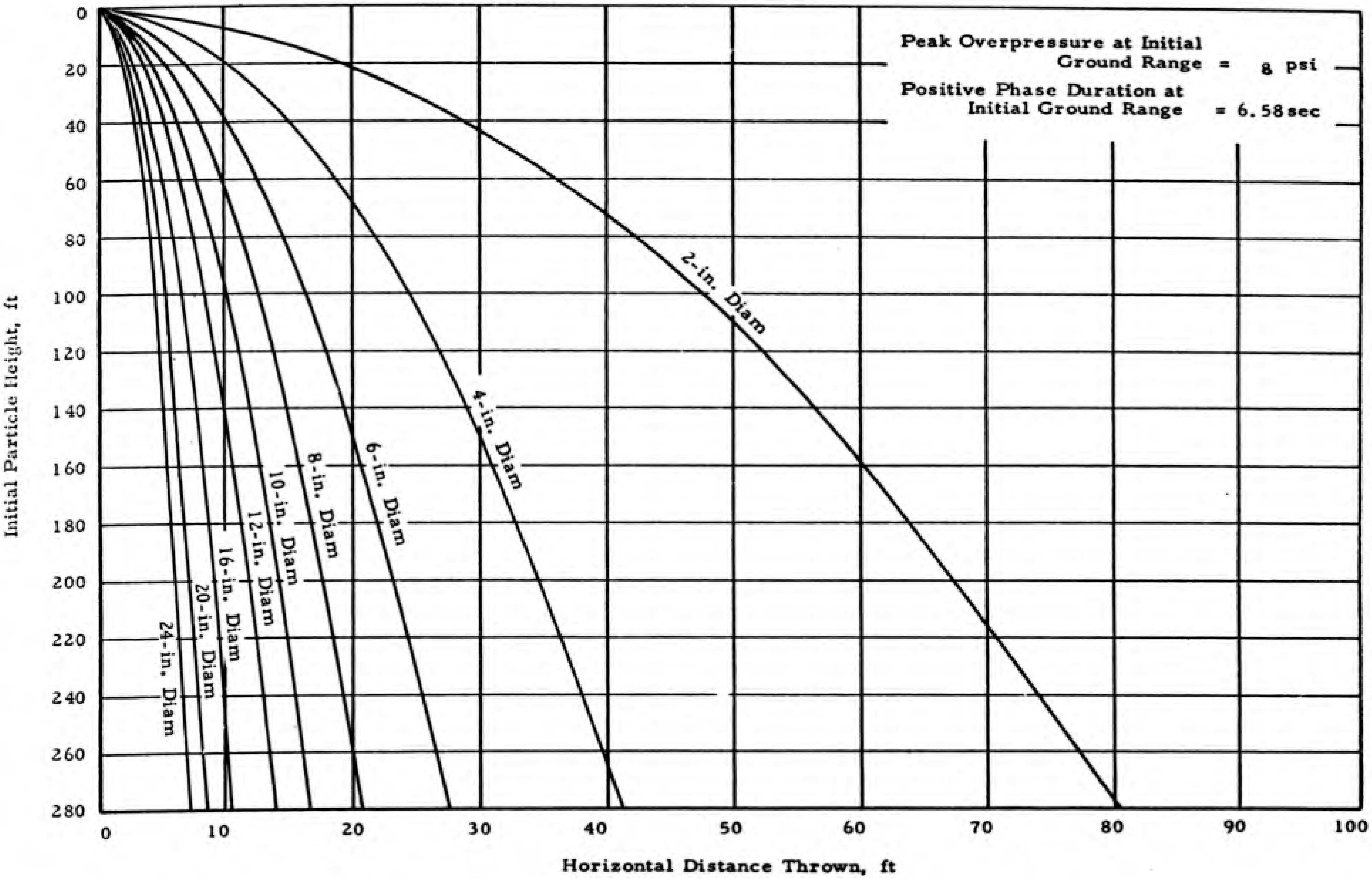

Fig. D-4.12 PARTICLE TRAJECTORIES AT 28,400 FT. FROM 20 MT SURFACE BURST

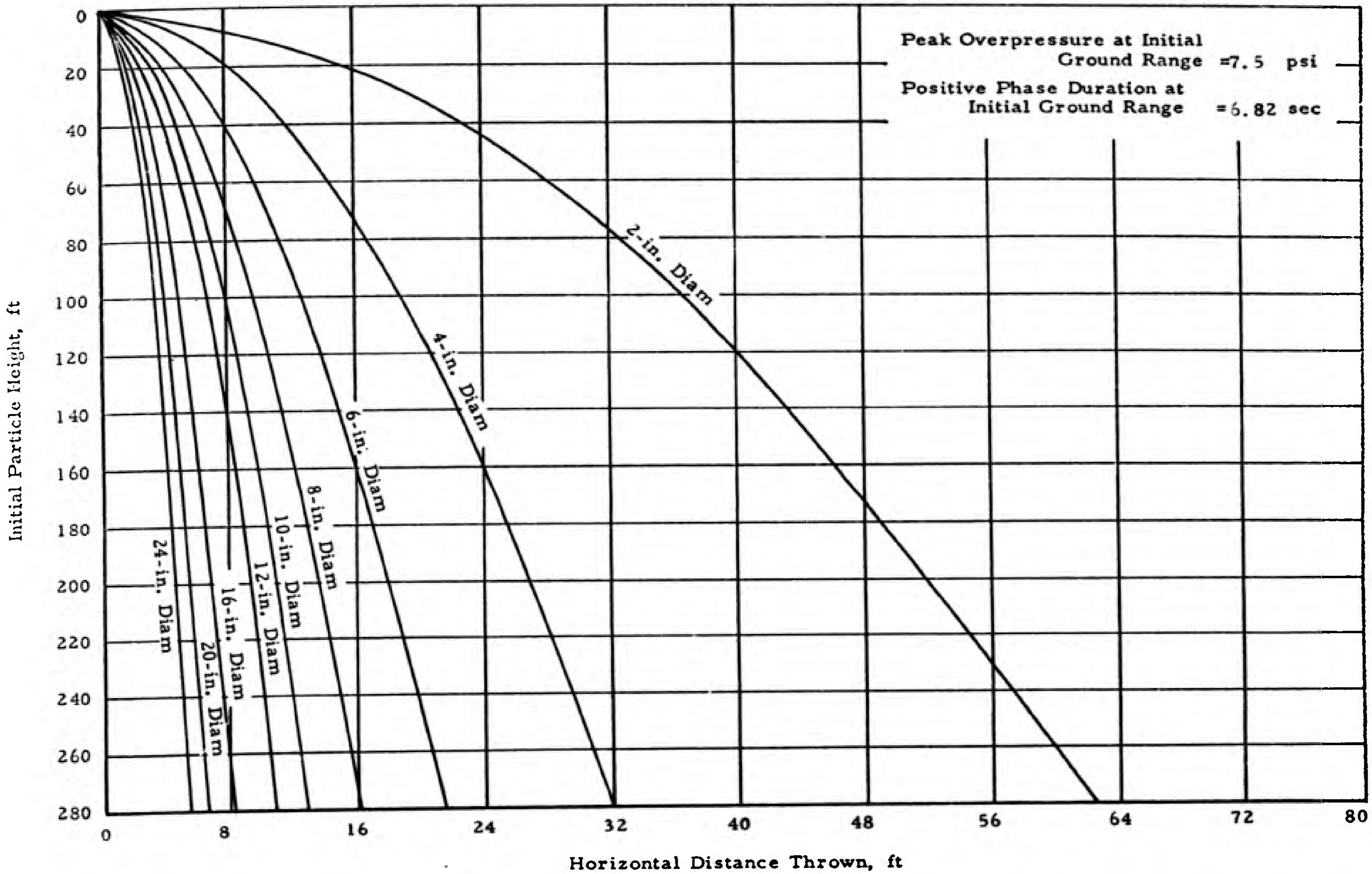

Fig. D-4.13 PARTICLE TRAJECTORIES AT 30,400 FT. FROM 20 MT SURFACE BURST

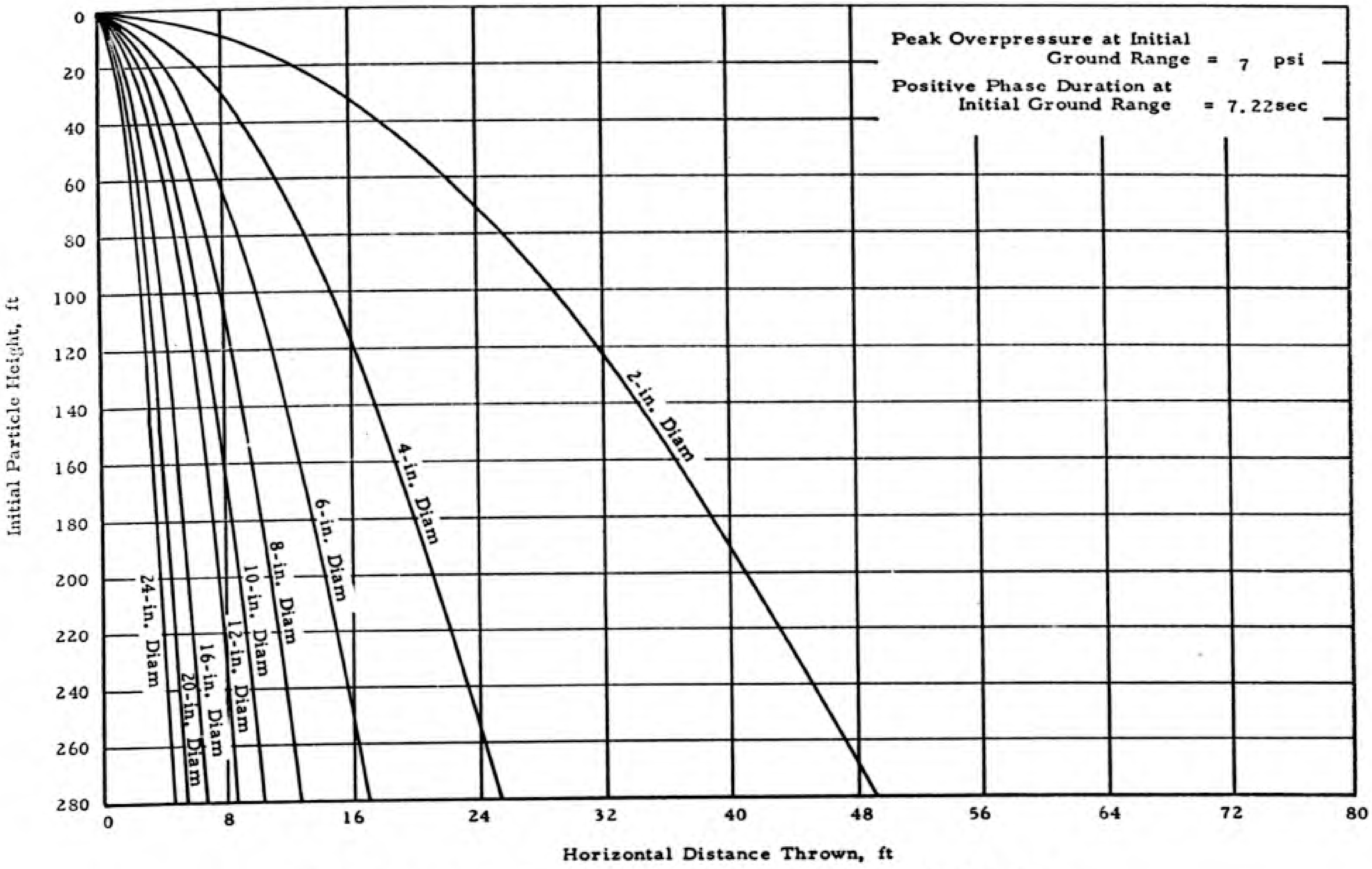

Fig. D-4.14 PARTICLE TRAJECTORIES AT 32,400 FT. FROM 20 MT SURFACE BURST

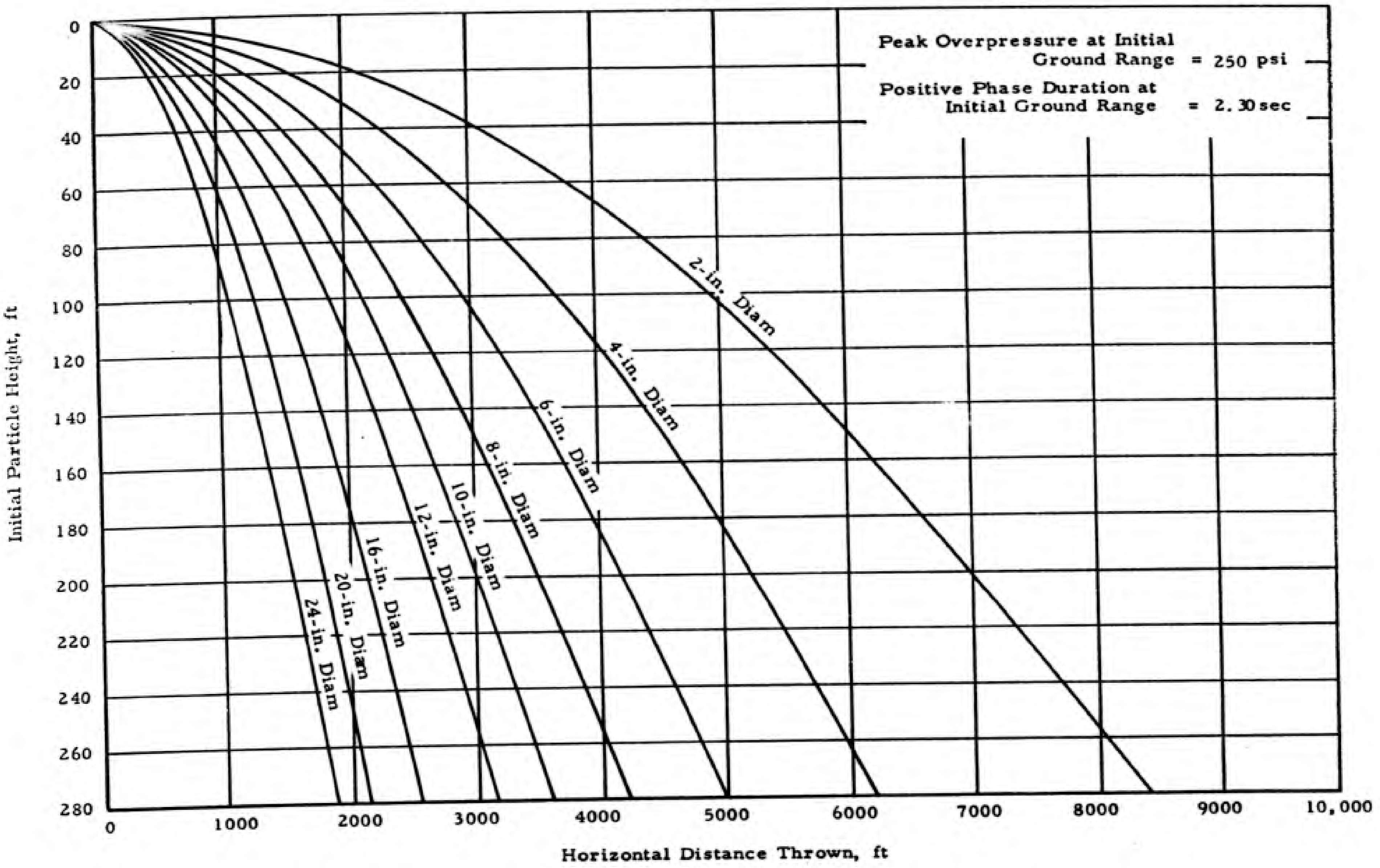

Fig. D-5.1 PARTICLE TRAJECTORIES AT 8,500 FT. FROM 50 MT SURFACE BURST

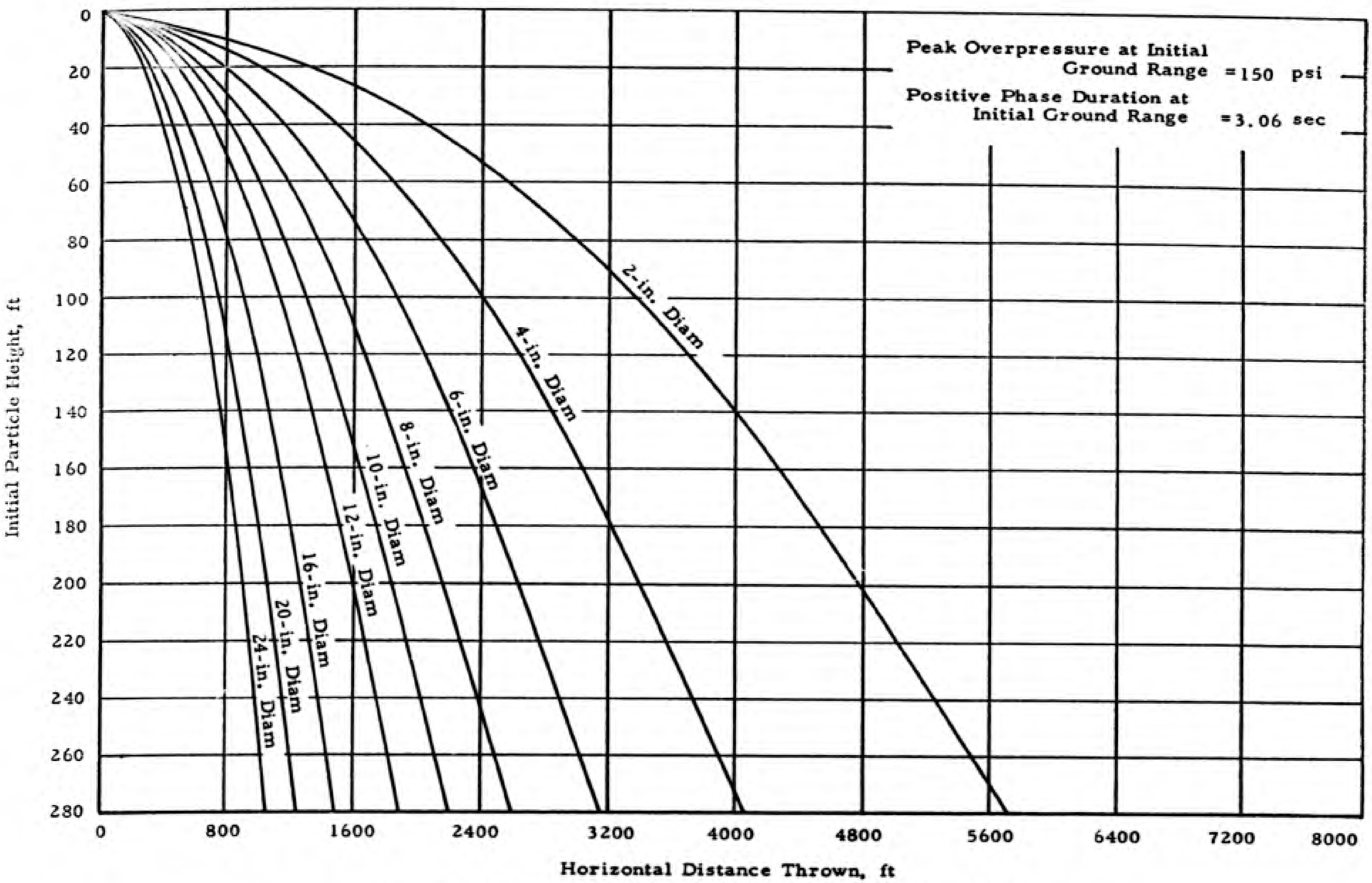

Fig. D-5.2 PARTICLE TRAJECTORIES AT 10,500 FT. FROM 50 MT SURFACE BURST

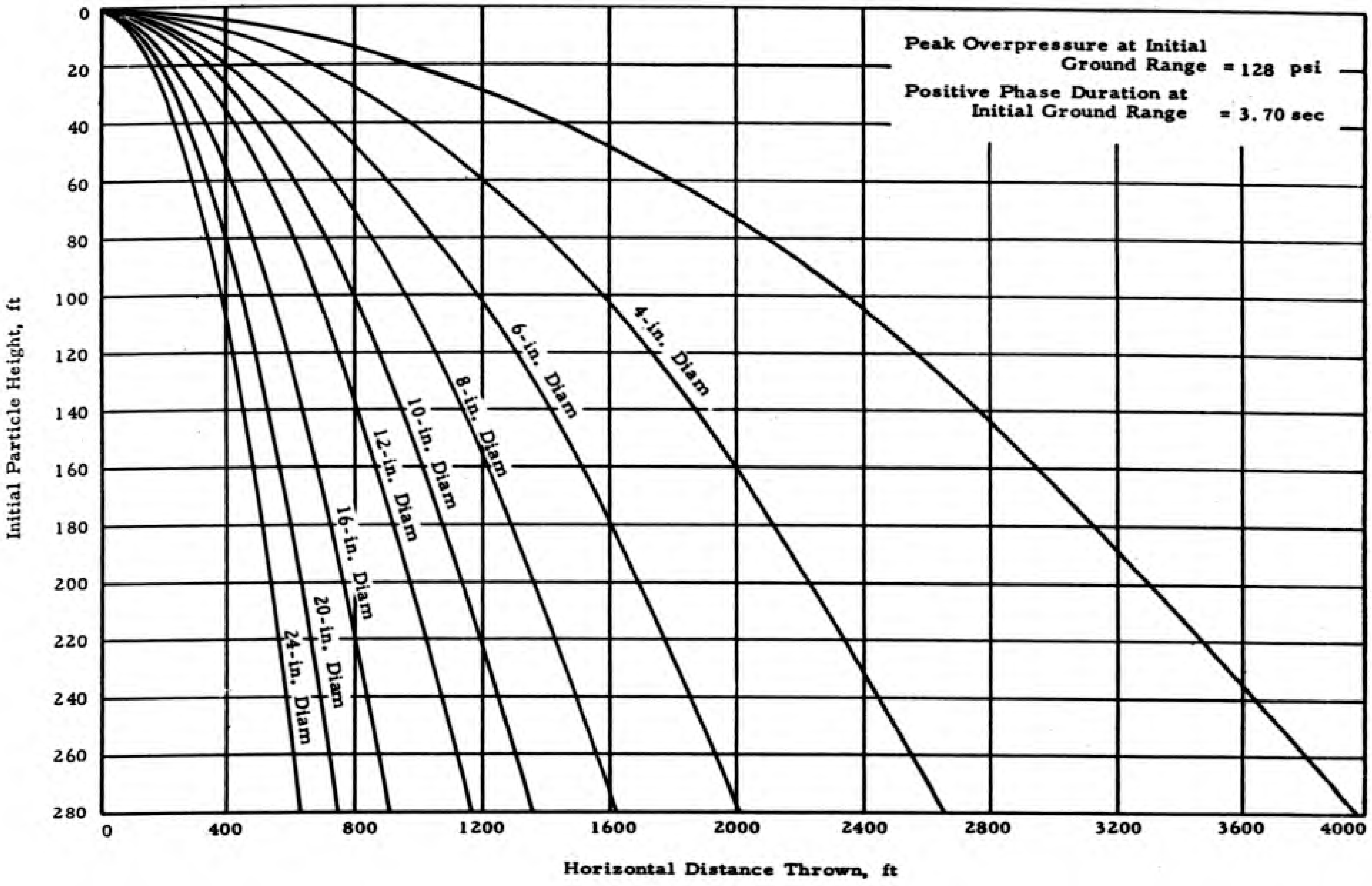

