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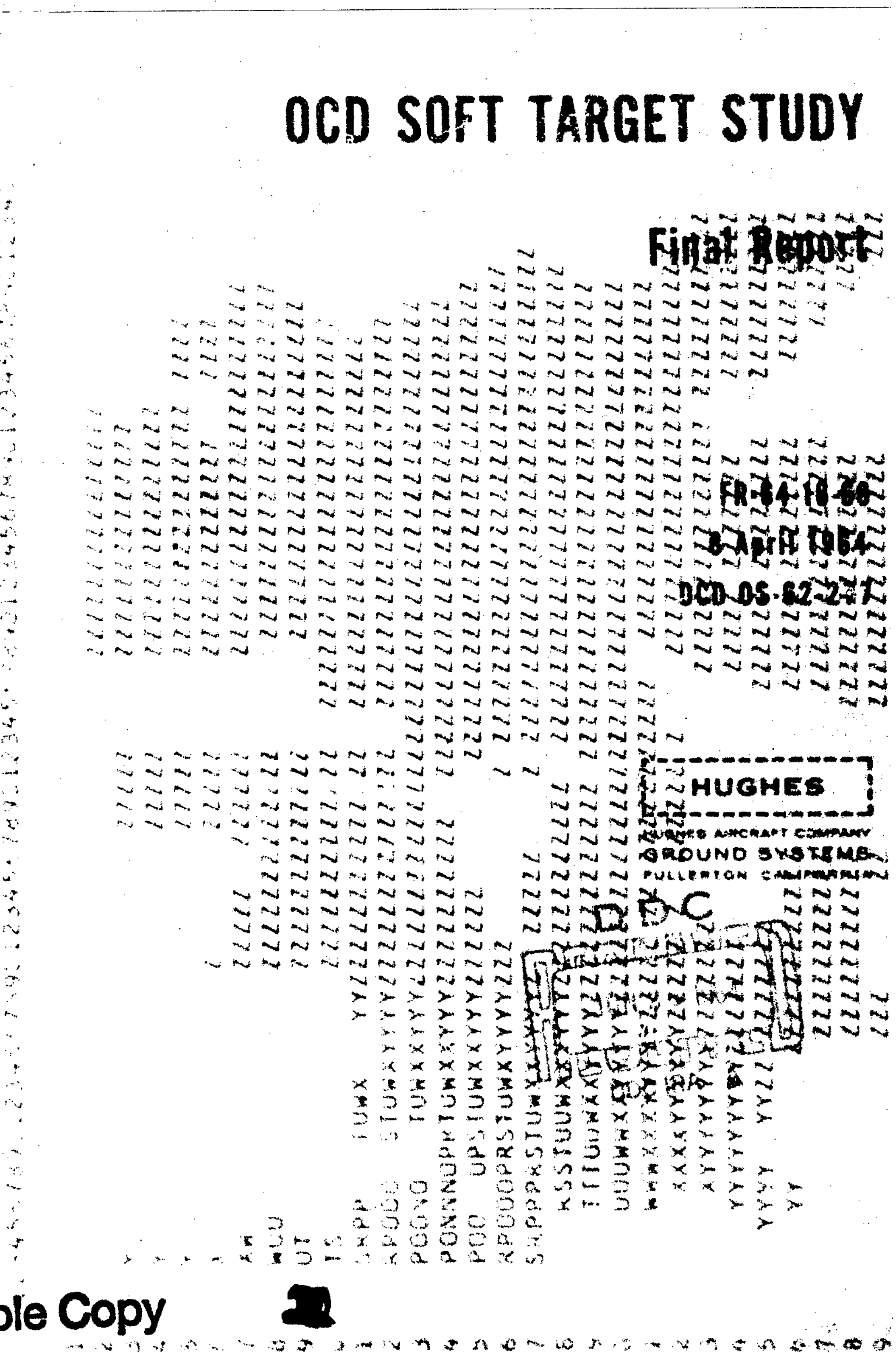
OCD SOFT TARGET STUDY

Final Report



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8 April 1964

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HUGHES
HUGHES AIRCRAFT COMPANY
GROUND SYSTEMS
FULLERTON CALIFORNIA

DDC

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OCD Soft Target Study

Final Report

FR-64-16-66
8 April 1964

Prepared for the Office of Civil Defense
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OCD REVIEW NOTICE

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.

HUGHES
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GROUND SYSTEMS
FULLERTON, CALIFORNIA

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LIST OF CONTRIBUTORS

Bogue, P. N.
Clemann, J. W.
Curtis, G. B.
Dibrell, R. A. Jr.
Fabrè, F. J.
Mahood, R. K.
Mc Kinney, N.
Pai, J. W.
Smith, D. L.
Wendland, D. E.
Wilt, M. L.
Zakich, D.

ABSTRACT

The objective of the OCD Soft Target Study includes developing procedures and methodology for studying patterns of attack, for evaluating local hazards, for determining potential civil defense countermeasures for cities closely associated with soft military targets and for computing the cost effectiveness of alternate systems of protection.

This report describes methodology and original computer programs which have been developed to assist in the accomplishment of the study objective. Two computer programs are emphasized. The "Dynamic Analyzer" program calculates the effectiveness of specified shelter systems in protecting the population from particular attacks. Population mobility and fallout fields which depend on both time and position are considered. The "Weighted-Strategy, Multiple Shelter Type Mix and Location Optimizer" computes the optimal effectiveness versus cost curve over the range from zero cost to the cost of the most effective system possible with a given shelter catalog. This program also determines the mix and deployment of shelters at desired cost/effectiveness levels.

Soft Target Study activity has shown that there is a difference in the intensity and relative intensity of the different weapon effects for cities near soft and hard targets. However, all weapon effects need to be considered for both cases. The significance of this fact is that the procedures developed under the Soft Target Study may be applied to the study of Civil Defense countermeasures for cities in any targeting situation.

INTRODUCTION

The objective of the OCD Soft Target Study includes developing procedures and methodology for studying patterns of attack, for evaluating local hazards, for determining potential civil defense countermeasures for cities closely associated with soft military targets and for computing the cost effectiveness of alternate systems of protection. The work was considered to be a pilot study, and the methodology developed was to be demonstrated using a particular locale. It is clear that the success of the study depended in large part on the utility of the procedures devised for considering the soft target problem.

Since cost effectiveness was to be the end product of the computations, the most important characteristic of the methodology to be developed was that it would consist of means of efficiently arriving at systems of protection of good cost effectiveness. The literature relating to Civil Defense, casualty estimation, damage assessment and related subjects contains descriptions of procedures for computing the effectiveness of target value distributions in withstanding the effects of particular attacks. These procedures could be used to compute the effectiveness of many systems of protection against all reasonable attack patterns. The most promising designs could then be refined and modified as indicated by the preliminary results and reanalyzed. This process might be repeated until the desired result was obtained. Such a procedure is described in Ref. 1.*

The repeated use of a damage assessment model would have been an economically feasible means of computing the cost effectiveness of alternate systems of protection for the Soft Target Study locale. It would not, however, have represented a pilot study solution to the soft

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* Office of Civil Defense working paper, Systems Analysis in Civil Defense, Parts I and II, John F. Devaney, Systems Evaluation Division, Research Directorate, Office of Civil Defense, August 1963. (Reference 1)

target problem. While the study tends to reveal the nature of the problem, it is not to be expected that other soft target situations would involve the same relative distributions of aimpoints and population. The previous results could be used to reduce the work involved in performing the number of studies required for an effective national program but would not eliminate the essential problem.

The approach here taken involves the initial machine computation of some kind of mathematically optimum solution. The solution is based on reasonably detailed information of a kind which can easily be obtained from national targeting estimates, census reports, local Civil Defense officials and persons familiar with local construction costs. The procedures do not, of course, produce detailed plans of a kind which might be considered for acceptance in some local situation. In particular, they comply with a recommendation of the Ref. 1 paper by not considering political implications of possible government decisions regarding any of the countermeasure systems generated by the procedure. They should, however, produce results useful in devising detailed local plans. The essential features of the modified plans could then be used as inputs to a straightforward analysis procedure to compute the effectiveness and cost effectiveness of the plan. We are aware of no previous attempt to automatically optimize Civil Defense countermeasure systems and our work on this aspect of the problem is considered to be a potentially important contribution of the Soft Target Study to the existing body of Civil Defense knowledge.

Another problem consideration is the total cost for which a particular Civil Defense system should be designed. Ref. 1 states that the systems analyst would properly make recommendations as to the distribution of investment among the various parts of the system but should do this as a function of alternative levels of effort. Given a procedure based on the repeated use of an analyzer, this adds another dimension to the problem. The automatic optimizing procedure herein described has been mechanized by first selecting the shelter type and location which results in the best cost effectiveness obtainable. Considered as a system, this shelter might have low cost and low effectiveness. The program continues by successively assigning and reassigning potential shelters until the system of the best possible effectiveness has been achieved. This system might be characterized by high cost and poor cost effectiveness. Each cycle of program operation involves some increasing total system cost and the corresponding system consists of a shelter mix and deployment yielding the highest effectiveness at that total cost. The program could be used to generate a possible optimum design for some specified cost level but this would involve generating and discarding the systems for all lower cost levels since these optimal systems are a necessary by-product of the computational process. From this point of view, devising potential optimal system designs as a function of total level of effort is not a problem complicating factor but something which would be done even if it were not required.

Another characteristic of the required methodology is that it must involve a representation of the locale in sufficient detail to produce results as accurate as the problem uncertainties and to be recognizable to those developing the local plan. A bivariate normal representation of the population distribution, for example, can be used for many analysis purposes. It is not likely to satisfy the needs of a passive defense system designer devising a local plan, however. The alternative is to divide the locale into many cells, the size of which is the resolution of the locale representation. The procedure which seems to be most widely used at present is to divide the area into arbitrarily shaped cells which in some way reflect local conditions. We have chosen to employ a matrix of geometrically related rectangles.

There is an interesting discussion of this subject in Ref. 2.* This report describes a tactical evacuation model based on the arbitrary cell system of describing the population distribution and its relation to the network of streets and highways. The major damage assessment procedures of which we are aware also employ the arbitrary cell method. While the rationale of the designers of these procedures is not known, it may have been similar to the Ref. 2 comments. Other factors, such as a large area of interest, limited fast access computer memory and a desire to directly employ census data, certainly contributed.

We did not choose to divide the area of interest into small rectangles (called artificial cells in Ref. 2) because it was easier, which it was not. The easier procedure would have been to use census tracts, or subdivided census tracts, the characteristics of which could be easily listed. We went to some trouble, even to the extent of devising computer programs to assist in the preparation of data, because the result seemed to be worth the effort. For our purposes, both procedures could have been made to work. We also appreciate that a form of rectangular element data (or a blend of diverse element shapes) could be used as input data to an arbitrary cell model. This argument, however, misses the point of using geometrically related population distribution elements.

The reason for the use of rectangular elements is to establish a correspondence between the computer memory and the real world. The values of the incremental cells are considered to be an array or matrix. If the indexing of the array with respect to a map and the array scale factor are known, it is not necessary to store the two position coordinates of each tract since the position of the record in memory provides the same information. This has the effect of greatly reducing the amount of stored data required. Corresponding to each tract of no value, however,

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* AIM 64-T-4, Tactical Evacuation Study Summary Report; Painter, Bialek and Sklarsky, November 1963, Academy for Interscience Methodology, Museum of Science and Industry, Chicago, Illinois 60637. (Reference 2)

a zero must be stored in memory to keep the value distribution correct. For some purposes, where spatial relationships are not important, we have achieved even greater computer memory economy by eliminating the zero records. This produces a compressed, distorted computer map of the real world which, however, contains the correct record values. The map is subsequently restored by comparing the records to the elements of a binary population distribution array which indicates where the zero records should be inserted.

Computer running time is perhaps an even better argument than computer memory conservation for the use of geometrically related elements. One might, for example, desire to compute blast casualties associated with some weapon impact point. A reasonable procedure would be to compute a radius beyond which casualties would not occur. If geometrically related elements were used, the computer could directly read the population of each element within this radius. More detailed computations would then be made for these elements. If arbitrary elements were used, the computer would examine each record in a list, read the position coordinates, compute the distance to the impact point, compare the distance to the lethal radius and decide whether detailed casualty computations were required. It would, of course, be possible to order the arbitrary element records, say by latitude and longitude intervals, and thereby avoid testing every record in the population distribution representations. This would, however, be similar to converting the arbitrary cell records to geometrically related elements.

It is clear that it would be possible to write a routine which would convert arbitrary cell type tract records to matrix type bookkeeping. Each element of the target array would first be set to zero. The computer would then scan the tract record list. For each tract, the track location coordinates would be converted to matrix i, j numbers by dividing by the scale and rounding. The target value would then be added to the proper matrix magnitude.

It would also be possible to write a program which would convert target data in matrix form to arbitrary cell type tract records. The routine would scan the entire matrix. For each non-zero element, the program would write a tract record giving the incremental area value and the location coordinates which would be computed as the product of the scale factor and i and j.

If arbitrary cell type tract records were converted to matrix form and then back to the arbitrary cell type again by the routines described above, the final records would not be exactly the same as the originals. Some of the records might be combined and the location coordinates might be changed by an amount less than half of the matrix scale factor. They would be operationally equivalent, however, if the incremental areas and matrix scale factors were properly chosen.

While the two kinds of tract records may be converted back and forth and the shape of some, or all, of arbitrary cell elements may be rectangular, the data processing programs which operate on the population distribution representation must be of one type or the other. If a program allows for the possibility that the tract elements are not geometrically related, it is an arbitrary cell type program and the advantages of requiring that the elements be geometrically related are lost. If the program exploits the properties of geometrically related elements, it is an artificial cell program and can not be used with arbitrary cell data.

An optimizing program would be expected to contain some kind of analyzing sub-model which would be continually re-evaluated while approaching the desired optimum. Since the analyzing sub-model required here would involve weapon effects, a necessary characteristic of the methodology used is that it permit the rapid application of weapon effects to the population distribution tracts. This was an important factor in the choice of geometrically related elements for the population distribution representation.

A possibly unique feature of the methodology here described is the use of a weapon effects matrix of the same scale factor as the target array. A simple example of the use of this concept is the computation of blast damage associated with a given DGZ. For this problem a square matrix would be used with an odd number of rows and columns. The center element is the DGZ. The value of each element of the matrix is the probability of target value kill for an element at that distance from the DGZ. The center element of the weapon array is then indexed to the DGZ element of the target array. Each element of the target array which has a corresponding element in the weapon array is reduced by the fraction indicated by the corresponding element of the weapon array. With this system it does not matter how complicated the weapons effect function is since it is only used to compute the weapons effects array and this operation need be performed but once. Model running time is therefore essentially independent of the weapons effect function used. This is not the case if arbitrary cells are used to represent the population distribution. The idea of a weapon effects array is not possible since there is no spacial regularity to the tract records. It would appear necessary to evaluate the weapons effect function over and over again during the operation of the model. A shelter mix and location optimizer program herein described involves the use of a composite weapons effect matrix. This matrix is the same size as the population distribution array and considers all weapon effects for any number of weapons.

Soft military targets are understood to mean air bases. Parked aircraft and the buildings required to support the operation of the base are damaged by relatively low overpressures. A reasonable attack against such targets was originally considered to be a small number of weapons detonated at the altitude which maximizes the weapon lethal radius for the required low overpressure. Such an attack would not be expected to create a fallout problem. Hard targets, typically, hardened missile launch sites, require many large yield weapons detonated at very low altitude or on the surface for their destruction. An attack of this kind would create intense radiation fields over a very large area. The presence or absence of significant fallout fields was considered to distinguish hard and soft targeting situations.

There are, however, reasons why a high altitude detonation might not be used against air bases. The aircraft might be airborne at the time of the attack or could have been deployed to secondary airfields. Vital supplies, such as fuel and weapons, are normally reasonably hard and can easily be specially hardened. A high altitude detonation is unlikely to damage ramps and runways. A low altitude burst might be used in an attempt to crater runways, destroy fuel and armament supplies and deny use of the base by the prolonged presence of intense radiation. A more extensive discussion of attacks on Air Force bases is given in Ref. 3.*

If it is admitted that low altitude detonations might be used against soft military targets, a necessary characteristic of the Soft Target Study methodology is that it handle all weapons effects. The difference between hard and soft target situations does not appear in the methodology appropriate for these cases. It will, however, appear in the study results as a consequence of the different weights of attacks which are reasonable against air fields and hardened missile launching complexes.

Another characteristic required of the methodology developed is that it emphasizes the systems aspect of civil defense countermeasures. Individual weapon effects, particular shelter designs and various kinds of countermeasure activity have all been extensively studied elsewhere. It is not the intent of the Soft Target Study to repeat this work. The objective is to combine the results of this activity into a systems analysis procedure capable of identifying countermeasure systems of good cost effectiveness given a particular targeting situation. To accomplish this objective, we have selected the most tractable weapon effects models and other submodels which appeared to provide an accuracy comparable with unavoidable uncertainties in this problem area. The validity of our results and conclusions will depend on the submodels used. The utility of the methodology developed should not, however, be judged by the accuracy of the submodels, since these can easily be changed as required for specific applications. The utility of the procedures used should be evaluated by the extent to which they produce the kind of data required for reasonable Civil Defense planning.

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* OCD Hard Target Study First Quarterly Report, The University of Arizona Engineering Research Laboratory, Tucson, Arizona, 4 September 1962. See also Strategy for Survival, Martin and Latham, University of Arizona Press, 1963. (Reference 3)

Developing a Civil Defense countermeasure system for a particular locality is frequently considered to be a local problem. However, the possibility of obtaining Federal financial support of the plan usually arises. Just as there exists an optimal effectiveness versus total system cost curve for a local countermeasure system, a similar curve must exist on the national level. Corresponding to each point on the curve would be an allocation of funds among the communities which would result in the greatest overall effectiveness attainable at that total cost level. A pilot study should involve procedures which could easily be applied to any number of localities. It would also be desirable if the procedures could be applied to large areas and would produce output information of a type which could be combined to produce optimal allocations of effort for as many localities as desired for all total cost levels.

Ref. 1* contrasts the Building and the Operating Systems. The methodology developed for the Soft Target Study contributes to the Building System. Emphasis is placed on optimization, flexibility, uncertainties, ease of parameter variation, etc. Procedures suitable for developing a plan of action for the period between warning and attack appear to have characteristics of both systems. They belong to the Building System in the sense that they could be applied before warning was received. Plans would be developed as a function of time available before the attack. The appropriate plan would be selected at the time that warning, and presumably an estimate of the time available, were received. The procedures may be considered part of the Operating System in the sense that the plans would be based on the countermeasure provisions actually available. Each time the Building System made significant changes to the potential Operating System, the procedures would be reapplied to develop an appropriately modified set of plans.

Procedures to be used by the Operating System in the post attack situation would involve even more specific inputs. The initial condition of the system at the time of the attack, the meteorlogical data and the yields, detonation points and burst altitudes of the attacking weapons would all be known. The problem is to develop a fast assessment of the situation upon which to base action decisions during the critical hours following the attack. The procedures should be capable of accepting actual damage information as it became available and of correcting the entire damage assessment picture according to data received. The procedures would be useful as long as prolonged weapon effects need to be considered by the surviving population.

While the Soft Target Study is not concerned with the System Analysis requirements of the Operating System, it would be desirable if techniques developed could be adapted for use in the post attack environment.

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*Devaney, ob. cit.

The literature contains examples of companies or organizations devising shelter designs with at least the implied recommendations that they be generally constructed. From the point of view of an entire community, it is unreasonable to restrict shelter planners to a small number (perhaps 1) of shelter designs. The kinds of shelters which should be considered depend on many factors including the availability of land and the character of existing and projected structures near the locations where shelters are desired. The use of a reasonable catalog of sheltering provisions, which would also include the possibility of various kinds of hardening of existing structures, tends to keep shelter costs down to reasonable cost levels except perhaps for very densely populated areas.

While the cost of a particular shelter design may not vary greatly over the areas where the shelter is reasonable, the cost effectiveness of the shelter will vary enormously depending on the threat at each location where the construction of the shelter is considered. The use of a catalog of sheltering provisions not only permits the shelter system designer to keep the total cost of the system within reasonable limits but permits achieving desirable cost effectiveness levels over the system. In general, if an optimal system is desired, the greater the variety of sheltering provisions in the catalog, the greater will be the effectiveness of the overall system at each cost level.

A required characteristic of the methodology developed is, therefore, that it accept a catalog of sheltering provisions and distribute these provisions in the way which will result in the greatest number of survivors for each total system cost level. This will usually mean that people in different locations will be provided shelters of quite different characteristics and many may be given no protection at all at the low total cost levels. This may be objectionable from some points of view but is reasonable for dollar limited situations since providing protection at some level of effort according to any other distribution rule will sacrifice expected survivors.

Another required property of the Soft Target Study methodology is that it take threat uncertainties into account. Assuming that an attack will occur, no one can predict exactly what form it will take in any local situation. This is not an argument for doing nothing or arbitrarily selecting one shelter or another. There are ordinarily a small number of local attacks which appear reasonable with, perhaps, different likelihoods and it is possible to devise a countermeasure system which maximizes the expected number of survivors at each cost level. The actual number of survivors, given that an attack occurs, will not be as great as if the system were optimized for that attack but will probably be greater than if the choice of shelters is arbitrarily made.

The analysis procedures should not consider that the population to be protected is an inert quantity of target value. The population can move during the interval between warning and attack and after the attack. The population can also perform tasks which reduce the effect of the attack. Procedures which do not take this capability into account will compute the effectiveness and cost effectiveness of a countermeasure system to be less than it actually would be.

The vulnerability of unsheltered population varies over the population distribution representation depending on the kind of existing construction within each element. It would be a mistake, for example, to associate the same critical overpressure with occupants of normal homes and reinforced commercial buildings. The Soft Target Study methodology should take these vulnerability differences into account.

The ability of an element to accept countermeasure provisions also varies over the population distribution representation. The removal of ignition points, for example, would only be an appropriate countermeasure over those neighborhoods where removable ignition points exist. The methodology developed should have a capability of determining which countermeasures of the catalog can be reasonably considered for each population matrix element.

The final characteristic of the methodology developed is that it be genuinely useful to Civil Defense planners while attempting to design a countermeasure system inexpensive enough to be realizable and effective enough to be worth while.

The preceding characteristics required of the Soft Target Study methodology are summarized as follows:

Efficiently determine system of best cost effectiveness

Level of effort a problem variable

Reasonable resolution of locale representation

Program efficiency

- Fast access memory conservation
- Convenient application of weapon effects
- Fast running

All weapon effects

Systems aspect emphasized

- Utility of the method not a function of particular submodels used

Optimal alocation of effort among localities

Procedures for use in the Building System

- Desirable for procedures to be adaptable for use in the Operating System

Countermeasure catalog

Uncertainties taken into account

Population mobility

Variation of unsheltered vulnerability characteristics with position

Variation of countermeasure acceptability with position

Genuinely useful for Civil Defense planning

SUMMARY OF METHODOLOGY CHARACTERISTICS

In general, ALL OF THE CHARACTERISTICS MENTIONED HAVE BEEN ACHIEVED, at least to some extent. In many respects the procedures seem ready for immediate use. In other areas, additional refinement appears desireable depending on the application. The Soft Target Study has been considered to be primarily a research study in Civil Defense countermeasure systems analysis methodology although a pilot city demonstration study is required. If the Office of Civil Defense should choose to apply procedures similar to those herein described it may be desirable to obtain expert advice regarding final programming details and input constants for each of the principle submodels of the basic systems analysis structure which has been developed.

The methodology is described in three sections. Section I contains summary descriptions of analysis procedures applicable to the soft target problem. Earlier forms of these were available at the beginning of the study, having been devised for other projects. They were used during the Soft Target Study as a basis for the development of new and more specifically applicable procedures.

The early activity under the Soft Target Study resulted in a computer program called the Single Shelter Type Deployment Optimizer. Experience with this program indicated that a countermeasure system of greater effectiveness could be obtained if a catalog of shelter provisions were available for use in the optimizer program. An improved program called the Multiple Shelter Type Mix and Deployment Optimizer was then written. It was finally appreciated that fallout might be a problem in soft target situations. Fallout is very difficult to include in programs primarily concerned with overall system effectiveness. A program was first written to generate fallout iso-field diagrams as a function of time after burst. This program was then incorporated in a countermeasure system evaluator program called the Dynamic Analyzer. This program is useful as an independent program and is described in Section II.

The final methodology development activity involved combining the optimizer techniques which had been devised, the method of handling fallout, threat and meteorological uncertainties and a scheme for correlating shelter cost and suitability data with locations in the population distribution representation in a program called the Multiple Effects Weighted Strategy Shelter Optimizer. This program is described in detail in Section III.

SECTION I
SUMMARY DESCRIPTION OF SOFT TARGET STUDY SYSTEMS ANALYSIS METHODOLOGY

INTRODUCTION

The Hughes Aircraft Company, Ground Systems Group in Fullerton, California, has performed the Soft Target Study for the Department of Defense, Office of Civil Defense. The methods herein described were developed by the Operations Analysis Section of the Systems Division. Programming and other assistance has been provided by the Mathematical Analysis Section. The scope of work includes developing procedures and methodology for studying patterns of attack, for evaluating local hazards, for determining potential civil defense countermeasures for cities closely associated with soft military targets and for computing the cost effectiveness of alternate systems of protection. Study of this problem has shown that there is a difference in the intensity and relative intensity of the different weapon effects for cities near soft and hard targets. However, all weapon effects need to be considered for both cases. The significance of this fact is that procedures similar to those herein described may be applied to the study of Civil Defense countermeasures for cities in any targeting situation.

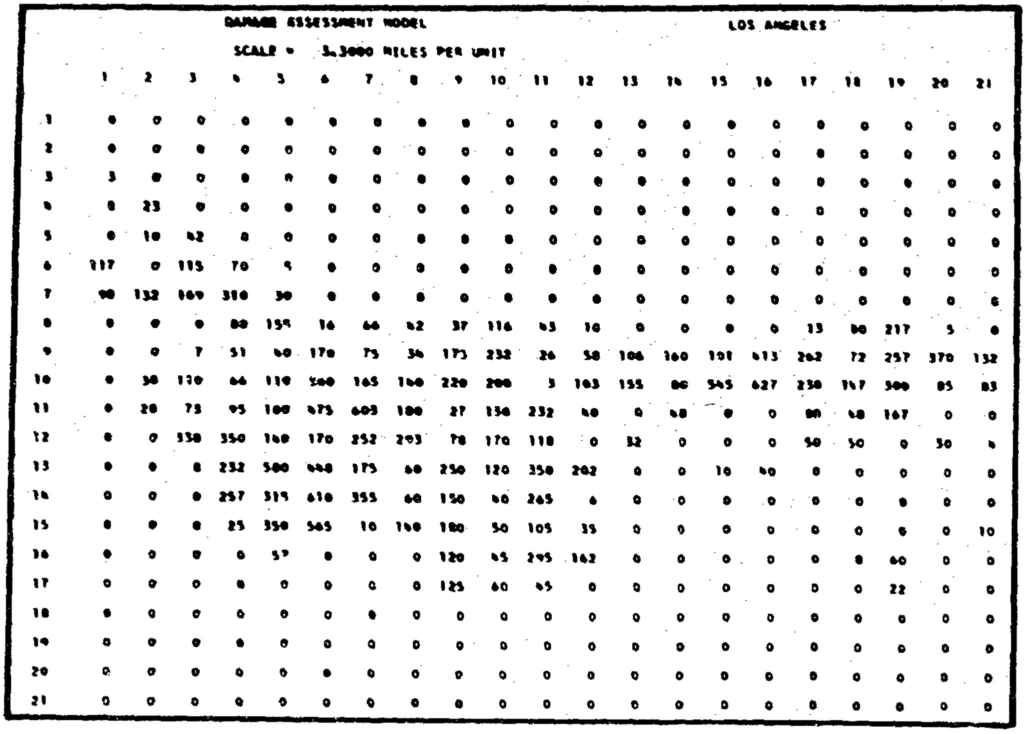
TARGET VALUE AND WEAPON EFFECTS

TARGET VALUE DISTRIBUTION MODEL

The first step in devising a procedure for quantitatively considering the pattern of attack and the local hazards problem is to establish the means of describing the area distribution of target value for the area of interest. A procedure which has been employed is the use of many small tracts of possibly irregular shape. These tracts are so small that the location of any point in the tract may be used as the location of the entire tract and weapons effects are considered constant over the area of the tract. Records containing the characteristics and location of these tracts are stored as a list in a computer. There is no systematic arrangement of these tracts although the computations can be facilitated by various kinds of sorts.

