REQUIREMENTS FOR LOCAL PLANNING TO COVER HAZARDS OF FALLOUT

VOLUME I

FINAL REPORT

PREPARED FOR:

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DEPARTMENT OF THE ARMY
WASHINGTON, D.C.

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VOLUME I

FINAL REPORT

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Contract No OCD-OS-63-161
Subtask 4531A

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.

January 1965

Prepared for

Office of Civil Defense
Department of the Army
Washington, D. C.

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SUMMARY OF RESEARCH REPORT

REQUIREMENTS FOR LOCAL PLANNING TO COVER HAZARDS OF FALLOUT

January 1965

OCD REVIEW NOTICE

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Contract No. OCD-OS-63-161
Subtask 4531A

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SCOPE OF WORK OF THE CONTRACT

The work under this contract has been concerned with the testing of Civil Defense plans. The testing of plans may be regarded as falling into three categories. The first category is: "Is such a plan as this desirable? Does it deal with a good way of saving lives and property?" The second category is: "Is this plan clear, consistent, logical? Is it appropriate to the environment in which it will have to be carried out? Does it consider the availability of people, facilities, and organizations which will be necessary for its success?" The third category is a practical test: "Does the plan as written work?"

In this study work has been confined to the first of these categories: the determination of what activities Civil Defense authorities ought to plan in order to maximize the saving of lives and property.

APPROACH

The most serious problems in civil defense which are soluble by local authority are those involving fallout shelter. A federal program has provided and stocked fallout shelters throughout the country. The local authorities are the only organizations which can usefully plan and organize the task of bringing people to shelter when alarm is given. For this reason, the study has concentrated upon developing effective plans for assigning shelters to population, and for bringing the population to the shelter.

Two medium-sized towns in Connecticut have been studied in detail. They are Stamford and Waterbury. Each has a population of about 100,000. Stamford is on the coast, and is asymmetrical, with its center of population and industry, with its large buildings, some distance seawards of its geographical center. Waterbury is inland and symmetrical.

For each town, a study was made on the effectiveness of a number of plans of varying detail and complexity in getting people to shelter. In all plans it was assumed that enough traffic control would be set up to avoid blockages of traffic near shelters, and that the population would know to what shelter areas they had been assigned, and how they were supposed to get there.

Two types of shelter assignment were made: the first was by census tract, the second by individual location. In the first, people from shelter-poor census tracts were directed to shelter-rich census tracts, according to a linear programming method aimed at minimizing distance traveled. In the second, a similar method was used to assign people to actual buildings.

CONCLUSIONS

When about an hour may be expected to elapse before the arrival of fall-out, about 90 per cent of the population may be expected to get to shelter in time by either assignment to tracts or assignment to individual shelters. However, if the time may be much shorter, shelter assignment gets more people in shelter faster. Similarly, in a situation in which there are barely enough shelter spaces to satisfy the population's needs, the last few per cent have trouble finding spaces when the assignment is on a census-tract basis, because they must search several shelter locations to find a shelter with unoccupied spaces. Thus, individual shelter assignments may be advantageous when either the city is close to a major target, or there are barely enough shelters for the population. If the city can confidently expect two hours' warning of fallout the method of shelter assignment scarcely influences matters at all.

Studies were made of various speeds of movement to shelter and their effects upon rate at which the population was sheltered. It was assumed that those living near their shelter tract would walk. Others would drive. Driving conditions were investigated ranging from single-lane traffic at 20 miles per hour through double-lane traffic at 40 miles per hour; an ostensible fourfold increase in flow. The two extreme conditions had a constant, but small, effect upon rate at which the population got into shelter.

Two other types of local planning problem were given cursory examination. Both concerned fire. The first dealt with "primary fires" defined as those started by radiation of heat from the fireball, or those ignited by such fires. The second dealt with "secondary fires": those which occurred due to the normal accidents of nature, and of leaving premises in unsafe conditions when evacuating them to enter shelter.

Primary fires are a problem, of course, close to ground zero. It is not possible to foretell, ahead of time, which areas of a target will be subjected to lethal blast, lethal fallout or severe primary fires: this depends upon the precise location of ground zero, the height of burst and yield of the bomb, and on weather. The problem faced was this: if several alternative plans were made ahead of time, so that the appropriate one(s) could be selected after the detonation, would substantial savings of life result? The results of the analysis suggest that, indeed, substantial numbers of people could be saved would would otherwise perish. This conclusion, however, needs confirmation.

Secondary fires are a potential problem wherever a population must be pinned down in fallout shelter. Even if the fires do not necessitate evacuation of the shelters, they will destroy property which would be useful after leaving shelter. The problems of fire incidence and fire spread are ill-understood. This necessitates a parametric analysis of the problem. It is apparent, however, that in many areas an organized body of fire wardens, who would inspect and make buildings safe as they were evacuated, would be both simple to achieve and of substantial possible value.

RECOMMENDATIONS

The characteristics of sound plans should be brought to the attention of local Civil Defense authorities. Further research should be done on planning required in target area, and on prevention or control of secondary fires.

CHAPTER I.

INTRODUCTION

General Description of the Studies

This report describes studies undertaken by Dunlap and Associates, Inc., for the Office of Civil Defense under Contract No. OCD-OS-63-161. The objective of all these studies is the evaluation of plans. It is recognized that the first question which ought to be asked, when evaluating a plan, is: "Should there be a plan at all? What should be its objectives?" Only later should one ask: "Given the need and the objectives, will this plan meet the need in a satisfactory way?" Thus, the common thread in these studies is the effect of plans of various sorts upon survival and, to a lesser degree, on preservation of property.

Operational civil defense plans are essentially plans to utilize available services and facilities for preservation of life and property. The civil defense organization has, until now, concentrated on the hazards of fallout, both because these constitute a very serious problem, and because the problem can largely be solved, with reasonable expenditures of money. These studies have therefore also concentrated on the fallout hazard, and given superficial attention to others.

All of the plans considered in these studies are contingency plans in the sense that they are designed to improve the likelihood of survival or minimize other effects of disaster in situations which are "liable, but not certain to occur" (Webster's New Collegiate Dictionary, 1960). In civil defense, there is a very large number of possible contingencies since their characteristics change with the intensity and distribution of the attack, the geographical area considered, the degree of preparation, the psychological orientation of the population, local meteorological conditions, etc. An important step in developing or evaluating specific plans, therefore, is the recognition of the fact that the plan is really for a contingency in the sense defined above. It has been recognized for a long time that fallout itself is such a contingency, and the considerations of plans for handling the problems posed by fallout are discussed in the following sections with no further reference to this point.

This is reasonable, because the wisest course, in the event of warning, is certainly for the general population to take shelter. If fallout turns out not to be a hazard, the population can emerge again. So plans to protect against fallout by entering shelter are contingent only upon receipt of warning of attack. However, in areas where fallout is not expected for an hour or two, due to geography or weather, the interval between warning and arrival of fallout could be used for other purposes if plans had been made. The question is: Are such plans worthwhile? Again, very close to ground zero, there may be hazards, immediately after the detonation, which are more serious even than fallout. Can anything be done about these hazards at the local level? Do such actions need preplanning?

Once it has been determined that planning for a particular contingency is desirable, it is then pertinent to investigate the relative merits of alternative plans. For this, the first requirement is a measure of effectiveness derived from the considerations which indicated that the plan was desirable in the first place. As a corollary, there must also be a clearly defined set of goals to guide the planning process. In the following discussions, only the sheltering study was completely carried through to this level of detail: the other studies concentrate on the preliminary considerations already discussed.

In summary, the studies are concerned with the determination of the answers to two key questions:

(1) Is a plan required?

(2) If so, what plan is most desirable?

and these considerations are applied in detail to taking shelter, and in outline to fire hazards in depopulated areas, and other emergency measures.

CHAPTER II.

SHELTER-SEEKING OPERATIONS

A. ANALYTICAL METHODS

1. Introduction

A very large part of our current civil defense effort is directed towards the establishment and provisioning of fallout shelters. The planning of the operations required to move the population into these shelters in the event of an emergency is therefore important. This study compares the effectiveness of a number of possible plans for doing this.

The first step was the establishment of an appropriate measure of effectiveness for the operations. The principal good effect of planning is the increase in the number of people arriving at available shelter spaces in a specified time interval. The principal uncertainty is the duration of the time interval which will be available. This will vary with the type of attack and, for any particular attack, with the weather and the geography, and the state of preparation of the region considered. In order to achieve a reasonable degree of generality, the measure selected was expressed parametrically as a function of time: $N(t)$ represents the number of individuals arriving at available shelter expressed as a function of time measured from the initial warning. This measure is not completely definitive, but it does make it possible to establish at least a partial preference ordering over a set of alternative plans. For example, four different plans might produce the four functions $N_i(t)$ shown in Figure 1. In this case all four plans are equivalent if the time between initial warning and the arrival of fallout is greater than t_4. If this time is less than t_2 the plan producing $N_4(t)$ is preferred to all others. $N_2(t)$ is preferred to $N_3(t)$ if t is less than t_1, and this preference is reversed if t lies between t_1 and t_3, after which the two plans are equivalent.[1]

The second step in the analysis was to establish the parameters which determine $N(t)$ and which could be altered by appropriate planning.

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[1] In some cases, it may be possible to achieve additional ordering by introducing cost considerations. Thus, if the plan producing $N_2(t)$ is more expensive than that resulting in $N_3(t)$, this extra cost must be balanced against the likelihood that the available time will be less than t_1, and the result may be a clearly defined preference for one of these two possibilities.

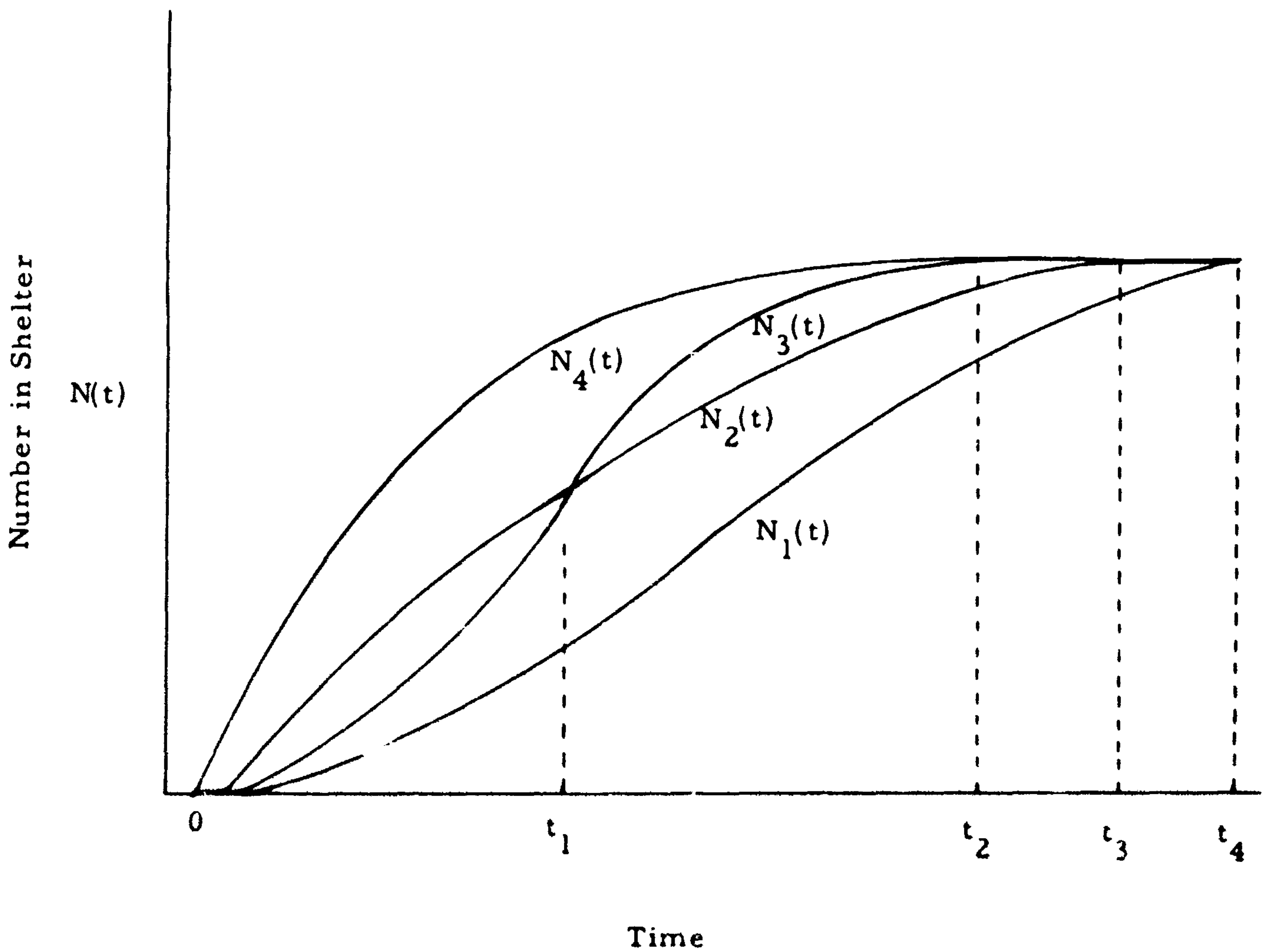


Figure 1. Illustrative Effectiveness Functions For Alternative Plans.

It was convenient to consider this problem in terms of the characteristics of several more or less independent subsidiary operations; namely warning, assignment, and the movement to shelter over varying distances and with varying modes of transportation. These are described in detail in the following sections and the associated appendices.

For many reasons, it was felt desirable to develop and test alternative plans with respect to a particular community. Stamford, Connecticut, was chosen because of its convenience, size, and resemblance to many other communities. However, any single town is unique, and it is important to have some basis for believing that conclusions drawn from one community will also apply to other similar ones. The City of Waterbury, Connecticut, was therefore used to provide a check upon the validity of the conclusions deriving from the study of the City of Stamford.

2. The Effect of Variations in Warning Procedures

The time used in the definition of N(t) is that between the occurrence of an event called "warning" and the arrival of N individuals at an available shelter. One of the several reasons for selecting this definition is that the additional time between the occurrence of the trigger event (dropping of the bomb, word from higher echelons, etc.) can be studied without reference to the operations which must be initiated subsequent to the receipt of warning. In actual fact, not everyone will be warned at the same instant; however, this is assumed later for analytical purposes since this variation will be unimportant relative to the variations in the subsequent processes.

The first problem to be considered is that of defining a "warned person". At this time the warning system of the City of Stamford (as well as most cities) consists exclusively of sirens, and it could be assumed that any individual who heard the sirens could be considered as warned. However, past experience resulting from the unexpected sounding of civil defense sirens suggests that such an assumption is not realistic--at least under normal peace time conditions. Furthermore, the siren system can be significantly enhanced with relatively little effort on the part of local civil defense planners by utilizing local radio and television stations. Finally, the reinforcement of the warning system following the introduction of NEAR should not be ignored in considering when an individual is warned.

