UNCLASSIFIED

AD NUMBER

AD815846

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; NOV 1966. Other requests shall be referred to Office of Civil Defense, Washington, DC.

AUTHORITY

OCD D/A ltr, 18 Nov 1971

THIS PAGE IS UNCLASSIFIED

AD815846

POSTATTACK RECOVERY OF DAMAGED URBAN AREAS

CONTRACT NO. OCD-PS-64-201
OCD WORK UNIT NO. 3331A

[redacted]

STANFORD RESEARCH INSTITUTE

MENLO PARK, CALIFORNIA

STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA

SRI

November 1966

POSTATTACK RECOVERY OF DAMAGED URBAN AREAS

By: PHILIP D. LaRIVIERE AND HONG LEE

SRI Project No. MU-4949-130

CONTRACT NO. OCD-PS-64-201
OCD WORK UNIT NO. 3331A

Prepared for:

OFFICE OF CIVIL DEFENSE
DEPARTMENT OF THE ARMY
WASHINGTON, D.C. 20310

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of ____________________

Through:

CIVIL DEFENSE TECHNICAL OFFICE
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA 94025

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

ABSTRACT

The report presents mathematical formulas and computational procedures for assessing damage due to blast and fire and for estimating the fallout hazards from nuclear detonations in urban areas. Major consideration is directed to the delineation of the damage areas for the purpose of defining the locations and the extent of the areas in which clearance and repair operations could be carried out. The constraints on these operations are determined by estimating not only the extent of the combined nuclear effects of blast, fire, and fallout radiation but also the timing of the events in the developing environment. The net result of applying the procedures is a definitive description of the prerecovery state of the urban population, urban facilities, and urban resources that would be available for use in recovery operations.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS

TABLES

INTRODUCTION

Background

Knowledge of the type and degree of the postattack operational problems to be countered by the survivors of a targeted city is of crucial importance to their continued survival and their capability for organizing recovery efforts. The nature and scope of the postattack operational problems will depend on the severity and extent of the damage, the number of surviving people, the quantities of resources, the extent to which outside aid may be obtained, and the degree to which applicable preattack planning and preparation have been carried out. The operational aspects of recovery are coupled in an important way with the concurrent development of an organizational structure capable of functioning effectively to guide the operations through the postattack period. To date, no research effort has been devoted specifically to these combined problems for a damaged urban environment.

Considerations of the problem for a damaged urban area may be divided into three classes: (1) technical, (2) operational, and (3) organizational. Most of the technical problems entailed in assessing the effects of nuclear weapons are well known and will not be repeated here, except to state that among the most difficult technical problems are the blast vulnerability of people in various structures, and the incidence and spread of fires from thermal radiation and secondary causes. These problems are currently being studied, and some progress has been made. For example, although no generalized fire model now exists for making detailed damage assessments of the thermal effects, a model for estimating significant interior primary fires has been developed.[1] In addition, each contemplated survival and recovery action requires the consideration of technical factors.

As for the operational problems, an excellent summary of the state of the art appears in a recent comprehensive study for the Director of Defense Research and Engineering, Department of Defense:[2]

> "Certain operational-type difficulties became apparent in the course of this study. The first of these was that differentiations in operational criteria between emergency and long-term operations were not made; in many cases the emergency operational criteria were also applied to the long-term type recovery operations with complete neglect of the intermediate emergency operations. In other words, no model systems have been developed to

estimate emergency operation requirements for personnel, equipment and supplies, exposure doses, and other needs which would carry over into the longer term."

It was also pointed out that the lack of a system for estimating losses of skills in manpower forced the assumption that certain operations would be carried out. An additional important deficiency noted was the lack of stated postattack recovery requirements for goals to be achieved or outputs to be met. In other words, specific relationships between the needs of the survivors, the usable resources, and recovery operations have not yet been derived for the purpose of testing the feasibility of achieving a desired national goal or posture in the postwar world.

The problems of maintaining a functional organization, degraded by the effects of an attack, have not been studied in any detail. In the work cited, these problems were recognized, however, and a statement was made that " . . . these problems are among the critical unresolved civil defense problems in terms of real capability of local and higher echelons of civil defense organizations to carry out operations in nuclear war environments."

In the present report, attention is focused on some of the operational problems of debris clearance and damage repair expected to confront the survivors in a targeted urban area. Part of the work consisted in integrating the results of other related research, such as the research on techniques of predicting debris production and debris clearance studies,[3-10] and industrial damage and repair.[11-14]

Objectives and Scope

The objectives of this research are to:

1. Develop conceptual and mathematical models for postattack debris clearance and repair operations in targeted metropolitan areas.

2. Analyze the damage environment and the operational problems entailed in the recovery of selected facilities by the survivors in or near a targeted urban area.

Other aspects of the recovery problems of damaged urban areas, not considered in this report, include procedures for planning and scheduling the use of debris clearance and repair countermeasures. It is clear that preattack preparation is most essential to the successful implementation of these countermeasures as is the postattack availability of manpower, equipment, and supplies. Other aspects not discussed in detail include specifications of the postattack situations in which these countermeasures may be useful and the training requirements of these operations for development of the operational capabilities of local civil defense organizations.

Method of Approach

Two general methods of approach to achieve the objectives are available: (1) case study analysis and (2) general parametric analysis. The disadvantage of case study analysis is that generalized conclusions cannot be drawn from the results. The disadvantage of general parametric analysis is that details must be smoothed out or may be missed entirely by simplifications and generalizations on whose accuracy the validity of the conclusions depends.

Depending on objectives, the case study at best might yield results sufficiently insensitive to the particular inputs employed that the study would have some general merit; but since a priori knowledge of this outcome is not available, many case studies are required to establish confidence in the general validity of the results. The parametric approach at best could lead to the identification of certain broad relations whose characteristics are immediately recognizable as generally applicable, and hence may be of great utility in identifying the major important variables for more detailed study. A modification of the parametric approach is used in the present analysis.

Major consideration in the study was given to the damaged areas of cities; however, some attention was also given to undamaged areas in which fallout would be deposited. The urban areas under study were assumed, in most cases, to be initially isolated from other communities, so that the recovery effort within the area depended only on the survivors and remaining resources within the area.

To obtain information on initial situation conditions and a general description of the damaged area (as well as the recovery problems), general assessments were made regarding damage from a direct hit by a nuclear weapon on an urban area. Although the yield range for these assessments was taken to be 1 to 20 megatons, most of the illustrative calculations were made using an assumed yield of 10 megatons. Emphasis was given to the surface burst with its attendant stem fallout, mainly because the additional problems caused by the presence of fallout in the damaged region have been examined only cursorily in the past. For the most part, only a single detonation in the target area was considered.

Plan of the Report

The report begins with information leading to a description of the damaged region (i.e., the setting within which debris clearance and repair operations would take place). A method is developed for describing the time phasing of the events, blast, fire, and fallout, culminating in the postattack environment of the damaged area. The feasibility of trans-attack countermeasure options that could change the outcome is examined in the light of the combination of events as they would occur. The roles of clearance and repair in the recovery process are examined, and short-term and long-term actions are identified. Operational goals and concepts are then proposed, and equipment and manpower capabilities in various environments are assessed. The discussion concludes with a description of the data inputs and functional relationships that would be required for a specific case study of the recovery of a damaged urban area.

THE POSTATTACK SCENE IN A TARGETED URBAN AREA

The explosion of a 13 KT nuclear weapon over Hiroshima produced one of only two known urban areas damaged by the effects of nuclear explosion. Within a radius of approximately 6,000 feet from ground zero, innumerable fires sprang up almost immediately in the densely built-up core of the city; these fires grew and coalesced, forming a firestorm which reached its maximum intensity about 2 hours after burst[15,16] and did not begin to subside until some 4 hours later.[16]

Dense black columns of mingled smoke and dust rose almost at once over the afflicted area, eventually reaching a height of several miles. The pall of smoke obscured the sun, so that in some places 30 minutes elapsed before daylight returned. Later, sooty rains that were chilling to the exposed survivors fell in various parts of the city.[16]

Those who were able made their way on foot out of the burning ruins to refuge in undamaged parts of the city and to the park across the river. They were not threatened with radioactive fallout, although they had no way of knowing it at the time.

A megaton-range weapon, exploded in the midst of a modern city, would produce many effects similar to those observed in Hiroshima but over a much larger area. Other effects could be different, depending on the degree to which the modern city differed from Hiroshima in geometry, type of structure, and building density (number of buildings per unit area).

If at the time of attack the weather and the target response of a large city were exactly similar to Hiroshima, and a 10 MT surface burst were centered on the city, the equivalent firestorm radius is estimated at somewhere between 7 and 11 miles (provided the city was sufficiently large so that exposed fuels existed at those distances). The dust and smoke clouds could darken parts of the city for 5 hours; and the smoke and flying embers at ground level would further impair the vision of those seeking a way out of the area. If the fire build-up rate were the same as in Hiroshima, a somewhat smaller fraction of the people would escape to the fringe of the burning area because of the longer distances to travel.

However, most modern cities are not similar to Hiroshima in structural types, geometry, and building density. In addition, the peak overpressures near ground zero for a 10 MT surface burst are much greater than the maximum peak overpressures directly at ground zero for the Hiroshima burst. Thus while the 10 MT surface burst would cause complete destruction of structures at greater distance from ground zero than that observed in Hiroshima, this destruction would retard the burning rate of the flattened fuels (as is discussed later) in the center of the damaged region. The area in which mass fires from a direct hit could develop in the modern city would therefore be in the shape of a circular band around the burst point.

The above differences in target characteristics and in weapon effects (as a function of yield and zero-point geometries) indicate that valid critical extrapolations of the Hiroshima experience cannot be made without considering the details of the individual city. On the other hand, for any city, the effects of a 10 MT surface detonation would be much more destructive and widespread than those from a 10 to 20 KT air burst.

Within 45 minutes after the 10 MT surface burst, radioactive fallout would begin to blanket a roughly circular area around ground zero, extending 12 to 13 miles upwind and crosswind. In the downwind direction, the city would be progressively enveloped in fallout from the stem and cloud. The extent of downwind fallout would be very large compared to city dimensions; hence, most of the fallout from this detonation would pose no immediate threat to the targeted city, but the fallout could effectively seal off potential evacuation or access routes in the downwind direction from the city for some period of time. (Fallout from other upwind detonations, however, could complicate the threat situation in the damaged area and could arrive either before or after the detonation of interest.)

For the single weapon detonation, preattack and transattack countermeasure operations can be described so that the geographical disposition of survivors may be obtained for the start of the postattack period. In general, the major problem area can be divided into two or three environmental zones: (1) the central zone of total destruction of all aboveground structures (except the heaviest of blast resistant structures); (2) the moderate to light damage zone that encircles the central zone but in which very little fallout is deposited; and (3) a zone with the damage condition of zone 2, but in which the fallout deposit is heavy enough to restrict outside operations.

Except for persons located in high blast resistant shelters, the survival probability of people in the central zone would be small. The rate of fire spread and maximum fire intensity attained would depend on the percentage of fuel in the buildings that are all reduced to debris. If the central area is a built-up area of the downtown type buildings (large, tall steel-frame reinforced-concrete structures), extensive, rapid fire spread would be unlikely, although spotty fires and smouldering embers would probably exist over a long period of time. The probability of escape without external help from shelters within high blast resistant structures would be small because the shelters would be buried under the weight of building debris. If the central area was a residential area of wood frame houses, the percentage of fuel in the debris would likely be sufficient to cause fire spread but the fires would be less intense and have a slower rate of spread than the fires in zone 2. If high blast resistant shelters have been constructed in this type of central area, the transattack countermeasure options for the users would be similar to those for the people located in the moderate to slight damage region of zone 2, except that the operational constraints would be more severe.

Within the circular band of moderate to light damage area where mass fires could develop, many of the non-ambulatory injured and trapped people (even from a warned, in-shelter population for the current shelter program) would die from the ensuing fire as they did in Hiroshima, unless they were rescued or the fires were extinguished. For the ambulatory survivors, there would be two additional alternative operational choices: to stay in shelter (which may be physically damaged) and face the fire threat, or to leave immediately after passage of the blast wave in the hope of reaching the fire perimeter or a fire-free island before heat rendered passage through the debris impossible. In any case, the next and final direct threat, the fallout, would have to be faced, with ultimate survival being dependent upon the combinations of gamma intensity, protection factor, and stay time in the fallout area.

Immediately outside the major problem zones described above, people in shelter would be in a reasonably good position to survive, except that superficial damage (i.e., no structural damage) such as broken windows and stripped roof coverings could impair the shielding integrity of some of the structures now designated as fallout shelters. Over most of this region, depending on the geography and fallout levels, it might be possible for people to drive or even walk out of the fallout area after a short shelter stay period, if they knew when to leave and where to go.

Beyond 20 miles or so downwind from the explosion, where fallout alone would pose the immediate hazard, adequate shelter would virtually ensure survival, and on balance, the problems encountered by the shelterees would be very small compared with the problems within the damage area around the burst point.

The above qualitative description of damaged urban areas, in terms of their recovery at some time after an attack, indicates that a very broad spectrum of recovery problems could occur. Some parts of such areas would not be recoverable since they would contain a very small amount of recoverable resources. Other parts might be recovered only after expending a great deal of effort, whereas in peripheral areas, the remaining resources might be readily recovered. Thus, one aspect of the study was to investigate the damage environment for the purpose of identifying recoverable resources and facilities, and to outline the operational problems that recovery would entail in terms of the distribution and survival needs of the survivors.

This approach, which included consideration of the damage to an urban area from a megaton-range weapon delivered in the center of a large city, was taken so that all known combinations of weapons effects possible from a single detonation would be covered. This is not the "worst" case conceivable for a damaged urban area, since a larger weapon or multiple bursts distributed over the city (perhaps augmented by upwind surface bursts so that the most intense fallout blanketed the city) would clearly be worse with respect to survival and recovery. Where identification can be made that no recoverable resources would remain, considerations of postattack recovery would cease, even though people in blast shelters survived the effects of the explosion(s) through the attack and trans-attack periods.

In the following assessment of the postattack situation, the individual weapon effects are assessed according to the seriousness and extent of the damage produced; the time constraints imposed upon actions are examined, and the attempt is made to sum up the overall situation and time frame in which recovery and other civil defense operations could take place. Although a yield of 10 MT has been arbitrarily chosen as representative of megaton-range weapons in the examples shown, some data are presented for yields of 1, 5, and 20 MT as well.

STRUCTURAL DEBRIS FROM BLAST AND FIRE

Debris Production

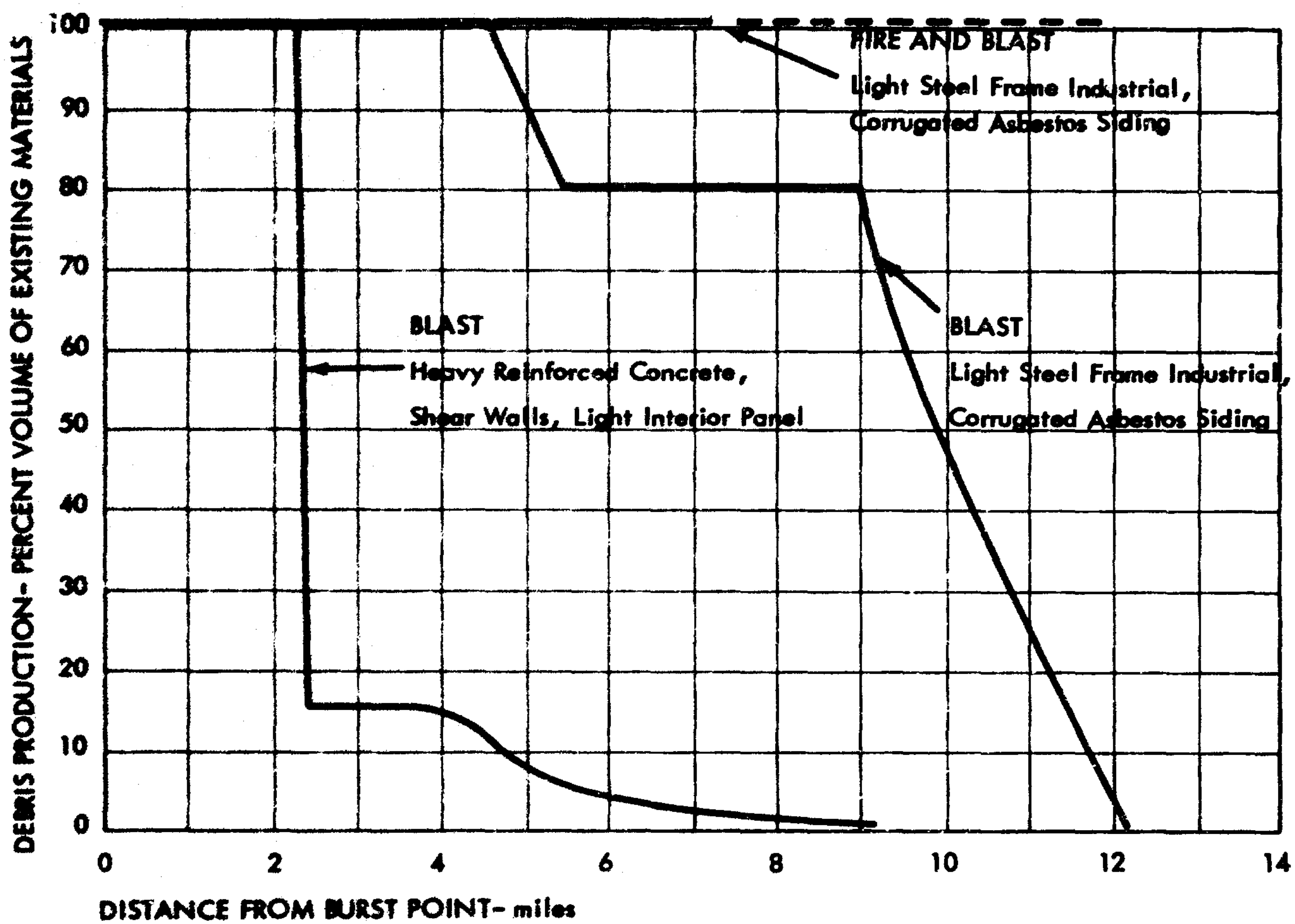
The URS Corporation has published three reports on the production of debris from buildings as a result of blast and fire.[8,9,10] Debris was defined in the first of these reports as "...the material contained in those portions of buildings or structures that have undergone complete failure due to air blast and, thus, impedes access to or through an area."