In order to reasonably analyze or optimize a Civil Defense system, some representation of the threat must be assumed. National estimates of the local targeting situation throughout the country are thought to exist and, if this information is available, may be used as the threat model. If this data is not available, idealized targeting problems have been exhaustively treated in the literature. In practical situations, however, these simple solutions rarely apply. One complication is the fact that most of the target value of interest for Civil Defense is not clustered around presumed enemy target points but is distributed at varying distances from these points. Another complication is that the target value is distributed around the aim points in a non-analytic way and this distribution is different for every community.

The procedure employed at Hughes is to divide the target area into a matrix or grid of small, incremental, rectangular areas. Since these areas are geometrically related, the computations proceed very rapidly. An example target matrix for Los Angeles is shown on Figure 1. The value of each element in this matrix is the fraction of the area of the element which is zoned industrial, on a parts per thousand basis. The main geographic features in this region are discernable on the map. We have written computer programs which convert tract data, the form in which original information is usually obtained, into the matrix format used for automatic computation.



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                        DAMAGE ASSESSMENT MODEL                                   LOS ANGELES
                        SCALE =   3.3000 MILES PER UNIT
       1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20   21

  1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  2    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  3    3    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  4    0   23    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  5    0   10   42    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  6  117    0  115   70    5    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  7   90  132  169  310   30    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  8    0    0    0   80  155   16   66   42   37  116   43   10    0    0    0    0   13   80  217    5    0
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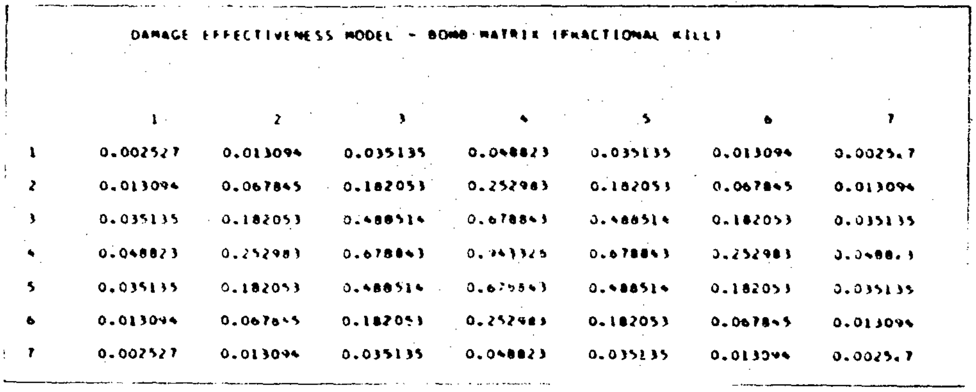
```

FIGURE 1 TARGET MATRIX

WEAPONS EFFECTS MODELS

The usual procedure for representing weapon effects is to devise expressions which relate probability of target kill to distance from the aim point. These relations are continually reevaluated as the computer program is executed. This procedure is time consuming but necessary if the small tract system of representing area distributions of target value is used. The target matrix concept, however, suggests a more desireable procedure. This procedure is the use of a weapons effects matrix as illustrated on Figure 2. The matrix is a square array with an odd number of elements in each row and column. The center element is the weapon aim point. The value of each element is the probability of kill for a particular kind of target value at that distance from the aim point. The matrix is used to compute the expected target value kill associated with an aim point by indexing the center of the matrix to the aim point element of the target value matrix and summing the product of the corresponding elements of the two arrays.

PS = 0.95 R = 2.38 σ = 0.14 SCALE = 1.37



```
            DAMAGE EFFECTIVENESS MODEL - BOMB MATRIX (FRACTIONAL KILL)

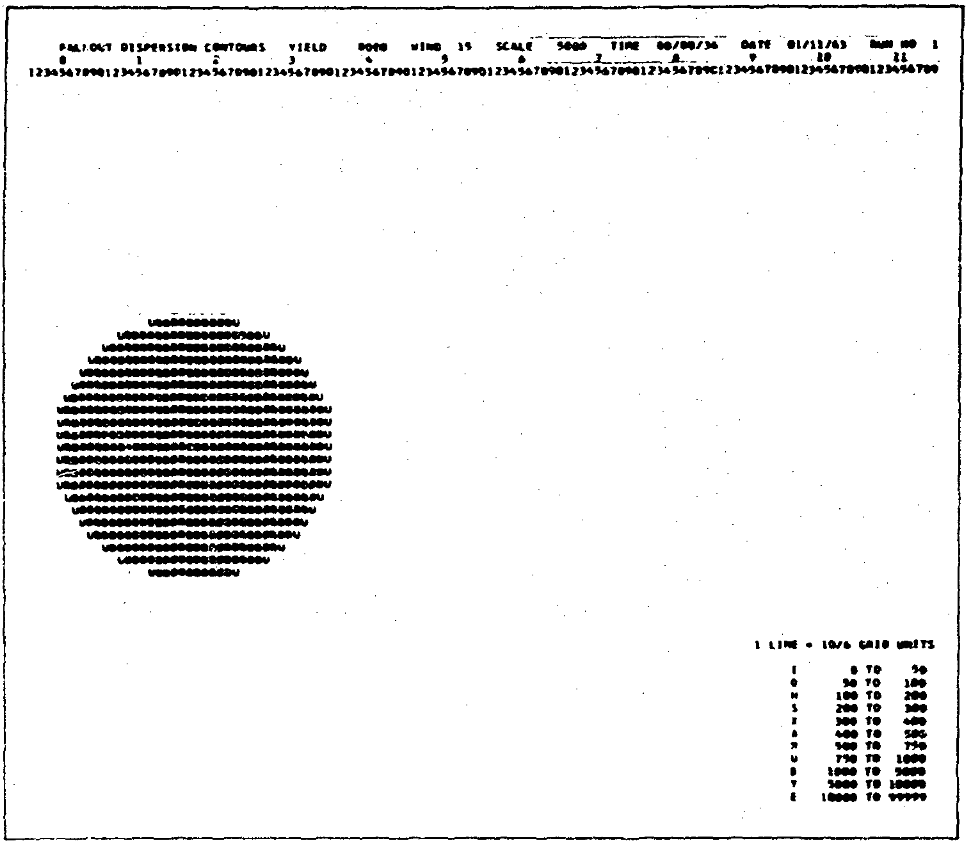

             1          2          3          4          5          6          7

   1     0.002527   0.013094   0.035135   0.048823   0.035135   0.013094   0.002527
   2     0.013094   0.067845   0.182053   0.252983   0.182053   0.067845   0.013094
   3     0.035135   0.182053   0.488514   0.678843   0.488514   0.182053   0.035135
   4     0.048823   0.252983   0.678843   0.943326   0.678843   0.252983   0.048823
   5     0.035135   0.182053   0.488514   0.678843   0.488514   0.182053   0.035135
   6     0.013094   0.067845   0.182053   0.252983   0.182053   0.067845   0.013094
   7     0.002527   0.013094   0.035135   0.048823   0.035235   0.013094   0.002527
```

FIGURE 2 EXAMPLE WEAPONS EFFECTS MATRIX

FALLOUT MODELS

The weapons effects functions used to compute the weapon matrices have been taken from the literature although some original work has been performed in adapting these procedures for rapid automatic computation. An example output of the fallout submodel is shown beginning on Figure 3. The elements of this array indicate the radiation fields due to fallout 36 minutes after weapon detonation, which occurred in the element indicated by the asterisk. In this example, the array is too large for the element values to be printed. Instead, the values have been coded by intervals and indicated by a single character. In this example, the wind is from the left. Figure 4 is the same situation 12 hours and 36 minutes after detonation. The result was computed by a later version of the program which prints iso-field contours rather than a solid area of characters. The decay of the field along the upwind side of the pattern and the growth of the field downwind is evident on the figure. Figure 5 is the situation 1 day, 3 hours and 36 minutes after detonation. Radioactive decay has occurred everywhere over the diagram.

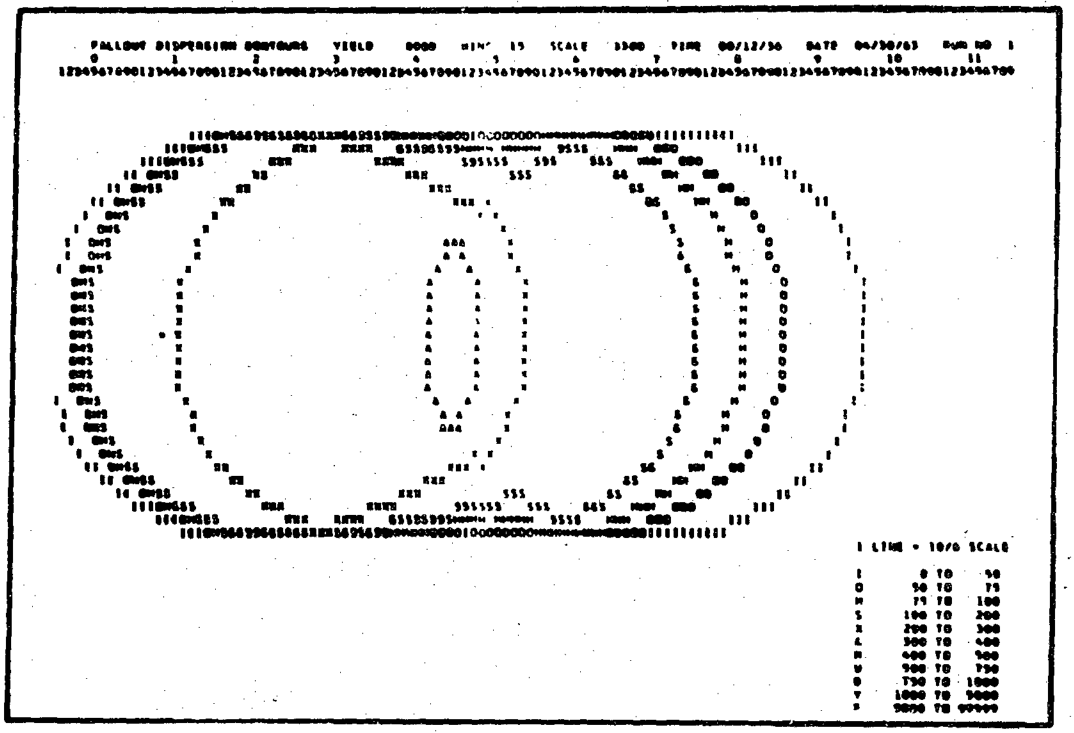


```
     FALLOUT DISPERSION CONTOURS   YIELD   [illegible]   WIND  15   SCALE   5000   TIME  00/00/36   DATE  01/11/63   RUN NO  1
     0         1         2         3         4         5         6         7         8         9        10        11
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

                                                                   1 LINE = 10/6 GRID UNITS

                                                                      I       0 TO    50
                                                                      O      50 TO   100
                                                                      H     100 TO   200
                                                                      S     200 TO   300
                                                                      X     300 TO   400
                                                                      A     400 TO   500
                                                                      X     500 TO   750
                                                                      U     750 TO  1000
                                                                      B    1000 TO  5000
                                                                      Y    5000 TO 10000
                                                                      E   10000 TO 99999
```

FIGURE 3 FALLOUT DISPERSION CONTOURS

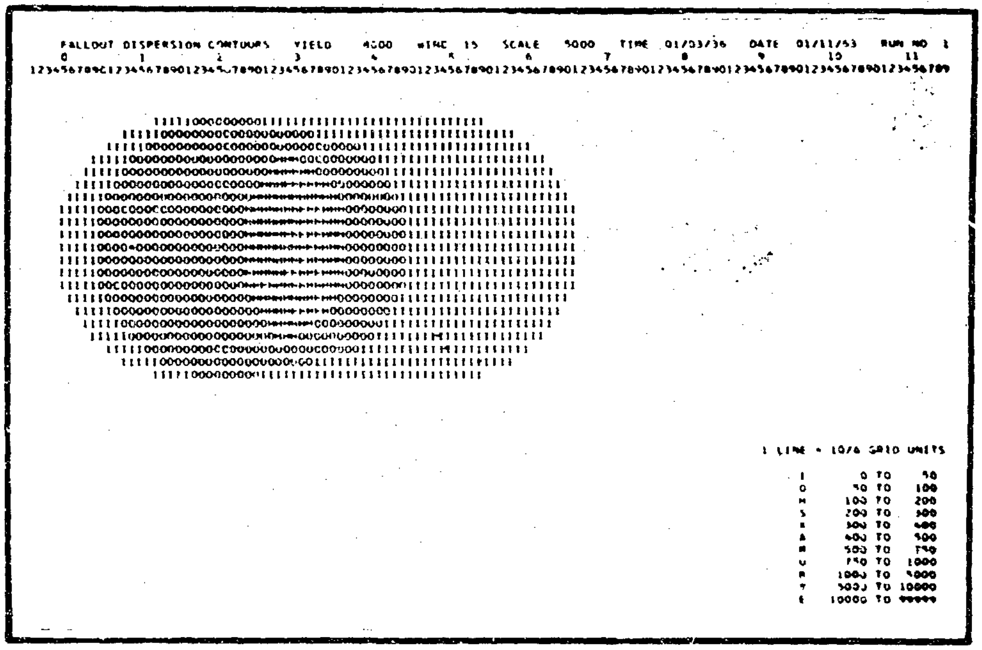


```
FALLOUT DISPERSION CONTOURS    YIELD    8000    WIND  15    SCALE   3300    TIME  00/12/36    DATE  04/30/63    RUN NO  1
0              1              2              3              4              5              6              7              8              9              10             11
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
```

```
1 LINE = 10/6 SCALE

I        0 TO     50
O       50 TO     75
M       75 TO    100
S      100 TO    200
X      200 TO    300
A      300 TO    400
R      400 TO    500
V      500 TO    750
B      750 TO   1000
Y     1000 TO   5000
Z     5000 TO  99999
```

FIGURE 4 FALLOUT DISPERSION CONTOURS



```
FALLOUT DISPERSION CONTOURS    YIELD    4000    WIND  15    SCALE   5000    TIME  01/03/36    DATE  01/11/53    RUN NO  1
0              1              2              3              4              5              6              7              8              9              10             11
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
```

```
1 LINE = 10/6 GRID UNITS

I        0 TO     50
O       50 TO    100
M      100 TO    200
S      200 TO    300
X      300 TO    400
A      400 TO    500
R      500 TO    750
V      750 TO   1000
B     1000 TO   5000
Y     5000 TO  10000
Z    10000 TO  99999
```

FIGURE 5 FALLOUT DISPERSION CONTOURS

AIM POINT ASSIGNMENT

AIM POINT OPTIMIZATION

These techniques for representing target value and weapon effects distributions have been used in programs employing several aim point assignment modes. Two of these are illustrated on Figure 6. An automatically synthesized bivariate distribution of target value was used in

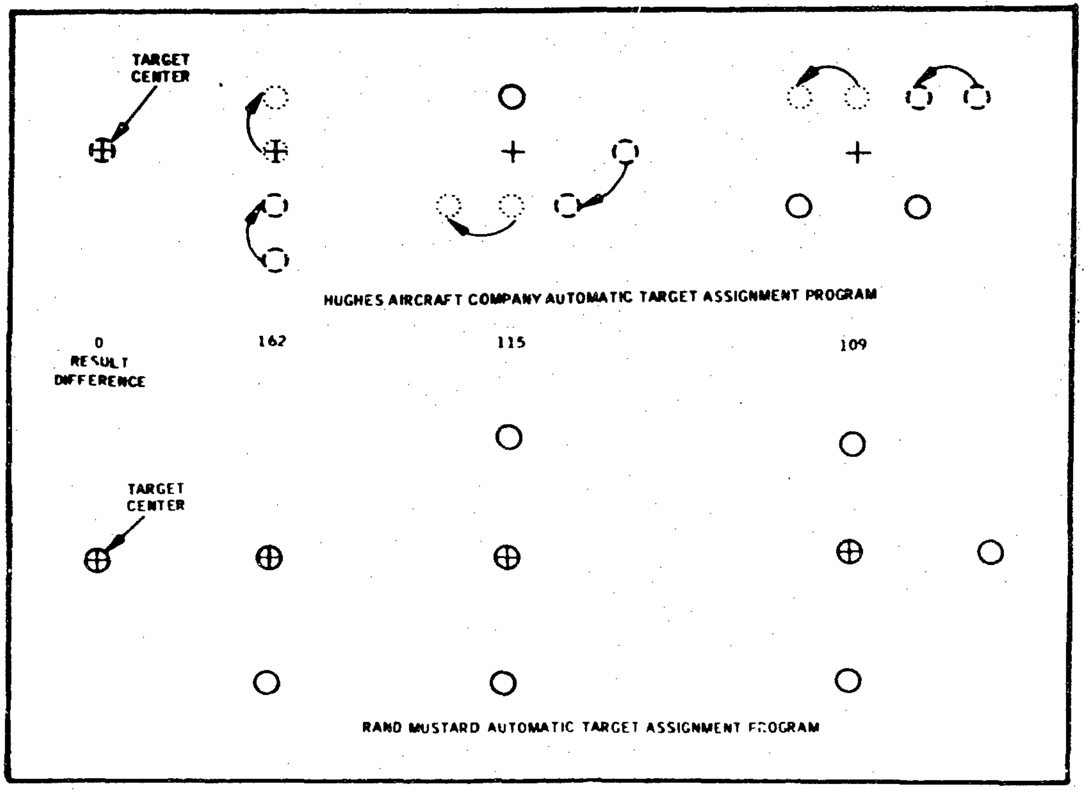


FIGURE 6 AIM POINT ASSIGNMENT

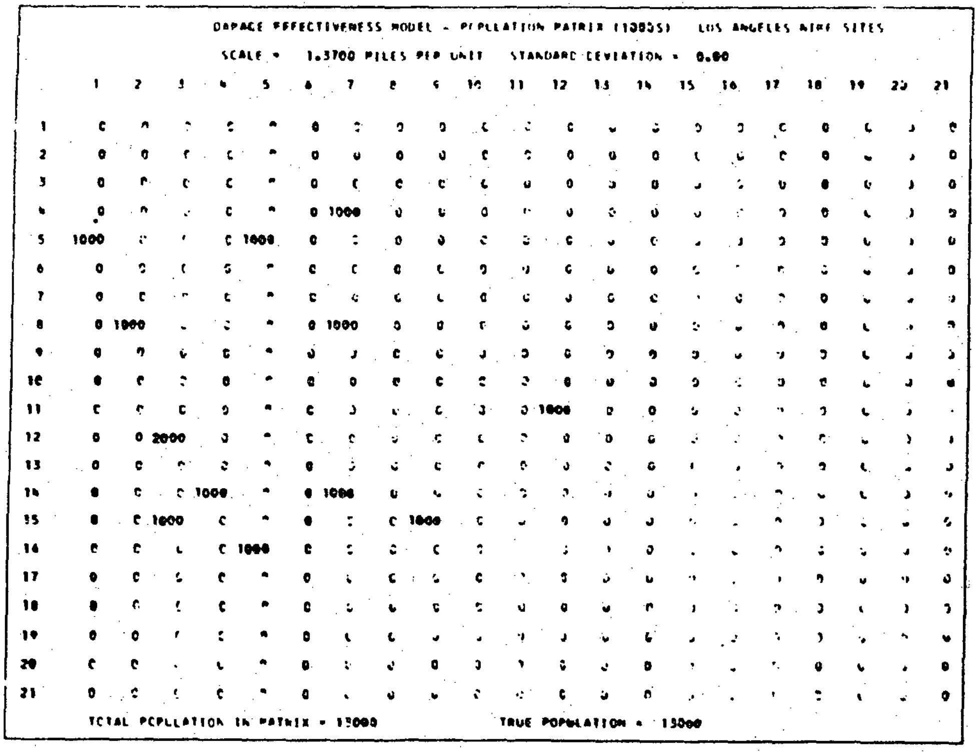
these examples. The procedure of merely assigning each succeeding round to the aim point which maximizes the expected damage against the remaining target value is illustrated across the bottom of the figure. The first round is assigned to the center of the target. The second attack is the second element below the center. The third aim point is two elements above the center, etc.

The aim point assignment procedure illustrated across the top of the figure is somewhat different. Each succeeding weapon is initially assigned to the aim point which maximizes the expected damage against the remaining target value as before. The entire aim point set is then readjusted by an optimizing procedure which alters the aim points in order to maximize the expected target destruction for that number of weapons.

The first round is assigned to the center of the target as before. The second is also initially assigned to the second element below the center of the target. During the iteration procedure, however, the first aim point is raised an element, which permits the second aim point to fall into the corresponding position under the target center. The third round is initially assigned to the right of the target center. This forces the lower aim point to the left one space and the new aim point moves down to complete the triangle. The optimum aim point set with four rounds is the square pattern shown. The greatest improvement obtained with the iterative optimizing procedure is 162 units, which occurs with only two rounds. In general, the iterative optimizer only achieves a significant improvement in the expected target value killed if the number of rounds is small and the precision of delivery is good.

AIM POINT INPUT MODE

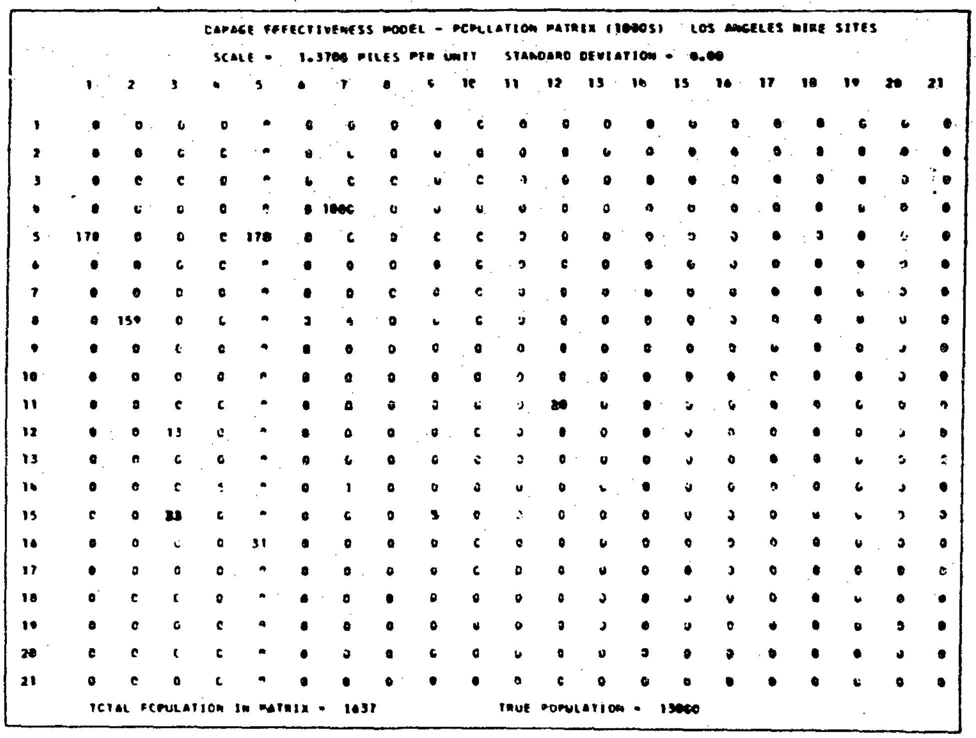
Figure 7 is an example of the use of the input aim point mode. An aim point list has been computed for 10 weapons using the Los Angeles target array shown on Figure 1. These aim points are used as inputs for evaluating the effect of this attack on another target value distribution. The target matrix shown here pretends to be the distribution of Nike sites in the Los Angeles area. Figure 8 is the probability of survival, again in parts per thousand, for these sites for assumed values of weapon yield and target hardness.



