final report

INDUSTRIAL RECOVERY
ASSESSMENT TECHNIQUES

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INTRODUCTION

The repair and operation of lightly or moderately damaged industrial facilities in the early postattack period could require rather large scale efforts especially if urban areas are systematically attacked. In the pre-planning of repair operations for such an event, the planning analysis should consider both operational and economic feasibilities of the repair function. The relative ease of returning a damaged facility to useful pro-duction is predicated on interdependent facility production, availability of raw materials, manpower, utility services, transportation, and so forth. If the operation of an industrial facility requires an external source of electricity, then regardless of the physical conditions of the facility, production must await the restoration of electrical power. It is easy to see that the recovery of an industry in a lightly to moderately damaged area will require the simultaneous or coordinated repair and operation of many industries and systems. All will require manpower, equipment, and supplies.

The long range objectives of this study are to:

1. Extend and revise the generalized industrial models that have been developed in Work Unit 3331B.
2. Develop mathematical functions that describe the dependence of the postattack recovery capability of industries on (a) attack effects, (b) civil defense countermeasures, and (c) the interaction between the effects and the countermeasures.
3. Develop data and methods for describing and estimating the time dependence of recovery efforts and restored industrial production.
4. Develop as required, data and methods for describing and estimating input-output relationships between interdependent industries.

Aside from brief descriptions of the various postattack recovery models that are needed to define the postattack environment and the various facets of recovery and to estimate the magnitude of recovery operations and the

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organizations required for its successful execution, the scope of this report, which is the 3rd and final report for the project, is basically limited to the extension of the assessment techniques of debris clearance and damage repair.

The other two published reports and their contents are as follows:

1. Industrial Vulnerability to Nuclear Attack--San Jose, California, by S. L. Brown, reports a vulnerability data base for 146 industrial facilities in the San Jose SMSA and indicates how various rating scales can be used to determine their suitability for a case study. The data are also used to perform a very rough damage assessment for illustrative purposes.

2. Occupational Skills and Civil Defense, also by S. L. Brown, reports a method for estimating the distribution of employees by industry and occupation in small geographical areas (census tracts) and uses a sample run on San Jose to demonstrate selective survival skills. It also discusses how a graphical presentation of detailed census data can suggest possibilities for exchanges between various occupation-industry skill groups.

POSTATTACK RECOVERY OPERATIONS

In general, there will be prerequisite postattack recovery operations
that must be carried out before or along with the initiation of industrial
production recovery operations. These operations would be conducted in a
variety of possible postattack environments. For example:

1. Resources close in to ground zero are totally destroyed. Some sur-
   vivors of the immediate weapons effects are able to leave the
   area, but in the process some may receive large exposure doses
   from the fallout if the damage is caused by a near surface deton-
   ation (depending on the type of available shelter and time at
   which they leave).

2. Areas at intermediate distances receive heavy to light damage.
   Some of those persons without adequate shelter who are able to
   evacuate the area before the development of large scale fires may
   receive large exposure doses in the process.

3. Areas more distant from ground zero are only superficially dam-
   aged. Fallout is heavy in the downwind direction but diminishes
   to inconsequential amounts at crosswind and upwind locations.
   Some people are also inclined to leave these areas without due
   regard of the fallout hazard.[1] Although the physical damage to
   urban centers in the more distant areas is superficial, it is
   not certain that the water system is functioning, that electric
   power and natural gas are available, and that telephones or other
   communications are operable.

If a damaged urban-industrial community is to be recovered, it is es-
sential that permanent mass exodus or irreversible emigration from the re-
gion does not occur. Manpower is the most critical resource for all recov-
ery operations and it must be preserved, organized, and concentrated to carry
out the physical work of the needed recovery operations at the location of
interest. The survivors must first concentrate on achieving recovery of the

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facilities and processes required for continued survival at a subsistence level. After this objective is met, the recovery efforts may be expanded to other sectors of the economy.

In the early stages of postattack recovery, the role of debris clearance and repair countermeasure operations would generally be in support of other countermeasures dealing with medical and health problems and with the recovery of water and food supplies and sources. These would include the clearance of transport and access routes for rescue, evacuation, and decontamination operations, burial of the dead, and on-site removal of debris around repairable facilities; and it would also include the repair of medical facilities, sewers, water processing and distribution facilities, power facilities, communications networks, food processing facilities, and structures for housing. In situations where the rate and degree of recovery is manpower-limited (capacity of surviving and recoverable facilities exceeds capacity of the manpower to operate), only the minimum facilities for subsistence would be recovered initially and, in some cases priority could be given to debris clearance operations for the purpose of opening transport routes to facilitate the distribution of surviving commodities from undamaged to damaged areas.

Debris clearance and damage repair functions have been important in the recovery efforts following many natural disasters and past wars as well as in recovery from a nuclear war. Thus a certain amount of past experience and information is available for application to the study of these functions.

RECOVERY MODELS

An urban community is a complex organization of people with many fa-
cilities within which some of the people apply services to raw materials,
converting them to products with a greater degree of utility; some provide
merchandising services for finished products, and some provide services to
other people. The net income derived from these services is used to pur-
chase the commodities to keep the community viable. For the community to
survive and then to thrive in the postattack period, it is necessary that
sufficient facilities be reactivated so that a net gain in revenue from the
various economic activities can be realized.

Even if an urban community were not damaged by blast or fire and did
not receive significant fallout, it is likely that the economy of the area
would be affected by the attack. The flow rate and characteristics of in-
coming and outgoing commodities and the demands for these commodities and
services will be changed because of the effects of the attack in other
areas. For example, if the crude oil supply were cut off, an oil refinery
in the undamaged community would shut down; also, if a printing facility
at another location were not operating, the local supplier of paper would
reduce production. Although the chain of events that would follow reduced
paper production may not be significant, the problems created by the shut-
down of the refinery probably would be.

Thus, while it is expected that the economic activities in an unaf-
fected or free area would be subject to several readjustments with a vary-
ing degree of severity (depending on the composition of the activities),
it may be assumed that all the activities of the area would be potentially
recoverable. However, the potential for recovery of an area within a short
period of time, even with appropriate allocations of manpower and supplies,
is expected to decrease as the damage increases. The lowest potential for
recovery is where all the facilities are destroyed and recovery would re-
quire complete reconstruction of the original facilities (which would not
be feasible in a short time, as a general rule). At present, the degree

of damage an urban community could sustain and still recover with or without outside assistance from the people in the free areas is not known. Because of this, a system for assessing the overall recovery problem is desirable before a detailed analysis of all the possible combinations of repair constraints is initiated. For instance, recovery planning would be greatly enhanced if it could be determined whether the output from the surviving industries is sufficient to sustain community survival on a continuing basis. Even for approximate analyses of the multi-tudinous interrelated facets in an industrial recovery program, a system of postattack recovery models is needed.

The postattack recovery models may be separated into four major classifications as follows:[2]

    I   Models for defining and estimating the blast and fire effects and the radiological hazards of nuclear weapons

    II   Models for delineating the various economic systems used in the production of survival and other items

    III   Models for defining individual postattack recovery countermeasure operations and procedures

    IV   Models for defining the civil defense organization and its role in the planning and scheduling of postattack countermeasure operations

The relationships of the models system in the four classifications are arranged in Figure 1 to show the input-output data processing sequences required for programming industrial recovery. Also included in Figure 1 are the facility component vulnerability submodel, the operations vulnerability submodel, and the countermeasures submodel. One of the weapons effects, fallout, has been extensively researched and a most comprehensive study is contained in Reference 3. Fallout models in Class I currently in use or in the process of being developed are discussed and summarized in Reference 4 and are not considered in this report.

The problem of industrial recovery, on the other hand, is very closely tied to the repair of physical damage incurred by industrial facilities.

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Figure 1

POSTATTACK RECOVERY MODEL SYSTEM

WEAPON EFFECTS
MODELS
          I

↓

VULNERABILITY SUBMODELS
COMPONENTS
OPERATIONS
COUNTERMEASURES   IIa

RECOVERY
REQUIREMENTS
MODEL   IV

ECONOMIC
SYSTEMS
MODEL   II

RECOVERY
OPERATIONS
MODELS   III

RECOVERY
PLANNING
MODEL   IV

↓

RECOVERY
MANAGEMENT
MODEL   IV

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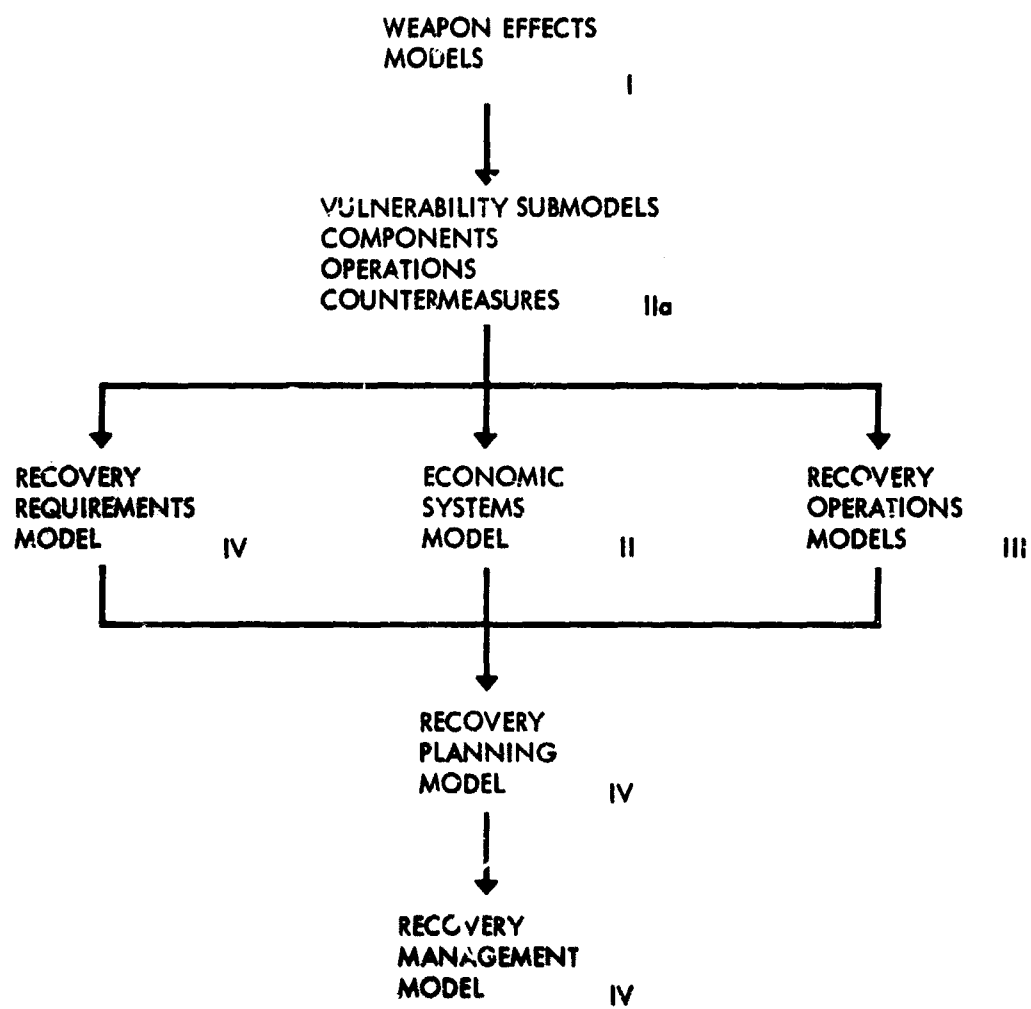
Very little information on damage assessment modeling is currently available. The difficulty of setting up industrial damage assessment models lies in the diversity of the industries and the differences in the characteristics of the physical facilities. Consequently, the practice has been to analyze the vulnerability of facilities on an individual basis. This procedure is not only time consuming but, because the degree of physical damage for any one facility, from "light damage" to "heavy damage," occurs over a narrow range of overpressures and because of the uncertainty in predicting fire, confidence in the predicted damage except in the region of total destruction (very high overpressures) and in the region of insignificant damage (very low overpressures) is lacking. Hence it is possible to categorize, within a reasonable degree of confidence, the nature of the damage into three broad classifications--insigificant; light to heavy; total destruction. Therefore, one of the first applications of the models is to determine the relative size and importance of the areas subject to damage. This would be the first step in estimating the magnitude of the recovery effort.

Included in the models of Class II are the Agricultural Production Model, the Mineral Production Model, the Industrial Processing Model, the Storage and Distribution Model, and the Utility and Energy Source Model. The development of Class II models has not progressed beyond preliminary simple designs; yet they are necessary to complete any postattack recovery analysis.[5]

Class III and Class IV models are also in the preliminary simple design stage. Because postattack recovery operations are most directly related to the three Recovery Operations Models of Class III, the Damage Repair Model, the Debris Clearance Model, and the Decontamination and Dose Control Model, they will be discussed separately in the following section. The Recovery Requirements Model determines the minimum rates of facility production that must be recovered or maintained at any time for continued population survival or to meet some predetermined recovery goals. The output of the Recovery Requirements Model along with the outputs of the Economics System Model, the Damage Assessment Model, and the Recovery Operations Models serve as inputs to the Recovery Planning Model to provide

various feasible recovery operations. The procedures for generating the minimum rate of recovery for continuing population survival are basically as follows:

1. Determine the minimum survival consumption rate of all survival items for the total number of survivors

2. Inventory surviving stocks

3. Develop a skeletal economic system network that is required to produce and distribute the survival items

4. Determine the production requirements of each component in the economic system network for survival

5. Determine the resources required from external sources and develop alternate procedures for their procurement

6. Inventory the production rate of surviving components

7. Provide a schedule of production recovery to attain the required production, taking into account the depletion rate of surviving stocks

Food is one of the many basic survival items, but a mere comparison of daily consumption with annual harvest is only a start in a food requirements analysis.[2] Support systems such as transportation, fertilizer industries, and food processing industries; secondary support systems such as fuel production; and tertiary support systems such as metals production, ad infinitum, all play a specific role in the process by which a food product in its final form is delivered to the consumer. All these systems must be examined not only with respect to food production but als' for intersystem dependence in conjunction with location and time. Interdependence among industrial production (input-output tables) in dollar units for 86 industrial sectors is presented in Reference 6. Reference 2, on the other hand, provides basic mathematical expressions of industrial input-output relationships for specific resources, processes, and commodities.