Fig. D-5.3 PARTICLE TRAJECTORIES AT 12,500 FT. FROM 50 MT SURFACE BURST

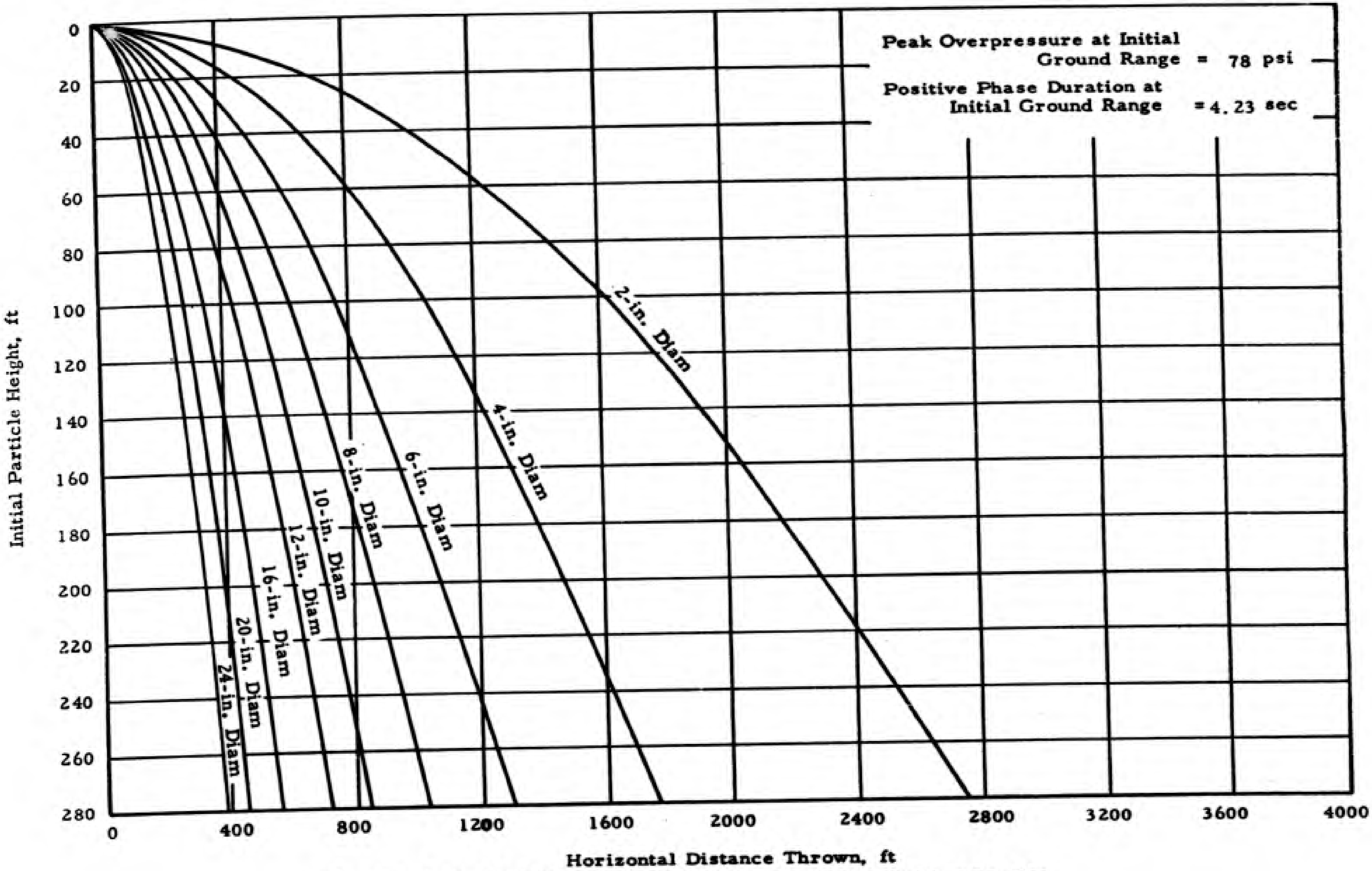

Fig. D-5.4 PARTICLE TRAJECTORIES AT 14,500 FT. FROM 50 MT SURFACE BURST

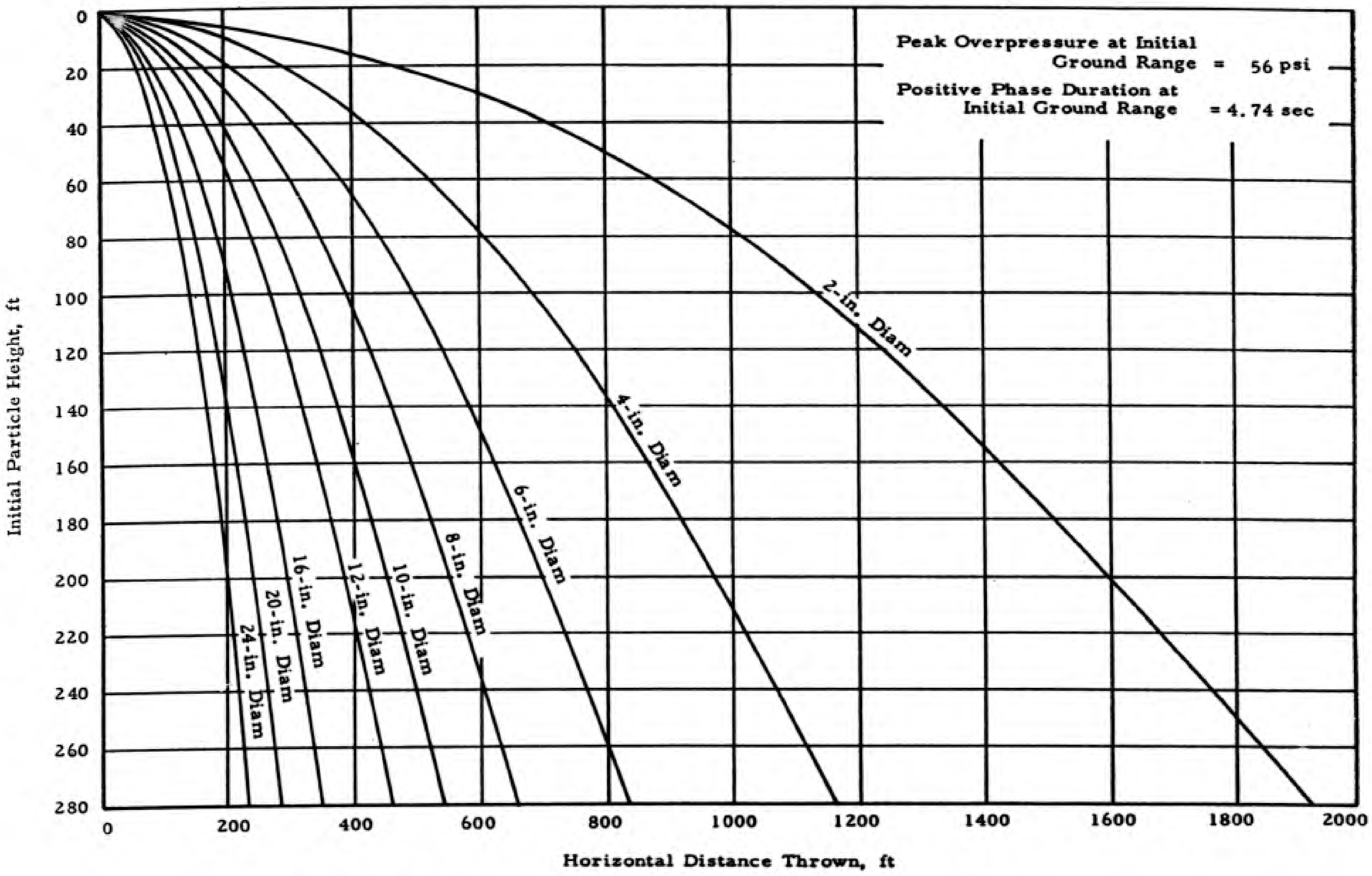

Fig. D-5.5 PARTICLE TRAJECTORIES AT 16,500 FT. FROM 50 MT SURFACE BURST

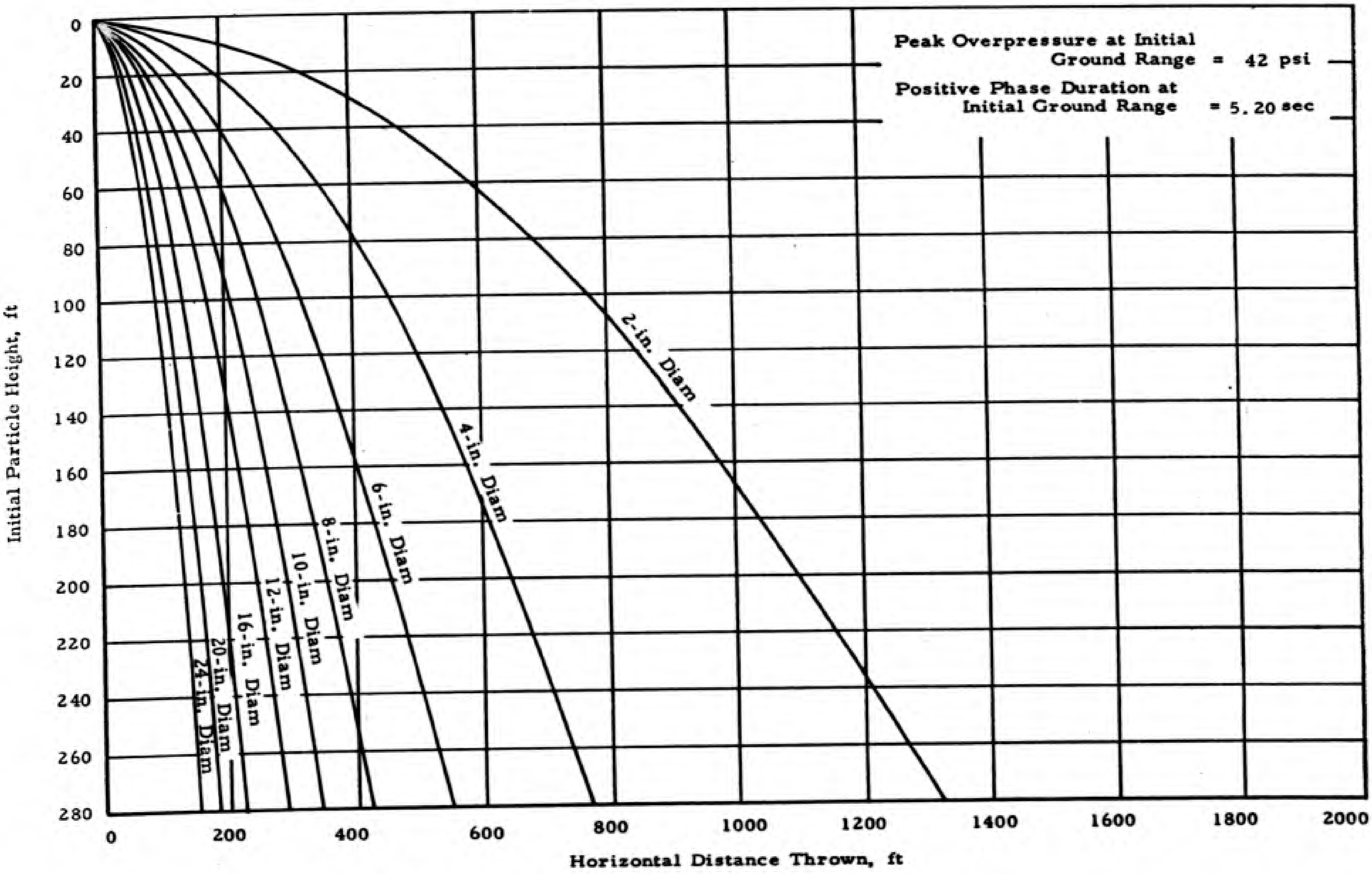

Fig. D-5.6 PARTICLE TRAJECTORIES AT 18,500 FT. FROM 50 MT SURFACE BURST

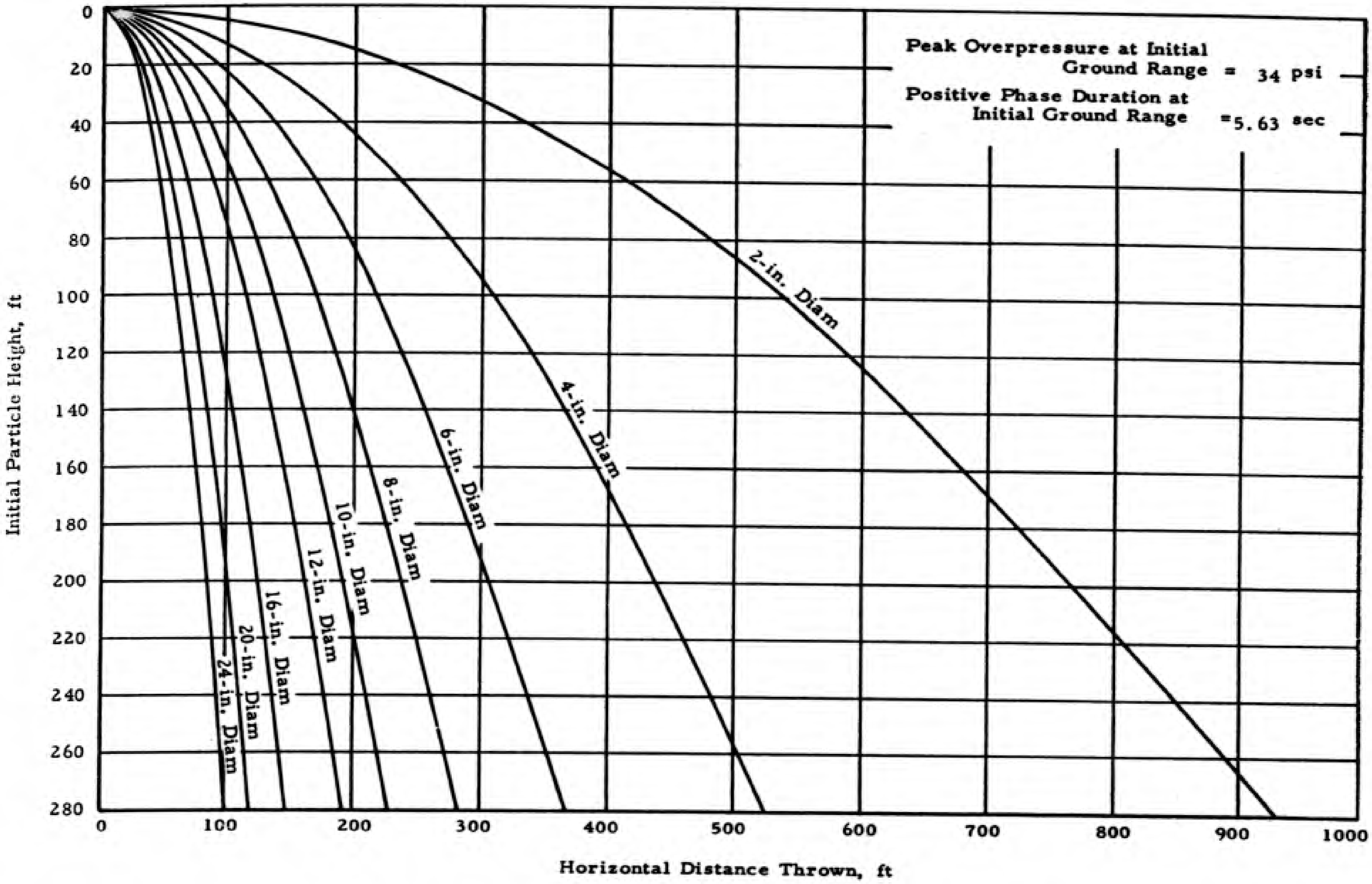

Fig. D-5.7 PARTICLE TRAJECTORIES AT 20,500 FT. FROM 50 MT SURFACE BURST

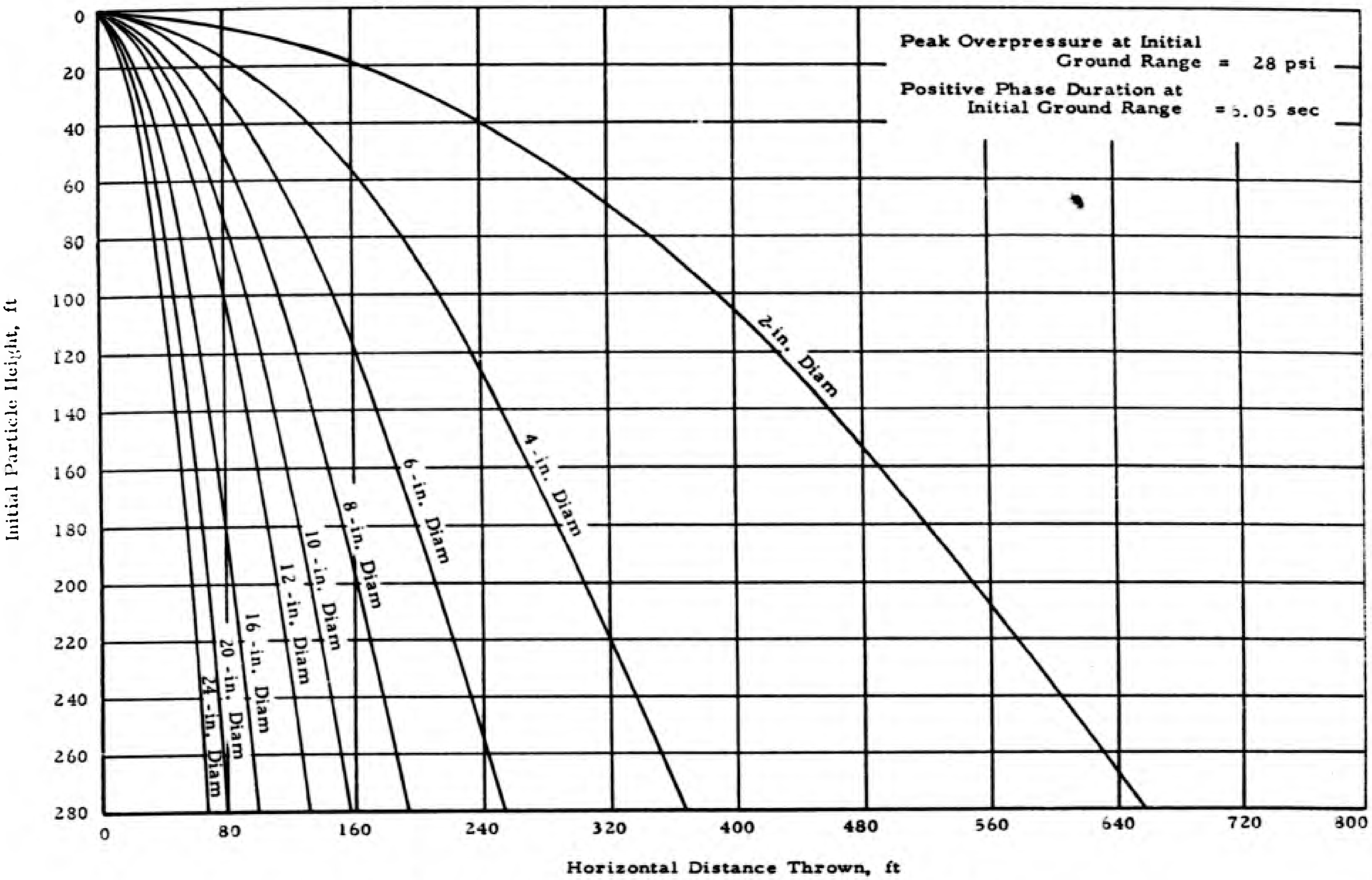