```
                   DAMAGE EFFECTIVENESS MODEL - POPULATION MATRIX (1000S)   LOS ANGELES NIKE SITES
                   SCALE =   1.3700 MILES PER UNIT   STANDARD DEVIATION =  0.00
        1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    19    20    21

  1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  2     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  3     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  4     0     0     0     0     0     0  1000     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  5  1000     0     0     0  1000     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  6     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  7     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  8     0  1000     0     0     0     0  1000     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  9     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 10     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 11     0     0     0     0     0     0     0     0     0     0     0  1000     0     0     0     0     0     0     0     0     0
 12     0     0  2000     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 13     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 14     0     0     0  1000     0     0  1000     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 15     0     0  1000     0     0     0     0     0  1000     0     0     0     0     0     0     0     0     0     0     0     0
 16     0     0     0     0  1000     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 17     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 18     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 19     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 20     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 21     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
            TOTAL POPULATION IN MATRIX = 13000                    TRUE POPULATION =  13000
```

FIGURE 7 EXAMPLE INPUT SECONDARY TARGET ARRAY



```
                   DAMAGE EFFECTIVENESS MODEL - POPULATION MATRIX (1000S)   LOS ANGELES NIKE SITES
                   SCALE =   1.3700 MILES PER UNIT   STANDARD DEVIATION =  0.00
        1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16    17    18    19    20    21

  1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  2     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  3     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  4     0     0     0     0     0     0  1000     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  5   170     0     0     0   178     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  6     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  7     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  8     0   159     0     0     0     3     4     0     0     0     0     0     0     0     0     0     0     0     0     0     0
  9     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 10     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 11     0     0     0     0     0     0     0     0     0     0     0    20     0     0     0     0     0     0     0     0     0
 12     0     0    13     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 13     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 14     0     0     0     0     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 15     0     0    33     0     0     0     0     0     5     0     0     0     0     0     0     0     0     0     0     0     0
 16     0     0     0     0    31     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 17     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 18     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 19     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 20     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
 21     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
            TOTAL POPULATION IN MATRIX =  1637                    TRUE POPULATION =  13000
```

FIGURE 8 SECONDARY TARGET ARRAY AFTER IMPACT OF TEN WEAPONS

ISO-DAMAGE CONTOURS

Figure 9 illustrates the final program aim point mode. The target matrix used in this example extended from Columbus, Toledo and Detroit to Washington, New York and Boston. A map outline has been superimposed on the grid to help identify the locations of the elements. When operating in this mode, the computer centers a weapons effect matrix on each element of the target matrix. Each output character represents a range of casualties summed over all population elements in the vicinity for a weapon detonated at that point.

It is clear that these targeting and local hazard evaluator programs could be used with population distributions protected by various shelter types. By making enough runs it would be possible to get some idea of which shelters should be used where to provide maximum protection as a function of total system cost. The programs would be very difficult to use in this way, however, since they were not intended for this purpose. We have preferred, therefore, to take a more direct approach to the problem of optimizing civil defense countermeasures.

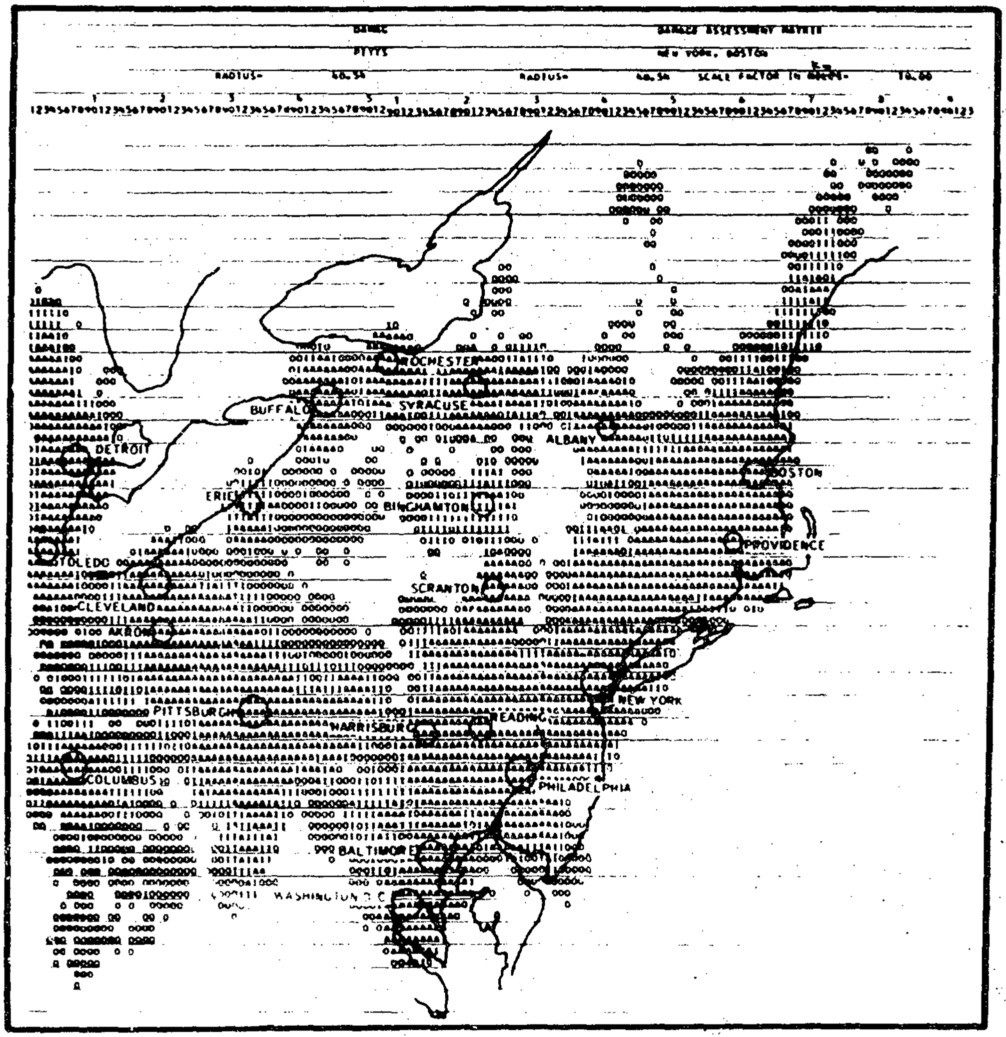


FIGURE 9 EXAMPLE DAMAGE ASSESSMENT MATRIX

SINGLE SHELTER TYPE LOCATION OPTIMIZER

Our first accomplishment under the task of evaluating the cost effectiveness of alternate systems of protection was a digital computer program called the Single Shelter Type Location Optimizer. The program was important for several reasons. It demonstrated the utility of the procedure for representing arbitrary, area distributions of target value in countermeasure optimization programs. The weapon effect matrix concept was expanded into a composite matrix of the same size as the target matrix which included the effect of all weapons in the attack. This modification was desireable since the aim points are held constant during a countermeasure optimization run. The program established the utility of generating optimal total system cost vs. countermeasure system effectiveness curves without specifying an operating point (which is left to those authorized and competent to make such decisions) and the worth of the inverse cost effectiveness (ICE) algorithm for computing optimal civil defense countermeasure systems.

A typical, optimal cost effectiveness curve is shown on Figure 10. The program assigned shelters to non-zero population matrix elements in the sequence of increasing ICE; that is, increasing cost per expected survivor added. Each assignment resulted in a point on the curve. The total system cost, and also the system effectiveness, are low. As more locations are assigned shelters, the cost effectiveness of the assignments are successively less desireable since the unassigned locations are either too near the aimpoints for the shelters to be effective or too far for the shelters to be needed. The curve terminates when all elements are assigned shelters. The final assignment typically adds to the total system cost without adding significantly to the effectiveness of the system. The cost effectiveness of this assignment is poor and the optimal cost vs. survivors added curve is quite steep. The objective of the countermeasures systems designer is to keep the slope of the curve as low as possible. The procedure for generating the curve automatically computes the corresponding optimal countermeasure deployment. This deployment, which is the deployment which maximizes the expected number of survivors at each total system cost level, is displayed for desired cost levels by what is called a shelter deployment matrix.

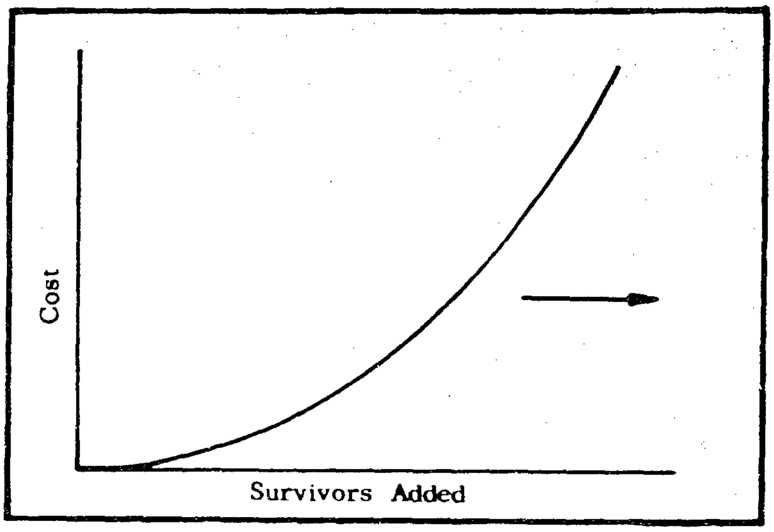


FIGURE 10 OPTIMAL COST EFFECTIVENESS CURVE

MULTIPLE SHELTER TYPE AND LOCATION OPTIMIZER

INTRODUCTION

An improved version of the single shelter type location program permits input of a catalog of potential countermeasures. This introduced the idea of an optimal mix and deployment of countermeasure provisions and resulted in the development of the conversion inverse cost effectiveness (CICE) algorithm, a more powerful analysis device for computing optimal systems of protection.

NOMENCLATURE

The following symbols will be used in this discussion:

(PM) = Population Matrix

= Denotes an Element of a Matrix

C_i = Capacity of Shelter i

$(DC)_i$ = Dollar Cost of Shelter i

$(SC)_i$ = Specific Cost (Dollars Per Person Sheltered) of Shelter i

(PSM) = Population Survival Matrix

U = Unsheltered

$(ICE)'_i$ = Inverse Cost Effectiveness of Assigning Type i Shelters to a Previously Unprotected Element

$(ICE)'_{i-j}$ = Inverse Cost Effectiveness of Converting Type j Shelters to Type i Shelters at Some Element

MATHEMATICAL RELATIONS

Assuming two shelter types are given, Type 1 and Type 2, the cost of using one or the other of the shelter types is found by dividing a particular element of the population, (PM)', by the shelter capacity to find the number of shelters required and multiplying this number by the shelter cost:

$\frac{(PM)'(DC)_1}{C_1}$ = Cost of protecting the population with Type 1 shelters

$\frac{(PM)'(DC)_2}{C_2}$ = Cost of protecting the population with Type 2 shelters

If fractional shelters are permitted as a computational convenience, it is permissable to define a quantity, called specific cost, which is the cost of the shelter per person sheltered. In this notation:

$$(SC)_1 = (DC)_1/C_1$$

$$(SC)_2 = (DC)_2/C_2$$

and

$(SC)_1(PM)'$ = Cost of protecting the population with Type 1 shelters

$(SC)_2(PM)'$ = Cost of protecting the population with Type 2 shelters

The expected number of persons surviving by using shelters is the product of the population and the probability of survival at the point:

$(PM)'(PSM)'_u$ = Expected number of survivors if no shelters are provided

$(PM)'(PSM)'_1$ = Expected number of survivors if Type 1 shelters are provided

$(PM)'(PSM)'_2$ = Expected number of survivors if Type 2 shelters are provided.

The expected number of persons "saved", called survivors added, given an attack is the difference between the number of survivors with and without shelters:

$$(PM)'(PSM)'_1 - (PM)'(PSM)'_u =$$

$(PM)'\left[(PSM)'_1 - (PSM)'_u\right]$ = Expected number of survivors using shelter Type 1

$(PM)'\left[(PSM)'_2 - (PSM)'_u\right]$ = Expected number of survivors added using shelter Type 2.

The inverse cost effectiveness of these shelter types, that is, the cost per survivor added, is obtained by dividing the cost by the number of survivors added:

$$\frac{(SC)_1(PM)'}{(PM)'\left[(PSM)'_1 - (PSM)'_u\right]} =$$

$$\frac{(SC)_1}{(PSM)'_1 - (PSM)'_u} = (ICE)'_1$$

$$\frac{(SC)_2}{(PSM)'_2 - (PSM)'_u} = (ICE)'_2$$

It is now convenient to mention the concept of relative hardness of shelters. It is required that the shelters be ordered by relative hardness and that the shelter numbers be assigned in sequence. It is also required that a shelter be at least as hard as any other shelter of lower shelter number everywhere, that is, that:

$$(PSM)'_u \le (PSM)'_1 \le (PSM)'_2$$

for every element of the array. This requirement was adopted to simplify the optimizer logic and is reasonable as long as only blast is considered. The final optimizer program, which is described in Section 3, takes all weapon effects into account. The idea of shelter ordering by hardness is not used in this program since the hazards vary from place to place and, in principle at least, the ordering of the shelters by the degree of protection they afford the occupants may be a function of shelter location.

Another concept used is that of conversion of one shelter type to a harder type. In practice, if the types were very dissimilar, this might involve digging out the old shelter, disposing of the debris, filling in the hole and starting over so that the cost might be even greater than the normal cost of the hard shelter. "Conversion" is never used in this sense in this report. We are trying to construct a maximum effectiveness vs. cost curve. This curve is developed by starting at zero cost, picking the shelter providing minimum inverse cost effectiveness and continuing until everyone is sheltered with the hardest shelter type at maximum cost. Selecting the point on this curve which is to be used is considered a problem beyond the universe of this study. The point selected implies a shelter mix and location distribution which must be generated with the effectiveness vs. cost curve. To generate the curve the program repeatedly asks whether it is better to add a new shelter of some type somewhere or whether it would be better to replace a previously assigned shelter with a better one. This, in the terminology of this report, is called "converting" a shelter into another type. The cost of the conversion in this sense is the difference in the specific costs

$$(SC)_{2-1} = (SC)_2 - (SC)_1$$

and the associated number of "survivors added" is

$$(PM)' \left[(PSM)'_2 - (PSM)'_1 \right]$$

so that the inverse cost effectiveness of this strategy would be

$$\frac{(PM)'(SC)_{2-1}}{(PM)' \left[(PSM)'_2 - (PSM)'_1 \right]} =$$

$$\frac{(SC)_{2-1}}{(PSM)'_2 - (PSM)'_1} = (ICE)'_{2-1}$$

It is clear from this discussion that conversions will only be made from one shelter type to a harder, more expensive shelter since if the harder shelter were less expensive, it would have been selected first.

THE SHELTER TYPE STATE-OF-THE-ART TEST

It is also clear that if the possibility is to exist that each shelter type may be chosen for some location at some total cost level, the shelter costs must be ordered in the same way as the shelter hardnesses. This fact may be used to eliminate inferior or obsolete designs from those which are state-of-the-art. A possible situation is shown on Figure 11. Three state-of-the-art shelter types exist as shown. The shelter numbers apply to their ordering with respect to both hardness and specific cost. A new shelter design is devised. Its hardness is greater than shelter Type 2 but less than shelter Type 3. It is asked what this new design contributes to the state of the shelter design art.

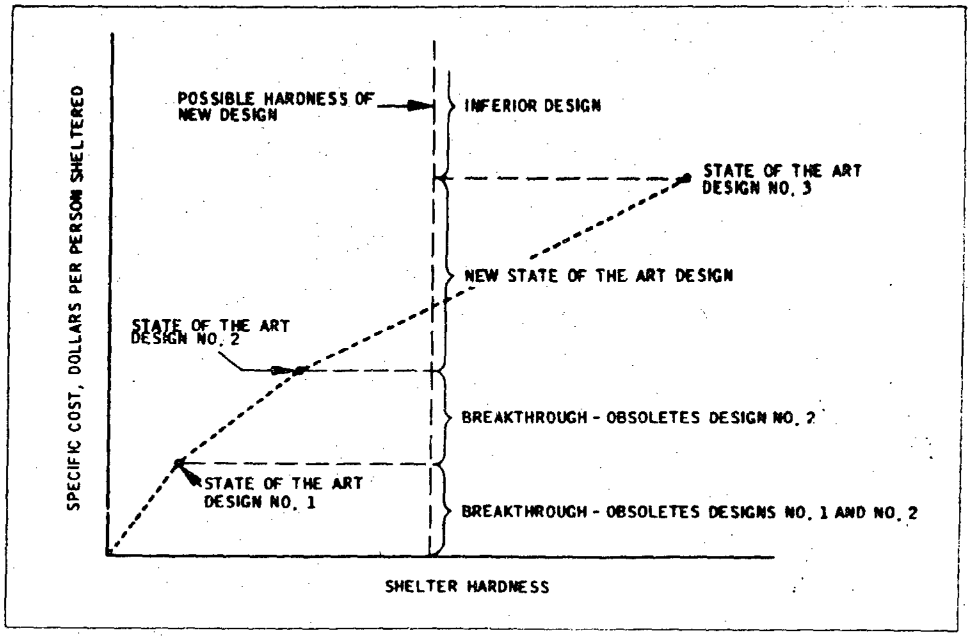


FIGURE 11 NEW SHELTER DESIGN TEST

The answer is that it depends on the specific cost. If the cost is less than that of shelter Type 1, it is a design breakthrough. It obsolates designs 1 and 2 and the new design and the old design Type 3 are the only types which need be considered for shelter systems at any cost level. If the specific cost is greater than the cost for Type 1 but less than the cost for Type 2, it is still a design breakthrough, but only obsoletes design Type 2. Type 1, Type 3, and the new design may all be used in the optimum shelter system at some total cost level. If the cost is greater than the cost of Type 2 but less than the cost of Type 3, it is a new state-of-the-art design.

It does not obsolete any existing designs but may permit the definition of a shelter system of greater effectiveness at some cost level. If the specific cost is greater than the specific cost for Type 3 shelters, it is an inferior design. It will never appear in an optimum shelter system at any cost level.

Similar tests can be applied to shelters of any hardness. It is noticed that if the hardness of a shelter of new design is less than the hardness of shelter Type 1, the new design can only be state-of-the-art or inferior. If the hardness of the new design is greater than the hardness of shelter Type 3, the new design may obsolete all existing shelter types, may obsolete Types 2 and 3, may obsolete Type 3 or may be state-of-the-art. It cannot be inferior.

MULTIPLE-SHELTER TYPE MIX AND LOCATION OPTIMIZER LOGIC

The operation of the mix and location optimizer is illustrated on Figure 12. This graph shows the cost effectiveness (survivors added per dollar) of three shelter types as a function of distance from threat weapon aim point for a particular set of assumptions. Type 1 is the softest, least expensive shelter. It also has the greatest cost effectiveness, which reaches a maximum at a moderate range and is low at the aim point, since it is too soft to help, and at large ranges where shelters are not needed. Type 2, a harder more expensive shelter, has its maximum effectiveness closer to the aim point and is optimum over a range of distances. Type 3, the hardest, most expensive shelter is optimum for the area around the aim point. Since each type is optimum at some distance, the shelter numbers must refer to their ordering with respect to both hardness and cost.

One shelter assignment scheme would be to provide the shelter at each location which has maximum cost effectiveness. If dollars available were limited, a reasonable approach would be to start at the maximum of the Type 1 curve and work both ways until the available money was exhausted. Locations at greater ranges would all receive Type 1 shelters. Working in toward the aim point, Type 1 shelters would be constructed until the radius at which the Type 1 and Type 2 curves intersect was reached. Type 2 shelters would then be constructed and finally the Type 3 shelters and remote Type 1 shelters would complete the program. At each point, working in and out, the cost effectiveness for each direction, though decreasing, would be kept equal. This procedure, though seemingly reasonable, would not provide the greatest numbers of survivors added per dollar spent unless the total allowable cost was so small that only Type 1 shelters would be used in a ring around the aim point, which would leave the region of the aim point and the remote areas unprotected.

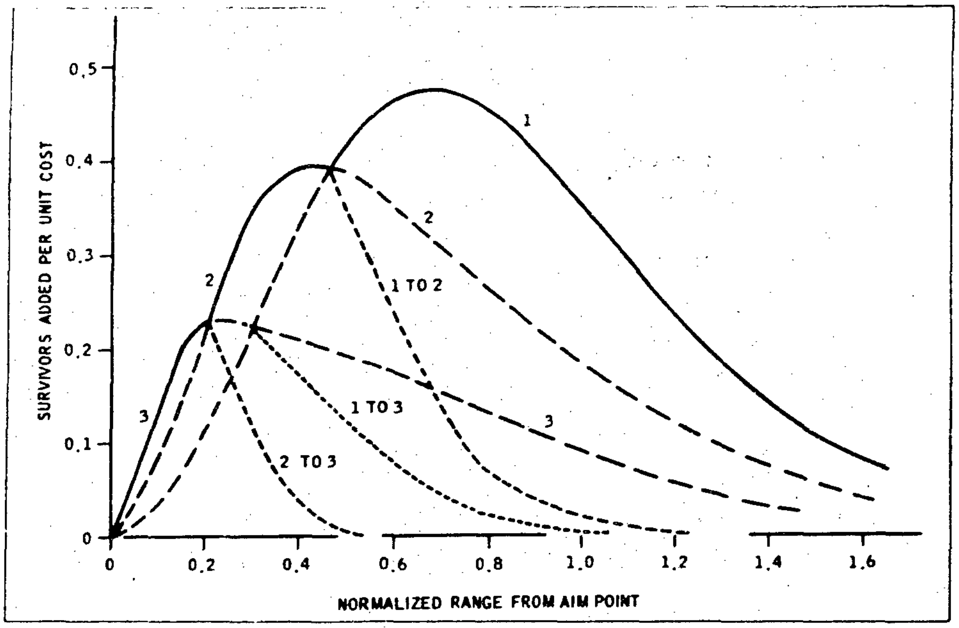


FIGURE 12 SHELTER SYSTEM OPTIMIZATION

The cost effectiveness curves for converting Type 1 shelters to Type 2, Type 1 to Type 3 and Type 2 to Type 3 are also shown on Figure 12. The Type 1 to Type 2 conversion curve originates at the intersection of the Type 1 and Type 2 curves and is defined for all greater radii. It has no meaning nearer to the aim point since Type 1 shelters would never be considered in this region. For the conditions assumed, all of the conversion curves originate at the intersection of the curves defining the conversion.

The proper procedure for constructing a maximum effectiveness versus total system cost curve is to first assign a Type 1 shelter at the distance yielding maximum cost effectiveness and then working both ways, keeping the cost effectiveness for both directions balanced, until the intersection of the Type 1 and Type 2 curves is reached. If new Type 1 and Type 2 shelters only are now assigned, the working points on these cost effectiveness curves will descend to values lower than the Type 1 to Type 2 conversion curve. A shelter system of greater effectiveness per dollar spent is obtained if this curve is used. It is, therefore, necessary to work toward the aim point assigning new Type 2 shelters as well as working out converting Type 1 to Type 2 shelters and to assign new Type 1 shelters. The working points on these curves are kept as equal as possible during this process.

When the cost effectiveness decreases to the value corresponding to the intersection of the Type 2 and Type 3 curves another complication is introduced. The Type 2 to Type 3 conversion curve originates at this point. It is, therefore, necessary to also consider this operation. The procedure now is to continue working toward the aim point by assigning new Type 3 shelters and to work out at three different radii by converting Type 2 to Type 3 shelters, converting Type 1 to Type 2 shelters, and to assign new Type 1 shelters. The trend here is to shelter more and more people with harder and harder shelters while the average cost effectiveness becomes lower and lower. Eventually, everyone is provided Type 3 shelters but the average cost effectiveness is low. The Type 1 to Type 3 conversion curve is never used.

This shelter mix and location optimizing process is illustrated in Figure 13. The optimum shelter system at a specific cost effectiveness level is also shown. No shelters have been assigned to the region around the aim point since none of the three shelters are efficient enough to achieve this cost effectiveness in this region. A ring of Type 3 shelters surrounds the aim point area followed by rings of Type 2 and Type 1 shelters. No shelters are assigned to the remote area since none of the shelters are sufficiently inexpensive to achieve the indicated cost effectiveness in regions where the shelters are not likely to be needed.

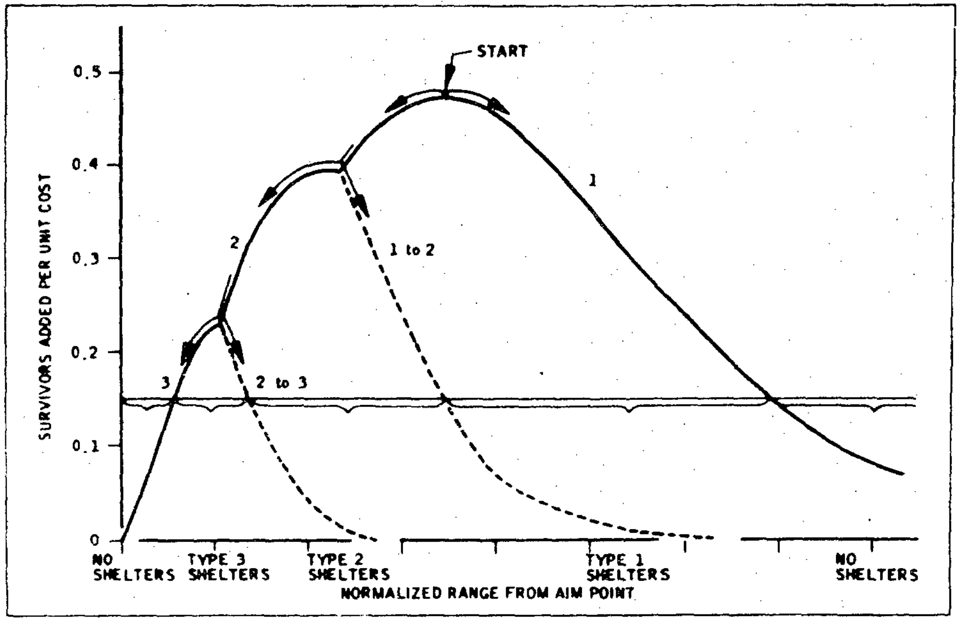


FIGURE 13 EXAMPLE SHELTER SYSTEM OPTIMIZATION

PROOF OF THE EXISTENCE OF THE TRIPLE-POINT

In the previous example, each conversion cost effectiveness curve originated at the intersection of the cost effectiveness curves for the initial and final shelter types of the conversion. It is asked whether this is an accident of the particular assumptions used in the example or whether this will always be true. Figure 14 contains the mathematics applicable to intersection of the shelter Type 1 and shelter Type 2 cost effectiveness curves. The first relation states that at the intersection

MATHEMATICAL BASIS OF THE MULTIPLE SHELTER TYPE MIX AND LOCATION OPTIMIZER

At some total cost level, shelter type 1 is optimum over some region while shelter type 2 is optimum for an adjacent region. On the boundary

$$\frac{(SC)_1}{(PSM)'_1 - (PSM)'_u} = \frac{(SC)_2}{(PSM)'_2 - (PSM)'_u}$$

$$\frac{(SC)_2}{(SC)_1} = \frac{(PSM)'_2 - (PSM)'_u}{(PSM)'_1 - (PSM)'_u}$$

$$\frac{(SC)_2}{(SC)_1} - 1 = \frac{(PSM)'_2 - (PSM)'_u}{(PSM)'_1 - (PSM)'_u} - 1$$

$$\frac{(SC)_2 - (SC)_1}{(SC)_1} = \frac{(PSM)'_2 - (PSM)'_1}{(PSM)'_1 - (PSM)'_u}$$

$$\frac{(SC)_2 - (SC)_1}{(PSM)'_2 - (PSM)'_1} = \frac{(SC)_1}{(PSM)'_1 - (PSM)'_u} = \frac{(SC)_2}{(PSM)'_2 - (PSM)'_u}$$

SC = Shelter Cost/Occupant

(PSM)' = Probability of Survival Matrix Element

FIGURE 14 MATHEMATICAL BASIS OF THE MULTIPLE-SHELTER TYPE MIX AND LOCATION OPTIMIZER

$(ICE)_1$ equals $(ICE)_2$. After performing the indicated algebraic operations, the final relation is obtained which states the $(ICE)_{2-1}$ equals $(ICE)_1$ and therefore must also equal $(ICE)_2$. The triple point is thus seen to be a characteristic of the problem, not a consequence of the particular assumptions made.

THE COMPUTER PROGRAM

The computer program is necessarily more complicated than the simple example shown. The civilian population is distributed in some non-analytic way throughout the population matrix at the time of the attack and multiple aim points may be present. While a complete flow diagram has not been included, a concept for the program is shown on Figure 15. Three shelter types are assumed in Figure 15.

The computer first computes an inverse cost effectiveness matrix for each shelter type. These are identified in Figure 15 as $(ICE)_1$, $(ICE)_2$ and $(ICE)_3$. For each zero element of the population matrix, the corresponding elements of $(ICE)_1$, $(ICE)_2$ and $(ICE)_3$ are set to infinity. The conversion matrices $(ICE)_{2-1}$, $(ICE)_{3-1}$ and $(ICE)_{3-2}$ are also computed and are considered arranged as shown. The blank spaces in the array, which correspond to undefined conversion matrices such as conversion to the same or a softer shelter type, are considered to be matrices each element of which is set to infinity. The result is an array of matrices as shown.

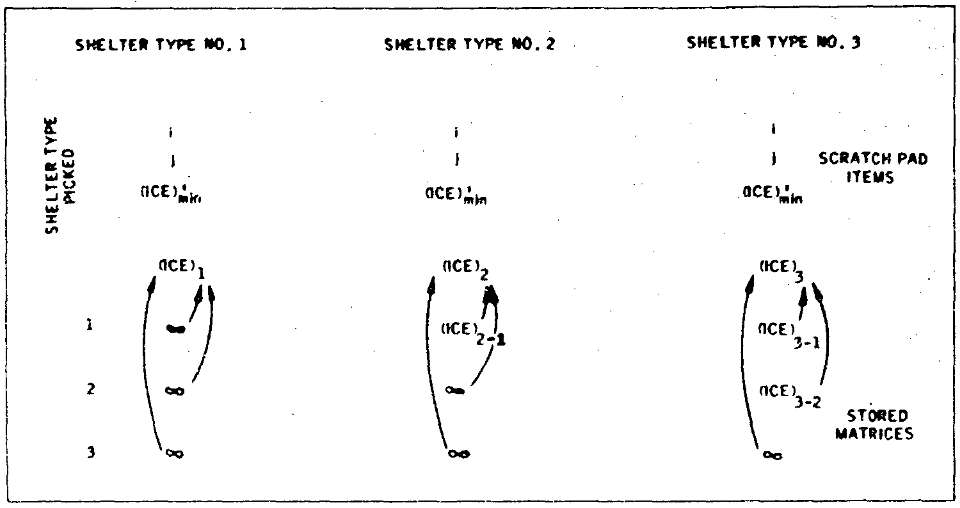


FIGURE 15 COMPUTER PROGRAM CONCEPT

Each of the primary matrices, $(ICE)_1$, $(ICE)_2$ and $(ICE)_3$, are now scanned to locate a minimum element and these elements as well as their i, j matrix locations are stored as scratch pad items.

One cycle of program operation involves the following processes. The three minimum (ICE) scratch pad items are examined and the minimum quantity is located. This identifies both the shelter type and the coordinates of the population matrix element to receive this shelter type. It may be, but not on the first cycle, that there are already softer shelters at this location. The shelter matrix element is read to determine which, if any, shelter type is at this location and the new shelter type is then read into the shelter matrix. The summary information is then updated in much the same way as in the single-shelter type program. These items would include total casualties, total survivors, total survivors added, total system cost, number of persons sheltered by each shelter type (obtained by substracting the population matrix element from the persons sheltered in the old shelter type and adding the same number to the total for the new shelter type), average inverse cost effectivenss for the current shelter system, inverse cost effectiveness for this shelter assignment, etc.

It is now necessary to correct the primary stored (ICE) matrices. How this is done depends on which shelter type was picked as is indicated on Figure 15. If the assigned shelter was a Type 1, an infinity is transferred to the proper $(ICE)_1$ matrix element. This will prevent reassigning Type 1 shelters to this location. It is also necessary to research the $(ICE)_1$ matrix for a new minimum element, if there are any less than infinity, and to use this data for the new shelter Type 1 scratch pad items.

If Type 2 shelters are ever to appear at this location, they must be conversions from Type 1. The $(ICE)_2$ matrix is therefore modified by replacing the element at this location by the corresponding element from the $(ICE)_{2-1}$ conversion matrix. Two complications are possible. If the new shelter assignment occurred at the same location as the minimum element of $(ICE)_2$, it will be destroyed when the matrix is altered. It is therefore necessary to search the $(ICE)_2$ array for a new minimum element for the scratch pad unless, of course, the altered element is less than the previous minimum in which case it becomes the new minimum element. In general, this will not be the case and searching the matrix will be unnecessary. The altered element is merely compared with the previous minimum element to determine the new minimum element. The element of the $(ICE)_3$ matrix is replaced with the corresponding element of the $(ICE)_{3-1}$ conversion matrix. The same complications with regard to the scratch pad items need to be considered.

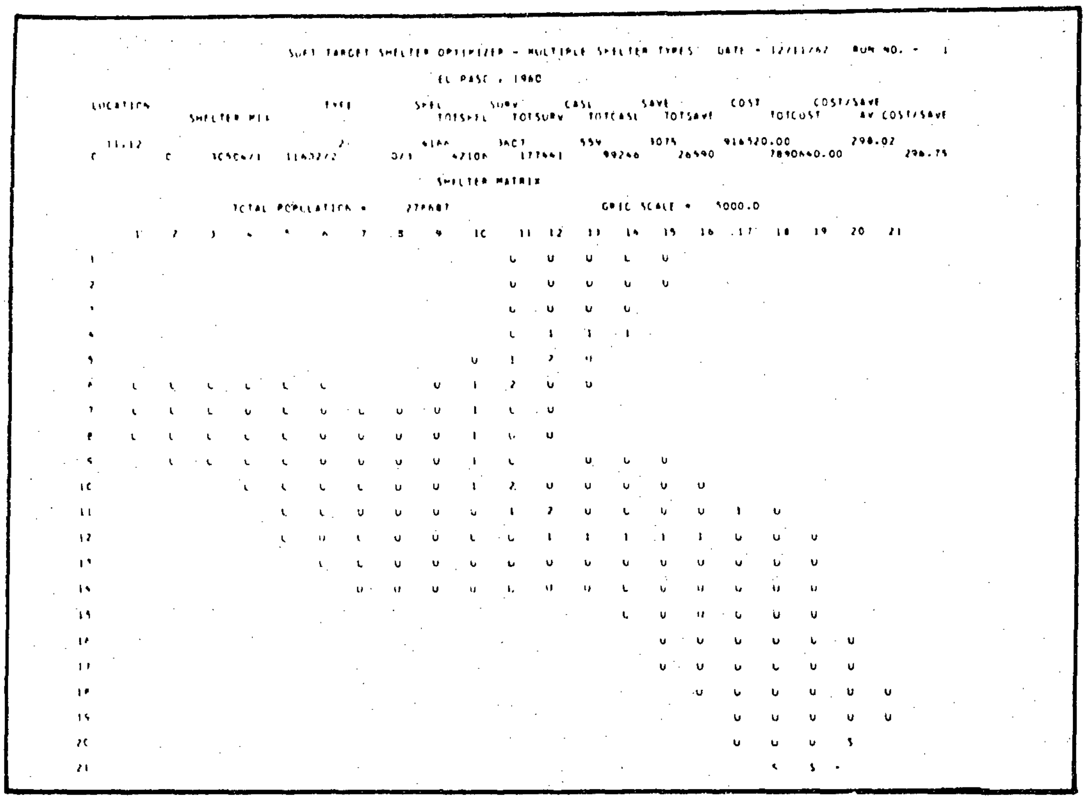
If shelter Type 2 is picked, an infinity is placed in the proper element of $(ICE)_1$. It is not necessary to search $(ICE)_1$ for a new minimum element unless the location of the minimum, as indicated by the scratch pad items, is the location of the assigned shelters. An infinity is also moved to the $(ICE)_2$ matrix location to prevent assigning more Type 2 shelters to this site. It will be necessary to search the matrix for the new scratch pad entries. Type 3 shelters will eventually be assigned to this element, but they will be conversions from Type 2. The $(ICE)_{3-2}$ element is therefore transferred into the $(ICE)_3$ matrix. The same complications exist with regard to the Type 3 scratch pad items as were described for Types 2 and 3 if a Type 1 shelter was chosen.

The procedure for correcting the primary matrices and scratch pad entries if a Type 3 shelter is picked should be clear from the information given on Figure 15 and in the previous discussion.

The program now begins a new computational cycle by again selecting the smallest of the three minimum elements in the scratch pad. In general, the $(ICE)_1$, $(ICE)_2$ and $(ICE)_3$ primary matrices will, in this order, become filled with infinity symbols. The process is complete after no non-infinity values exist in the $(ICE)_3$ matrix. Provisions for stopping the program after some input number of computational cycles is also provided.

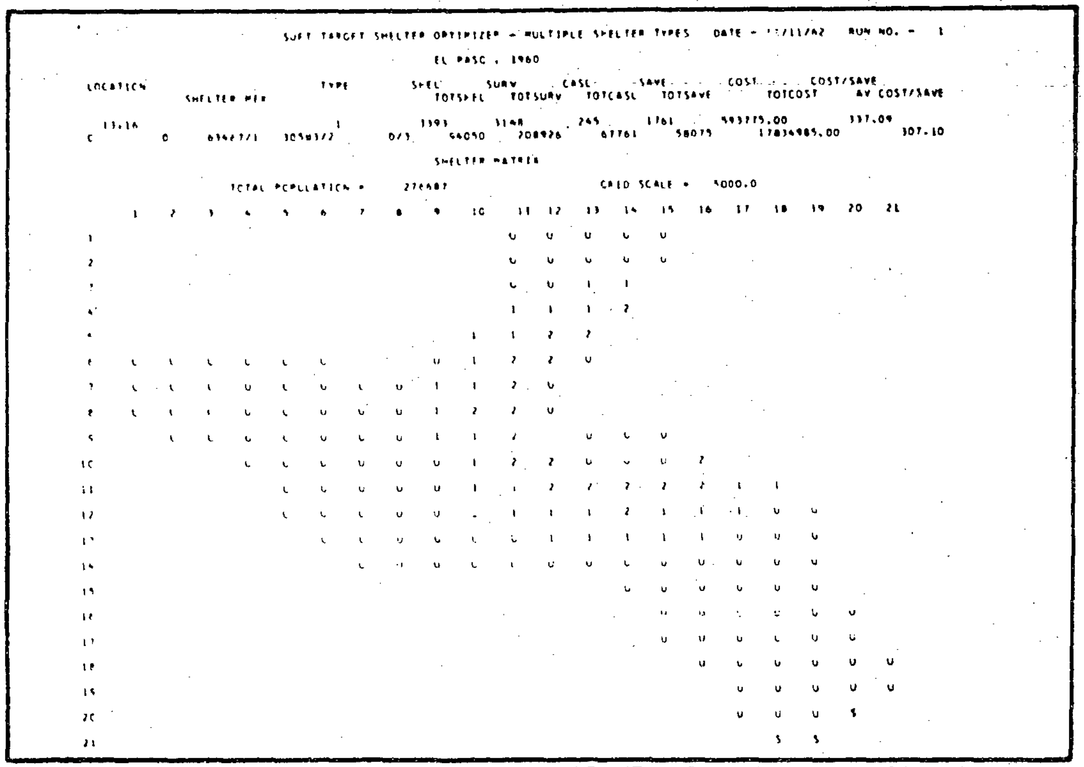
OUTPUT FORMATS

A simple case which has been used for checkout of the program is shown in the following figures. Figure 16 indicates optimum distribution of shelters at the level where the ICE averaged 297 dollars per survivor added but at a time when the cost was 298 dollars per additional survivor added. Figures 17 and 18 indicate the situation at later stages in the system development process and the high cost, in terms of dollars per additional survivors added, of shelters after shelters have been provided those locations where they are both needed and effective. The case was run with an arbitrary threat and example, though not necessarily unrealistic, shelter costs.



