Report R-113

THE EFFECTS OF NUCLEAR WEAPONS ON A SINGLE CITY

A Pilot Study of Houston, Texas

Samuel Ewer Eastman

INSTITUTE FOR DEFENSE ANALYSES
ECONOMIC AND POLITICAL STUDIES DIVISION

September 1965

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INSTITUTE FOR DEFENSE ANALYSES
ECONOMIC AND POLITICAL STUDIES DIVISION

FOREWORD

The work reported in this document is part of a continuing effort in the analyses of alternative civil defense systems by the Institute for Defense Analyses under Contract No. OCD-OS-63-134 (dated June 28, 1963) with the Office of Civil Defense, Department of the Army. The studies were performed in the Economic and Political Studies Division of IDA under the direction of Mr. Samuel Ewer Eastman, Project Leader, and Mr. William C. Truppner, Deputy Project Leader.

This Report outlines an approach to estimating the effects of single-weapon nuclear attacks at the local level, describes the methodology that has been developed to make such evaluations, and presents the results of a pilot study of Houston, Texas. The research underlying the Report has been underway in the Civil Defense Project for more than a year, and virtually everyone on the Project contributed to it: Dr. Abner Sachs compiled costs and descriptions of selected population protection systems for Houston from his own work and that of Dr. Harry Williams, Mr. Wayne Allen, and (under subcontract) Dr. J. Edwin Becht, University of Houston, Dr. Howard Harrenstien, University of Arizona, Mr. Luis Sanchez of the Planning Research Corporation, and Mr. Curt Harvey, formerly of The Planning Research Corporation, now a member of the IDA staff. Mrs. Grace Kelleher developed procedures for evaluating alternative population protection systems on the basis of a damage assessment system and shelter allocation model designed and developed with the help of Dr. John D. Wells, Mrs. Jane-Ring F. Crane, Miss Jane Gleason and (under contract) Mr. Robert A. Dibrell and Mr. Donald Wendland of the American Research Corporation (formerly a part of the Hughes Aircraft Company). These data are available in the files of the IDA Civil Defense Project.

IDA Studies directly supporting or supplementing this Summary Report are:

S-186 A Damage-Limiting Shelter-Allocation Strategy by Grace J. Kelleher, April 1965,

S-187 Protecting Industrial Resources Against a Nuclear Attack: Interim Report of an Economic Analysis by Henry M. Peskin, February 1965, and

S-209 Nuclear Blast Effects on a Metropolitan Economy by William C. Truppner, October 1965.

The task of editing this Report and the supporting studies was undertaken by Mr. Charles Lerner.

The research reported here and in the studies is based on many data which were used in computer programs to provide damage assessment calculations, locate weapon ground zeros and allocate shelters. The data were collected and the computer programs were written and employed in production runs by the Research Assistants assigned to the Project: Miss Judith Crumlish, Mr. John Diesem, Miss Jane Gleason, Miss Dorothy Harris, Miss Elizabeth Johnston and Miss Judith Napoleon.

At the Office of Civil Defense, Department of the Army, contract liaison was provided by Mr. Lloyd Woodward under the supervision of Mr. John Devaney, Director, Systems Evaluation Division, Research Directorate.

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SUMMARY

This Report summarizes and focuses the current results and status of on going IDA research into the effects of nuclear attacks on a single city. This work has dealt principally with developing analytic methods for evaluating the performance of alternative civil-defense systems at the local level, and with applying these methods in pilot studies of a single large metropolitan area (Houston, Texas) subjected to selected single-weapon surface-burst attacks in the 0.1 to 100 megaton range.

The local area approach appears to be fruitful. Detailed analyses under this program have permitted insights into the effectiveness of shelter programs that would have been lost in the aggregations necessary for any evaluation at the national level.

The analytic method used here rests on two devices: a matrix of target value elements of constant area and uniform weapon effects, and a damage-limiting shelter-allocation model. The matrix of target value elements is used to describe the distribution of population, property and industrial output (or capacity) in the local area. Each element in the matrix is assigned a value representing the population, property values, or industrial output (capacity) within it. The damage-limiting shelter-allocation model determines efficient combinations of shelter locations and protective capacity: i.e., it allocates shelters of various types to target value elements in such a way that the cost of maintaining a specified percentage of survival is minimized for any actual ground zero within the protected area.

Two basic types of population protection systems are considered: systems where shelter location is fixed (for example the National Fallout Shelter Survey, which identifies shelter in existing buildings) and systems where shelter location and type are planning options.

The procedure for defining an efficient shelter system is perhaps best illustrated by an example. The costs of a Universal 300-psi System, a 300-psi Damage-Limiting System designed for a 10-Mt attack, and a 300/100-psi Damage-Limiting System designed for a 10-Mt attack are estimated to be $1,014 million, $828 million, and $548 million, respectively. Each system holds Houston fatalities to 2 percent of the population against a 10-Mt single-weapon surface burst targeted to maximize fatalities. The Universal 300-psi System is thus least efficient; because it provides 300-psi blast-shelter protection for everyone, it overprotects. The 300-psi Damage-Limiting System also overprotects because when a shelter is needed to hold fatalities to the prescribed minimum (2 percent of the population), the allocation model can select only a 300-psi shelter. The most efficient system (i.e., the one with the lowest cost for equal performance) is the 300/100-psi Damage-Limiting System. In this case the model can match shelter location with the lowest protection level needed in a target value element to ensure a given survivorship in the city as a whole.

In order to establish a base case against which the performance of all systems could be measured we postulated a number of attacks on the at-home and at-work populations in the absence of any special shelter or warning. These attacks were single-weapon surface bursts (ranging from 0.1- to 100-Mt) targeted to maximize fatalities. Fatalities run from about 20 percent for the low yield weapons to virtually 100 percent for the 100-Mt weapon. In all cases, the at-work population suffers heavier losses than the at-home population because the city's inhabitants are more concentrated during the working day. For a 1.0-Mt attack, the at-home population suffers about 52 percent fatalities, the at-work population about 62 percent; for a 10-Mt attack the at-home population suffers about 84 percent fatalities, the at-work population about 87 percent. This suggests that in the absence of any special population-protection system the timely instruction to "Go home" is good civil defense against a single-weapon attack on Houston. Against a single 1-Mt bomb it could mean the lives of some 123,000 of the city's 1,226,000 inhabitants.

"Go home" is good civil defense for a single-weapon attack if the population is provided with the shelter identified by the National Fallout Shelter Survey (NFSS), provided the attack is population-oriented and against the city itself. Against indirect attacks this shelter provides adequate fallout protection for the population at a modest initial cost of $56 million (Table 5). But the NFSS is a bad compromise; the shelter it affords is heavily concentrated in downtown Houston. Thus, against direct attack the population is concentrated in shelters in the city center, just as the at-work population (Figure 3). For this reason NFSS shelter in downtown areas should be limited to that needed for the peak downtown population and additional shelter spaces should be provided near places of residence. For multiple-weapon attacks, total fatalities are relatively insensitive to the distribution of population within a city; a significant defense against such attacks can only be provided by active defense, blast shelters, or evacuation.

These findings suggest the possible merit of a fallout shelter system with shelters removed from the blast effects of an attack upon the city and with the shelters themselves quite widely dispersed. Such a system has been studied here under the heading of Movement to Shelter (MTS); for estimated initial costs of about $182 million, relatively simple fallout structures can be constructed in counties around the city for the entire population. The promise of a huge life saving value at relatively low cost suggests that this population-protection system receive further study. However, since about six hours are required to disperse the population from the city to the shelters, a "cry wolf" problem is associated with this system. How many times can the population be dislocated as national crises come and go before reluctance or apathy begins to take effect? What incentives and sanctions will make the people move? Since at least a part of the population may be dispersed for long periods, answers are needed to such questions as: How can we minimize the impact on the city's economic, political, and social activity of movement to shelters and long periods of residence in them? In short, how can the system be made "livable"?

A second class of location-optional systems--alternatives to the MTS--are the in-city shelter systems. These systems, in which shelter strength and location were balanced by the damage-limiting shelter-allocation model, are efficient against a single-weapon 10-Mt attack. These systems build on the Universal Fallout System (which affords the protection of NFSS but locates shelter with the at-home population) adding "heavier" protection as the stipulated survivor level is increased. In-city shelters permit population survival levels from 63 percent (the level for the Universal Fallout System) to 98 percent against a single-weapon 10-Mt surface burst (Table 6 and Figure 4). For the combinations of type and location which make up these efficient or "best" systems against a 10-Mt weapon, total initial costs rise rapidly with the demand for survivors: The 63 percent survivorship can be bought for about $104 million with Universal Fallout, 70 percent survivorship for about $142 million with an efficient 35-psi Damage-Limiting 10-Mt system, 80 percent for $201 million by a 100-psi Damage-Limiting 10-Mt system, and so forth (Table 6). If shelter location and type are optional, efficient in-city shelter systems can be designed against a specific attack, and their performance under off-design conditions, i.e., against other than the design attack, can be tested by methods developed in the course of the work reported here.

The table below summarizes the cost and effectiveness of selected in-city shelter systems studied. The marginal costs per survivor added indicate the average per capita cost of buying the next bloc of survivors as the requirement for a larger fraction of survivors increases.

These data show the not-at-all surprising fact that, above a certain level, survivorship can indeed be increased with progressively harder in-city population protection systems, but only at an increasingly higher price per survivor. Average costs to obtain survivors are increasing and marginal costs are increasing even more rapidly.

COST AND EFFECTIVENESS OF IN-CITY SHELTER SYSTEMS[a]

System	Percent Survivors	Initial System Cost,[b] Millions of $	Average Cost Per Survivor Added, $	Marginal Cost Per Survivor Added, $
Base Case (No Special Shelter)	18	-	-	-
NFSS (Full Shelter Occupancy)	30	56	385	384
Universal Fallout	63	104	188	118
DL 100 psi (10 Mt)	70	144	226	470
DL 100 psi (10 Mt)	80	201	264	463
DL 100 psi (10 Mt)	90	296	335	772

a. 10-Mt, single-weapon surface burst; shelter co-located with the at-home population.
b. These costs are preliminary estimates applicable only to Houston.

The data also show that the average cost of a survivor decreases from the NFSS value of $384 to a low of around $194 at slightly below the 65 percent survival level--the level of protection afforded by the Universal Fallout System--and then starts to increase again as higher survival levels are prescribed. If, therefore, the single 10-Mt attack upon which this analysis is based is accepted as a reasonable description of the threat for which protection is desired, then efficient in-city systems can be designed at reasonable cost which guarantee survivorship at the 60 to 65 percent level. If for reasons of national policy or to fulfill some other condition outside the scope of the analysis covered here, the survivorship must be higher than this, then other ways of protecting population should be exhaustively explored before commitment is made to a massive, heavy in-city shelter program which the higher levels portend. The Movement to Shelter System is a case in point. Under the assumption we have made regarding this system, higher survival levels at lower costs than in-city systems, and with comparable survival levels, appear to be possible.

Our studies of the effects of attack upon property and economic capacity in Houston are limited to estimating the losses that might follow from the population oriented attacks that we have considered above. We have been unable, so far, to develop and evaluate ways to harden national capital stock. Nevertheless, losses of nonhuman as well as human resources must be considered if the surviving population is to emerge as a viable economic and social environment.

The evidence we have accumulated concerning Houston shows that in terms of the pre-attack economic values, a sheltered population is less well off on a per capita basis after an attack than it was before, and perhaps far worse off because of our inability to properly consider all the factors describing the economic activity of the city. In addition, it appears that damage to the capital stock of Houston is uneven across kinds of property and types of industry.

Thus, property values attributed to real-estate improvements stand up better against attack than durable property composed of machinery, equipment and inventories which tend to be more concentrated in the city center. Less obvious intuitively, this same unevenness persists across industry types. For example, of 127 industry types in a particular damage category, the calculations show that about half are either immediately operable or, for practical purposes, lost permanently after a 10-Mt attack. These findings are important to civil defense planning for industrial recovery. The property and industry types receiving heavy damage can be examined to determine to what extent their contribution is critical to a viable post-attack city. Those which qualify become candidates for protection.

The finding that a sheltered population in Houston is less well off on a per capita basis than before the attack has a special import. If we are to ensure that the post-attack "economy" of Houston meets standards with which we are at all familiar, population protection necessarily implies the protection of industrial resources.

INTRODUCTION

The work reported here was carried out by the Institute for Defense Analyses under a continuing two-part program in civil-defense research: The analyses of alternative civil-defense systems and the integration of research conducted by other groups. The long-range goal of this program is to develop, and as far as possible apply, damage-assessment models to evaluate alternative civil-defense systems at the local and national levels. Such a goal implies a methodology for measuring the effectiveness of protective systems not merely in terms of the lives they save, but in terms of their contribution to an economically viable post-attack United States. Thus, it is necessary to study not only systems that protect people, but also various ways to protect nonhuman industrial resources or national capital stock which, with the surviving population, constitute a complete economic society.