It is easy to visualuze that the Recovery Requirements Model will encompass virtually all facets of endeavor in our economic system. Even though the output of a recovery requirements model fundamentally could be

used to plan and implement all postattack recovery operations, no model
for such a purpose exists today.

Recovery planning can proceed after data become available from
Class II and Class III models, and the Recovery Requirements Model; con-
sequently recovery planning, as well as the framework for its management,
except for specific operations, are now only in the general concept stage
of development.

RECOVERY OPERATIONS

As previously mentioned, the major tasks in the first stage of post-attack recovery would be accomplished when continued survival at a subsistence level is assured. Thus in the initial stages, the recovery of urban complexes situated in unaffected (i.e. free) areas, in areas receiving fallout, or in areas receiving light damage, major attention would be given to the recovery of those facilities and operations associated with the provision of water, food, medical and health assistance, law and order, and housing. Further, only the minimum capacity for meeting survival requirements would have to be recovered to achieve the objective of assuring continued survival. In the second stage of recovery (reconstruction), other industrial and business complexes would be recovered as needed to achieve a reasonable per capita production rate of all commodities.

In the first stage of recovery, the recovery feasibility is defined as the production rates of survival commodities being equal to or greater than that needed at the subsistence level (considering stockpiles). The relative effectiveness of a combination of recovery operations may be measured in terms of the time at which the production rates are achieved and the amount of production capacity recovered per unit of recovery cost. The recovery time, as a relative measure of the operational effectiveness, is equal to the required recovery effort divided by the recovery rate that is or can be applied (or, in the sense of conserving supplies, equipment, effort, and radiation dosage, the recovery rate that needs to be applied).

In principle, the recovery effort may be estimated by listing all the major tasks to be done (assuming prior knowledge of the state of damage of all facilities in the area of interest) and, from information on the effort required to accomplish each task, computing the total effort for all tasks required to restore a given amount of production capacity in terms of physical facilities. The recovery rate is estimated from the available manpower and the scheduling of the use of the manpower and supplies in carrying out the recovery tasks, giving due consideration to the sequence in which the operations would take place.

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In the above definition of recovery feasibility and relative effectiveness of a recovery operation, when referred to subsistence levels of production, gross costs of recovery are properly excluded. However, costs are included in such cases where alternative methods are possible and especially when several of these methods require preattack investments. For these, the costs include the investment in repair equipment, materials and supplies, spare parts, and labor (including the preattack effort in planning and training).

Three recovery operations models are considered with respect to industrial recovery. They are the Decontamination and Dose Control Model, the Damage Repair Model, and the Debris Clearance Model. The implementation of each of these recovery operations will require the use of surviving manpower, surviving equipment, and surviving supplies. Because many of the skills and equipment required by these operations are similar, the implementation of any one operation could effect a constraint on the other two. For this reason, it is necessary for planning and management to coordinate these operations to satisfy recovery requirements.

Decontamination and Dose Control

Experimental research and analysis on decontamination and dose control operations have been carried out over the last two decades. Of the three Recovery Operations Models, the most complete set of available input data is that for decontamination and dose control. Fundamental understanding exists on the general interpretation and measurement of the exposure dose, and experimental tests have shown that the operational procedures of decontamination and for dose control generally consist of tasks or procedures that are easy to understand (and perform) and that can be universally applied with minor variations for any fallout contaminated target complex. Decontamination and dose control information is still rather sparse, however, for damaged structures and special targets that have a great deal of equipment components and parts that are not housed within structures. Although decontamination and dose control model research needs are not within the scope of this study, the inputs and outputs of the model are listed here to indicate the interrelationships of operational constraints that exist among the recovery operations models. Methods and procedures for calculating

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decontamination and dose control operational outputs are proposed and dis-
cussed in References 1, 3, and 7 through 11.

Model Inputs

1. Weapons effects data

    a. Standard intensity
    b. Fallout arrival time
    c. Fallout physical characteristics
    d. Fallout chemical characteristics
    e. Fallout deposit density
    f. Fallout decay

2. Facilities data

    a. Fallout distribution
    b. Surface types and areas
    c. Shielding geometry
    d. Operating exposure

3. Decontamination data

    a. Method effectiveness
    b. Effort
    c. Equipment
    d. Supplies
    e. Decontamination exposures

4. Dose control data

    a. Limiting exposure doses
    b. Shelter effectiveness and stay time
    c. Decontamination scheduling
    d. Scheduling of other operations

Model Outputs

1. Shelter exit times

2. Decontamination schedules

    a. Methods
    b. Men
    c. Equipment and supplies
    d. Time

3. Decontamination exposures

4. Debris clearance exposures

5. Damage repair exposures

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6. Facility operational schedules

7. Facility operational exposures

8. Dose distributions among the population

Debris Clearance

In damaged areas, debris clearance operations may be required before the initiation of facility repair or other operations. Three general types of debris clearance operations need to be considered: (1) early-time clearance of transportation routes, (2) early-time clearance of access ways to vital facilities, and (3) removal and disposal of on-site debris.

Just as it is necessary to obtain an evaluation of damage before a repair estimate can be made, it is necessary to hypothesize or to obtain an evaluation of the amount and type of debris created before estimating debris clearance. The amount of debris created is a function of the facility hardness, size, type of construction materials, and their ignition characteristics, and weapon parameters such as the yield, height of burst, and distance (as well as atmospheric conditions for fire effects). The debris clearance effort, on the other hand, will depend on the amount and type of debris and the debris clearance equipment or procedures used. The locations where the debris is deposited by the weapon effects are also important, e.g., a greater amount of debris deposited in the streets would increase the effort for clearing transportation routes; if not properly disposed of, the debris may have to be relocated with additional effort at a later time (this may be desirable). Finally, more effort is required to remove a partially destroyed structure than a totally destroyed structure because of the additional effort required for demolition before removal. Consequently, whereas the repair effort should increase with increasing blast pressures to the point of complete destruction, the on-site debris removal effort in the region of high blast pressures could in some cases decrease with increasing blast pressures.

For the first two of the three general types of debris clearance operations, only the debris that reaches the street surface (transportation routes and access ways) is important. Besides the debris

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created from shattered building structures and building contents, parked vehicles will add to the debris mass and volume. Although there will be exceptions, the rubble that lands in the streets will be amenable to removal by normal earth moving equipment. For the short removal distances necessary to clear a path through a debris laden street, the bulldozer is most versatile. In this operation the debris is merely pushed from the center of the streets to the sides, onto the damaged building sites, or into side streets.

Detritus removal rates by bulldozers of various sizes and under various diverse conditions are generally estimable. Consequently if the amount and type of debris are hypothesized or determined, the required clearance effort can be calculated and a clearance operation scheduled. The clearance time is the area covered by debris divided by the clearance rate. The clearance rate will depend on the amount and nature of the debris, the type of equipment used, the number of units employed, and the type of clearance operation that is planned.

In light to moderate blast damage regions, the debris in the streets will generally be of small cross-section and consequently its removal can be facilitated by normal earth moving equipment such as bulldozers, power shovels, crane-clamshell combinations, and various types of loaders. In areas of relatively shallow debris, the removal of vehicles can generally be expedited by a separate procedure, e.g., attaching cables and towing through the debris with tractors; if the vehicles are not left in a traffic-jam situation, they could be pushed aside with bulldozers or other heavy vehicles. Where the depth of debris makes such a procedure nonfeasible, the removal of parked vehicles must be carried out concurrently with debris removal operations. If the crane-clamshell combination were used for debris removal operations, damaged vehicles would be treated as part of the debris and be removed along with the other material.

In areas where the debris depths are less than 4 feet, heavy bulldozers are ideally suited for the task of clearing a pathway through the debris. This operation requires only that the debris be moved from the center of the street to each side. Where the debris depths are in excess of approximately 4 feet, power shovels and crane-clamshell combinations, either with

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or without dump truck hauling, will generally be more effective. Estimates of bulldozer street clearance rates (not including vehicle removal) are plotted as a function of cleared path width for fragmented debris of small cross-section of various shallow debris depths in Figure 2. The estimated rates presented are those of the author and represent consideration of dozer capability, assumed debris composition, a mode of operation and a degree of completeness.

The clearance rates in miles per dozer hour are approximated by the following equation:

$$R_c \text{ (bulldozer)} = 1000/\left[200 + 50d + W^{1.9} + c/4\right] \tag{1}$$

where

R_c is the clearance rate in miles of street per dozer hour,

W   is the cleared width in feet, and

d   is the depth of debris in feet.

The range of the equation is $10 < W < 40$, and $1/2 < d < 4$.

As can be seen, debris clearance for the purpose of opening through-ways in areas where the average debris depth is less than two feet will not be difficult. Estimates of street clearance rates for a debris depth of 4 feet as a function of cleared path width are plotted in Figure 3 for a 2-yard power shovel and a 2-yard short-boom clamshell. These rates are based on soil excavation data and it is not known whether debris which is loosely packed and has a lower density is easier or more difficult to remove. For a greater amount of debris of the same type, the clearance rates are inversely proportional to debris depth.

The clearance rate equations for the 2-yard power shovel and the 2-yard short-boom clamshell in street miles per equipment hour are:

$$R_c \text{ (power shovel)} = 1/dW \tag{2}$$

and

$$R_c \text{ (clamshell)} = 0.5/dW \tag{3}$$

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Figure 2

STREET DEBRIS CLEARANCE RATES
(1/2-to 2-ft DEPTH)

EQUIPMENT - 40,000 - 50,000 LBS BULLDOZER

O 1/2 FOOT

△ 1 FOOT

◇ 2 FEET

CLEARANCE RATE - miles/dozer-hour
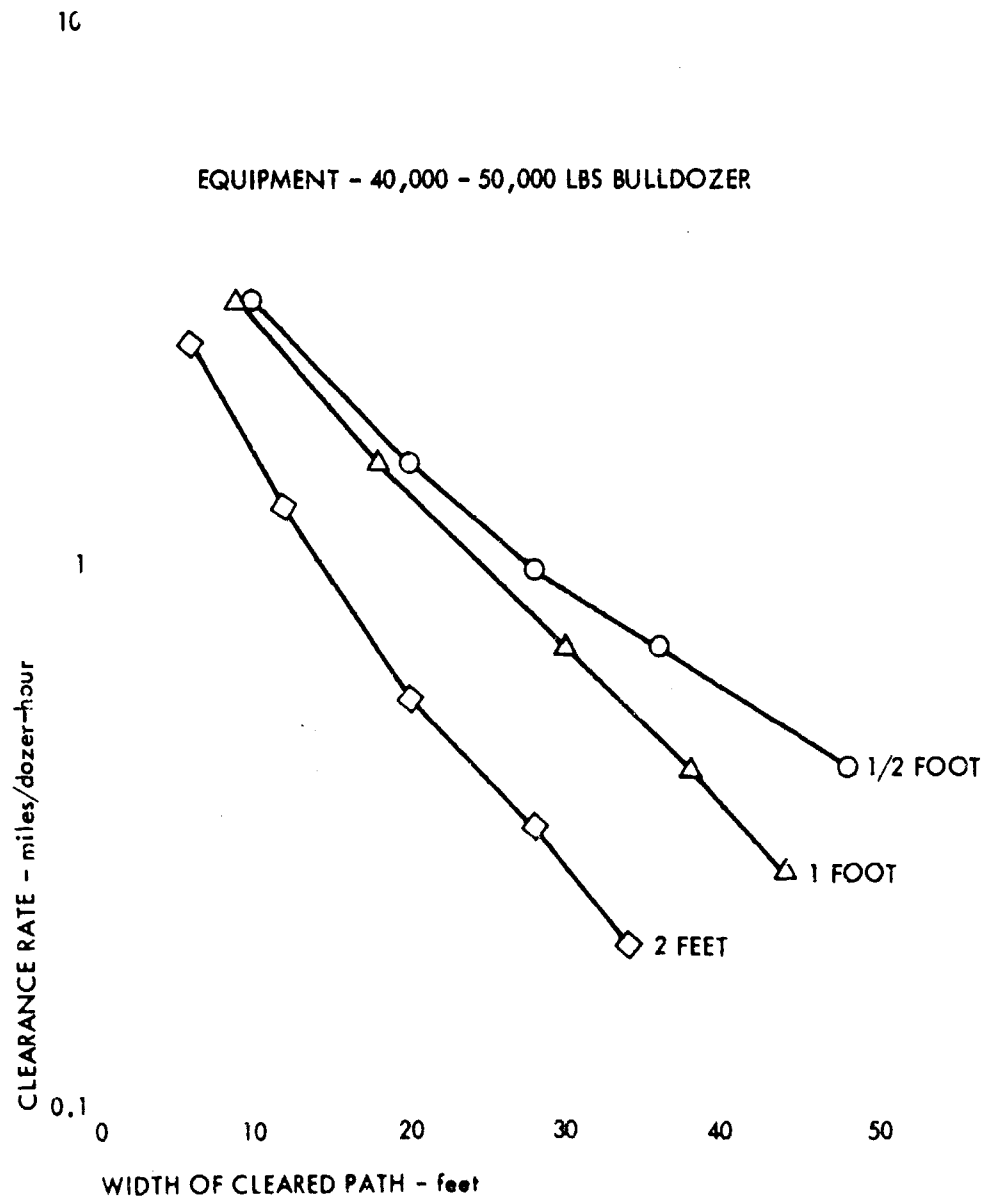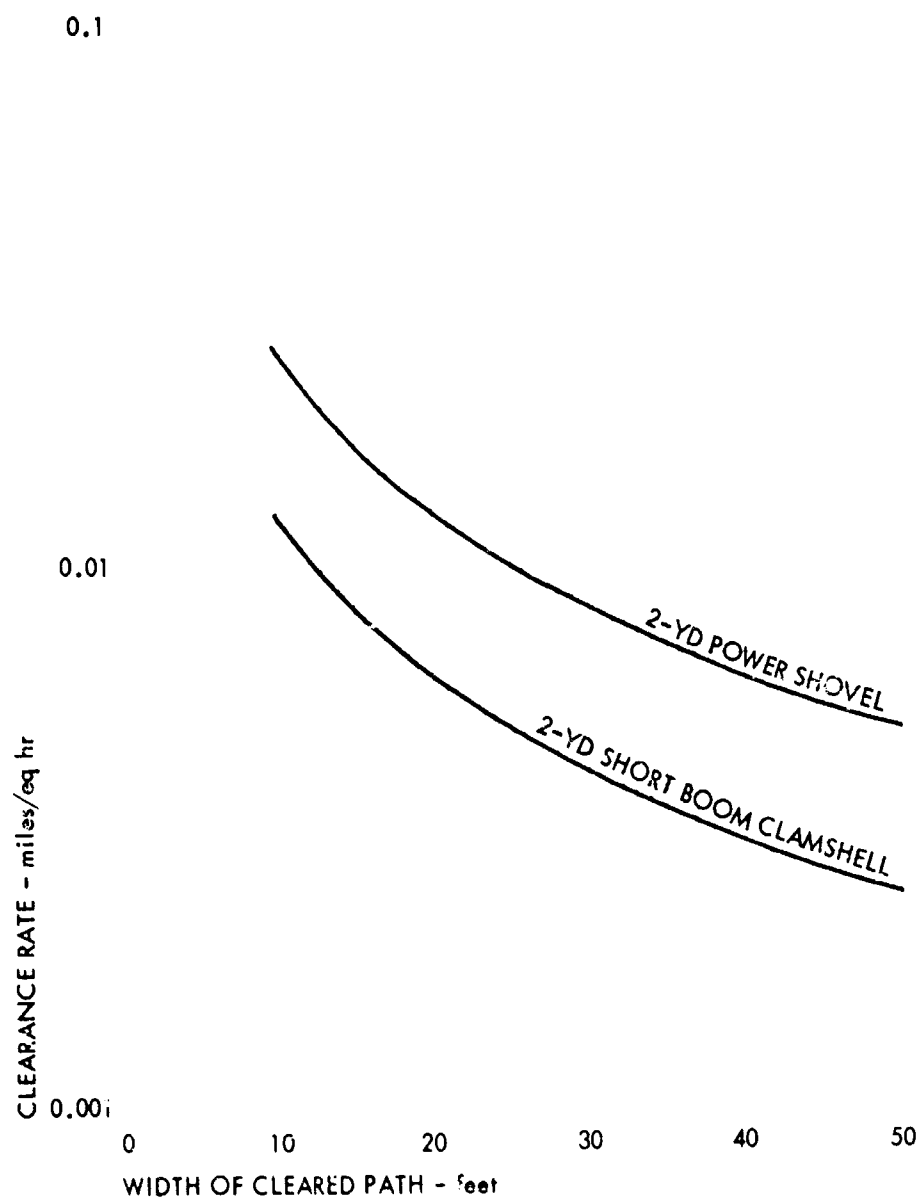
WIDTH OF CLEARED PATH - feet