At least one additional factor must be considered in defining a warned person: this factor is the degree to which a person is preconditioned to expect a warning. It appears reasonable to assume that an individual would take a civil defense warning, regardless of its source, very seriously during periods of international crisis. On the other hand, as noted in the preceding paragraph, past experience indicates that during normal peace time, warning received from a mechanical device such as a siren is not sufficient to cause the civilian population to seek shelter. Thus, for purposes of this paper, a warned person is defined in terms of two situations: normal peace time, and a period of international crisis. The fraction of the civilian population warned in each of these situations is discussed in the following paragraphs.

Normal Peace Time: It is postulated that in this case a person must receive the warning from more than one source. For example, a person is not considered warned if he hears only a siren or only his NEAR device. More specifically a person is defined as warned if any of the following combinations of events occur. The individual

a) hears the siren and receives an additional warning via radio;

b) hears the siren warning and receives an additional warning via television;

c) receives the warning via both NEAR and sirens;

d) is warned via radio and confirms the warning by tuning in a second radio or television station;

e) is warned via television and is able to confirm the warning from a second television or radio station;

f) receives the warning via NEAR and confirms via radio;

g) receives the warning via NEAR and confirms via television.

The prediction of the expected fraction of the population warned requires that certain data be collected. It is necessary to know the probability that an individual will hear a siren, the probability that a NEAR device is installed, the probability that a radio and/or television is available, and finally the probability that a radio and/or television is turned on. Data on listening to radio and watching television have been collected for the daytime population of the City of Stamford. A telephone survey showed that 23 per cent of the population were either listening or watching on a typical Summer day; while another 15 per cent had radio or television available to them if they wanted it. The following table which has been arranged to illustrate the way the total fraction warned changes when the two important individual elements, siren and NEAR, vary in effectiveness, and all other factors remain unchanged from those which exist currently.

TABLE 1

Total probability that a person is warned, $p(W_1)$, when varying percentages of the population hear sirens, NEAR devices, or both.

(The data are for Stamford, Connecticut, on a typical Summer working day.)

Per cent of population alerted by siren p(S)						
100%	.38	.53	.66	.78	.90	1.00
80%	.35	.48	.59	.70	.80	.90
60%	.32	.43	.53	.62	.70	.78
40%	.29	.37	.45	.53	.59	.66
20%	.26	.32	.37	.43	.48	.53
0%	.23	.26	.29	.32	.35	.38
	0%	20%	40%	60%	80%	100%

Per cent of population alerted by a NEAR device p(N)

The entry in the lower left hand corner shows that in this case about 23 per cent of the population will be warned by radio or television even if no sirens nor NEAR devices are used. The actual conditions in Stamford at the time of this study are that there are no NEAR devices, but that about 60 per cent of the population will hear the sirens. Of these, 38 per cent have radio or television available, so those receiving both warning and confirmation will be (.6 x .38 + .4 x .23) or 32 per cent.

The two parameters shown are singled out for special attention because their effectiveness can be changed by civil defense planning.

The detailed derivation of these results is presented in Appendix 1.

Period of International Crisis: The principal difference between the warning in this situation and the peacetime one is that, in a period of international crisis, the person hearing a siren, or a radio warning, will act as if it were true, until it is proven false; whereas, in peacetime, the warned person will not act until he has received confirmation that the warning is a real one.

The expected fraction of the population of Stamford warned under the conditions of international crisis is as shown in Table 2. Again the coverage of both sirens and NEAR is treated parametrically. The methods used to compute the quantities included in Table 2 are contained in Appendix 1 of this report.

TABLE 2

Probability of being warned[1] $p(W_2)$, on a typical Summer working day in Stamford, Connecticut, as a function of the percentage of the population which is alerted by a siren and a NEAR device.

Percent of Population Alerted by Siren p(S)						
100%	1.00	1.00	1.00	1.00	1.00	1.00
80%	.85	.88	.91	.94	.97	1.00
60%	.69	.75	.82	.88	.94	1.00
40%	.53	.63	.72	.82	.91	1.00
20%	.48	.51	.63	.75	.88	1.00
0%	.23	.48	.53	.69	.85	1.00
	0%	20%	40%	60%	80%	100%
	Percent of Population Alerted by a NEAR Device p(N)					

The model predicts the expected fraction of the population which receives the initial warning but does not consider that part of the population which will be warned by "word of mouth." It is believed reasonable to expect that many people having received the warning from the civil defense warning system will tell their neighbor that a warning has been transmitted.

[1] People in transit are not included.

Furthermore, the increased activity in foot and automotive traffic will certainly generate enough curiosity among some of the "unwarned" to cause them to determine for themselves what has happened. This is particularly true of those individuals occupying a major reception tract. Because the analysis includes only those individuals who receive the warning directly from the warning system, the results are to be considered conservative in the sense that more people are probably warned than are predicted by the model.

Before leaving the subject of warning, one item of interest should be mentioned. It became clear during the analysis of warning and the collection of data required that the number of people warned could be substantially increased if plans were made by the local civil defense organization to provide a special warning (e.g., a telephone call) to factories, office buildings, and other points where a large number of people are concentrated but do not usually have access to other than a single source of warning information, such as a siren. As an example of the number of people who could be warned by special warning messages, consider the following data collected for the City of Stamford. Table 3 shows the ten largest industrial organizations of the city ranked according to number of employees.

TABLE 3

Industrial employment in the City of Stamford

Rank	People Employed	Cumulative People Employed
1	2,500	2,500
2	2,000	4,500
3	1,250	5,750
4	1,250	7,000
5	875	7,875
6	875	8,750
7	625	9,375
8	625	10,000
9	625	10,625
10	625	11,250

Thus, it can be seen from Table 3 that ten special warning messages (e.g., telephone calls) could result in 11,250 people being warned or almost 10 percent of the daytime population of the city. Stamford is generally not considered an industrial town, and it is possible that in other cities ten telephone calls could result in even more people being warned.

3. Assignment Operations

One of the chief problems for the local civil defense planner is that of assigning individuals to shelters. The possible alternatives range from complete laissez-faire to specific assignments for each individual for each hour of the day and each day of the week. In this collection of alternatives the procedures for which data is most easily obtained are those based on the use of census tracts as geographical units. This, of course, is a result of the fact that Census Bureau data on population distributions is organized in this way. The ideal redistribution of the population when individuals are moved from a tract without enough shelters to tracts with an excess of shelters for the population in the tract when warning is received can be determined by use of simple linear programming techniques.

The only variation examined in this study is the effect of assigning individuals to specific shelters within a tract as opposed to allowing individuals to select shelters at random once they are in the tract. N(t) calculated for these two conditions provides a basis for determining the effectiveness of any other procedure which may adopt a completely different rationale for arriving at assignments.

The results of applying the linear programming procedure to the data for the resident population of the City of Stamford are contained in Appendix 2.

4. Traffic Between Tracts

Even with an assignment procedure which minimizes the number of man miles to be travelled in arriving at a shelter, there will be considerable movement of people from place to place, most of it over distances requiring the use of automobiles. Expediting this traffic is clearly a sensible problem for local planners. Accordingly, this study investigated the sensitivity of N(t) to several of the controllable parameters involved--walking versus the use of private automobiles, use of all lanes in one direction on streets which normally carry two way traffic, variations in driving speed, etc.

The analytical technique used in the study can be characterized as a "point-by-point calculation." The actual routes to be used were selected on the basis of maps and field inspections. Then for each case considered, the point-to-point progress of the traffic was determined until all traffic had arrived. When there was interference between two moving groups, it was planned that the group arriving at the intersection or merge point first would pass completely before the second group moved again. Simple sensible rules were adopted to distinguish between individuals who should walk to shelter and those who should attempt to use automobiles. The cumulative arrivals expressed as a function of time were calculated in this way for each tract containing destination points. The detailed description of the analysis is presented in Appendix 3. A generalization of this analysis suggested in part by the results of these calculations is presented in Appendix 4. An example of the results obtained in shown in Table 4.

TABLE 4

People arriving at Census Tract #1
as a function of time
(Stamford, Connecticut)

Cumulative Arrivals	Time (Hours)
1,691	0.1
2,865	0.15
4,277	0.19
4,581	0.20
9,090	0.38
9,262	0.39
11,093	0.53
12,234	0.59
15.949	0.79
16,509	0.82
17,255	0.86
20,751	1.04
22,279	1.16
23,981	1.44
26,445	1.84
29.091	2.26

5. Time Spent Within the Tract

The final operation affecting N(t) is time spent within a tract when individuals are attempting to find a shelter with available space. Three specific possibilities were examined. In the first, it was assumed that this time is small enough to be ignored. This will be the case when specific individuals are assigned to specific shelters, when planning, marking, and traffic directing are at peak efficiency, or in the rare case when there is a very large excess of shelters over people so no searching for available space is needed.

The second case analyzed applies primarily to individuals who do not have to leave their tract in order to find shelter. These persons will start for shelters more or less simultaneously and the stragglers may find their first choice fully occupied. In this case, they will proceed to the next closest shelter, etc., until they find an available space. A typical result is shown in Table 5. The analytical details are in Appendix 5.

TABLE 5

Residents of Tract #18 sheltered as a function of time

Residents Sheltered (Cumulative)	Time (Hours)
1,170	0.02
5,098	0.06
6,019	0.18
6,459	0.30
6,665	0.42
6,775	0.54
6,858	0.66
6,913	0.78
6,940	0.90

The final case is a variation applying to persons arriving from points outside of the tract. For these people, the arrivals at the tract will be spread out over time and proportionally more of the late arrivals will have to try two or more shelters before they find an available space. The details are in Appendix 6. A typical result is shown in Table 6.

TABLE 6

People arriving at Tract #12 sheltered as a function of time

Residents Sheltered (Cumulative)	Time (Hours)
0	0.19
1,355	0.57
2,974	1.29
3,392	1.51

6. Summary

Analytical procedures for determining the number of individuals arriving at available shelter as a function of time have been developed. The complete operation is subdivided into warning, assignment, inter-tract movements, and intra-tract movements. This analysis provides a basis for determining the effectiveness of alternative plans for carrying out each of these phases. Both the rationale used in developing this analysis and the experience gained in applying it to the cities of Stamford and Waterbury, Connecticut, indicate that this procedure can be used for most of the communities in the United States. The results obtained for the two communities studied in detail are described in the next major section.

B. RESULTS OF ANALYSIS OF STAMFORD AND WATERBURY, CONNECTICUT

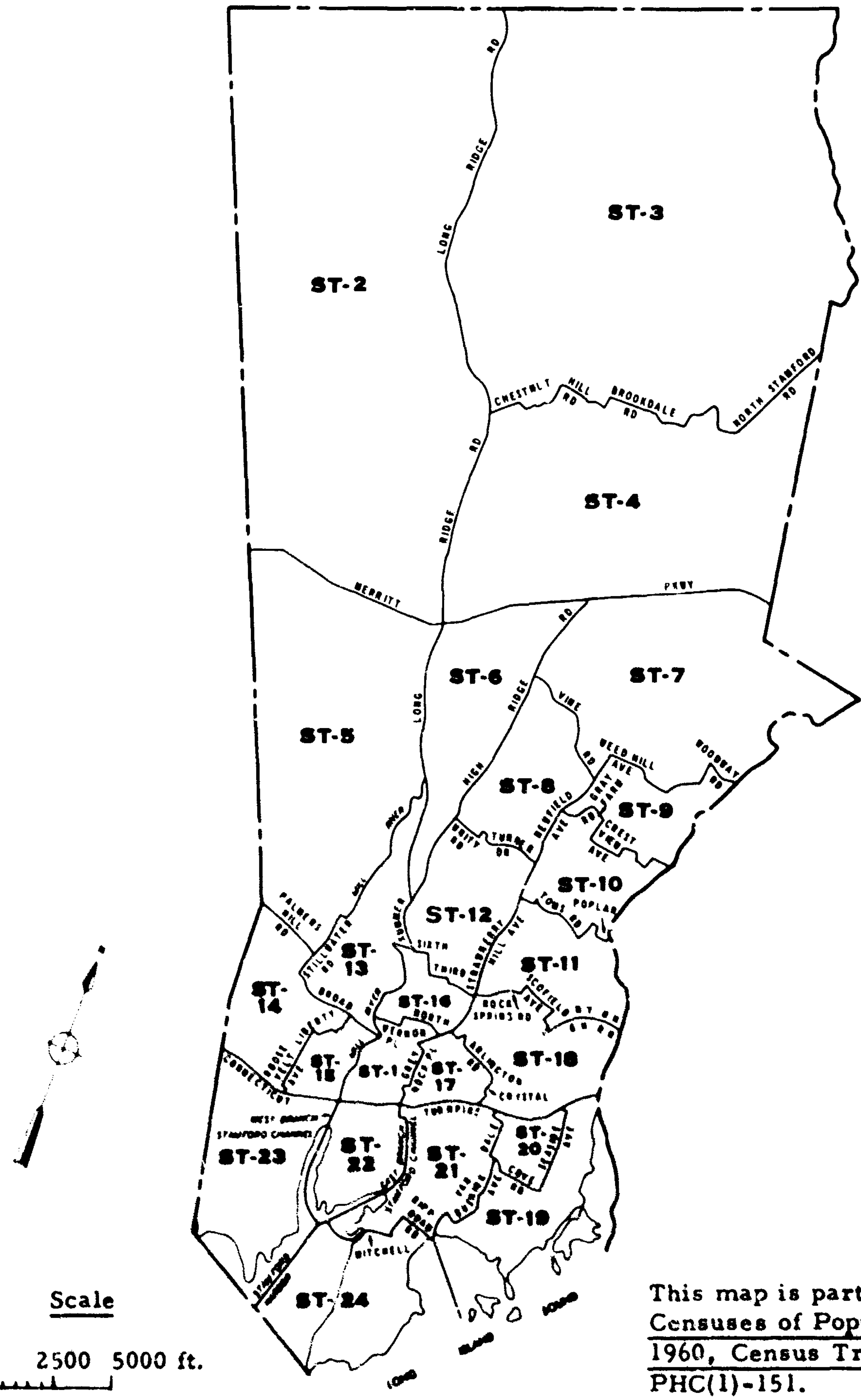
1. General Characteristics of Stamford and Waterbury

The cities of Stamford and Waterbury, Connecticut, have been analyzed using the procedures described in Section A. Both cities are of moderate size. Stamford has a resident population of about 92,000 and an area of 37.6 square miles, while Waterbury has a resident population of about 107,000 and occupies an area of 27.6 square miles.

The geographical boundaries and census tract designation of Stamford and Waterbury are shown on Figures 2 and 3, respectively. As can be seen, the actual layout of these cities is quite different. Stamford is a seacoast city, bordering on Long Island Sound. Since census tracts are laid out to contain approximately the same number of people, it can be seen that the high population density areas are located in the south end of the city. Further, our investigations indicate that the high population density areas of a city correlate with those areas having a high density of multi-story buildings and consequently a high density of fallout shelter spaces. As a result, most of the shelters in Stamford are located in census tracts in the southern area of the city. Many of these tracts have more shelter spaces than the residents of these tracts require. People living in the northern part of town generally do not have sufficient shelters within their own census tracts and, in order to find shelter, are forced to move south to areas nearer the water which have shelter spaces in excess of the needs of their resident populations.