Previous work in this field has concentrated on the nationwide performance of protective systems. The principal feature of the work reported here, both on population and property protection systems, is that it focuses on local-level problems and the effectiveness of systems in their local environment. Thus, population-protection systems are evaluated at the local level and the groundwork has been laid for evaluating property-protection systems at both the local and national levels.

Population-protection systems are evaluated against a criterion of minimum costs to achieve a specified upper level of population losses. The damage-limiting model used to allocate shelters is presented by Kelleher in S-186.[1] The work on property-protection systems is less complete than that on population-protection systems. The studies reported here dealing with nonhuman factors of production do not compare the costs or effectiveness of property-protection systems; instead, the work is in an earlier phase: measurement of the effects of an attack on an unprotected economy, in terms of losses in property values and output (capacity). A study of the problem at the local level is reported by Truppner in S-209;[2] on the national level it has been studied by Peskin in S-187.[3] Truppner investigates the effects of nuclear attack on the economic capability of a single city, and Peskin presents a linear programming model that maximizes Gross National Product under various post-attack constraints.

The purpose of this Report is to apply the model developed in S-186 to cost data on various shelter systems, and to summarize the result and current status of the research embodied in S-187 and S-209. The result is a pilot study of the effects of nuclear attacks on the City of Houston, Texas from the standpoint of both population and economic effects.

Since most of the effort during the past year or more was devoted to the methodology required for detailed local studies, it was necessary, in preparing this Report, to devote careful attention to costs and population-protection systems appropriate to the community under scrutiny.[4] Detailed descriptions of weapons phenomena and effects have been prepared, programmed and realized on the CDC 3600 computer at the National Civil Defense Computer Facility in Olney, Maryland.

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1. Grace J. Kelleher, A Damage-Limiting Shelter Allocation Strategy, Institute for Defense Analyses, Economic and Political Studies Division, IDA Study S-186 (Arlington, Virginia, April 1965).

2. William C. Truppner, Nuclear Blast Effects on a Metropolitan Economy, Institute for Defense Analyses, Economic and Political Studies Division, IDA Study S-209 (Arlington, Virginia, September 1965).

3. Henry M. Peskin, Protecting Industrial Resources Against Nuclear Attack: Interim Report of an Economic Analysis, Institute for Defense Analyses, Economic and Political Studies Division, IDA Study S-187 (Arlington, Virginia, February 1965).

4. The detailed data are available in the files of the IDA Civil Defense project.

No attempt has been made here to reproduce in detail all programs written and operational.

This Report lays the groundwork for further local area studies now contemplated by the Office of Civil Defense in the "Five City Study."[5] Accordingly, its main burden is to explore in detail the local area approach to the analyses of alternative population protection systems and to describe the tools that have been developed to make possible such studies. Nevertheless, the preliminary findings reported here are themselves important.

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5. Office of Civil Defense, Research Directorate, Systems Evaluation Division, Five City Study, Guide for Participants, Interim Draft, 1 May 1965 (For Official Use Only).

THE USE OF A TARGET VALUE MATRIX IN SHELTER ALLOCATION AND DAMAGE ASSESSMENT

The standard format for studies of nuclear effects on urban populations has relied on census tracts for population. A particular census tract is treated as a homogeneous unit with uniform weapons effects and population density. The chief virtue of census tracts as the basic unit of analysis is convenience: population data are readily available from the Bureau of the Census in this form.

In this Report, census tracts have been replaced as a basic unit with a uniform grid consisting, in the present model, of sixty-five rows and sixty-five columns of one-square-kilometer elements. Each of these square Target Value Elements, or TVE's, can be assigned uniform values of population density (either at home or at work), property values, or industrial output (capapacity). The characteristics of any local area--Houston, Texas is the pilot city in the present case--can then be represented by this Target Value Matrix of 4225 TVE's. Figure 1 shows the Houston Target Value Matrix for the at-home population.

The Target Value Element is the analytical framework for the study of a single city or local area. Depending upon the protective system under analyses, the population in a particular TVE is either restricted to using shelters within that TVE, or permitted to move from element to element to obtain shelter. The TVE is the basis for the damage-assessment systems developed to estimate weapons effects upon both population and property.

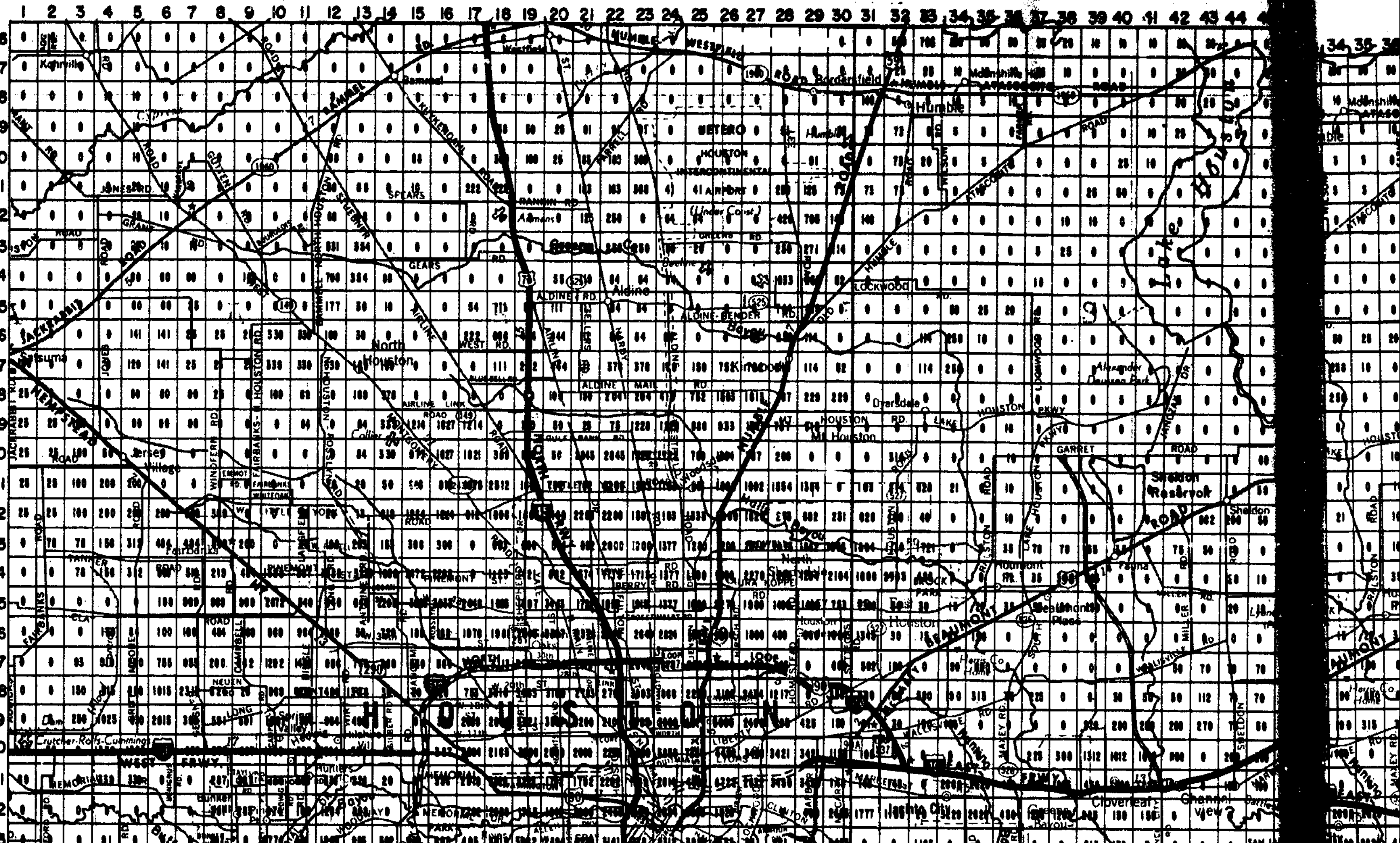
The TVE is also a basic input to the model designed to allocate shelter in accordance with a damage limiting shelter allocation strategy.[1] In this study shelters are considered to fall into one

1. Grace J. Kelleher, A Damage-Limiting Shelter Allocation Strategy, Institute for Defense Analyses, Economic and Political Studies Division, IDA Study S-186 (Arlington, Virginia, April 1965).

of two categories: shelter location in the city is either fixed or it is optional. The National Fallout Shelter Survey (NFSS) is an example of a population protection system in which shelter location is fixed or restricted. These are dual purpose shelters, established in existing buildings.

The shelters used in the population-protection systems analyzed in this Report are not dual-use or dual-purpose, but are built principally, if not exclusively, as shelters. Shelter is thus not "piggy-backed" onto some other use of the facility and shelter location may be said to be optional. That is, the shelters may be located where they are most effective as shelters.

The allocation of shelter to TVE's by location and type of shelter is accomplished so as to reflect a damage-limiting shelter-allocation strategy. Specifically, shelters are allocated so as to minimize cost at a prescribed fatality level independent of the ground zero or detonation point (surface burst).



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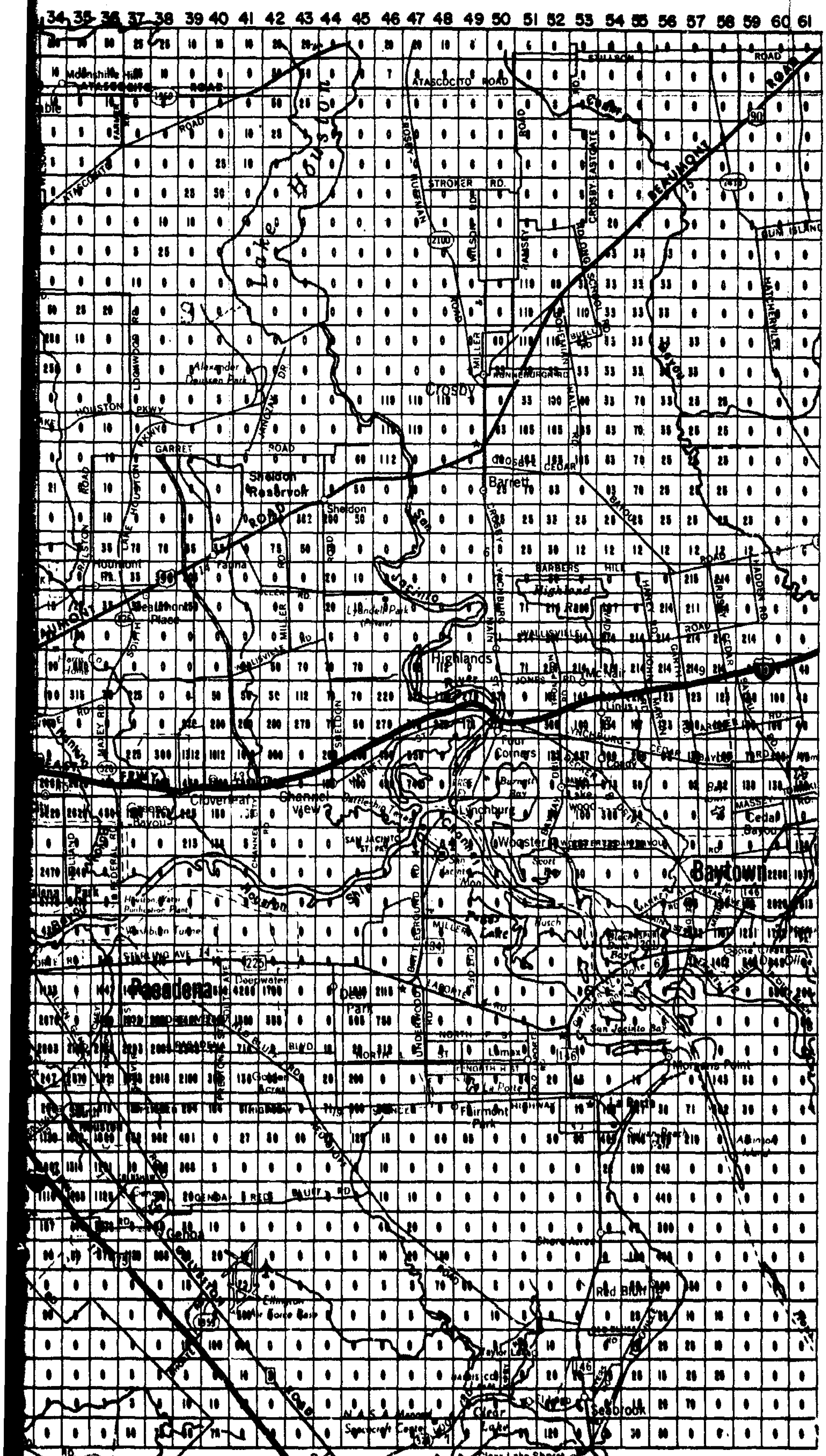

FIGURE 1 Houston Target Value Matrix, At-Home Population

428 = Persons per square kilometer

2

3

POPULATION-PROTECTION SYSTEMS

3.1 PROTECTIVE SYSTEMS CONSIDERED

The cost and effectiveness of a number of shelter systems offering different levels and types of protection have been examined. The protective characteristics of these are shown in Table 1.