Fig. D-5.8 PARTICLE TRAJECTORIES AT 22,500 FT. FROM 50 MT SURFACE BURST

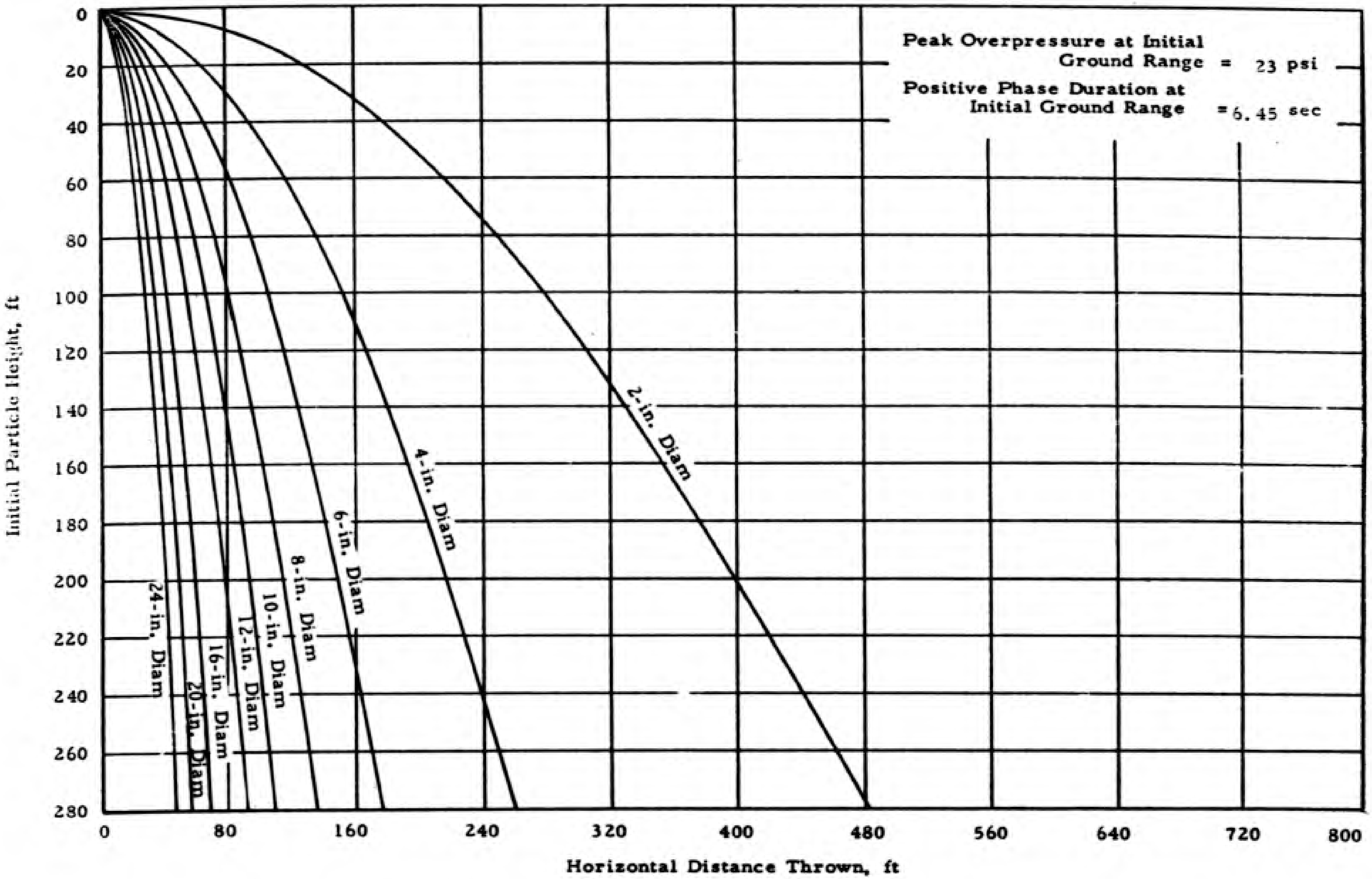

Fig. D-5.9 PARTICLE TRAJECTORIES AT 24,500 FT. FROM 50 MT SURFACE BURST

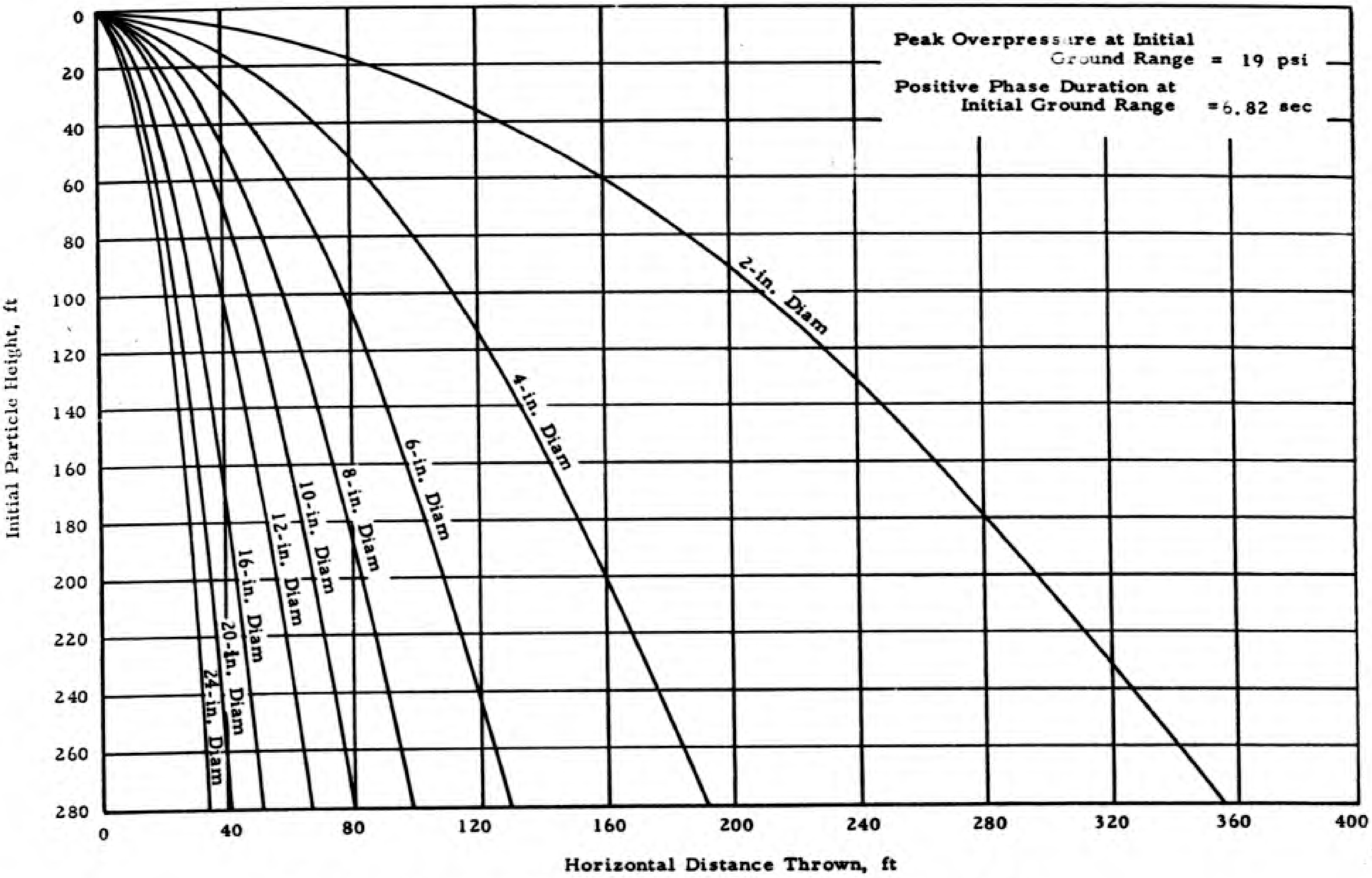

Fig. D-5.10 PARTICLE TRAJECTORIES AT 26,500 FT. FROM 50 MT SURFACE BURST

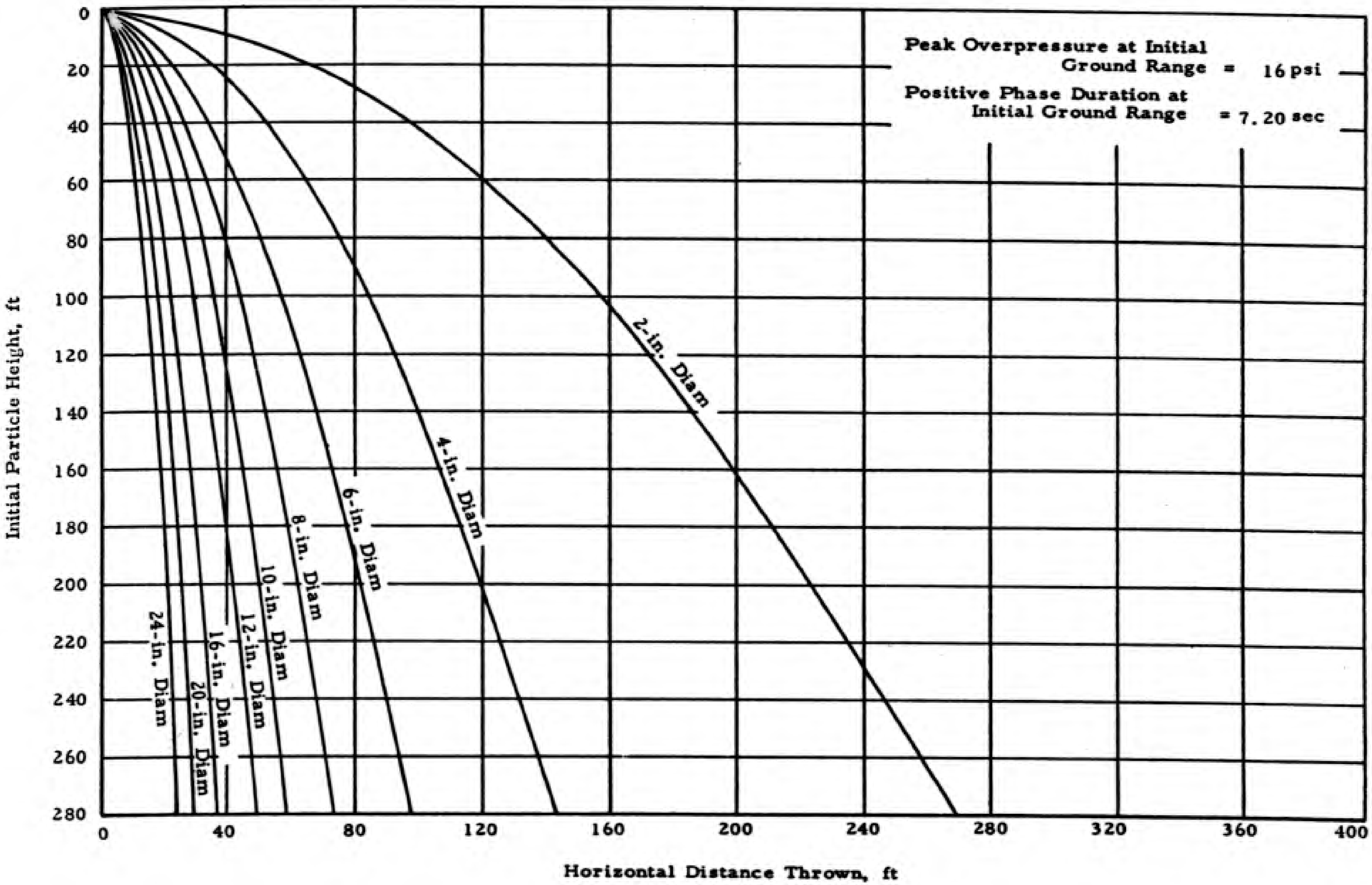

Fig. D-5.11 PARTICLE TRAJECTORIES AT 28,500 FT. FROM 50 MT SURFACE BURST

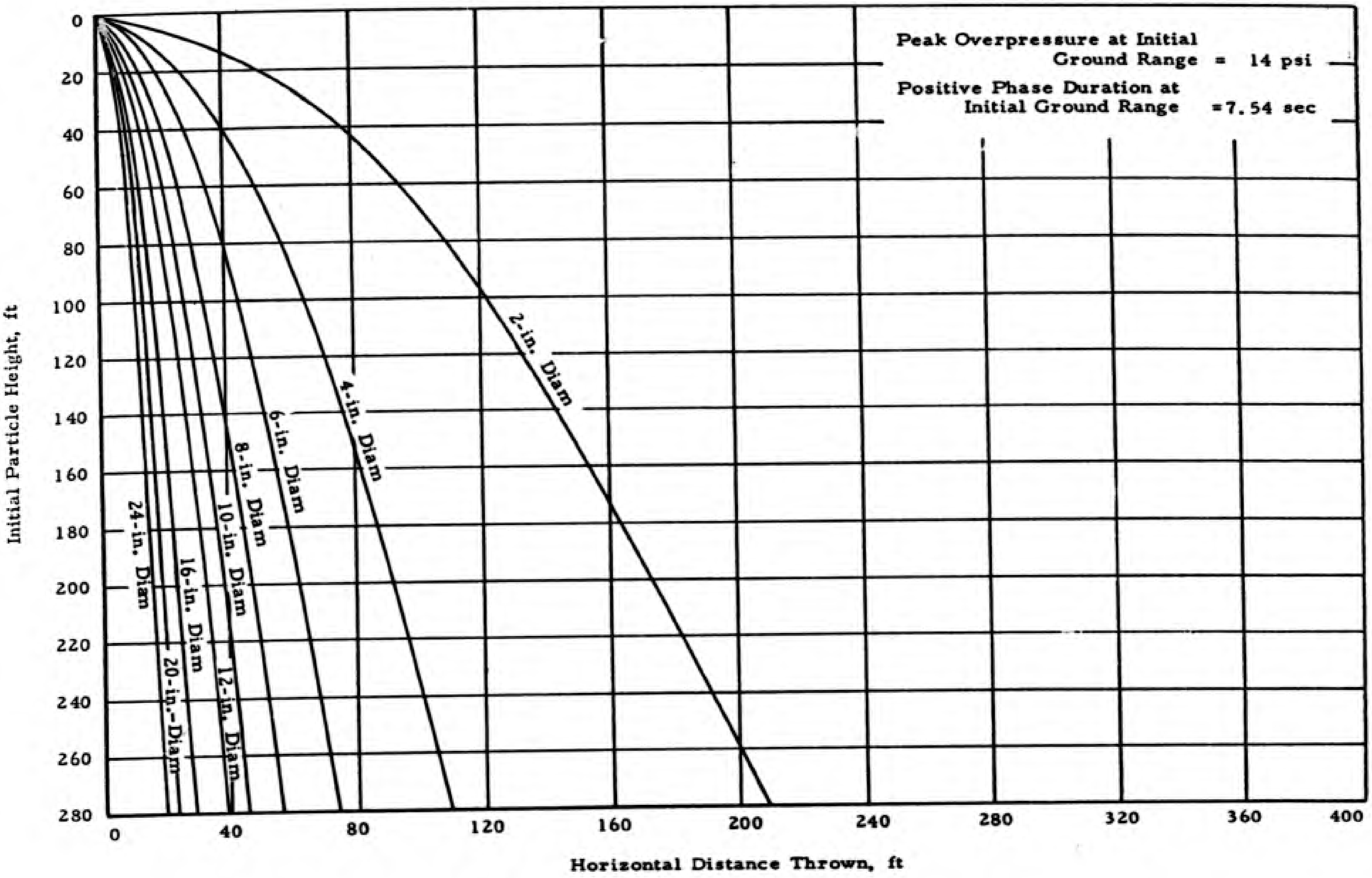

Fig. D-5.12 PARTICLE TRAJECTORIES AT 30,000 FT. FROM 50 MT SURFACE BURST

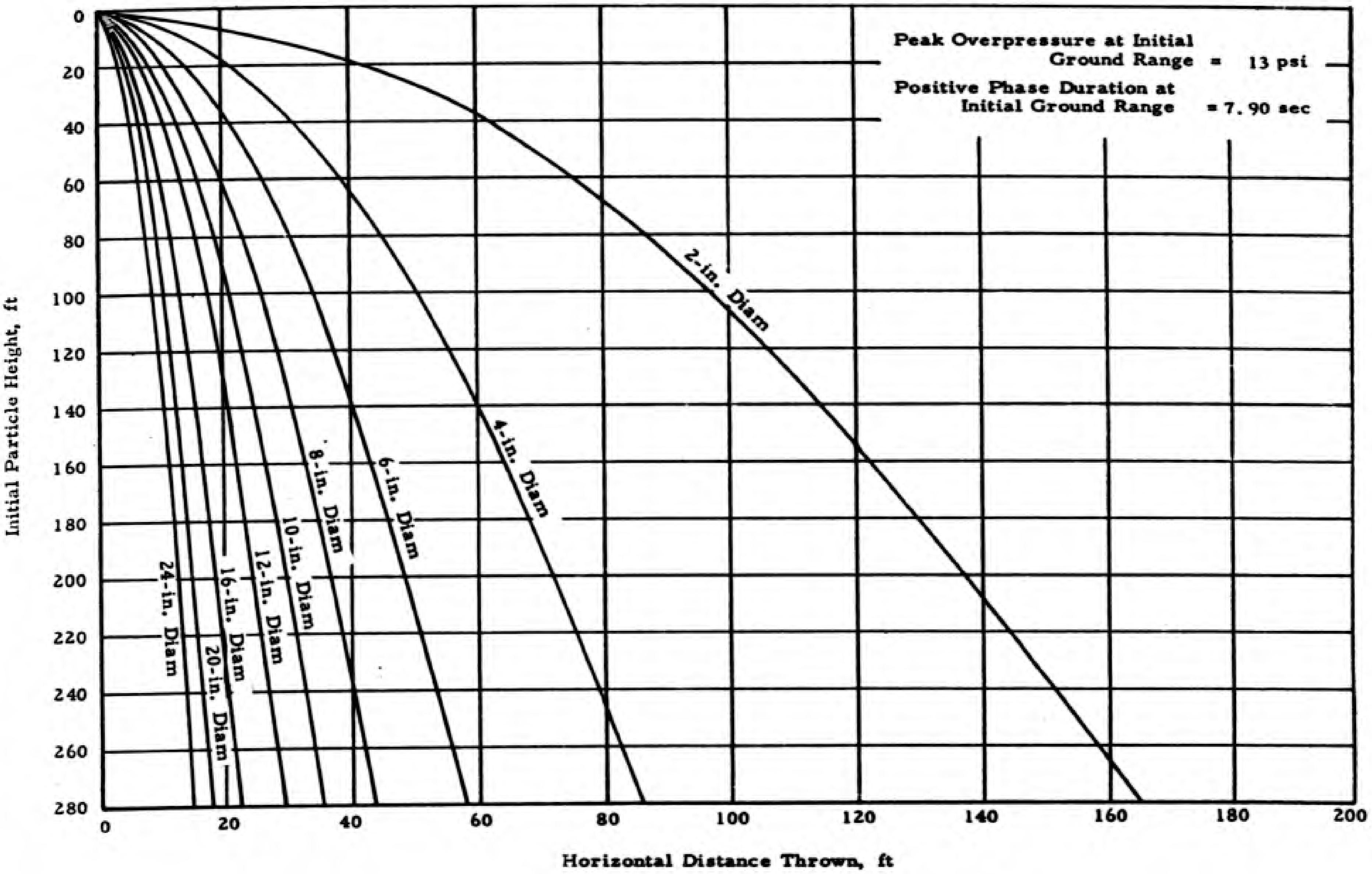

Fig. D-5.13 PARTICLE TRAJECTORIES AT 34,500 FT.
FROM 50 MT SURFACE BURST