In these referenced studies, debris production is expressed in terms of percent of volume of the structural material that forms debris at a given overpressure, for yields of 20 KT and 20 MT. Reference 10, the final report of the series, presents debris production curves for blast, as well as debris from both fire and blast, for 15 building types; it also includes data and guides for estimating the contribution of building contents to the structural debris. Also important for estimating debris removal rates or the rate of travel that can be attained through the debris are the physical characteristics of the debris and its distribution. For example, the degree to which debris hinders travel, or the degree of difficulty of clearing debris from streets, does not depend upon the debris production but upon the amount and characteristics of the debris that lands in the streets. Reference 9 suggests that work should be continued in refining debris distribution procedures to increase the usefulness of the debris prediction techniques developed.

To determine where structural debris might be encountered in a damaged urban area, thereby delineating the extent or magnitude of the area in which clearance and repair operations could be carried out, the debris production curves in Reference 10 were used to select the most and least vulnerable structural type. Heavy reinforced shear-wall buildings, up to 3 stories high, were found to withstand the highest overpressure (33 psi) before complete destruction, and the onset of debris from light steel-frame industrial buildings with corrugated asbestos siding occurred at the lowest overpressure (1.5 psi). Debris production vs distance for these building types is plotted in Figure 1 for a 10 MT surface burst. It was assumed in this plot that the 20 MT curves of Reference 10 adequately reflect debris vs overpressure for the 10 MT yield also--i.e., scaling overpressure with yield to account for a slightly different blast duration was not justified, considering the inherent uncertainty in the basic debris data.

Figure 1

DEBRIS PRODUCED BY BLAST AND FIRE FROM A 10 MT SURFACE BURST



The bold 100% line in Figure 1 represents the combined debris produced by fire and blast. No line is shown for the heavy reinforced concrete building, since it differs only slightly from the blast-alone curve, because of the low volume of combustible building materials in this type of construction. Fire-produced debris from steel-frame industrial buildings is given in Reference 9 as 100%, independent of overpressure, under the assumption that the unprotected steel frame would be completely destroyed by heat from burning contents or from burning adjacent buildings. The right-hand end of the fire-debris line in Figure 1 is dotted, indicating an unspecified distance to which intense fires might be encountered, but this distance should be less than the maximum distance at which newspapers would ignite. According to ENW,[17] newspapers require 15 cal/cm^2 for ignition from a 10 MT thermal pulse, which by methods discussed later, is calculated to occur out to 11.8 miles in a clear standard atmosphere. Hence, the onset of debris production with fire should always occur within the distance at which blast debris commences.

From Figure 1, if the figure is read starting with the right-hand side, it can be seen that the onset of damage to the siding of the steel-frame buildings occurs at 12.2 miles. Since no structural failure of buildings is indicated beyond this distance, the region of debris clearance and repair operations would be between 2.4 miles and 12.2 miles from the burst point. And finally, the concrete building debris curve rises sharply at 2.4 miles to 100%, so that inside this distance, all ordinary buildings would be completely destroyed and no repair operation to above-ground facilities would be feasible.

Heavy duty machine tools and even lighter machine tools housed within sturdy structures that may be heavily damaged by the blast would not suffer substantial damage in the 2.4 to 12.2 mile region, barring damage caused by other than blast effects.[17] Thus, upon the removal of debris and perhaps some minor repairs, the machinery and equipment of certain facilities could be made usable. Also, whereas the heaviest earthmoving engineering equipment within the 2.4-mile radius would be damaged, even its lighter counterparts located within most of the 2.4-12.2 mile region should be usable, again barring damage caused by other than blast effects.

In these considerations, superficial debris has been ignored. This class of debris consists of stripped wall and roofing materials, exterior trim, light partitions, doors, window frames, skylights, window glass, tree limbs, signs, fences, and similar miscellaneous items. Superficial debris may be expected out to an overpressure of 0.7 psi,[17] or about 20 miles for the 10 MT surface burst example. While in ordinary context this kind of debris would represent an enormous cleanup and repair task, it is viewed here only in terms of a minor impediment to pedestrians and as a moderate obstacle to automobile traffic.

The consequences of loss of integrity of the lightly damaged structures with respect to protection from fallout radiations and to weather effects will be considered later. In sum, the zone in which major clearance and repair operations would take place is taken as the annulus from about 2.5 to 12 miles from the burst point. With the criteria developed above, this zone for some other surface burst yields would be: 1 MT--1 to 6 miles; 5 MT--2 to 10 miles; and 20 MT--3 to 16 miles.

Fire Limits

At Hiroshima, the burned over area about ground zero was approximately circular and covered 4.4 square miles,[15] so that the range was about 6,300 feet. It was also reported that there was little outward spread of the fire beyond the original perimeter of numerous ignitions. Hence, taking the yield of the Hiroshima weapon as 13 KT,* and the height of burst as 1,900 feet, the overpressure at this range was about 3.6 psi.

The thermal radiation at this range, employing a clear standard atmosphere (12-mile visibility) can be calculated as follows. From elementary considerations, the radiant energy in cal/cm^2, per unit area normal to the direction of propagation, at a distance S cm from the surface of the fireball, may be written as

$$Q = \frac{10^{15} FWT}{4\pi S^2} \tag{1}$$

where the constant 10^{15} is the equivalent yield in calories per MT, F is the thermal partition factor, W is the total yield in MT, and T is the atmospheric transmittance. For S in miles, Equation 1 reduces to

(for airbursts) $$Q = 1.014 \times 10^3 WT/S^2 \tag{2}$$

(for surface bursts) $$Q = 0.645 \times 10^3 WT/S^2 \tag{3}$$

employing thermal partition factors,[16] respectively, of 0.33 and 0.21. Following the methods of Gibbons[20] and Martin,[19] the empirical relationship between the transmittance T and visibility V is

$$T = (1 + 1.4\ S/V) \exp(-2\ S/V) \tag{4}$$

---

* The yield of the Hiroshima weapon was recently calculated from experimental measurements as 15.2 KT.[18] The overpressure and thermal flux values for this yield are respectively 5.5% and 17% higher than those used in the calculations above--values that do not significantly influence the results of this study.

if the effective height H_t of the radiation source is less than 0.25 miles. If H_t is greater than 0.25 miles, then

$$T = \exp(-\tau 6/H_t) \tag{5}$$

where τ is the extinction optical thickness from any altitude to sea level.

The effective height of the radiation source is related to the height of burst H or fireball radius R as follows:

$$H_t = 0.4\ R \text{ for surface bursts} \tag{6}$$

$$H_t = 0.7\ R \text{ for surface intersecting burst heights} \tag{7}$$

$$H_t = H \text{ for airbursts} \tag{8}$$

The fireball radius R can be computed from

$$R = kW^{0.35} \exp 0.0465H \tag{9}$$

where the coefficient k has the value 0.53 for surface bursts, 0.47 for intermediate burst heights, and 0.41 for airbursts.

Values of τ have been computed by Elterman[21] as a function of altitude and wave length. It has been argued that the most appropriate wave length to use in thermal radiation calculations is 0.65 microns, and that the visibility, as commonly observed, is about half as great as the meteorological range.[20] Since Elterman's tables are computed for a meteorological range of about 25 km at sea level, the corresponding implicit visibility is approximately 12.5 km or 8 miles. Martin has made an adjustment of τ for a visibility of 12 miles in his calculations,[19] from which it appears that Elterman's values were multiplied by about 2/3.

For a cloud layer between the fireball and ground surface, Gibbons prescribes that the transmittance for the clear standard atmosphere be multiplied by suitable constants, values of which are given.[20] Hence, it is important to note that although visibilities are often associated with atmosphere cloud type (e.g., for light haze, visibility = 6 miles), the association is inappropriate since it naturally leads to the erroneous use of visibility in Equation 4 or 5.

The results of some radiant exposure calculations for yields of 1, 5, 10, and 20 MT are shown in Figure 2 for surface bursts, and in Figure 3 for airbursts at the Hiroshima scaled height. For the 1 MT surface burst, H_t is 0.21 miles, and hence use of Equation 4 is indicated; however, Equation 5 was evaluated also, since H_t was close to 0.25 miles. The extent of the disagreement shown in the plot suggests that there is some discontinuity present at $H_t = 0.25$.

From Equations 2 and 3, Q is seen to be directly proportional to the transmittance; hence, the Q values in Figures 2 and 3 at any distance may be multiplied by the factors listed in Table 1 to obtain an estimate of the reduced Q at that distance for the cloud covers listed.

Table 1

TRANSMISSIVITY REDUCTION FACTORS
FOR AN INTERPOSED HAZE OR CLOUD LAYER

Type of Cloud	Factor
None	1
Light Haze	0.7
Medium Haze (bright gray-white)	0.5
Heavy Haze (dull gray-white)	0.3
Light Cloud (sky light gray)	0.3
Medium Cloud (sky dull gray)	0.2
Heavy Cloud (sky dark gray)	0.1

Sources: References 20 and 22.

In the Hiroshima case, for a clear standard atmosphere, the methods detailed above lead to a thermal exposure of the ground to 8.4 cal/cm^2 from the burst height of 6,300 feet.

The equivalent radiant exposure for ignition from a 10 MT weapon is 21.2 cal/cm^2. This value was obtained from a comparison of the average ignition exposures of a number of fabrics given in Tables 7.40 and 7.44 of ENW[17] for yields of 40 KT, 1 MT, and 10 MT. On the average, the ignition exposures for 1 MT were 1.75 times larger than 40 KT, and those for 10 MT were 1.44 times larger than those for 1 MT. If it is assumed that ignition exposures for 13 KT or 40 KT are approximately the same, then the factor from 13 KT to 10 MT would be 2.52, hence 2.52 × 8.4 = 21.2 cal/cm^2. For other yields greater than 1 MT, the ignition exposure might scale as $(W/10)^{0.16}$ where W is the yield in MT.

Since ignitions (secondary) could be a result of blast effects (likely to be coupled with blast damage to structures that contain easily

Figure 2

RADIANT EXPOSURES FOR SURFACE BURSTS, VISIBILITY = 12 MILES

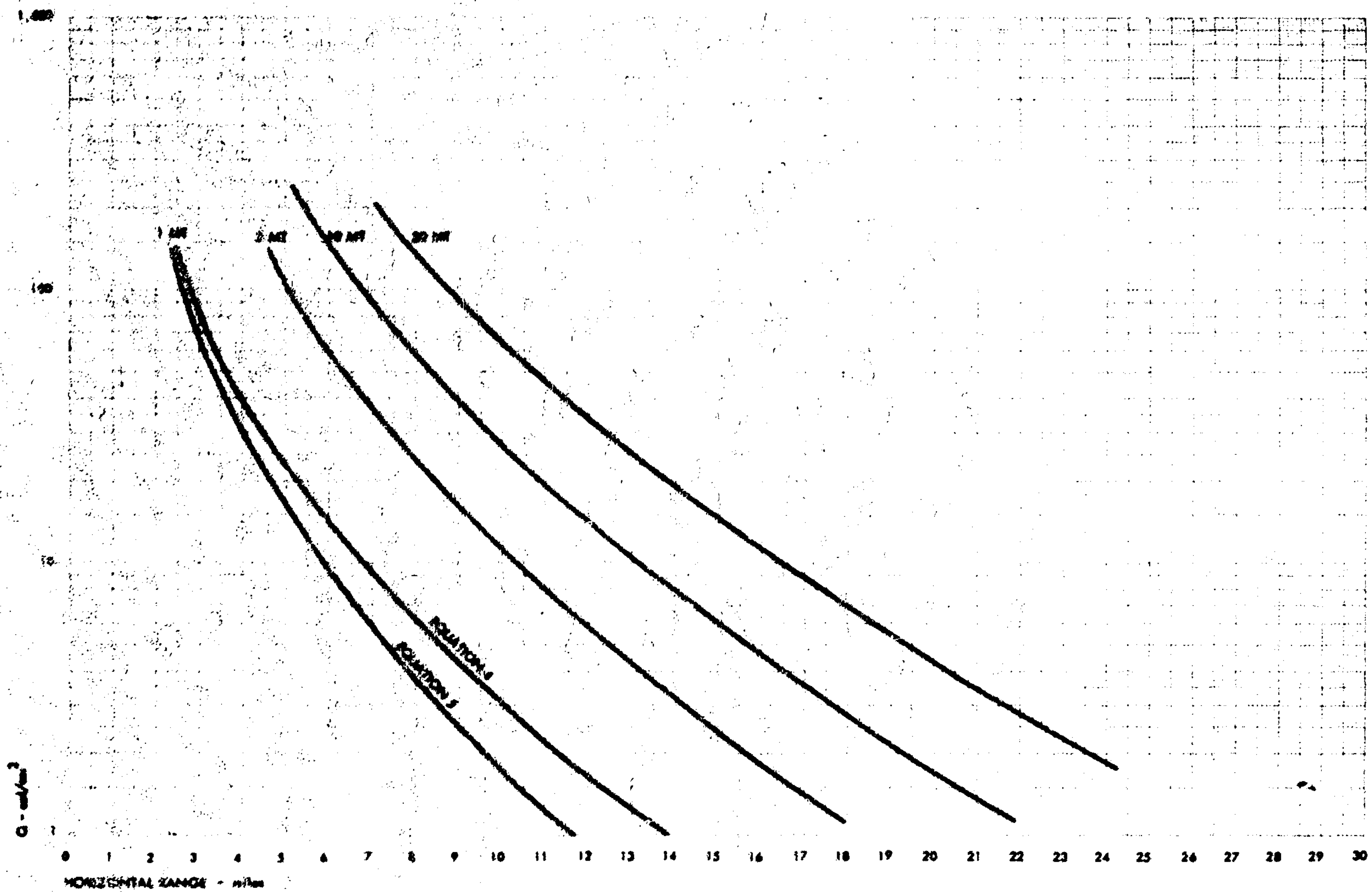
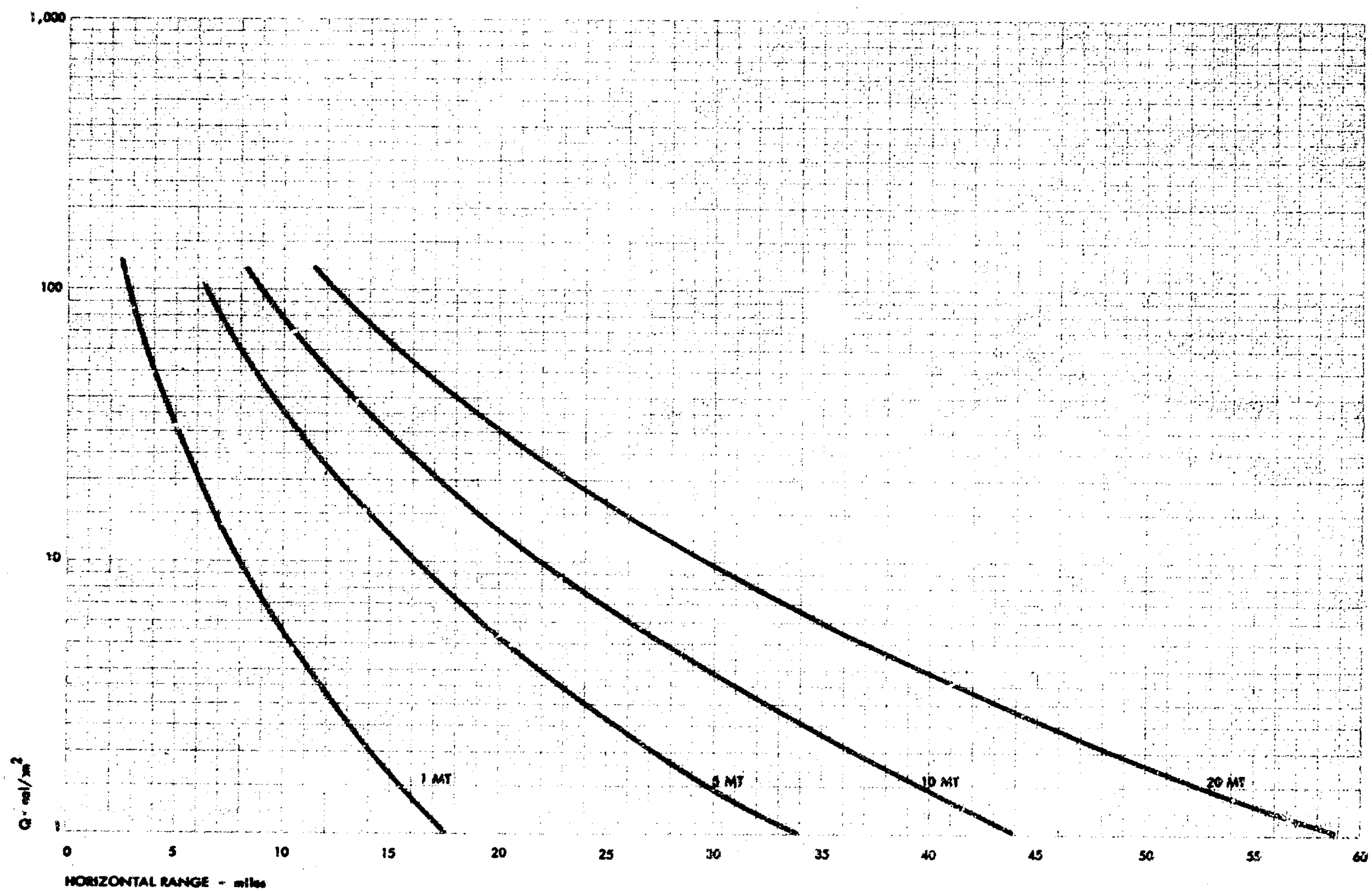


Figure 3

RADIANT EXPOSURES FOR AIR BURSTS - HIROSHIMA SCALED HEIGHT OF BURST, VISIBILITY = 12 MILES



ignitable fuels) as well as of thermal radiation (primary), both these criteria are employed for the 10 MT example. By this means, the maximum distance at which many ignitions could occur is determined for any weather condition. In clear weather, the thermal exposure could cause widespread ignition out to 10.7 miles (21.2 cal/cm^2), whereas the limiting distance of widespread ignitions in specific structures from blast is estimated at 7.2 miles (3.6 psi). Even with cloud cover, the range at which 21.2 cal/cm^2 will be delivered always extends beyond the 3.6 psi line, until a transmissivity reduction factor of 0.2 is reached, which from Table 1 is seen to correspond to a medium cloud cover, with the sky in the daytime appearing dull gray. In the case of a surface burst, the altitude of the clouds is also important because whereas a low cloud cover would reduce transmissivity, a high cloud cover would provide an additional reflected thermal exposure that could increase the 21.2 cal/cm^2 range beyond 10.7 miles.

The range indicated represents the maximum potential mass fire limits for a city, on level terrain, in which the building density and fire vulnerability are similar to those of Hiroshima. The maximum potential will not be reached, and a smaller perimeter and possibly fire-free islands will result, where (1) buildings are shielded from thermal exposure by other structures or terrain, or (2) the fuel density is low or nil.