The fallout protection attributed to NFSS is a Protection Factor of 40 against lethality based on a 50-percent-lethal dose (LD50) of 450 roentgens equivalent residual dose (ERD). Blast protection is assumed to be that afforded by steel frame buildings according to the mortality curves developed by the Dikewood Corporation--an LD50 of 7 to 8 psi.[1] All defenses are compared with the Base Case (No Special Shelter), where a PF of 2 with the same lethality function has been assumed for fallout, and where the Dikewood curve for wooden frame buildings (a mean fatality at 6 to 7 psi)[2] was employed to estimate blast effects.

Three location-optional systems are considered: the Universal Fallout shelter posture, blast-shelter systems employing 35-, 100-, and 300-psi shelters in various combinations, and a Movement to Shelter System (MTS). The Universal Fallout System provides the same protection against fallout and blast as NFSS, but the shelter locations are different. The fallout protection provided by blast

1. The Dikewood Corporation, Prediction of Urban Casualties from Immediate Effects of Attack (U) CONFIDENTIAL, (Albuquerque, New Mexico, 1964).

2. The damage-assessment systems employed make no explicit determination of loss due to thermal radiation and possible ensuing fires.

Table 1

ASSUMED PROTECTIVE CHARACTERISTICS OF SYSTEMS CONSIDERED

System	Fallout Protection Factor (PF)[a]	Blast Protection[b]
Base Case - No Special Shelter	2	wooden frame building (psi rating = 6 to 7)
Location-Fixed - (National Fallout Shelter Survey)	40	steel frame building (psi rating = 7 to 8)
Location-Optional:		
Universal Fallout	40	steel frame building (psi rating = 7 to 8)
Blast Shelters 300, 100, and 35 psi	adequate	concrete shelters (psi rating = 300, 100, and 35)
Movement to Shelter (MTS)[c]	adequate	adequate

a. The protection factor is the ratio of radiation levels outside a structure to those inside the shelter.
b. Structures are assumed 100% effective at overpressure up to their psi rating; 0% effective at overpressure above their rating.
c. The MTS system was not subjected to direct attack.

shelter was assumed adequate for all the attacks considered, and blast resistance was assumed to be completely effective for pressures at or below rated psi and completely ineffective for those above the rating. In the MTS system, the population was protected by means of fallout shelters located in the adjacent counties surrounding the city. The system included an evacuation team whose full-time year-round task was to plan for and direct the movement of the population to these peripheral shelters.

Estimates of the effectiveness of the systems presented are based on 100 percent occupancy of the available shelter unless otherwise specified.

Table 2

ESTIMATED ADDITIONAL COSTS OF THE NATIONAL FALLOUT SHELTER SURVEY-EXTENDED FOR HOUSTON, TEXAS[a]

Cost Element	Total Cost, $[b]	Cost per Space Added, $[c]
Movement to shelter	3,104,280.00	4.70
Construction costs	16,443,625.00	25.00
Hotel package	15,303,437.00	23.17
Ventilation package	9,610,057.00	14.55
Auxiliary power package	3,863,837.00	5.85
Decontamination	7,470,085.00	11.31
Total	55,795,321.00	84.58

a. Costs are for needed shelter spaces not provided in NFSS.
b. These costs are preliminary estimates applicable only to Houston,Texas.
c. 657,745 spaces added by NFSS-X.

3.2 SHELTER-SYSTEM COSTS

The costs of fallout shelter systems are shown in Table 2, the costs of blast shelter systems in Table 3. Costs of shelter already identified by NFSS were treated as sunk costs. The fallout shelter costs shown are for shelters needed in addition to those identified in NFSS in order to give the population full coverage. Extending shelter coverage in this way conforms with the philosophy of the Shelter Development Bill[3] introduced in, but not passed by, Congress in 1963. Under that Bill, eleemosynary institutions were to be subsidized in an amount up to $25 per space in new construction. In order to extend the NFSS shelter to provide full coverage, schools and hospitals in Houston were identified by street address. This provided less than 90,000 additional shelter spaces against the approximately 600,000 additional spaces needed for the entire population. This gap was filled by identifying manufacturing plants, which appeared to possess facilities capable of sheltering over a half million people. This shelter system is called National Fallout Shelter Survey - Extended, or NFSS-X.

3. H.R. 8200,"Providing for Fallout Protection in Federal Structures and Nonprofit Institutions," House of Representatives, 88th Congress, 1st Session, Report No. 715, August 27, 1965.

Table 3

ESTIMATED BLAST-SHELTER-SYSTEMS UNIT COSTS

BY STRENGTH AND SIZE[a]

Cost Element	Cost, $/Unit[b]						
	35 psi			100 psi			300 psi
	100 person	500 person	1000 person	100 person	500 person	1000 person	100 person
Movement to shelter	$ 337	$ 1,684	$ 3,367	$ 337	$ 1,68[illegible]	$ 3,367	337
Shelter shell	21,451	61,703	121,736	29,954	91,134	176,307	45,776
Shelter communications	500	500	500	500	500	500	500
Hotel package	3,180	15,898	31,796	3,180	15,898	31,796	3,180
Environmental package	16,605	66,420	132,840	16,605	66,420	132,840	16,605
Sites[c]	4,500	4,500	4,500	4,500	4,500	4,500	4,500
Decontamination	1,637	8,185	16,370	1,637	8,185	16,370	4,822
Movement from shelter	1,347	6,734	13,467	1,347	6,734	13,467	1,347
Total	$49,557	$165,624	$324,576	$58,060	$195,055	$379,147	$77,067

a. Initial or "one time" costs only.
b. These costs are preliminary estimates applicable only to Houston, Texas.
c. Based on average cost of $4,500 per shelter, which results from acquiring 75 percent of the required sites @ $6,000 per site. Remaining sites are located on public property and assumed to be available at no cost.

All costs shown are initial or "one time" costs; no attempt has been made to estimate recurring or annual operating costs. Subject to this limitation, however, an effort was made to estimate relatively complete shelter-system costs, not just the cost of shelter shells alone, and to base the estimated costs on local rates in Houston, Texas. Thus, estimates are included for teams and equipment to move people to and from shelter, and to perform decontamination activities post-attack; moreover, the climate and high water-table of Houston were taken into account--blast shelters waterproofed and provided with air conditioning.

Not all costs associated with a complete population protection system have been included. Thus, no special provision is made for pre-attack warning (taken as a sunk cost), for rescue operations, for emergency hospitalization, feeding, temporary housing, fire fighting, emergency repair of utilities, or a host of other services that would be required immediately after the attack and for several months thereafter. To some extent the existing resources in Houston which survive the attack may supply the material and servi[illegible] required. The shelter costs we have used represent an attempt to str[illegible] a balance between, on the one hand, complete duplication of existing pre-attack resources, and, on the other, sole reliance on a system which provides a shelter shell but no more.

Finally, the costs shown in Tables 2 and 3 must be regarded as applicable only to the location studied and, despite our considerable efforts in their preparation, as preliminary.

3.3 THE BASE CASE: NO SPECIAL SHELTER

Figure 2 shows the percent fatalities for a range of weapon yields associated with direct, single-we[illegible]on surface-burst attacks on Houston. Ground zero was selected to maximize blast fatalities among the at-work and at-home populations taken separately.

Against these attacks population losses are very high: 82 per cent of the at-home population for a single 10-Mt weapon. Note, further, that 87 percent of the people in Houston are lost if the attack should occur in the daytime when the population is at work.

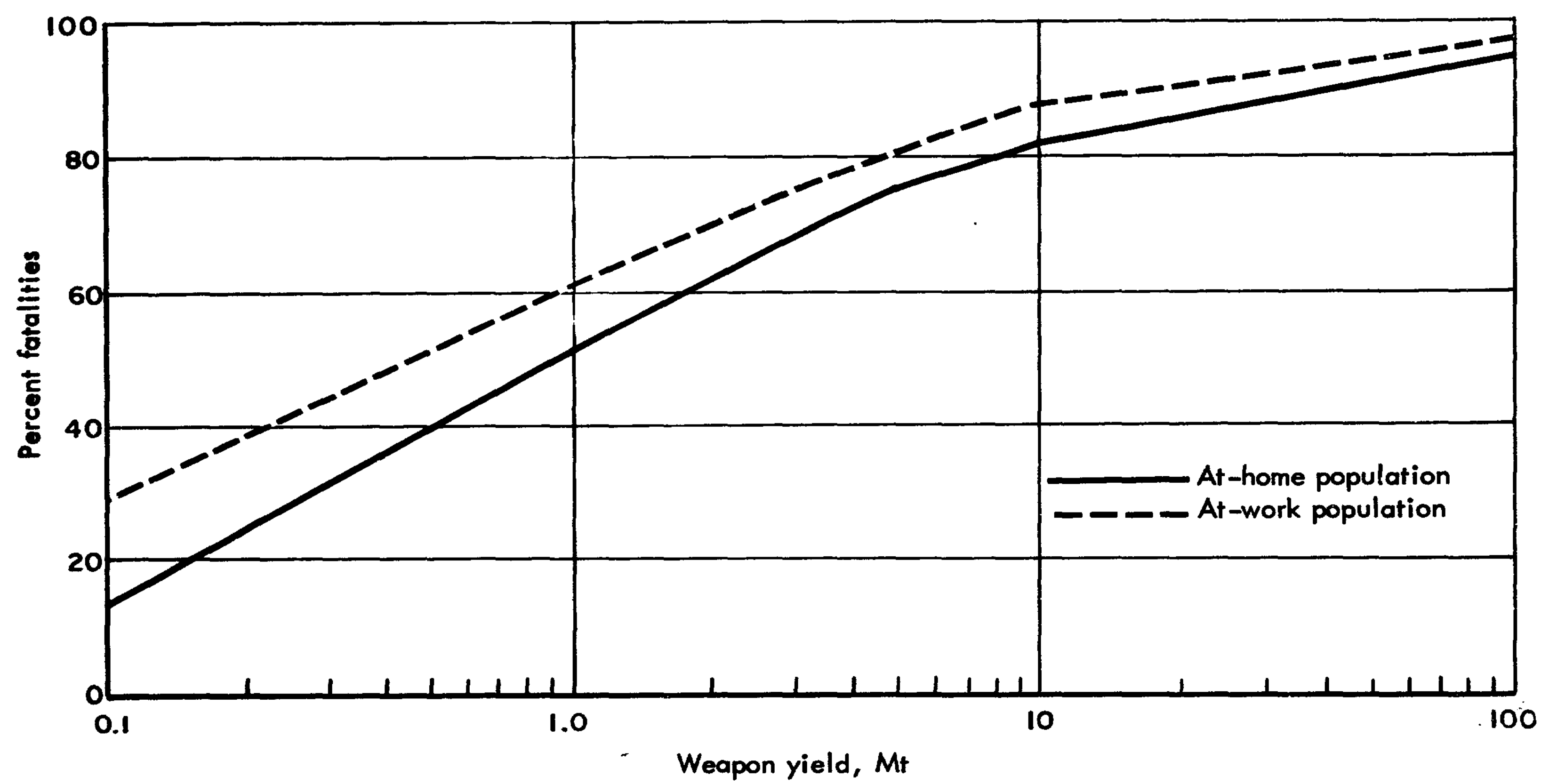

FIGURE 2 Fatalities as a Function of Weapon Yield: Base Case (No Special Shelter). (Direct attack, single-weapon surface burst.)

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Fatalities in an unsheltered population appear to depend on the time at which the attack occurs; this might be used as a basis for showing the worth or utility of warning systems. It takes about one and one-half hours for Houston to switch from the at-work to the at-home posture on a typical working day. Thus, against the 10-Mt weapon considered here, the simple instruction to "Go home," if executed properly and in time, might save 5 percent of Houston's population, or about 60,000 people.[4] The life-saving value of "Go home" appears to persist for direct attacks at lower yields where over-all fatalities are lower and the city's survival possibly more certain. "Go home" thus appears to be good civil defense for an unprotected Houston, and as is shown below, it is probably good civil defense in terms of the shelter provided by the National Fallout Shelter Survey.