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Figure 3

STREET DEBRIS CLEARANCE RATES
(4-ft DEPTH)

The total effort for debris clearance operations to provide access and transportation routes is the sum of the path lengths divided by the clearance rates. The total clearance time is obtained by dividing the effort by the number of equipment units employed. The total path length requiring clearance operations is the sum of the path lengths that are needed in the network minus those paths that are open. The transportation and access network needed depends on the number and locations of the various facilities (industrial and others) in the community and the traffic requirements, both freight and people, between facilities.

The basic minimum network depends on the locations of the points of arrival and departure and the distances between arrival and departure points. The traffic load depends on the tonnage of materials transported and the number of people transported. The number of paths in the network depends on the number of nodes and the number of interconnections among the nodes. The length of a path depends on the distance between nodes. As an urban-industrial area increases in size, the number of nodes and the number of paths increases whereas the distances between nodes generally remain relatively constant. Consequently the total length of all the paths is directly proportional to the area size and the number of paths per unit area. The combined lengths of the basic network segments can thus be expressed as

$$L_B = \frac{AN^a}{b} \qquad (4)$$

where A is the area of interest, N is the number of points (nodes) in the network, and a and b are equation constants that relate the number of nodes to the number of paths. The total length required is given as

$$L_T = F_E L_B \qquad (5)$$

where F_E, the enlargement factor, is equated as

$$F_E = 1 + \frac{T - T_1}{c} + \frac{D - D_1}{d} \qquad (6)$$

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where $\frac{T_1}{c} + \frac{D_1}{d}$ is the limiting capacity of the basic transportation network, T is the tonnage of materials transported, D is the population density, and the values of c and d depend on the path capacity, the mode of transportation utilized, traffic regulation, and utilization scheduling.

If it is assumed that $D/d > T/c$, and the traffic is scheduled so that T/c does not interfere with the requirements of D/d, then

$$F_E = 1 + \frac{D - D_1}{d} \tag{7}$$

The length of transportation paths that require debris clearance, on the other hand, is equated as

$$L_c = L_T - L_o = \frac{N_D}{N} L_T \tag{8}$$

where L_o is the total length of the network that is free of debris, and N_D/N is the ratio of number of damaged facilities to the total number of facilities. By combining Equations 5, 7, and 8

$$L_c = \frac{N_D}{N} \times \frac{AN^a}{b} \left[1 + \frac{D - D_1}{d} \right] \tag{9}$$

Also, since D is equal to the population divided by the area

$$L_c = N_D N^{a-1} b^{-1} \left[A + \frac{P - P_1}{d} \right] \tag{10}$$

The clearance effort in equipment hours is equated as

$$E_c = \sum_{L=1}^{L=n} \left(L/R_c \right) \tag{11}$$

where R_c depends on the debris depths (as well as the type of debris) at various path locations, the width of the path cleared and the equipment used, and

$$\sum L = L_c$$

or

$$E_c = \frac{L_1}{R_{c1}} + \frac{L_2}{R_{c2}} + \frac{L_3}{R_{c3}} + \ldots \frac{L_n}{R_{cn}} \qquad (12)$$

The elapsed time of debris clearance is

$$T_c = \sum E_c/N_e \qquad (13)$$

where the number of equipment, N_e, varies with location and time but is generally a function of area size and population.

Besides debris clearance, debris removal operations will ultimately be required at rehabilitated areas. This type of operation will generally be delayed until the final recovery stage. The amount of debris per square mile even in a burned light residential area is estimated at 2×10^5 cubic yards. The amount of debris per square mile in built-up areas is orders of magnitude greater. Ultimately all of the debris would probably be re-moved. At 2 to 5 yards per truck load, 20,000 to 50,000 truck loads of debris would be contained in one square mile of burned light residential areas alone. Because the availability of debris removal equipment and trucks for removal will be limited by destruction losses and by other post-attack operational needs, the time required for total debris removal (all areas), even if scheduled at a high effort level, could be as much as sev-eral years. However, debris clearance scheduling will be critical only in the early stages of postattack recovery, i.e., the survival and emergency stages. Salvage operations could be conducted before or simultaneously with debris clearance.

Debris Production

The data available for predicting debris production as a function of weapon parameters are very limited, and there is no satisfactory method available for predicting the amount of debris that would reach the street. An elementary method for calculating the amount of debris and distribution of debris in a contiguous built-on urban area is to assume the same debris depth both on on-site and off-site,[12,13,14] where on-site is defined as the

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built-on area and off-site is the nonbuilt-on area. The total mass of all
the buildings and their contents under this assumption is distributed evenly
over the total land area (including streets). Although this method provides
estimates of the total debris produced, it may over-predict the amount of
debris in the streets in light to moderate damage regions. Yet it is the
debris in the streets that require attention in the early emergency period
after an attack when recovery planning may be critical. Another approach
for predicting debris production and distribution is to estimate the debris
sizes created and then estimate their subsequent transport.[15] Much follow-
on research will be required before this latter method is developed into a
readily usable debris production and distribution model.

In general, more uniformity in the debris depth over the area is ex-
pected as the overpressure increase; thus at overpressures greater than are
required for complete destruction of all the structures, the depth of debris
in the streets could very well be the same as the on-site depth. The region
over which this may occur will depend not only on the weapon effects but
also on the type of structures at any location. Where the overpressure is
relatively small, the collapse of some structures will only produce on-site
debris. The distribution of debris at most places with moderate damage will
generally be somewhere between these two extremes.

The estimation of the depth of debris in the streets is complicated by
the resulting on-site/off-site ratio and the degree of debris combustion.
If the on-site/off-site ratio and the degree of combustion are high the
amount of residual debris in the street would be low. The other extreme
is the case where the on-site/off-site ratio and the degree of combustion
are low. The two factors are dependent on the debris production processes.
Two distinct debris producing processes can be envisioned as well as a third
combination debris producing process. They are: (1) debris produced by
blast, (2) debris produced by fire, and (3) debris produced by blast and
fire. In the first process, the blast wave envelops a structure with such
force that structure fracture, fractured parts displacement, and structure
collapse occur simultaneously as a single event. In the second process,
the structure may or may not be partially damaged from the blast wave but
remains standing and then is consumed by fire and finally collapses. In

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the combination process, some of the fractured parts are displaced by the blast wave; this is accompanied by partial st.uctural collapse (which displaces some more debris), and the remaining weakened structure is partially consumed by fire and finally undergoes additional collapse.

Where the blast wave is strong enough to cause instantaneous collapse, the on-site/off-site ratio is the lowest, and under these conditions both the on-site and the off-site debris even if ignited are unlikely to be able to sustain burning to consume all combustible materials. In the region where street debris is produced as a result of building collapse from subsequent fires, the on-site/off-site ratio will be relatively high, and, because the structures are erect during the burning period, maximum combustion of available fuels can occur. At intermediate regions where the partially collapsed structures are ignited, the structures will collapse at an earlier stage of burning and maximum combustion of available fuels is not so likely to occur. Some of the debris that was displaced by the blast wave could also be ignited and consumed by fire.

Using the general hypotheses stated above and the volume factors in Reference 14, the estimated street debris depths for the 3 regions--blast, fire, and blast and fire--are depicted in Figure 4 for a 4-story steel frame, reinforced concrete department store to show estimated debris depth for various assumed on-site/off-site debris ratios. For the construction of this figure, the calculations include the assumptions that the on-site area is equal to the off-site area and that the void ratio is unity, i.e., the volume of voids is equal to the volume of materials. If the on-site area is smaller than the off-site area or the void ratio is lower, the debris depth off-site would be lower. Conversely, if the on-site area is larger than the off-site area or the void ratio is higher, the debris depth off-site would be higher. The data furnished in Figure 4 were then plotted in terms of the on-site depth and the off-site depth versus distance from the ground zero point of a surface detonated 10 MT weapon by estimating the location of the three regions from blast vulnerability data.[12,16] This plot, which was constructed from three estimated points only, is shown in Figure 5. If the debris were assumed to be evenly distributed on-site and off-site the resulting debris depth in the street would be equal to one-half