The uncertainty in the area over which significant fires might occur is extremely large. For example, the critical ignition energies of most kindling fuels listed in Reference 16 are uncertain under field conditions to about $\pm$ 50%, with a greater likelihood of higher rather than lower values. If it is assumed that the method used to calculate radiant exposures for the stated conditions is accurate to within $\pm$ 25%, then these two uncertainties alone combine to produce a maximum fire radius from 8.8 to 11.4 miles. The area of uncertainty is therefore 165 square miles. While there is no direct relation between the exposure level at the final fire perimeter at Hiroshima and the critical ignition energies referred to above, the results nevertheless indicate the magnitude of the possible errors that can be involved.

Fire Buildup and Duration

Firestorms

At Hiroshima and Nagasaki, it is known that some people were able to make their way out of the fire area.[23] At Hiroshima, the firestorm was well-established only 30 minutes after the explosion;[23] it reached its peak intensity by 2 hours after burst,[15,16] burning at that rate for an additional 4 hours.[16] The inward-flowing wind also reached its maximum speed of 30-40 mph at about 2 to 3 hours after burst.[15]

The duration of the peak intensity at Hamburg was also about 4 hours, and the buildup period was about 3-1/2 hours, during the first 2-1/3 hours of which the attack was delivered in four waves.[24] Dikewood[23] reports that the intensity of most fires observed in urban areas had usually diminished greatly after 5 or 6 hours, but burning continued for as long as 36 hours. The fire burned itself out by about 12 hours after the explosion at Hiroshima, and by 19 hours at Nagasaki.[15] Smouldering persisted over a large part of the burned areas in both cities for three or four days, and three warehouses containing grain burned for weeks.[15]

From these data, we may conclude tentatively that if a firestorm develops, (1) only about 30 minutes may be available for limited movement or other action, (2) the earliest possible re-entry time into the fire area is about 12 hours, and (3) in regions of massive fire debris, entry may be denied by heat for several days.

Mass Fires

The growth rate and extent of a mass fire are so dependent on a host of conditions involving the ignition density, building density, fuel content, and weather that it is difficult to formulate any statements of general validity. A recent study by Crain, et al,[25] however, may serve as an example of a conservative estimate of the growth of a mass fire. In the study, only light residential structures were considered, and the choice of parameters was always such as to minimize the number of ignitions and the fire spread rate. It was also assumed that organized rescue operations could not be conducted in an area where 25% of the structures were at or beyond the violent burn stage. When the criteria of the Crain study were related to a walking speed of 1 mph, it was found that the fire perimeter could be reached only if travel originated (at zero time) outside a radius of 6 miles around the burst point.

The Crain fire limit was 9.4 miles, which is comparable to the value of 10.7 miles in the present study; however, the former limit was (perhaps inappropriately) ascribed to fires from secondary causes. Thus even a conservative analysis of the mass fire threat indicates a region approximating 100 square miles around a 10 MT surface burst, within which escape to the periphery of a mass fire is improbable. This indication must be tempered by consideration of the possibilities that other kinds of structures might be less susceptible to ignition, that burning rates could be considerably lower, and that the rate of spread might also be lower, depending principally on the building type, windspeed, and spacing.

It is difficult to conceive that numerous fire-free islands would not be present within the 300 square miles that would be enclosed by a

10-mile radius circle. If it is assumed for the moment that urban fuels even existed out to this distance, there are several sources of shielding which could reduce the radiant exposure to parts of the target area: (1) pre-burst fog, haze, industrial smoke, and smog, (2) the smoke generated almost instantly over combustible surfaces upon impingement of the thermal rays, and (3) structures and topography. For instance, with a clear atmosphere, at 5 miles from a 10 MT surface burst (for which the height of the effective radiating fireball center is 0.48 miles), a building or topographical feature 1 unit high would cast a shadow 10 units long. At 10 miles from the burst, the shadow would be about 20 units long. In addition, there would be a penumbra volume from within which only a part of the fireball semicircle could be seen. Of course, the three-dimensional case is more complicated than this simple illustration, but it at least may serve to point out the fact that significant shielding from thermal radiation from a surface burst can exist in the target area.

CLOSE-IN FALLOUT

Close-in fallout patterns based on the Miller fallout pattern scaling system[26] for yields of 1, 5, 10, and 20 MT and a wind speed of 15 mph are shown in Figures 4 through 7. The standard intensities in r/hr at 1 hour, are for 100% fission, and include a terrain factor of 0.75, and an instrument response factor of 0.75. Either of these may be removed by multiplying the stated intensities by the reciprocal of the factor. Intensities for less than 100% fission may be obtained by multiplying the intensities shown by the desired fission/total yield ratio.

The windspeed of 15 mph was selected as reasonably representative for the close-in pattern. For other windspeeds, the stem pattern dimensions in the upwind and crosswind directions change only slightly; the principal effect is on the downwind extent of the stem, and on the distance at which cloud fallout becomes important. In the present case, interest is directed toward fallout in the damaged area; hence, unless winds were exceedingly light, the cloud fallout would be of secondary importance. In addition, for these distances close to the burst point, shear in wind direction, unless extreme, would also not be an important factor.

To determine the potential exposure dose for alternative countermeasure actions that may be taken by individuals surviving the blast effects, it is necessary to obtain not only a fallout pattern but also the fallout arrival and dose rate buildup characteristics within the pattern. With these data, the cumulative exposure dose may be calculated for an individual whether he remains at one location (e.g., he remains in shelter), or moves (e.g., he makes an attempt to leave the developing environment).

Fallout Arrival and Cessation Times

The fundamentals for describing the dynamics of fallout arrival, buildup, and cessation for the stem and cloud fallout have been treated in the Miller model.[26] The deposition dynamics are based on a stylized stem and cloud configuration of particles; however, when translated to the ground by gravitational settling and wind transport, without consideration of shear, the calculated particle deposit locations do not extend laterally to the distances that are obtained from the pattern scaling system. In addition, the dynamic models do not reproduce the scaling system patterns in the areas upwind from ground zero.

Figure 4

CLOSE-IN FALLOUT PATTERN FOR A 1 MT SURFACE BURST, WINDSPEED = 15 MPH

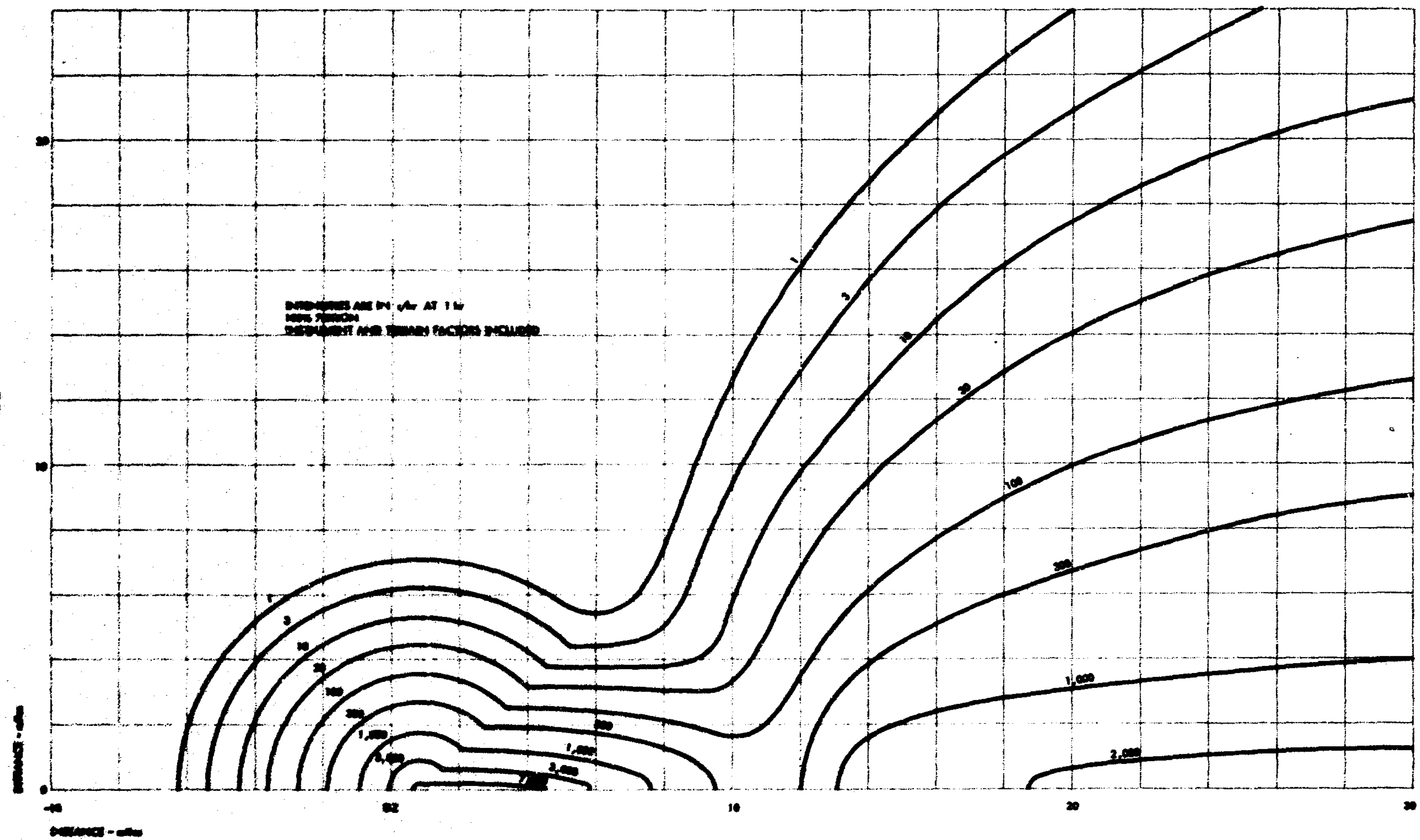


Figure 5

CLOSE-IN FALLOUT PATTERN FOR A 5 MT SURFACE BURST, WINDSPEED = 15 MPH

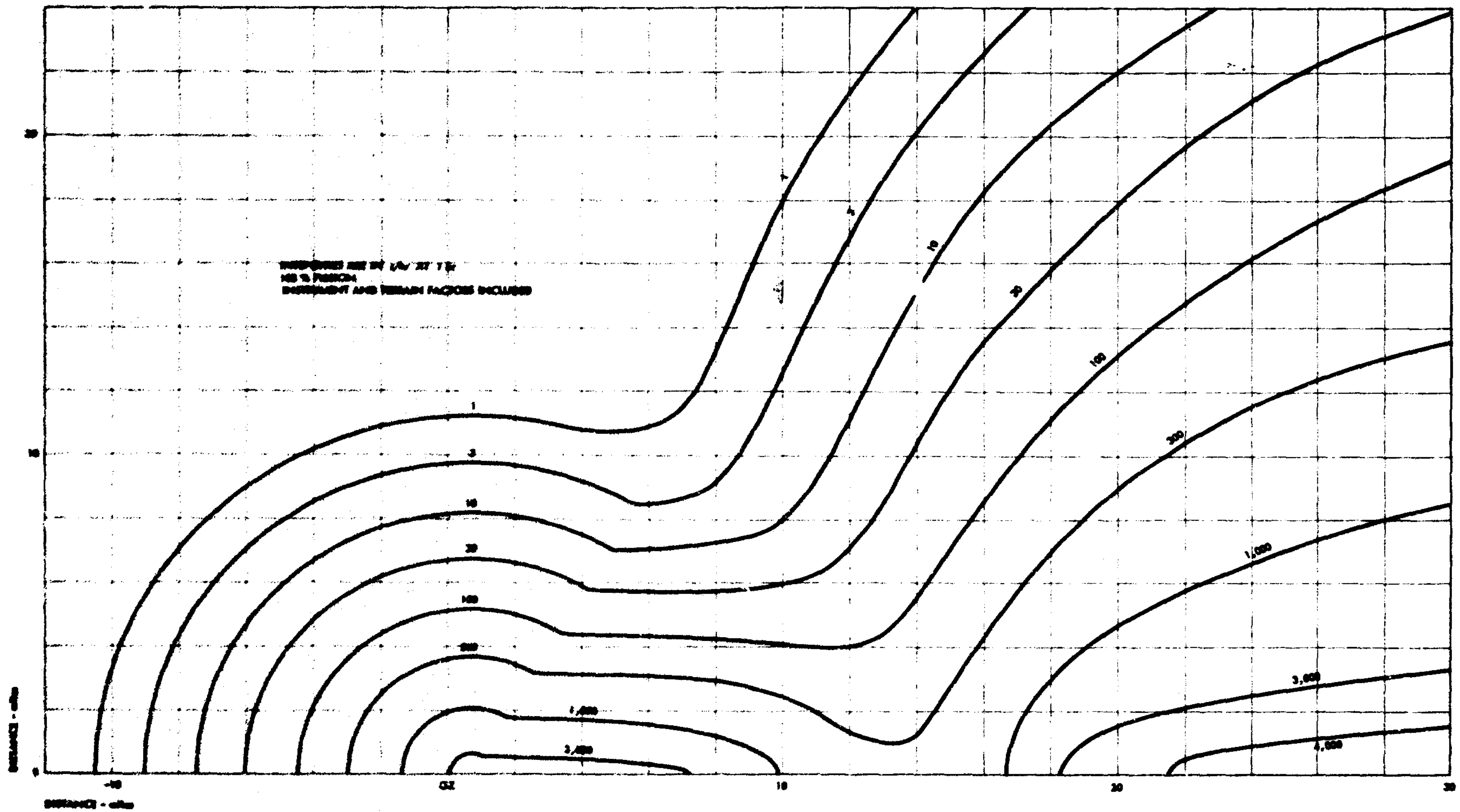


Figure 6

CLOSE-IN FALLOUT PATTERN FOR A 10 MT SURFACE BURST, WINDSPEED = 15 MPH

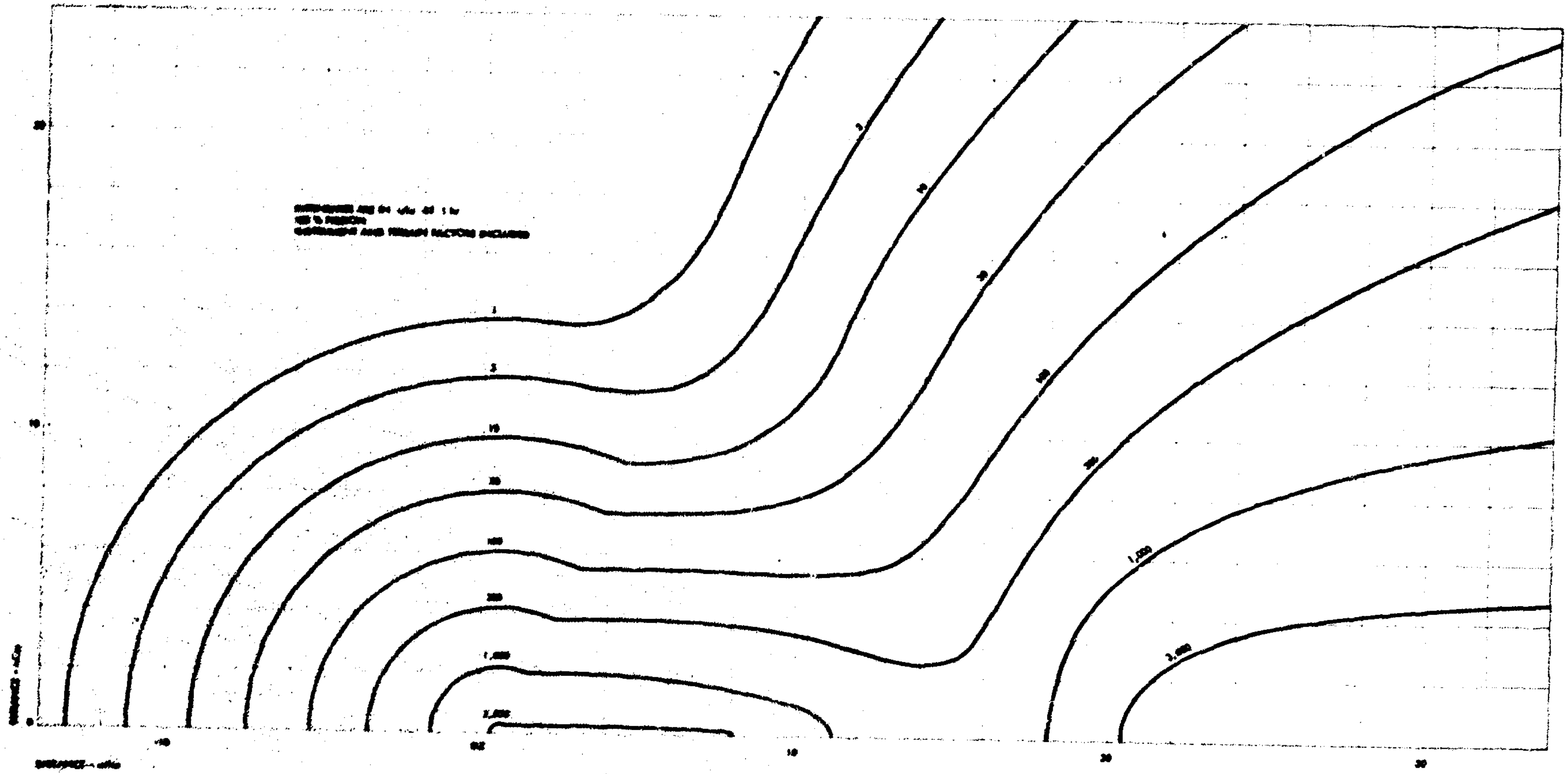
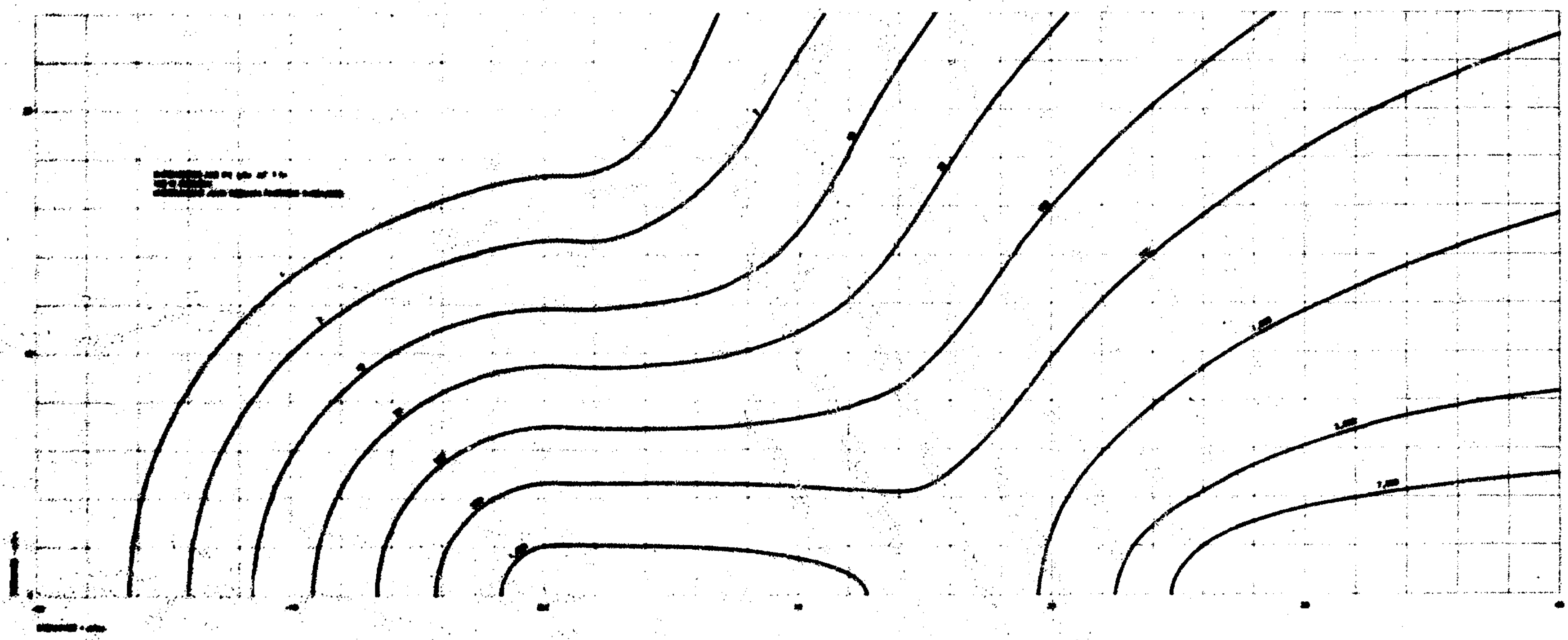


Figure 7

CLOSE-IN FALLOUT PATTERN FOR A 20 MT SURFACE BURST, WINDSPEED = 15 MPH



The pattern scaling system is derived from observed fallout patterns that contain effects of crosswind shear not given explicitly in the deposition dynamics models. Accordingly, it was necessary to develop a method of predicting arrival and cessation times for two types of point locations in the fallout field given by the pattern scaling system: (1) points whose lateral distance from the center of the pattern is greater than the cloud or stem radius, and (2) points upwind from ground zero. Because the fallout buildup phenomenon close to ground zero has never been mathematically described, an extrapolation procedure was developed in which the computed fallout arrival and cessation times of point locations along the X-axis (calculated from the Miller model) are translated to points laterally away from the X-axis.