3.4 LOCATION-FIXED SYSTEMS: THE NATIONAL FALLOUT SHELTER SURVEY

3.4.1 Performance Under Direct Attack

Shelter locations in NFSS or in NFSS-X do not correspond closely with either the at-home or at-work population. That is, the most populous TVE's are not necessarily those with the most shelter spaces. For this reason, two versions of the NFSS-X were studied: NFSS-X_1, in which movement of the population from one element to another from a base posture is prohibited; and NFSS-X_2, in which movement anywhere in the matrix is permitted. (With NFSS-X_1, only 29 percent of the at-home population is sheltered, whereas 46 percent of the at-work population receives shelter.) These two cases were compared in an attempt to test the effect of strategic and tactical warning. It was assumed that strategic warning would permit the population to move anywhere within the Houston area to find shelter, but that tactical warning would limit movement to within a particular TVE at the time warning was received.

Survey shelter is highly concentrated in downtown Houston: about 30 percent is located within four adjacent TVE's in the

4. However, for a 10-Mt attack population fatalities are such that, even with a 5 percent increase in survival, the viability of the city is most uncertain.

central city. This compactness seriously limits the utility of the NFSS-X System against direct attack. Figure 3 shows the percent fatalities in the NFSS-X_1 and X_2 cases, for the same weapon yields assumed in the unsheltered case (Figure 2). Ground zero for NFSS-X was the TVE for each weapon yield which maximized blast fatalities of the unsheltered at-home and at-work populations; for the NFSS-X_2 it was that TVE which maximized blast fatalities of the population fully sheltered, i.e., the attack was against the shelters.

Under direct attack from the higher-yield weapons, NFSS-X_1 provides some relief from the disaster that would befall the unsheltered population--but not much. For an outlay of $56 million in initial costs, fatalities are held about 8 percent lower than those in the base case for the at-home population against the 10-Mt attack. Again, as was found to be true in the unsheltered case, at-work population fatalities are higher than those for an at-home population--at 10-Mt about 5 percent higher. It should be emphasized that fatalities for the at-work population are higher despite the fact that substantially larger numbers of people are shelter occupants.

What these curves reflect is the trade-off between reduced fall-out fatalities due to occupancy of NFSS shelter and increased blast fatalities due to the location of a large part of that shelter in areas of greater risk from blast effect. The NFSS shelter concentrates its occupants in the city center. This may be seen quite clearly from a comparison of the curve in Figure 3 for NFSS-X_2 (100 percent shelter occupancy) with that for the restricted movement NFSS-X_1 (at-home population, 29 percent shelter occupancy). The data from which these curves are plotted are shown in Table 4. For a single 10-Mt surface burst the effect of full shelter occupancy (NFSS-X_2) is 70 percent blast fatalities and no fallout fatalities; the NFSS-X_1 system, which limits movement, results in 41 percent blast fatalities and 33 percent fallout fatalities, a total of 74 percent. Thus, for a 10-Mt attack, fatalities are reduced by only 4 percent if NFSS shelter is fully exploited. However, as the weight of the attack decreases, the

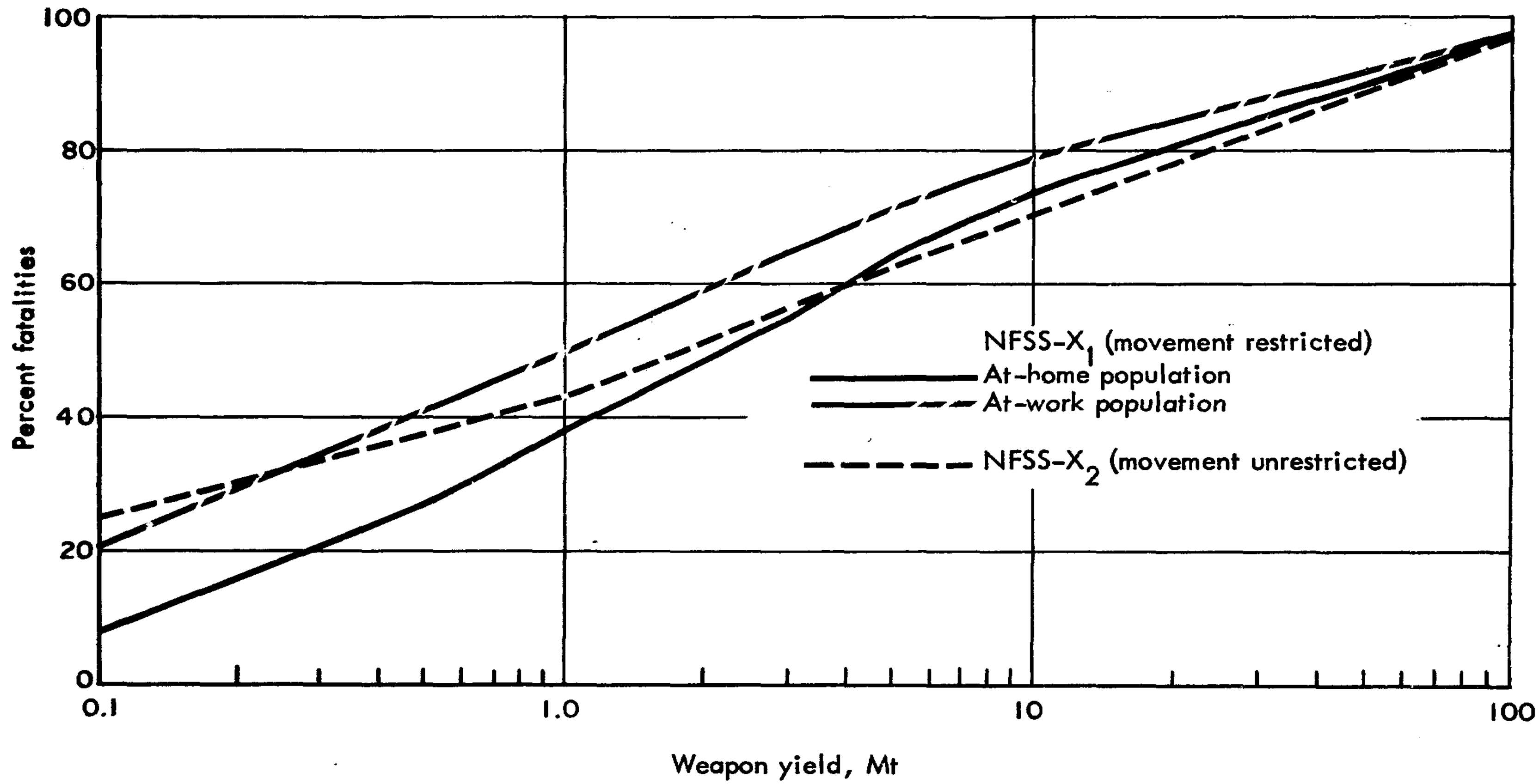

FIGURE 3 Fatalities as a Function of Weapon Yield: NFSS-X_1 and NFSS-X_2.
(Direct attack, single-weapon surface burst.)

Table 4

FATALITIES FOR SELECTED WEAPON YIELDS AND COSTS: BASE CASE, NFSS-X_1 AND X_2

(Direct Attack, Single-weapon Surface Burst)

Protective System and Population Posture	Percent Fatalities[a] 100kt	500kt	1Mt	3Mt	5Mt	7Mt	10Mt	100Mt	Percent Shelter Occupancy	Initial System Cost[b] millions of $
Base Case (no special shelter)[c]:										
At-home population:									-	-
Blast	4	9	13	23	30	36	42	84		
Fallout	10	30	39	45	46	42	40	13		
Total	14	39	52	68	76	78	82	97		
At-work population:									-	-
Blast	18	28	34	45	51	55	59	88		
Fallout	11	24	28	31	30	29	28	10		
Total	29	52	62	76	81	84	87	98		
NFSS-X_1(Restricted Movement)[d]:										
At-home population:									29	56
Blast	4	8	12	22	29	35	41	84		
Fallout	4	19	26	33	35	34	33	13		
Total	8	27	38	55	64	69	74	97		
At-work population:									46	
Blast	17	27	33	44	50	54	58	88		
Fallout	4	14	17	21	21	21	21	9		
Total	21	41	50	65	71	75	79	97		
NFSS-X_2(Unrestricted Movement)[e]:									100	56
Blast	26	38	44	56	61	66	70	93		
Fallout	0	0	0	0	0	0	0	2		
Total	26	38	44	56	61	66	70	95		

a. 1960 population = 1.226 million
b. These costs are preliminary estimates applicable only to Houston, Texas.
c. PF=2; Dikewood blast mortality curve for woodframe building.
d. PF=40; Dikewood blast mortality curve for light steel frame building.
e. Same results for at-work or at-home population postures; NFSS-X shelters assumed to be 100 percent occupied.

relative utility of a system based on full occupancy of survey shelter not only decreases, but for attacks of about 3-Mt or less, the city is better off if the shelters remain relatively unused.

These observations suggest that elaborate warning and evacuation or movement to shelter sub-systems, which might be associated with NFSS-X to increase the occupancy of survey shelter, will not be found very useful. Based on the data that have been studied so far, full use of nearby shelter by the at-home population is more effective protection for Houston than to move from the outskirts to NFSS shelter in downtown areas.

3.4.2 Performance Under Indirect Attack

In order to evaluate the effectiveness of NFSS-X against indirect or remote attack, several hypothetical weapons were laid on Austin, Texas and the effect of the local fallout downwind at Houston was calculated. Attacks with the following weapons were considered (Table 5): one 1-Mt, five 10-Mt, three 10-Mt; two 5-Mt, two 3-Mt, and one 100-Mt weapons (all surface bursts). Calculations of fallout fatalities at Houston were made for wind speeds of 10 and 50 mph.

The results show clearly that as compared with its modest contribution to survival against direct attack, NFSS-X is totally effective against the otherwise lethal effects of an indirect attack for the examples studied. Thus, for a single 10-Mt weapon on Austin, Houston fallout fatalities with the population unsheltered (PF = 2) are negligible with a 10-mph wind. For all of the larger attacks on Austin and the higher wind speeds, fallout destroys 100 percent of Houston's population if unsheltered. Even with a 10-mph wind, fatalities in the unsheltered population in Houston increase from essentially zero for a single 10-Mt weapon to 100 percent for the single 100-Mt surface burst.

If NFSS-X shelters are fully occupied, the Houston population suffers virtually no fatalities from fallout for either wind speed

Table 5

EFFECT ON HOUSTON OF FALLOUT FROM AUSTIN
(Houston Directly Downwind from Austin)

Windspeed, mph	Alternative Attacks (All Surface Bursts)	Fatalities[a] by Population Mode					
		No Special Shelter[b]				NFSS-X_2[c]	
		At-Home		At-Work			
		Number	Percent	Number	Percent	Number	Percent
10	One 10-Mt	3	0	2	0	0	0
	Five 10-Mt	831,992	68	847,636	69	0	0
	Three 10-Mt, two 5-Mt, two 3-Mt	586,152	48	584,120	48	0	0
	One 100-Mt	1,225,839	100	1,221,945	100	0	0
50	One 10-Mt	418,501	34	354,477	29	0	0
	Five 10-Mt	1,225,891	100	1,221,886	100	3	0
	Three 10-Mt, two 5-Mt, two 3-MT	1,225,575	100	1,221,518	100	2	0
	One 100-Mt	1,225,898	100	1,221,973	100	57	0

a. Based on total 1960 Houston Population: 1.226 million
b. PF = 2.
c. PF = 40; 100 percent shelter occupancy, day or night, assuming unrestricted population movement.

and any of the four attacks upon Austin. Against indirect attack the NFSS shelter is strikingly effective; against direct attack its population saving features are modest, even negative against the lighter direct attacks considered.

3.4.3 Summary of Results for Location-Fixed Systems

The National Fallout Shelter Survey System as we have studied it in Houston, Texas, is an example of a bad compromise. The design performance of the system, that is, the protection it affords against indirect attack, is excellent. But the off-design performance of the system, i.e., against direct attack, is poor. In fact, merely the instruction to "Go home," made in a timely manner, protects the population in a number of the cases studied as much as the $56 million which the NFSS-X costs. By the same token, additional expenditures on elaborate warning and training systems to increase NFSS shelter occupancy can hardly be justified.

On the other hand, under the NFSS or NFSS-X system, people may not be able to find fallout shelter near their homes. Giving special consideration to locating, marking and stocking fallout shelter spaces aligned more closely to the needs of the at-home population would be a step forward. In addition, spaces in the central city need not and, therefore, should not, exceed requirements for the at-work or peak population. The value, and even the use, of such spaces in excess of these requirements are questionable because moving people from the suburbs to downtown actually increases their vulnerability to direct attack.