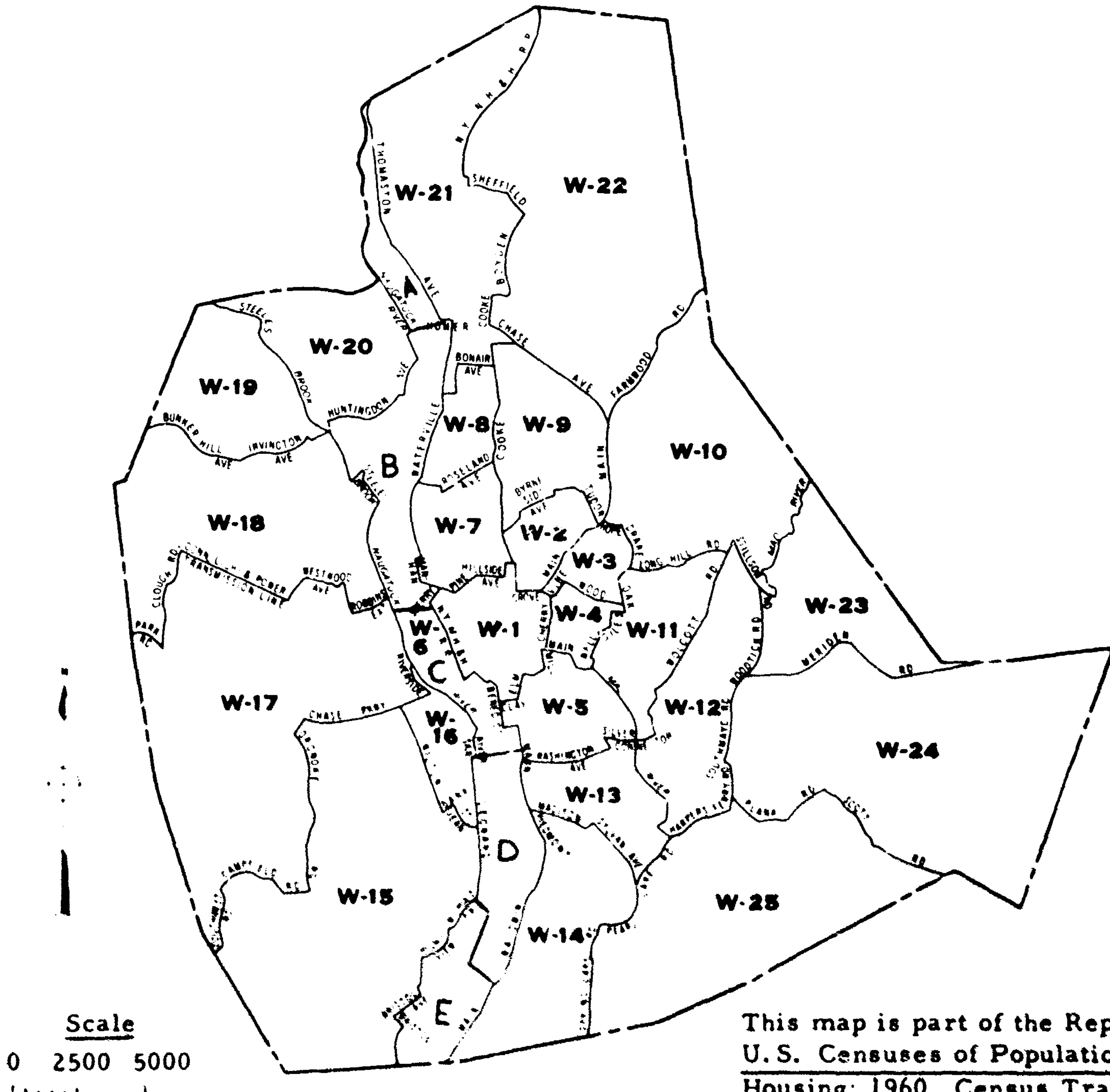
Waterbury, on the other hand, is an inland city. Reference to Figure 3 shows that the high population density areas and consequently the tracts having excess shelter capacity are found toward the center of the city. Tracts with insufficient shelter spaces for their resident populations are seen to ring this central core area.

The movement pattern of people from tracts with insufficient shelter spaces to tracts with excess shelter spaces is quite different for Stamford and Waterbury. In Stamford this movement occurs almost entirely from the north into the southern part of the city. In Waterbury, however, the movement is from the outlying areas toward the center of town.



This map is part of the report U. S. Censuses of Population and Housing: 1960, Census Tracts, Final Report PHC(1)-151.

Figure 2. Census Tracts in the Stamford SMSA
Inset Map - Stamford City



This map is part of the Report U.S. Censuses of Population and Housing: 1960, Census Tracts, Final Report PHC(1)-151.

Figure 3. Census Tracts in the Waterbury SMSA
Inset Map - Waterbury City

There is one other significant difference between these two cities. Stamford was found to have fewer shelter spaces than residents. For the purpose of this analysis, it was assumed that in order to shelter the entire resident population all existing shelters would be "overcrowded" by a factor of 1.44. This notional overcrowding resulted in an exact balance between the number of residents and the number of shelter spaces. Waterbury, on the other hand, had about 165,000 shelter spaces for a resident population of only 107,000.

These are the primary differences between these two cities. The effect these differences have on the speed with which people find shelter will be discussed later in this chapter.

2. Assumptions

The determination of N(t) for the cities of Stamford and Watebury was based on the census data for the residential population. Thus, the results are those which might be expected if the warning was received during the evening hours (i.e., 6 p.m. - 11 p.m.) or the night time hours (i.e., 11 p.m. - 6 a.m.) of weekdays or at anytime on holidays. It does not apply, however, to the working and shopping hours of the weekday.

Civil defense authorities in the cities of Stamford and Waterbury have made virtually no plans to cope with the problems addressed in this study. It is possible, though difficult, to develop a model which predicts the number of people sheltered in a city when there are no sheltering plans. However, it is believed more useful to establish a basic set of plans for a city and predict the results of both implementing the plans as well as introducing (or deleting) plans into the basic set. The plans discussed in this section are related specifically to the problem of sheltering people. The assumptions and some of their implications were as follows.

(1) Population has been educated as to general location of shelter

It is assumed in this study that shelters have been well enough marked and their location sufficiently publicized so that the civilian population will have no trouble finding the shelters.

(2) Population has been assigned to appropriate census tracts

Except where designated otherwise, it is assumed that each individual knows within which census tract he is to search for a shelter. This implies, of course, that the boundaries of the census tract have been made known to the civilian population. The assignment was determined by use of linear programming as discussed in Chapter II. A. 3., which provides assignment on the basis of minimum total travel distance.

(3) Routes between tracts have been established and the civilian population informed of the correct routes to be used

The appropriate routes to be followed by the civilian population are determined in conjunction with the assignment of the population to various tracts. Once the routes have been established, the public must be informed of them. It is to be anticipated that certain of the routes will intersect at one or more points; therefore, appropriate plans must be made to control the traffic at these intersecting points.

(4) Individuals have been instructed to walk to shelter or to use their automobiles

In this study it has been assumed that if an individual is within one mile of the census tract in which he is to find shelter or if he is to seek shelter in the tract in which he resides he will walk to a shelter. If the travel distance is greater than one mile, we assume that the individual will generally use his automobile. This is merely a reasonable rule, but the effect of varying it was not analyzed. However, this can be done with the existing techniques and data.

(5) Traffic control within the reception tract

In the case of both Stamford and Waterbury, large numbers of people will be assigned to the downtown areas to find shelter. If the entrances to these tracts were to become blocked by early arrivals who, say, abandoned their cars upon spotting a shelter near the periphery of the tract, then large numbers of people would be delayed in entering the tracts. It was assumed in using the model that this would not happen. This implies that parking of automobiles would be planned and controlled (e.g., side streets and sidewalks as well as the principal streets and parking lots in the tract would be utilized).

(6) Warning the population via television and radios

Possible deficiencies in warning effectiveness were not considered in this analysis.

3. Discussion of Results

Figure 4 shows the number of people that are sheltered in Stamford as a function of the elapsed time after they begin their search for shelter, for various conditions of automobile speed, shelter assignment, road conditions, and walking speed. Figure 5 contains a similar presentation for Waterbury. All are based on the assumptions discussed in Section 2, above.

Curve 1 in Figures 4 and 5 shows what may be expected when driving speeds and walking speeds are 20 mph and 3 mph respectively, single lane traffic is maintained and no specific shelter assignments are made, then about 75,000 people or 81% of the resident population of Stamford and 95,500 people or 89% of the resident population of Waterbury are sheltered within .8 hours of departure from their homes. The time period of .8 hour is selected because it is about the earliest time that fallout can be expected from nuclear explosions that are far enough away not to have seriously damaged these cities with their blast or thermal effects. The most interesting feature about curve 1 is that it demonstrates that with the aid of a very minimum amount of planning, i.e., no shelter assignment, 20 mph auto speeds, and single lane traffic, a large proportion of people can be sheltered before the probable arrival of fallout.

Curve 2 in Figures 4 and 5 is developed under the assumption that control of traffic in the approaches to the reception tracts permits an average automobile speed from origin to destination of 40 mph. If this can be accomplished, the number of people sheltered in Stamford after .8 hour is about 77,000 or 83.5% of the population. Under the same conditions about 98,500 people or 92% of the residents of Waterbury are sheltered. By comparing curve 1 with curve 2, it can be seen that the number of people sheltered as a function of time is rather insensitive to changes in speed.

Curve 3 in Figures 4 and 5 shows the influence of introducing shelter assignments on the number of people sheltered. For Stamford, with individual shelter assignments, 40 mph driving speed, 3 mph walking speed, and single lane automobile traffic, about 80,000 people or 87% of the population would be sheltered within .8 hour. For Waterbury under the same conditions, about 102,000 people or 95% of the population are sheltered.