The major feature of the scheme is the superimposition of the stem or cloud diameter (at the height of origin) on a location on the X-axis, and the extension of the circumference of the circle in the Y direction to the 1 r/hr standard intensity contour of a 100% fission weapon, to form arrival and cessation-time ellipses. For this geometry, all points on the ellipse convex <u>away</u> from ground zero are assigned the same fallout arrival time, and therefore are equal to the fallout arrival time at the point on the X-axis where the ellipse intersects the X-axis. For the same geometry, all points on the ellipse convex <u>toward</u> ground zero are assigned the same cessation time. As all fallout arrival times and fallout cessation times along the X-axis can be determined, a succession of ellipses provides corresponding fallout arrival and cessation times for locations off the X-axis.

The use of this scheme is not free of complications, and the scheme cannot be uniformly applied for all parts of the pattern, not only because the pattern is discontinuous but also because the results would be significantly in error. A major region where the scheme must be modified is the stem fallout region around ground zero. In this region (see Figure 8), the same fallout arrival time is assigned to the fallout pattern upwind from the downwind semi-ellipse line that is drawn through X_3 on the X-axis. (Note: for definition of X_3 and other symbols given below, see Reference 26.) The minor diameter of this ellipse extends from X_2 to X_3, and its major diameter (in the Y directions) is equal to $2(X_2 - X_1)$. The points X_2 and X_3 on the X-axis are the limiting distances of the stem fallout high intensity ridge $I_{2,3}$ from ground zero. To obtain the iso-cessation time contours for this region, it is convenient to draw them parallel to the X-axis, and the values assigned are determined by the intersection points of fallout cessation semi-ellipses with the fallout arrival semi-ellipse that has been drawn through X_3.

Other modifications necessary to make the scheme consistent with particle transport dynamics and make the results consistent with empirical data are:

1. The downwind pattern lateral limits are modified to equal the limit at X_2 except where the stem diameter at particle origin exceeds this width.

2. The earliest cloud arrival time is at the distance $(X_5 + a)$ on the X-axis, where a is the fallout cloud radius.

3. Linear interpolation is used to obtain fallout arrival times between points on the semi-ellipse passing through $(X_5 + 2a)$ and the point $(X_5 + a)$ on the X-axis. The resulting concentric iso-arrival semi-ellipses and their mirror images then form the iso-arrival contours around the point $(X_5 + a)$.

4. A straight line from X_6 to the intersection point of the cloud 1 r/hr standard intensity contour and the modified stem pattern limit was used as a convenient limit for stopping stem fallout calculations. Upwind from this line, the earliest particle arrival time and the latest particle arrival time, be they from stem or cloud, are the fallout arrival time and cessation time, respectively.

The above scheme for obtaining the fallout arrival time, t_a, and the fallout cessation time, t_c, is still in the development stage and is being pursued (by other research personnel) as a separate research effort. Although more modifications or adjustments will probably be made before this method is reported, specific results of the method, for the 10 MT-15 mph wind case, were made available for this study.

For this case, the stem and cloud fallout arrival times and cessation times along the X-axis are shown in Figure 8. The data is generally confined to the area of physical damage, which is this study's primary area of concern. The times of fallout arrival and cessation for locations off the X-axis, from computer output for the +Y port of the symmetrical pattern to about 15 miles downwind, are plotted in Figure 9. With the times of the fallout arrival and cessation determined, the exposure dynamics over various periods, including the time period in which the fallout is depositing and the exposure dose rate is increasing, can now be explored.

Exposure Dose Dynamics

The input requirements for calculations of exposure dose include the variation of the accumulated fallout with time during deposition, the standard intensity, and the air ionization decay rate of the radionuclide mixture in the fallout.

Figure 8

FALLOUT ARRIVAL AND CESSATION TIMES ON X AXIS--
10 MT SURFACE BURST, 15 MPH WINDSPEED

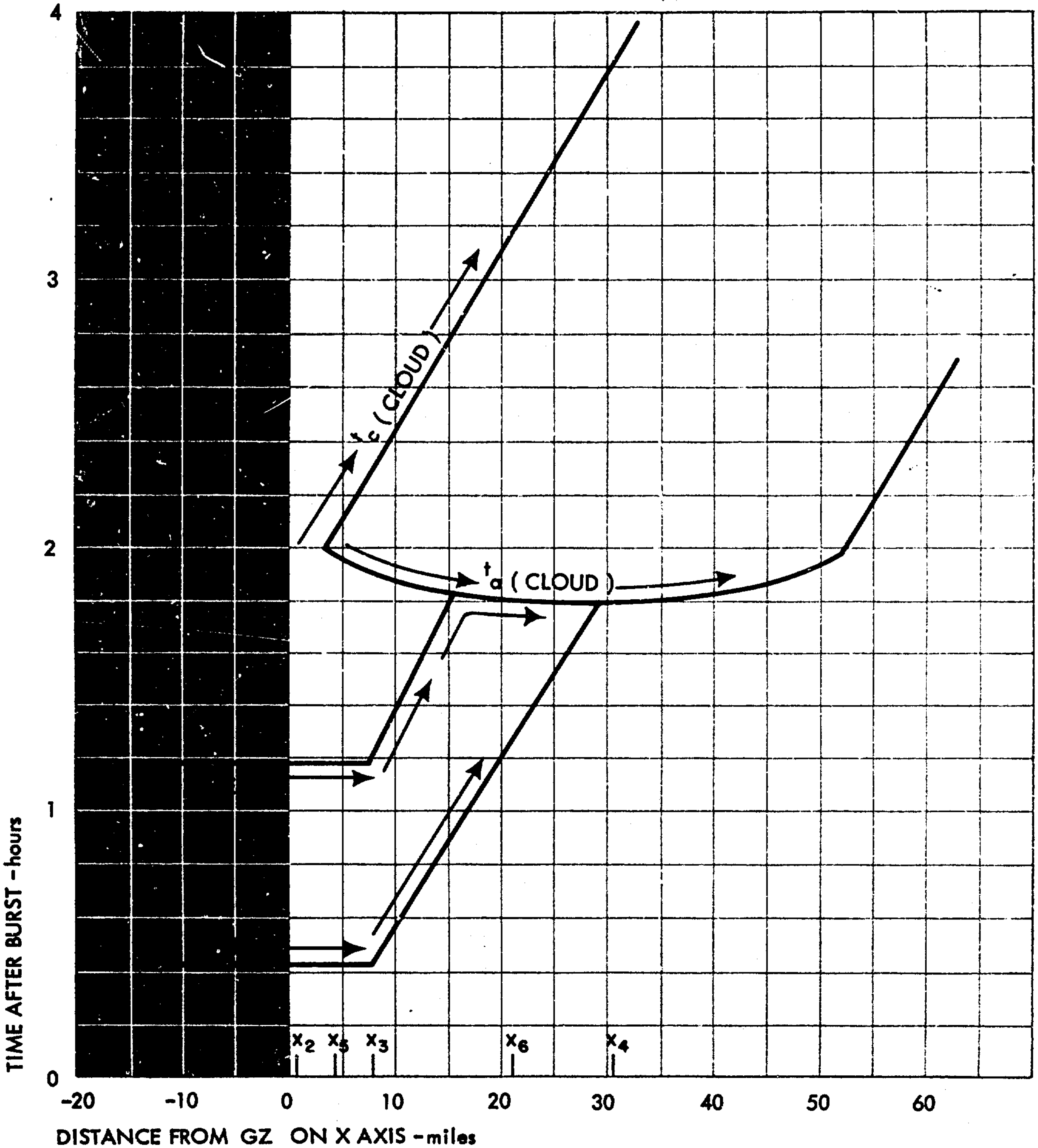
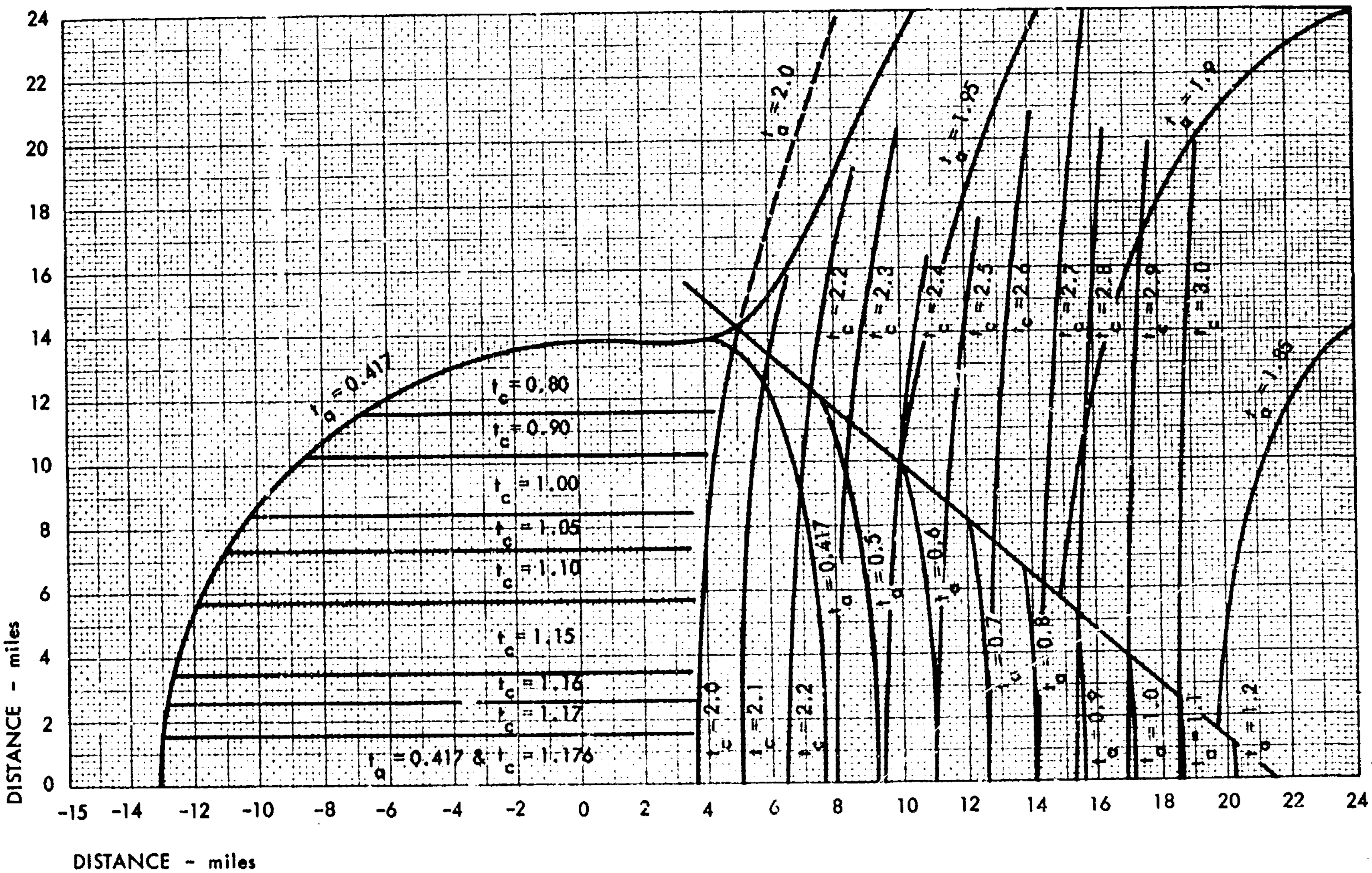


Figure 9

FALLOUT ARRIVAL AND CESSATION TIMES ON FALLOUT PATTERN--
10 MT SURFACE BURST, 15 MPH WINDSPEED



The Miller model[26] includes methods of calculating the deposit rates for both stem and cloud fallout. The procedure involves laborious iterations, and numerical solutions depend on knowledge of the activity per unit volume in the cloud associated with particles of a given falling velocity. From a number of hand-solutions at various locations in the stem and cloud fallout patterns from megaton-range bursts, it was found that the integrated deposit rate, in terms of the standard intensity, in the stem fallout pattern could be approximated by

$$f(\tau) = \frac{4\,\tau}{1 + 3\,\tau}\,,\ 0 \le \tau \le 1 \tag{10}$$

where

$$\tau = \frac{t - t_a}{t_c - t_a} \qquad t_a < t < t_c \tag{11}$$

The function $f(\tau)$ is the fraction of the fallout deposited at time t after burst, t_a is the time of arrival of fallout, and t_c is the time of fallout cess ion.

For cloud fallout, the integrated deposit rate may be represented approximately by

$$f(\tau) = \frac{3\,\tau}{2 + \tau} \qquad 0 \le \tau \le 1 \tag{12}$$

In the region of the fallout pattern where both stem and cloud deposit fallout, the stem deposit function is used for the entire fallout duration period. This convenient simplification of the deposition calculations will produce a slightly higher potential exposure dose over the deposition periods in this region. It is assumed that Equations 10 and 12 adequately represent the integrated deposit rate of fallout at all other points in the fallout pattern produced by a megaton-range burst. Then the variation of the intensity with time at a point, including decay, is given approximately by

$$I(t) = f(\tau)d(t)I_s \tag{13}$$

where d(t) is an appropriate ionization decay factor, and I_s is the standard (1 hour) intensity. The potential exposure dose is the integrated value of Equation 13:

$$D = \int_{t=t_a}^{t} I(t)dt = I_s \int_{t=t_a}^{t} f(\tau)d(t)dt \qquad (14)$$

The decay function d(t) may take several forms. One simple expression is $d(t) = t^{-1.2}$, which has some experimental support from weapon test measurements[27] under certain conditions; or the decay function may be a computed or observed curve not simply expressed by an analytical function, in which case, numerical integration may be made from a table giving the relative intensity as a function of time after detonation.

From Equation 14, we may define a dose rate multiplier, DRM, as

$$DRM = D/I_s \qquad (15)$$

which is simply the factor by which the standard intensity is multiplied to yield dose between 1 hour after burst and any other specified time. Such factors have been calculated previously for the case of completely deposited fallout, and for times greater than 1 hour.[28] Figure 10, extracted from Reference 28, is a graph of DRM vs time, based on a computed decay curve for the fractionated products of 8-Mev neutron fission of U-238, and U-239 capture ratio of about 1 atom per fission.[29] The curve is appropriate for very close-in fallout from a high-yield land surface detonation on an idealized soil melting at 1400°C.