3.5 LOCATION-OPTIONAL SYSTEMS

If the requirement to place shelter in existing buildings is lifted, shelter type and shelter location are both options available to the planner. Two general situations have been explored under these assumptions: first, the population is removed from the city and provided with "light" shelter which is adequate for fallout protection (the MTS system); second, the population is left in the city and provided with a number of combinations of shelter types co-located with the population.

3.5.1 Movement to Shelter (MTS)

Protective systems which stress warning and movement or evacuation can be valuable in saving population. An extreme example of such a system is MTS, in which the population is separated from the direct effect of weapons by transporting them to fallout shelters in surrounding counties before the attack.[5] In such circumstances not everyone can be expected to reach shelter before the attack. It has been assumed that 5 percent of the population does not make it, in order to allow for "left behinds" and those who might choose to remain on their jobs until the last minute. In this examination of the MTS system, hard shelter in the city for a small number of truly key people has not been costed, and perhaps more important, it is assumed no attack is made against the population located in shelter outside the city.

With these assumptions--stressing again the requirement of obtaining and effectively using a warning time of at least six hours--the system appears to be most efficient. For an investment of about $182 million, or about three times that of NFSS-X, fatalities may be held to the 5 percent assumed in the Report. Moreover, by separating the population from industrial resources, MTS confronts the enemy with separate targets.

The promise of huge life saving value of MTS at low cost recommends further study of the system. There are, however, a number of practical problems associated with effective exploitation of MTS. First, there is the "cry-wolf" problem. How many times will the population dislocate themselves as national crises come and go? What incentives or sanctions are effective in encouraging the necessary movement to shelter?

Second, the system relies on strategic warning for its effectiveness. It is quite possible that users of the system could be deployed to shelter outside the city for relatively long periods during times of national crisis. A proper subject for study, therefore, would be

5. The MTS system evaluated here is described in detail in an internal IDA document: A. Sachs and G. Kelleher, Cost Data and Damage Assessment Procedures Used to Estimate the Effects of Nuclear Weapons on a Metropolitan Area, IDA Internal Note N-311.

the effect of long periods of shelter residence on the day-to-day workings of the city and its activities. It will be necessary to know who should be moved to shelter first in order to minimize the possibly deleterious consequences of interrupting the normal economic, political, and social life of the community. In short, can the MTS system be made "livable"? If so, how?

3.5.2 In-City Shelter Systems

The second set of location-optional systems considered are combinations of various shelter types at selected locations in the city itself. Up to this point in the discussion of shelter systems we have been dealing with single systems with associated single costs. Performance has been measured in terms of how well the system limits fatalities as weapons of different yield are laid upon the city. However, when the planner can select both shelter location and type, shelter systems can be designed to be most efficient in performing a specific task and the performance of these systems can then be considered under off-design situations.

3.5.2.1 Note on Methodology. The performance or effectiveness of protective systems is measured in percent of immediate population fatalities. Competing systems are compared with each other through their relative cost in holding fatalities to a given level. By plotting fatalities against cost, a curve is generated whose slope indicates the rate of change of effectiveness with cost. A steep negative slope means small increases in costs produce relatively large increases in effectiveness. The objective is to identify systems which minimize the cost of limiting fatalities to a specified level.

A 10-Mt surface burst delivered to maximize fatalities of the at-home population of the target city Houston, Texas, has been taken as the design condition for study of the in-city systems. Using the damage-limiting shelter-allocation strategy discussed earlier, a number of "optimum" or "best" blast shelter systems have been described that consist of 35-psi, 100-psi, and 300-psi shelters, as well as combinations of shelters of these strengths. The method proceeds from the assumption that all members of the population not receiving blast shelter are provided fallout shelter; hence the blast shelter systems are "added on" to this base, called Universal Fallout Protection Posture.[6]

A sample case will illustrate the procedure and the efficiency of the damage-limiting shelter-allocation model. The cost data in Table 6 indicate that the 300-psi Universal System costs $1,014 million, the 300-psi Damage-Limiting System costs $828 million, and the 300/100-psi Damage-Limiting System costs $548 million. Each system performs identically: Houston fatalities are held to 2 percent of the population against a 10-Mt single-weapon surface burst targeted to maximize fatalities. The 300-psi Universal System is the least efficient; by providing 300-psi blast shelters for everyone, it overprotects. The 300-psi Damage-Limiting System also overprotects in the sense that when a shelter is needed to hold fatalities to the prescribed minimum, the allocation model can select only a 300-psi shelter. As would be expected the lowest cost system results when the allocation model is not so constrained--i.e., in the 300/100-psi Damage-Limiting System, where a wider choice of protection level is available to the model.

For these studies, only a single type of blast shelter has been considered. It is a simple concrete box in module sizes of 100, 500, and 1000 spaces for 35- and 100-psi systems, and 100 spaces for 300-psi systems. How sensitive the results may be when other, more modern, more individualized shelter types are used in a similar analysis is yet to be determined.

3.5.2.2 Efficiency of Systems Designed for a 10-Mt Attack. Each point shown on the solid curves in Figure 4 represents, for a 10-Mt attack with a single weapon, the least costly system that will ensure

6. Universal Fallout protection is, in quality and quantity, identical to that afforded by NFSS-X; the shelter is co-located with the population (at-home posture) by TVE, as are all blast-shelter systems considered here.

Table 6

FATALITIES AND INITIAL COSTS FOR LOCATION-OPTIONAL SYSTEMS

Shelter Postures	Initial Cost[b] $ millions	Percent Fatalities[a] 10-Mt Surface Burst	3-Mt Surface Burst	100-Mt Surface Burst
No special blast or fallout[c]	-	82	68	97
Universal fallout only[d]	104	37	19	84
Universal 300 psi	1014	2	1	9
Universal 100 psi	562	5	4	19
Universal 35 psi	481	11	7	37
Damage-limiting (Best 10 Mt Systems)[e]:				
300 psi	828	2	1	15
300/100 psi	548	2	1	16
300/100/35 psi	554	2	1	15
300 psi	748	4	1	21
300/100 psi	434	4	2	25
300/100/35 psi	449	4	2	22
300 psi	706	5	2	26
100 psi	393	5	4	32
100/35 psi	399	5	4	28
300 psi	521	10	4	45
100 psi	296	10	6	52
100/35 psi	298	10	7	59
300 psi	502	11	4	48
100 psi	287	11	7	53
35 psi	290	11	7	62
300 psi	299	20	8	68
100 psi	201	20	11	71
35 psi	201	20	12	78
300 psi	181d	30	14	80
100 psi	144	30	17	77
35 psi	142	30	16	82
300 psi	135	35	17	83
100 psi	120	35	18	84
35 psi	117	35	18	81

a. Houston resident population, 1960 = 1.226 million.
b. These costs are preliminary estimates applicable only to Houston, Texas.
c. PF = 2, population inside wooden frame buildings.
d. PF = 40, population inside steel frame buildings.
e. All postures designed by allocation model; population not blast sheltered ass[illegible]d to have fallout shelter with PF = 40.

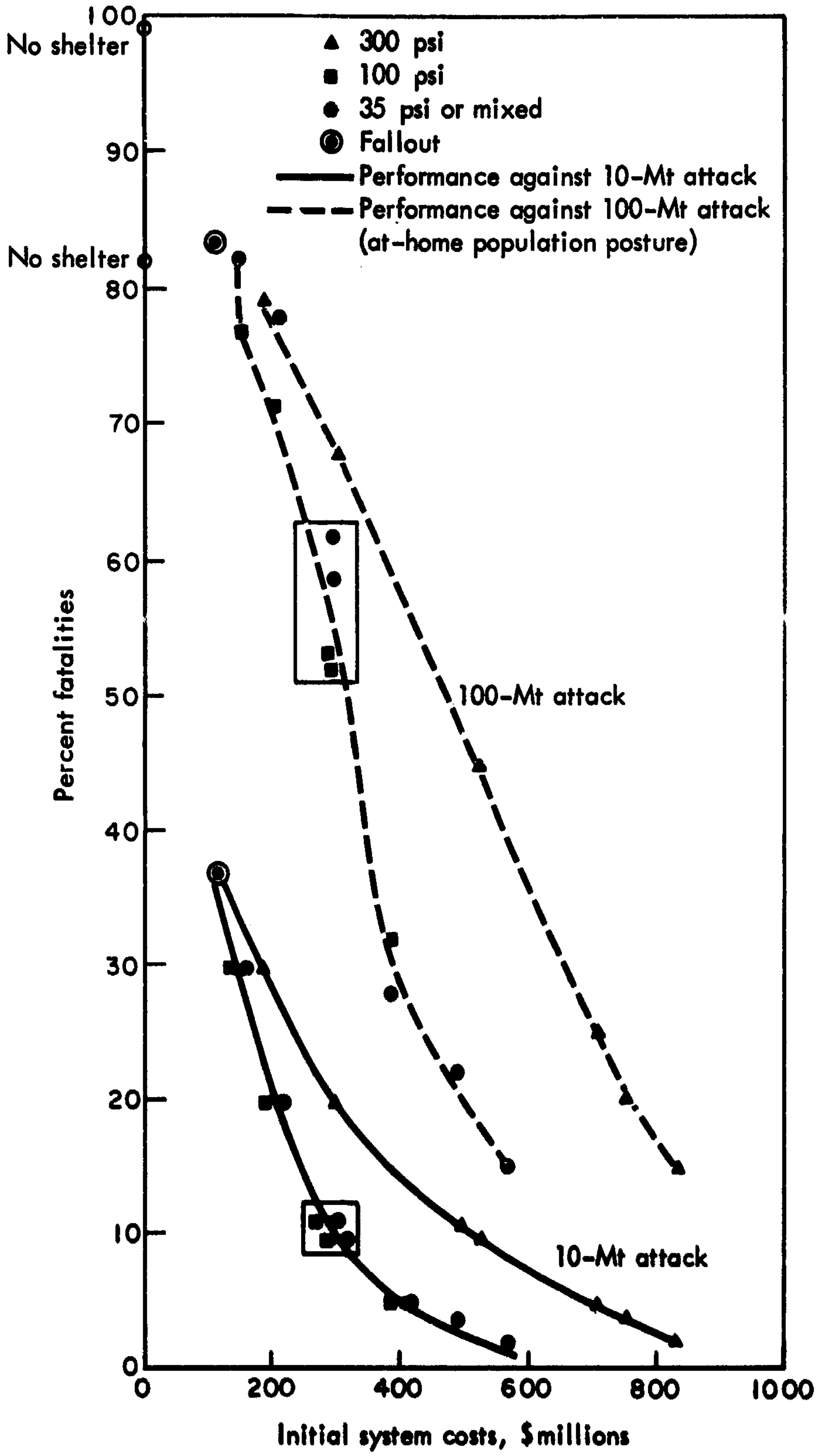

FIGURE 4 Efficiency of Location-Optional Systems Designed for a 10-Mt Attack

a prescribed fatality limit given the shelter combinations shown. The curves are based on the data in Table 6. The four systems enclosed by a black box will be discussed later in considering system effectiveness for an off-design attack.

The 300-psi shelter systems shown may be eliminated from further consideration at the outset. They are all inferior to 100-psi, 35-psi or mixed systems: The entire 300-psi curve is farther from the origin of the two axes, where both fatalities and costs are zero.

Perhaps the most striking observation from the data presented, is the very large payoff that results from relatively small initial investments. In the base case (No Special Shelter) shown in Figure 2, fatalities are 82 percent of the population; for an investment of $150 million in blast shelters, fatalities may be held down to 30 percent, an additional saving of about half the pre-attack population. To reduce fatalities further, the required additional investment increases rapidly. For example, the 5 percent gain in reducing fatalities from 10 percent to 5 percent costs about $100 million.

The boxed points shown in Figure 4 represent four systems: two 100-psi systems, one 35-psi system, and one mixed 100- and 35-psi system. For the 10-Mt attack, all four of these systems hold fatalities to about 10 percent, at roughly the same initial cost-- $290 to $300 million.

The heavier systems, however, perform somewhat better against attack by a larger weapon. The design condition for all the systems considered was a 10-Mt attack. For a more complete evaluation of the systems, the design postures were subject to an off-design condition: a 100-Mt surface burst, shown by the broken curves in Figure 4. Note the relative performance of the four systems singled out in the analysis of the 10-Mt attack. The heavier 100-psi systems appear to hold fatalities from 5 to 10 percent lower in this heavy off-design attack. The heavier systems thus provide some hedge against the possibility of attack by larger weapons.