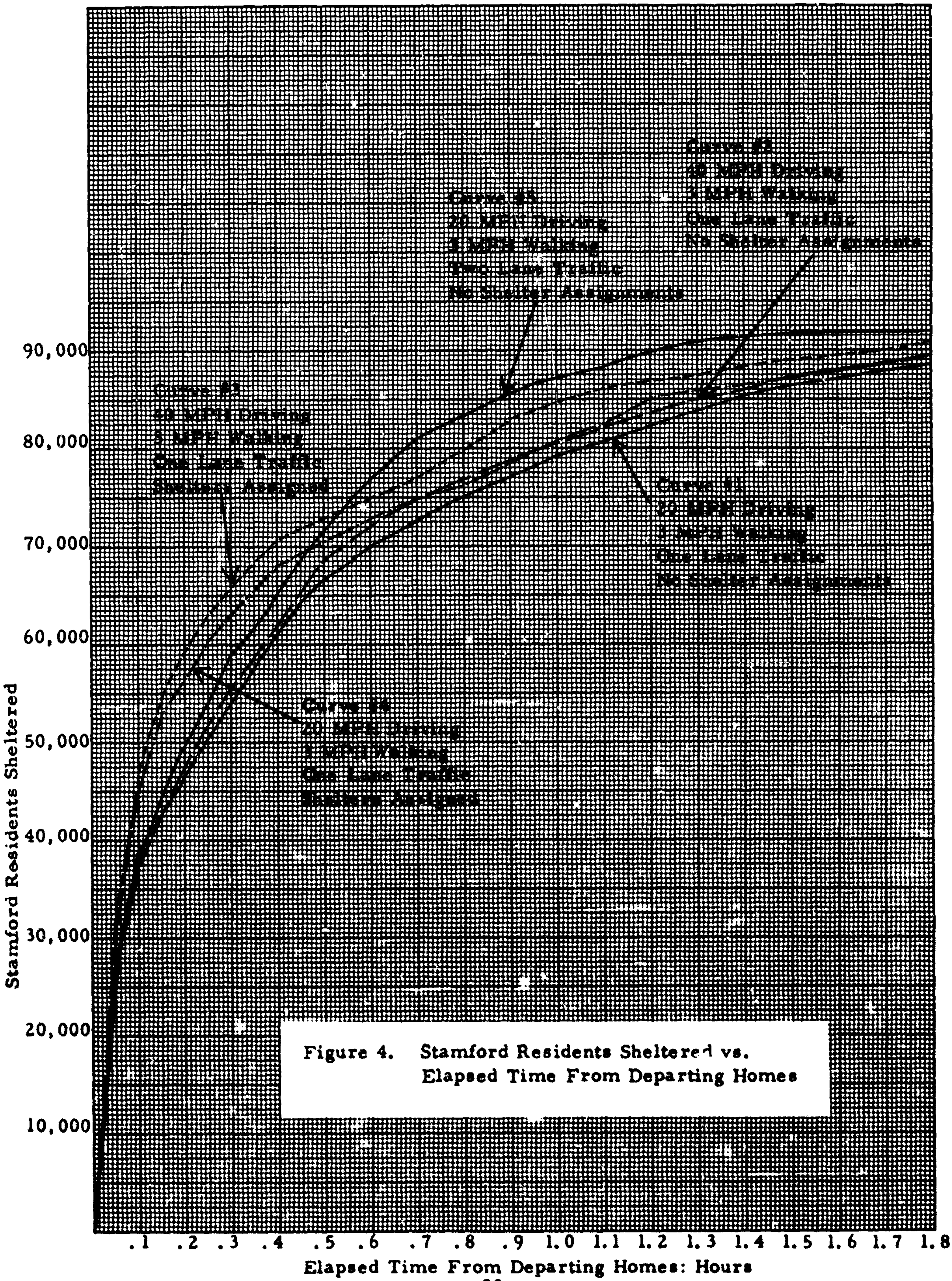


Figure 4. Stamford Residents Sheltered vs. Elapsed Time From Departing Homes

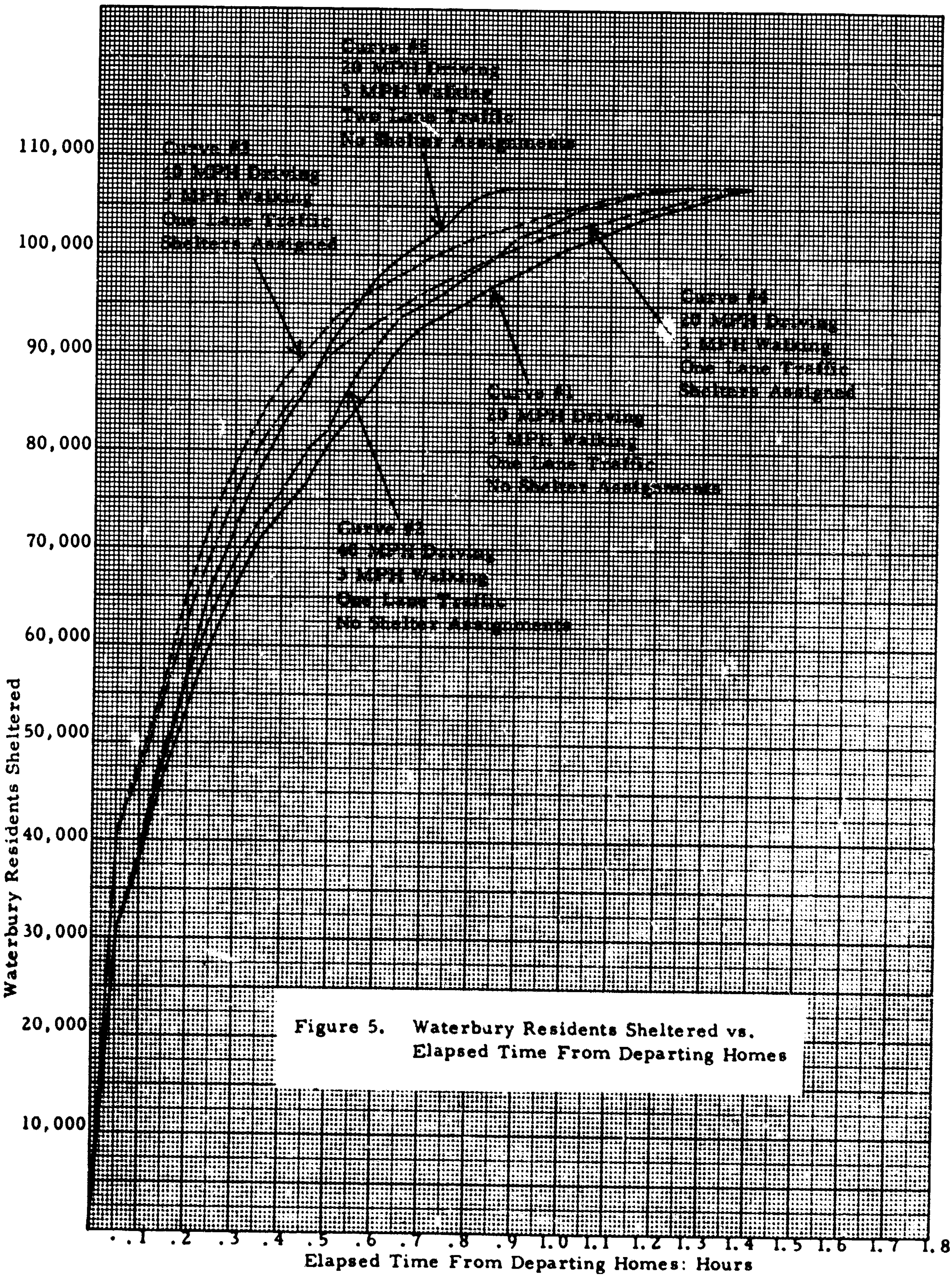


Figure 5. Waterbury Residents Sheltered vs. Elapsed Time From Departing Homes

Curve 4 in Figures 4 and 5 is developed for conditions identical to curve 3 except that the traffic speed is reduced from 40 mph to 20 mph. Under these conditions, 76,000 people or 83% of the Stamford resident population are sheltered within .8 hour. For Waterbury, these figures are 99,000 people or 92% of the population. Comparing curves 4 and 5 it can be seen that the influence of changing speeds from 40 mph to 20 mph is not large.

Curve 5 in Figures 4 and 5 shows the influence of using two lanes of traffic for all routes leading to reception tracts. From Figure 4 it is seen that the two lane traffic permits about 83,000 people or 90% of the resident population of Stamford to be sheltered within .8 hour. Figure 5 shows that under the same conditions about 106,000 people or 99% of the resident population of Waterbury are sheltered. While there is some speed-up in the shelter-taking cycle after the .6 hour mark, it is doubtful whether this improvement is worth the added burden a two lane traffic system imposes on any traffic control system.

Certain conclusions are suggested by the group of curves in Figure 4 and Figure 5. It is seen that of the various alternatives considered, i.e., the change from one lane to two lane traffic, from shelter assignment to no shelter assignment, and from 20 mph driving speed to 40 mph driving speed, none cause a very large change in the number of people sheltered before the earliest arrival of fallout. The difference between curve 1 and curve 5 (at the .8 hour point) on Figure 4 is a change of about 9% of the total resident population of Stamford. For Waterbury the difference is also about 9%.

A second conclusion is that with the exception of the early part of the shelter-taking cycle, i.e., before .1 hour, there is a uniform relation between curves in Figure 4 and Figure 5. In each case, curve 1, which is based on a 20 mph driving speed, 3 mph walking speed, single lane traffic and no individual shelter assignment, represents the slowest procedure for taking shelter. Curve 2, based on the same conditions as curve 1 except that the driving speed is 40 mph, represents a somewhat faster procedure for taking shelter. Curve 4, based on 20 mph driving speed, 3 mph walking speed, single lane traffic with each individual assigned to a specific shelter, gets people into shelter faster still. Curve 3, based on the same conditions as curve 4 except that the driving speed is 40 mph rather than 20 mph, shows that people enter shelter faster than they do under conditions represented by curves 1, 2, and 4. Reference to Figures 4 and 5 reveals that with one brief exception, curve 3 is uniformly higher than curve 4, curve 4 is uniformly higher than curve 2, and curve 2 is uniformly higher than curve 1.

The situation depicted by curve 5 (20 mph driving speed, 3 mph walking speed, two lane traffic and no individual shelter assignment) is somewhat different. Curves 1, 2, 3, and 4 maintain a uniform relation to one another, curve 5, on the other hand, begins at a point between curves 2 and 4, but does not maintain this position. In both Figures 4 and 5, curve 5 crosses above curve 4 at about the .45 hour mark and then crosses above curve 3 at about the .55 hour mark. Beyond .55 hour curve 5 represents the situation having the largest number of people in shelter at any future point in time. The relation between the 5 curves, one to another for Stamford, presented in Figure 4, is then substantially identical to the relation between the 5 curves for Waterbury presented in Figure 5. This relation is obviously independent of the physical differences of the two cities as well as the difference in excess shelter capacity (Stamford has no excess capacity while Waterbury has 54% excess shelter capacity).

A third conclusion that can be drawn from a comparison of Figures 4 and 5 is that the entire resident population of Waterbury is able to find shelter sooner than the resident population of Stamford. Figure 5 shows that regardless of the shelter-taking plan used, the last Waterbury resident is in shelter 1.4 hours after he begins his search. On the other hand, it takes 3 hours for the entire population of Stamford (Table 4) to be safely sheltered. The reason for this discrepancy is solely due to the existence of excess shelter space in Waterbury as opposed to an artificially induced exact balance between residents and shelter spaces in Stamford. The existence of excess spaces in Waterbury gives the Waterbury resident a greater chance of finding an empty shelter space sooner after he commences his search, than his counterpart in Stamford. This situation becomes more pronounced as the last residents of both cities begin their search for shelter. In Waterbury the last residents to arrive begin their search for an empty shelter space in tracts having relatively high proportions of the shelters with excess capacity. In Stamford, on the other hand, the proportion of shelters with excess capacity toward the end of the shelter-taking cycle is much lower.

Table 7 shows how the percent of residents in shelter varies over time for the 5 curves in Figures 4 and 5. It is seen that early in the shelter-taking cycle the percent of residents in shelter for Stamford and Waterbury is substantially the same where the same shelter plan is used. As time passes, however, a greater percentage of the Waterbury residents find shelter. This difference reaches a maximum at about .5 hour with differences between 8 and 10 percent. After 1 hour, the differences decrease and at 3 hours, when the last Stamford resident has found shelter, the difference is of course zero.

TABLE 7

Percent of population sheltered as a function of time using data in Figures 4 and 5

	Curve 1		Curve 2		Curve 3		Curve 4		Curve 5	
Time (hours)	Stamford	Waterbury	Stamford	Waterbury	Stamford	Waterbury	Stamford	Waterbury	Stamford	Waterbury
.2	51.3	49.9	52.4	42.6	64.8	61.6	61.6	57.9	53.8	63.1
.4	66.6	69.2	67.5	71.8	76.9	81.4	73.8	78.2	70.3	77.7
.6	75.9	81.5	78.8	84.9	81.4	90.4	78.7	87.2	83.5	91.5
.8	81.5	89.1	83.5	92.0	86.9	95.0	82.6	92.2	90.2	98.7

The differences in effectiveness of the different plans for moving people into shelter are shown in a different way in Figures 6 through 10. In each of these figures, a pair of conditions is compared both for Stamford and Waterbury. The comparison is made by subtracting, for each time-after-warning, the percentage sheltered under one plan from the percentage sheltered under the other. Thus, each curve shows the advantage of the better of the two plans compared in terms of extra percentage of people in shelter versus ime-after-warning. The list of comparisons made in this manner is given in Table 8.

Figure 6 shows, for example, that doubling the speed of automobile traffic, from 20 mph to 40 mph, while maintaining single lane traffic, is responsible for very roughly a 3% increase in population sheltered, when shelter assignments are made. Figure 7 shows that the advantage of faster driving drops a little when shelter assignment is on a tract basis; this is to be expected, because driving time is a smaller ingredient of total time, when people must search for shelters. Figure 8, on the other hand, shows that the merits of planning for use of two lane are much greater. About 7 or 8% more people may be expected to find shelter quickly in these circumstances.

Figures 9, 10, and 11 show the effects of individual shelter assignments. There is a big increase in speed of taking shelter, especially at first. In cities in which fallout may arrive very early, or which have a shortage of shelters, individual assignment of shelters would be a good planning goal. However, arrival of fallout, without blast damage, within half an hour of the detonation is probably the exception rather than the rule, and where blast damage is to be expected, plans for shelter assignment would have to take account of possible damage to buildings from fire or blast, as well as blockage of access to them.

4. Shelter Seeking During Working Hours

Both in Stamford and in Waterbury, the distribution of the population on a working day is very different from that at night. More people are present in the center area of the town, where businesses and shopping facilities tend to be located, and less are in the outlying residential areas. There is also an influx of workers from other nearby communities. This means that a shelter assignment scheme which is optimal for non-working hours is not optimal during normal hours of business. It would be possible to work out a scheme in which assignment by census tract would be different for the two periods. This was not done in the present study.

TABLE 8

Figure No.	Description of Curves
6	Curve 3 (40 mph driving speed, 3 mph walking speed, single lane automobile traffic with individual shelter assignments) minus curve 4 (20 mph driving speed, 3 mph walking speed, single lane automobile traffic, with individual shelter assignments).
7	Curve 2 (40 mph driving speed, 3 mph walking speed, single lane automobile traffic, no individual shelter assignments) minue curve 1 (20 mph driving speed, 3 mph walking speed, single lane automobile traffic, no individual shelter assignments).
8	Curve 5 (20 mph driving speed, 3 mph walking speed, two lane automobile traffic, no individual shelter assignments) minus curve 1 (20 mph driving speed, 3 mph walking speed, single lane automobile traffic, no individual shelter assignments).
9	Curve 3 (40 mph driving speed, 3 mph walking speed, single lane automobile traffic, with individual shelter assignments) minus curve 2 (40 mph driving speed, 3 mph walking speed, single lane automobile traffic, no individual shelter assignments).
10	Curve 4 (20 mph driving speed, 3 mph walking speed, single lane automobile traffic, with individual shelter assignments) minus curve 1 (20 mph driving speed, 3 mph walking speed, single lane automobile traffic, no individual shelter assignments).
11	Curve 3 (40 mph driving speed, 3 mph walking speed, single lane automobile traffic, with individual shelter assignments) minus curve 1 (20 mph driving speed, 3 mph walking speed, single lane automobile traffic, no individual shelter assignments).

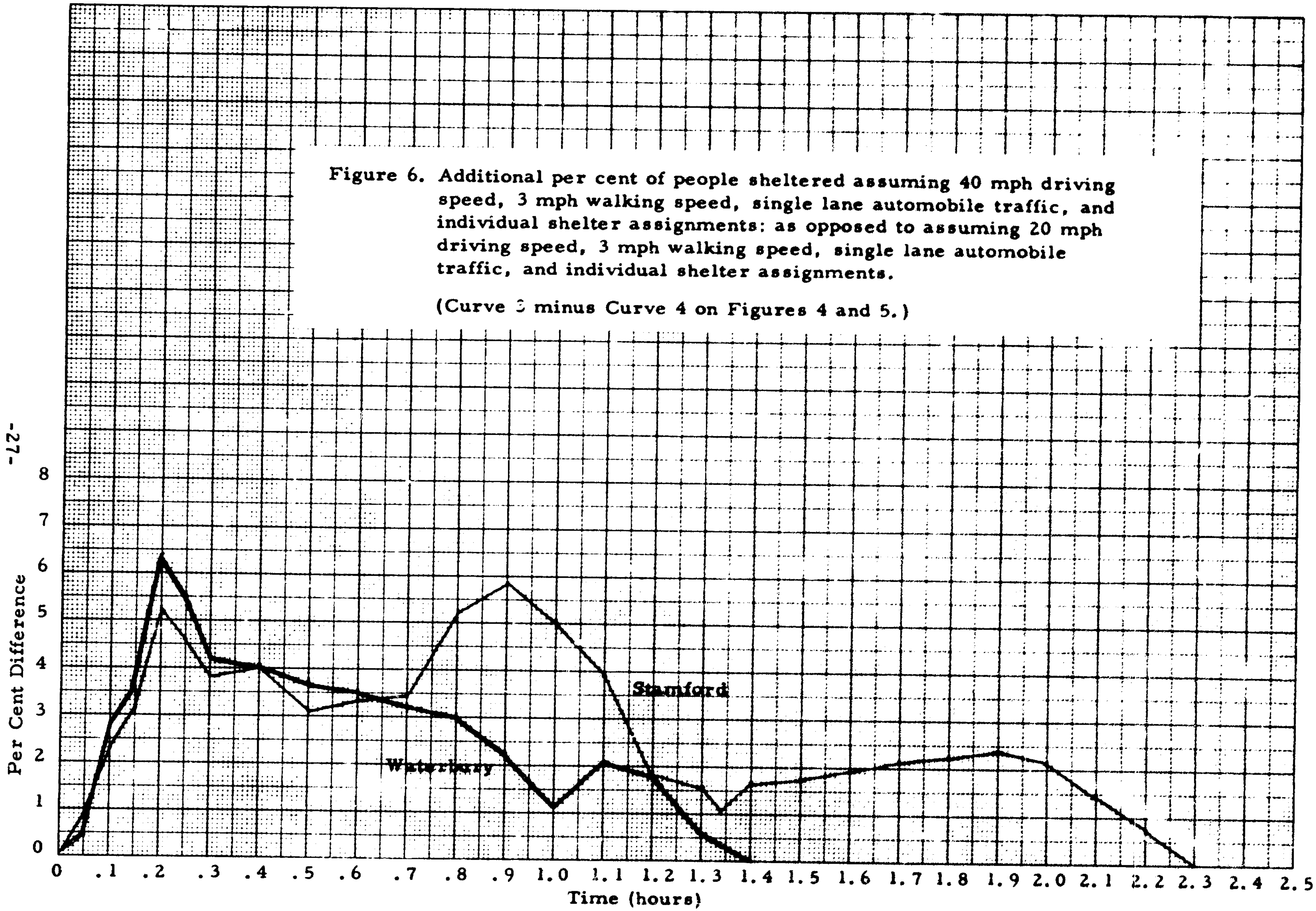


Figure 6. Additional per cent of people sheltered assuming 40 mph driving speed, 3 mph walking speed, single lane automobile traffic, and individual shelter assignments: as opposed to assuming 20 mph driving speed, 3 mph walking speed, single lane automobile traffic, and individual shelter assignments.