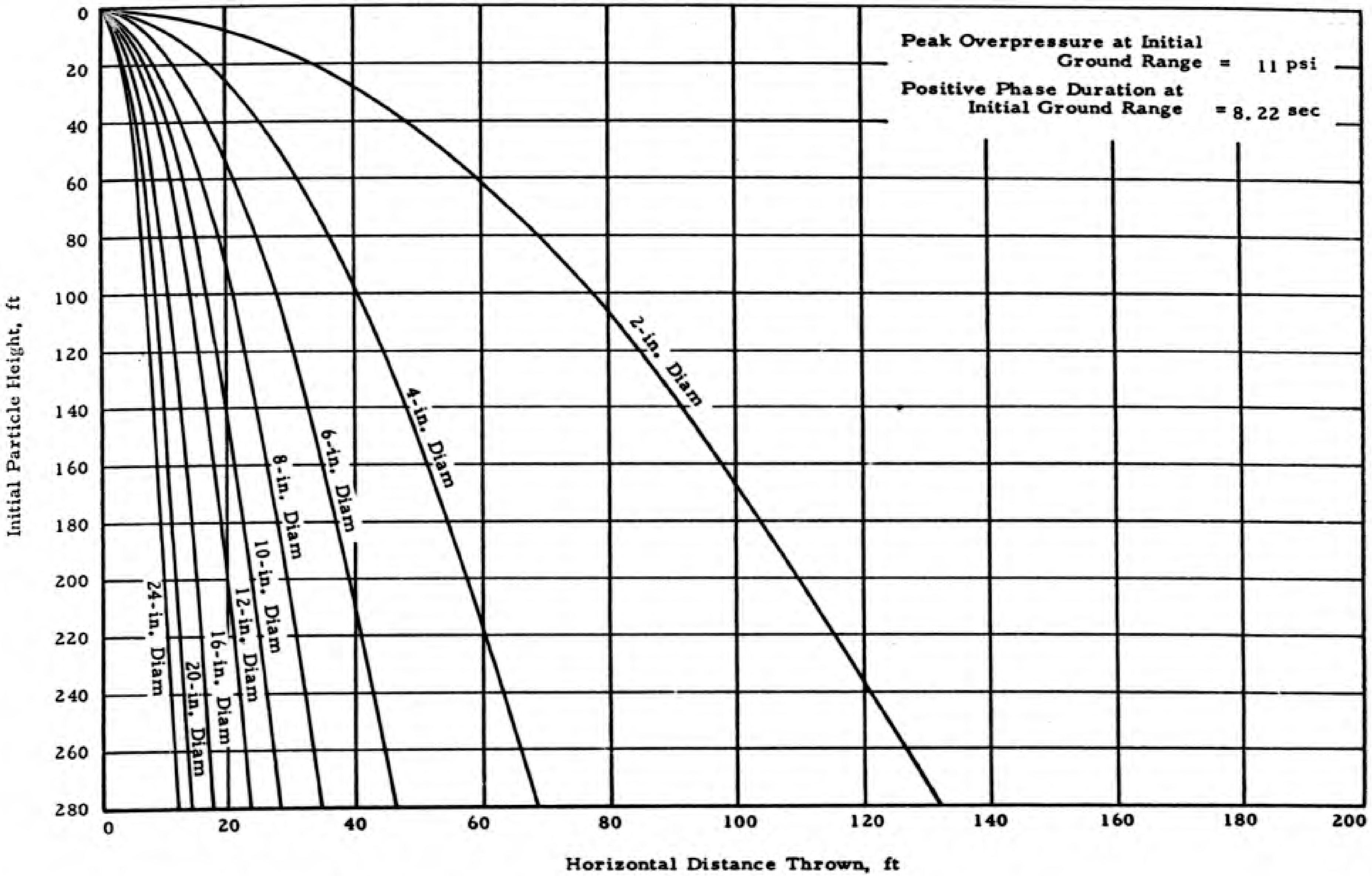

Fig. D-5.14 PARTICLE TRAJECTORIES AT 34,500 FT. FROM 50 MT SURFACE BURST

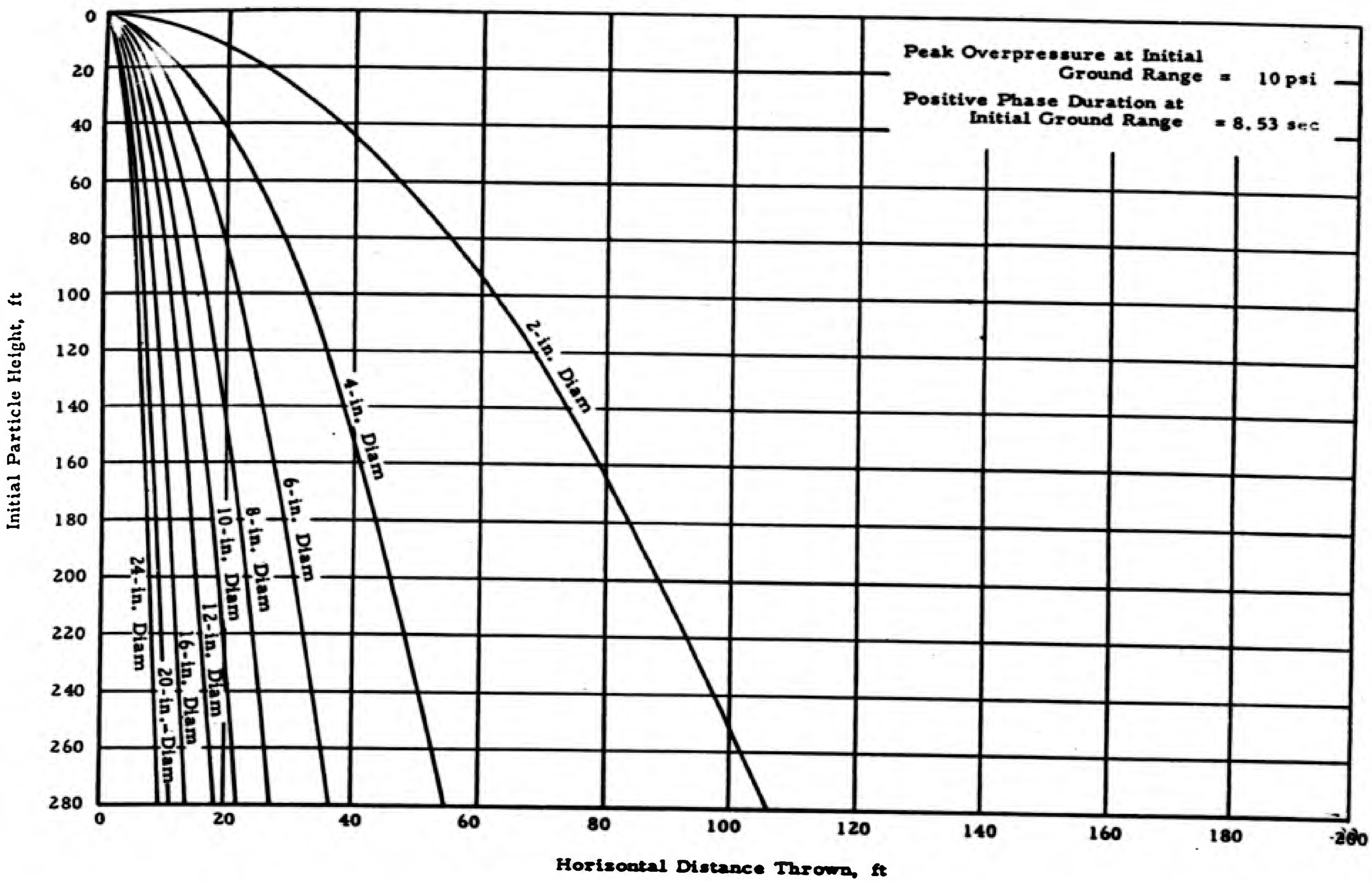

Fig. D-5.15 PARTICLE TRAJECTORIES AT 36,500 FT. FROM 50 MT SURFACE BURST

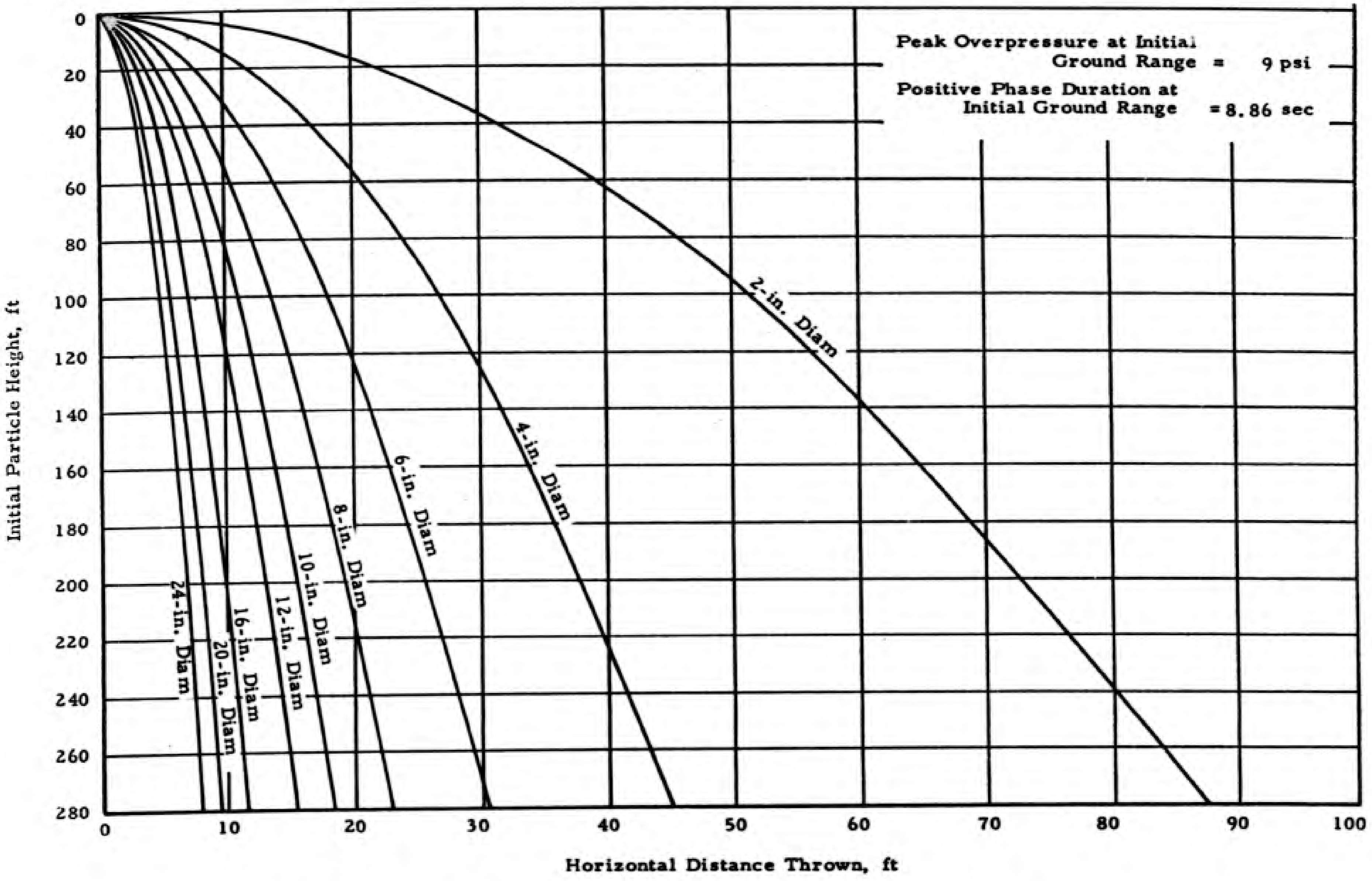

Fig. D-5.16 PARTICLE TRAJECTORIES AT 38,500 FT. FROM 50 MT SURFACE BURST

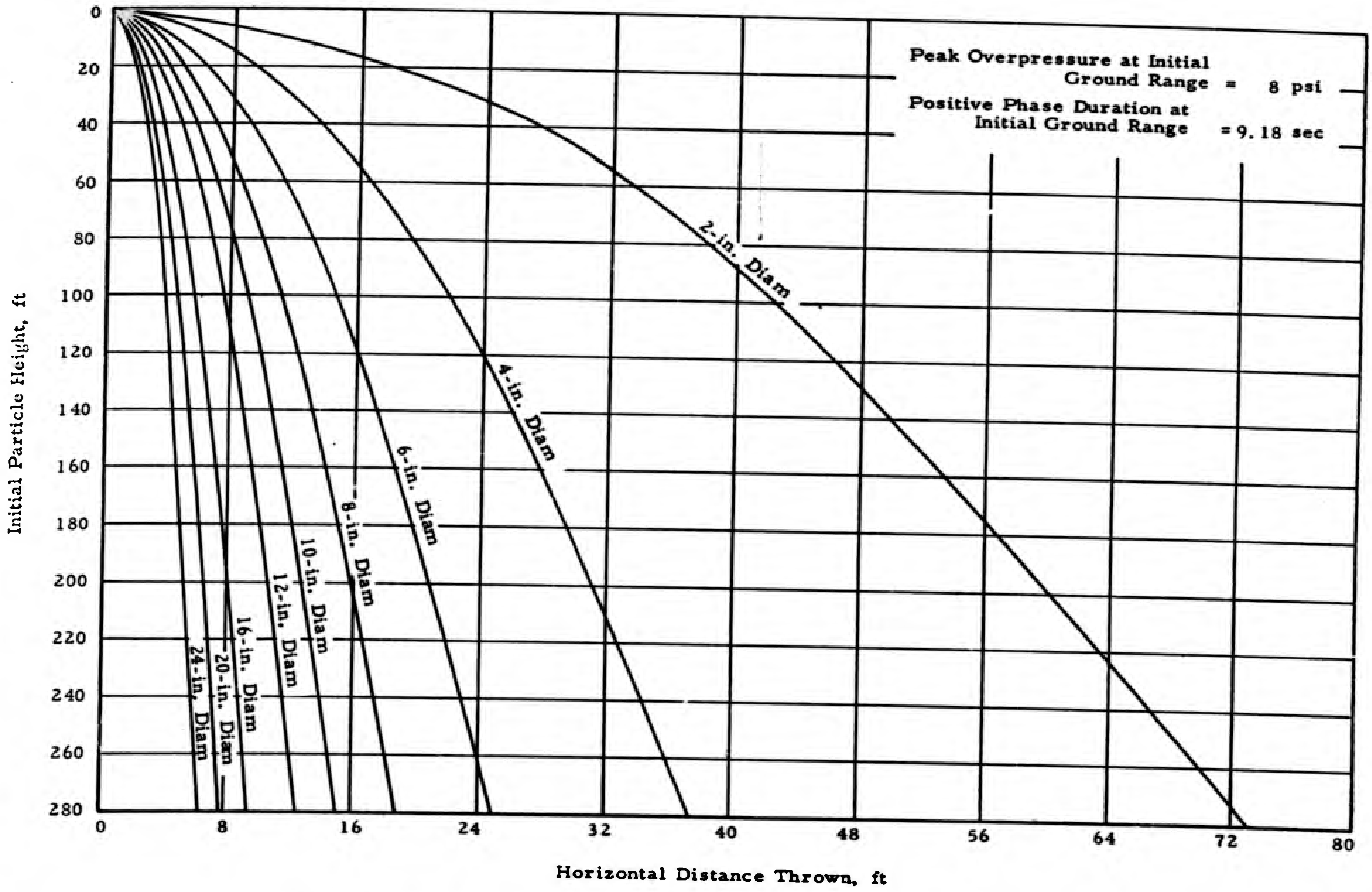

Fig. D-5.17 PARTICLE TRAJECTORIES AT 40,500 FT. FROM 50 MT SURFACE BURST

To perform these calculations on the digital computer, it was advantageous to derive approximate general experssions for pear overpressure and positve phase duration, in terms of ground range, for the five selected weapon yields. The expressions derived for this purpose are plotted, along with valves obtained by using effects of Nuclear Weapons 1962, in the following Figures:

Figure Number	Weapon Yield	Weapon Parameter Plotted
D-6.1	100KT	Peak Overpressure
D-6.2	100KT	Postive Phase Duration
D-6.3	500KT	Peak Overpressure
D-6.4	500KT	Postive Phase Duration
D-6.5	1MT	Peak Overpressure
D-6.6	1MT	Postive Phase Duration
D-6.7	20MT	Peak Overpressure
D-6.8	20MT	Positive Phase Duration
D-6.9	50MT	Peak Overpressure
D-6.10	50 MT	Positive Phase Duration