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Figure 4

STREET DEBRIS DEPTH FROM 4-STORY STEEL FRAME, REINFORCED
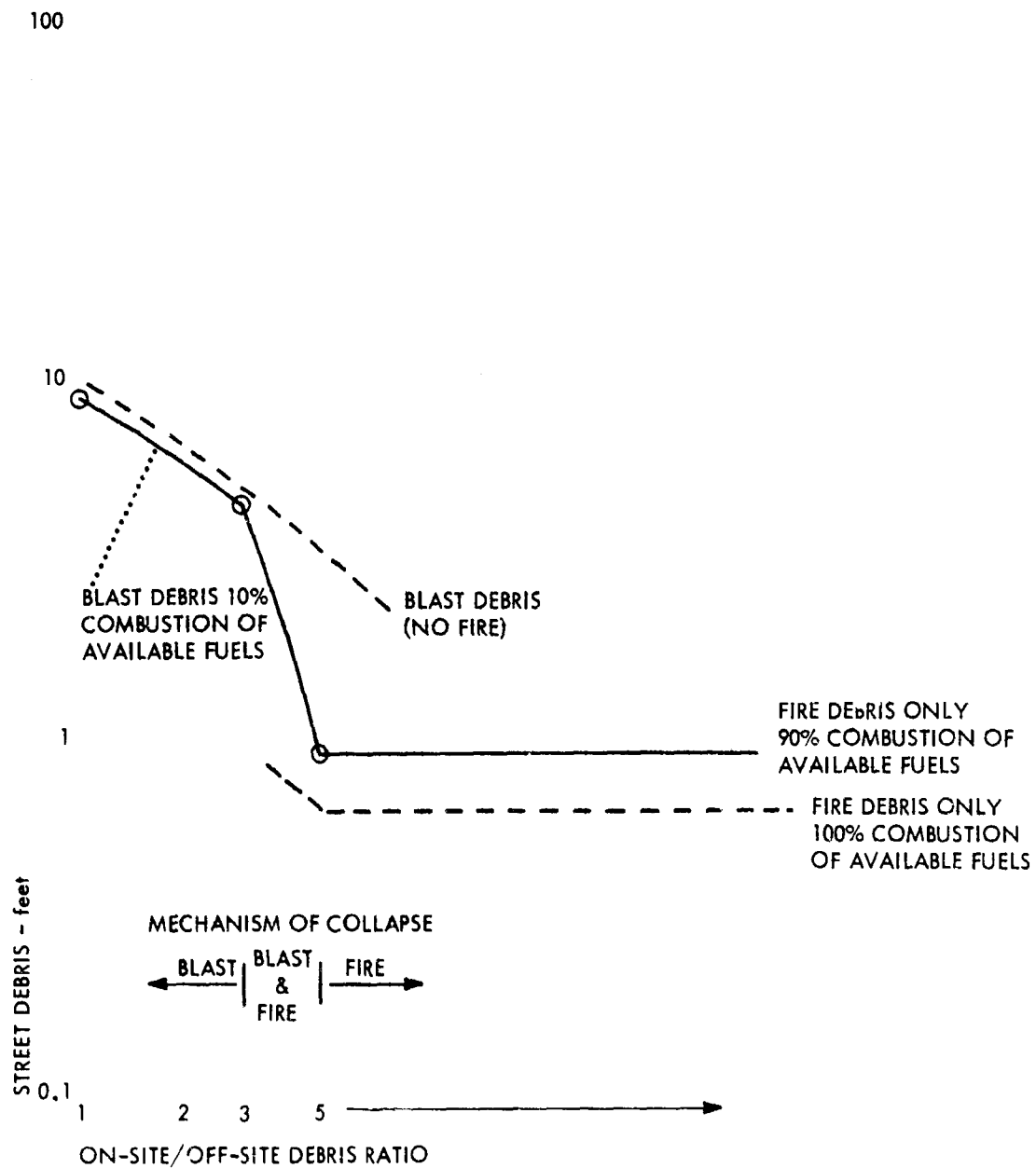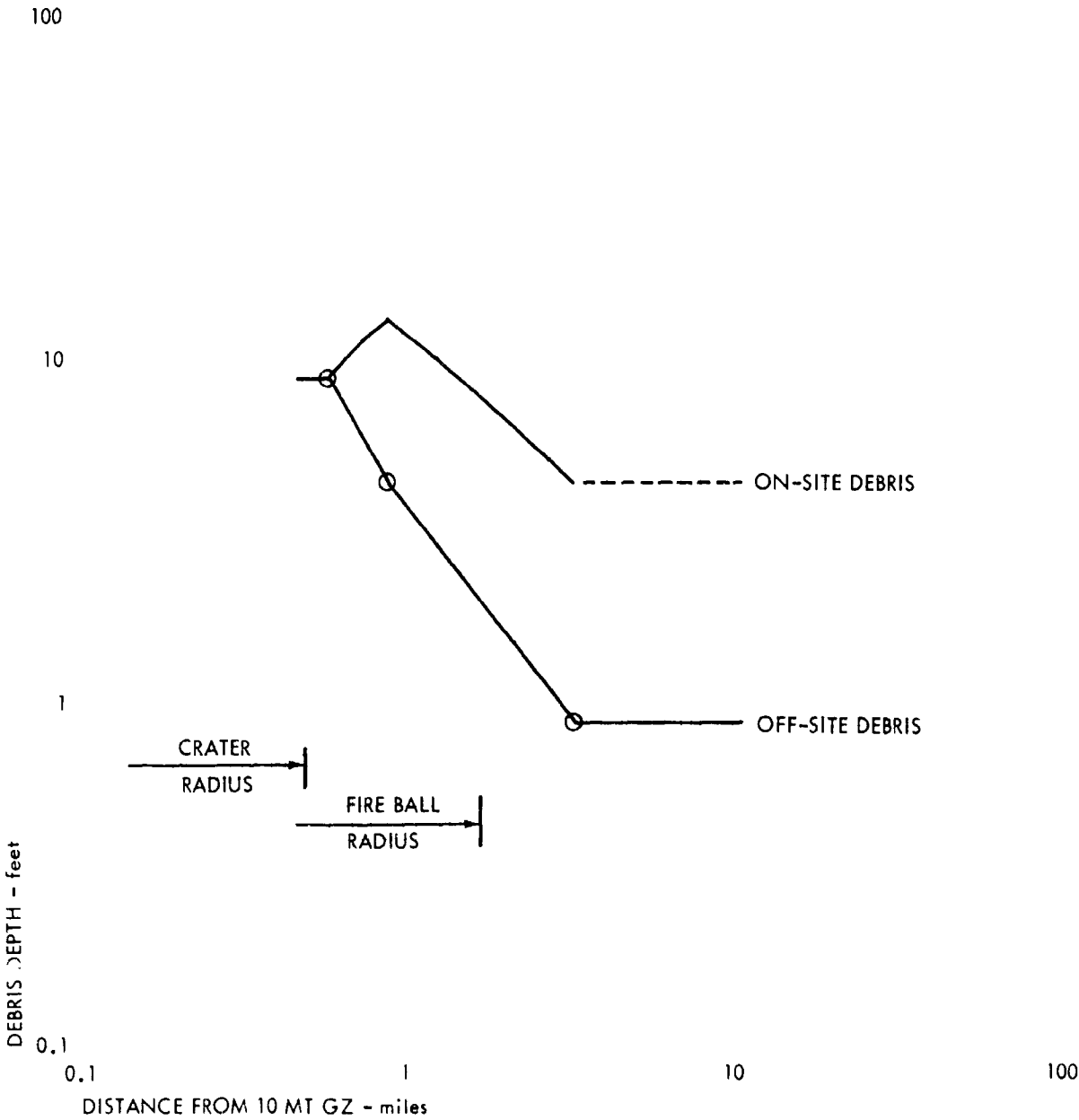CONCRETE DEPARTMENT STORE WITH LIGHT INTERIOR PANELS

Figure 5

DEBRIS DEPTH AND LOCATION FROM 4-STORY STEEL FRAME
REINFORCED CONCRETE DEPARTMENT STORE WITH LIGHT INTERIOR PANELS

of the sum of the on-site debris depth and the off-site debris depth or
2.6 feet in the light damage zone rather than the depth of 0.87 feet indi-
cated in Figure 5. For comparison, the same procedure was utilized on two
other structures and the results are shown in Figures 6 and 7. The dotted
line in Figures 5, 6, and 7 for on-site debris depth indicates the equiva-
lent depth if the incompletely collapsed structure had a void ratio of 1.

A similar analytical procedure was used to estimate the debris depth
and location from a 2-story, wood frame residential structure. In this
case, because the locale is a densely built-on single unit residential area,
an on-site/off-site area ratio of 4 was used (on-site/off-site area ratios
for any locale can be estimated from Sanborn maps). It was assumed that
on structure collapse from fire, only insignificant amounts of debris would
reach the street. It was also assumed that a debris depth less than 0.3
feet would not support combustion. The results are presented in Figure 8.
As can be seen, the final on-site and off-site debris depths are not ex-
pected to exceed 0.3 feet.

The equations used for calculating the debris depths are summarized
as follows:

$$V_{sm} = \left[a + (N - 1)b \right] A_p(1 - FM_c) \tag{14}$$

$$V_{sm} = CV_c(1 - FM_c) \tag{15}$$

$$V_{cm} = KA_pN \left(1 - F \frac{K - K_f}{K} \right) \tag{16}$$

$$V_{tn} = V_{sm} + V_{cm} \tag{17}$$

$$V_{td} = V_o + V_{tm} \tag{18}$$

$$V_{on} = RV_{td} \tag{19}$$

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Figure 6

DEBRIS DEPTH AND LOCATION FROM 8-STORY STEEL FRAME
REINFORCED CONCRETE HOTEL WITH MASONARY INTERIOR PANELS

Figure 7

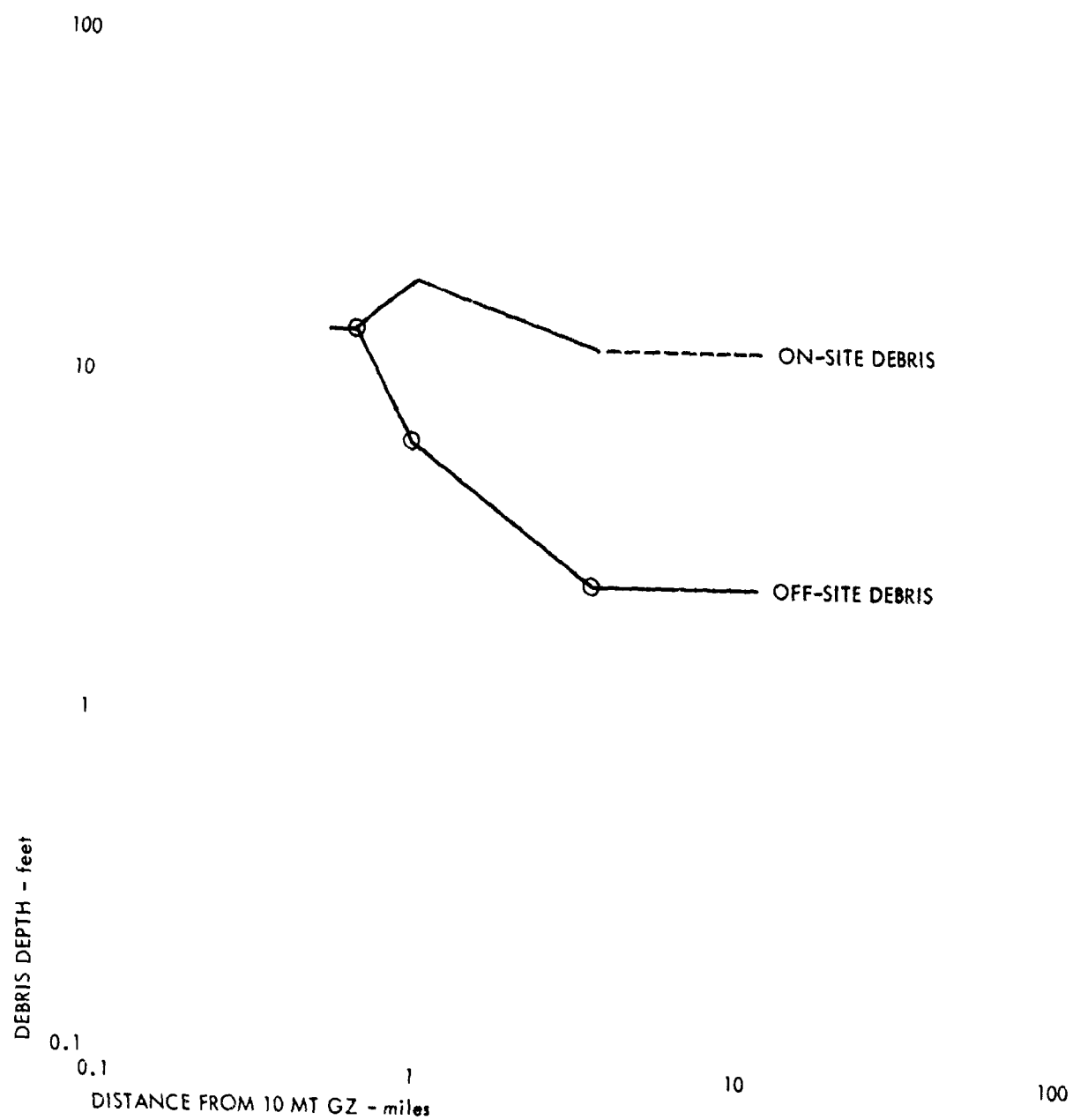DEBRIS DEPTH AND LOCATION FROM 16-STORY STEEL FRAME
REINFORCED CONCRETE OFFICE BUILDING WITH LIGHT INTERIOR PANELS

28
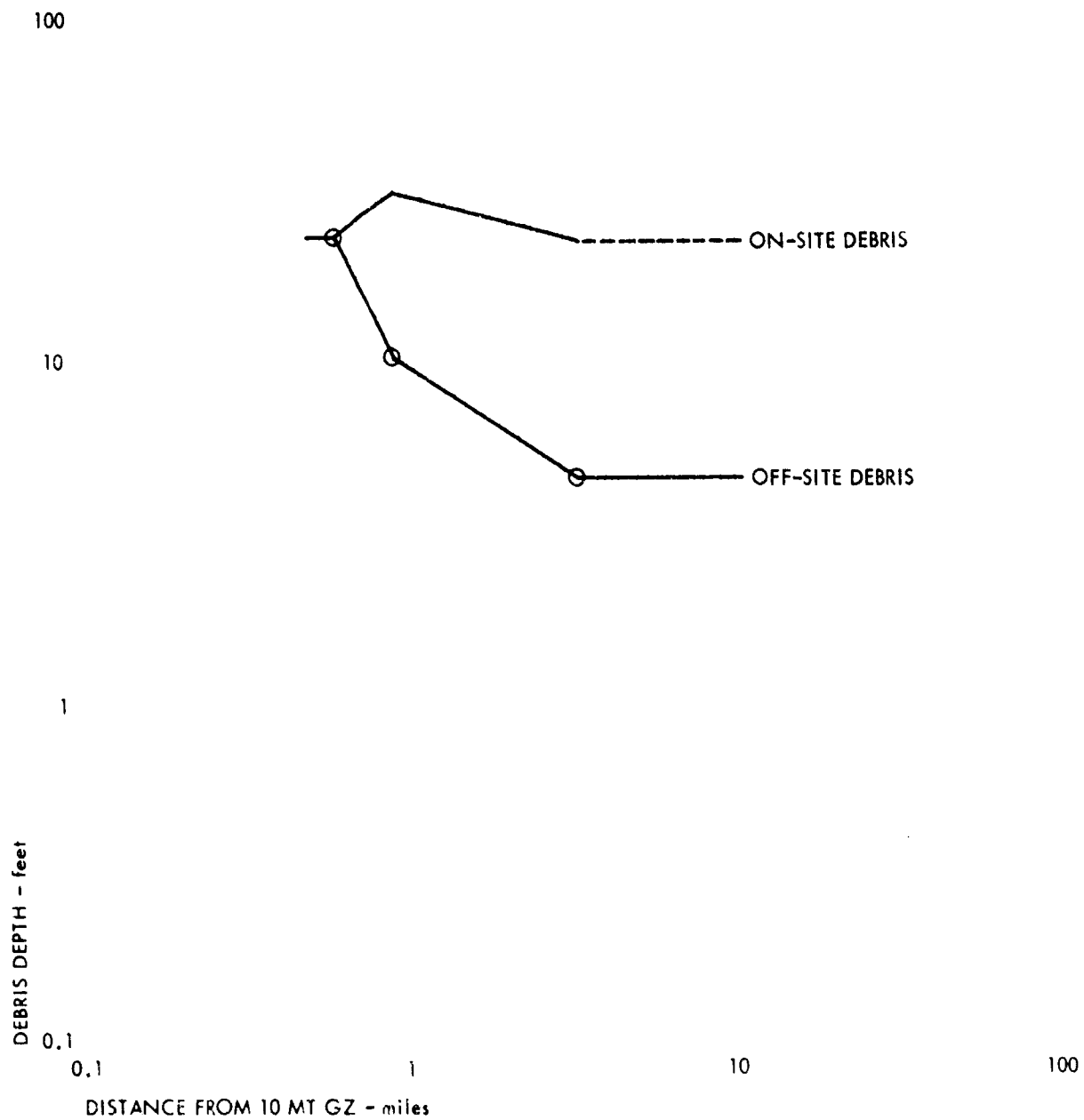
Figure 8

DEBRIS DEPTH AND LOCATION FROM 2-STORY WOOD FRAME RESIDENCE

△ ON-SITE WITH NO FIRE

ON-SITE AND OFF-SITE
BLAST SHATTERED DEBRIS
80% COMBUSTION

ON-SITE 90% COMBUSTION

OFF-SITE
(INSUFFICIENT FUEL TO
SUPPORT COMBUSTION)