(Curve 3 minus Curve 4 on Figures 4 and 5.)

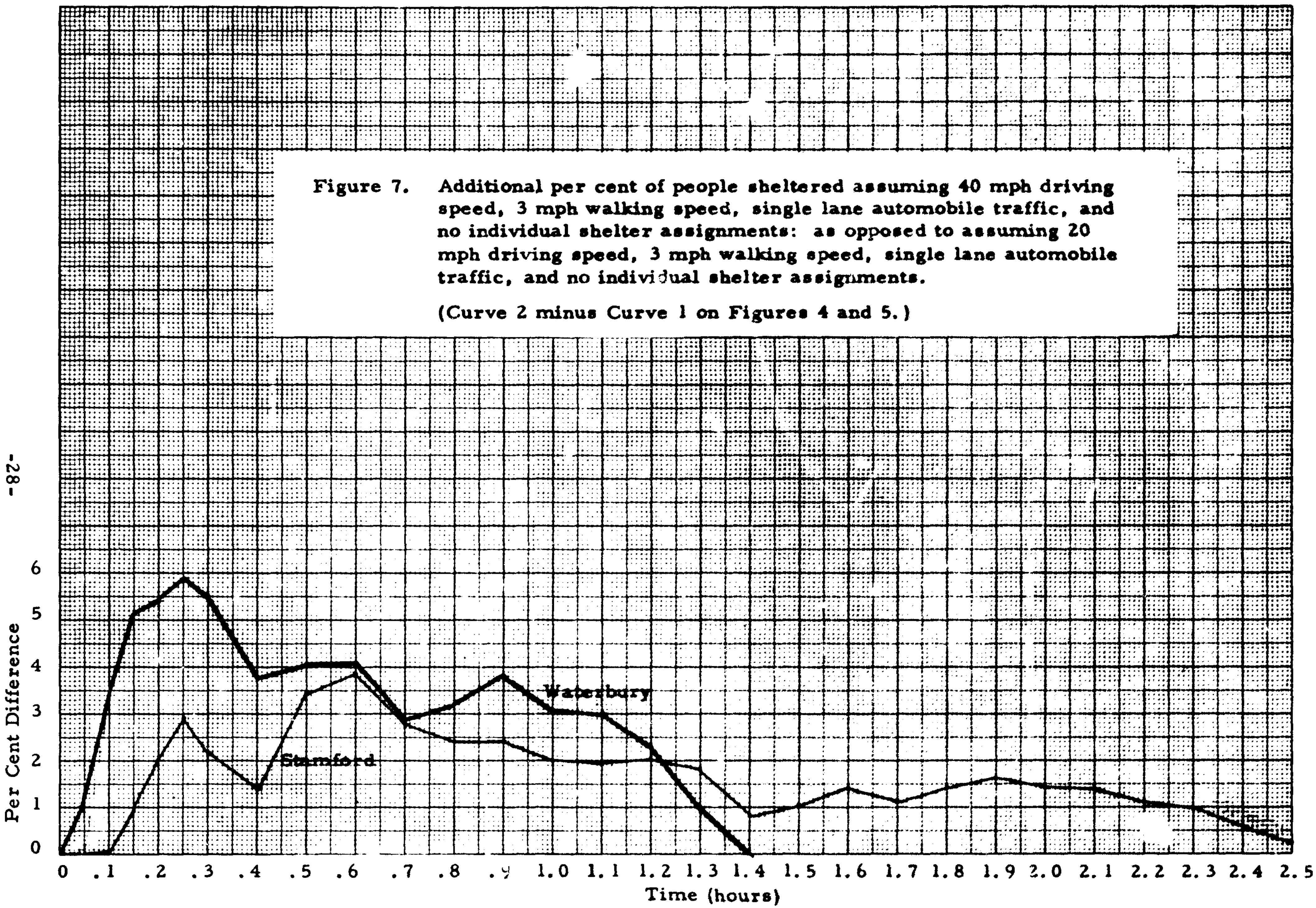


Figure 7. Additional per cent of people sheltered assuming 40 mph driving speed, 3 mph walking speed, single lane automobile traffic, and no individual shelter assignments: as opposed to assuming 20 mph driving speed, 3 mph walking speed, single lane automobile traffic, and no individual shelter assignments.

(Curve 2 minus Curve 1 on Figures 4 and 5.)

Time (Hours)

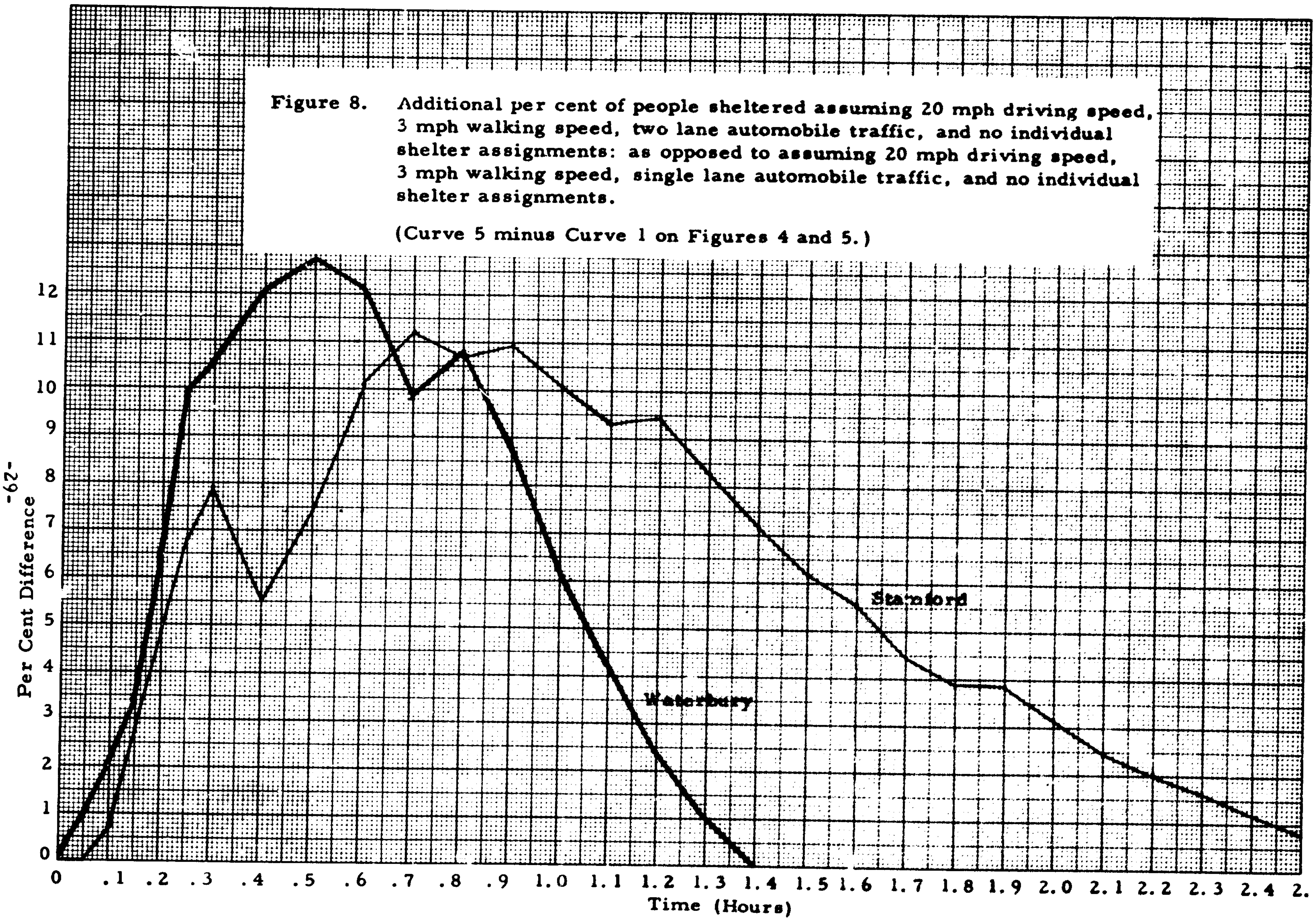


Figure 8. Additional per cent of people sheltered assuming 20 mph driving speed, 3 mph walking speed, two lane automobile traffic, and no individual shelter assignments: as opposed to assuming 20 mph driving speed, 3 mph walking speed, single lane automobile traffic, and no individual shelter assignments.

(Curve 5 minus Curve 1 on Figures 4 and 5.)

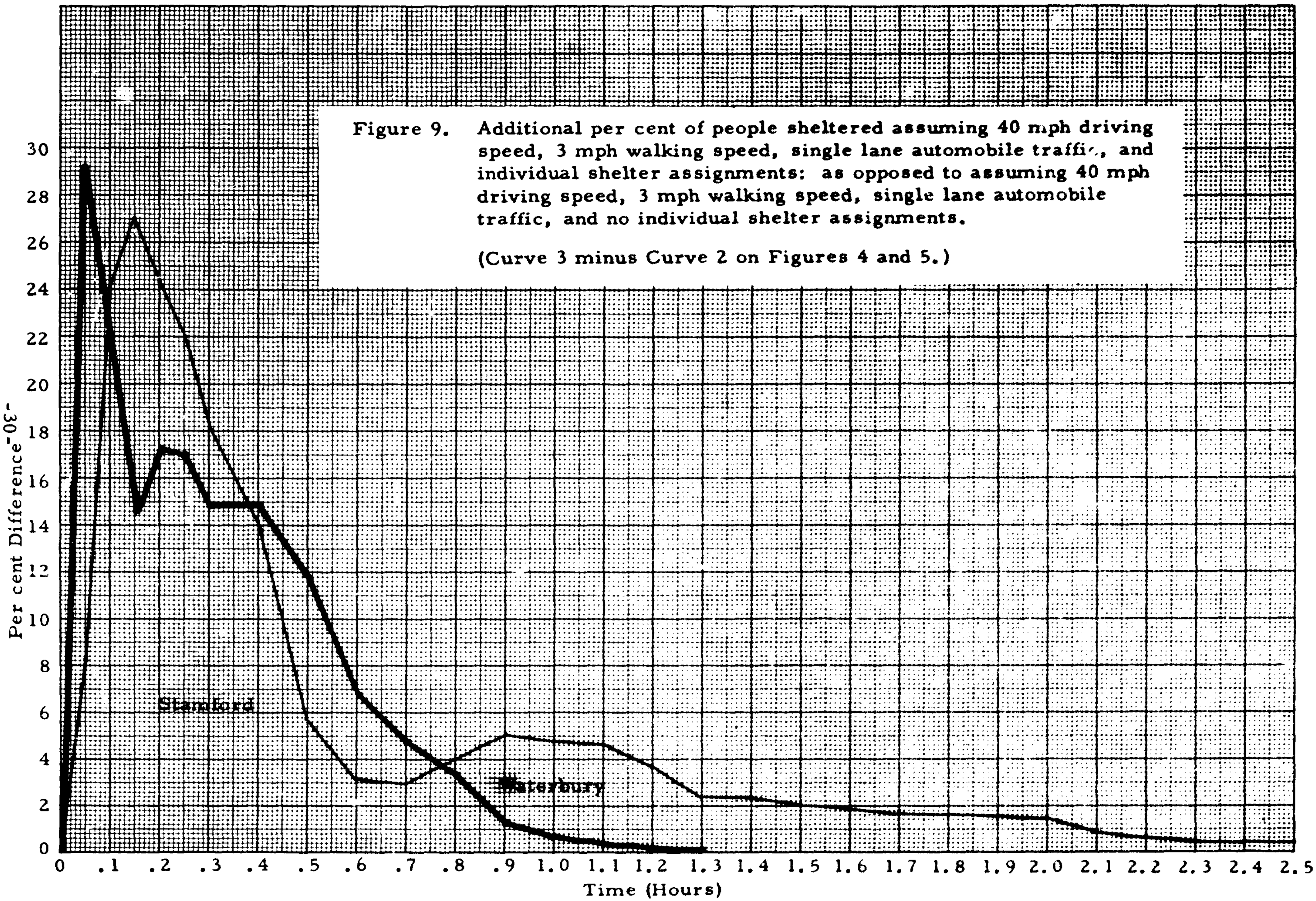


Figure 9. Additional per cent of people sheltered assuming 40 mph driving speed, 3 mph walking speed, single lane automobile traffic, and individual shelter assignments: as opposed to assuming 40 mph driving speed, 3 mph walking speed, single lane automobile traffic, and no individual shelter assignments.

(Curve 3 minus Curve 2 on Figures 4 and 5.)

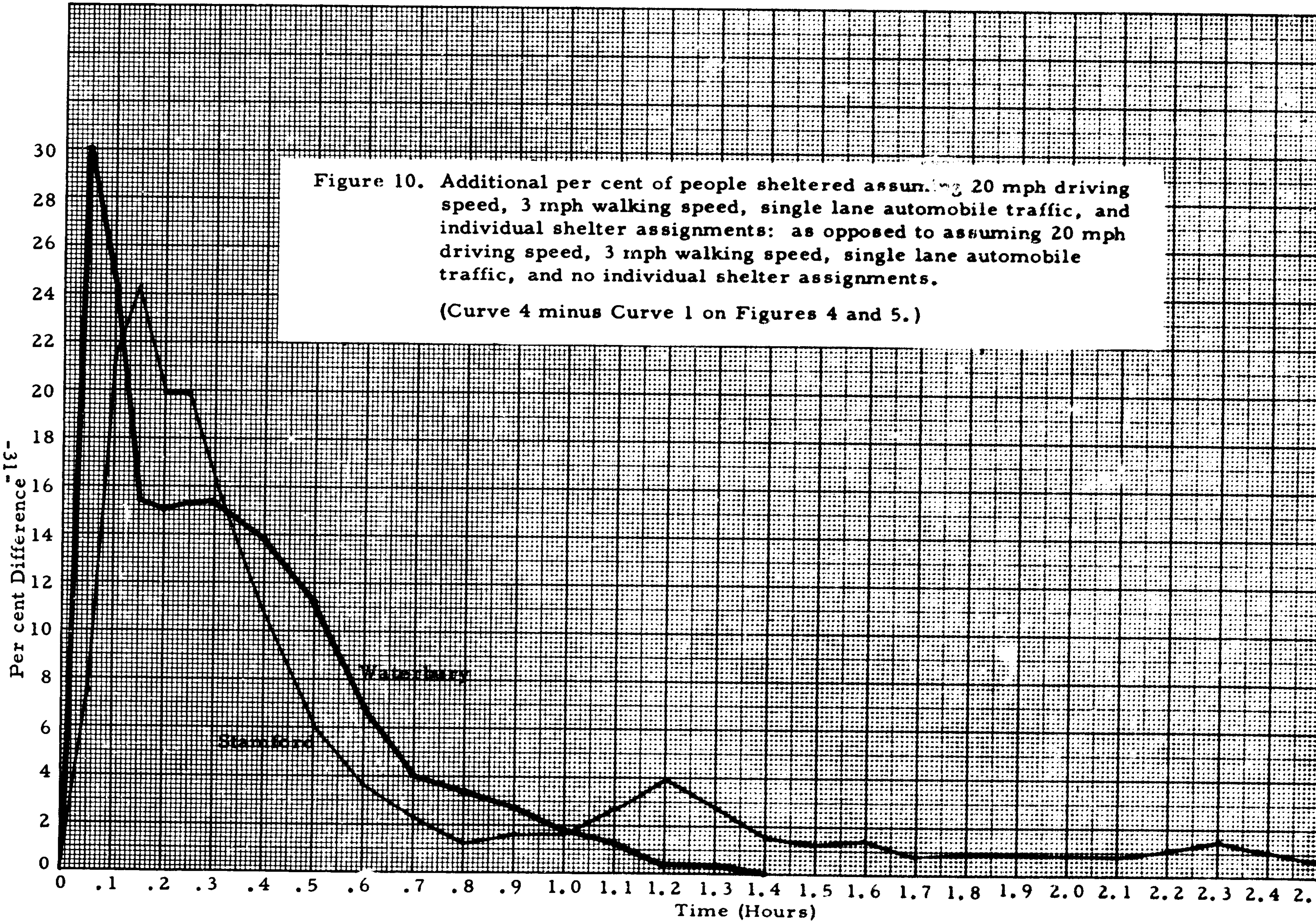


Figure 10. Additional per cent of people sheltered assuming 20 mph driving speed, 3 mph walking speed, single lane automobile traffic, and individual shelter assignments: as opposed to assuming 20 mph driving speed, 3 mph walking speed, single lane automobile traffic, and no individual shelter assignments.