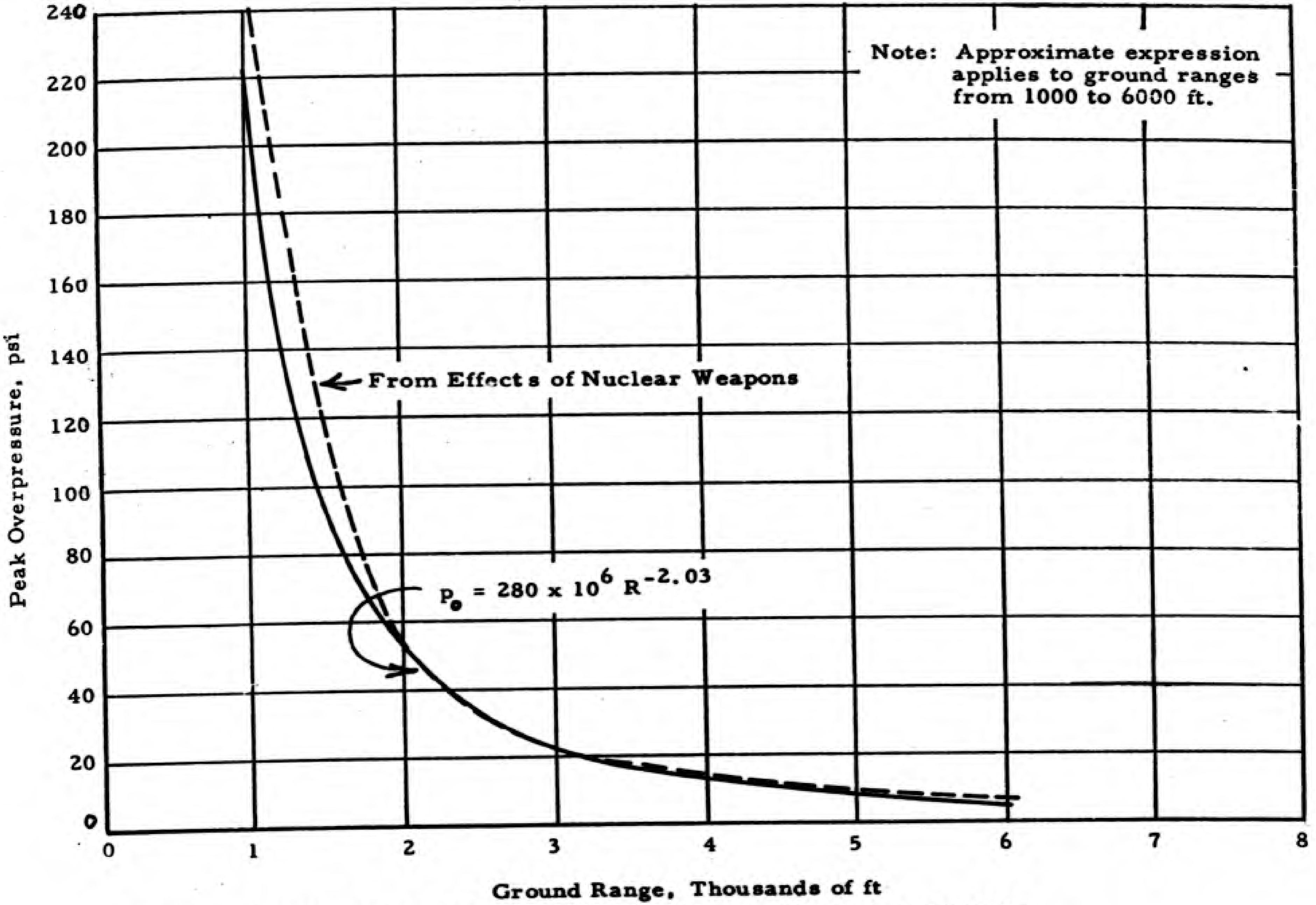

Fig. D-6.1 APPROXIMATE EXPRESSION FOR PEAK OVERPRESSURE FOR 100 KT WEAPON

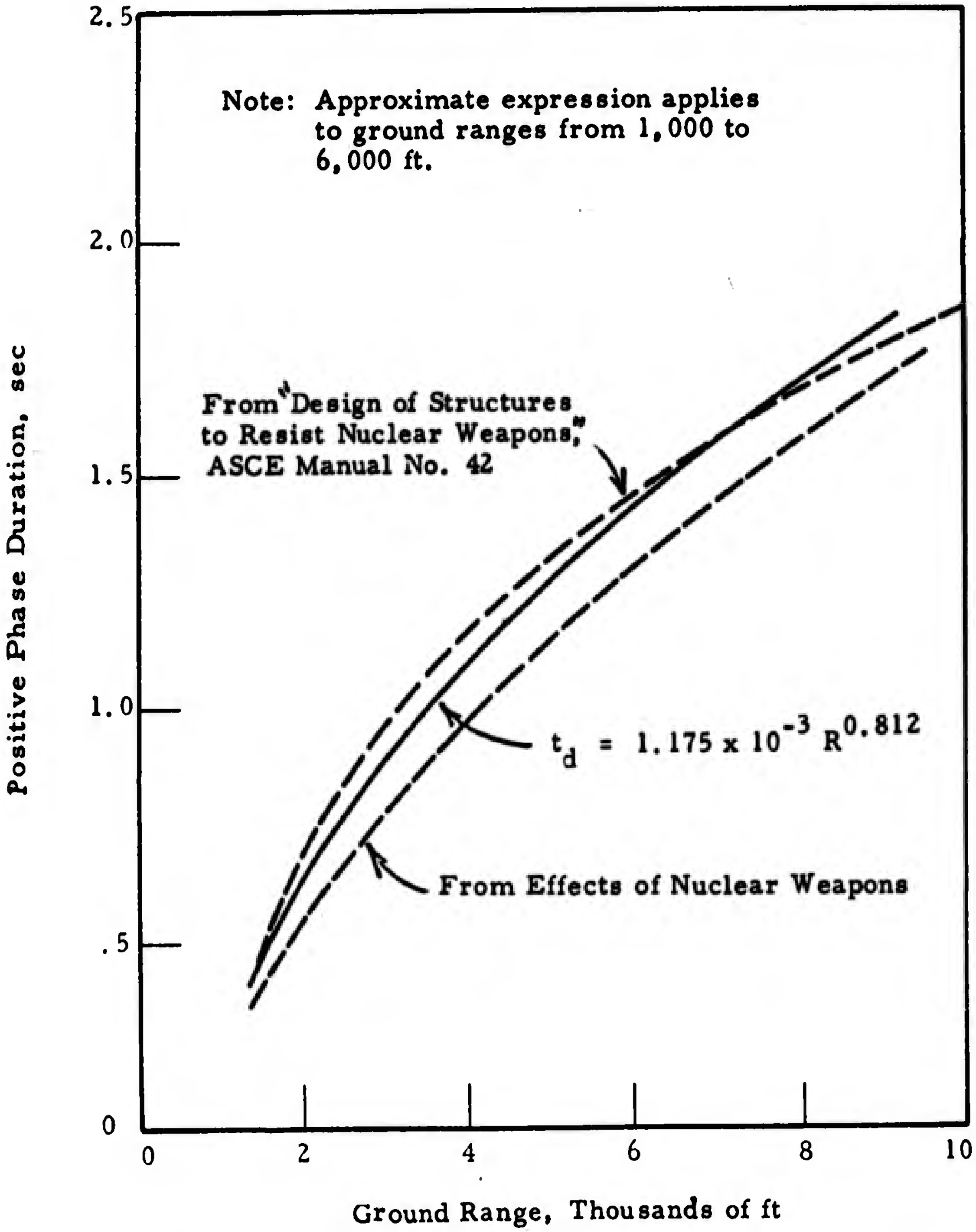

Fig. D-6.2 APPROXIMATE EXPRESSION FOR POSITIVE PHASE DURATION FOR 100 KT WEAPON

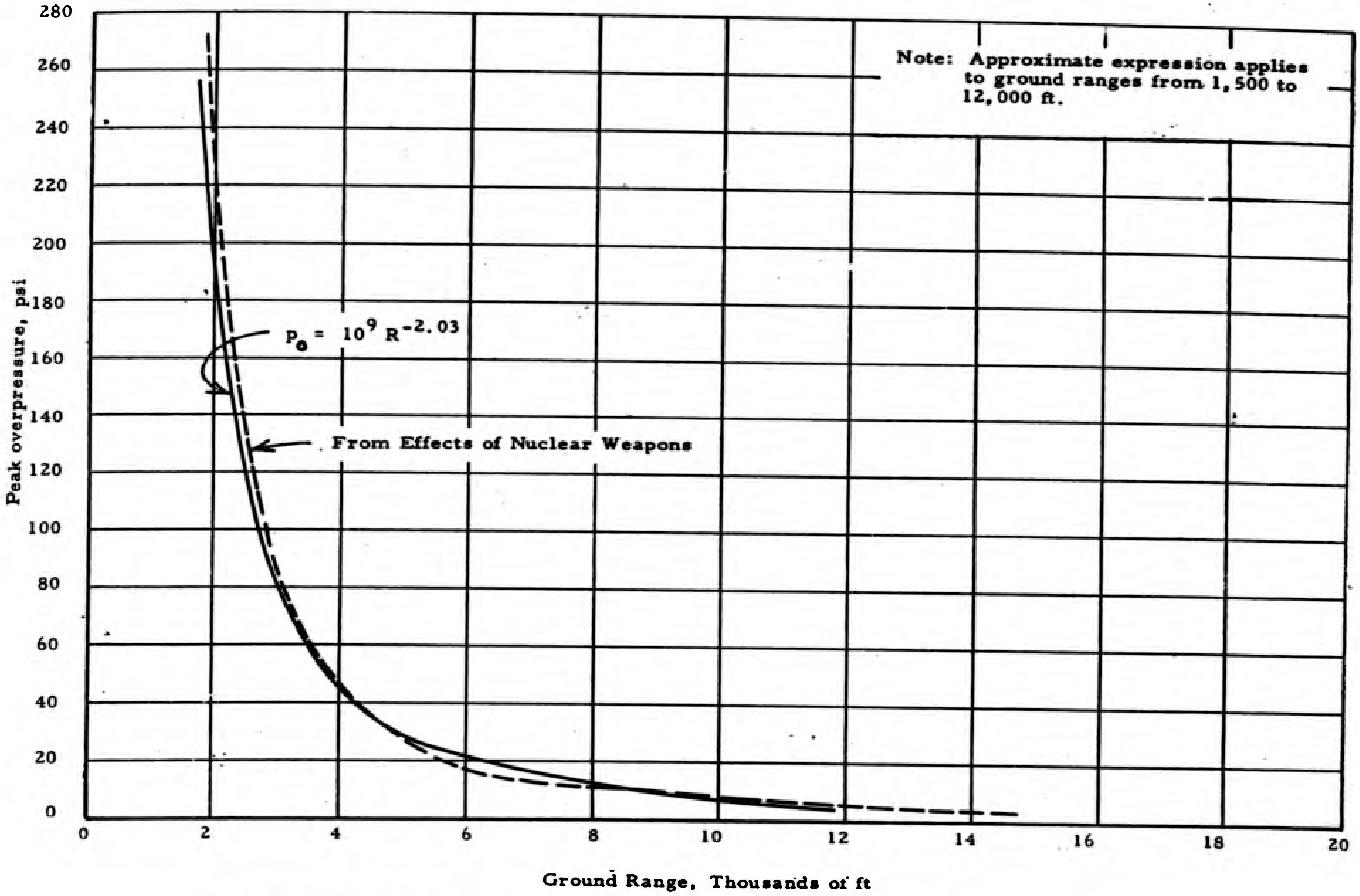

Fig. D-6.3 APPROXIMATE EXPRESSION FOR PEAK OVERPRESSURE FOR 500 KT WEAPON

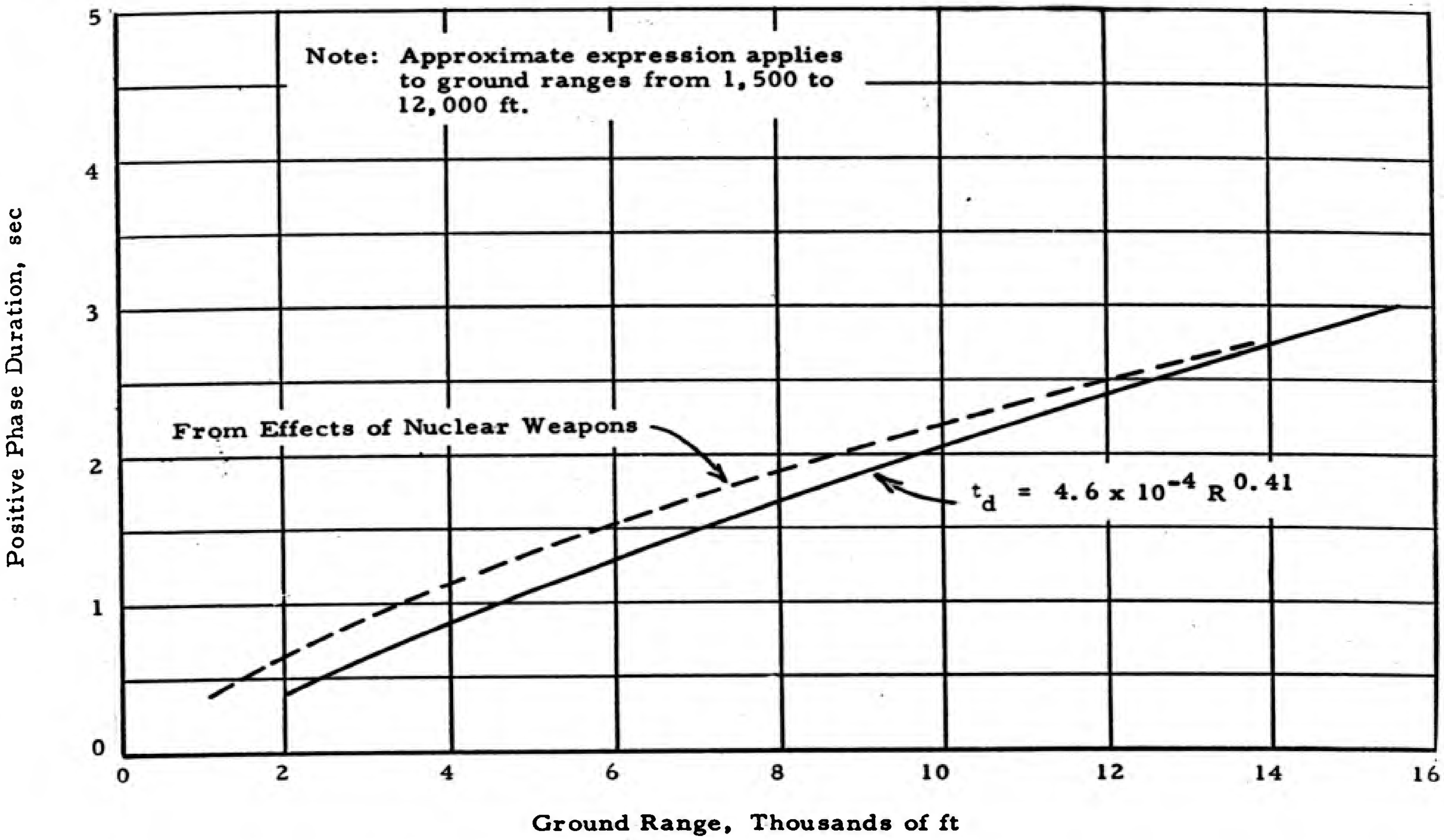