DEBRIS DEPTH – feet

DISTANCE FROM 10 MT GZ – miles
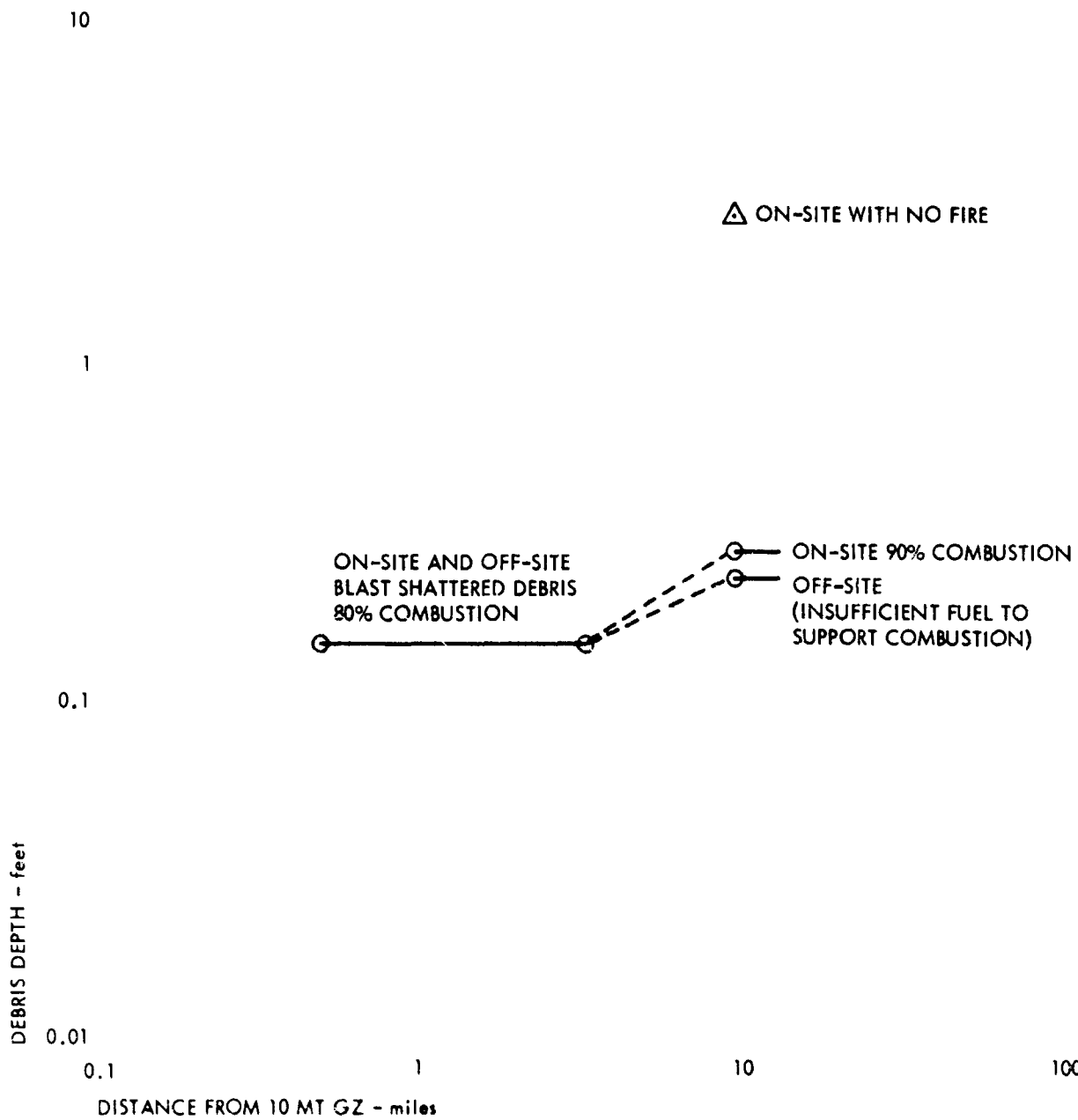
$$V_{off} = (1-R)V_{td} \qquad (20)$$

$$d_{on} = RV_{td}/A_p \qquad (21)$$

$$d_{off} = (1-R)V_{td}/(A_t-A_p) \qquad (22)$$

Where equations 14 through 18 are adaptation of equations from reference 14, and

V_{sm} is the volume of structure material

a is a constant

N is the number of stories

b is a constant

A_p is the structure plan area

F is the degree of combustion

M_c is the fraction of combustible materials

C is a constant

V_c is contained volume of the structure

V_{cm} is the volume of the building contents

K is the volume factor (no combustion)

K_f is the volume factor (combustion)

V_{tm} is the total volume of materials

V_o is the void volume

V_{on} is the on-site volume

V_{td} is the total debris volume

R is the ratio of the on-site to off-site debris volume

V_{off} is the off-site volume

d_{on} is the on-site depth

d_{off} is the off-site depth, and

A_t is the total ground area

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The values used for the example calculations are as follows:

Blast region $F = 0.1$

$1 \leq R \leq 3$

Fire region $F = 0.9$ except where the blast debris is
is less than 0.3 ft

Blast and
Fire region $0.1 < F < 0.9$

$3 < R < 5$

$A_t = 2A_p$ in the downtown area, and

$A_t = 5A_p$ in the residential area

The values of a, b, c, K, and K_f (from Reference 14) are listed in Tables A-1 and A-2 in the appendix for the various building types.

Presented in Figure 9 are smoothed curves of off-site debris depths obtained by extrapolating the data in Figures 5. 6, and 7 to different building heights. The same procedure used to construct Figures 5 through 9 can be used for various building types and usages by using the data in Tables A-1 and A-2. The debris depths as a function of distance from ground zero could also be estimated for various weapon sizes. It appears from the debris depth plots in Figure 9 that, except for downtown areas with very tall buildings, and downtown areas with moderately tall buildings in the severe blast damage region, the off-site debris can be expected to be rather shallow, i.e., less than 10 feet deep beyond 1 mile and less than 5 feet deep beyond 3 miles from a 10 MT ground zero.

The total time required for clearing debris to provide access and transportation paths in a damaged region can, therefore, be estimated from determining the debris depths (in the streets) with Equations 14 through 22, the data provided in Tables A-1 and A-2, and the rates of debris clearance from Equations 1, 2, or 3 (for fragmented debris suitable for the designated debris clearance equipment), in conjunction with Equations 11 and 13.

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Figure 9

OFF-SITE DEBRIS DEPTHS FOR VARIOUS BUILDINGS
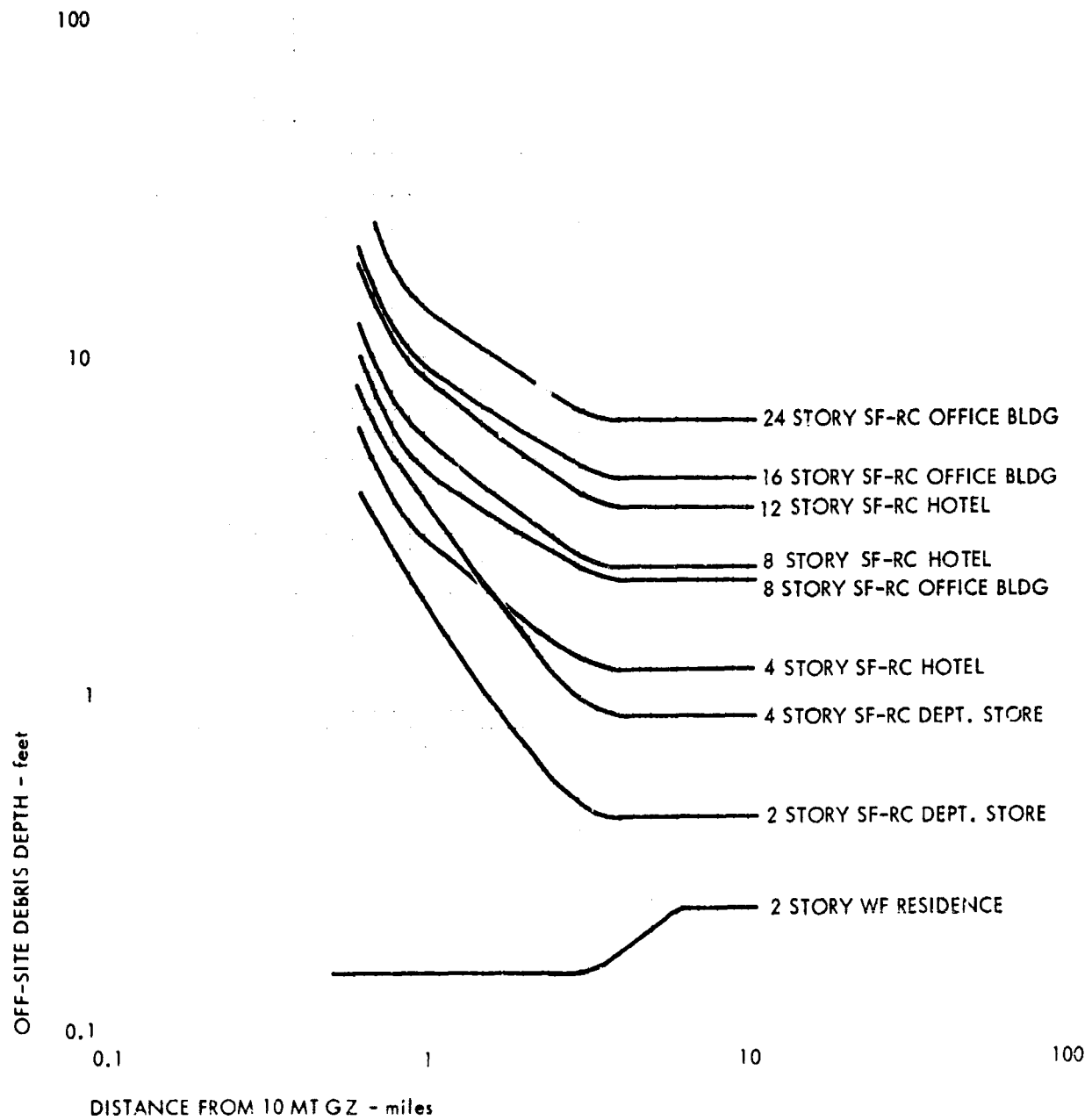
Debris Clearance Model Inputs and Outputs

The example data presented on debris production, debris location, and debris clearance operational rates were based on rough estimates only. More will have to be known about the mechanism of debris production and transport (by blast overpressures and dynamic pressures) as well as fire phenomenology to obtain reliable quantitative data. As will be shown in a later section, recovery operations in the light damage areas assume considerably greater importance than areas of intermediate and heavy damage because the area of light damage is so much larger than the latter two areas. It is also in the light damage areas that debris will not be evenly distributed. Debris removal rates for various debris characteristics in combination with removal equipment and procedures will also require development. The basic input data for the Debris Clearance Model are:

1. Weapon effects data

    a. Overpressures
    b. Dynamic pressures
    c. Thermal flux
    d. Fallout parameters

2. Debris production data

    a. Structural characteristics

        (1) Type
        (2) Size
        (3) Materials
        (4) Strength
        (5) Failure characteristics
        (6) Ignition vulnerability
        (7) Combustibility

    b. Building contents

        (1) Amounts
        (2) Ignition vulnerability
        (c) Combustibility

3. Debris clearance vulnerability

    a. Personnel

        (1) Location
        (2) Protection

    b. Equipment and supplies

        (1) Inventory
        (2) Location
        (3) Vulnerability

4. Debris clearance data

    a. Methods
    b. Effort and rates
    c. Skills required
    d. Clearance requirements

The basic outputs from the Debris Clearance Model are:

1. Debris clearance schedules

    a. List of tasks

        (1) Start times
        (2) Completion times
        (3) Methods and task descriptions

    b. Manpower assignments

2. Equipment lists

3. Supply requirements

Damage Repairs

The Recovery Requirements Model identifies the industrial systems and the minimum production rates that must be attained at any time to meet the need of the survivors. There is no point in repairing a facility if materials inputs or service inputs to the facility will not be available or if the output products of the facility cannot be used. For instance, if flour, fuel, or electricity is unavailable or there is a shortage of qualified operating personnel, then the repair of a damaged bakery still does not enable it to produce bread. Also, if only a few bakeries were needed to meet the demands for bread by the surviving population within a geographical region, the repair of all damaged bakeries in the region would only produce a surplus bread baking capacity. Thus, before any recovery effort is initiated, the combined production capabilities of undamaged facilities and damaged but reparable facilities should be compared with the minimum production requirements.