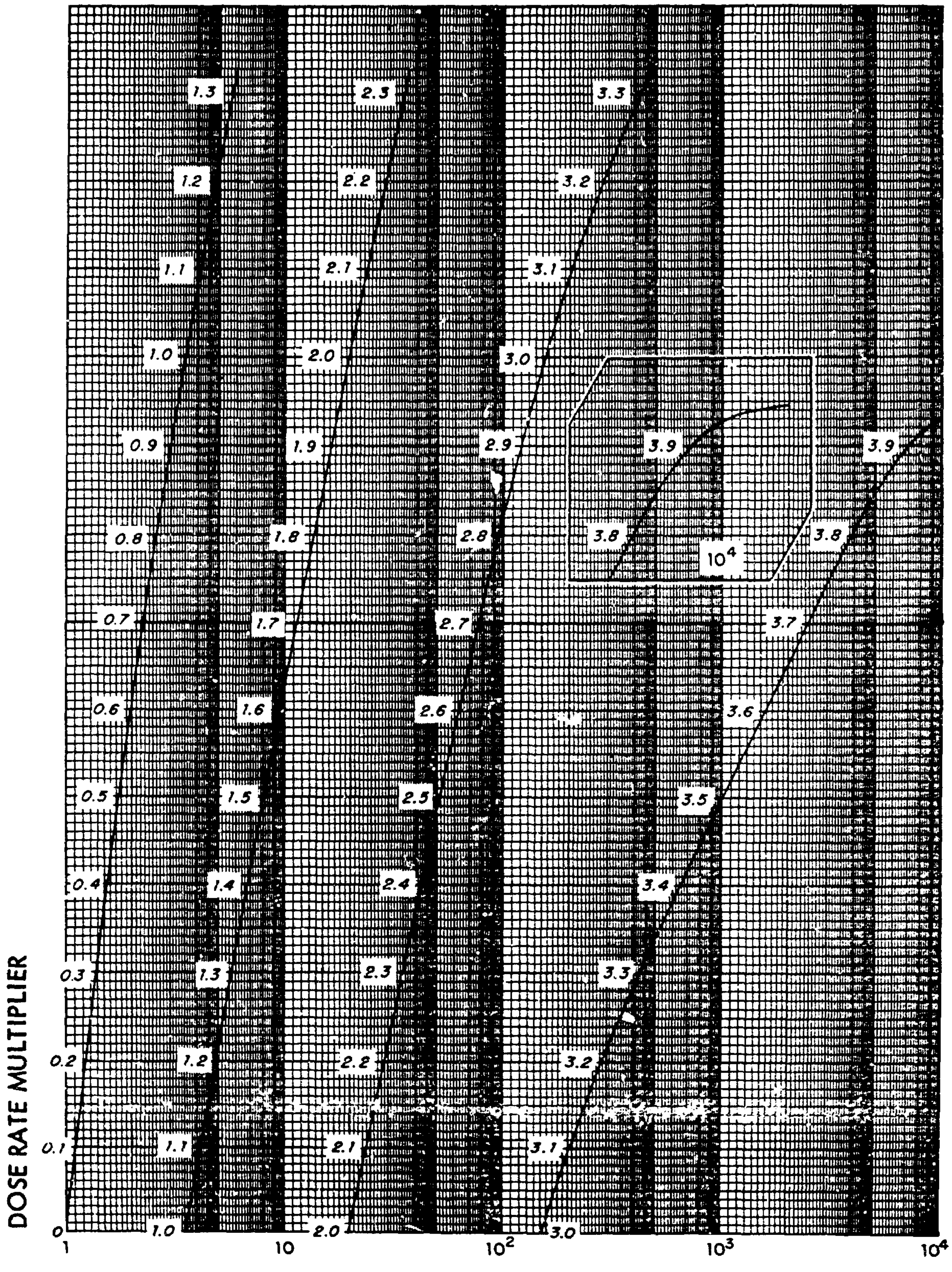
In Figure 10, the standard intensity multiplied by the DRM at time t yields the exposure dose from 1 hour to t hours; hence, if dose is required between t_1 and t_2 ($t_2>t_1>1$ hr), the multiplier is DRM = DRM (t_2) - DRM (t_1).

By means of Equations 14 and 15, additional DRM curves were prepared for a range of arrival and cessation times, in order to include the cases of fallout buildup, and times less than 1 hour. For consistency, the same decay curve was used as formerly (extrapolated somewhat to earlier times); hence Equation 10 was used for $f(\tau)$. Thus, the results are particularly appropriate for stem fallout, but are probably reasonably adequate for close-in cloud fallout as well.

The results of the calculations are shown in Figures 11 and 12. Figure 11, which is drawn for times of arrival and cessation less than 1 hour, yields the DRM to 1 hour after burst. Figure 12 covers cessation times greater than 1 hour, and yields the DRM to time of cessation. Thus the results from either figure may be conveniently combined with those in Figure 10 to yield exposure doses from stem fallout over a wide range of conditions.

Figure 10

DOSE RATE MULTIPLIER CURVES FOR COMPLETELY DEPOSITED FALLOUT



The Miller model[26] includes methods of calculating the deposit rates for both stem and cloud fallout. The procedure involves laborious iterations, and numerical solutions depend on knowledge of the activity per unit volume in the cloud associated with particles of a given falling velocity. From a number of hand-solutions at various locations in the stem and cloud fallout patterns from megaton-range bursts, it was found that the integrated deposit rate, in terms of the standard intensity, in the stem fallout pattern could be approximated by

$$f(\tau) = \frac{4\tau}{1 + 3\tau}, \quad 0 \le \tau \le 1 \tag{10}$$

where

$$\tau = \frac{t - t_a}{t_c - t_a} \qquad t_a < t < t_c \tag{11}$$

The function $f(\tau)$ is the fraction of the fallout deposited at time t after burst, t_a is the time of arrival of fallout, and t_c is the time of fallout cessation.

For cloud fallout, the integrated deposit rate may be represented approximately by

$$f(\tau) = \frac{3\tau}{2 + \tau} \qquad 0 \le \tau \le 1 \tag{12}$$

In the region of the fallout pattern where both stem and cloud deposit fallout, the stem deposit function is used for the entire fallout duration period. This convenient simplification of the deposition calculations will produce a slightly higher potential exposure dose over the deposition periods in this region. It is assumed that Equations 10 and 12 adequately represent the integrated deposit rate of fallout at all other points in the fallout pattern produced by a megaton-range burst. Then the variation of the intensity with time at a point, including decay, is given approximately by

$$I(t) = f(\tau)d(t)I_s \tag{13}$$

where d(t) is an appropriate ionization decay factor, and I_s is the standard (1 hour) intensity. The potential exposure dose is the integrated value of Equation 13:

Figure 11

DOSE RATE MULTIPLIER CURVES FOR STEM FALLOUT--TIMES OF CESSATION LESS THAN 1 HOUR

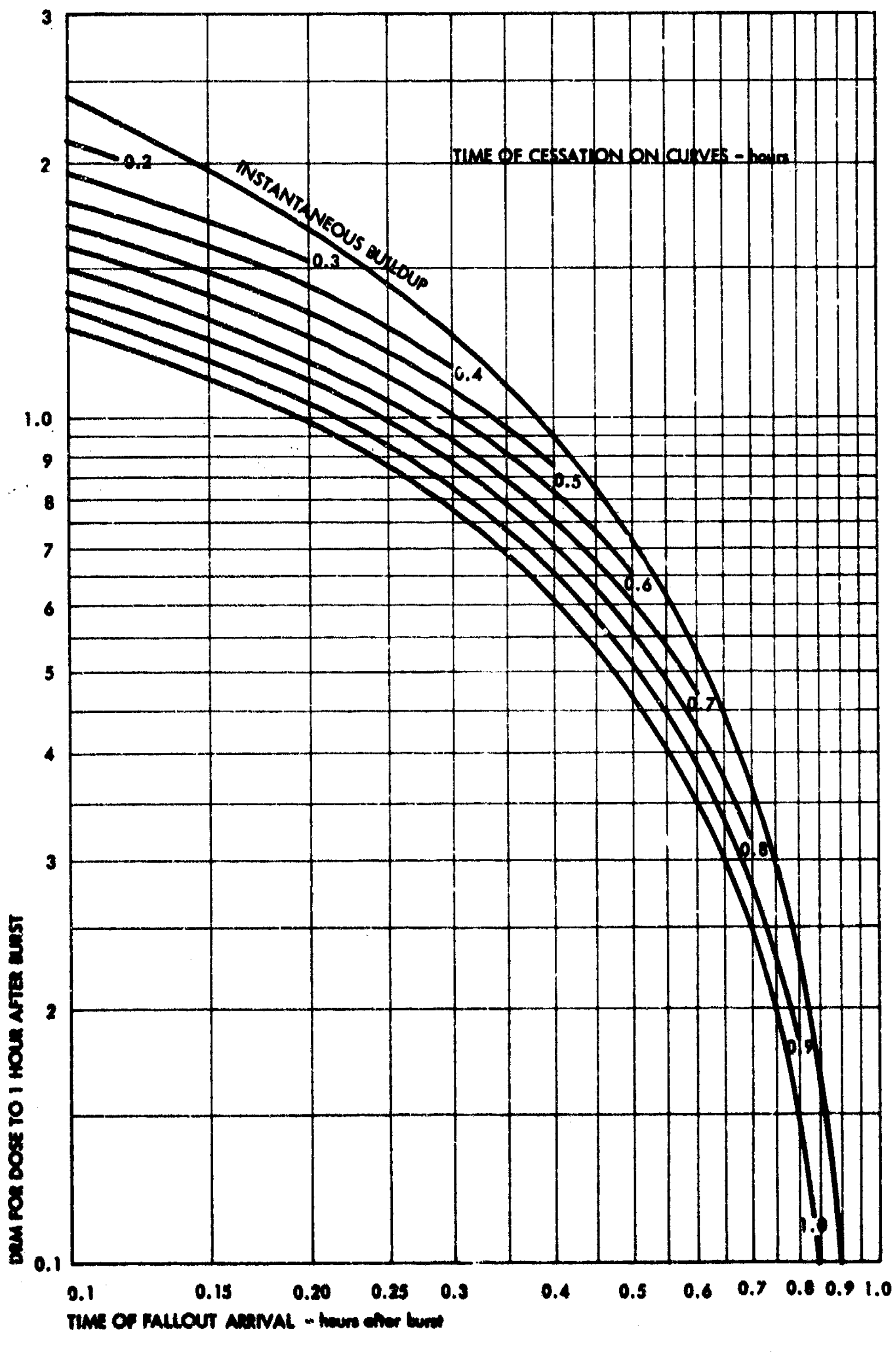
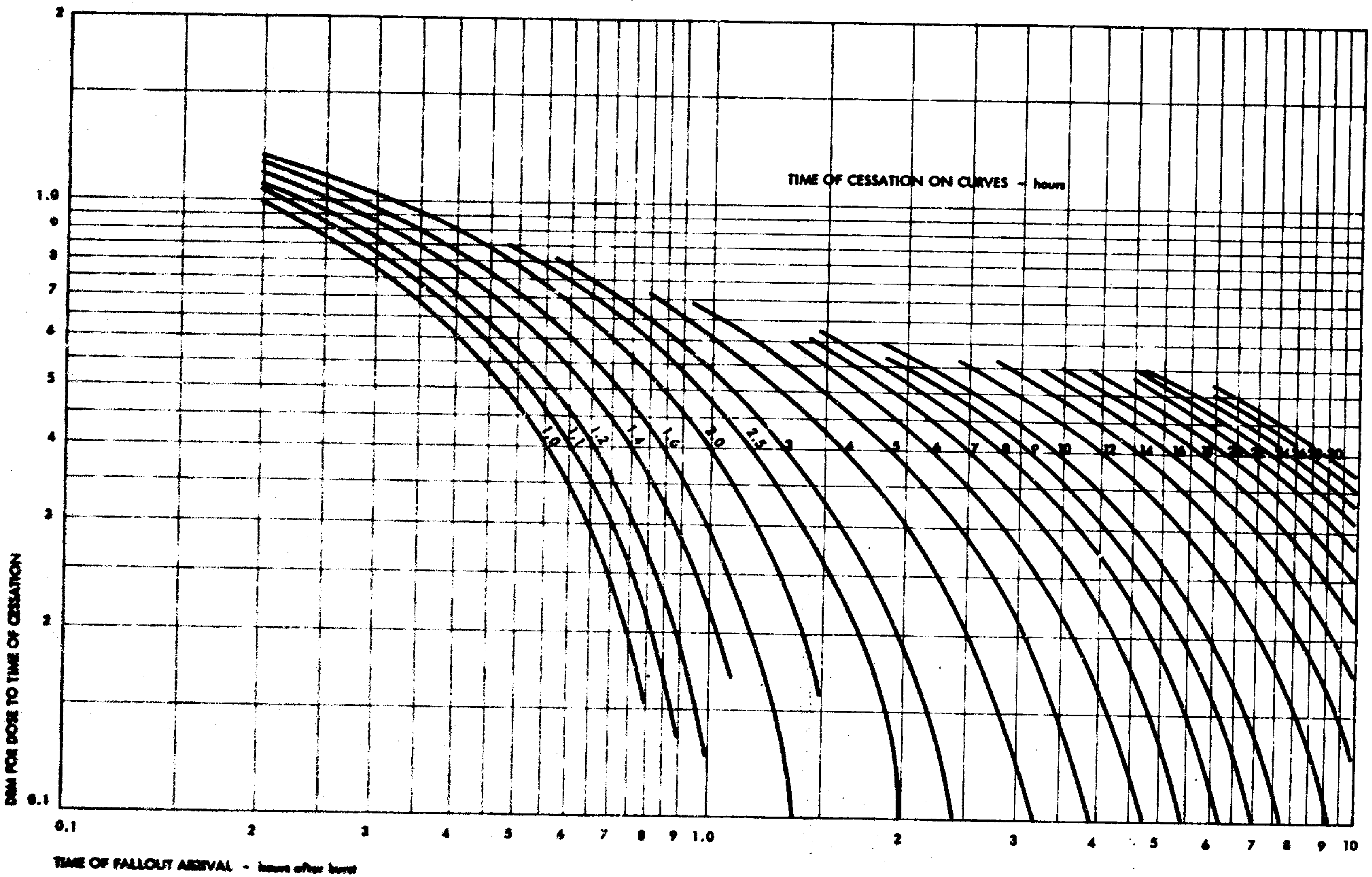


Figure 12

DOSE RATE MULTIPLIER CURVES FOR STEM FALLOUT-- TIMES OF CESSATION GREATER THAN 1 HOUR



It was also assumed that motion would start at burst time. Note that the operational feasibility of knowing which direction to take at zero time is not under discussion here, but rather, the chances of evasion _if_ the optimum direction were known. Hence in an actual situation of this kind, one could not reasonably expect to do better than is indicated here.

The paths chosen are shown in Figure 13 as arrows. The calculation procedure, for which a small computer program was written, was to calculate the dose during travel between a point on an arrow and the boundary. In each case, travel was started at zero time. The dose contours used in Figure 13 include a terrain attenuation factor of 0.75, and hence the effective PF value employed is 1/0.75 = 1.33. For analytical simplicity, a decay function of $t^{-1.3}$ was employed, rather than the decay curve previously described; however, most of the path doses are incurred between approximately 0.4 hours and 15 hours after burst, and over this interval, the two decay curves are reasonably similar.

The 200 r and 600 r escape dose contours (escape initiation locations, starting at zero time, to incur 200 r and 600 r) are shown in Figure 13. The significance of these particular values is that recovery from a dose of less than 200 r is virtually certain, recovery from a dose of 200 r to 600 r is uncertain, and recovery from a dose greater than 600 r is highly unlikely.

Although the travel dose presented in Figure 13 is for the special case of zero shelter stay time, the computer program developed for the above dose calculations may also be used to calculate dose for any shelter stay time up to some exit time and a travel dose thereafter. Figure 14 is an example of these additional calculations incorporating shelter stay time doses. The figure presents a shelter* and travel dose history, vs shelter exit time, for a point selected arbitrarily from those shown in Figure 13.

The case illustrated in Figure 14 (together with others not reproduced here) shows that in at least the close-in fallout region: (1) the

---

* In Figure 14, the shelter-dose curve applies to a shelter in which the Residual Number (RN) is 1/40--i.e., the intensity in the shelter is 1/40th of the outside intensity, 3 feet above an open area. The PF at a point is defined as the ratio of the intensity 3 feet above a smooth infinite plane to the intensity at the point. Hence 1/RN is not equivalent to PF; and with a terrain attenuation factor of 0.75, as employed here, PF = 1.33/RN.

Figure 13

200 R AND 600 R ESCAPE DOSE CONTOURS FOR TRAVEL OUT OF THE CLOSE-IN FALLOUT PATTERN FROM A 10 MT, 50% FISSION SURFACE BURST