Fig. D-6.4 APPROXIMATE EXPRESSION FOR POSITIVE PHASE FURATION FOR 500 KT WEAPON

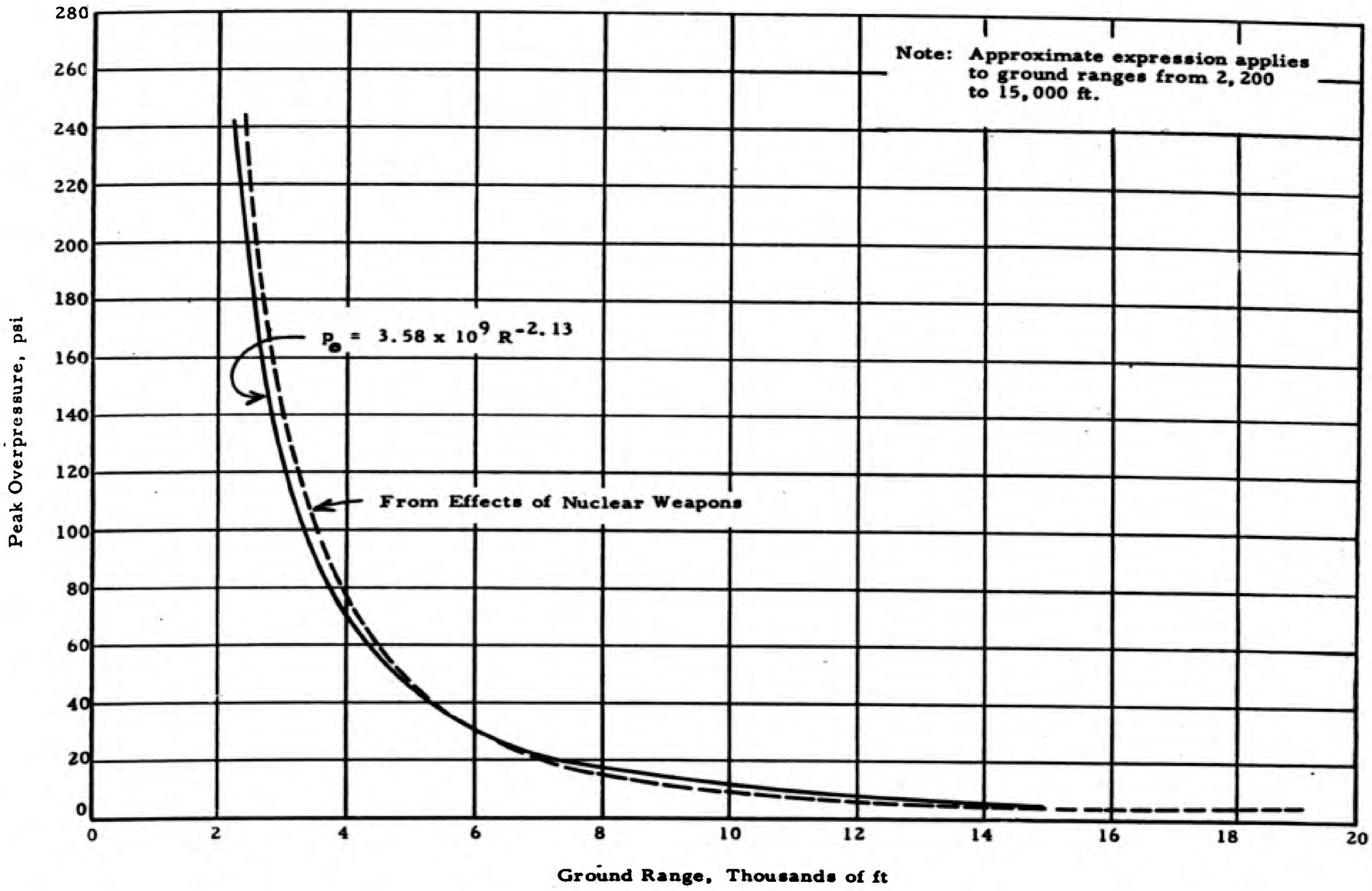

Fig. D-6.5 APPROXIMATE EXPRESSION FOR PEAK OVERPRESSURE FOR 1 MT WEAPON

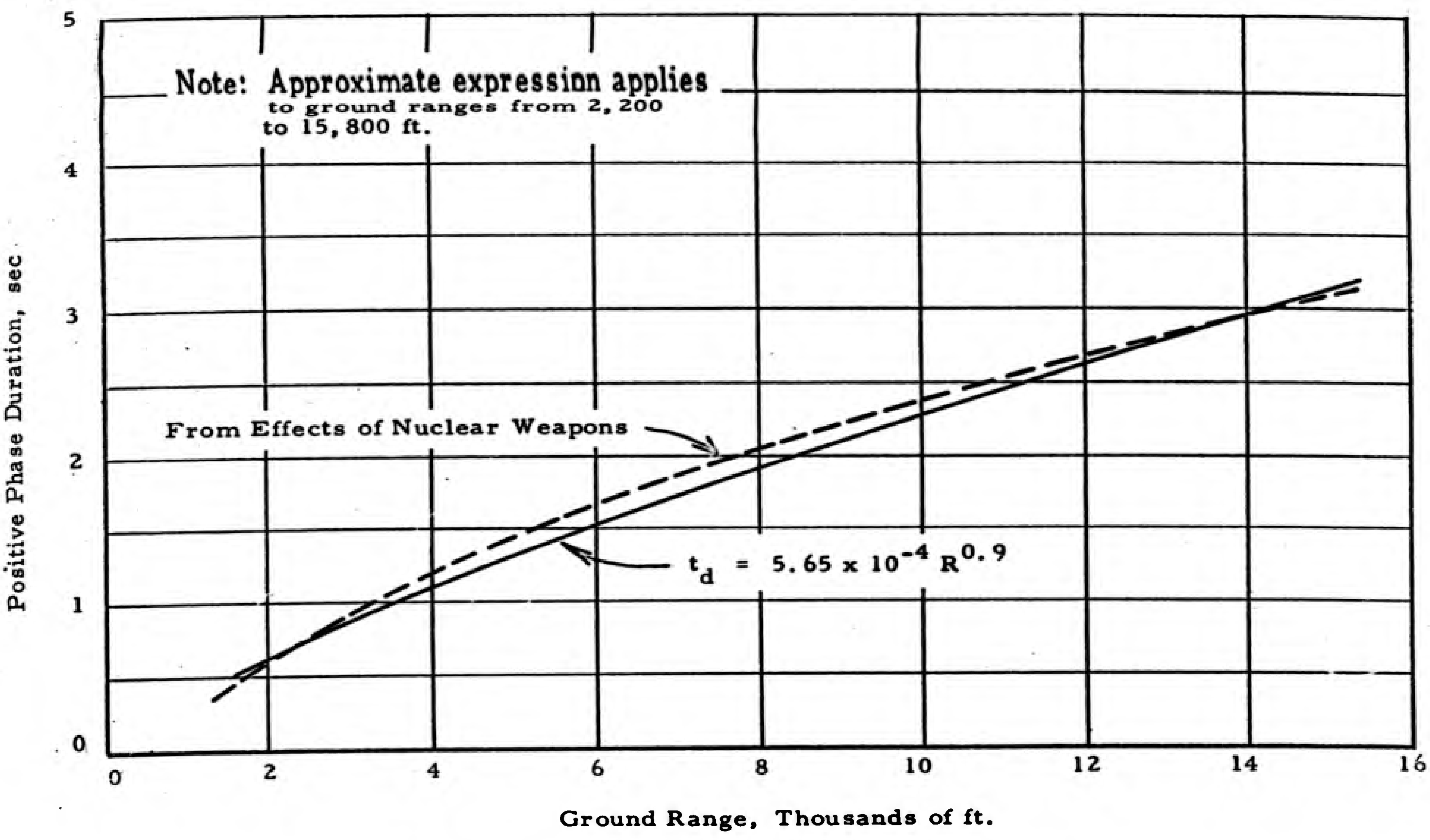

Fig. D-6.6 APPROXIMATE EXPRESSION FOR POSITIVE PHASE DURATION FOR 1 MT WEAPON

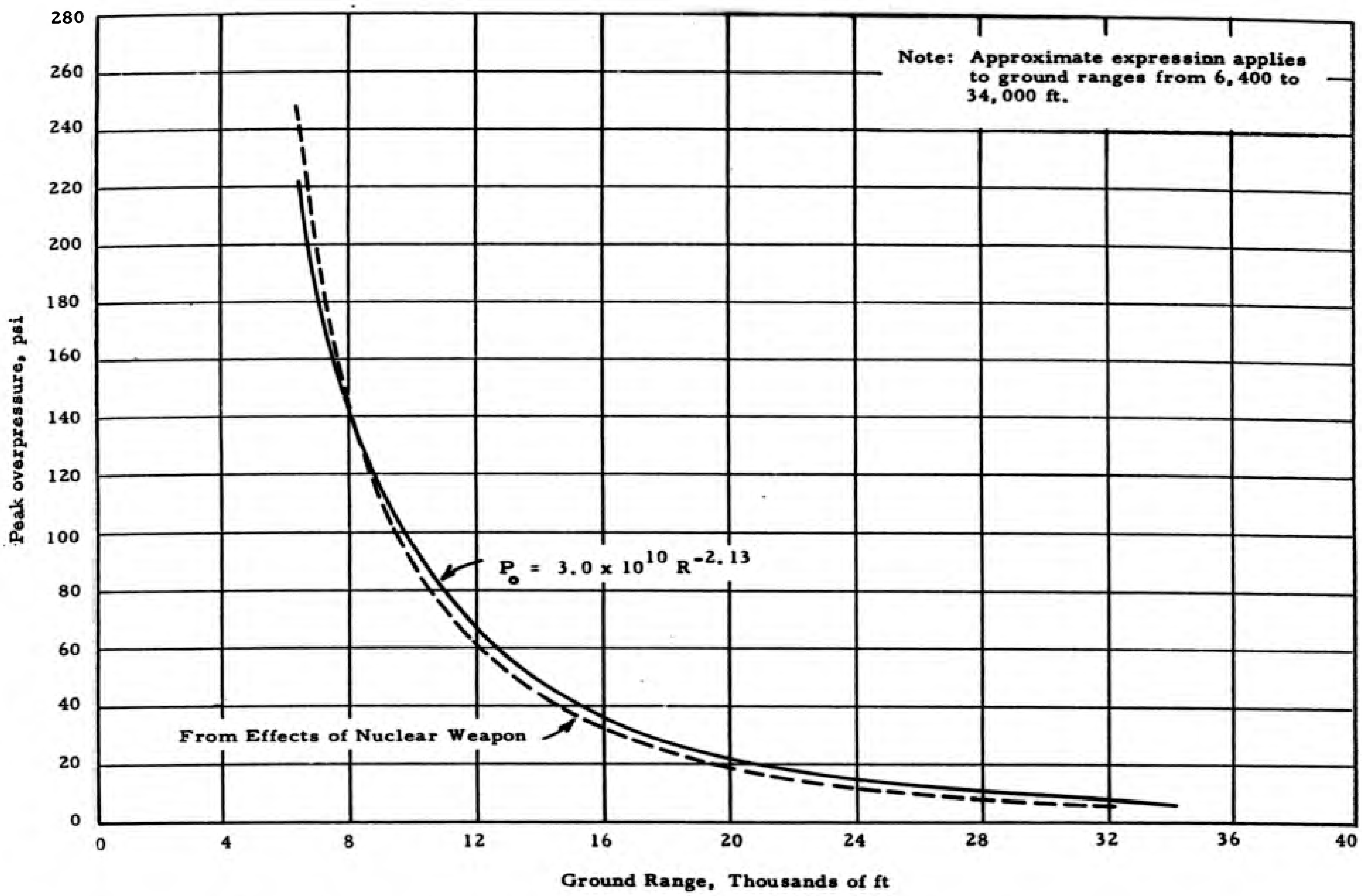