```
SOFT TARGET SHELTER OPTIMIZER - MULTIPLE SHELTER TYPES   DATE - 12/11/62   RUN NO. - 1
EL PASO , 1960
LOCATION    SHELTER MIX    TYPE    SHEL     SURV     CASL     SAVE     COST     COST/SAVE
                                   TOTSHEL  TOTSURV  TOTCASL  TOTSAVE  TOTCOST  AV COST/SAVE
SHELTER MATRIX
GRID SCALE = 5000.0
```

FIGURE 16 SHELTER-TYPE LOCATION PRINTOUT FOR ICE OF 298 DOLLARS



```
SOFT TARGET SHELTER OPTIMIZER - MULTIPLE SHELTER TYPES   DATE - 12/11/62   RUN NO. - 1
EL PASO , 1960
LOCATION    SHELTER MIX    TYPE    SHEL     SURV     CASL     SAVE     COST     COST/SAVE
                                   TOTSHEL  TOTSURV  TOTCASL  TOTSAVE  TOTCOST  AV COST/SAVE
SHELTER MATRIX
GRID SCALE = 5000.0
```

FIGURE 17 SHELTER-TYPE LOCATION PRINTOUT FOR ICE OF 337 DOLLARS PER SURVIVOR ADDED

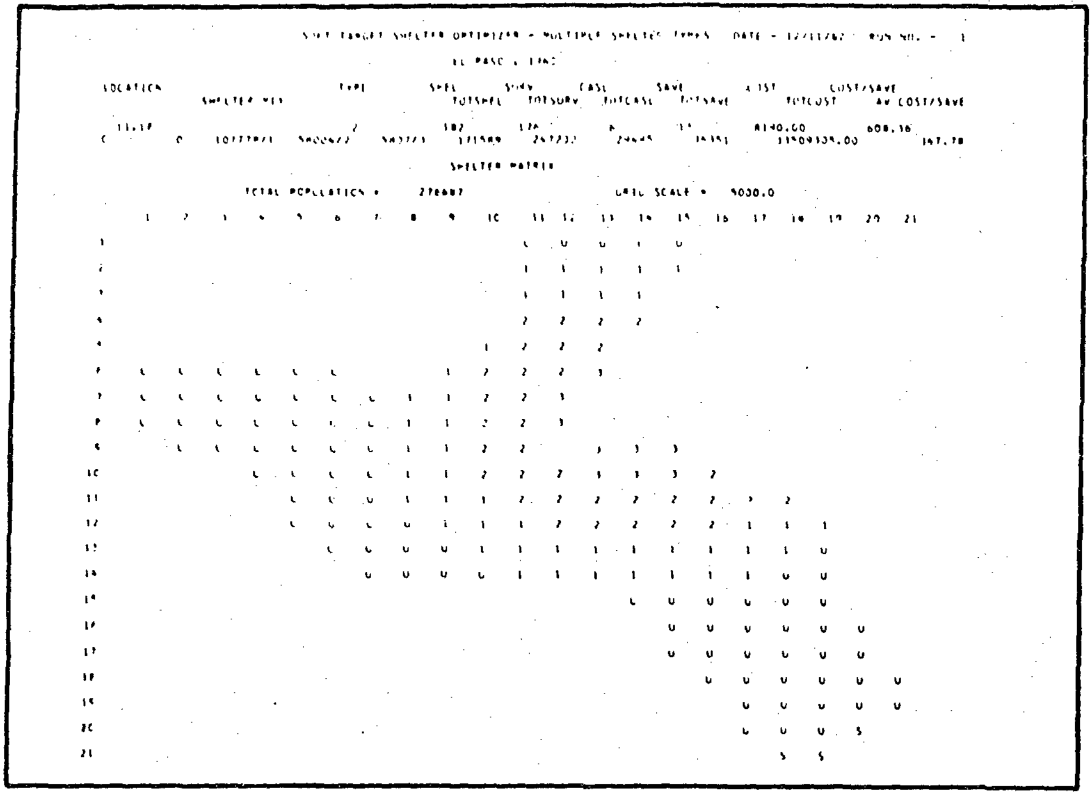


FIGURE 18 SHELTER TYPE LOCATION PRINTOUT FOR ICE OF 608 DOLLARS PER SURVIVOR ADDED

Figures 16 through 18 illustrate typical shelter mix and deployments corresponding to points along a maximum effectiveness versus total system cost curve. A typical optimal cost effectiveness curve, which might have been generated by either of the optimizer programs previously described, is shown on Figure 19. The significant variable is plotted as a function of the number of shelters in the system.

The total system cost curve rises linearly from zero at zero shelters in accordance with the constant cost assumption of these programs. The number of survivors increases rapidly with number of shelters for small numbers of shelters and then flattens off as the marginal effectiveness of additional shelters becomes low. The total casualties curve is identical in the opposite sense. It falls rapidly until all the locations where shelters are useful have been filled and then levels off. It does not go to zero when all of the population is sheltered since shelters will not help in neighborhoods near the aim point.

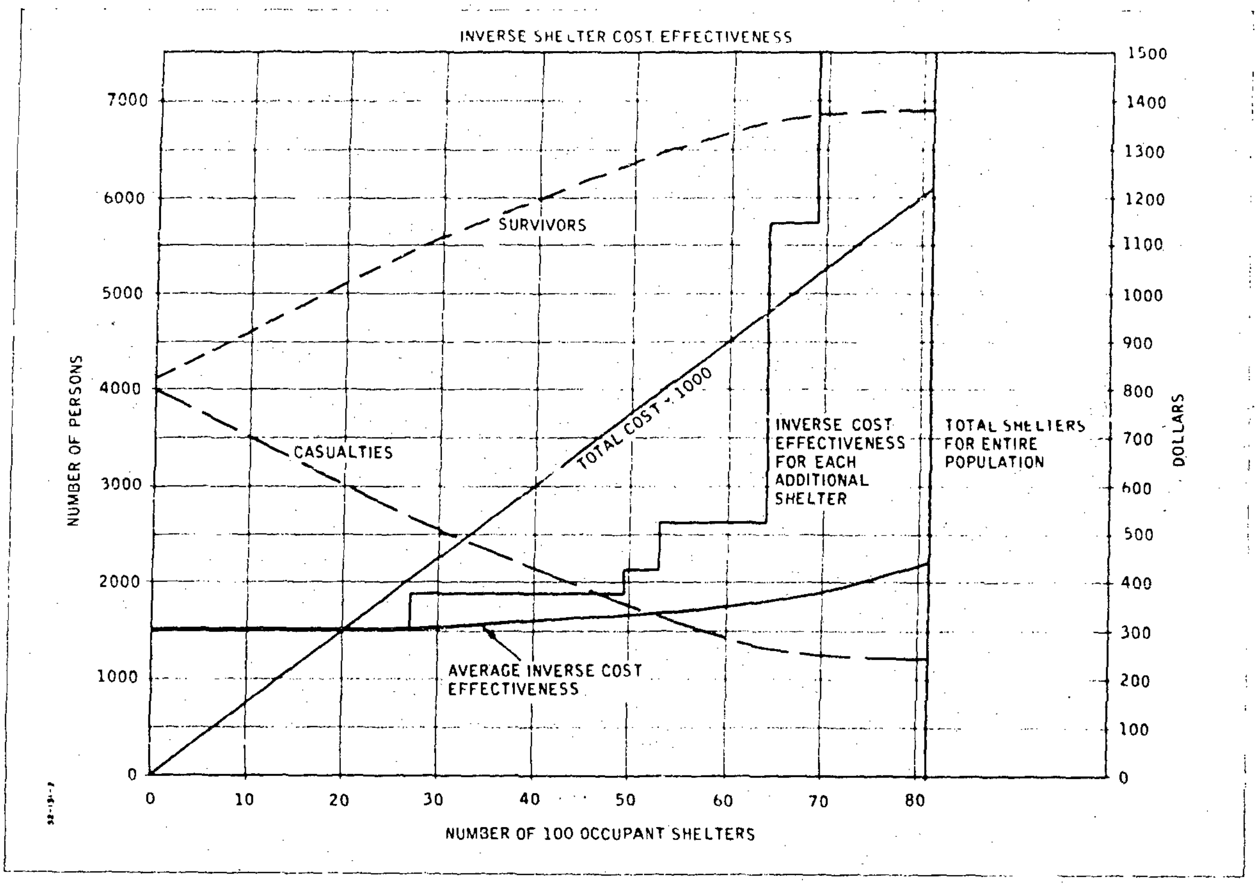


FIGURE 19 TYPICAL SHELTER OPTIMIZER RESULTS

The average inverse cost effectiveness is relatively flat except for the last shelters. The reason for this is that most of the shelters have reasonable locations and similar (ICE)'s and these tend to average the effect of shelters at a few extreme locations. The average (ICE) is, of course, based on the total cost and total saves, and is not the average of the marginal (ICE)'s.

The (ICE) for each additional shelter is perhaps the most interesting curve. It is low and constant for the first shelters and then increases at intervals, the marginal (ICE)'s for the last shelters being extremely high.

Each (ICE) for an additional shelter is equal to or larger than the (ICE) for any earlier shelter. This must be true for a maximum effectiveness versus number of shelters curve and may be considered a test of the proper operation of the optimizer action.

Arguments based on political, psychological or sociological realities may indicate that it would be impossible to obtain the support required to construct a shelter system in this locality unless shelters were provided for everyone. While this may be true, application of the Soft Target Study methodology indicates that sheltering everyone is highly wasteful. It might be argued that even though the cost per additional survivor is very high for the last 20 or so shelters in this community, they should be purchased if they have any chance of adding as few as one survivor. This attitude would not reflect a value for human life in a dollar limited situation since dollars spent for shelters in the high (ICE) areas would deny shelters in areas of other communities where they would be more effective. The high (ICE) regions in this example occur near the aimpoint, where the shelters were not hard enough, and at larger distances from the aimpoint where they were not needed. Section 3 describes procedures which may be used to obtain the allocation of a limited effort between localities which maximizes the expected number of total survivors.

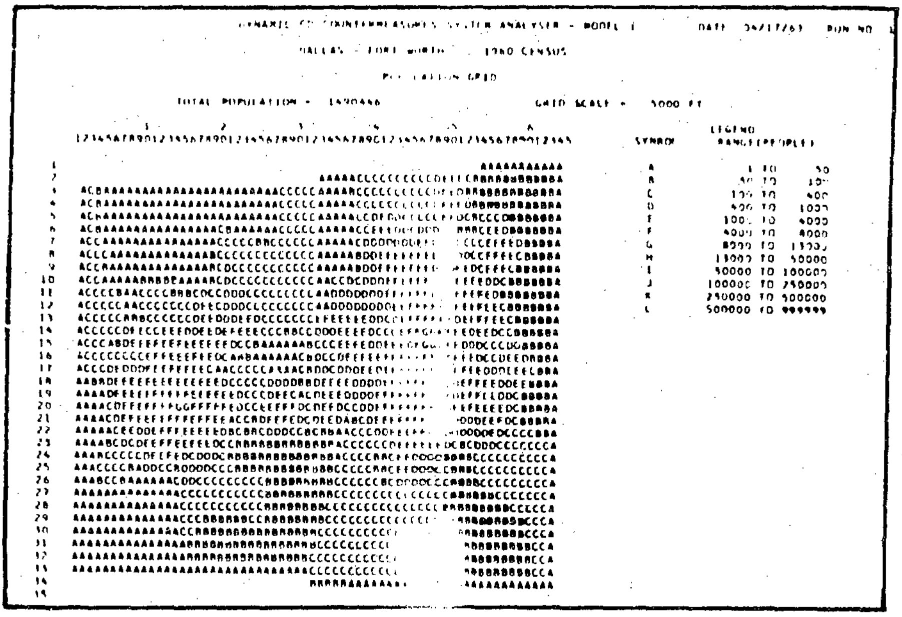
DYNAMIC ANALYZER

INTRODUCTION

The first multiple weapons effects program written during the study is called the Dynamic Analyzer. This program does not develop optimal countermeasure systems but rather determines the effectiveness of any particular system against a specified threat. This program may be used to compute the penalty, in terms of loss of expected survivors, of selecting a countermeasure system upon some basis other than maximizing the expected number of survivors at each total system cost level. The program was written to demonstrate that fast running computer programs using large population distribution arrays can be written and to test the feasibility of including phenomena which are functions of time such as fallout (which cannot be considered independent of prompt nuclear radiation) and population motion during the warning time and after the attack.

OUTPUT FORMATS

Figure 20 is a population matrix generated by this program. It applies to a situation involving two adjacent population centers. Figure 21 is a survival probability grid for the blast and thermal radiation effects of two weapons of different characteristics each detonated at one of the population centers for the unsheltered population case. The casualties due to these effects can be computed by summing the product of the corresponding elements of the two arrays shown.