Curves similar to those in Figure 4 can contribute to civil defense decisions other than that of selecting good combinations of shelter strength to protect population. For example, the effect of shelter occupancy rate may be shown. The efficiency of the best shelter postures designed for 10-Mt attacks is shown in Figure 5 for 100 percent and 50 percent occupancy. At 50 percent occupancy the same investment buys much less. Initial system outlays of $100 to $300 million now limit fatalities to a range of 55 to 45 percent, whereas at full occupancy these expenditures hold fatalities to a range of 30 to 10 percent.

The shelter occupancy rate has, therefore, a marked effect on the efficiency of a system. Additional expenditures for shelter strength of $154 million at 50 percent occupancy reduce fatalities only 10 percent; if those same funds could be used to increase the occupancy rate from 50 to 100 percent, fatalities would be reduced by 26 percent. Thus, funds for warning systems and training systems which increase shelter utilization might be worth as much as two and one half times the funds spent for heavier shelter hardware in the case illustrated. If data were available showing warning and training costs as a function of shelter occupancy rate, the trade-off in effectiveness between expenditures for shelter hardness on the one hand and warning and training systems on the other could be made explicit.

3.6 SUMMARY: EFFICIENCY OF SHELTER SYSTEMS

The relative performance of the shelter systems considered has been shown above in a number of ways. Since, under certain assumptions and in selected situations, all shelter systems are in competition not only with each other but often with other military systems, it is convenient to discuss supply curves for the shelter systems we have considered to protect the population of Houston, Texas. These curves show in a broad sense what can be bought (survival level or number of survivors) and at what price ($). They can be used to show the comparative efficiency of one system over another.

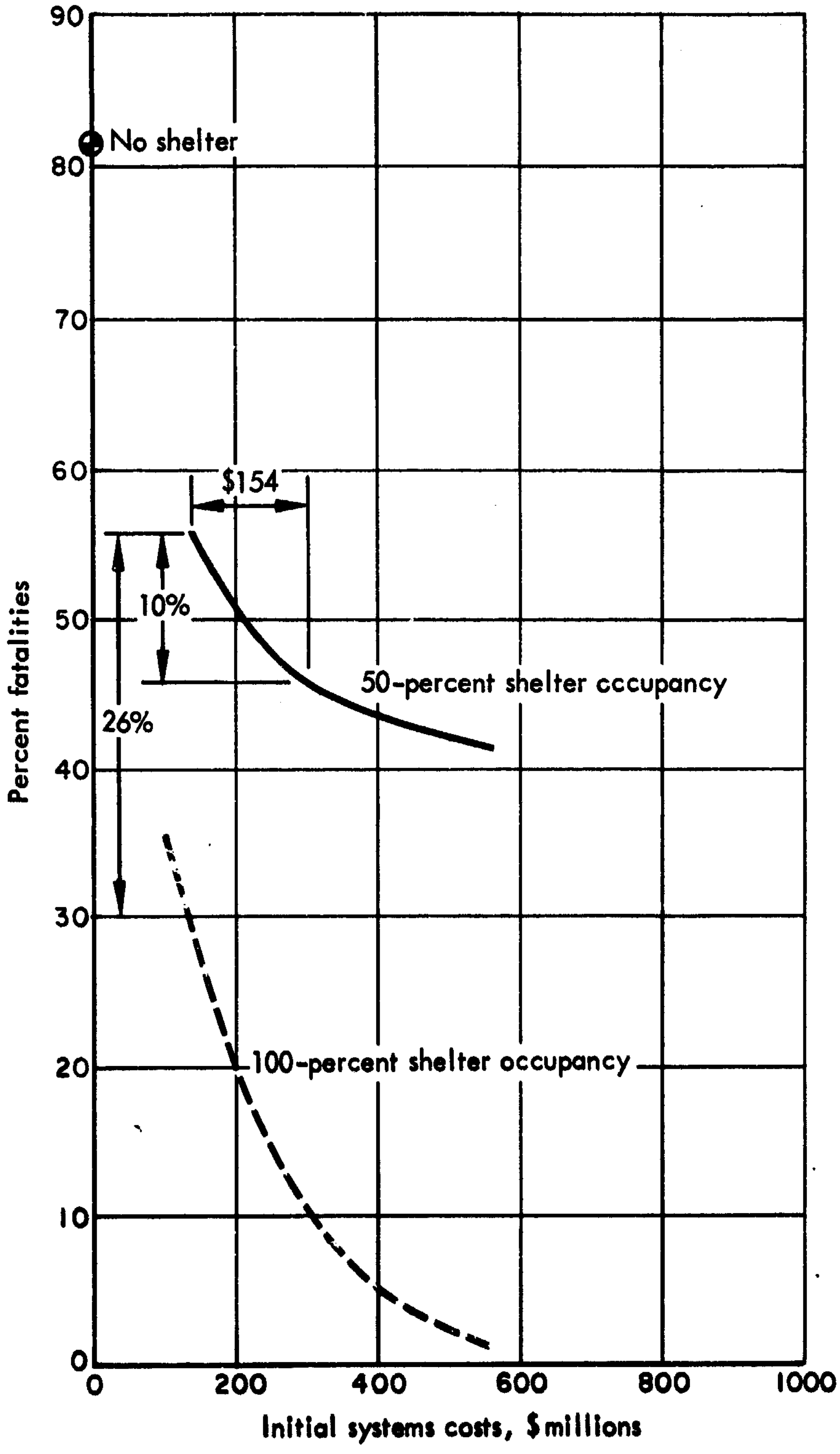

FIGURE 5 Effect of Shelter Occupancy or Efficiency of Location-Optional Systems

One form of such a curve is shown in Figure 4. Given location and shelter type as options, the curve can be used directly to select a good shelter system to protect Houston if the funds available for the job are known and firm (and if the threat were known to be a 10-Mt surface burst). By the same token, the same curve could be used to estimate the initial funds required to guarantee that fatalities did not exceed a fixed level.

However, when resources must be allocated among different urban areas or between, say, competing active and passive defense measures, another form of supply curve may be more helpful. Such a curve is presented in Figure 6, a plot of marginal cost per survivor added, against percent fatalities of the entire Houston population based on a 10-Mt single weapon. Figure 6 shows how much the next survivor costs for increasing levels of survival achieved by using more effective but more costly population protection systems.[7] The following summary discussion of the efficiency of the shelter systems is based on Figure 6.

In the base case (No Special Shelter), 18 percent of the at-home population survives the 10-Mt weapon. NFSS-X_1 raises the survivor level to about 26 percent (cost \$56 million) but the cost of saving people with this system is high, even at this low survival level--about \$570 per person saved.[8] NFSS-X_2 is a better bet in the event of this attack--the survivorship is somewhat higher (about 30 percent of the population survives) and, since no additional costs are incurred for the larger population shift to fully occupy the NFSS-X shelters, marginal costs are zero. The average cost per survivor added is lower than that of NFSS-X_1; about \$384.

7. Given a similar supply curve for a particular active defense system for example, a proper selection between systems for a specified survival level would be to "buy" that system, or combination of systems, which provided the last survivor desired at the lowest marginal cost.

8. Average costs per survivor added are the same in this particular instance.

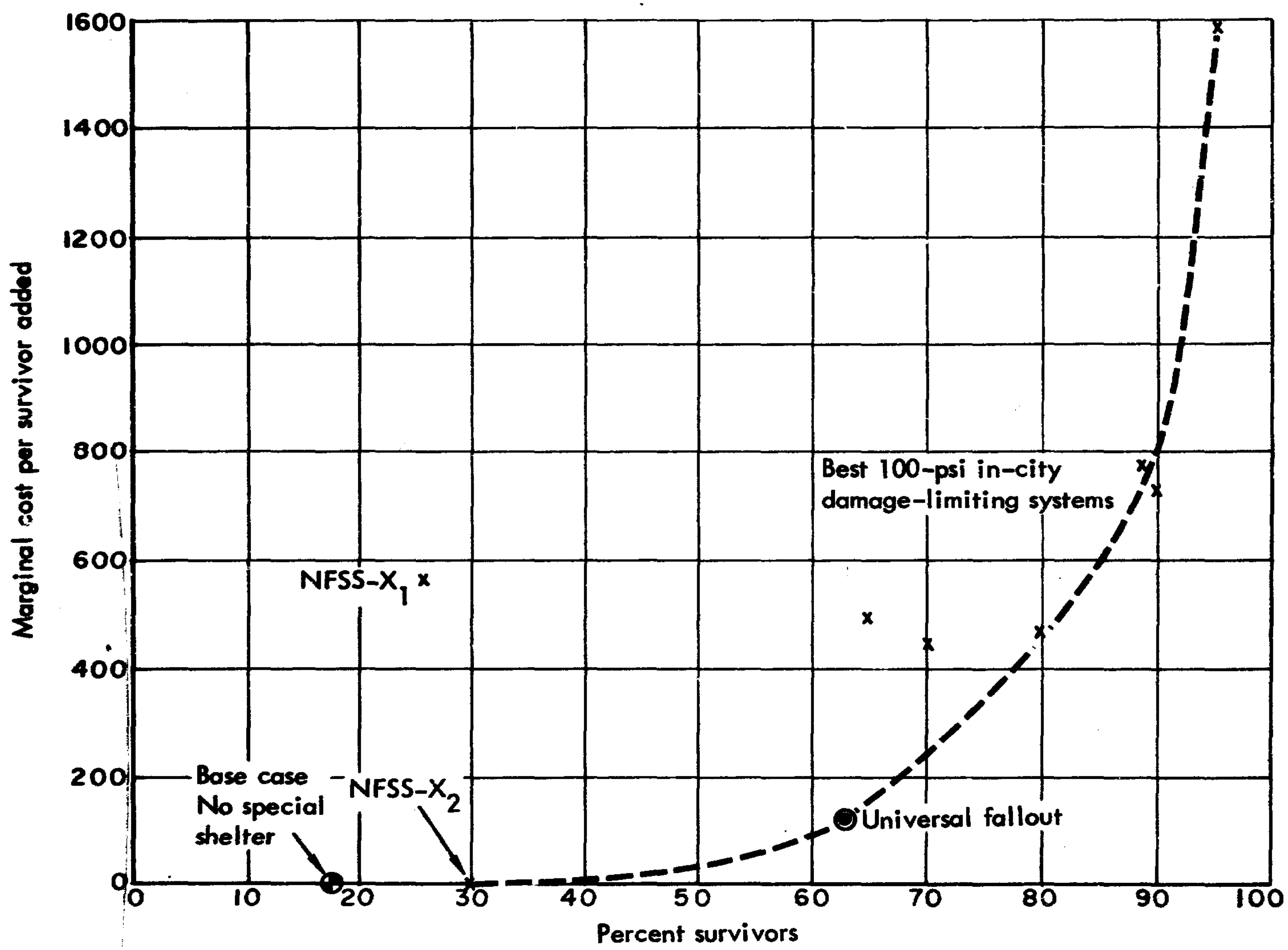

FIGURE 6 Marginal Cost Per Survivor Added: NFSS-X and Best 100-psi Damage-Limiting Systems Designed for 10-Mt Attack (10-Mt surface burst against the at-home population)

The next system considered in detail, which results in higher survival levels, is the Universal Fallout System.[8] The marginal cost per survivor added, (i.e., the cost of adding survivors beyond those saved by NFSS-X_2) is low; about \$118 per survivor. This system provides a [illegible] percent survival; average costs per survivor added are lower than that for NFSS-X_2--about \$188, the lowest for all systems summarized in Figure 6.

However, the Movement to Shelter System (MTS), not shown in Figure 6, has even lower average costs per survivor. It saves 95 percent of the population for an initial system cost of \$182 million for an average cost of \$157 per survivor. This low average cost for a high survival level strongly suggests that further careful study of MTS is warranted.

The comparative advantage of MTS may be further emphasized by considering the "hard" in-city shelter systems shown in Figure 6 which raise the survival level above the 63 percent mark of the Universal Fallout System. Beyond this level of survival, marginal costs increase steeply to around \$500 per survivor added at the 70 percent level, remain relatively constant in the survival range between 70 and 80 percent, and soar to over \$1500 per survivor between levels of 80 and 95 percent. An in-city system providing 95 percent survivorship (comparable to MTS under the assumptions made) buys survivors at \$1500 each, on the average, for the last 5 percent increase (see Figure 6). The 90 percent survival level is achieved under these systems at costs of about \$750 each on the average for those survivors above the 80 percent level.

In sum, then, shortly above the 63 percent survival levls of the Universal Fallout System, marginal costs of in-city systems increase rapidly, and survivorship becomes more and more expensive as higher survival levels are specified. If the single 10-Mt attack is accepted as a reasonable description of the threat for which

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8. Survival at all levels between NFSS-X_2 and Universal Fallout can be obtained by decreasing the full coverage of the latter.

protection is desired, it would appear that in-city systems which hold survivors at the 60 to 65 percent level can be obtained at reasonable initial costs, i.e., efficient systems can be designed which have relatively low average and marginal costs at survival levels of this order. If the survivorship to be guaranteed against this threat must be higher, for reasons of national policy or to fulfill some other condition outside the scope of this analysis, then other ways of protecting population should be exhaustively explored before commitment is made to a massive, heavy in-city shelter program. The data we have studied shows clearly that survivorship in the city can be enhanced by resorting to heavy structures of reinforced concrete, but only at relatively high cost.