(Curve 4 minus Curve 1 on Figures 4 and 5.)

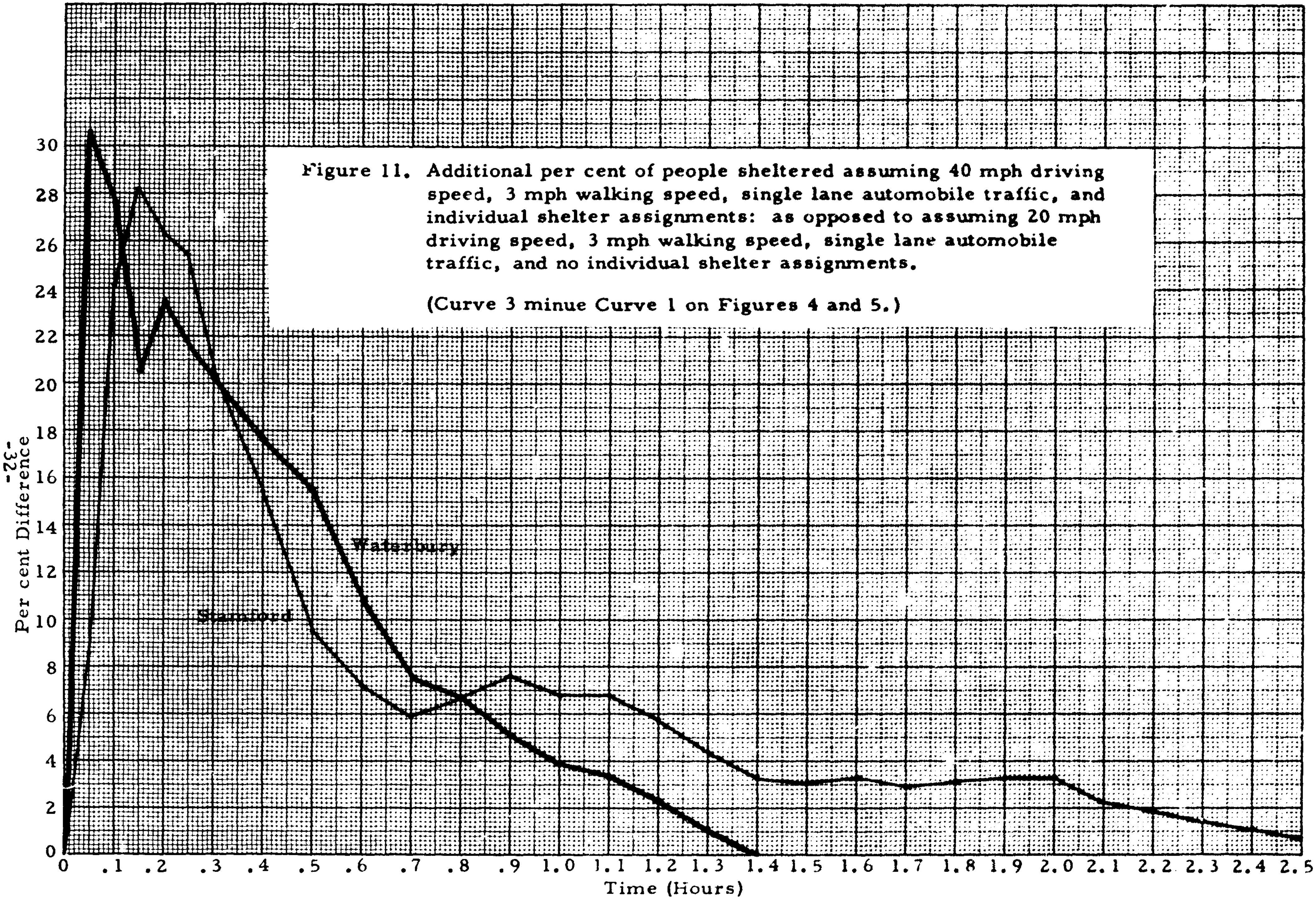


Figure 11. Additional per cent of people sheltered assuming 40 mph driving speed, 3 mph walking speed, single lane automobile traffic, and individual shelter assignments: as opposed to assuming 20 mph driving speed, 3 mph walking speed, single lane automobile traffic, and no individual shelter assignments.

(Curve 3 minue Curve 1 on Figures 4 and 5.)

Instead, movement analysis was carried out on the assumption that shelter assignment would be determined by place of residence. (In Stamford, this would mean that many shelters in the downtown areas would be severely overcrowded, because of the influx of workers from other communities, and would necessitate that more shelters should be provided. They should be located so as to maximize the number of people who can achieve shelter within some time of the order of an hour or so after warning is received. This might mean that some of them would be built in residential areas, so as to reduce movements. Then, at night, some of the downtown shelters would be only poorly utilized.)

The number of people sheltered as a function of time is shown by the curve of Figure 12. This curve was developed with the assumption of perfect warning, and also no time was allowed for preparing to depart for shelters. This would have to be considered in real life. It can be seen from Figure 12 that at the .75 hour point (i.e., the expected arrival of fallout) 105,000 people or about 90% of the daytime population has been sheltered.

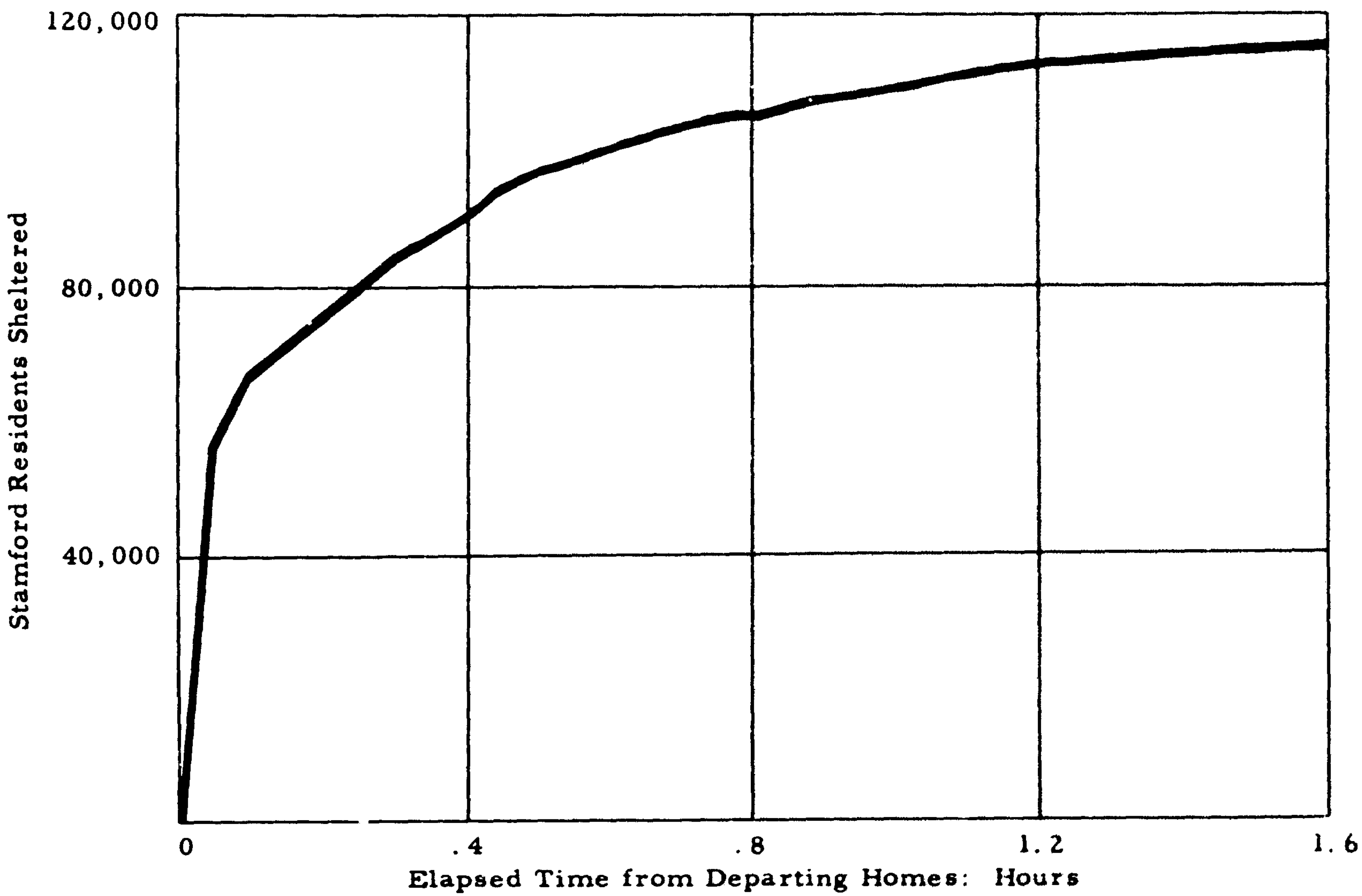


Figure 12. Stamford Residents Sheltered Versus Elapsed Time from Departing Homes (Daytime Population Distribution). 20 mph Driving, 3 mph Walking, One Lane Traffic, No Shelter Assignment.

C. CONCLUSIONS ON TIME NECESSARY TO SHELTER POPULATIONS

The following conclusions are based upon detailed study of two moderate-sized (c. 100,000 population) New England towns. The conclusions apply to both towns, and there is every reason to expect them to apply to a great many others.

1. Assignment of shelterees from the census tract where they live to a census tract (where they will find shelter) can be achieved by a simple linear programming procedure to minimize distance travelled. It leads to the shelter of about 90% of the population within an hour after warning.

2. If there are only just enough shelter spaces for the total population, the last few percent of the population are slow to find shelter, because they have to examine many shelters before they find one with space.

3. Assignment of shelterees to individual shelters is more trouble, but it significantly speeds up the shelter-finding process, particularly where there is little or no excess of shelter spaces.

4. Some broad traffic planning, to avoid blocking roads, or blocking entries to shelters, is undoubtedly valuable. But within these broad limits there is very little value in trying to move traffic faster by increasing speed limits (e.g., 20 mph to 40 mph) or making normally two way streets into one way streets.

5. Unless there is a considerable excess of shelter spaces over persons to be sheltered, an efficient plan of shelter assignment will be different during working and non-working hours, because of difference in distribution of the population. This will naturally lead to some difficulties in training the population. If the city concerned is far from target areas, so that fallout is not likely to arrive for two hours or more, a single shelter assignment plan might be satisfactory for both working and non-working hours.

6. In any event, unless time is unimportant, it will be necessary to plan to inform the population concerning:

- shelters or shelter areas assigned
- routes to shelters, and methods of transportation
- parking and other aspects of traffic control

CHAPTER III.

EFFECTIVENESS OF PLANNING TO PREVENT DESTRUCTION BY FIRE

A. INTRODUCTION

The discussion of fire initiation and spread in the following sections presents a specialized aspect of the subject somewhat different from the mechanisms of ignition and fire spread currently being investigated in other studies. As discussed in the Introduction, the work being carried out at Dunlap and Associates, Inc., is directed towards answering the following two questions: can some substantial benefit be obtained from prior planning of specified civil defense operations? if so, what plans are the most effective in achieving these benefits? The operations considered in these studies are those which must be planned and/or implemented at the local level.

There are two classes of problem, which need to be treated separately. First is the problem close to the ground zero, where, according to weather conditions and height of burst, those surviving the initial detonation will be subjected either to danger from fire, or to danger from fallout, or to both dangers. The planner cannot tell which dangers he must guard against until a time very close to the attack. Second is the problem in areas not subject to direct thermal effects of the detonation. In these areas, the chief danger will be from fallout, but this may be compounded by danger from accidental fires, which could normally be easily controlled. In the conditions of depopulation of buildings, and danger from fallout, this control is likely to prove impossible. If this is so, there is danger of loss of life, because of the need to evacuate fallout shelters which are threatened by fires, and there will be loss of property which will make recovery more difficult. To summarize, then, there are dangers both from primary fires and from secondary fires. The purpose of this chapter is to examine how planning can affect these dangers. Because the spread of fire varies greatly with conditions, and is in any event ill-understood, any conclusions must be regarded as tentative.

B. PRIMARY FIRES

1. The Problem

It was mentioned in Chapter I that any civil defense plan is a contingency plan. In most of the studies discussed in this report there is only one such plan: it is to be put into effect if the contingency occurs; otherwise, it is ignored. In this section, situations are described in which it is reasonable to establish several alternative plans of action and then select the most attractive alternative after the emergency occurs; in other words, these are situations in which it is necessary to "wait to see what happens" before selecting a particular preplanned course of action. In these cases, it is not only important to plan the actions, it is also necessary to plan the operations which will assess the conditions that determine the final decision.

In order to 'tie down' the problem, we may assume a 10 MT weapon, burst at such a height that its fire ball comes in contact with the ground. This weapon, burst over a large urban area, will offer serious hazards of the following kinds:

- blast, very serious within a range of 6 miles from ground zero. (See "Effects of Nuclear Weapons," 1962, Table 12.21; Revised Edition, Reprinted February 1964)

- initial neutron radiation, effective over an area much less than 6 miles in radius

- radiation from fallout, carried down-wind from the burst

- heat radiated by the fire ball. This may be expected to cause second-degree burns and frequent fires out to a radius of about 20 miles. (Ibid., Table 7.44, Fig. 7.47)

- general fire hazards from buildings, etc., ignited by the initial radiation or from fires started by spread of such ignitions

For smaller weapons, these distances will of course be reduced. For example, a 1 MT weapon could cause serious blast effects out to about 3 miles instead of to 6 miles, and numerous fires out to about 7 - 10 miles.

The relationship between these hazards and the distribution of the population is affected by height of burst of the bomb, yield of the bomb, ground zero with respect to the population, and weather. None of these is predictable ahead of time, with any certainty. But once the detonation has occurred, all of the required information on the relationship of hazard to population may become available. If there has been adequate planning, it can conceivably be used to save lives.