Fig. D-6.7 APPROXIMATE EXPRESSION FOR PEAK OVERPRESSURE FOR 20 MT WEAPON

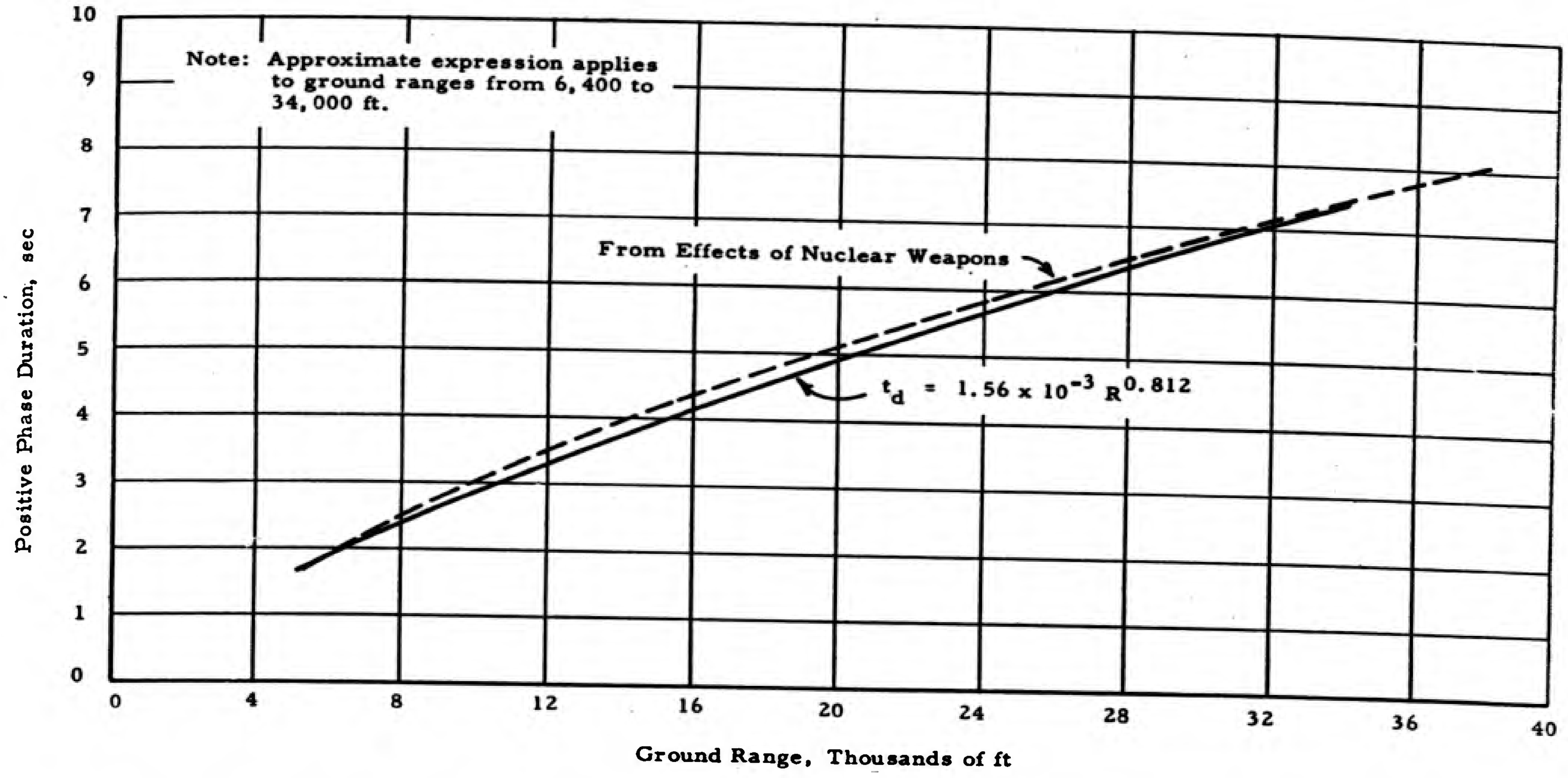

Fig. D-6.8 APPROXIMATE EXPRESSION FOR POSITIVE PHASE DURATION FOR 20 MT WEAPON

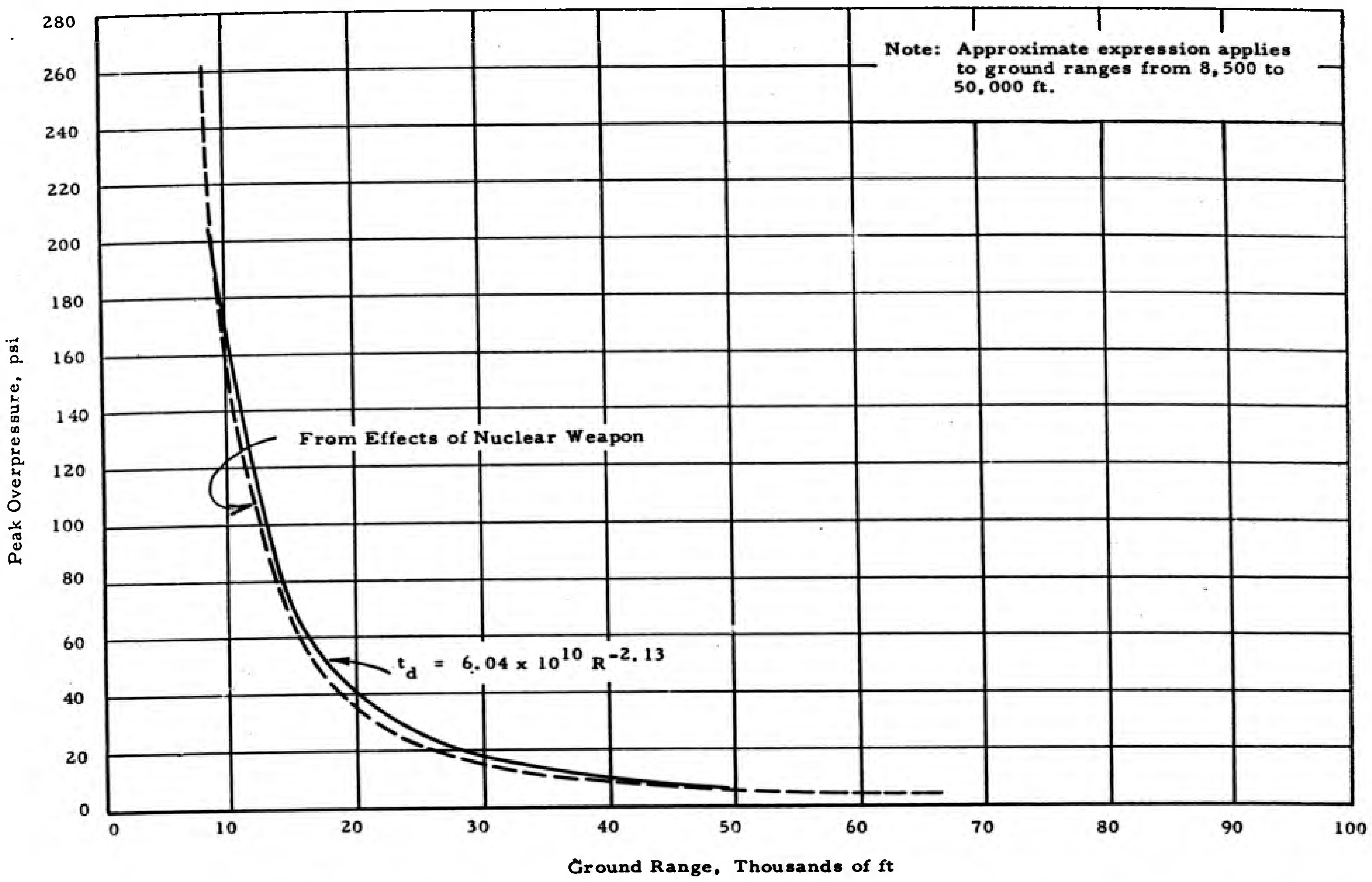

Fig. D-6.9 APPROXIMATE EXPRESSION FOR PEAK OVERPRESSURE FOR 50 MT WEAPON

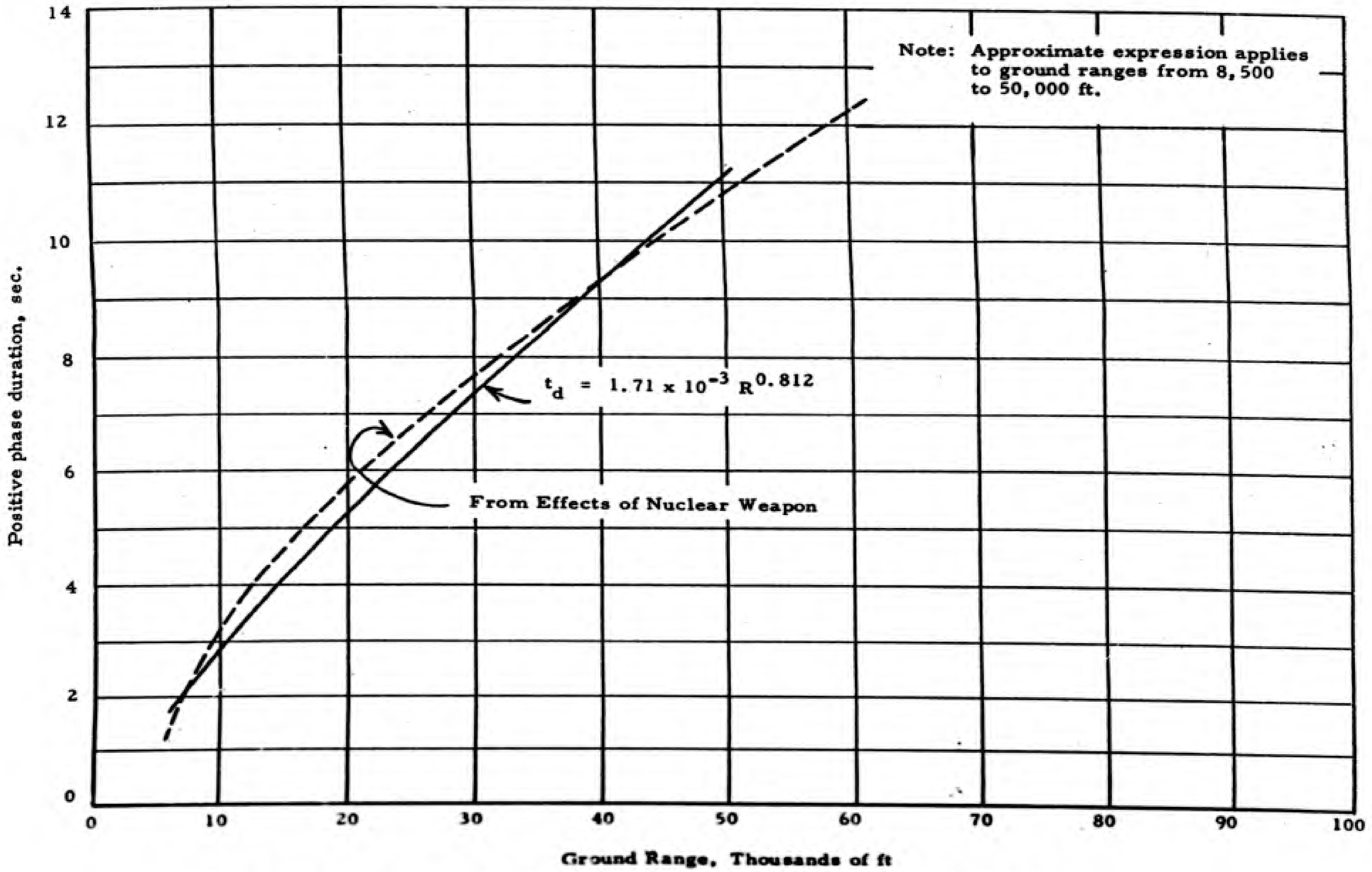

Fig. D-6.10 APPROXIMATE EXPRESSION FOR POSITIVE PHASE DURATION FOR 50 MT WEAPON