4

LOSS OF PROPERTY VALUES AND ECONOMIC OUTPUT

The purpose of any civil defense system is to save the lives of as many citizens as possible. However, the likelihood of long-term human survival clearly depends not only on the proportion of human resources surviving, but on the proportion of property and individual resources surviving as well.

The effects of a nuclear attack on property value and economic output are, unfortunately, inordinately difficult[1] to determine, whether the area of interest is a single city as it is here, a geographic region, or a whole nation. The economic data describing the operation of the US economy at the national level are plentiful. There are relatively fewer data about activity in geographical areas of the country taken separately, and fewer still pertaining to the workings of the economy of a single city. The national data are based on the continued operation of the US transportation systems--certainly a questionable assumption in the event of a major attack upon this country. There are no adequate data that treat, in isolation, flows to and from cities associated with activity in those cities.

In addition, property values and economic output should be expressed in terms of post-attack utility; but without any vector of post-attack prices, pre-attack values must be used. The development of pre-attack values is conceptually simple; but again, the data available are not in a form that is immediately usable for this purpose.

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1. We have put to one side an equally difficult problem, namely that of the effect of a given nuclear weapon on a specific piece of property or the capacity of a specific plant. The rules we have used for estimating damage are outlined in the text and are stated in detail in William C. Truppner, Nuclear Blast Effects on a Metropolitan Economy, Institute for Defense Analyses, Economic And Political Studies Division, IDA Study S-209 (Arlington, Virginia, September 1965).

The post-attack economic output of a single metropolitan area can be studied to answer any of a number of questions, the principal of which are: Whether the city is self-sustaining, the degree to which it can contribute to the national economy, and the degree to which viability depends on the national economy. The work reported here is aimed at the first of these questions; the latter two remain as subjects of future research.

Property losses and loss in economic output have been estimated for the range of attacks previously considered in comparing population systems.[2] Since no inter-industry relationships were used, the economic output figures essentially reflect the proportion of capacity that survives. In short, there is a tacit assumption that the necessary inputs of labor, capital, and materials are available to the degree needed to produce the economic output shown. This assumption tends to overstate post-attack output. On the other hand, process and product substitutions have been prohibited, which tends to understate output.

4.1 METHODOLOGY FOR ESTIMATING PRE-ATTACK AND POST-ATTACK ECONOMIC RELATIONSHIPS

The most reliable data on property values for the pilot city, Houston, Texas, were taken from the file of tax assessments in the Houston Tax Office. We estimated the value of all physical property, defined as: (1) structures and other above-grade improvements; (2) durable property including machinery, equipment and inventories of goods, (3) nontaxable property, and (4) household furnishings including automobiles and miscellaneous nontaxable property. These estimates were allocated to TVE's and subjected to attack in the same manner as population in the earlier studies. Damage calculations were based on blast effects alone; property exposed to overpressures of 3.0 psi or less was assumed to survive intact; that exposed to 5.0 psi or more was assumed to be 100 percent destroyed. Loss value for overpressures greater than 3.0 psi but less than 5.0 psi were assumed to be step functions of overpressure.

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2. These estimates and the difficulties and limitations associated with their preparation are reported by Truppner (S-209).

The loss in industrial output (capacity) for Houston was estimated somewhat differently. The measure used, gross product, was derived from US economic censuses and employment surveys supplemented by various local sources. A number of procedures were employed to distribute sector values of gross product to the individual TVE's, because the availability of data varied widely among the sectors.

Weapon effects in the manufacturing and mining sectors were determined by applying physical vulnerability codes developed by the National Resource Evaluation Center, Office of Emergency Planning (NREC). By this system, three categories of damage--light, moderate and heavy--are related to levels of overpressure for each industrial class. For all other sectors a procedure similar to that employed for estimating loss of property value was used: Various overpressures were selected as bounds for the NREC light, moderate, and heavy damage categories. Finally, all capacity was treated as "undamaged" if the overpressure created by the weapon at that TVE was equal or less than the lower bound which defined the light damage category.

4.2 EFFECTS OF AN ATTACK ON THE ECONOMY OF HOUSTON

Two observations will be made in this section: First, unprotected property and output (capacity) appear to be somewhat less vulnerable or "harder" than unprotected population; second, losses are not distributed evenly by kind of property or type of industrial capacity. It should also be noted that estimates of loss, particularly of output, are extremely sensitive to the assumptions used in damage assessment calculations. These findings are closely related to the selection of weapon ground zero, as will be shown.

First, consider the effects of attack upon property values. Figure 7 shows the post-attack property value, population and output as percentages of pre-attack values, plotted as functions of weapon yield. The attacks shown in Figure 7 are directed at the at-home unsheltered population--one of the attacks used earlier in the study of shelter systems. Under this assumption, property values

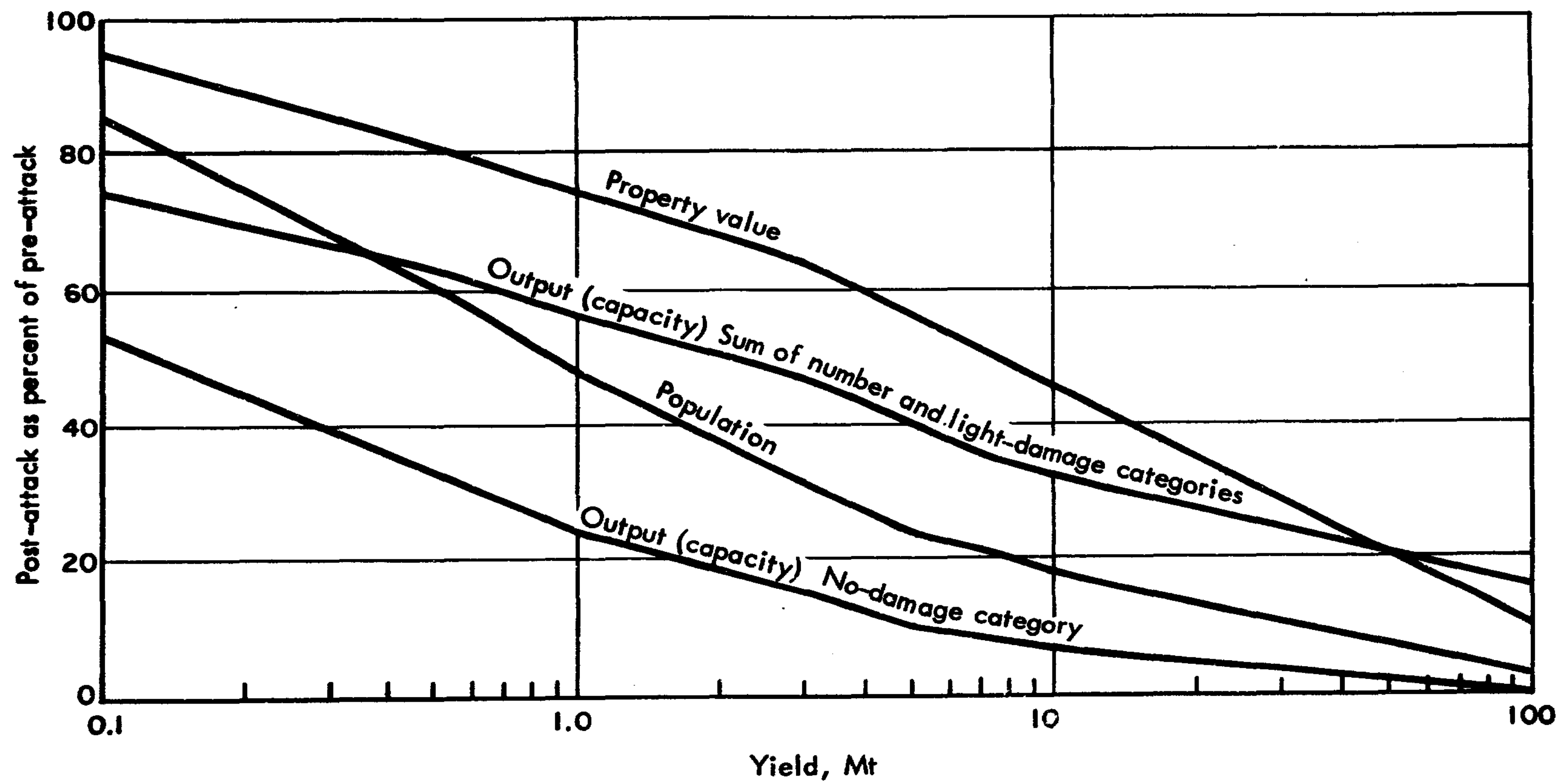

FIGURE 7 Post-Attack Property Value, Population, and Output (Capacity), as Functions of Weapon Yield (single weapon surface bursts)

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fare better than does population. The data in Figure 7 show that the difference between the loss of property values and population varies from about 10 percentage points for a 0.1-Mt weapon to a maximum of 35 percentage points for a 3.0-Mt weapon.

Specifically, the Houston data show that, in relation to all property, the proportion of two of the four types of physical property shifts with increasing weapon yields. The proportion of surviving property represented by real-estate improvements increases continuously with weapons of greater yield; machinery, equipment and inventories decrease. This reflects the relative concentration of the latter grouping in the inner city nearer the selected ground zero. In turn, this implies that measures to protect or preserve materiel necessary for economic output (whether machinery, equipment or inventories) should be included in civil-defense planning, particularly measures to "harden"[3] those items critical to survival which now tend to be concentrated in the city center.

On the other hand, nontaxable property, and household furnishings and automobiles, which tend to be distributed more evenly over the matrix, retain fairly constant relationships to the total physical property value as the weight of the attack increases.

These findings provide guidance in planning for the protection of property values. If the relative proportions among the components of property values after an attack are to be maintained near their pre-attack values, consideration should be given first to the property suffering the greatest relative loss--machinery, equipment and

3. The word "harden" is used here in a broad context. It includes all protective measures that enhance the survivability of non-human resources, such as dispersion of property, carrying "excess" inventories and the like, as well as underground protection facilities and measures associated with a liberal application of reinforced concrete.

inventories now located in the center of the city. This is based, of course, on the fact that this is the area containing the population centroid, and that this, in turn, represents an attractive target to the attacker.

It is less obvious, intuitively, that economic output (capacity) also stands up better than population (except against light attack) on the basis of our crude yardstick. (Contrary to the situation with regard to property values, output tends to be more concentrated in Houston, along with the population, toward the center of the city.) However, taking estimates obtained by that receiving no more than light damage under the NREC vulnerability code (sum of no damage and light damage), a 10-Mt surface burst directed at the unsheltered at-home population, will kill about 82 percent of the people; but only 67 percent of the economic output is lost (Figure 7) if all property receiving either no damage or light damage is taken as surviving.

The sensitivity of the estimates of output loss to the method of estimating damage is startling. This may be seen by comparing, in Figure 7, the values shown by the no-damage category with the sum of the no-damage and light-damage categories. Except in the manufacturing sector where the data were in sufficient detail to permit the use of the NREC code, the difference between the two curves reflects a mere 2 psi of overpressure--light damage occurs when the overpressure is greater than 1 psi but less than 3 psi. But for a 10-Mt surface burst, the difference between including or excluding light-damage property among the surviving property is the difference between a post-attack output of 33 percent (of pre-attack) and 7 percent.

No brief is made here for the accuracy of one estimate of blast effect upon output (or capacity) over the other. What is of vital importance to Houston is that a large fraction of the city's total productive facilities are either "in" or "out" because of a relatively slight change in estimates of resistance to overpressure. Critical facilities falling in this range should be studied in detail; they should be marked as candidates for the hardening required to enhance their chances for survival.

As with property value, the loss in output did not fall evenly among the different kinds of property considered. For example, the percentage output of the 127 individual manufacturing industries in Houston that fell into the no-damage or light-damage categories from a single 10-Mt surface burst directed at the night population is shown by decile in Figure 8. Of the 127 industries, 40 suffered 10 percent or less no-damage or light-damage to their productive facilities. These are the industries that lost 90 percent or more of their capacity. At the other extreme, the data show 25 industries whose capacity was between 90 and 100 percent in the no- and light-damage categories. These are the industries that appear to have survived the attack more or less intact. Thus, 65 industries (about half of 127 individual manufacturing industries in Houston) were either immediately operable or for all practical purposes permanently lost following this attack. Clearly, damage from the attack was not evenly distributed by type of industry.