2. An Example

We consider a large city attacked by a single 10 MT weapon, burst at such a height as to give fallout, blast, and incendiary effects. A height of 1 mile may be assumed. The relationship of ground zero, city center, limits of built-up areas, and population densities are assumed to be those shown in Figure 13.

3. Population Segments, the Hazards to Which They are Subject, and Possible Ameliorative Measures

(1) The Group Within 6 Miles of Ground Zero

It is not likely that any plan put into effect after the detonation will save significant numbers of these people. They will be in buildings largely destroyed by blast, heavily subject to conflagration, and exposed to fallout within minutes of the detonation. A few may survive, but almost nothing can be done--after the event--to help them. In our example, the people in this area number about 475,000.

(2) The Group Within an Annulus of 6 - 20 Miles Radius, and Within the Fallout Area

The population within this annulus numbers about 400,000. Most of these people will have survived the initial blast, and will now be subjected to two hazards: fallout and fire. If almost all have fallout shelter which has a high enough protection factor, and is also not threatened by fire, then there is no serious problem. But, in the present state of civil defense, this is not likely; many fallout shelters may have to be evacuated.

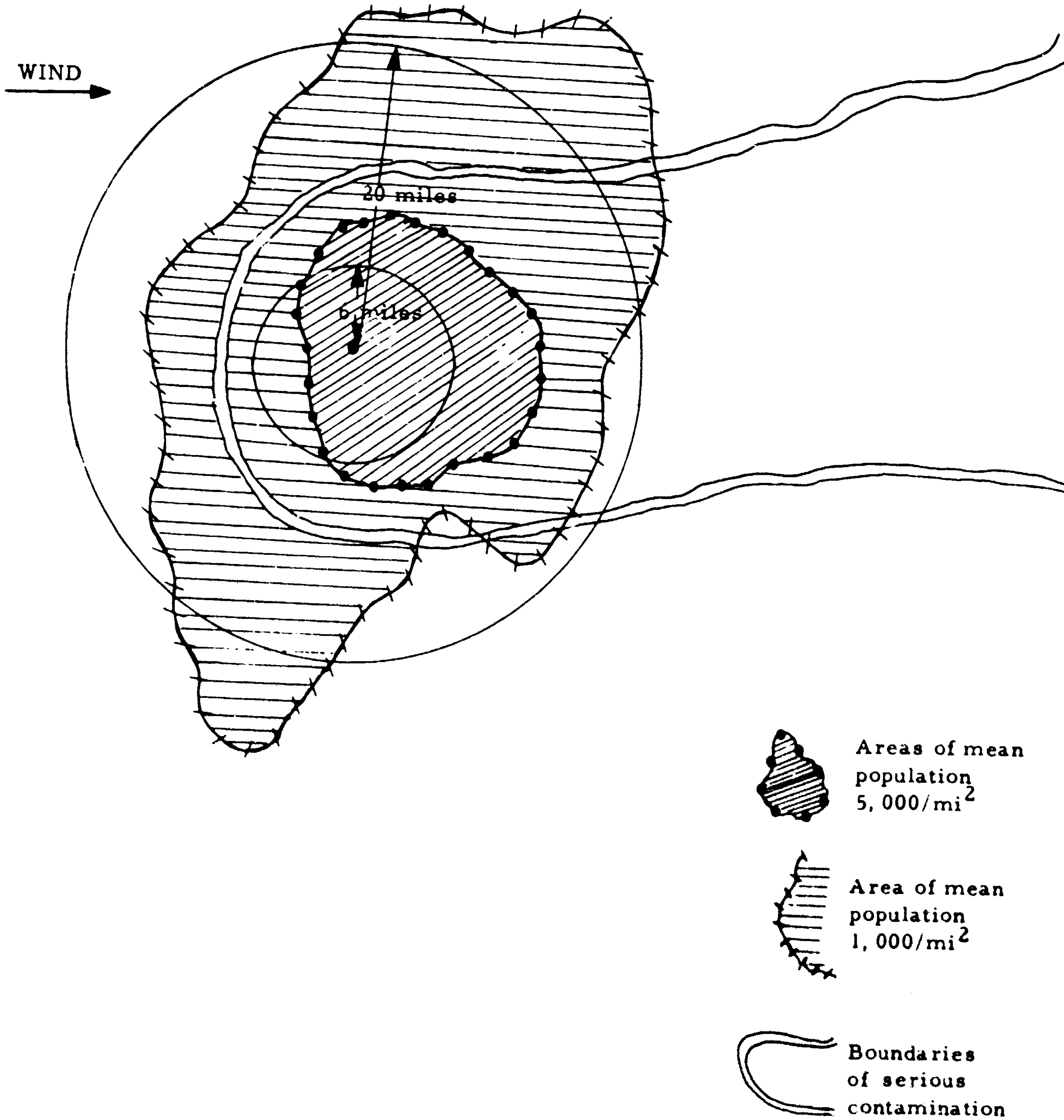

WIND
20 miles
6 miles
Areas of mean population 5,000/mi²
Area of mean population 1,000/mi²
Boundaries of serious contamination

Figure 13

Those who should be evacuated are those who are either in fallout shelter of substandard protection factor, or those who are in shelter susceptible to fire hazards. Because of the distances involved in evacuation, it is unlikely that all who need to be removed will be evacuated. However, if those at the edges of the fallout area were able to be directed to run across-wind (they might have to be told in which direction that was) they might be able to move one or two miles before being seriously endangered by fallout. (Distance will depend upon many factors, of which the chief may be wind speed.) The proportion evacuable may thus be of the order of 20% (two strips, each 2 miles wide, in a strip 20 miles wide). If half of these had shelter inadequate against fallout or fire, we might expect to be able to save of the order of an extra 10% of the 400,000 inhabitants by preplanned, well-organized evacuative measures. These must necessarily wait until after the detonation to be chosen and put into effect.

(3) The Group Unaffected by Fallout, But in Danger from Fire

This group numbers about 90,000 people in our example. Under a single contingency plan, they will all take shelter, in order to protect themselves from fallout which will not arrive. In so doing, they will expose themselves to danger of fire, and will fail to save, from the spread of fire, property which might be of inestimable value to them in the post-attack period. A system which would inform them that the wind direction and ground zero had combined to protect them from fallout might save many lives--perhaps 25% of the lives--and some property--again, perhaps 25% of it. These, of course, are very gross guesses.

4. Discussion: Totals Saved with Single and Multiple Contingency Plans

By a single contingency plan, we imply one aimed at getting the population into shelter as soon as there is expectation of immediate attack, or an attack has occurred. By multiple contingency plans, we imply that population will be got into shelter, as in the single plan, but that a set of plans will also be made to deal with the varying hazards from fallout and fire, once the nature of the weapon, the ground zero, and the ballistic wind are known.

In the example discussed above, the relative merits of the two types of planning appear in the following Table 9, which shows vary approximately, the numbers and percentages of lives which might be saved in the two situations.

TABLE 9

Lives saved with single and multiple contingency plans.

	Single Plan	Multiple Plans
Population Group (a)	few	few
(b)	200,000	240,000
(c)	45,000 (?)	67,000 (?)
Total	245,000 +	307,000 +

Percentage increase, due to multiple plans, perhaps about 25%.

These are significant increases, which would cost large sums of money to obtain by any other means. To obtain them will demand multiple not single, contingency plans, and information and communication systems which will allow a sensible choice between the multiple plans and allow this choice to be communicated to the population. The information to be obtained will include:

- presence or absence of fallout
- predicted fallout pattern, if any
- areas expected to be involved in conflagration

The directions to be sent out would need to include little more than:

- stay put in shelter, or
- evacuate, in a specified direction

They would have to be addressed to specific (large) geographical areas of the community.

5. Further Work

The above example has been confined to a single, over-simplified and purely hypothetical area. Savings should be estimated for many actual areas, where the weather, height of burst, and ground zero are carefully sampled. Actual population densities, expected conflagrations, and shelter availabilities should be used. Realistic estimates could then be made of savings possible, and of the plans which would have to be made to achieve these savings (including planning for communication).

C. SECONDARY FIRES

1. Definition

Secondary fires, for present purposes, are defined as those which do not result directly from heat radiated by the fire ball, nor spread from fires so generated. Rather, they are those fires which are due to accident or natural causes, and whose incidence or whose danger is affected by the fact that normal life has been disrupted by the attack. Concern is directed chiefly to the types of fire which may start and become important in residential districts, rather than fires which commence due to the shutdown or desertion of specialized facilities such as power complexes, chemical plants, etc. These are topics for more specialized study.

Even when fires due to these special hazards are excluded, there remains a large number of possible sources of fire in individual homes, stores, miscellaneous business establishments, etc., and the possibility of uncontrolled spread make fires from these sources as potentially disastrous as those from the primary ones. As a consequence, it is clear that these prima facie considerations indicate that the planning of operations which may help to reduce this hazard is a subject which is appropriate to the scope and intent of the Dunlap and Associates, Inc., studies of civil defense planning.

2. Approach to the Problem

The primary problems are developing estimates of the likelihood that fires of the type described will start, the extent to which they will spread, the consequences which may ensue, and what might be done to limit damage. Reference to the literature and consultation with experts has shown that information on each of these topics is incomplete, and that there are no definitive answers to direct questions about what is likely to happen in given circumstances. However, there is an alternative approach to the question of planning effectiveness which is basic to this discussion though not to the problem as a whole. This consists of describing the situation parametrically to determine the conditions under which planning may be effective and the nature of the additional information needed to develop useful operational procedures. Accordingly, the following sections present an example of such a parametric formulation. It makes no strong pretense to being an accurate representation of the physical processes involved nor to completeness; it is merely an example of the fact that even a very rough approximation may be useful in clarifying some of the questions involved in determining the effectiveness of planning operations which may reduce the hazards described in Section 1. It is offered in the hope the individuals familiar with the results of more expert investigations of these phenomena will suggest appropriate alternative formulations or modifications of the one described.

3. Initial Assumptions

The areas being considered will be subject to fallout but not to direct thermal or blast effects. These areas will be depopulated for periods ranging from several hours to several weeks with primary interest centering on depopulations which last about 10 days. The causes of fire being considered are those which exist normally in every home and work area, i.e., those associated with electrical appliances, heating systems, spontaneous combustion, electrical storms, etc. Specialized hazards such as oil refineries, or combustible gas storage and distribution systems, are not of direct interest. The operations of interest are those which reduce either the likelihood that such fires will start, or the likelihood that they will spread. Typical examples are inspections before taking shelter, public education and instruction about special precautions to be taken before taking shelter, rapid re-enforcement of existing barriers to fire spread, setting up remotely controlled water spreading or blasting systems, etc. There is a large range of variation in both the cost and effectiveness of such measures.

The formal analytical structure is suggested by the concept that the "accidents" which cause the fires under consideration are events distributed randomly in time; in a very large number of practical instances such events obey Poisson distributions. As is pointed out in Feller[1], the observed distributions for such events can be derived from the assumption that the probability that the random event will occur in a given time interval is proportional to the magnitude of the interval. Fire-causing accidents in normally populated areas probably obey this assumption very closely if the constant of proportionality is adjusted to certain recognized seasonable variations. Its extension to depopulated areas is probably valid for some initial period. Modifications of this initial assumption are introduced at the appropriate points in the later discussion.

[1] Feller, William. An introduction to probability theory and its applications, Vol I. John Wiley and Sons, New York, 1950. In particular, see Chapter 17.

It also appears reasonable to characterize fire spread as a sequence of random events, as suggested, for example by Willis et al[1]. However, even if such an assumption is valid, it will only hold for some finite homogeneous area, probably definable in terms of fuel densities. Water fronts, open fields, etc., would be typical boundaries for such areas.

4. Analytical Results

A detailed description of the development of an analytic model from these assumptions is presented in Appendix 7. The principal results of this development are as follows.

The model provides a way of estimating the probability that certain events will occur in a cluster. This is an entity suggested by the historical observation that even when fires are uncontrolled, the damage is confined to a finite region. Some boundaries for such a region are determined by the natural absence of fuel, e.g., a large body of water. Other boundaries are determined by happenstance, e.g., wind drives a fire in one direction, and the burned region is a barrier to further spread, if the wind direction changes. Thus, we know that the fires in depopulated areas will be confined to some collection of buildings and other structures which we have labeled a "cluster," with the understanding that the problem of specifying the boundaries of the cluster is yet to be resolved.

Three basic conditions or "states" of the cluster are distinguished.

State 0: no fire has occurred
State 1: cluster is burning
State 2: fire burned out

We identify "zero time" as the moment at which depopulation "occurs," and assume that the cluster is in state 0 (no fire) at this instant. We label the probability that the cluster is in any one of the three possible states "t" time units later $P_0(t)$, $P_1(t)$, and $P_2(t)$ respectively. The analytic expressions are:

1 Willis, K. E., Brooks, E. R., and Dow, L. J. Crash civil defense program study. Research Triangle Institute, Operations Research Division, Final Report R-85-1. April 30, 1963. In particular, see Appendix D, page D-6, 7.

(1) $$P_0(t) = e^{-at}$$

(2) $$P_1(t) = \frac{a}{b-a}\left[e^{-at} - e^{-bt}\right]$$

(3) $$P_2(t) = 1 - \frac{1}{b-a}\left[be^{-at} - ae^{-bt}\right]$$

In these equations, the constant "a" can be interpreted as the reciprocal of the mean time between accidental fires, or equivalently, as the average rate at which fires occur. Similarly, "b" is the reciprocal of the average time between ignition and burnout in the cluster. If we do not specify the time units for the moment, we can arbitrarily select b = 1 and plot P_0, P_1, and P_2 for various values of a. This has been done in Figure 14.

5. Discussion of Results

Qualitatively, the results shown in Figure 14 agree with what might be expected intuitively. As time advances, the probability that a fire will start at some point in the cluster increases. If we were to adjust the model further, we would probably seek some form in which P_0, the probability of no fires, approaches some small constant value rather than zero, and this is easily achieved.

The curves provide a useful qualitative indication of the nature of the effort required to reduce the hazard of accidental fire destruction of depopulated areas. If the area is really depopulated, we cannot alter the value of b. For illustrative purposes, let us assume it is about five days. Then one time unit in the figure is also five days. In this case, we could then conclude:

a. If the mean time between ignitions is 2.5 days (a = 2), then at the end of ten days, the probability of no fire is negligibly small, the probability that the cluster is still burning is 0.23, and the probability that it is already burned out is 0.77.

b. If the mean time between ignitions is 5 days (a = 1), the probabilities at the end of ten days are P_0 = 0.13, P_1 = 0.27, and P_2 = 0.60 Thus, halving the likelihood of ignition does not halve the probability of finding the cluster on fire at the end of ten days; however, the probability that the cluster is burned out is reduced while the probability that no fire has started is correspondingly enhanced.