Reference 2 gives the maximum production rate for a process k producing commodity i as the minimum production rate obtained from the following four equations:

$$\dot{O}_{ik} = a_{ijk}\dot{R}_{ij} \tag{23}$$

$$\dot{O}_{ik} = b_{ik}N_k \tag{24}$$

$$\dot{O}_{ik} = e_{ijk}\dot{I}_{\ell k} \tag{25}$$

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$$\dot{O}_{1k} = \epsilon_{ik}\dot{P}_k \qquad (26)$$

where $\dot{R}_{ik}$ is the magnitude of the input rate of resources j (materials), N_k is the number of people associated with process k, $I_{\ell k}$ is the magnitude of the input rate of resources ℓ (other than people and materials), $\dot{P}_k$ is the maximum capacity rate, and a, b, e, and ϵ are production limiting coefficients.

If a process or facility is damaged, the product of $\epsilon_{ik}\dot{P}_k$ may be reduced or may be equal to zero until the damage is repaired for the pre-damage mode of operations. By altering the operations within the facility, on the other hand, such as increasing the manual operations to compensate at least in part for the damaged mechanical functions, additional $\dot{O}_{ik}$ could be recovered. For the equations to be independent, it is necessary to consider the alternate production processes that are feasible within a damaged facility and include a set of values for the production parameters for each alternate process. The minimum $\dot{O}_{ik}$ obtained for each set of equations representing an alternate process is the maximum production for that process, and the maximum of the minimum production rates obtained from each set of equations is the maximum production capability of the facility for producing commodity i.

If the combined production capabilities of undamaged and damaged-reparable facilities, taking into account the availability of input materials and services and operating personnel, can meet or exceed the minimum production requirements, then recovery procedures can be planned. If the combined production capabilities of undamaged and damaged-reparable facilities cannot meet the minimum production requirements, alternate counter-measures other than or in conjunction with facility recovery must be considered.

With respect to time, the repair of the various facilities should be scheduled to provide facility recovery with sufficient lead time for resumption of production when and in the amount that is needed. To develop the schedule, analysis of the interrelationships of inputs and outputs among the vital industrial systems is required. Because the production of different products is regionally oriented, the analysis is not restricted

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to geographical regions but must include the transport of imports, and the production and transport of exports from one region to another as well as local distribution. The damage repair capabilities within a geographical region must therefore be programmed not only to meet internal requirements but also to meet external requirements. Figure 10 presents a procedure that would provide postattack planning decisions at the local level.
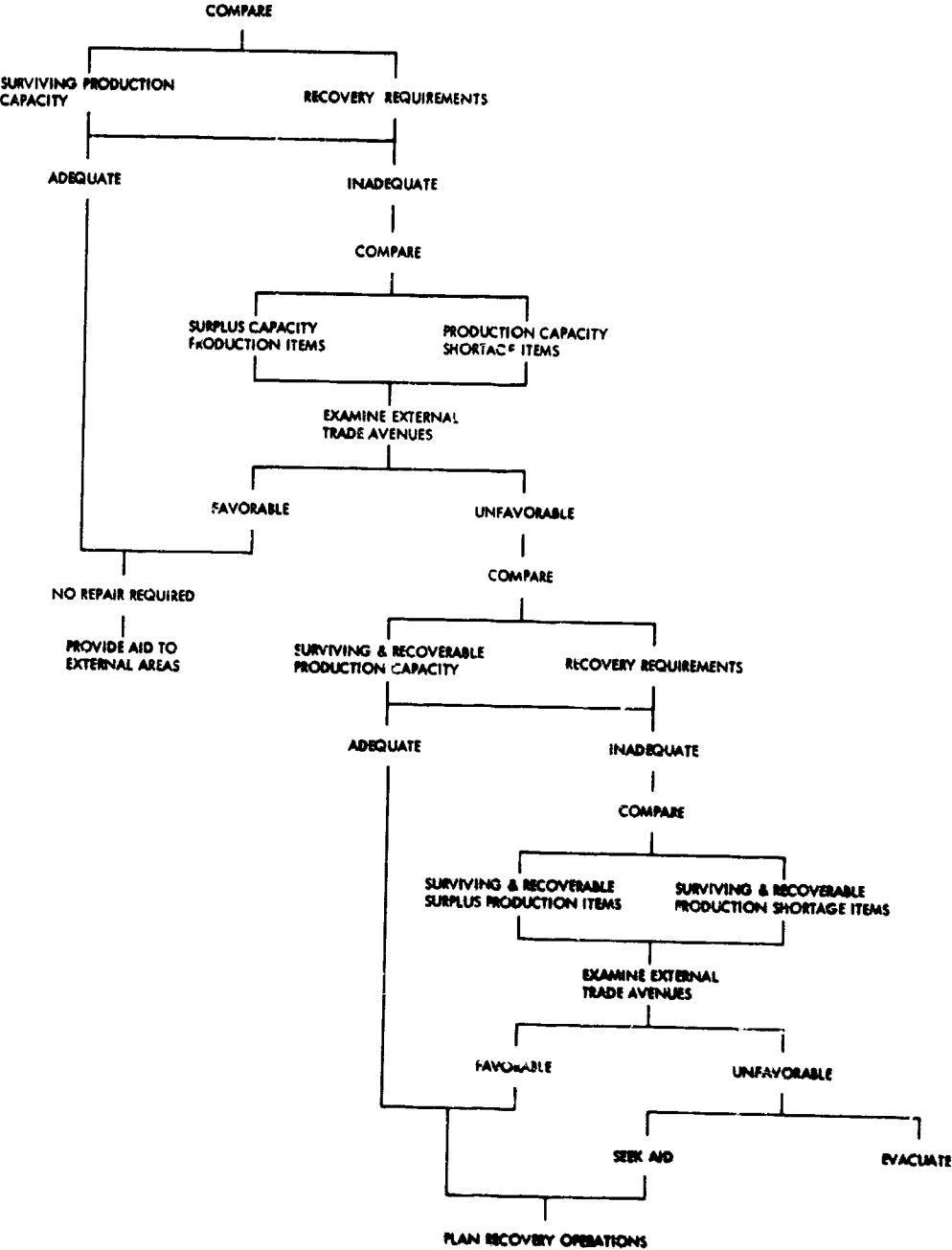
At the national level, all local postattack data would be summarized in the following categories to facilitate recovery planning.

1. Surviving productive capability in each industrial sector

2. Surviving facility potential in each industrial sector

3. Surviving personnel potential in each industrial sector

4. Productive potential in each damage category for each industrial sector

5. Surviving stockpiles

The fact that a facility survives would be insufficient reason for reactivating its functions. The above information along with interindustry requirements data is needed to provide the basis for selectively scheduling the reactivation of surviving facilities, the repair of damaged facilities, the movement of personnel, and the rebuilding of facilities (at least to the extent needed for continued survival of the population, especially if manpower is a limiting factor; where the latter is not the case, the scheduling of manpower utilization would not be critical).

For any postulated or actual condition of a nage, a repair requirement could arise; if the type and degree of damage could be adequately described, those familiar with the particular types of damage and the attendant repair problems could provide a damage repair estimate. Past practice has been to consult with plant personnel in ascertaining the magnitude of the repair problems. In general, plant personnel are only familiar with minor damage repair and maintenance operations under normal conditions, and consequently their estimates can be assumed to be reasonably reliable where the assumed damage is relatively light.

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Figure 10

LOCAL LEVEL PLANNING

COMPARE

SURVIVING PRODUCTION CAPACITY — RECOVERY REQUIREMENTS

ADEQUATE — INADEQUATE

COMPARE

SURPLUS CAPACITY PRODUCTION ITEMS — PRODUCTION CAPACITY SHORTAGE ITEMS

EXAMINE EXTERNAL TRADE AVENUES

FAVORABLE — UNFAVORABLE

NO REPAIR REQUIRED

PROVIDE AID TO EXTERNAL AREAS

COMPARE

SURVIVING & RECOVERABLE PRODUCTION CAPACITY — RECOVERY REQUIREMENTS

ADEQUATE — INADEQUATE

COMPARE

SURVIVING & RECOVERABLE SURPLUS PRODUCTION ITEMS — SURVIVING & RECOVERABLE PRODUCTION SHORTAGE ITEMS

EXAMINE EXTERNAL TRADE AVENUES

FAVORABLE — UNFAVORABLE

SEEK AID — EVACUATE

PLAN RECOVERY OPERATIONS

The repair of moderate to heavy damage is generally outside the experience of most repair personnel. The repair constraints on materials, support services, and manpower will undoubtedly be significantly altered by the attack. For these reasons, estimates of repairs obtained from informal interrogation of plant personnel about damage in the moderate to heavy range may generally be considered only educated guesses. The estimation of time and cost for major repairs or construction is normally the pursuit of professional staffs of engineers and estimators. These estimates are made with the use of standard labor rates for specific tasks, e.g., a glazier is expected to set 30 lights of size 22-inch by 16-inch glass to steel windows per 8-hour day. For a reliable estimate of the time and cost for the recovery of several damaged facilities within an urban complex, it is necessary to make detailed repair estimates for each damaged critical component within each facility. The total cost is obtained by the summation of the detailed costs, but the elapsed time will depend on the availability of repair personnel, repair equipment, and repair supplies, e.g., a carpenter who must use a hand saw because electricity is unavailable for powering an electric radial saw will be far less effective, and more time must be allowed for the same task than for the case where electricity is available.

Reference 2 gives the maximum recovery lead time for each successive stage in the recovery of the output from the k processes (because of lack of inputs) as

$$T_i = t_i + \sum_{\ell=1}^{r} \sum_{k=1}^{p} \Delta t_{ik\ell} \tag{27}$$

where $\Delta t_{ik\ell}$ is the maximum additional delay resulting from any cause other than processing, transport, and storage, e.g. radiological recovery operations or repair of damaged facilities. The double sum indicates a maximum delay for sequential recovery, which probably would not be the general case where several recovery countermeasures are carried out simultaneously by different groups of people. The minimum delay time requirements would be established by comparing estimates from

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$$T_i^O = \frac{E_i^O + O_i}{N_i \dot{c}_i} \tag{28}$$

to determine feasible limits for the second term of Equation 27.

Reference 2 defines the symbols in Equations 27 and 28 as follows:

t_i consumption delay time

r   number of inputs ℓ in the production of commodity i

p   number of processes or types of equipment k in the production of commodity i

E_i^O inventory of commodity i at the start of the postattack period

O_i magnitude of the output of commodity i

N_i total number of people or consumers of commodity i

$\dot{c}_i$ rate of consumption of commodity i per person

Collectively, the human resources within an urban community, just before attack, are equal to the sum of the individual capabilities. Within a population group, the total human resources may be expressed as $\sum N_s$, where N_s denotes the number of people in each ability category or occupational code (see Reference 17). However, with supervision, other people within the population group have some degree of proficiency for performing the specified tasks. Also, some recovery tasks do not require a great deal of skill or training.

The consumption delay time, t_i, in Equation 27 is the delay time (processing, transport, and storage) for a series of processes in a production system to convert raw materials to a consumption commodity i, and therefore a series of time phased process recovery schedules (sequential or overlapping) is indicated for each consumption commodity. The additional delay for the repair of damages (or for radiological recovery operations), $\Delta t_{ik\ell}$, is tied directly to each process in each production system requiring repairs. The repair required for any one process within a production system may also necessitate time phased scheduling. The repair

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personnel, on the other hand, are not necessarily tied to any one process or production system, and thus their efforts may be scheduled over several processes within a production system or over several production systems. This is also true for various equipment required to perform certain repair tasks.

The resolution of the repair portion of $\Delta t_{ik\ell}$ for any process not only requires a detailed knowledge of the repair skill and effort that is needed and the order and time that each skill and effort could be applied, but also the availability of repair personnel, repair equipment, and repair supplies. All the processes in all the production systems requiring repairs, on the other hand, must use repair personnel from the survivors, surviving repair supplies, and surviving repair equipment. Other recovery operations, such as radiological decontamination and debris clearance as well as the repair of nonproduction facilities, will also use these surviving resources. Any delay in the initiation of recovery operations (e.g. because of radiological restrictions on the unavailability of recovery resources) must be added to $\Delta t_{ik\ell}$; the result is an increase in the total elapsed time before production output can be re-established. The resolution of $\Delta t_{ik\ell}$ for any process, therefore, requires the collective resolution of the $\Delta t_{ik\ell}$ for all processes.

The Recovery Requirements Models identify the systems that must be recovered and provide estimates of the minimum production requirements, including the latest time after attack when the system must be operable. To meet the minimum production requirements, the damaged facilities that constitute the production deficit for each production process must be repaired. The scheduling of the repair effort, to be drawn from the surviving repair resources, requires the identification of the repair tasks, estimates of the repair efforts for each task by skills, estimates of repair equipment and supplies, and the times and magnitudes of their application for each process in each production system.

The recovery requirements can be met only if the repair requirements can be met. The repair requirements, therefore, consist of a schedule of the repair personnel needed by number and skill, and the equipment and supplies needed each day over the entire repair period. The ability to

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meet the repair requirements is tested by comparing the daily repair needs
of the combined production processes of all the critical production sys-
tems with the surviving repair resources that could be fielded each day.

Constraints on continuous full employment of surviving repair re-
sources are mismatches among surviving repair personnel, surviving repair
equipment, surviving repair supplies, and the specific repair tasks.
Utilization of repair equipment is also interrupted whenever it is nec-
essary to transport the repair equipment from one process location to
another. A possible additional constraint on the use of surviving repair
personnel is a limiting radiation exposure. This constraint limits af-
fected personnel, depending on their past and projected future exposures
and the limiting exposure dose criteria, to specific periods of employment
or specific locales of employment, or both.

Thus if the repair requirements are to be met, it is necessary that

$$\sum N_s, \ E_s \geq \dot{N}_j, \dot{P}_j \tag{29}$$

and

$$\sum S_s \geq \sum R_j \tag{30}$$

where the availability of N_s, the surviving number of repair people in
each skill, is determined by the Decontamination and Dose Control Model;
the availability of E_s, the surviving number of specific repair equipment,
depends on the number of surviving and the time required to transport the
equipment from one location of use to another (including shut-down and
set-up times), S_s is the surviving amount of specific repair supplies,
$\dot{N}_j$ and $\dot{P}_j$ are the instantaneous peak repair requirements of specific re-
pair people and equipment, and R_j is the amount of specific repair sup-
plies required.