There are serious implications to this finding. An obvious one is that data in this form identifies those industries which require hardening, the amount depending upon the relative cost balanced against the contribution each industry makes to the viability of the city. A less obvious implication relates to how estimates of post-attack national income are calculated. The usual estimates of national income following nuclear attack upon the country overstate capability because interference with intra- and inter-sector flows are not considered. The impact upon the post-attack economy occasioned by the loss of transportation is neglected, for example. The impact of intra- and inter-sector flows which stem from the uneven distribution of loss in capacity among industries is similarly neglected. As shown in Figure 8, this omission, if Houston is characteristic of the nation, could lead to further overestimation of post-attack national income.

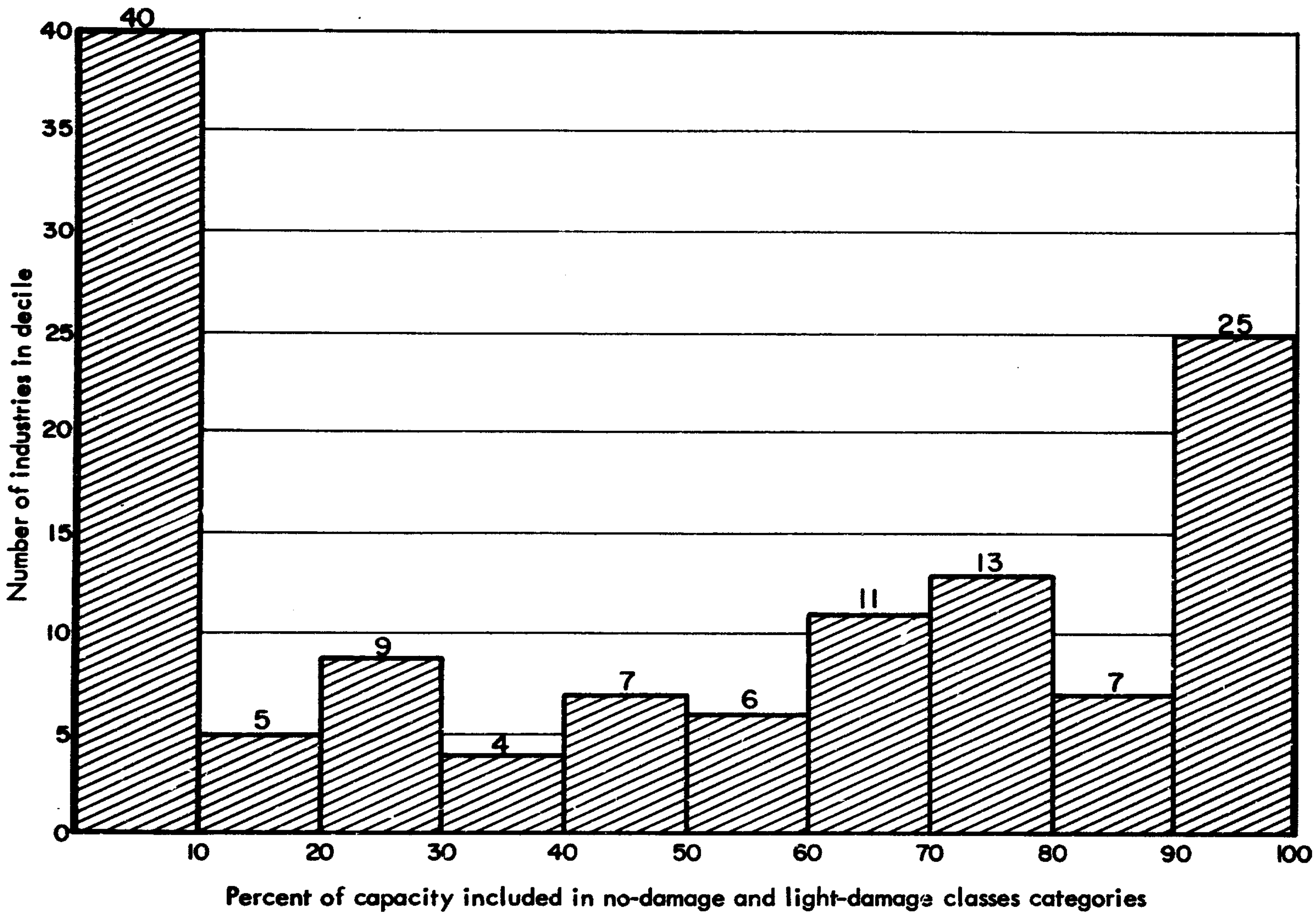

FIGURE 8 Effects of a 10-Mt Attack on 127 Manufacturing Industries

4.3 PER CAPITA LOSS IN PROPERTY VALUES: SHELTERED AND UNSHELTERED

As noted earlier, Figure 7 suggests that property is somewhat harder than unsheltered population. For single surface bursts of 3- and 10-Mt, about 64 percent and 46 percent of the property values survive, while only 32 and 18 percent of the unsheltered population survives. In a macabre sense, the surviving population would be individually "wealthier" than before the attack. For a single 10-Mt weapon, surviving property value per capita nearly doubles from a pre-attack value of about $9,000 to slightly more than $16,000 and, as the weight of the attack increases, the greater the per capita gain in "wealth" of the survivors. For a 100-Mt surface burst, the surviving population is nearly four times wealthier than pre-attack ($34,000). However, any joy among the surviving population may be quite shortlived; none of these gross estimates of the effects of nuclear attack indicate whether or not the immediate metropolitan area is viable, either by itself or with the assistance of the rest of the country.[4]

This situation is reversed if the population is sheltered but no attention is paid to hardening property: Surviving per capita property value is less than pre-attack. Consider the population of Houston protected by the Universal Fallout System noted earlier--that is, fallout protection of the quality afforded by the National Fallout

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4. See Henry M. Peskin, Protecting Industrial Resources Against Nuclear Attack, Institute for Defense Analyses, Economic and Political Studies Division, IDA Study S-187, (Arlington, Virginia, February 1965). Study of the effect of attack on the unprotected national economy bears this out. In Peskin's study, post-attack GNP per capita for a sheltered population was estimated to fall to about 15 percent of pre-attack values (30 percent of pre-attack with maximum labor utilization). It was stated (p. 21): "The post-attack per capita GNP under a maximum labor utilization is approximately six times that of the average African (in 1958) and over twice that of the average South American. This might suggest that the attack did not affect the economy as severely as originally supposed. However, whether this society could adjust to such a great reduction in the standard of living is a serious question."

Shelter System but with the shelter co-located with the at-home population. In this case, per capita property values decrease with weapon yield. For example, from the same single 10-Mt weapon, the decrease is about 20 percent from $9,200 per capita pre-attack to $7,200 post-attack in pre-attack values.

These comparisons suggest that any massive plan for the protection of the population carries with it the requirement to protect key elements of national capital stock which make the greatest contribution to economic viability. This may be shown, at least intuitively, as follows.

In a post-attack world many factors making up the business environment upon which we are totally dependent, will be at best disrupted, and at worst nonexistent. Thus, even if we could determine precisely the location and extent of physical damage from attack to a specific production facility, i.e., a plant or factory, we would still have to reckon with the impact the loss of these intangibles would have on the ability of that plant to produce its product and of the surviving population to consume it. Hence, we may not know what any given per capita measure of economic activity really means in post-attack terms except that by any measure it will be lower than pre-attack. If it is the purpose of a civil-defense system to provide, to the extent possible, a post-attack United States in any pattern with which we are even remotely familiar, it follows that a massive shelter program carries with it an equal burden of protecting essential non-human resources.

The details of how to do this, principally what property to protect in what locality, and how to protect it, cannot be known until further study is made of a number of specific metropolitan areas. From such analyses it should be possible to determine those output vectors which are the key to viability of the community in isolation, and the critical flows and possible substitutions for them between such areas and the rest of the nation. Let us be quite frank about the task. It is a momentous undertaking.

4.4 CHARACTERISTICS OF THE SURVIVING POPULATION

The characteristics of the surviving population were examined (Truppner, S-209) by calculating changes due to a single 10-Mt attack in:

(1) General population characteristics (age, sex, employment status),

(2) total employed by industry,

(3) total employed by occupation

(4) total experienced civilian labor force.

Pre-attack population composition was taken as a base and post-attack composition compared to these values for both sheltered and unsheltered postures.

Changes in general population characteristics as a result of the attack were relatively minor whether the population was sheltered or unsheltered. The distribution of the population among the various age groups and by sex, remained about the same as pre-attack. With one or two exceptions, the post-attack population showed the same relative composition by general employment status.

The data for various occupational groups and classes within those groups showed that losses were by no means as uniform as were losses by general population characteristics. Furthermore, these comparisons show that the National Fallout Survey Shelter, in addition to reducing the over-all level of fatalities, tends to minimize disproportionate changes among worker groups. In short, NFSS seems to dampen, to some degree, the "unevenness" in relative loss among worker classes that results when the population is unsheltered. To the extent that a net gain for survival is realized by some reasonable conformance of the post-attack to the pre-attack distribution of skills among the experienced labor force, this finding argues for a shelter program.

4.5 SUMMARY OF PROPERTY AND ECONOMIC EFFECTS

To be effective, civil-defense systems must treat losses of non-human as well as human resources to ensure the long-term viability of the population when they emerge from shelters.

There are formidable barriers to this work. Data describing local economic activity before the attack are not available. Post-attack prices (or the nature of a price mechanism) and the impact of the loss of intangibles on the exploitation of surviving industrial capacity, are unknowns.

Within these limitations, however, this study of the loss of property values and economic output (capacity) resulting from an attack on a single city contains a number of findings which are significant to civil defense planners and which contribute to work in this field.

The study shows that the physical resources that make up the "economy" of the pilot community, Houston, Texas, suffer relatively less from attack than the unsheltered population; i.e, relatively more property and capacity survive than people. For a 10-Mt surface burst, about 20 percent of the unsheltered population survives, yet 35 to 55 percent of property values and output survive.

It is also shown that the reverse is true when the population is sheltered but no steps are taken to protect property and output. In pre-attack terms the per capita well-being of survivors of the shelter system is reduced after the attack. From the same 10-Mt attack, post-attack property values per capita (based on pre-attack values) are 20 percent below pre-attack levels if the population receives Universal Fallout protection. Since the measures used, property and output, are incomplete descriptions of the economy and tend to understate the effects of attack, the individual well-being of shelter survivors in economic terms alone, would, as a practical matter, be far below that of pre-attack. The import of these findings for the pilot city is clear. If the economy of Houston is to be maintained in reasonable conformity with familiar standards, key non-human industrial resources must be protected together with population.

The studies reported here cast some light on what resources to protect and point up two additional related facets of the problem: the unevenness of damage and the sensitivity of output (capacity) calculations to slight changes in overpressure. For the attacks against population that have been examined, the analysis shows that both property and output are destroyed unevenly, by kind of property and type of industry, respectively. As the yield of the weapon goes up, improvements to real-estate outlive durable property composed of machinery, equipment and inventories of goods. Of 127 industry types in a particular damage category, the calculations show that after a 10-Mt attack, about half are either available immediately after an attack or permanently lost. The calculations also show that changing the assigned vulnerability criteria of industry types by as little as 2 psi markedly affects their survivorship.

From this it may be concluded that the kinds of property and types of industries hit the hardest, and those most affected by slight changes in assigned vulnerability, merit careful consideration as candidates for protection. A broader implication of the "unevenness of destruction" is that studies of post-attack national income overstate income, since intra- and inter-sector bottlenecks which such unevenness suggests are not taken fully into account.

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13. ABSTRACT

An approach to estimating the effects of nuclear attack at the local level is outlined, the methodology developed to estimate these effects is described, and the results of applying this approach in a pilot study for Houston, Texas are presented. Population protection systems in which shelter location is fixed and systems in which shelter location and type are optional are evaluated for single-weapon attacks ranging from 0.1- to 100-Mt against both the at-home and at-work population. One fixed shelter system is considered: a system based on data from the National Fallout Shelter Survey. The location-optional systems considered use in-city shelters with strength and location determined by a damage-limiting shelter-allocation model.

The results of the analyses of population-protection systems suggest that: (1) NFSS shelter, although effective against fallout from a distant attack, may be counter-productive against direct attack; (2) a system of dispersed shelters promises huge life savings at low cost and warrants further study; and (3) the in-city damage limiting systems while expensive can be efficient against a single-weapon 10-Mt attack.

The effects of attack upon property and economic capacity were also estimated. Damage to the capital stock of Houston is shown to be both severe and uneven across various kinds of property and types of industry. This suggests that some types of property and industry might warrant priority protection and that viability for the surviving population requires protection of industrial resources.

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