```
DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE 04/17/63   RUN NO 1

                    DALLAS - FORT WORTH     1960 CENSUS

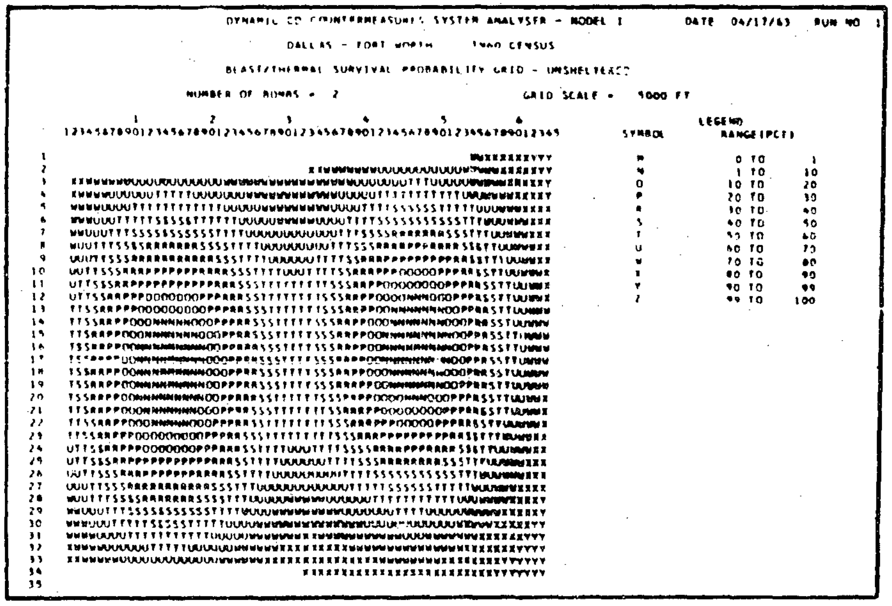
                          POPULATION GRID

          TOTAL POPULATION =   1490466                    GRID SCALE =   5000 FT

                                                                           LEGEND
                                                           SYMBOL      RANGE(PEOPLE)

                                                             A            1 TO     50
                                                             B           50 TO    100
                                                             C          100 TO    400
                                                             D          400 TO   1000
                                                             E         1000 TO   4000
                                                             F         4000 TO   8000
                                                             G         8000 TO  13000
                                                             H        13000 TO  50000
                                                             I        50000 TO 100000
                                                             J       100000 TO 250000
                                                             K       250000 TO 500000
                                                             L       500000 TO 999999
```

FIGURE 20 POPULATION GRID



```
DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE 04/17/63   RUN NO 1

                    DALLAS - FORT WORTH     1960 CENSUS

           BLAST/THERMAL SURVIVAL PROBABILITY GRID - UNSHELTERED

          NUMBER OF BOMBS =  2                             GRID SCALE =   5000 FT

                                                                           LEGEND
                                                           SYMBOL      RANGE(PCT)

                                                             M            0 TO      1
                                                             N            1 TO     10
                                                             O           10 TO     20
                                                             P           20 TO     30
                                                             R           30 TO     40
                                                             S           40 TO     50
                                                             T           50 TO     60
                                                             U           60 TO     70
                                                             W           70 TO     80
                                                             X           80 TO     90
                                                             Y           90 TO     99
                                                             Z           99 TO    100
```

FIGURE 21 BLAST THERMAL SURVIVAL PROBABILITY GRID

Figure 22 indicates the radiation survival probability for unsheltered population elements assuming no attempt is made to move from the contaminated areas. Both prompt and fallout nuclear radiation is included in this figure. The survival probabilities were computed by calculating the time integral of fallout fields similar to those shown on Figures 3 through 5 and using a biological damage model which considers absorbed lethal radiation and partial tissue repair.

The composite effect of blast, and thermal and nuclear radiation is shown in Figure 23. The weapon attacking the population center on the right was detonated at a lower altitude than was the weapon impacting on the left of the diagram. The lethal effect of the greater amount of fallout is clearly shown on these illustrations.

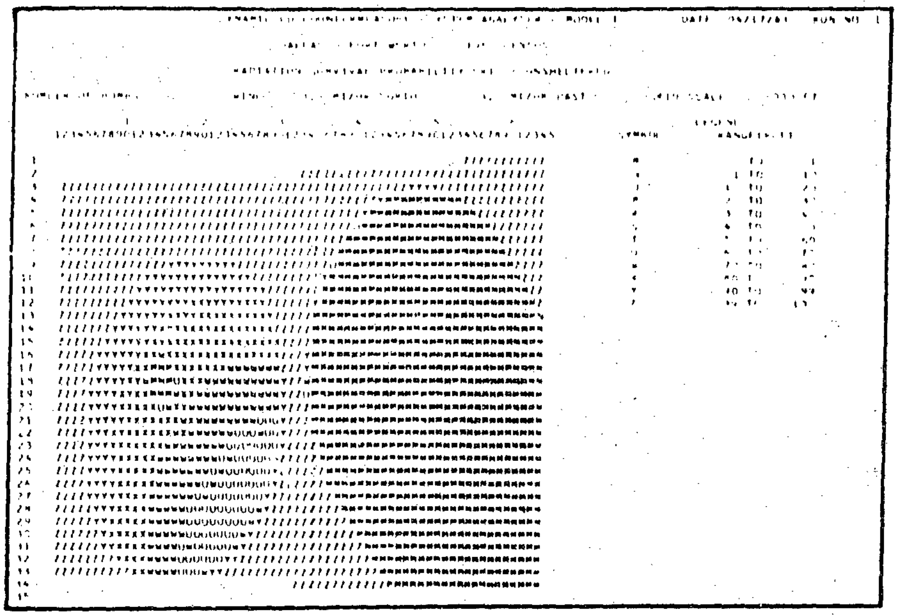
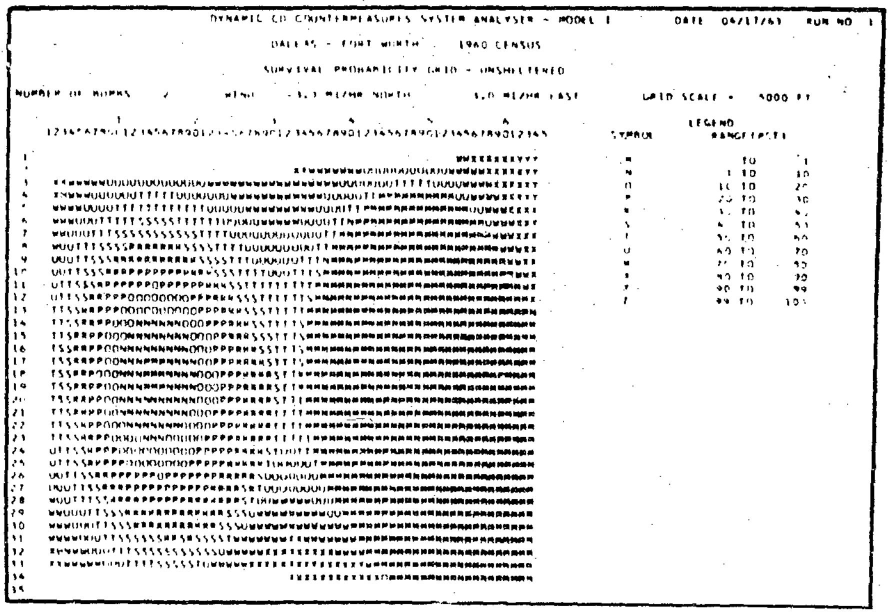


FIGURE 22 RADIATION SURVIVAL PROBABILITY GRID



DALLAS - FORT WORTH 1960 CENSUS

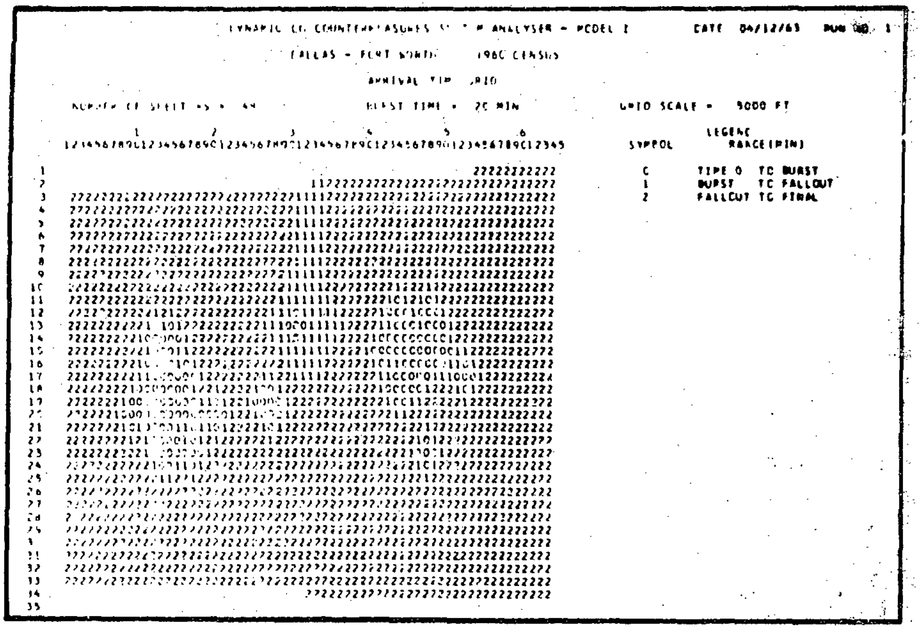
SURVIVAL PROBABILITY GRID - UNSHELTERED

GRID SCALE = 5000 FT

FIGURE 23 SURVIVAL PROBABILITY GRID - UNSHELTERED

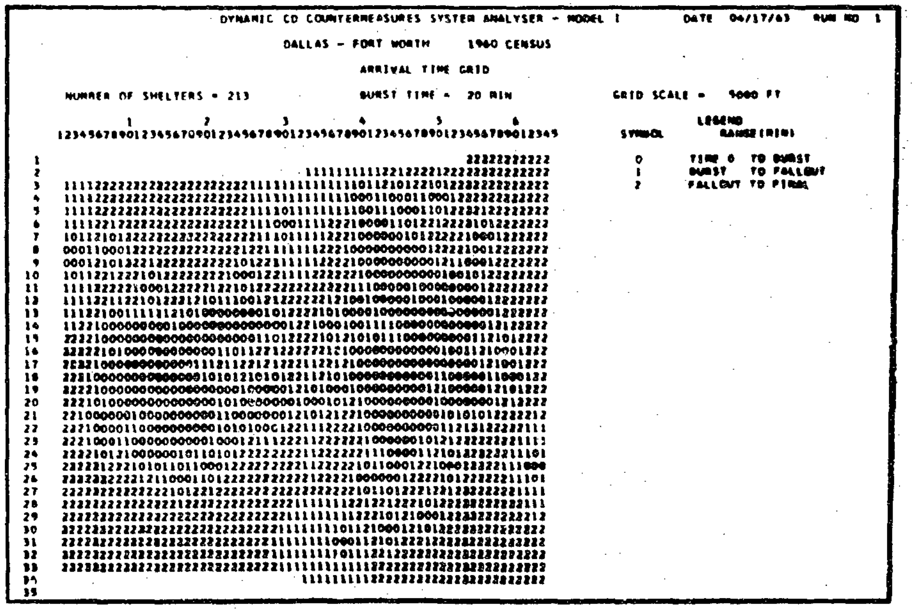
The next diagrams illustrate the arrival times of the population elements at their assigned shelters relative to the occurrence of the weapon effects. Figure 24 applies to a shelter system in which shelters are, in general, located in the central cores of the two population centers only. In Figure 25 the shelters are distributed at greater distances from the center of the cities.

The symbol "0" indicates that with this warning time the population at that element would be expected to be able to reach their shelters before occurrence of the blast. The distribution of this symbol is a function of warning time only, not on the characteristics of the attack. The symbol "1" indicates the blast would occur while the population element was enroute to the shelter. It should not be necessary to cross fallout fields to reach the shelter, however. The symbol "2" indicates that for this warning time and attack, this population element would be required to cross fallout fields to reach the shelter.



```
DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE 04/12/63   RUN NO. 1
                 DALLAS - FORT WORTH      1960 CENSUS
                         ARRIVAL TIME GRID
NUMBER OF SHELTERS = [illegible]      BURST TIME =  20 MIN        GRID SCALE =  5000 FT
                                                                        LEGEND
                                                               SYMBOL      RANGE(MIN)
                                                                 0      TIME 0  TO BURST
                                                                 1      BURST   TO FALLOUT
                                                                 2      FALLOUT TO FINAL
```

FIGURE 24 ARRIVAL TIME GRID, SYSTEM I

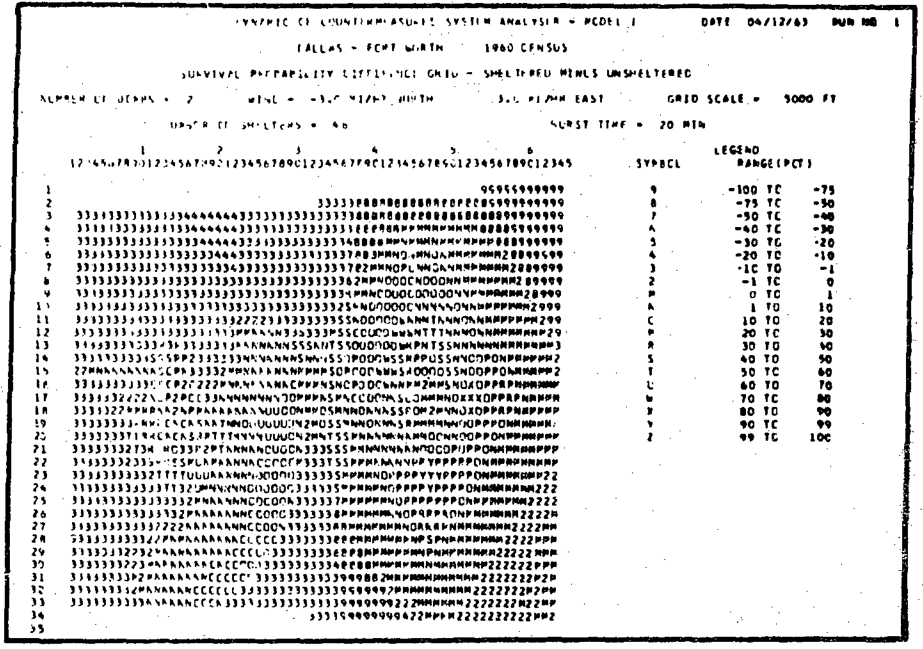


```
DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE 04/17/63   RUN NO 1
                 DALLAS - FORT WORTH      1960 CENSUS
                         ARRIVAL TIME GRID
NUMBER OF SHELTERS = 213          BURST TIME =  20 MIN        GRID SCALE =  5000 FT
                                                                        LEGEND
                                                               SYMBOL      RANGE(MIN)
                                                                 0      TIME 0  TO BURST
                                                                 1      BURST   TO FALLOUT
                                                                 2      FALLOUT TO FINAL
```

FIGURE 25 ARRIVAL TIME GRID, SYSTEM II

Figures 26 and 27 illustrate the concept of the probability difference matrix. The arrays apply to the same shelter systems as the previous illustrations. Each is compared to the no shelter countermeasure performance level although they could have been compared to each other. If this had been done, a single array would have indicated where each of the systems was the better and by how much.

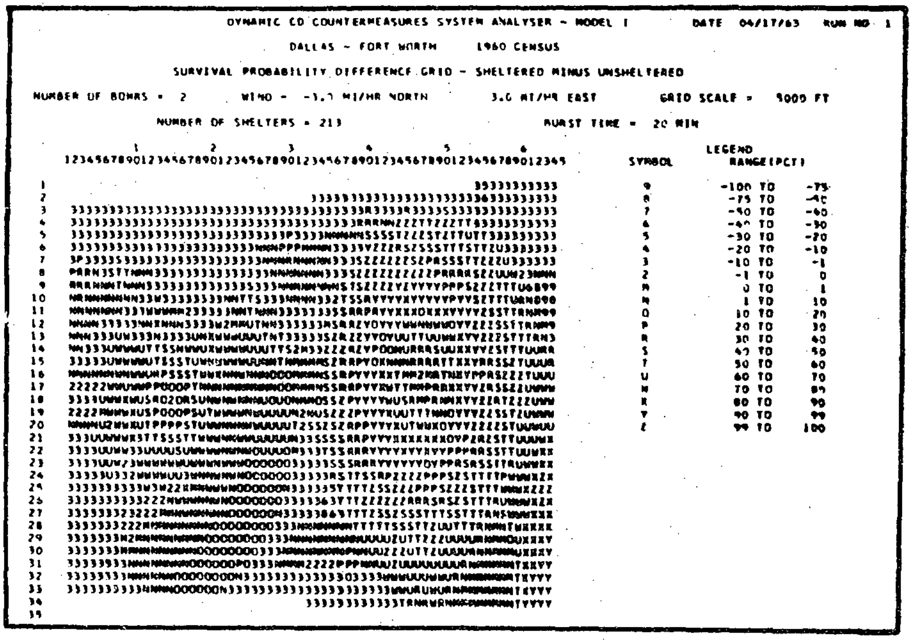
In the illustrations alphabet symbols such as "X", "Y", or "Z" indicate almost certain population loss without the shelter system and almost sure survival with the shelters given the instructions for the population to start for their assigned shelters at the beginning of the warning period. Symbols such as "N", "M", "2", or "3" indicate population elements for which the countermeasures had little effect. Other printouts of the program reveal whether this is a result of the situation being so severe that survival is hopeless in either case or whether the location of the element is so favorable that survival is essentially certain. Numerical symbols such as "8" and "9" mean survival was likely if the population in the element remained at their warning time locations, but was unlikely if the population at that element attempted to reach their shelters. This is a result of population moving from relatively safe locations toward the impact points and across the fallout fields.



```
DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE  04/12/63   RUN NO  1
                    DALLAS - FORT WORTH      1960 CENSUS
          SURVIVAL PROBABILITY DIFFERENCE GRID - SHELTERED MINUS UNSHELTERED
NUMBER OF BOMBS =  2      WIND =  -3.0 MI/HR NORTH      3.0 MI/HR EAST      GRID SCALE =   5000 FT
          NUMBER OF SHELTERS =  46                         BURST TIME =  20 MIN

                                                              LEGEND
                                               SYMBOL      RANGE(PCT)
                                                 9       -100 TO   -75
                                                 8        -75 TO   -50
                                                 7        -50 TO   -40
                                                 6        -40 TO   -30
                                                 5        -30 TO   -20
                                                 4        -20 TO   -10
                                                 3        -10 TO    -1
                                                 2         -1 TO     0
                                                 M          0 TO     1
                                                 N          1 TO    10
                                                 O         10 TO    20
                                                 P         20 TO    30
                                                 R         30 TO    40
                                                 S         40 TO    50
                                                 T         50 TO    60
                                                 U         60 TO    70
                                                 W         70 TO    80
                                                 X         80 TO    90
                                                 Y         90 TO    99
                                                 Z         99 TO   100
```

FIGURE 26 SURVIVAL PROBABILITY DIFFERENCE GRID, SYSTEM I

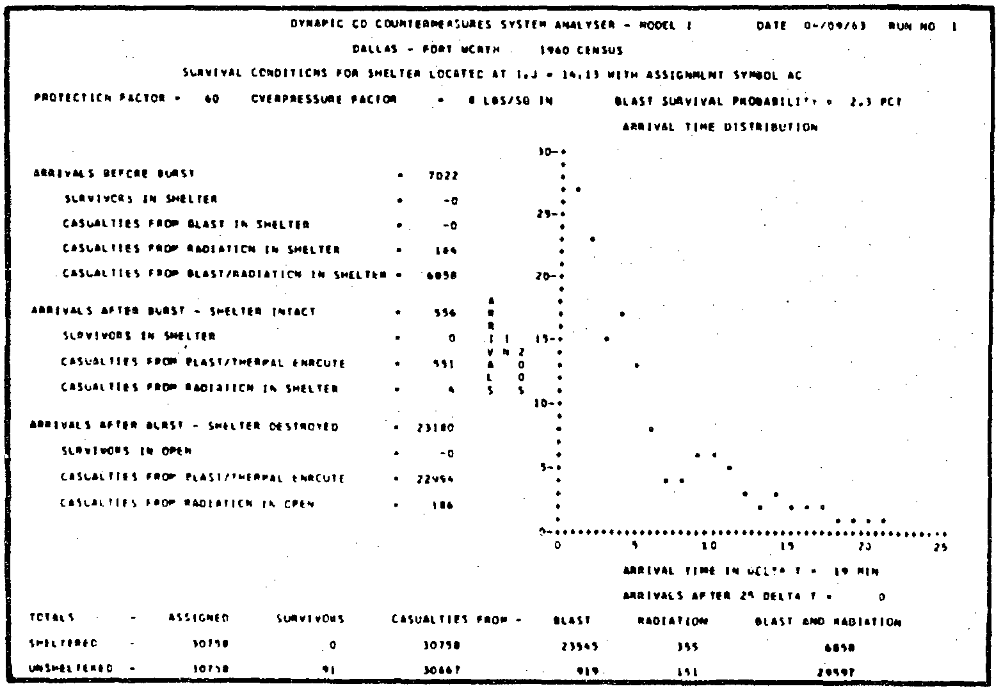


```
DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE  04/17/63   RUN NO  1
                    DALLAS - FORT WORTH      1960 CENSUS
          SURVIVAL PROBABILITY DIFFERENCE GRID - SHELTERED MINUS UNSHELTERED
NUMBER OF BOMBS =  2      WIND =  -3.0 MI/HR NORTH      3.0 MI/HR EAST      GRID SCALE =   5000 FT
          NUMBER OF SHELTERS =  213                        BURST TIME =  20 MIN

                                                              LEGEND
                                               SYMBOL      RANGE(PCT)
                                                 9       -100 TO   -75
                                                 8        -75 TO   -50
                                                 7        -50 TO   -40
                                                 6        -40 TO   -30
                                                 5        -30 TO   -20
                                                 4        -20 TO   -10
                                                 3        -10 TO    -1
                                                 2         -1 TO     0
                                                 M          0 TO     1
                                                 N          1 TO    10
                                                 O         10 TO    20
                                                 P         20 TO    30
                                                 R         30 TO    40
                                                 S         40 TO    50
                                                 T         50 TO    60
                                                 U         60 TO    70
                                                 W         70 TO    80
                                                 X         80 TO    90
                                                 Y         90 TO    99
                                                 Z         99 TO   100
```

FIGURE 27 SURVIVAL PROBABILITY DIFFERENCE GRID, SYSTEM II

The tabulated data on Figure 28 indicates the number of persons assigned to a shelter, how the arrival of the persons was distributed with respect to the time of the attack and the distribution of casualties and survivors among those persons arriving before and after the attack. Also included in this printout is a graph of the time distribution of arrivals at the shelter door. The time unit in this graph is the time required for the population to move from one grid element to another. The Dynamic Analyzer program is described in detail in Section 2.



```
                         DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE  0-/09/63   RUN NO  1
                                        DALLAS - FORT WORTH     1960 CENSUS
                  SURVIVAL CONDITIONS FOR SHELTER LOCATED AT I,J = 14,13 WITH ASSIGNMENT SYMBOL AC
PROTECTION FACTOR =   60     OVERPRESSURE FACTOR     =  8 LBS/SQ IN        BLAST SURVIVAL PROBABILITY =  2.3 PCT
                                                                             ARRIVAL TIME DISTRIBUTION

ARRIVALS BEFORE BURST                            =   7022
    SURVIVORS IN SHELTER                         =     -0
    CASUALTIES FROM BLAST IN SHELTER             =     -0
    CASUALTIES FROM RADIATION IN SHELTER         =    164
    CASUALTIES FROM BLAST/RADIATION IN SHELTER   =   6858

ARRIVALS AFTER BURST - SHELTER INTACT            =    556
    SURVIVORS IN SHELTER                         =      0
    CASUALTIES FROM BLAST/THERMAL ENROUTE        =    551
    CASUALTIES FROM RADIATION IN SHELTER         =      4

ARRIVALS AFTER BURST - SHELTER DESTROYED         =  23180
    SURVIVORS IN OPEN                            =     -0
    CASUALTIES FROM BLAST/THERMAL ENROUTE        =  22994
    CASUALTIES FROM RADIATION IN OPEN            =    186