Preattack Damage Assessments

The vulnerability of a facility or industrial system component to
nuclear attack depends on the type of facility or component as well as
its "hardness" and its distance from burst points. For instance, a sugar

refinery complex may be so located that each component in the complex would be subjected to approximately the same blast overpressures. Here the hardness of each component determines not only its vulnerability but also, where key components are concerned, the vulnerability of the entire refinery. A network of streets and roads on the other hand would be subjected to a wide range of effects because of the differences in the distance of each segment from a burst point; but in this case, the sections of the network that are heavily damaged could be bypassed by rerouting the traffic, and the system remains operable even though parts (noncritical) of the system network are totally destroyed.

Finally, the vulnerability of nonstationary and interchangeable components of a system, e.g., vehicles, must be analyzed by another procedure. Here the locations of the vehicles vary from time to time, also the vehicles located near the blast point and destroyed could be replaced by vehicles at other locations because of their inherent mobility. The degree of damage, in this case, is generally expressed as a percentage of the total number of vehicles (according to type and capacity) destroyed within a given area.

The first type of facility generally consists of equipment housed or partly housed within stationary structures and is generally confined to a limited area within an urban community. The viability of these facilities is dependent on the facilities of the second type. The facilities of the second type are characterized by central stations or complexes and an extensive network system that extends beyond the urban community boundaries. The critical network systems are as follows:

1. Electrical power

2. Telephone communications

3. Water

4. Sewage

5. Natural gas

6. Transportation

The productivity of people and industrial facilities are heavily dependent on the above critical systems; consequently, they are candidate systems for the initiation of urban-industrial recovery assessment. The first two systems are similar in that their networks consist mainly of wires. The water, sewage, and natural gas systems are similar to each other in that their networks consist of pipelines. The transportation system is different from the other five systems in that carriers are required along with a network of streets and roads, railways, shipping lanes, and airways, and also the materials transported are solids or in solid containers that come in all shapes and sizes and must be handled by men and equipment.

In the event of a nuclear attack on an urban community, the probability that these systems will be disrupted is virtually certain. The damage to the systems could be extensive, but total destruction of the system networks is unlikely. Because these systems are normally low maintenance systems, the need for repair manpower is expected to be critical. Where the repair requirements for complete recovery are excessive, system bypasses may provide for partial capacity operations. Thus the repair requirements for these systems may be analyzed as two separate components: (1) central complexes that are crucial to systems operations must be repaired or replaced (just like any industrial facility) and (2) damaged network sectors may either be repaired, bypassed, or properly disconnected.

The relative damage incurred by a facility is a function of facility characteristics with respect to the damaging effects of nuclear weapons. The facility characteristics that affect the degree of damage are equipment hardness, structural protection hardness, and ignition vulnerability. The damaging weapon effects are primarily overpressures, dynamic pressures, and thermal radiations; all are functions of weapon size, burst geometry, and distance. Dynamic pressures are important only at close ranges, and, at distances where they are unimportant, overpressures sufficient to cause virtual total destruction to most targets do occur.

In general, without considering the advent of fire, the area of light damage to processing facilities, where only moderate repairs are required to reactivate the facilities, is within the 0.5 to 2 psi overpressure

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region. The intermediate damage range is within the 2 to 10 psi region, and the heavy damage area where damage repairs are considered uneconomical, is in the region with overpressures in excess of 10 psi. These three damage areas are plotted as a function of radius versus weapon size for surface and air bursts, respectively, in Figures 11 and 13, and area size versus weapon size for surface and air bursts, respectively, in Figures 12 and 14. Also included in Figures 11 and 13 are the calculated thermal exposure maximum potential ignition radii.[1] As can be seen, the area of light damage for both types of detonations is many times larger than the intermediate damage area (6.7 times larger for both types of detonations), and the heavy damage area (35 and 55 times larger respectively for surface and air bursts). Thus, one can generally expect that about 85 percent of the damaged facilities within a target area will be in the light damage category, about 13 percent in the intermediate damage category, and only about 2 percent in the heavy damage category. Exceptions are where the urban-industrial area is relatively small (less than 1,000 square miles), where more than one weapon or very large weapons are used (multimegaton-age), or where a direct hit is made on a very concentrated industrial complex.

The importance of the light damage areas in postattack industrial recovery operations is further emphasized if the probability of uncontrolled fires is considered. As can be seen in Figures 11 and 13, the area enclosed by the maximum potential ignition radii includes all of the heavy damage area and all of the intermediate damage area for surface bursts, and all of the heavy damage area and most of the intermediate damage area for air bursts.

Damage Repair Model Inputs and Outputs

For process facilities in the light damage category, facility recovery generally entails such tasks as: clean-up operations that require no skill (laborers), replacement of glass and some structural repairs (carpenters, masons, and ironworkers), and some instrument and machinery repairs (technicians and mechanics). A nomograph is provided in Reference 18 for estimating moderate and severe damage to various building structural types as a function of weapon size, type of burst, and distance.