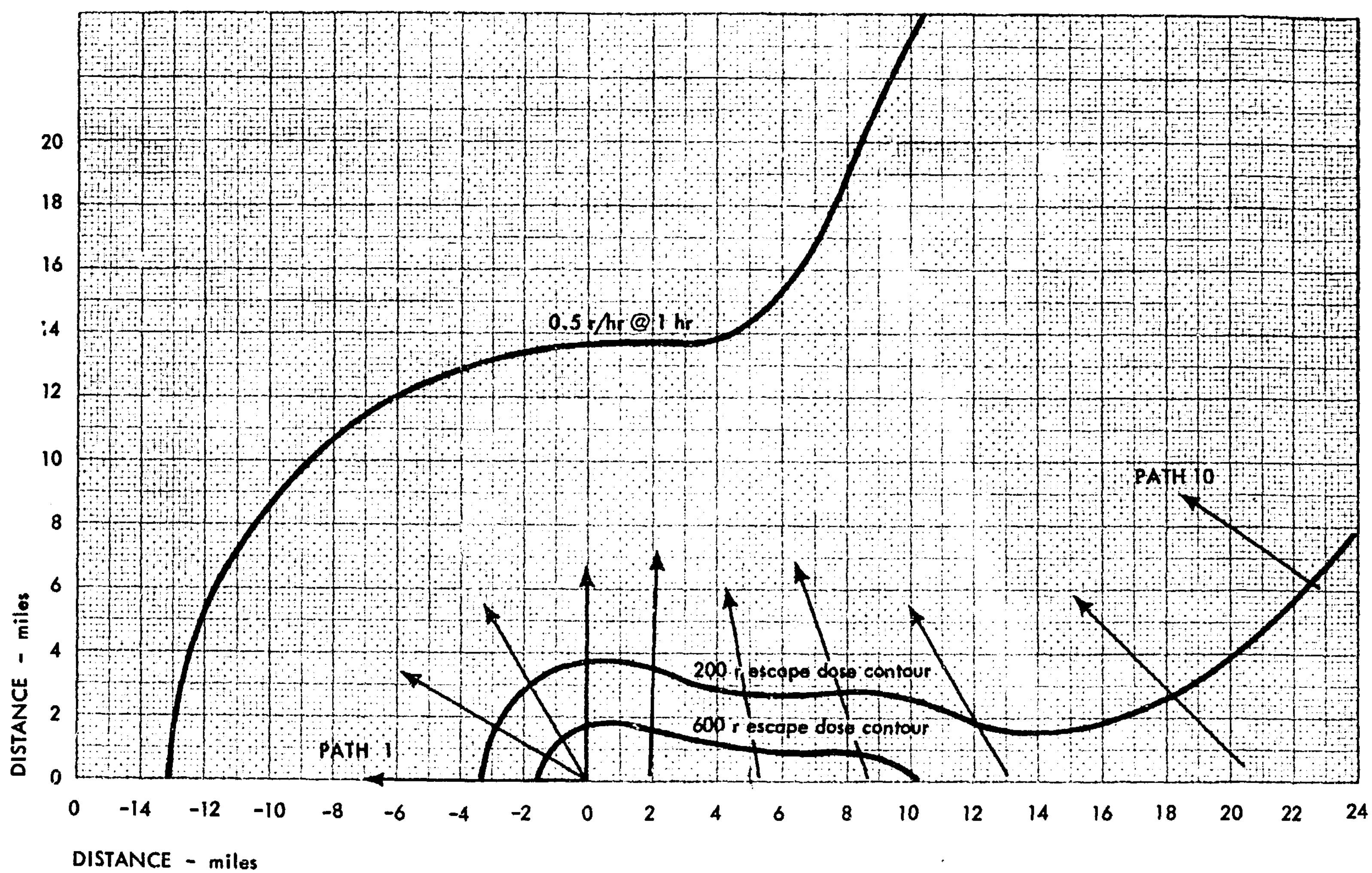
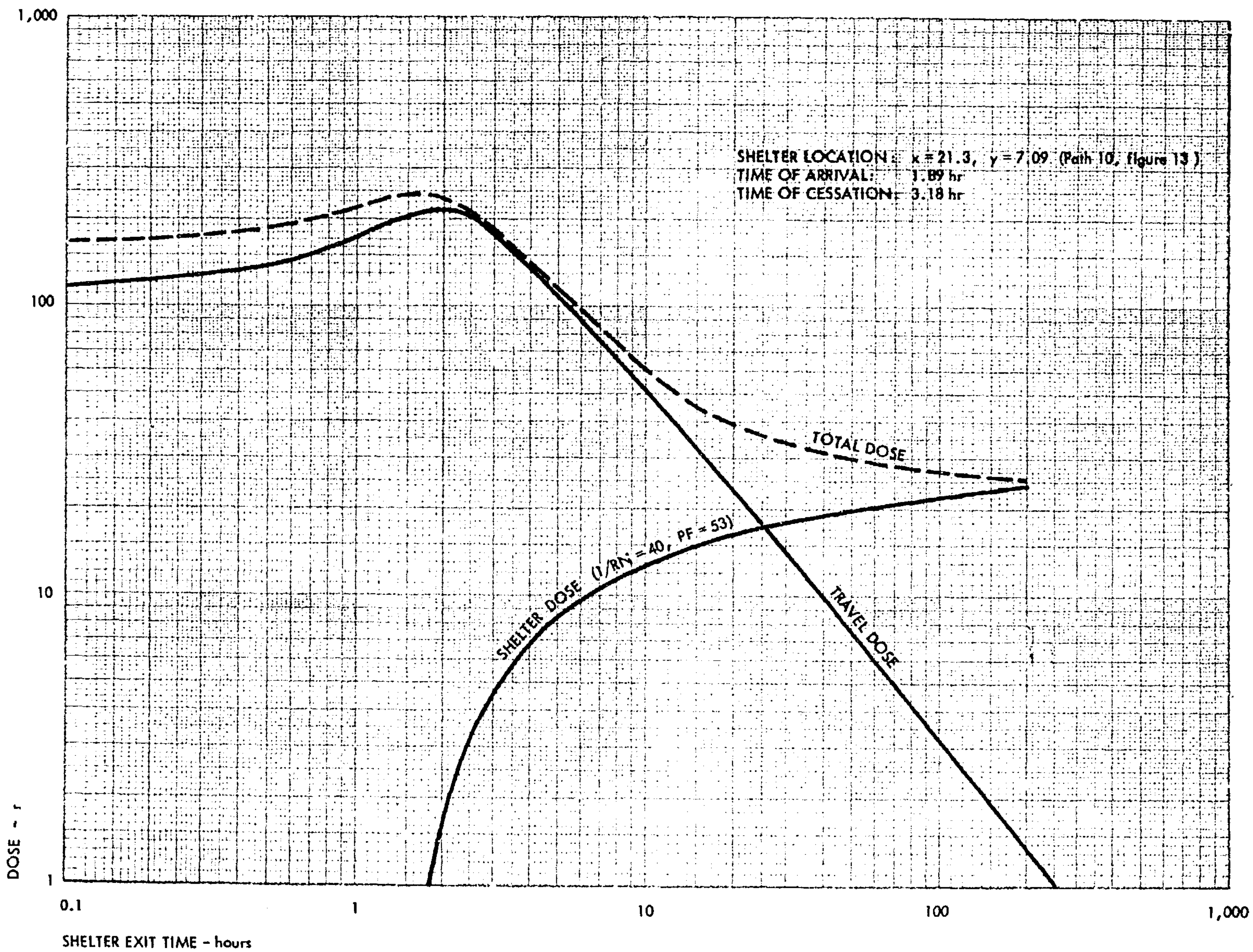


Figure 14

EXPOSURE DOSE INCURRED IN SHELTER AND DURING TRAVEL OUT OF A FALLOUT FIELD--10 MT SURFACE BURST, 50% FISSION, 15 MPH WINDSPEED



exit time that results in the maximum total dose is about the time when fallout arrives at the shelter; (2) the exit time for the least total dose occurs at the time when the travel dose becomes negligible. In the case shown, the minimum total exposure dose would be incurred at an exit time of about 200 hours after burst. This time will vary with other cases, of course, depending on the standard intensity, shelter PF, and shelter location relative to the boundary of the fallout pattern.

In relation to the possibility of evading fires by taking refuge in a large open area, it is necessary to estimate the fallout doses that might be encountered during the time when such refuge might be necessary. As previously stated, the Hiroshima and Nagasaki fires burned out in about 12 to 19 hours; hence, in this calculation, doses were computed from 0 to 20 hours after burst. The results are applicable, within a small error, to exposures terminating from 6 hours to 24 hours after burst.

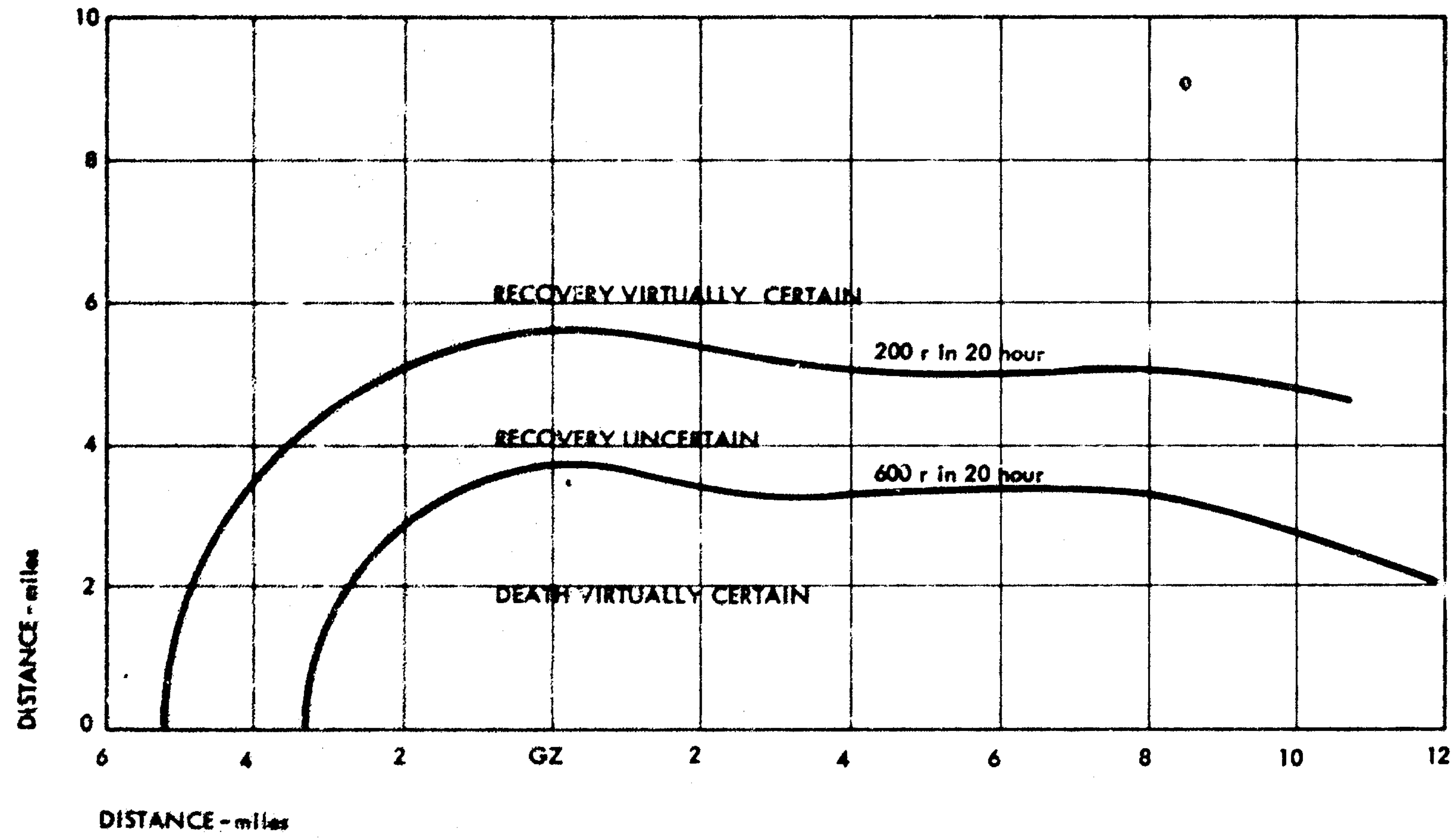
The computer program was used to calculate the 20-hour doses at appropriate points on the paths shown in Figure 13; locations at which the dose was 200 r and 600 r were found by interpolation and extrapolation. The results are shown in Figure 15 in the form of contours at these dose levels.

The transattack conditions in various regions of t e targeted area may now be estimated by combining the individual effects of blast, fire, and fallout developed above.

Prompt nuclear radiation has been ignored as unimportant compared to other effects from megaton-range weapons. Also, the electromagnetic pulse and the damage it might produce in electrical equipment, over and above blast damage in the close-in region, have been omitted, primarily because few quantitative data are available on this effect.

Figure 15

LIMITING DOSE CONTOURS FOR 20 HOUR STAY IN OPEN--
10 MT SURFACE BURST, 50% FISSION, 15 MPH WINDSPEED



COMBINED EFFECTS AND CONSTRAINTS

In order to evaluate the early postattack situation, Figure 16 was prepared for a 10 MT, 50% fission surface burst depicting the combined threats developed singly in the previous sections. The assumptions and limitations employed therein are also used here. From the information contained in Figure 16, a number of conclusions may be drawn concerning the disposition and possible action options that might be taken by the survivors. Also, the regions in which recoverable physical resources might be located can be identified, and the attendant time constraints to operations can be delineated.

First, it can be seen that all structural debris would be contaminated to some extent with stem fallout. Second, most of the damaged region (77%) would be within the maximum potential fire radius. Third, there would be an area of complete destruction around ground zero, within which probably no repair or salvage operations would be worthwhile. The dimensions of some of the effects limits shown in Figure 16 are listed in Table 2.

Table 2

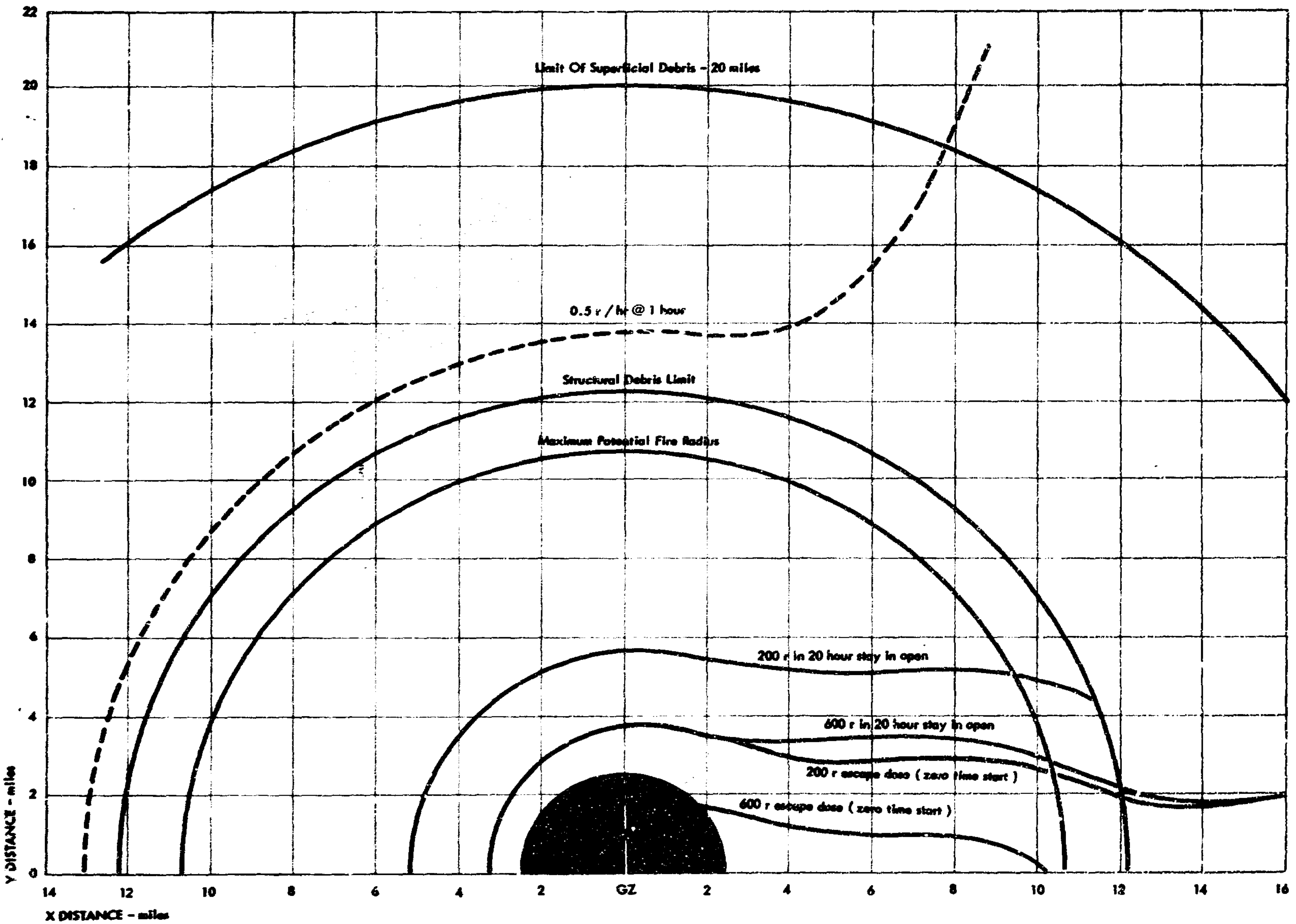
DIMENSIONS OF REGION DAMAGED BY BLAST AND FIRE
(10 MT Surface Blast)

Region	Range from Burst Point (miles)	Area (square miles)
Complete destruction	0-2.4	20
Structural damage and debris	0-12.2	470
Superficial debris	12.2-20	790
Maximum potential fires	10.7	360
Unburned damaged structures	10.7-12.2	110

Since the area of Los Angeles, the largest single city in the United States, is about 450 square miles,[30] structural damage due

Figure 16

COMBINED THREATS IN AREA SURROUNDING THE BURST POINT-- 10 MT SURFACE BURST, 50% FISSION, 15 MPH WINDSPEED



to blast from a centrally located 10 MT burst will be limited by city size, not weapon effects. Also, except for Los Angeles, all of the 50 largest U.S. cities cover less than 360 square miles, so that on an area basis, they are potentially vulnerable in their entirety to fire from thermal radiation. If urbanized areas* are considered instead of individual cities, there are still only 11 such areas larger than 470 square miles, and 14 larger than 360 square miles.[30]

As to the possible desirability of relocating or grouping survivors at the periphery of the damaged region, one reasonable range criterion that might be employed is the 2 psi line, at 10.5 miles. At this distance, wood frame structures should be no more than moderately damaged.[17] Since this distance happens to be almost the same as the maximum radius postulated for potential fires, the same considerations relative to city size and urbanized area size apply as indicated above. Hence it appears that only in the 14 largest urbanized areas would residential structures be found at and beyond 10.5 miles. An ameliorating consideration is that urbanized areas are not necessarily circular, and therefore residential regions exist in many urbanized areas beyond 10.5 miles from the centroid.

Within the limiting radius of structural debris shown in Figure 16, the total areas included within the various radiological zones are listed in Table 3.

Table 3

AREAS OF RADIOLOGICAL ZONES WITHIN LIMITING RADIUS
OF STRUCTURAL DEBRIS--10 MT SURFACE BURST

Radiological Zone	Area (square miles)
Travel out of fallout pattern	
> 600 r	30
200 r to 600 r	60
< 200 r	380
20-hour stay in open	
> 600 r	100
200 r to 600 r	70
< 200 r	300

* In general, an urbanized area is the thickly settled core of a standard metropolitan statistical area.

From data in Tables 2 and 3, it can be seen that over most of the damaged area of 470 square miles, the radiological restrictions on movement would be less severe than those posed by a mass fire or conflagration.

Geographic Vulnerability of People

From any point within the 600 r escape dose contour shown in Figure 16, a lethal fallout dose would be incurred by anyone who left the shelter very early in an attempt to walk out of the fallout field. In addition, only a small part of this area, in the downwind direction, would lie outside the maximum potential fire radius. In the region between the 200 r and 600 r escape dose contours, there would be a radiological chance that escape was possible; and outside the 200 r dose contour, there would be no radiological constraint on escape from the fallout radiation field. Both of these regions would overlap with the maximum potential fire radius. However, outside the fire radius in the downwind direction, distances to the pattern boundary would rapidly increase so that walking would generally be neither feasible nor necessary, since the constraints on vehicular traffic imposed by debris would be minimal. In the present analysis, the welfare of people located initially in the undamaged areas will not be further considered.

Within the 600 r contour there would be virtually no possibility of survival if refuge from fires was sought in the open; this region would include about 20% of the damaged area. Over about 15% of the damaged area, there would be a possibility of surviving the radiological hazard in the open. Over the remaining 65% of the damaged area, the unshielded dose would be less than 200 r, and therefore the fallout radiation mortality rate would be nil.

The physical state of the survivors at about one day after burst is qualitatively summarized in Table 4. It is assumed that virtually no survivors would be found in the zone of complete destruction, except for those near the periphery of the zone to whom strong fireproof shelters were available. Also, within the 600 r stay-in-open contour, death from radiation exposure would be virtually certain, eventually, so that for this region, no survivors are indicated in Table 4.

It is also assumed that there would be a spontaneous movement of all ambulatory survivors from fire-threatened shelters, in the damaged and burning areas, and that such movement would tend to stop at the periphery of the damaged area.* It is also assumed that after the fire threat subsided, departure from heavily damaged shelters would be voluntary (and

* It can be seen from Figure 4 that two-thirds of the periphery is substantially free from hazardous fallout.