                                                                   ARRIVAL TIME IN DELTA T =  19 MIN
                                                                   ARRIVALS AFTER 25 DELTA T =      0
TOTALS        -    ASSIGNED      SURVIVORS      CASUALTIES FROM -    BLAST     RADIATION      BLAST AND RADIATION
SHELTERED     -       30758           0             30758            23545        355                6858
UNSHELTERED   -       30758          91             30667              919        151               29597
```

FIGURE 28 SURVIVAL CONDITIONS FOR SHELTER AC

MULTIPLE EFFECTS WEIGHTED STRATEGY SHELTER OPTIMIZER

INTRODUCTION

The techniques for optimizing shelter systems which were used in the Multiple Shelter Type Mix and Location Optimizer, the procedures for handling the deposition and decay of fallout used in the Fallout Radiation Field Diagram Generator, the effect of radiation fields on the population used in the Dynamic Analyzer and critique of these programs by others were applied to the final shelter optimizer program written during the study.

This program has been named the Multiple-Effects, Weighted Strategy Shelter Optimizer. The procedure takes into account multiple weapon effects, uncertainties in the threat, uncertainties in the Meteorological conditions existing at the time of the attack and the fact that natural protection afforded otherwise unsheltered population elements differs from place to place. The routine employs large, variable size population distribution matrices and the results of a single computer run may be combined with other results so the program is easily applied to geographic regions of any desired size.

PROGRAM CHARACTERISTICS

The shelter catalog concept used in previous programs has been extended to include the fact that the suitability of a shelter type at some location depends on the present condition at that location. A catalog listing the characteristics of the different kinds of unsheltered situations in the area of interest, which may include existing shelters, is a new program input. A shelter correlation input matrix is shown on Figure 29. The numbers of the unsheltered situations are shown across the top of the matrix. The numbers of the countermeasures, or combinations of compatible countermeasures, appear in the column at the left. The matrix entries are binary yes or no symbols which indicate whether that countermeasure should be considered at locations where that particular unsheltered condition occurs. The matrix is used to permit consideration of such limitations as: basements of large buildings can only be stocked if such buildings exist, the cost of adding fallout shelters to schools depends on whether the schools exist or are planned and the cost of blast shelters depends on the subsurface conditions.

UNSHELTERED SITUATION TYPE

COUNTERMEASURES TYPE

	1	2	3	4	5	6	▬	▬	▬	▬
▬								●		
5					●					●
4	●		●			●			●	
3		●	●							
2		●			●		●			
1			●	●						

FIGURE 29 SHELTER CORRELATION INPUT MATRIX

It may seem that optimization of countermeasure systems for a particular threat is undesirable since it is unlikely that, given that war occurs, the attack would exactly correspond to the threat assumed. It is true that if nothing whatever is assumed about the threat, no quantitative, which is to say reasonable, study of the problem can be made. It is, however, possible to optimize a Civil Defense system if several attack patterns are considered possible with perhaps different likelihoods. The optimization procedure here described accepts any reasonable number of attack possibilities and the probability of occurrence of each as input. For each weapon of each attack pattern, the aimpoint, yield, CEP, and burst altitude are also required. The program maximizes the expected number of survivors at every total system cost level for this uncertain threat picture.

The weapon effects considered are blast, thermal radiation, prompt nuclear radiation and fallout. Prompt nuclear radiation and fallout are not considered independently. The effect of fallout depends upon the winds at the time of the attack. These winds are as uncertain as the threat. For this reason, program inputs include any number of wind seasons and the probability of occurrence of each. The probability may be the fraction of the year to which the wind season applies or, if the threat definition includes time of the year when an attack is to be expected, the likelihood for the season may be weighted to include the additional information in the optimization process. A wind season is specified by a mean wind vector and vector standard deviation

The previous countermeasure optimization programs have employed fixed size population matrices. The present program applies what we have termed the shelter vector concept. This idea has not only given us a greatly improved understanding of the ICE/CICE algorithms but has suggested bookkeeping procedures which have resulted in a very easily applied program. The matrix size is variable but has not been made essentially unlimited since the requirement for very short running time is still present. The maximum width of the target matrix is 134 elements, the number of useable output characters per line for the printer used. The length of the array is only subject to the limitation that the number of non-zero elements must not exceed a large number (about 25,000) divided by the number of shelter types plus 1. The unsheltered condition number is added to the input card required for each non-zero population matrix element. While the maximum size of a population matrix is limited, shelter assignment matrices computed at the same ICE/CICE level may be directly combined. The total system cost and total survivors added legends for these arrays are also directly additive. The program can, therefore, be easily applied to geographic regions of any size.

One of the operations of the program is to apply the optimization process to one element at a time. A typical situation is shown on Figure 30. The position of three shelters on a cost versus survivors added plane are shown. It is clearly proper to initially assign Type 1 shelters to this location since the slope of the line (ICE) corresponding to assigning shelters to this location is the least possible. The program would next consider whether to convert the Type 1 shelters to Type 2 or Type 3. Both possibilities improve the effectiveness of the system at an increase in total system cost. The slope of the lines connecting the Type 1 point with the other points are the CICE levels associated with these conversions. In the example, the optimal assignment sequence is to convert directly from Type 1 to Type 3 countermeasure types. Type 2 shelters, although in the proper order with respect to both cost and survivors added, do not appear in the optimal assignment sequence for this element. It may, however, appear in the optimal assignment sequence at another location where the threat is different.

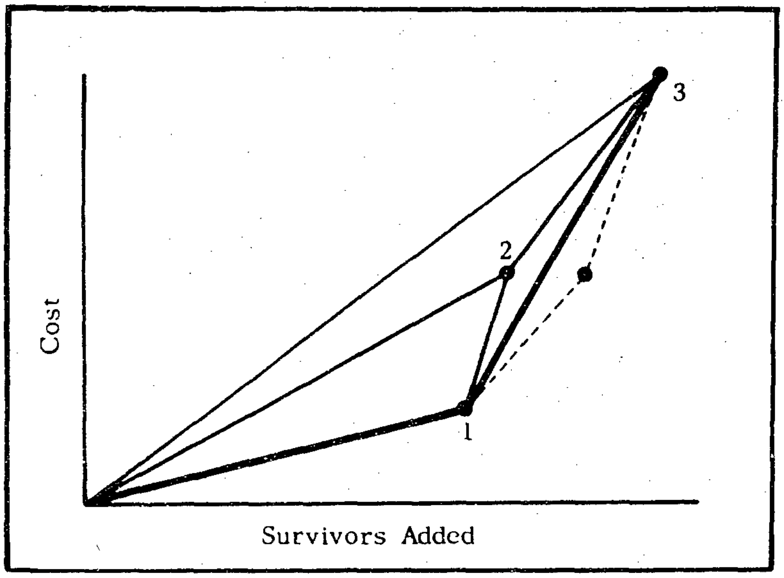


FIGURE 30 EXAMPLE SHELTER ASSIGNMENT ALGORITHM

Another operation of the program is to apply the optimization algorithm by merging the optimal assignment sequences for the individual elements to obtain the optimal sequence for the entire array. Figure 31 illustrates the procedure of merging two, two stage sequences by increasing CICE. This simple illustration also illustrates the fallacy of local countermeasure system optimization. Given a level of effort indicated by the arrow, one might ask whether the money would be best spent protecting Region 1, Region 2, or both. Providing optimal protection for Region 2 would result in more expected survivors added than would expending the money in Region 1. The optimal division of funds between the two regions results in the greatest system effectiveness at this cost level. This would indicate that Civil Defense planning should be accomplished at the highest level if the total number of expected survivors added for the total system cost is the only factor to be considered.

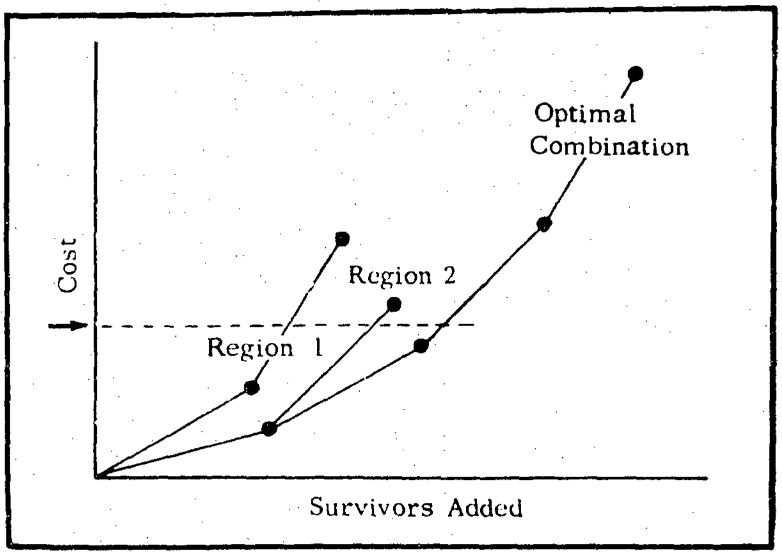


FIGURE 31 OPTIMAL COMPOSITE COST EFFECTIVENESS

Civil Defense decision makers would reasonably be interested in total system cost, total expected survivors added and many other factors. To the Civil Defense analyst taking the point of view herein described, the ICE/CICE level is the important parameter. Cost and survivors added are considered to be functions of the ICE/CICE parameter. The program could, for example, be used to develop the optimal cost versus effectiveness curves for two geographic areas. One might be tempted to say that the areas deserve the same total expenditure, or possibly the same expenditure per person, and develop the composite curve on this basis. These procedures would sacrifice expected survivors added. Shelter assignments grids, however, remain optimal if arrays generated at the same ICE/CICE level are pasted together. The composite costs and survivors added for the composite array are found by adding the values printed on the individual grids.

ACTIVE-PASSIVE DEFENSE

INTRODUCTION

It would seem reasonable that a Civil Defense countermeasure system optimizing procedure should take the possible existence of an active defense system into account. While this subject has not been seriously considered during the Soft Target Study, one start which has been made is a program which indicates the trade off between shelter hardness, active defense system area of coverage, maximum acceptable target value loss per missile, and intercept altitude for some stated threat and target value distribution. It is emphasized that acceptable target value loss is not here taken to be a value to be set by the analyst. It is rather a convenient independent variable not unlike ICE/CICE in other programs. This program has been coded for the Hughes H-330 computer. The procedure is to first make runs using the Damage Assessment program previously described as a function of weapon lethal radius. The results are then tabulated and used as input to the new program.

ANALYSIS PROCEDURE

Figure 32 is a cut-through of a damage assessment matrix of a type shown previously. The curve indicates the casualties to be expected from the stated weapon, detonating at optimum altitude, if the weapon is permitted to descend to its optimum burst altitude. A maximum acceptable loss level is also shown. The problem is how best to reduce the curve to the maximum acceptable level.

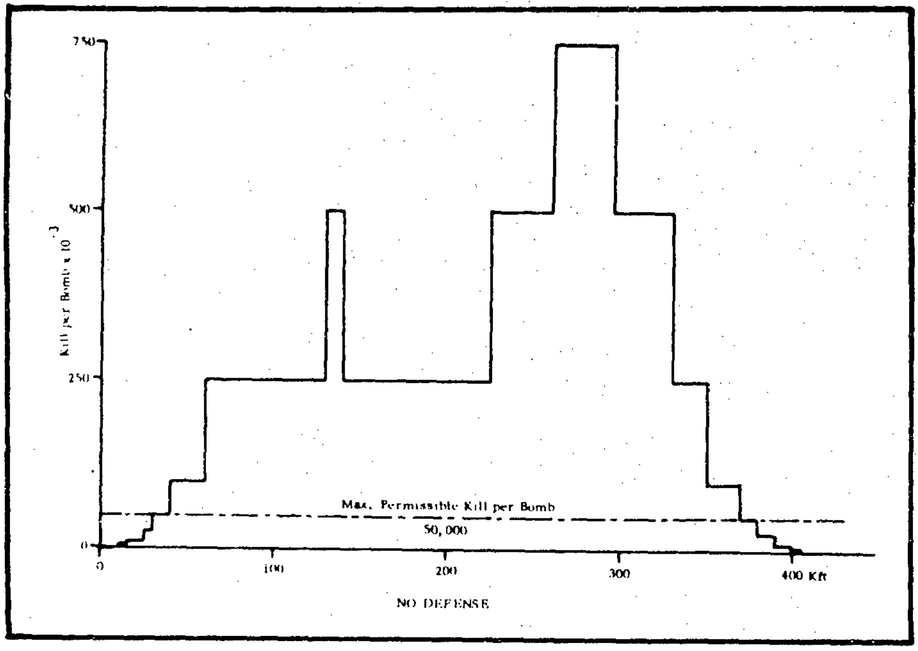


FIGURE 32 KILL PER WEAPON (NO DEFENSE)

It seems possible that the optimum defense system would consist of active and passive defense systems which would have different characteristics at each point. To avoid this complication, and perhaps to be practically realistic, the program considers only one shelter hardness at a time and provides everyone in the area with a shelter of this type. It is appreciated that everyone in the region should be provided with some form of passive defense to prevent an enemy from detonating a fallout producing surface burst upwind of the area, out of reach of the active defense system. Figure 33 illustrates the situation if everyone is protected by shelters of the stated hardness. It is noted that over some regions the expected target kill still exceeds the maximum acceptable level. The program now provides active defense for these intervals and these intervals only. It is clear that the size of these intervals, which correspond to areas in the computer program, are independent of the active defense system minimum intercept altitude.

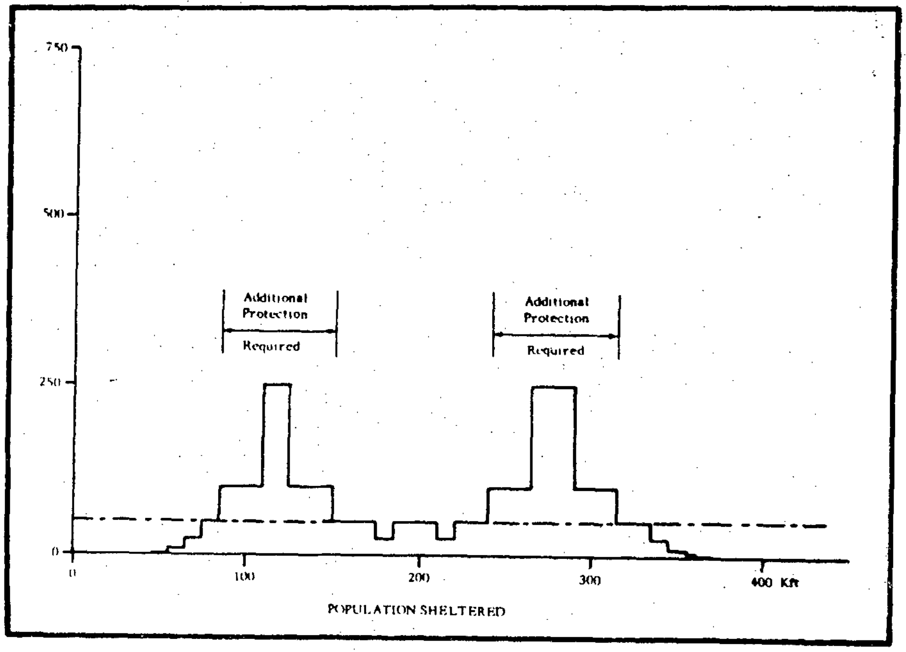


FIGURE 33 KILL PER WEAPON (PASSIVE DEFENSE)

The program now raises the minimum intercept altitude over the region requiring active defense from the optimum burst altitude to the burst altitude at which the expected target kill for the most critical element is reduced to the maximum acceptable level. The result is shown on Figure 34. The expected target kill value has been reduced to at least the maximum acceptable level everywhere. There are no attractive aimpoints and an effective attack would presumably be too expensive for an enemy to consider.

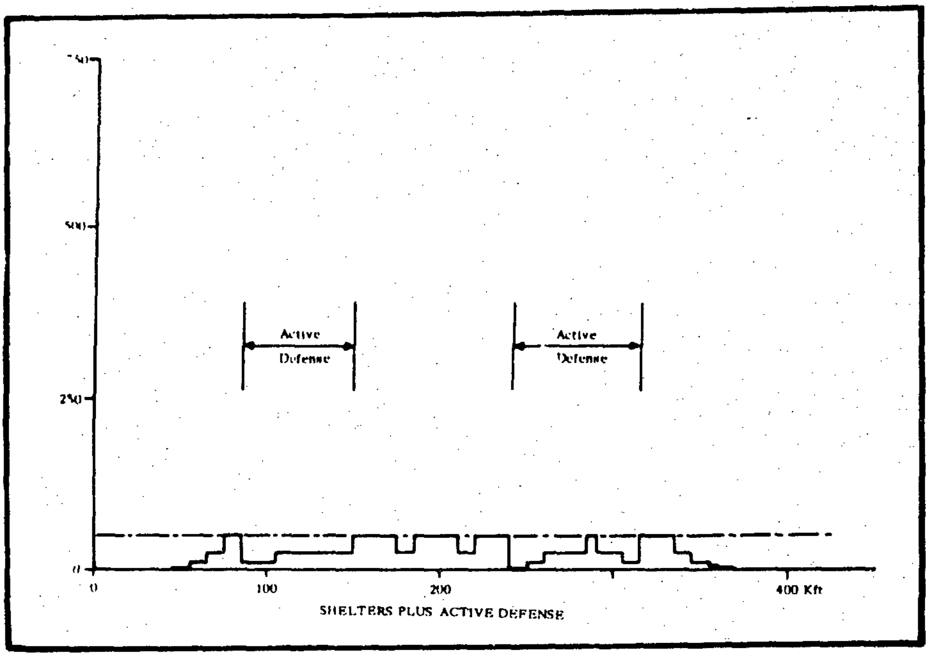


FIGURE 34 KILL PER WEAPON (ACTIVE AND PASSIVE)

In order to devise an optimum system in this way it would be necessary to repeat the analysis for a range of acceptable kill levels and shelter hardnesses. A cost analysis would then be performed to determine the cost of the minimum cost system as a function acceptable kill level. To provide this data the computer program prints a table of pairs of values of area of active defense coverage and the corresponding minimum intercept altitude as a function of shelter hardness and acceptable kill level. A separate page is required for each combination of area of interest and weapon yield of interest.

Three of a series of damage assessment runs which were made to obtain input data for the program are shown on Figures 35-37. An example trade-off table for a particular weapon yield is shown on Figure 38.

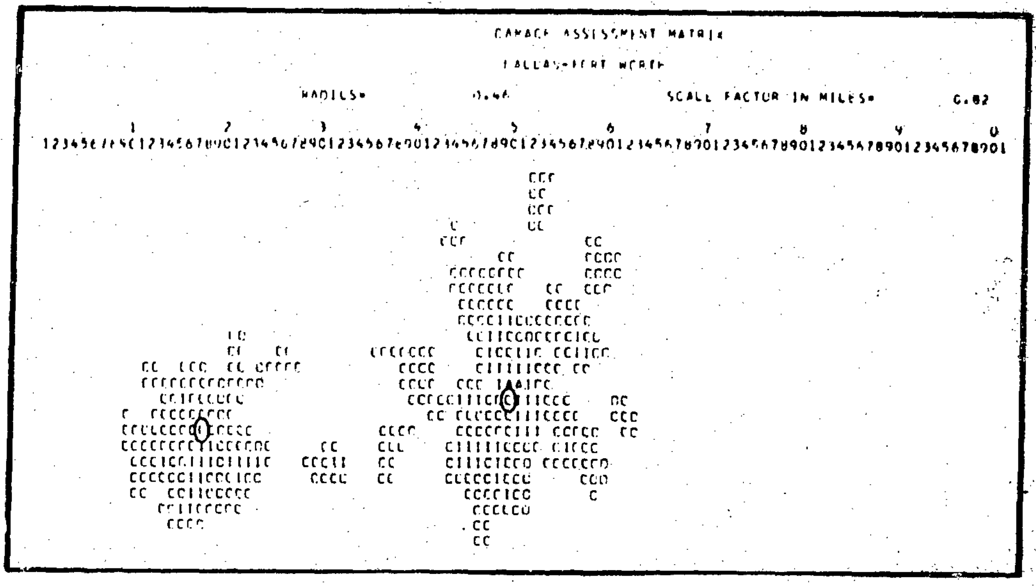


FIGURE 35 DAMAGE ASSESSMENT MATRIX, R = 0.46

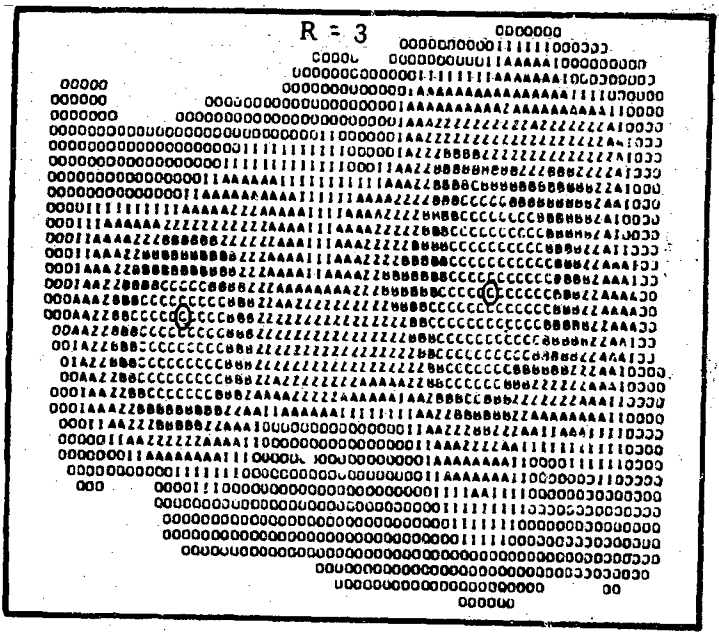


FIGURE 36 DAMAGE ASSESSMENT MATRIX, R = 3.0

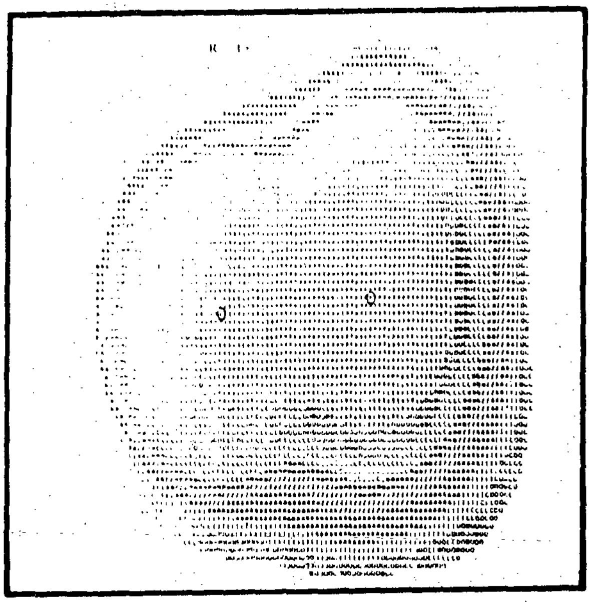
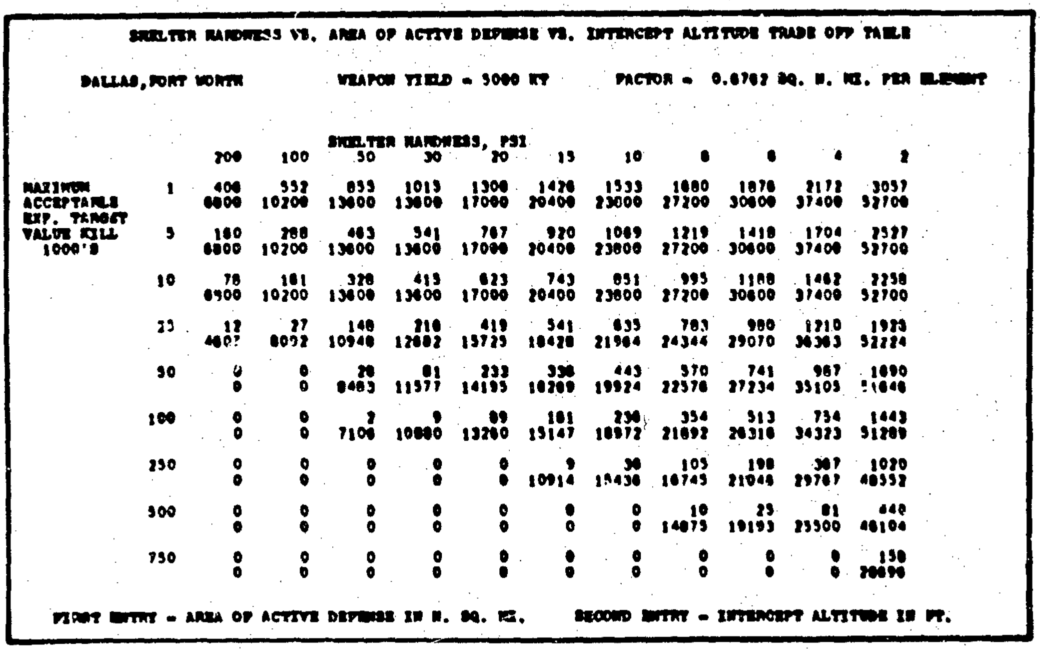


FIGURE 37 DAMAGE ASSESSMENT MATRIX, R = 15.0



SHELTER HARDNESS VS. AREA OF ACTIVE DEFENSE VS. INTERCEPT ALTITUDE TRADE OFF TABLE

DALLAS,FORT WORTH   WEAPON YIELD = 5000 KT   FACTOR = 0.0782 SQ. N. MI. PER ELEMENT

		SHELTER HARDNESS, PSI										
		200	100	50	30	20	15	10	8	6	4	2
MAXIMUM ACCEPTABLE EXP. TARGET VALUE KILL 1000'S	1	406 6800	552 10200	855 13600	1015 13600	1300 17000	1426 20400	1533 23800	1880 27200	1878 30600	2172 37400	3057 52700
	5	180 6800	288 10200	483 13600	541 13600	787 17000	920 20400	1089 23800	1219 27200	1418 30600	1704 37400	2527 52700
	10	78 6500	181 10200	328 13600	415 13600	623 17000	743 20400	851 23800	995 27200	1188 30600	1482 37400	2258 52700
	25	12 4607	27 8092	148 10948	218 12882	419 15725	541 18428	635 21984	783 24344	980 29070	1210 36363	1923 52224
	50	0 0	0 0	28 8483	81 11577	233 14195	338 18289	443 19924	570 22578	741 27234	987 35105	1890 51848
	100	0 0	0 0	2 7108	9 10880	89 13280	181 15147	238 18972	354 21892	513 28318	734 34323	1443 51289
	250	0 0	0 0	0 0	0 0	0 0	9 10914	38 15438	105 18745	198 21048	387 29787	1020 48552
	500	0 0	0 0	0 0	0 0	0 0	0 0	0 0	10 14875	25 19193	81 25500	449 48104
	750	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	150 28898

FIRST ENTRY = AREA OF ACTIVE DEFENSE IN N. SQ. MI.   SECOND ENTRY = INTERCEPT ALTITUDE IN FT.

FIGURE 38 ACTIVE - PASSIVE TRADEOFF TABLE

ACTIVE DEFENSE SYSTEM ANALYSIS

INTRODUCTION

The output of the Active-Passive Defense System program may be used to estimate the cost of an optimal system if the appropriate active and passive defense system costs are known. The cost of shelters has been considered by many Civil Defense investigators and is discussed in the Soft Target Study Second Quarterly Report. Active defense system costs have not been considered in the Soft Target Study since the existence of a possible active defense system has not been assumed. From a Systems Analysis point of view, the interesting problem is the computation of area of coverage and intercept altitude for a particular set of defense system components. For completeness in this summary discussion, two computer programs which perform these calculations will be briefly described.

DEFENSE SYSTEM MODEL I

The first program written was a three-dimensional geometry, timing and rate of fire model called Ballistic Missile Defense System Model I. The simulated system consisted of deployed sensor functions, called target acquisition radar, target evaluation radar, target tracking radar and missile tracking radar, and any number of deployed missile launch sites. The threat consisted of clouds of discrete objects. Each cloud could have any number of objects and any launch time. Each radar was characterized by such parameters as range, scan limits, location, required target tracking time, number of channels and whether it was subject to beam broadening with increasing scan angle. The interceptor missiles were of the command, command plus semi-active terminal homing or command plus active or passive terminal homing types.

MODEL I COVERAGE DIAGRAM GENERATOR

In order to obtain performance data for many impact points during a single computer run, a program called a two dimensional coverage diagram generator was written. This program used Model I as a subroutine to compute the area which could be defended by the defense system. A coverage diagram, labeled "Impact", is shown on Figure 39. The active defense system for this run consisted of a multi-function, single-array radar and colocated missile launcher. The threat missile position at significant event times for the impact points on the periphery of the coverage diagram and the threat trajectory for one impact point are also shown.

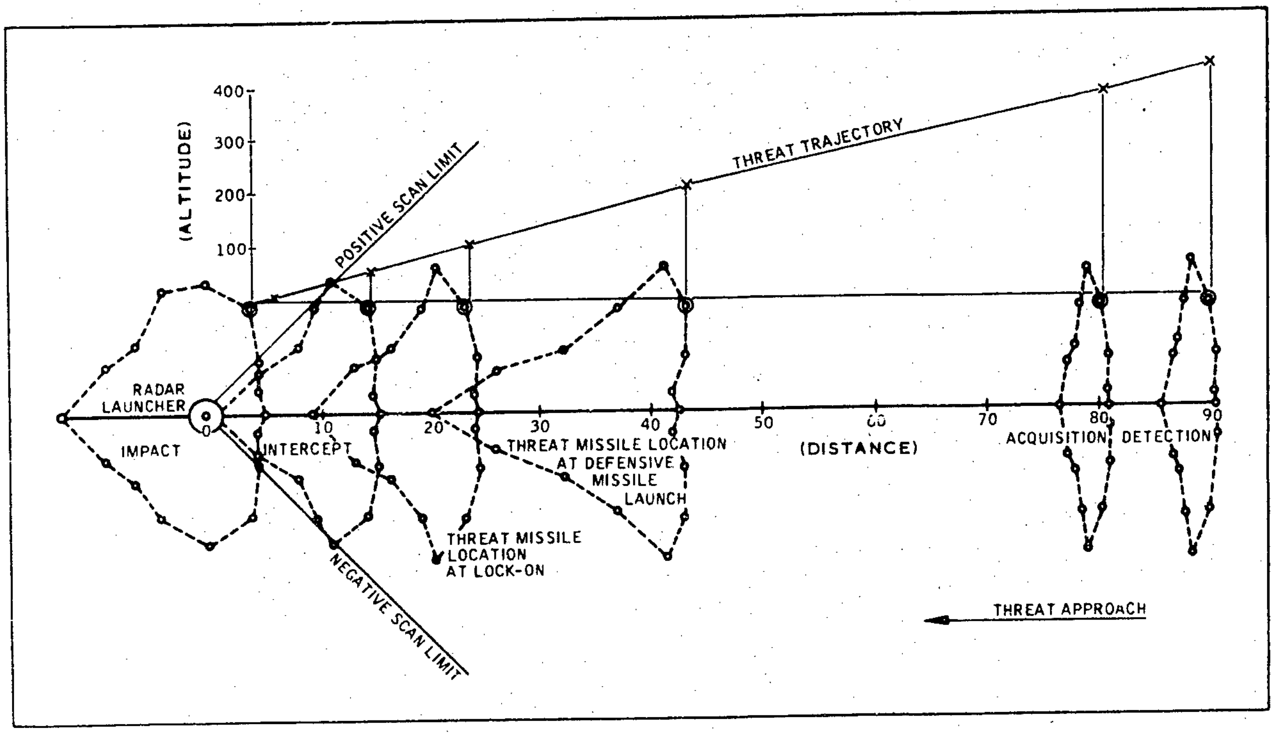


FIGURE 39 THREAT MISSILE POSITION AT SIGNIFICANT EVENT TIMES

The coverage diagrams were computed for a single threat missile azimuth of approach angle. The effect of this angle is shown on Figure 40. The defense system for this example consists of a multifunction, single-array radar and five deployed launch sites.

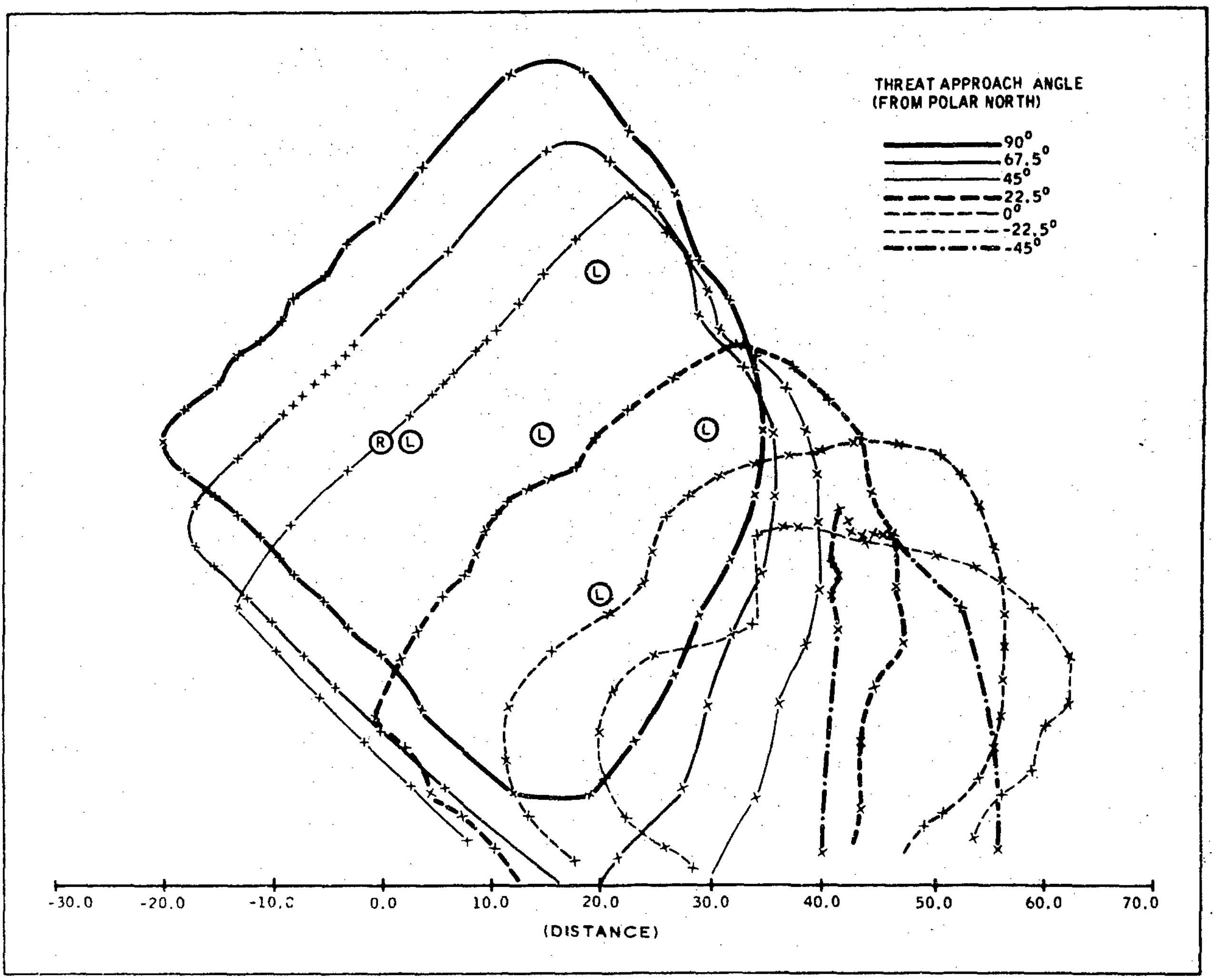
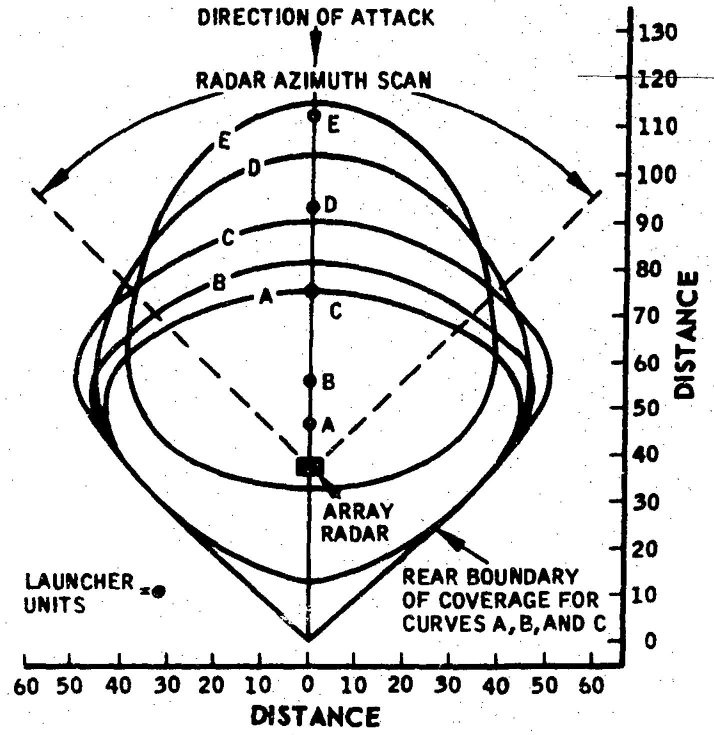


FIGURE 40 EFFECT OF THREAT MISSILE AZIMUTH BEARING

The use of the coverage diagram concept to study the effect of radar-launcher deployment is shown on Figure 41.



CURVE	SEPARATION BETWEEN LAUNCHER UNIT AND RADAR
A	9.3
B	18.5
C	37
D	55.5
E	74

FIGURE 41 COVERAGE DIAGRAMS FOR VARIOUS LAUNCHER RADAR DEPLOYMENTS

An example of the effect of jamming on the defense system coverage diagram is given on Figure 42. In Model I, the effect is considered due to a degradation in radar range. The reduced range is a program input.

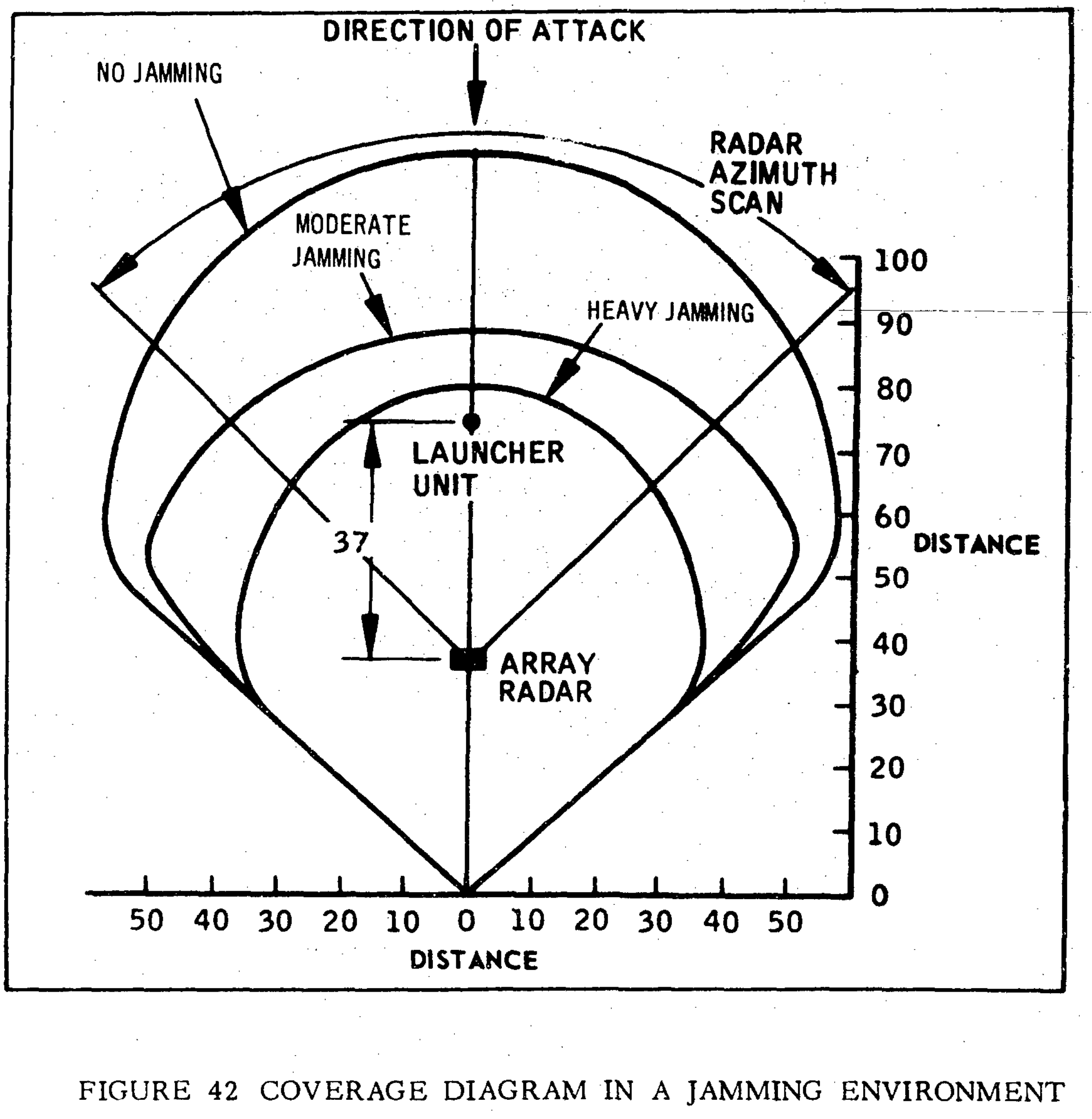


FIGURE 42 COVERAGE DIAGRAM IN A JAMMING ENVIRONMENT

DEFENSE SYSTEM MODEL II

Model I has many applications in the analysis and design of active defense systems. It is unsuitable for detailed calculations however. To provide a capability of studying detailed design problems another defense system model, called Model II, has been written. This program includes a pulse-by-pulse simulation of the system array radar.

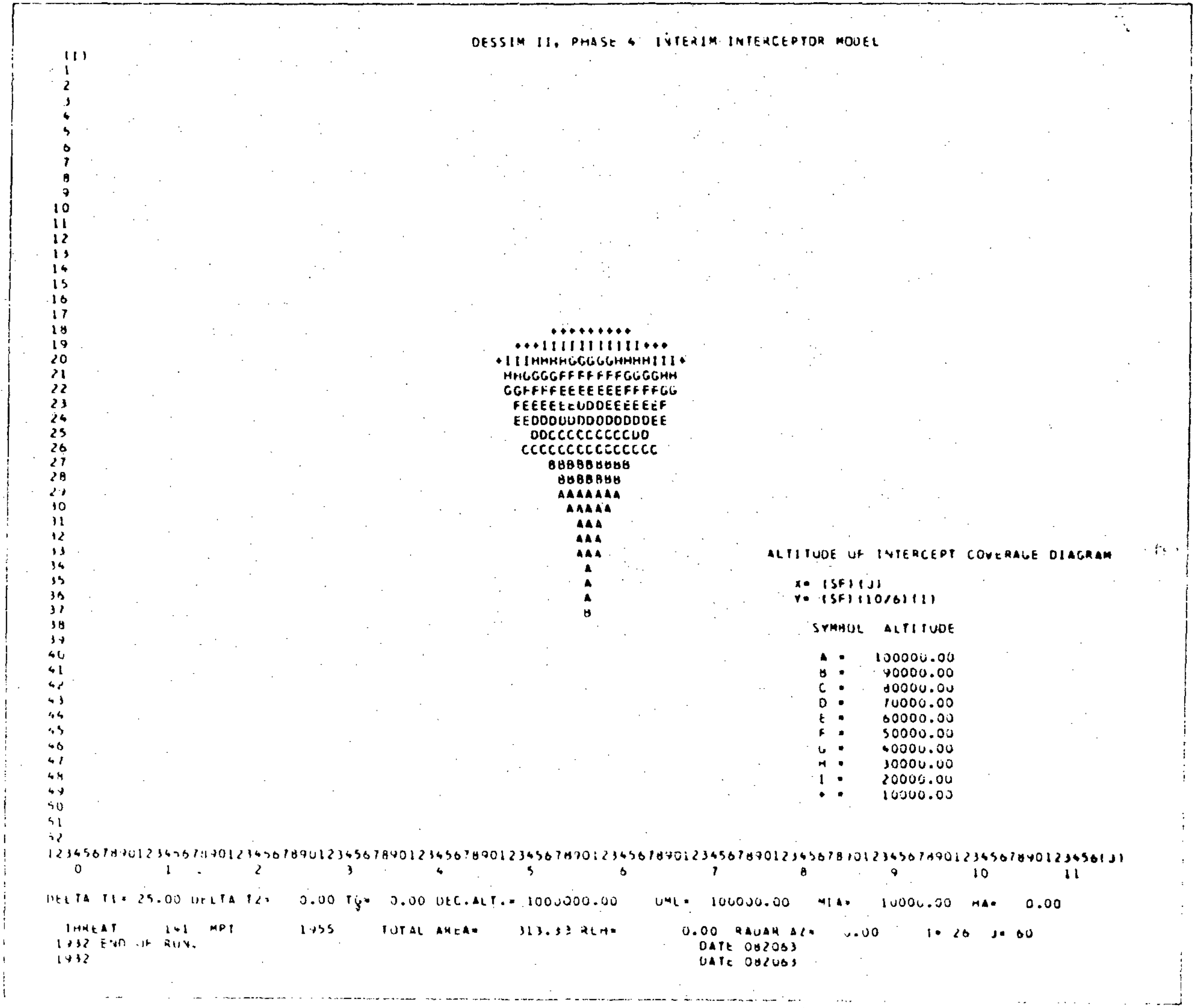
MODEL II COVERAGE DIAGRAM GENERATOR

The Model I coverage diagram generator was only three dimensional in the sense that the highest altitudes of intercept for the peripheral impact point were included as a separate printout table. A three-dimensional coverage diagram generator which uses the geometry mode of the Model II radar sub-model has been programmed. It is more accurate for a fixed running time, runs faster for a given accuracy, handles a greater variety of threat object trajectories, and has a more useful output format since it indicates the intercept altitude everywhere in the region of coverage. The region of coverage is indicated by a field of printout characters each of which represents a small interval of intercept altitudes. An example coverage diagram of this kind is shown on Figure 43.

COVERAGE DIAGRAM APPLICATION

The Active-Passive Defense System program which has been described considers the capability of an active defense system to be completely defined by area of coverage and intercept altitude. The example active defense system results which have been presented indicate the problem is more complicated than this. The area of coverage may not correspond to the areas computed by the active-passive program. It would not, in general, be possible to provide active defense system coverage over the desired area without overlapping the coverage of adjacent systems and overlapping the regions over which coverage is not required for a given acceptable loss level. Maximum intercept altitude is not constant over the coverage diagram. Both area of coverage and intercept altitude may depend on the threat missile trajectory.

The programs would be used by computing coverage diagrams for representative threat trajectories and approach angles. A composite coverage diagram indicating the minimum active defense system capability against these possible threats would then be constructed. The area and the lowest of the highest intercept altitudes in the diagram could be used with the Active-Passive Defense System program data to obtain preliminary estimates of the active-passive cost trade-off. More realistic costs can be determined by superimposing the composite coverage diagram on Damage Assessment maps of the type shown on Figures 35, 36, and 37.