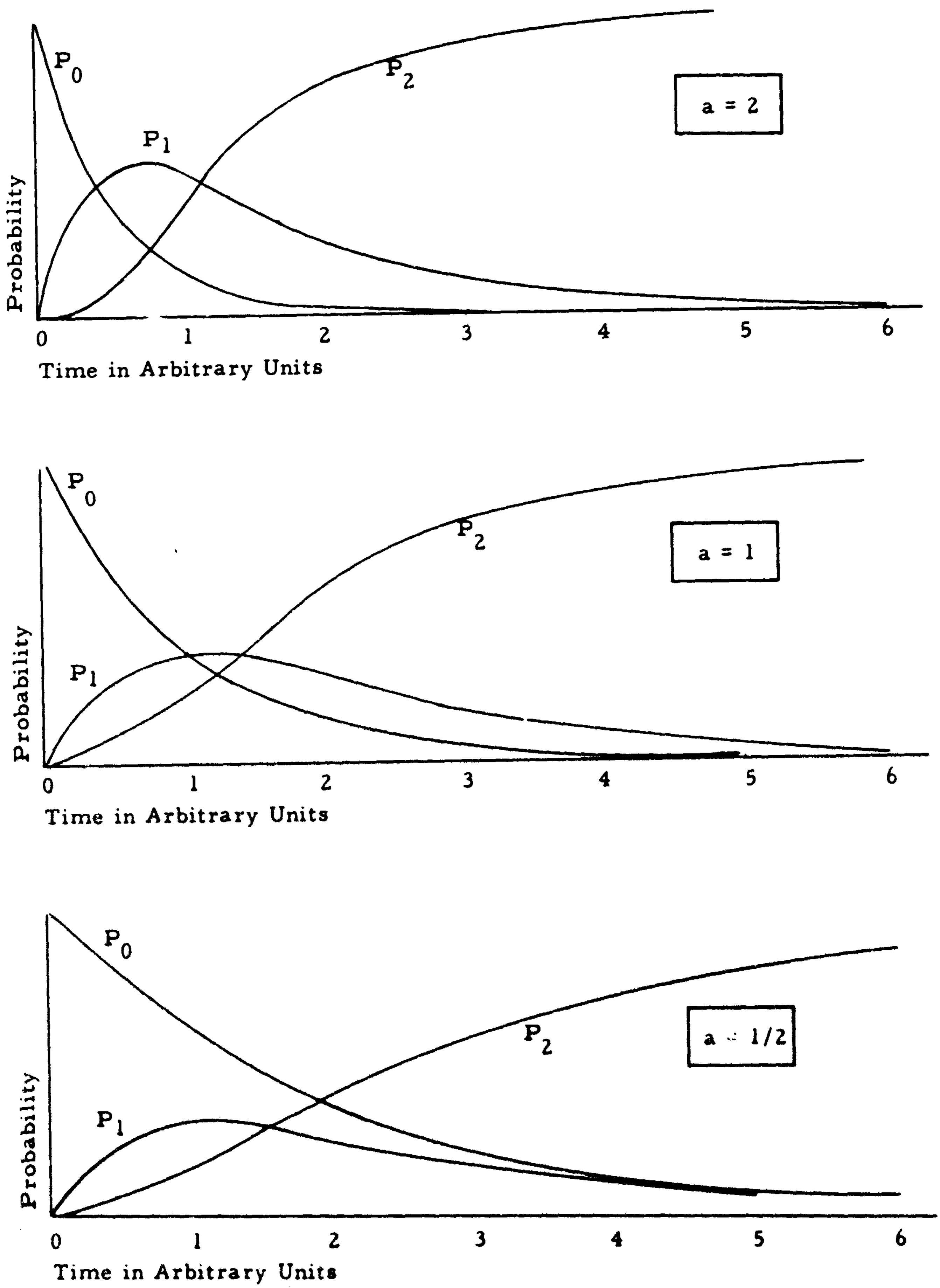


Figure 14. State Probabilities When b = 1.

c. If the mean time between ignitions is ten days (a = 0.5), then at the end of ten days, P_0 and P_2 are both about 0.37, and P_1 is about 0.25. We note that although the initial likelihood of ignition has been halved again, the probability of finding the cluster burning is about the same. However, the probability of finding it unburned completely is increased and the probability of finding it burned out correspondingly decreased.

We make no claim for the validity of these numerical illustrations. They are quoted merely to show that if the general mechanism postulated here is correct, the problem of preventing fires in depopulated regions is a rather difficult one if tackled purely in terms of reducing the initial incidence rate. In the example, even a fourfold decrease in incidence probability raised the probability of no fire from essentially zero to merely 0.37.

This suggests that we should also investigate the possibility of changing the value of b. The model as described up to this point, however, is not adequate for a description of the results of these measures. To investigate this, we change our definition of a cluster so that it becomes a geographical entity contiguous to other clusters. Then it is capable of igniting these other clusters or of being ignited by them. Appendix 7 illustrates how this analysis can be set up, but there was no time available for more detailed exploration of this aspect of the subject.

6. The Feasibility of Fire Prevention

(1) Planning for Fire Prevention

Accepting for the moment that fire prevention in depopulated areas is an appropriate activity for civil defense planning, the remaining question of interest is the feasibility of devising suitable plans. To demonstrate this, it is sufficient to demonstrate that there is at least one plan which can produce useful results; this can then be used as a basis for evaluating alternative plans as they are devised. One reasonable class of plan to prevent fires might be the following. At the sounding of the alert, certain designated people should physically inspect premises as they are evacuated. The inspection might consist of: extinguishing open fires of all kinds (e.g., trash, those in fireplaces, and those in heating and cooking apparatus); extinguishing cigarettes; turning off electrical supply; stopping internal combustion engines; etc. An indication of the feasibility of such an operation is derived in the following section.

(2) Model

In the operation indicated above, the important parameters are:

time interval between warning and arrival of fallout during which fire wardens may safely operate	w minutes
rate at which spaces can be inspected. In a residential area, this might be rooms/minute	i rooms/minute
number of spaces to be inspected	r rooms
number of fire wardens	n fire wardens
size of population from which fire wardens might be selected (e.g., adult males of good character)	N adult males

The number of spaces to be inspected in a residential area is evidently related to population of the area, and hence to N. For initial computations, assume that there are four rooms/spaces per adult male. Thus:

(4) $r = 4N$

The number of wardens needed is related to number of rooms and warning time and inspection rate as follows:

(5) $n = r/w \cdot i$

From eqs. (4) and (5), the proportion of adult males, who would have to be fire wardens, in order to inspect all spaces within the time available:

(6) $p = n/N = 4/w \cdot i$

Figure 15 shows the results of computing p for inspection rates of 2 rooms/minute, 1 room/minute, 1 room/2 minutes, 1 room/4 minutes, and 1 room/8 minutes, for intervals between warning and arrival of fallout ranging from 10 to 1,000 minutes.

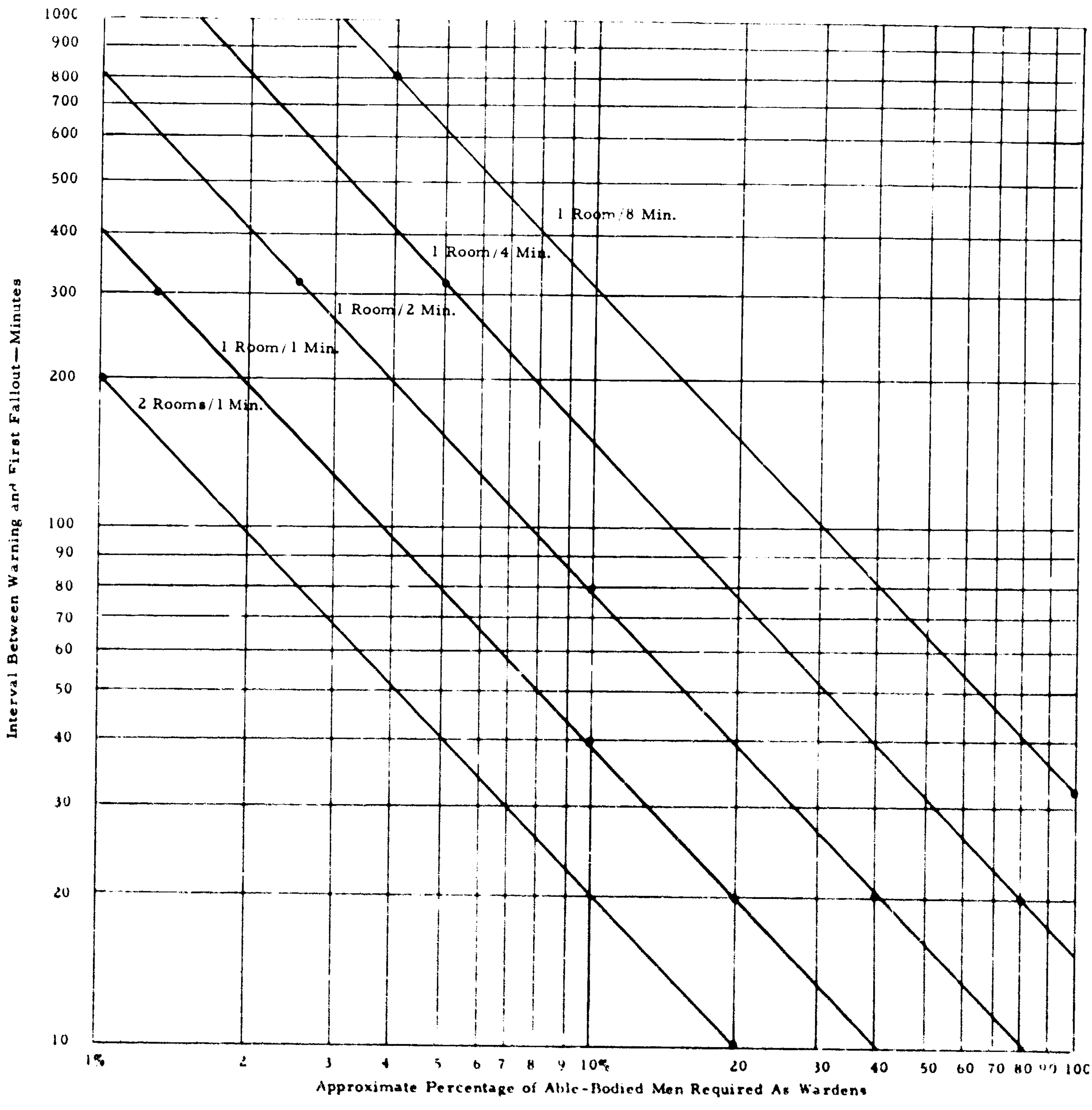


Figure 15. Warden Corps Size As a Function of Warning Time

(3) Discussion

If we are going to assume 10 or 20 MT bombs, then places with fallout arrival times of less than 30 minutes will generally have far more fires to cope with than little accidental ones; there will be substantial primary fires under many circumstances. Thus, we can reasonably ignore all w's of less than 30 minutes.

With training, it is reasonably certain that i would lie between 2 rooms/minute and 1 room/2 minutes.

In some places, serious fallout necessitating shelter for several days may take as long as 300 minutes to arrive after the warning; perhaps even longer, though, in general, the longer w is, the shorter the shelter-stay is. There are many areas in the country which could reasonably expect that they would almost never have a w less than 100 minutes, and even many where w could hardly be less than 200 minutes.

The proportion of able-bodied adult males who would have to be trained as wardens might vary between 25% and 1% (depending on (a) location with respect to targets, and (b) figures for i, which can be derived experimentally); and seem likely to be around 5%. For example, the home of one of the authors is on a street such that 5% of the adult males (i.e., two of them) could easily check the whole street within half an hour to an hour.

If further study confirms the general correctness of this preliminary analysis, then it is clearly both practicable and advisable to plan for a fire warden system. Such a system could also have other functions (prevention of looting, for example), and would necessitate certain other plans (uniforms, training, prediction of arrival of fallout, communications, and the like) which ought to be examined in future studies.

7. Conclusions

This chapter describes work in progress on fire hazards rather than a completed study since the exigencies of yearly contracting made it impossible to progress beyond the point reported. The only conclusion which can be supported at this stage is that this is a problem which warrants further investigation along the lines indicated in the preceding sections.

The statistical analysis of ignition provides an intuitively satisfactory way of determining the probability of accidental fires in depopulated regions, and this probability, in turn, is a satisfactory measure of the effectiveness of various possible plans for reducing this hazard. Additional study can provide the missing link; namely, an estimate of the probability that an inspection will actually remove the cause of a potential accident. Additional study will also uncover alternate plans, including those designed to prevent fire spread as well as accidental ignition.

CHAPTER IV.

GENERAL CONCLUSIONS

The general conclusions which may be drawn from this study cover two major areas: taking shelter to protect a population from fallout, and protection from the effects of fire and fallout combined. Only the former was fully treated within the resources of the study. Thus, conclusions on protection from fire are to be taken as very tentative.

A. TAKING SHELTER FOR FALLOUT PROTECTION

The following conclusions are based upon careful study of two New England towns, one inland and the other on the coast, neither of which is likely to be a prime target, but in both of which fallout could be very hazardous.

1. To ensure thorough warning of the population, during working hours, it seems worthwhile to supplement the standard warnings (sirens, NEAR, radio, and television) by direct telephone calls to major places of business.

2. When ample shelter spaces for the population exist, and/or when a period of hours may be expected to elapse between warning and the arrival of fallout, shelter assignments may be made on a basis of census tracts. That is, people living in a census tract with an excess of population over shelter spaces can be directed to census tracts with an excess of shelter spaces over population. A simple linear program, minimizing distance travelled, proved adequate. On the other hand, if shelter spaces do not considerably exceed shelter needs, or if the city being considered is so disposed with respect to probable target areas that fallout might well arrive in an hour or so, individual shelter assignments will be desirable. These individual assignments greatly reduce the time which late arrivals at shelters take in finding a shelter which has room for them.

3. Traffic planning should encompass measures to make parking near shelters easy and fast, without blocking later arrivals. Travel over short distances should be on foot, but automobiles may be used in getting to the center (where excess shelters are generally found) from outlying areas.

It makes little difference to rate of sheltering to arrange for special one-way streets, or very fast driving, provided traffic blocks at intersections are prevented.

4. In both towns studied, quite simple plans were capable of getting 90% of the population into shelter within an hour of the warning being given.

B. COMBINED HAZARDS OF FALLOUT AND FIRE

Fire hazards may combine with hazard from fallout in two sorts of situation. The first is in the target area itself, where heavy and immediate radiation hazards, in areas determined by bomb burst and wind, may be combined with major conflagrations. The second is in areas in which the normally-expected hazard is from fallout alone, but in which accidental fires may start, and then spread, probably endangering shelterees and certainly destroying property.

In target areas, it is conceivable that a set of alternative plans could be developed which would save more lives than any single plan could, because they would take advantage of information showing, for each of several sub-areas, whether the main threat was from fallout (requiring shelter) or fire (requiring the evacuation of buildings or of whole areas). A simple example shows that such sets of alternative plans indeed have possible good effects, but much more work is required to explore the matter and reach sound conclusions.

In non-target areas, in which fallout is not likely to arrive until at least thirty minutes after the warning, analysis shows that a system of fire wardens, who would inspect buildings as they were evacuated and reduce the chance that accidental fires would occur, is indeed feasible. Far too little, however, is known either about the probable rate at which fires will start, or the speed with which they will spread, to be sure that such a system would be worthwhile.