Table 4

PHYSICAL STATE OF SURVIVORS AT ABOUT 1 DAY AFTER BURST IN AND AROUND THE DAMAGED REGION

Location	Origin of Survivors	Physical State	
Structural debris limits	Originally present	Uninjured, injured, ambulatory and non-ambulatory; no radiation injury	
	From within 600 r escape contour	Recuperation from radiation exposure highly unlikely	Uninjured and ambulatory injured
	From 200 r-600 r escape contours	Recuperation from radiation exposure uncertain	Uninjured and ambulatory injured
	From outside 200 r escape contour	Recuperation from radiation exposure virtually certain	Uninjured and ambulatory injured

Survivors within Structural Debris Limit		Physical State
Undamaged, unburned shelters		Uninjured[a]
Damaged but unburned shelters		Uninjured, injured (ambulatory / non-ambulatory); Variable radiation injury possible
Open areas:	Outside 200 r dose contour	Uninjured, ambulatory injured; recuperation from radiation exposure virtually certain[b]
	Within 200 r-600 r dose contours	Uninjured, ambulatory injured; recuperation from radiation exposure certain

a It is assumed that the radiation protection factor of the undamaged shelter is sufficient to ensure that no radiation injuries are incurred

b Provided that movement to shelter or out of fallout field occurs before, or not much later than, 1 day after burst

Source: Stanford Research Institute

desirable) in order to avoid the further hazards of delayed collapse of seriously damaged structures.

It appears that there would be a case for organized rescue activity before about H + 20 hours, for those stranded in the open between the 200 r and 600 r stay-dose contours. As far as early-time rescue is concerned--that is, rescue before firespread and fallout rendered unprotected movement impossible--it would appear that the time required to organize such activities and to work through debris-laden areas would be too great to credit much of a potential payoff to such activities. In addition, within the first few hours after attack, it is questionable that the location of the fallout perimeter would be known.

The variation with time in the number of able-bodied people in the vicinity of the damaged region can be estimated only from detailed analyses of a specific case. The direct effects of an explosion will produce the initial distribution of mortalities, injured, and uninjured: thereafter, the injured will decrease, since the people in this category must either recover or die.*

If the survivors of the immediate effects are subsequently exposed to fallout radiation, then the mortality and recuperation rates become complex functions of the kind and degree of initial injuries, if any, and the magnitude of the radiation dose and the period of delivery. The data required for estimating mortalities and recuperation rates from multiple injuries are less than complete, but ENW[17] contains some information on recuperation times for radiation exposures between about 200 r and 600 r, and Dikewood[23] presents U.S. Army World War II data on hospital release rate for mechanically traumatized personnel. Predictions of mortalities or recuperation times for the possible combinations of mechanical injury, burns, and radiation exposure would be very uncertain, and in any event, are beyond the scope of this study.

If such computations could be made, the results would show the number of able-bodied people vs time after attack. Those outside the periphery of the damaged zone would be physically capable of instituting recovery operations, and their numbers could be augmented by people coming out of shelter, as radiation rates permitted, and possibly by people arriving at the scene from neighboring undamaged communities. Yet the total work force would be smaller than the number of able-bodied people, since allowances would have to be made for age group and possibly for the skills of the survivors.

---

* However, there may be various degrees of permanent disability in the recovered group.

Facilities and Equipment Vulnerability

Figure 17 shows the ranges from a 10 MT surface burst at which debris and damage to urban facilities and equipment may be found. The debris data are from Reference 10; the damage to utility systems was taken from Reference 31, and the remaining data came from ENW.[17] While little that is new can be said about this kind of data, an important point is that earthmoving engineering equipment, such as would be required to clear and remove debris, is very resistant to blast damage; hence, barring damage from other causes, such equipment should be usable even if located as close as $\sim$ 3.5 miles from a 10 MT explosion. In other words, usable engineering equipment would be found in the debris region, so that it is not necessary to assume that such equipment would always have to be brought to the damaged area.

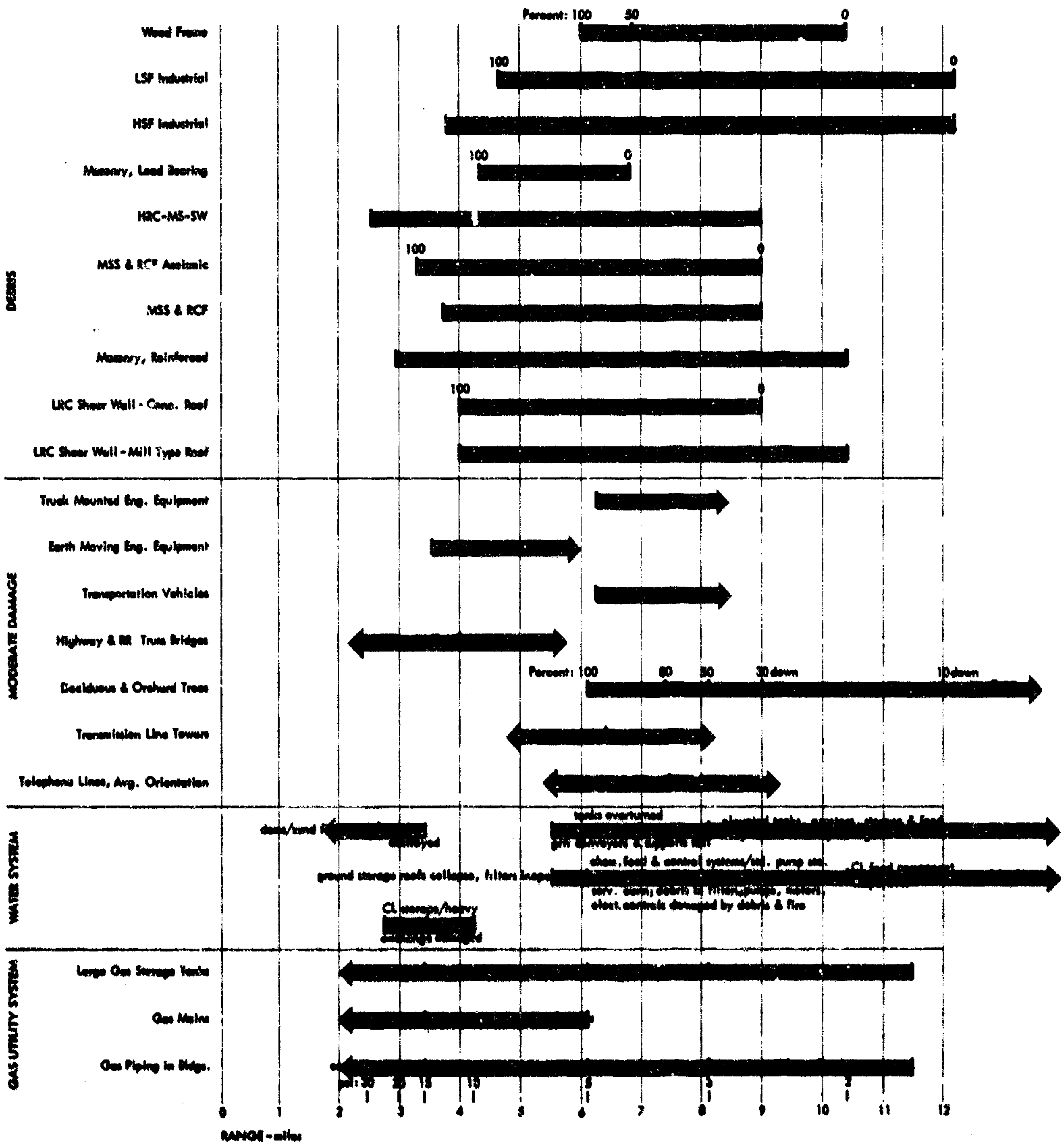
Damage to engineering equipment from causes other than direct blast effects include the possibility of destruction by fire and the crushing or immobilization in debris from surrounding structures. It would seem likely that equipment in use in high-overpressure downtown areas at the time of the attack would be more subject to these kinds of damage than would equipment stored in corporation yards or at job sites in the open.

It can also be seen in Figure 17 that debris from trees may be expected out to about 25 miles, or about the same distance to which glass breakage would be general. It is likely that earthmoving equipment would have little difficulty pushing aside such debris, but that automobiles, while operable beyond 6 miles from the burst point--i.e., exposed to overpressures less than 5 psi--would be effectively immobilized over much of this region.[17] Tree branches and trunks could probably be rather quickly removed by hand, in low fallout-radiation zones, with branches or other suitable pieces of debris employed as levers. It may be fair to conclude that all such superficial debris, including corrugated asbestos and metal siding from steel frame buildings, would not constitute too serious an impediment to vehicular travel. Thus the major problem area regarding clearance for access would lie between 2.4 miles and 9 miles from the the explosion. (Beyond 9 miles, siding failure would not occur.)

As stated previously, within 2.4 miles of the explosion, the damage would be so severe that the term "clearance" would hardly apply; the situation there would be one of abandonment or complete rebuilding at some much later date. It would also be academic there as to whether the debris was distributed on-site or on the former streets. Hence, it is visualized that there would be no compelling reason to enter this zone for some rather long time, and that the zone would be completely avoided in all initial recovery efforts.

Figure 17

BLAST DAMAGE RANGES FOR URBAN FACILITIES AND EQUIPMENT-- 10 MT SURFACE BURST



ENTRY TIMES INTO THE DAMAGED AREAS

Before clearance or repair activities can be scheduled, it is necessary to consider the constraints on such activities. Fire has already been discussed; it will be assumed that by 20 hours after burst, the major hazard from fires would be passed, and except for islands of smouldering debris and residual heat, fire would impose minimal restrictions on access and movement.

The only other major environmental restriction to operations would be caused by fallout. Figure 18 was prepared to show the re-entry times into the accessible area without receiving more than a dose of 100 r for 1 week of continuous stay in the area. The contours in Figure 18 are conservative in the sense that short term operations could be carried out over greater areas for any given entry time, or conversely, the areas indicated could be entered at times earlier than indicated. The contours are also conservative in that radiation from fallout deposited in areas littered by building material debris would be subjected to a greater degree of attenuation due to surface roughness and shielding than radiation from fallout deposited on open terrain.

The results indicate that over 60% of the damaged area would be accessible as early as 2.5 hours after detonation. Table 5 shows how the accessible area increases with time after detonation, as a result of radioactive decay. On the basis of these calculations, it is unlikely that the maximum rate at which clearance and repair operations can be conducted would be constrained by fallout radiation.

Comparison of Figure 18 with Figure 16 shows that by 1 day after burst, rescue personnel from the undamaged areas could penetrate to over more than half of the region between the 200 r and 600 r, 20-hour open-area dose contours, and could rescue disabled persons who might otherwise become radiation casualties.

Figure 18

RE-ENTRY TIMES FOR LIMITING DOSE OF 100 R, ERD--
10 MT SURFACE BURST, 50% FISSION, 15 MPH WINDSPEED

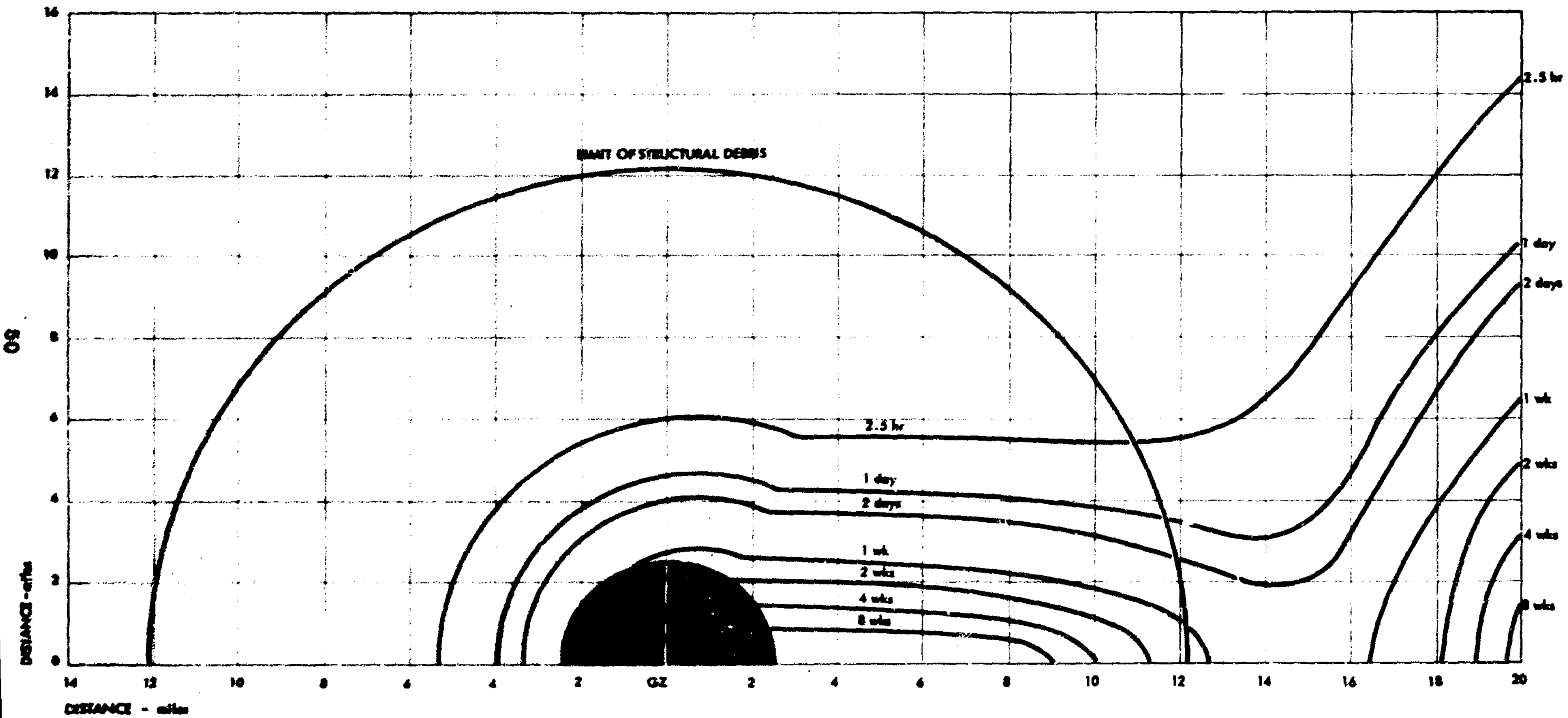


Table 5

PERCENTAGE OF DAMAGED AREA (RADIUS = 12.2 MILES)
RADIOLOGICALLY ACCESSIBLE AFTER A 10 MT SURFACE BURST
50% FISSION, 15 mph WINDSPEED

Time of Entry After Burst	Percent Area Accessible
2.5 hours	62%
1 day	73
2 days	78
1 week	87
2 weeks	91
4 weeks	95
8 weeks	97
15 weeks	100

DEBRIS CLEARANCE

The previous sections have provided methods for determining the degree and extent of fire and blast damage, and for delineating the radiological environment and constraints. Although debris production was given as a percent of the volume of existing materials (see Figure 1), the actual amount of debris produced at any location will also depend on the types of structures, sizes of structures, and the building density. The latter depends on the structural characteristics of the urban community targeted and the aiming point within the urban community. As rough estimates, References 3 and 9 suggest debris-building volume ratios of 0.11 for load-bearing masonry buildings and steel-frame structures, and 0.16 for reinforced concrete buildings. For the calculation of debris depth, a void volume equal to the debris volume was also suggested.

The degree of debris reduction by fire depends not only on the building materials used, the internal furnishings, and other conditions previously mentioned, but also on the degree of fire supression exerted by the distribution of the debris itself. The distribution in turn can be influenced in two ways: by whether debris suppresses fire, and by whether debris is a mixture of combustible and noncombustible fragments. As to the first way, the series of curves in Reference 10 for estimating debris production for blast as well as for blast and fire for various building types require adjustments for suppression of fire by environmental debris. As to the second way, readily ignitable material such as wood would burn completely in the light damage area, whereas in the heavy damage area, the wood might not burn because it was mixed with nonignitable debris (say, masonry fragments). Hence, in the latter case, no debris reduction would result.

The choice of debris clearance equipment and the clearance rates that can be attained also depend on the physical characteristics of the debris and its location with respect to the damaged structures and the area to be cleared. Except for tall slender structures that may be toppled, the major components of damaged structures outside the zone of total destruction will generally remain on the building site. Wood frame and wall-bearing masonry structures will either collapse in place or be shattered to strew rubble within and beyond the building bounds. Therefore the debris found off building sites outside the zone of total destruction will generally (but not entirely) be of the type that can be removed by ordinary earthmoving equipment and by hand labor.

The removal of debris remaining on building sites will be hindered by the damaged structures that are still standing. On the other hand, wood frame structures in various states of collapse, and the debris within these structures, will provide only minor difficulties to the removal operation. The removal of debris located within the bounds of steel frame structures that have been damaged or totally destroyed will be greatly hindered by the steel structural members; if these structural members are not removed first, the removal of debris must be carried out by hand. The removal of steel structural members is a piecemeal process. Cutting torches will be required to free the steel members for removal; such operations are very time consuming.

The rate of debris clearance also depends on the clearance procedure. If the objective is to open avenues of travel and transport, debris clearance merely requires the debris on thoroughfares to be pushed or cast aside; such an operation would apply to the establishment of a transport route through the area as well as an access route to a vital facility requiring recovery. This type of operation outside the zone of total destruction is ideally suited to bulldozing but could also be accomplished manually. On the other hand, if the operation calls for the removal of debris from the area to a designated dump site, the follow-up operations will include loading and trucking, although motorized or towed scrapers may be used to some extent for short hauls. The loading operation may include manual loading as well as the use of loading equipment. In the areas of light to medium amounts of debris, the front-end loader, because of its versatility and mobility, will be very useful. In areas where the debris is massive in size as well as amount and the operating space is adequate, the crane-clamshell combination or the power shovel will probably be required in a clearance operation.

At early times after the attack, debris clearance will generally be for the purpose of opening avenues for travel and transport. As stated earlier, this type of operation is ideally suited to bulldozing. Two or more heavy bulldozers, e.g., in the 40,000 lb. class, depending on the width of cleared path desired, operating "blade-to-blade" should be able to make a continuous run through the debris in the streets, spilling it to the sides for later removal. By skirting the zone of total destruction, these bulldozers can clear a swath through the diameter of the debris zone ($\sim$20 miles for a 10 MT surface burst) in a single day. Because a large portion of the damage area is accessible at early times after the attack, and because the street clearing operation, with the proper equipment in the accessible areas, is rather rapid, this type of debris clearance is useful for operations such as the rescue and evacuation of trapped or non-ambulatory personnel from the damaged areas, as well as for the transport of emergency supplies and equipment. For the same reasons, a cleared narrower path may be useful for laying emergency power lines, emergency communications lines, or a temporary water pipeline. However, the bulk of debris clearance operations during the early postattack period will primarily support damage repair operations, and the emergency supplies and equipment requiring transport over cleared areas will generally be for this purpose.

Operations that require the removal of debris from the general locale are not normally considered to be of an emergency nature. The rate of this type of debris clearance is therefore not of paramount interest to this study. The rate that debris can be loaded into trucks depends on the characteristics of the debris and the tools and equipment available for debris loading. Where the debris consists of relatively fine rubble, the loading rate may be compared to that of loading small irregular aggregates--e.g., the rate of manual loading with a shovel may be estimated at 6 to 8 cubic yards per 8-hour day; also, the loading rate of a 1/2 yard front-end skid loader may be estimated at 200 cubic yards per 8-hour day.