```
                                                    DESSIM II, PHASE 4  INTERIM INTERCEPTOR MODEL
(I)
 1
 2
 3
 4
 5
 6
 7
 8
 9
10
11
12
13
14
15
16
17
18                                                              ++++++++++
19                                                       +++IIIIIIIIIIII+++
20                                                       +IIIHHHHGGGGGHHHHIII+
21                                                        HHGGGGFFFFFFFGGGGHH
22                                                        GGFFFFEEEEEEEEFFFFGG
23                                                          FEEEEEEDDDEEEEEEEF
24                                                          EEDDDDDDDDDDDDDDEE
25                                                            DDCCCCCCCCCCDD
26                                                           CCCCCCCCCCCCCCCC
27                                                              BBBBBBBBBB
28                                                               BBBBBBB
29                                                               AAAAAAA
30                                                                AAAAA
31                                                                 AAA
32                                                                 AAA
33                                                                 AAA                     ALTITUDE OF INTERCEPT COVERAGE DIAGRAM
34                                                                  A
35                                                                  A                        X= (SF)(J)
36                                                                  A                        Y= (SF)(10/6)(I)
37                                                                  B
38                                                                                             SYMBOL  ALTITUDE
39
40                                                                                              A =    100000.00
41                                                                                              B =     90000.00
42                                                                                              C =     80000.00
43                                                                                              D =     70000.00
44                                                                                              E =     60000.00
45                                                                                              F =     50000.00
46                                                                                              G =     40000.00
47                                                                                              H =     30000.00
48                                                                                              I =     20000.00
49                                                                                              + =     10000.00
50
51
52
123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456(J)
    0         1  .      2         3         4         5         6         7         8         9         10        11