Figure 11

DAMAGE ZONES--SURFACE BURST

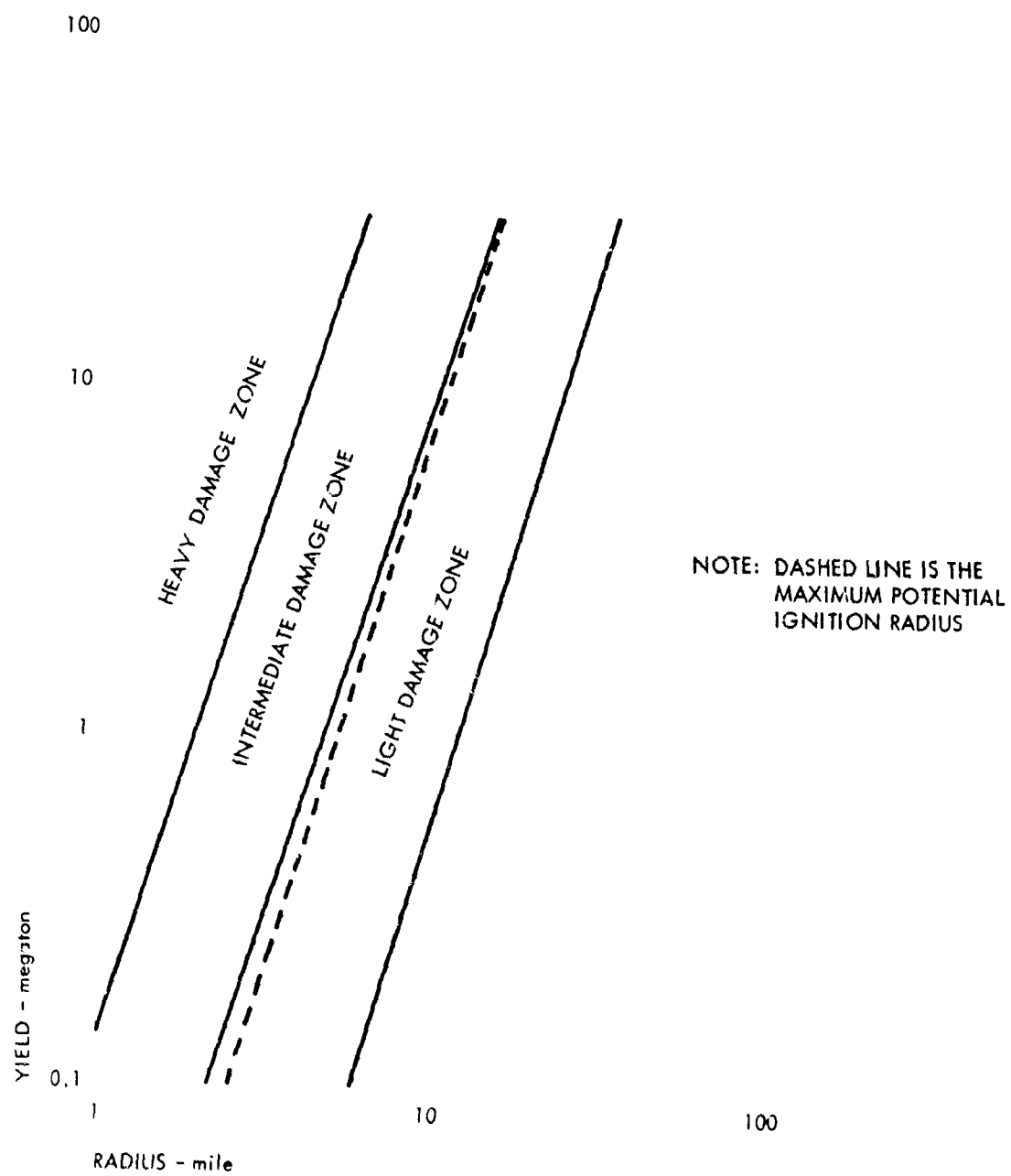NOTE: DASHED LINE IS THE
MAXIMUM POTENTIAL
IGNITION RADIUS

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Figure 12

AREA OF DAMAGE ZONES--SURFACE BURST

Figure 13
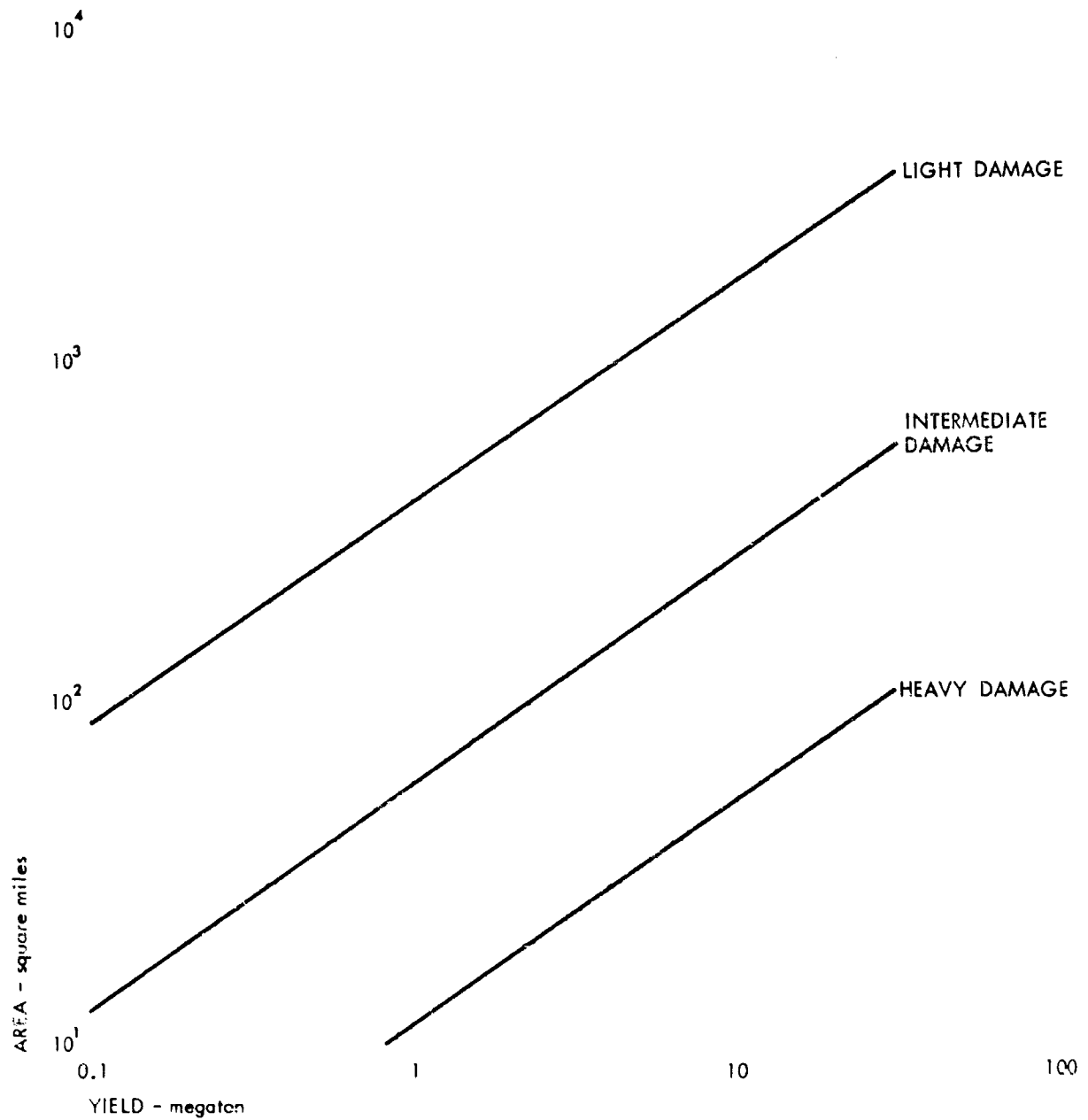
DAMAGE ZONE--AIR BURST

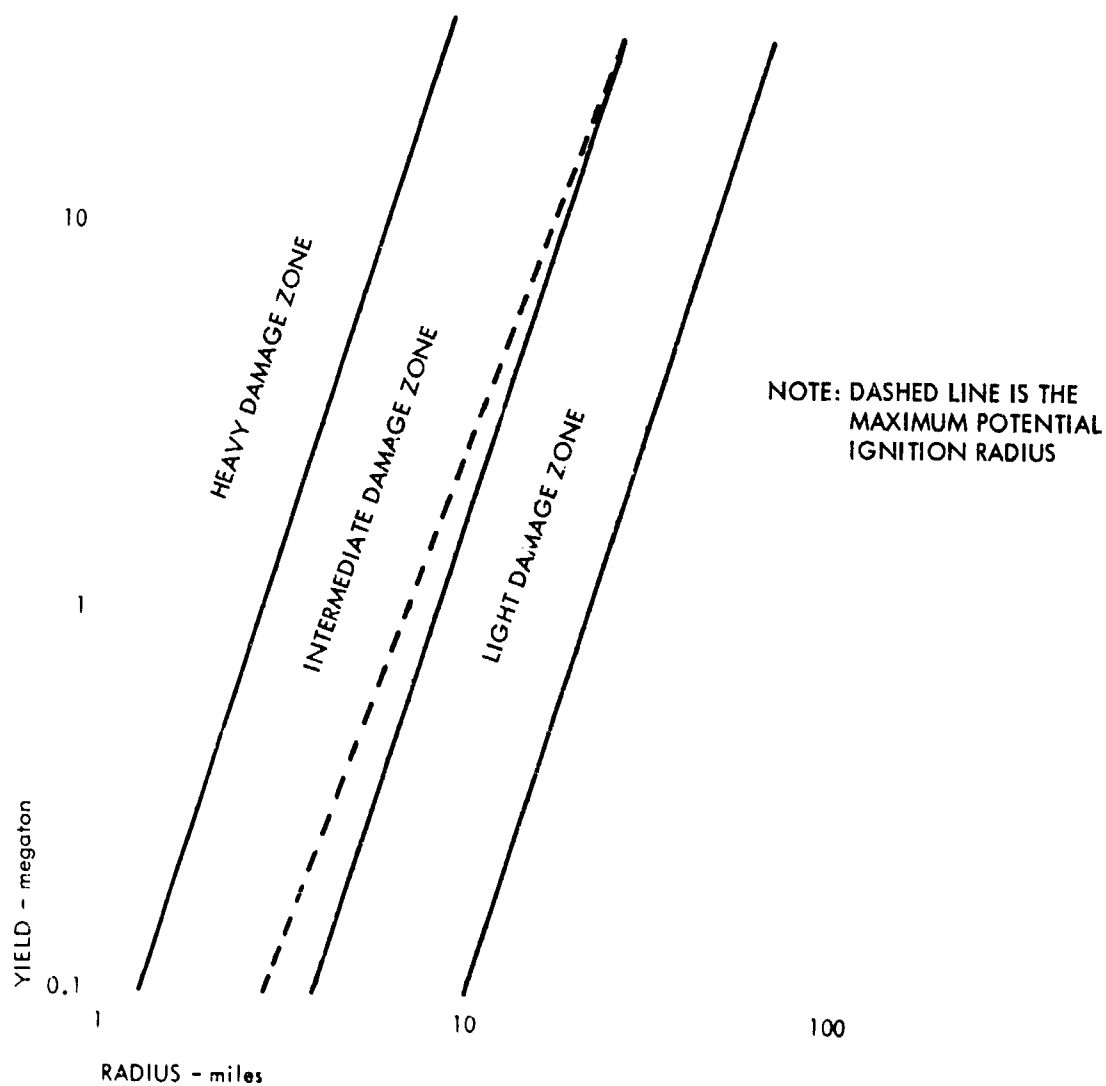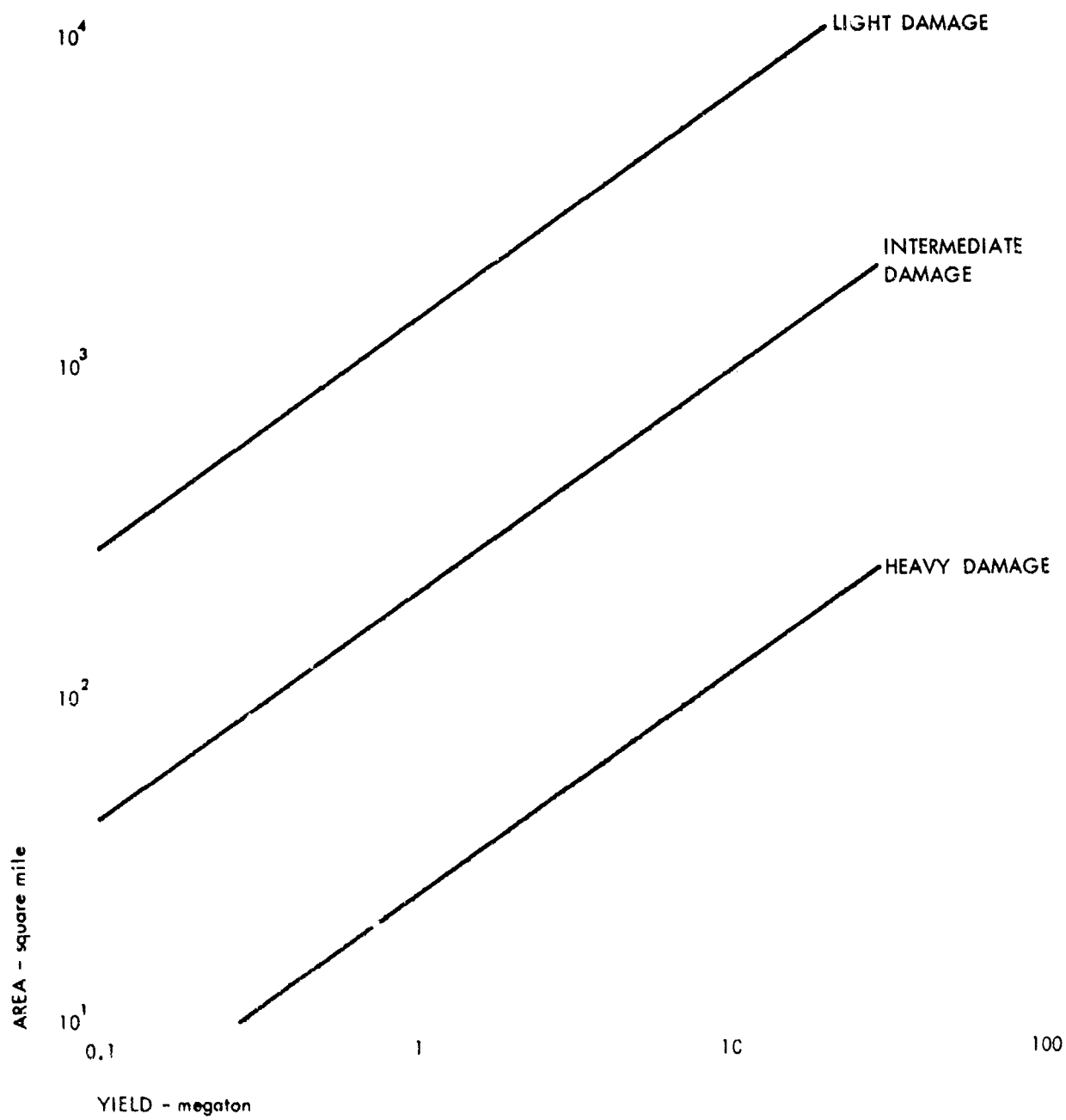NOTE: DASHED LINE IS THE
MAXIMUM POTENTIAL
IGNITION RADIUS

Figure 14

AREA OF DAMAGE ZONES--AIR BURST

Also some repair effort and elapsed repair time data as well as repair task descriptions, to various degrees of detail, are available for specific industrial process facilities as a function of overpressure exposures.[19],[20],[21] When this type of data is improved, expanded, and developed into model form for general application, it would be possible, with the use of the weapons effects models and the Recovery Requirements Models to predict the surviving resources, the constraints on the surviving resources, and the repair requirements for any locale. The basic input data for the Damage Repair Model are:

1. Damage assessments

2. Repair capabilities
    a. Personnel
        (1) Locations
        (2) Protection
        (3) Skills
        (4) Availability
    b. Equipment and supplies
        (1) Inventory
        (2) Location
        (3) Hardness
        (4) Availability

3. Repair Data
    a. Skills
    b. Effort
    c. Rates

The basic outputs from the Damage Repair Model are:

1. Damage repair schedules
    a. Number of repair personnel according to skills or occupational codes
    b. List of all facilities to be repaired
        (1) Start times
        (2) Completion times
        (3) Repair personnel assignment

2. Supplies requirements

3. Equipment requirements

4. Services support requirements

5. Facility production schedules

6. Exposure doses

An examination of the listed input and output requirements of the Damage Repair Model points to the necessity of obtaining the bulk of the basic input data from industrial facilities.

SUMMARY AND CONCLUSIONS

A Recovery Requirements Model is required for identifying the systems that must be recovered and for providing estimates of the minimum production requirements. At present, only general mathematical expressions relating recovery requirements model parameters to industrial model parameters have been developed. Since the Recovery Requirements Model when used in conjunction with industrial systems models is needed to provide a basic input for the Recovery Operations Models, it is recommended that it along with the industrial systems models be developed.

Recovery planning on the other hand can proceed only if the feasibility of various recovery operations can be assessed; this requires output from the Recovery Operations Models. The three recovery operations models, with respect to industrial recovery, are the Decontamination and Dose Control Model, the Debris Clearance Model, and the Damage Repair Model. Of the three recovery operations models, the most complete set of available data is that for Decontamination and Dose Control.

A start in the Debris Clearance Model, relating debris production to debris clearance efforts and rates, was presented. To the extent that the model will provide reliable output for recovery planning and scheduling, considerable more work in debris clearance modeling is recommended.

As a first step in damage repair modeling, the relative sizes of the areas of heavy damage, intermediate damage, and light damage were estimated. The light damage area is generally expected to be very large when compared with the areas of greater damage and generally constitutes the area where short term repairs will be feasible. Thus on industrial vulnerability and damage repair research, it is recommended that emphasis be placed on obtaining definitive data in the light damage area for the construction of a damage repair model.

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APPENDIX

The tables in the appendix were taken from Reference 14.

Table A-1

STRUCTURE VOLUME VS BUILDING TYPE

Building Type	Volume Formula	Percent Incombustible
1. Wood Frame Residential		
a. 1st floor slab on ground	$\left[0.55 + (N-1)(0.525)\right]A_p$	42 - S&P 28 - W&P
b. 1st floor on std. joists	$\left[0.7 + (N-1)(0.525)\right]$	2 - W
2. Steel Frame Industrial		
a. Light W/CI sheathing	$0.02\ A_p$	0
W/CA sheathing	$0.087\ A_p$	0
b. Heavy W/CI sheathing	$0.037\ A_p$	0
W/CA sheathing	$0.095\ A_p$	0
3. Load-Bearing Masonry With or Without Reinforcing - Combustible Interior Framing	$0.12\ V_c$	$80 - \frac{1}{300}\ (A_p - 1000)$ $1000 < A_p < 7000$
4. Heavy Reinforced Concrete Shear-Wall		
a. W/lt. interior panels	$0.07\ V_c$	90
b. W/masonry interior panels	$0.12\ V_c$	93
5. Multistory Steel and Reinforced Concrete Frame With Earthquake Design		
a. W/lt. interior panels	$0.07\ V_c$	88
b. W/masonry interior panels	$0.11\ V_c$	92

55

Table A-1 (continued)

Building Type	Volume Formula	Percent Incombustible
6. Multistory Steel and Reinforced Concrete Frame (Non-earthquake design)		
a. W/lt. interior panels	$0.063\ V_c$	88
b. W/masonry interior panels	$0.10\ V_c$	92
7. Light Reinforced Concrete Shear-Wall (single story)		
a. Concrete roof w/lt. interior panels	$0.07\ V_c$	92
b. Concrete roof w/masonry interior panels	$0.075\ V_c$	94
c. Mill roof w/lt. int. panels	$0.037\ V_c$	85
d. Mill roof w/masonry interior panels	$0.05\ V_c$	92

LEGEND:

V_c	contained volume
A_p	plan area
N	number of stories
S&P	stucco exterior, plaster interior
W&P	wood exterior, plaster interior
W	all wood
CI	corrugated iron
CA	corrugated asbestos

Table A-2

BUILDING CONTENTS LOADS AND VOLUME FACTORS

Occupancy	PSF Combustible	PSF Total	Volume Factor K $(V = KA_p N)^*$	
			Total	After Fire
1. Apts. and Residential	3.5	5	0.625	0.02
2. Auditoriums and Churches	1	1.5	0.25	0.007
3. Garage				
a. Storage	1	15	0.75	0.30
b. Repair	1	11	0.55	0.20
4. Gymnasium	0.3	0.5	0.09	0.003
5. Hospitals	1.2	3	0.375	0.03
6. Hotels	4	5	0.625	0.013
7. Libraries	24	26	0.75	0.027
8. Manufacturing				
a. Comb. mdse. fabrics, furniture	13.5	18	1.8	0.07
b. Incombustible	1	11	0.55	0.20
9. Offices	7	12	1.2	0.10
10. Printing Plant				
a. Newspaper	10	23	0.9	0.20
b. Books	50	60	1.7	0.13
11. Schools	9.5	11	1.6	0.02

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* V = Volume in cubic feet

A_p = Plan area in square feet

N = Number of stories

** 25 percent of design load

Table A-2 (continued)

Occupancy	PSF Combustible	PSF Total	Volume Factor K $(V = KA_p N)$*	
			Total	After Fire
12. Storage				
a. Gen. mdse	14	35	6	0.3
b. Special		**		
13. Stores				
a. Retail dept.	7.5	12	2	0.10
b. Wholesale	10	16	2.7	0.12
14. Restaurant	2	3.5	0.6	0.02

* V = Volume in cubic feet
  A_p = Plan area in square feet
  N = Number of stories

** 25 percent of design load

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13. ABSTRACT

This report outlines a postattack recovery model system for recovery assessment and recovery planning. A major component in the model system is the Recovery Operations Models. These models consist of the Damage Repair Model, the Debris Clearance Model, and the Decontamination and Dose Control Model. The most complete set of available input data is that for Decontamination and Dose Control Model. Preliminary findings regarding the Debris Clearance Model, relating debris production to debris clearance efforts and rates, were presented. Also, as first step in damage repair modeling, the relative size of the areas of heavy damage, intermediate damage, and light damage were estimated. The light damage area is generally expected to be very large when compared with the areas of greater damage and generally constitutes the area where short term repair will be feasible. A recommendation was therefore made that emphasis be placed on obtaining definitive data in the light damage area for the construction of a damage repair model.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Decontamination						
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Nuclear attack						
Postattack planning						
Recovery operations						