As the size of rubble increases and the shapes become more ungainly and more awkward to handle manually or with light equipment, the loading rate by these methods, and consequently the removal rate, will be reduced. Efficient loading under these more difficult conditions requires the use of larger and more specialized debris handling equipment. Loading rates of 1,000 cubic yards a day are not unusual with heavy equipment.

Within the zone of total destruction, the collapse of steel-frame reinforced concrete structures will provide combinations of distorted and displaced steel members and entire sections of buildings as well as smaller sized debris. Thus, if the total destruction area were predominantly reinforced concrete structures, the type of debris described would be found both on the building site and off the building site. The removal of this type of debris would be very difficult and slow. The removal of debris on the building sites would be most difficult because of the greater number of steel members to be cut loose prior to removal.

In built-up areas, the debris removal procedure will be slow not only because of the difficulty of removal but also because of the sheer mass of debris to be removed. For example, the clearance of a 7-yard wide path through debris 7 yards deep may require the removal of a trapezoidal section 7 yards wide at street level and 35 yards wide at the 7-yard level. This is equivalent to an area cross-section of approximately 150 square yards. Thus for each yard of distance along the street, 150 cubic yards of debris must be moved. Even if it is assumed that all the steel members in the debris were previously cut free, and this really could not be done because many of the members would be deeply buried, a large power shovel (2-1/2 cubic yards) excavating but not loading at 2,000 cubic yards per day day would be able to clear only 40 feet of street per 8-hour day. Because of these slow removal rates, debris removal in highly built-up areas within the zone of total destruction would necessarily be delayed and carried out later in the reconstruction period.

On the other hand, if the central total destruction area were of the wood frame type of urban complex, the debris would be widespread, but because the total amount of debris would be relatively small, debris removal from streets by bulldozers could be readily accomplished. Except for large heavy items like damaged and overturned vehicles, a great deal of debris in such areas could be removed manually. Thus, for this type of target area, a pathway through the area of total destruction could be rapidly opened at early times. However, since destruction would be total, there would be no compelling reason to remove debris from the area at early times except perhaps to establish a needed transportation route through the area.

DAMAGE REPAIR

Estimates of the manhours and equipment hours or the elapsed time to partly or completely repair a facility or industry depend on the extent of damage incurred. If the extent of damage could be described in detail, then the effort or cost of repair could be estimated by normally practiced estimating techniques of repair or construction. The required repair time will depend on the availability of resources such as manpower, equipment, and supplies.

The extent of damage is determined by the vulnerability of the facility components (which include supporting services as well as facility structures, processing equipment, and raw materials) to the effects of blast, fire, and fallout. It is for the above reasons that the studies discussed below have emphasized damage assessment.[11-14]

Reference 14 presented case studies of eight specific segments of the food industry, as follows: flour, yeast, sugar, citrus fruit (frozen orange juice), edible oils, fish, meat, and packaging. In these studies, the vulnerability of various components in the chosen facility was assessed, the probable damages incurred were summed, and manpower requirements for repair and the down time were estimated, all with respect to blast overpressures. The likelihood of fire and the effects of fallout were qualitatively and briefly discussed. However, the repair data from these selected plants within the industry have not been projected to the entire industry. The dependence of these industries on transportation was stressed, as was the dependence of transportation on the petroleum industry. References 11 and 12 were similarly conducted studies of the steel and electrical industries, respectively.

Reference 13 is the culminated output of a detailed study of the effects of nuclear weapon attack on the petroleum industry. Because refineries were deemed the most important link (subsystem) in the petroleum industry, and were found to be the most vulnerable, major emphasis was addressed to the analysis of the refineries. [illegible]e total research effort, which spanned several years, included voluminous detailed vulnerability and damage assessment calculations for various components in three refineries selected for the study. Qualitative generalizations from specifics were made. In the generalization of repair estimates, damage, of course, is one criterion; and the other criteria are size of plant and type of equipment. The following relationship was presented:

$$\frac{\text{Repair Cost Facility A}}{\text{Repair Cost Facility B}} = \left[\frac{\text{Capacity A}}{\text{Capacity B}}\right]^n$$

where n = 0.75 was for high damage levels, and n = 0.35 was deemed appropriate for low damage levels. The equation applies only to the petroleum industry, which generally is made up of the same type of components, and the construction methods are generally governed by rather uniform engineering safety criteria. It may be expected that a more complex equation will be required for industries with greater diversity of component types, process methods, and a wider range in vulnerability.

In their repair scheduling estimates, the above described research studies assumed normal peacetime availability of supplies, new components, and component parts. The operational problems of scheduling repair in the postattack period will have additional complications because not only will the manpower and the tools and equipment for repair operations be curtailed, but also supplier industries may be damaged or destroyed by the attack. Where the delay in delivery of replacement parts or equipment is found to be unduly long, the option of repairing rather than replacing the damaged equipment may be exercised (unless the equipment is irreparable) even though this procedure would incur greater unit (effort) cost. This condition prevails not only for the petroleum industry but also for all industries. Thus the repair estimation and scheduling methods employed must extend beyond the area of knowledge normally required in peacetime practices. In other words, the operational recovery of a particular industry or facility requires the integration of its recovery problems with the recovery problems of other interdependent industries. The research data available for this type of integration are rather incomplete and a satisfactory integration model has yet to be developed. Until a comprehensive integration model is developed, the validity or accuracy of damage repair estimates and schedules will remain questionable. A preliminary semiquantitative treatment of some operational aspects of damage repair problems in industrial facilities has been undertaken in a related research project.[32]

SUMMARY AND CONCLUSIONS

The following nuclear detonation phenomenon were compared with respect to time and location: blast vulnerability and debris production; thermal ignition exposure; fire buildup, growth, and duration; and fallout deposition. Methods for obtaining the comparative data as a function of weapon size were presented. The combined transattack effects and their resulting constraints on transattack and postattack countermeasures were examined; the findings for a representative attack, the 10 MT surface burst, are:

1. Virtually all U.S. cities would be potentially vulnerable in their entirety to fire from thermal radiation
2. Most of the blast damaged region (77%) would be within the maximum potential fire radius
3. By 20 hours after burst, the major fire hazard would be passed and would impose only minimal restrictions on access and movement
4. A reasonable range for relocating or grouping survivors would be beyond the 2 psi line, at 10.5 miles from the point of detonation
5. All structural debris would be contaminated to some extent by stem fallout
6. The radiological restrictions over most of the damaged area would be less severe than those posed by a mass fire
7. Within 20% of the damaged area, there would be virtually no possibility of surviving the radiological hazard if refuge from fires was sought in the open
8. Within about 15% of the damaged area, there would be a possibility of surviving the radiological hazard in the open
9. Over the remaining 65% of the damaged area, the fallout mortality would be nil
10. The fallout hazard would not prohibit access to over 60% of the damaged area as early as 2.5 hours after detonation

11. The major problems of debris clearance for access would occur between 2.4 and 9 miles from the point of detonation

12. Earthmoving engineering equipment would be relatively resistant to blast, and therefore usable debris clearance equipment could be found within the debris region

13. The time required to organize early-time rescue and the time required to work through debris-laden areas would be too long to credit much potential pay-off for early-time rescue activities.

REFERENCES

1. John, F. I. and T. O. Passell, Evaluation of Nuclear Weapon Thermal Threat, OCD-PS-64-201, Stanford Research Institute, Menlo Park, California, August 1966, SRI Project No. 4949-360

2. Hopkins, G. D., C. F. Miller, C. Henderson, F. W. Dresch, et al, A Survey of the Long-Term Postattack Recovery Capabilities of CONUS (U), Stanford Research Institute, Menlo Park, California, SRI Project No. IMU-4500, December 1963 (Secret)

3. Ahlers, E. B., Debris Clearance Study, Final Report on Contract No. OCD-OS-62-202, September 1963, IIT Research Institute, Chicago, Illinois

4. Ungar, A., et al, Logistics of Debris Removal, Phase I Final Report, Contract No. OCD-PS-64-50, undated, IIT Research Institute, Chicago, Illinois

5. Catrambone, J. A., et al, Logistics of Debris Removal, Final Report on Contract No. OCD-PS-64-50, undated, IIT Research Institute, Chicago, Illinois

6. Feinstein, D. I., Debris Distribution, Revised Final (draft) Report on Contract No. OCD-PS-64-50, July 1965, IIT Research Institute, Chicago, Illinois

7. Barnett, R. L., J. F. Costello, and D. I. Feinstein, Accumulation and Removal of Blast-Initiated Debris, IIT Research Institute, Chicago, Illinois, Project No. M6103-2, November 1965

8. Edmunds, J. E., C. K. Wiehle, and K. Kaplan, Structural Debris Caused by Nuclear Blast, URS Corporation, Burlingame, California, URS 639-4, October 1964

9. Rotz, J., J. E. Edmunds, and K. Kaplan, Effects of Fire on Structural Debris Produced by Nuclear Blast, URS Corporation, Burlingame, California, URS 639-9, January 1965

10. Rotz, J., J. E. Edmunds, and K. Kaplan, Formation of Debris from Buildings and Their Contents by Blast and Fire Effects of Nuclear Weapons, URS Corporation, Burlingame, California, URS 651-4, April 1966

11. Fernald, O. H., et al, Critical Industry Repair Analysis, Steel Industry, Advance Research, Inc., Needham Heights, Massachusetts, Contract No. OCD-OS-62-257, undated

12. Fernald, O. H., et al, Critical Industry Repair Analysis, Electric Power, Advance Research, Inc., Needham Heights, Massachusetts, Contract No. OCD-OS-62-257, undated

13. Fernald, O. H., et al, Critical Industry Repair Analysis, Petroleum Industry, Advance Research, Inc., Needham Heights, Massachusetts, Report No. CIRA-4, Contract No. OCD-PS-64-201, October 1965

14. Fernald, O. H., et al, Critical Industry Repair Analysis, Food Industry, Advance Research, Inc., Needham Heights, Massachusetts, Report No. CIRA-3, Contract No. OCD-OS-62-257, April 1965

15. U.S. Strategic Bombing Survey, The Effects of the Atomic Bomb on Hiroshima, Japan, Vols. I, II, and III, and The Effects of the Atomic Bomb on Nagasaki, Vols. I, II, and III, Washington, D.C., May 1947

16. Michitaka, UDA, The Report on the Atomic Bomb Damage in Hiroshima, Meteorological Conditions Related to the Atomic Explosion in Hiroshima City, The Hiroshima District Central Meteorological Observatory, November 1947

17. Glasstone, S., (ed.), The Effects of Nuclear Weapons, Department of Defense, USGPO, Washington, D.C., Revised Edition, February 1964

18. Caudle, Kenneth F., Yield of the Hiroshima Weapon, NOLTR 65-143, December 1965 (U), Naval Ordinance Laboratory, White Oak, Maryland

19. Martin, Stanley B. and Stephen Holton, Preliminary Computer Program for Estimating Primary Ignition Ranges for Nuclear Weapons, U.S. Naval Radiological Defense Laboratory, San Francisco, California, USNRDL Draft Report, December 1964

20. Gibbons, M. G., Criteria for Estimating Structural Damage and Personnel Casualties from Nuclear Weapon Effects (U), U.S. Naval Radiological Defense Laboratory, San Francisco, California, USNRDL-TR-900, August 1965 (Secret)

21. Elterman, L., Atmosphere Attenuation Model, 1964, in the Ultraviolet, Visible, and Infrared Regions for Altitudes to 50 Km., AFCRL-64-740, September 1964. Air Force Cambridge Research Laboratories, L. G. Hanscom Field, Massachusetts

22. Passell, T. O., Transmission by the Earth's Atmosphere of Thermal Energy From Nuclear Detonations Above 500 Km Altitudes, Stanford Research Institute, Menlo Park, California, SRI Project No. IMU-4021-302, 30 April 1963

23. Davis, L. W., et al, Prediction of Urban Casualties from the Immediate Effects of a Nuclear Attack, DC-FR-1028, The Dikewood Corporation, Albuquerque, New Mexico, April 1963 (Confidential)

24. Leutz, Hermann, Fireproof Shelters With Secured Ventilating Systems, Protective Structures for Civilian Populations Symposium, National Academy of Science, Washington, D.C. (NAS-NRC), April 1965

25. Crain, John L., et al, Supplemental Analysis - Civil Defense Rescue, Phase 1b Analytical Report, Contract No. OCD-PS-64-55, Stanford Research Institute, Menlo Park, California, SRI Project No. 4727, August 1965

26. Miller, C. F., Fallout and Radiological Countermeasures, Vol. I, Stanford Research Institute, Menlo Park, California, SRI Project No. IMU-4021, January 1963

27. LaRiviere, P. D., H. Lee, and K. H. Larson, Ionization Rate Measurements (U), Project 2.11, Operation SUN BEAM, Shot Small Boy, POR-2217, U.S. Naval Radiological Defense Laboratory, San Francisco, California, September 1962 (Confidential)

28. Owen, W. L. and J. D. Sartor, Radiological Recovery of Land Target Components - Complex I and Complex II, U.S. Naval Radiological Defense Laboratory, San Francisco, California, USNRDL-TR-570, May 1962

29. Miller, C. F., Fallout and Radiological Countermeasures, Vol. II, Stanford Research Institute, Menlo Park, California, SRI Project IM-4021, January 1963

30. U.S. Census of Population, 1960, United States Summary, Final Report PC (1) - 1A, U.S. Dept. of Commerce, Bureau of the Census, Washington, D.C.

31. EOSD Phase 1 Analytical Report - Engineering, Description, Inventory, and Damage Assessment of Engineering Resources, Draft Report, December 1965, Carroll E. Bradberry and Associates, Consulting Engineers, Los Altos, California

32. Brown, Stephen L., Industrial Recovery Techniques, Stanford Research Institute, Menlo Park, California, SRI Project No. MU-4949-350, April 1966

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) STANFORD RESEARCH INSTITUTE Menlo Park, California 94025	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

POSTATTACK RECOVERY OF DAMAGED URBAN AREAS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (Last name, first name, initial)

LA RIVIERE, Philip D.
LEE, Hong (nmn)

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1966	63	32

8a. CONTRACT OR GRANT NO. OCD-PS-64-201 b. PROJECT NO. OCD Work Unit No. 3331A c. SRI Project No. MU-4949-130 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. AVAILABILITY/LIMITATION NOTICES

[redacted]d.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Office of Civil Defense Department of the Army Washington, D.C. 20310

13. ABSTRACT

The report presents mathematical formulas and computational procedures for assessing damage due to blast and fire and for estimating the fallout hazards from nuclear detonations in urban areas. Major consideration is directed to the delineation of the damage areas for the purpose of defining the locations and the extent of the areas in which clearance and repair operations could be carried out. The constraints on these operations are determined by estimating not only the extent of the combined nuclear effects of blast, fire, and fallout radiation but also the timing of the events in the developing environment. The net result of applying the procedures is a definitive description of the prerecovery state of the urban population, urban facilities, and urban resources that would be available for use in recovery operations.

DD FORM 1 JAN 64 1473

UNCLASSIFIED

Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Nuclear attack						
Blast damage						
Thermal ignition						
Fallout contamination						
Recovery operations						
Decontamination						
Debris clearance						
Damage repairs						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
____________________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
____________________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
____________________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

DD FORM 1 JAN 64 1473 (BACK)

UNCLASSIFIED
Security Classification

TITLE: Postattack Recovery of Damaged Urban Areas

By: Philip D. LaRiviere and Hong Lee

SUMMARY:

Major consideration is directed at the operational problems of postattack recovery in the damaged urban areas. Initial situation conditions were introduced by recounting the events and conditions as they evolved in Hiroshima immediately following the explosion of a nuclear weapon over that city. The parallel effects and sequence of events that would result from exploding a large yield thermonuclear weapon in an American city are discussed in general terms to set the scene for recovery operations.

The development of planning and scheduling concepts for postattack recovery operations requires some definitive descriptions of postattack environments. To provide such descriptions, representations of the various effects of nuclear detonations are explored in detail both as separate entities and in combination. Mathematical formulas for assessment of damage due to blast and fire and a procedure for estimating the fallout environment in the damage area and the consequent hazards of transattack and postattack operations are presented. The net results of applying the computational procedures is a description of the prerecovery state of the urban population, urban facilities, and urban resources that would be available for recovery operations.

Although the combined effects of a nuclear detonation and hazard constraints imposed upon recovery operations can be determined for any weapon size and detonation configuration, those produced by a 10 megaton 50 percent fission surface burst are summarized as a point of reference.

SRI Project No. MU-4949-130 November 1966

Contract No. OCD-PS-64-201
OCD Work Unit No. 3331A

STANFORD RESEARCH INSTITUTE

333 Ravenswood Avenue
Menlo Park, California 94025

Tel. (415) 326-6200
Cable: STANRES, MENLO PARK
TWX: 910-373-1246

Regional Offices and Laboratories

Southern California Laboratories
820 Mission Street
South Pasadena, California 91030
Tel. (213) 799-9501 • 682-3901

SRI-Washington
1000 Connecticut Avenue, N.W.
Washington, D.C. 20036
Tel. (202) 223-2660
Cable: STANRES, WASH.D.C.
TWX: 710-822-9310

SRI-New York
270 Park Avenue, Room 1770
New York, New York 10017
Tel. (212) 986-6494

SRI-Huntsville
Missile Defense Analysis Office
4810 Bradford Blvd., N.W.
Huntsville, Alabama 35805
Tel. (205) 837-3050
TWX: 510-579-2112

SRI-Detroit
303 W. Northland Towers
15565 Northland Drive
Southfield (Detroit), Michigan 48075
Tel. (313) 444-1185

SRI-Chicago
10 South Riverside Plaza
Chicago, Illinois 60606
Tel. (312) 236-6750

SRI-Europe
Pelikanstrasse 37
8001 Zurich, Switzerland
Tel. 27 73 27 (Day/Night) • 27 81 21 (Day)
Cable: STANRES, ZURICH

SRI-Scandinavia
Skeppargatan 26
Stockholm Ö, Sweden
Tel. 60 02 26; 60 03 96; 60 04 75

SRI-Japan
Nomura Securities Building
1-1 Nihonbashidori, Chuo-ku
Tokyo, Japan
Tel. Tokyo 271-7108
Cable: STANRESEARCH, TOKYO

Representatives

Canada
Cyril A. Ing
86 Overlea Boulevard
Toronto 17, Ontario, Canada
Tel. (416) 425-5550

Italy
Lorenzo Franceschini
Via Macedonio Melloni 49
Milan, Italy
Tel. 72 32 46