DELTA T1= 25.00 DELTA T2=    0.00 TQ=  0.00 DEC.ALT.= 1000000.00    UML=  100000.00    MIA=   10000.00  HA=    0.00

  THREAT     141  MPT        1955      TOTAL AREA=     313.33 RCH=        0.00  RADAR AZ=   0.00      I= 26  J= 60
 1932 END OF RUN.                                                         DATE 082063
 1932                                                                     DATE 082063
```

FIGURE 43 EXAMPLE THREE DIMENSIONAL COVERAGE DIAGRAM

WEAPON DETONATION POINT LOCATION SYSTEM ACCURACY

INTRODUCTION

It is important, given that an attack occurs, that local Civil Defense leaders be aware of the yield altitude and GZ of weapons detonating in the vicinity, since prompt action during the minutes and hours following the attack can significantly decrease the effectiveness of the attack. If these quantities are known, the procedures which have been described may be used to perform damage assessments and to determine appropriate counteraction. Many of the uncertainties present in Building System studies no longer apply. There may, however, be inaccuracies in the weapon detonation point location system. The analysis procedures would be used by substituting the measured GZ coordinates for the estimated aimpoints used for planning studies. The accuracy of the detonation detection system would be used in the same way as weapon delivery system CEP is used during studies performed before the attack.

ERROR MAP GENERATOR

The accuracy of a weapon detonation point detection system may depend strongly on the geometry of the burst point relative to the deployed detection sites. The mathematics of several detection schemes have been programmed. Checkout results are shown on Figures 44, 45, and 46.

Figure 44 indicates the accuracy obtainable with two detection stations deployed on the oceans on either side of the United States as a function of weapon impact point. The detectors may be considered to be direction finders. The detonation points are computed by triangulating between the detection sites. The angular accuracy of these direction finders does not depend on the angle, but the CEP of the system depends on range and the angle between the intersecting LOP's.

The meaning of the map is indicated by the following:

Symbol	CEP
O	negligible
A	very small
B	small
C	medium
D	large
E	very large

The symbol "E" on Figure 44 is used in a band along the great circle connecting the two detection sites. Triangulation between two stations can not be used for impact points on or near the line of sight between the detectors because the LOP's are essentially parallel. The symbol "D" corresponds to an interval of large CEP's (but smaller than the "E" interval). It appears in two bands on either side of the great circle.

The symbols "A" and "O" normally only appear very near a detection site. The inputs used to generate the Figure 44 map specified that computations were not to be made for water map points since this would destroy shape of the land masses. The CEP of both land and water detonation points may be computed, but then it is necessary to determine the location of any symbol by referring to the latitude and longitude scales. Since the detectors were placed on the ocean for this run, no "A"s or "O"s appear. The symbol "B" occurs over land areas which are reasonably near one of the detectors or the other but not near the great circle connecting them. The symbol "C", corresponding to an interval of medium CEP's, appears over a large portion of the map.

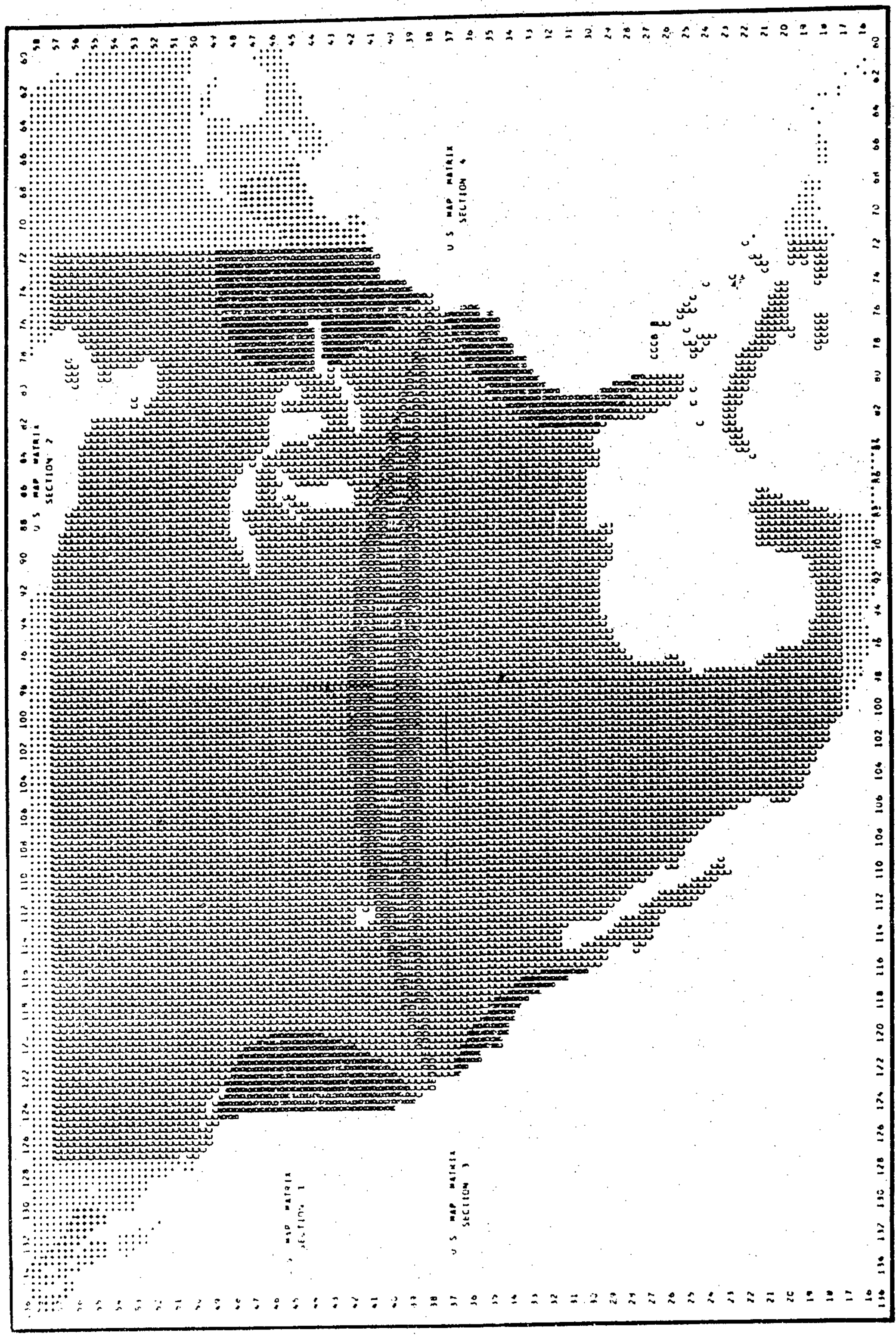


FIGURE 44 ERROR MAP, TWO SITES, CONSTANT D.F. ERROR

Figure 45 applies to the same deployment of two direction finders but the characteristics of the direction finders have been changed to make the angular accuracy a function of the angle. The orientation of the sites is east or west, whichever is toward the center of the map. The angular error of the direction finders approaches infinity as the angle approaches 90 degrees from the direction finder axis. While this change reduced the area occupied by the symbol "B" somewhat, it did not change the situation near the great circle connecting the detectors or over the major part of the country significantly. The change is most apparent on the corners of the map within the latitude and longitude limits for which the computations were made. Since these detonation points involve angles from one or the other detector which are essentially 90 degrees from the axis, the system CEP is very poor.

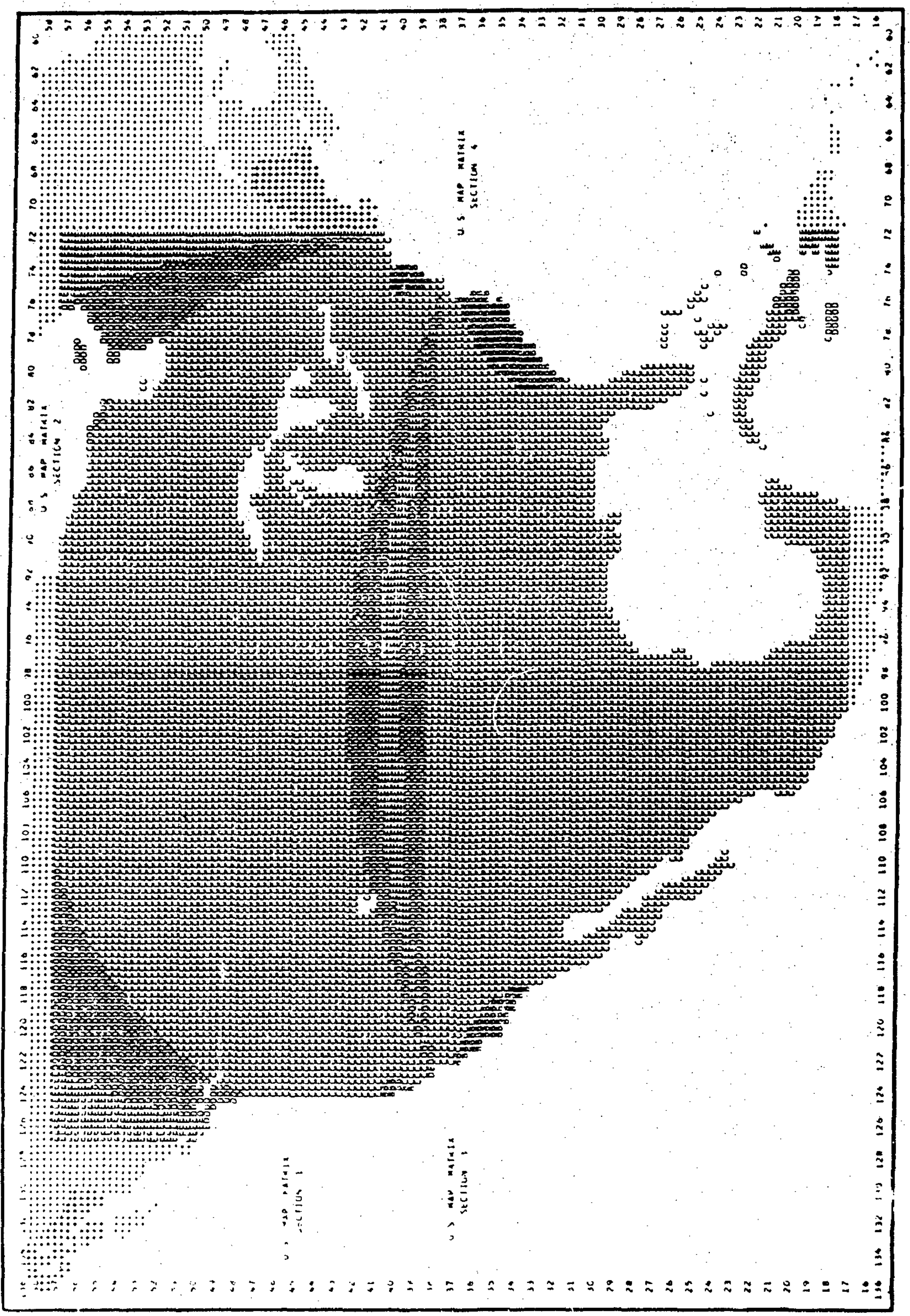


FIGURE 45 ERROR MAP, TWO SITES, D.F. ERROR f(1/cos θ)

Figure 46 is a CEP map for three direction finders deployed approximately in an equilateral triangle with a base line of 2 map elements. This results in the 6 lobed diagram shown. Each of the three major lobes are along the normal bisector of a base line in the direction of the third detector.

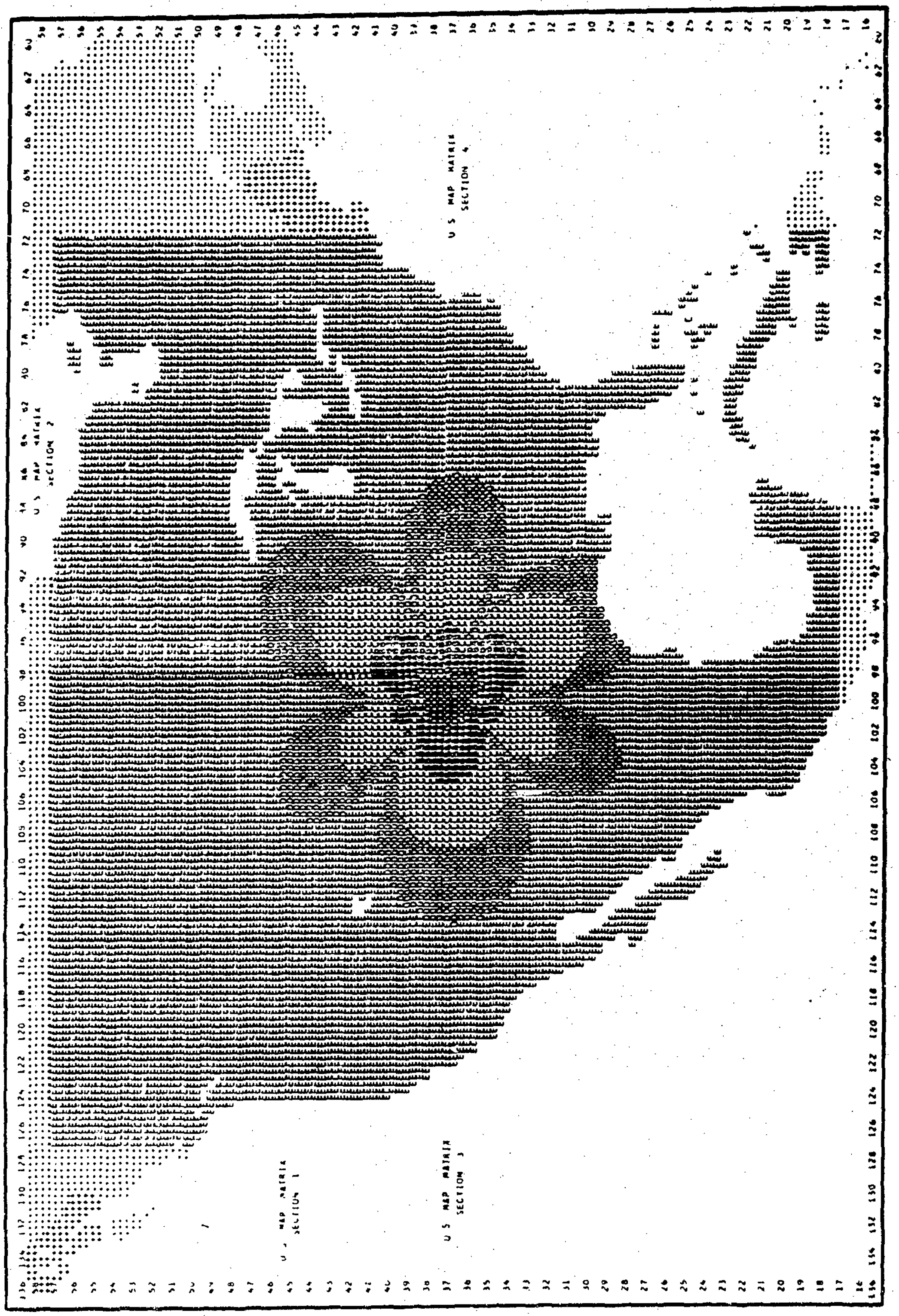


FIGURE 46 ERROR MAP, THREE SITES, CONSTANT D.F. ERROR

SECTION II
DETAILED PROGRAM DESCRIPTION — DYNAMIC CIVIL DEFENSE COUNTERMEASURE SYSTEM ANALYZER

INTRODUCTION

This section describes a computer program for analyzing civil defense countermeasures systems. The program, called the "Dynamic Civil Defense Countermeasure System Analyzer", is sufficiently general to permit analysis of a wide variety of threat/population/countermeasure situations.

The program accepts specific threat information and detailed description of the target area population and countermeasures system and presents a comprehensive, readable printout of what happens. Not only is the effectiveness of the entire system displayed, but detailed analysis of each countermeasure unit is printed to show the effectiveness of that unit and to help identify inadequacies or reasons for lack of effectiveness.

The program description is divided into three major areas for presentation in this report:

- Weapon Effects Submodels - Methods for determining the probability of kill from blast/thermal effects and from radiation from single and multiple bombs are described
- A computer program utilizing these submodels to determine various aspects of effectiveness of a given Civil Defense Countermeasures System is described.
- Actual population distribution and countermeasures system data for the pilot city was assembled and used in the program to demonstrate the capabilities of the analysis program.

It should be understood that it is not the intention of Section II to present an evaluation of the effectiveness or worth of the Civil Defense programs of the pilot city area or to make recommendations regarding improvements or additions to the present system.

WEAPON EFFECTS SUBMODELS

BLAST AND SHOCK

The peak overpressure at any ground range from ground zero can be obtained providing the altitude of burst, bomb yield, terrain, and climatological conditions are known. For the purposes of this study, the data from pages 137 and 139 of Reference 4* were used. These data are based on near ideal terrain conditions in a standard sea-level atmosphere. It did not appear that the data could be approximated by simple functions and so a tabular representation of height of burst versus range and overpressure was decided upon for the computer input. The data are presented in tabular form in Table I for a 1-kiloton burst. Height of burst and range scaling are as the cube root of the yield in kilotons.

To determine the peak overpressure at a specified horizontal range given the height of burst and bomb yield, the desired overpressure may be found by entering Table I at the scaled height of burst and finding the scaled range. Linear interpolation is used. For example, suppose the peak overpressure at 5000 feet from ground zero for a 1-megaton burst at 12,000 feet is desired. The scaled height of burst is $12,000 \div (1000)^{1/3} = 1200$ feet. The scaled ground range is $5,000 \div (1000)^{1/3} = 500$ feet. Entering the table at 1200 feet altitude, the peak overpressure corresponding to 500 feet range is between 10 and 8 psi. Linear interpolation gives about 9 psi. Double interpolation would be required if exact values of both height of burst and range are not in the figure.

Table I can also be used to determine the ground range (radius) to which a given peak overpressure extends when the height of burst and yield are known. Personnel at that ground range will experience the biological consequences of the overpressure expected there.

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* (Ref. 4) Glasstone, Samuel, "The Effects of Nuclear Weapons", United States Atomic Energy Commission, April, 1962

HEIGHT OF BURST (FEET)	PEAK OVERPRESSURE (PSI)										
	200	100	50	30	20	15	10	8	6	4	2
0	250	325	460	580	710	820	1025	1125	1350	1625	2500
200	260	360	475	600	750	875	1115	1225	1475	1875	2875
400		270	525	625	810	1000	1225	1340	1620	2060	3250
600			215	525	940	1180	1400	1500	1750	2250	3560
800					450	670	1440	1675	1950	2450	3875
1000						290	760	1025	1990	2560	4100
1200							310	680	1125	2450	4125
1400								200	850	1560	3875
1600									375	1300	2950
1800										1000	2750
2000										550	2560

TABLE I DISTANCE FROM GROUND ZERO (FEET) FOR 1 KT

Blast and shock casualties and fatalities are caused by direct and indirect consequences of the blast wave. The direct type of injury is due to exposure of the body to the pressure variations accompanying the wave and the indirect types are due to impact of flying debris on the body or displacement of the body as a whole. Although both peak overpressure and dynamic pressure contribute to casualties and fatalities, it is assumed that the biological effects of the blast phenomenon can be related to the peak overpressure experienced. The fatalities due to blast at some location from ground zero will be dependent on many factors such as terrain, weather, types of structures in the vicinity and time of day. The human body can withstand peak overpressures in the open of about 45 to 55 psi with a probability of fatality of about 50 percent. * At about 6 to 8 psi overpressure, most buildings except earthquake resistant and other specially built buildings will experience moderate to severe damage and flying glass and masonry missiles will be a source of injury and death. Thus, small peak overpressures may give rise to high probability of fatality in non-open areas due to structure collapse and flying debris.

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* Glasstone, op. cit.

THERMAL RADIATION

The thermal radiation at any slant range from an air burst was obtained from page 365 of Reference 4* for a 50-mile visibility environment. The graphical data presented is nearly linear when the logarithm of the radiant exposure is plotted against the logarithm of the slant range. A least-squares linear fit to the data was determined.

The thermal radiation expected at a given slant range from an air burst in a 50-mile visibility environment is given by Equation 1.

$$Q(\mathrm{cal/cm^2}) = 4.42\ D^{-2.072} \times 10^6\ W \qquad \text{Equation (1)}$$

where

D = slant range (yards)
W = yield (kilotons)

An air burst is defined to be one which occurs at or above 180 $W^{0.4}$ feet above the surface, where W is the yield in kilotons. The thermal radiation of a surface burst may be expected to be about 2/3 of that from an air burst.(*) By considering the thermal radiation to increase linearly with altitude, the effect of height of burst on the thermal radiation received is shown in Equation 2.

$$Q(\mathrm{cal/cm^2}) = 4.42kD^{-2.072} \times 10^6\ W \qquad \text{Equation (2)}$$

where

D = slant range (yards)
W = yield (kilotons)

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* Glasstone, op. cit.

$$k = \begin{cases} 0.67 + \dfrac{0.33\,H}{180\,W^{0.4}} & 0 \leq H \leq 180\,W^{0.4} \\ 1 & H \leq 180\,W^{0.4} \end{cases}$$

H = height of burst (feet)

Thus, for a given height of burst and yield, the slant range (and consequently the ground range) can be obtained for any desired thermal radiation intensity.

The thermal radiation at any location and the resulting injuries and fatalities depend on many uncertainties which include meteorological factors such as wind velocity, relative humidity and visibility; fuel characteristics such as types of combustible materials, their surface density and moisture content; number, type and separation of structures; etc. The effects of thermal radiation on personnel can be divided into two classes, primary and secondary. The primary effects are flash burns and temporary and permanent eye damage. The secondary effects are flame burns as a consequence of conflagrations, burning structures, etc. Any type of opaque material interposed between the burst and the observer will attenuate nearly all of the thermal radiation, hence, any type of cover would protect personnel from primary thermal effects.

The thermal radiation required to produce second degree burns to bare skin is yield dependent and is about 8 calories/cm^2 for megaton range bursts while 9 to 11 cals/cm^2 are required to produce third degree burns to bare skin for similar yields. The consequences of the primary effects depend on the severity and area of the burn which is a function of shielding by both structures and clothing. Exterior ignitable materials such as newspapers, ignite at about 3-8 cal/cm^2, while other household materials will ignite at about 15 to 25 cal/cm^2 for megaton range yields.

CALCULATIONS OF PROBABILITY OF FATALITY FROM BLAST/ THERMAL EFFECTS

A number of bomb damage functions have been considered for use in the Soft Target Study which relate the probability of target kill with separation distance between the impact point and the target. The RAND-Von Neumann function was selected over the "Cookie Cutter" and the "Two Radius" bomb damage functions for use in the study because it realistically relates probability of kill with miss distance and because the probability of kill of targets displaced from the aim point for the RAND-Von Newmann function can be calculated quite easily. The conditional probability of kill given a separation, r, between the target and the impact point, is

$$CP(r) = e^{\frac{-r^2}{R^2}}$$

where R is a bomb constant which is a function of the weapon yield and target hardness and mathematically represents the 37 percent probability of kill radius. The 50 percent probability of kill radii, which are common in the literature and which are used in this study, can be converted to the 37 percent level by dividing by 0.83. The conditional probability of kill given by

$$e^{\frac{-r^2}{R^2}}$$

allows for certain kill only when the bomb impacts on the target, and gives some probability of survival to targets when impact points are not on the target, no matter how close.

The probability of killing a target at a separation d from the aim point is given by

$$P_K = \frac{P_s R^2}{2\sigma^2 + R^2} e^{\left(-\frac{d^2}{2\sigma^2 + R^2}\right)} \qquad \text{Equation (3)}$$

where

P_K = probability of kill of target

P_S = reliability-survivability multiplier for the bomb

σ = aiming error (assumed equal) in the x and y direction (approximately 85 percent of the CEP)

d = distance of the target from the aim point

R = 37 percent probability of kill radius

Equation (3) above is used to determine the probability of fatality from blast and thermal effects when aiming errors are present. Given a peak overpressure value corresponding to 50 percent probability of kill, the height of burst, and the bomb yield, the peak overpressure table (Table 1) is used to determine the required ground range (50 percent probability of kill radius). The 50 percent radius is converted to the 37 percent probability of kill radius by dividing by 0.83. This determines R in Equation (3). Then for a given aim point, P_S, σ, d, and R, the probability of kill by blast can be obtained.

Similarly, given a value of thermal radiation representative of 50 percent lethality, Equation (2) is used with the desired height of burst and bomb yield to determine the required slant range. By using the slant range and height of burst, the ground range (50 percent probability of kill radius) can be determined. The 50 percent radius is converted to the 37 percent probability of kill radius by dividing by 0.83 This determines an R for Equation (3) which can be used with the inputs of aim point, P_S, σ, and d, to determine the probability of kill by thermal radiation.

Since the interaction of the blast and thermal effects on personnel is not well defined, it was decided to use a single radius within which the probability of kill from either blast or thermal or both can be represented The radius is obtained by determining the 37 percent radii for blast effects and also for thermal effects, and choosing the larger of the two radii for use in Equation (3) to compute the probability of kill from blast/thermal effects. For personnel in designated shelters, the thermal kill radius is taken to be zero, and the blast radius is used to compute probability of kill from blast/thermal effects. For unsheltered personnel, generally the thermal radius will be the largest of the two and is used in the computations.

For application in the Soft Target Study, the lethal median peak overpressure for unsheltered personnel was assumed to be 5 psi. Unsheltered personnel in this case are defined to be those persons who are not in a specifically designed and designated shelter. Those persons in residences and buildings not designated as shelters are assumed to be unsheltered and if exposed to 5 psi peak overpressure, will have a probability of survival of 50 percent. For personnel in designated shelters, the shelter hardness is considered to be the overpressure of interest. Shelters designated as a certain psi shelter could probably take several times the design overpressure and still remain intact, conversely, the shelters might take less than the design hardness and fail. In the absence of data relating shelter hardness to probability of shelter survival, the assumption is made that if a shelter designated by an overpressure receives that overpressure, its probability of survival is 50 percent. The probability of survival of personnel in a designated shelter is taken to be the shelter survival probability. For example, personnel in a 40 psi shelter have a probability of survival of 50 percent if the shelter experiences 40 psi while personnel not in designated shelters have a probability of survival of 50 percent if exposed to 5 psi peak overpressure.

Due to the extreme uncertainties and difficulties in assessing the damage from primary and secondary thermal effects, an average value of 25 cal/cm^2 was used as the median lethal dose for application in the Soft Target Study. It was assumed that at the time of burst, those personnel not in designated shelters at any grid element receiving 25 cal/cm^2, would have a probability of 50 percent of surviving the primary and secondary effects of thermal radiation. Personnel who are in designated shelters at the time of burst would have a 100 percent probability of surviving both primary and secondary thermal effects. When multiple bombs are employed, the probability of kill from blast/thermal is computed separately for each bomb. The probability of surviving blast/thermal effects for all bombs will be the product of the probabilities of surviving the blast/thermal for each bomb.

INITIAL NUCLEAR RADIATION

The prompt nuclear radiation effects were considered to be those caused by gamma rays and neutrons. The gamma radiation dose in roentgens as a function of slant range from a 1 kiloton air burst at 0.9 sea-level air density is given on page 409 of Reference 4* as

$$I_o \text{ (roentgens)} = \frac{3.2 \times 10^9}{D^2} e^{-D/360} \qquad \text{Equation (4)}$$

where

D = slant range (yards)

The scaling factor for yields other than 1 kiloton is given graphically as a function of yield in Reference 4.* The curve which is plotted on log log paper was approximated by a linear function over three different yield (KT) ranges, $1 \leq W \leq 20$; $20 \leq W \leq 100$; $100 < W \leq 5000$. The linear functions were determined by taking the scaling factor values at the end points of the intervals and passing the line through these points. Using this method, the initial gamma radiation can be expressed as a function of slant range and yield by

$$I_o \text{ (roentgens)} = \frac{3.2 \times 10^9 \, W'}{D^2} e^{-D/360} \qquad \text{Equation (5)}$$

---

* Glasstone, op. cit.

where

D = slant range (yards) and

$$W' = \begin{cases} W & 1 < W \le 20 \quad (KT) \\ 0.614\, W^{1.163} & 20 < W \le 100 \quad (KT) \\ 0.485\, W^{1.214} & 100 < W \le 5000 \quad (KT) \end{cases}$$

Equation (5) is applicable at ranges over 1200 yards.

The integrated neutron flux in neutrons per square centimeters as a function of slant range from a 1 kiloton air burst for 0.9 sea-level air density is given on page 411 of Reference 4.* Assuming the integrated flux is directly proportional to the yield, the integrated neutron flux can be expressed as a function of slant range and yield by Equation (6):

$$N_o \text{ (neutrons/cm}^2\text{)} = \frac{8.6 \times 10^{18}\, W}{D^2}\, e^{-D/210} \ldots$$

...... Equation (6)

where

D = slant range (yards)

W = yield (KT)

This equation is applicable for ranges in excess of about 500 yards.

The absorbed neutron dose in rads can be obtained by multiplying Equation (6) by 1.8×10^{-9} since an integrated flux of 1 neutron per square centimeter is equivalent to an absorbed dose of 1.8×10^{-9} rad. This substitution yields

$$N_o = \frac{8.6 \times 10^{18}\, W}{D^2}\, e^{-D/210} \times 1.8 \times 10^{-9} \text{ rads}$$

or $$N_o = \frac{15.5 \times 10^{9}\, W}{D^2}\, e^{-D/210} \text{ rads} \ldots\ldots \text{ Equation (7)}$$

Since the relative biological effectiveness of gamma rays is unity by definition and is taken to be 1.0 for nuclear weapon neutrons (Reference 4*, page 579), Equations (5) and (7) above can be considered to give the gamma and neutron radiation in the biological effect dose units of rems.

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* Glasstone, op. cit.

As an example of the use of the equations, the gamma radiation dose and the neutron dose at a slant range of 13,000 feet from a 1 megaton air burst will be found.

Substituting the slant range and appropriate W' in Equation (5),

$$I_o = \frac{3.2 \times 10^9 (0.485 (1000)^{1.214})}{(\frac{13000}{3})^2} e^{-\frac{13000}{3}/360}$$

$$\simeq 2 \text{ roentgens}$$

Substituting the slant range and yield in Equation (6),

$$N_o = \frac{8.6 \times 10^{18} \times 10^3}{(\frac{13000}{3})^2} e^{-\frac{13000}{3}/210}$$

$$\simeq 5 \times 10^5 \text{ neutrons per square centimeter.}$$

or by multiplying the above result by 1.8×10^{-9}

$$N_o \simeq 9 \times 10^{-4} \text{ rads}$$

The initial nuclear radiation dose can be obtained by combining the dose in rems from gamma rays and neutrons from an air burst which were given previously and correcting the equation for height of burst. By considering an air burst to occur at altitudes equal to and greater than $180 \ W^{0.4}$ feet, and assuming the initial radiation from a surface burst to be 2/3 that from an air burst at the same slant range*, Equation (8) gives the expected initial radiation dose in rems as a function of slant range.

$$R_{initial} = \frac{10^9 k}{D^2} \left[3.2 \ W' e^{-D/360} + 15.5 \ W e^{-D/210} \right] \qquad \text{Equation (8)}$$

where

$R_{initial}$ = initial nuclear radiation dose (rems)

D = slant range (yards)

W = yield (kilotons)

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* Glasstone, op. cit.

$$W' = \begin{cases} W & 1 < W \leq 20 \\ 0.614\, W^{1.163} & 20 < W \leq 100 \\ 0.485\, W^{1.214} & 100 < W \leq 5000 \\ 0.005\, W^{1.740} & 5000 < W \leq 10,000 \end{cases}$$

$$k = \begin{cases} 0.67 + \dfrac{0.33\, H}{180\, W^{0.4}} & 0 \leq H < 180\, W^{0.4} \\ 1 & H \geq 180\, W^{0.4} \end{cases}$$

H = height of burst (feet)

From Equation (8), given the height of burst and the yield, the slant range (or consequently the ground range) for any desired initial nuclear dose can be calculated.

FALLOUT DEPOSITION AND DECOY MODEL

Several fallout deposition models were studied in an attempt to find a suitable model which could be incorporated in the Soft Target Study Civil Defense countermeasure systems analysis programs. At one time the NRDL model (Ref. 5)* was considered most desirable and the required flow diagrams were drawn. Additional study and coordination with an expert in the field (Ref. 6)** indicated, however, that the differences in the models studied were not due entirely to progress in the state of the art but that fundamental differences exist in models currently being used. Since there does not seem to be any reason to believe that any one model will yield significantly better results than any other, a simple composite model has been devised and programmed. It has proven useful in learning how such models can be incorporated into overall Civil Defense countermeasure systems analysis procedures. The model can be replaced by a more elaborate program whenever such a model is accepted and required to achieve a fallout prediction accuracy comparable to the accuracies of the other submodels used by the procedures.

The following paragraphs describe the simple fallout deposition model which has been programmed.

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* (Ref. 5) Anderson, A. D., "The NRDL Dynamic Model for Fallout from Land Surface Nuclear Blasts", U.S. Naval Radiological Defense Laboratory Technical Report USN RDL-TR-410, 5 April 1960.

** (Ref. 6) Miller, Carl, Office of Civil Defense, Personal Communication.

Cloud Stabilization Time (Initial Conditions)

In the first version of the program, the weapon was considered to detonate at the surface of the ground at zero time. At some later time the top and bottom of the resultant cloud stabilize in altitude. For yields greater than 100 kilotons this occurs at

$$t_s = 510.3 - 33.9 \ln W$$

seconds where W is the weapon yield in kilotons (a model input). For yields of 100 kilotons or less, altitude stabilization is considered to occur at 360 seconds. Altitude stabilization occurs, therefore, earlier for weapons of large yield than for weapons of 100 kilotons or less.

The cloud is assumed to be a right circular cylinder at the time of stabilization. The heights of the top and bottom of the cloud at altitude stabilization in feet, are, respectively

$$Z_T = 750\ W^{1/4}\ t_s^{\ 1/2} \text{ and}$$

$$Z_B = 340\ W^{1/4}\ t_s^{\ 1/2}$$

where t_s is the altitude stabilization time in seconds.

The radius of the cloud is considered to stabilize in 360 seconds regardless of yield and is given by

$$R = \frac{1085}{2}\ t_0^{\ 0.25}\ W^{0.11}\ t_0^{\ 0.22}$$

feet where t_0 is the 360 second radial stabilization time. The numerical integration of the deposited radioactivity is accomplished by dividing the cylindrical cloud into N (a model input) equal disks. The radioactivity associated with each of these disks is

$$r_N = \frac{6 \times 10^{10}\ f W}{\pi N R^2}$$

where f is the efficiency of the weapon radiation production process and R is the radius of the cloud in feet. The units are considered to be curies per square foot per disk (the radioactive material surface density) or roentgens per hour per disk (a radiation field strength unit) based on the one hour after detonation amount. The altitude of the top and bottom of the cloud, the radius of the cloud, the radioactivity of each disk and the radial stabilization time (360 seconds) are considered to be the initial conditions at the beginning of fallout. The particle size distribution at this time is considered to be uniform throughout the cloud. The turbulence and updrafts which have been supporting the fallout particles now subside and each particle begins to fall through the air mass from its initial altitude at a speed which is a function of particle size and instantaneous altitude. As the particles fall, the air mass moves at a rate called wind velocity. Since the particles only move downwind while falling, the downwind displacement of a particle from its initial position is a function of fall time which is a function of particle size and initial altitude. The fallout deposition computations are most conveniently made using minutes as the time unit so that t_0, the time fallout begins, occurs at 6 minutes.

The thickness of each cloud disk and the altitude of the midpoint of the lower disk at t_0 are, in feet:

$$\frac{Z_T - Z_B}{N} \quad \text{and}$$

$$Z_B + \frac{Z_T - Z_B}{2N}$$

where Z_T and Z_B are the altitudes of the top and bottom of the fallout cloud at t_s.

Fallout Deposition Computations

It is now necessary to set up some kind of bookkeeping scheme in which the effect of the fallout disks on the resultant fallout patterns can be recorded. The number of disks to be considered is the product of N, the number of cloud altitude increments, and the number of particle size classes to be used. The particular computational device decided upon is a time to fall versus radioactivity table. At one time it was thought that a 61 entry table with a 1-minute time interval would be sufficient. Local fallout would then be defined to be that fallout which lands within an hour of t_0. It has since been discovered that, under some conditions, an appreciable fraction of the total fallout is still airborne after an hour and that local wind velocities can be quite low. For these reasons it has been decided to use a larger number of table entries and to make the time interval between entires a model input. The radioactivity level associated with each time entry of the table is initially set to zero.

Other model inputs required for these computations relate to particle sizes. The range of significant particle sizes is divided into classes and the mid-size of each class is specified. The fraction of total radioactivity in each class is also given, The remaining inputs are constants for each particle class to be used in the time to fall functions.

Particle Descent Time

To determine the time required for a given particle size to descend to the ground from any given altitude, the fall velocity of the particle must be known. The fall velocity will be a function of particle size, acceleration of gravity, particle density, air density and air viscosity. Anderson (Reference 5*) and Kleinecke (Reference 7**) give equations which express terminal velocity as a function of these parameters.

Kellogg, Rapp, and Greenfield (Reference 8***) present a graphical relationship between terminal velocity and altitude as a function of particle radius. The particles are assumed to be spherical and of density 2.5 gm cm^{-3}. The curves are nearly linear when the logarithm of the velocity is plotted against the altitude. A linear approximation to the curves was made by fitting two straight lines for each particle size, one line representing the velocity as a function of altitudes up to 30,000 feet and the other representing velocity as a function of altitudes above 30,000 feet. The resulting equations are of the form

$$v = k_1 e^{k_2 h}$$

Table II gives the fit to the curves over the two altitude regions for the particle sizes given in Reference 8.*** Extrapolation of the data was performed to obtain a relationship for the 40 micron diameter (20 micron radius).

The time required for the particle to descend from any given altitude can be obtained by solving the differential equation

$$v = \frac{dh}{dt} = k_1 e^{k_2 h}$$

The solution is given by

$$t = k_1^{-1} k_2^{-1} (1 - e^{-k_2 h}) \text{ for } h \leq 30,000$$

where t is in seconds and h in feet.

For the case, $h > 30,000$, the differential equation becomes

$$v = \frac{dh}{dt} = k_3 e^{k_4 h}$$

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* Anderson, op. cit.

** (Ref. 7) Kleinecke, D.C., "Deposit Location Predictions for a Single Fallout Particle," University of California, IER, Civil Defense Research Project, Series 2, Issue 35, 15 May 1961.

*** (Ref. 8) Kellogg, W.W., Rapp, R R., and Greenfield, S.M., "Close-In Fallout" Journal of Meteorology, Volume 14, No. 1, February 1957.

Particle Diameter (Microns)	Velocity (feet/sec) at altitude h	
	$0 < h \le 30,000$ ft	$h > 30,000$ ft
40	$0.52\, e^{36 \times 10^{-7} h}$	$0.52\, e^{36 \times 10^{-7} h}$
80	$1.3\, e^{59 \times 10^{-7} h}$	$1.4\, e^{28 \times 10^{-7} h}$
120	$2.3\, e^{65 \times 10^{-7} h}$	$2.4\, e^{51 \times 10^{-7} h}$
160	$3.4\, e^{93 \times 10^{-7} h}$	$3.8\, e^{58 \times 10^{-7} h}$
200	$4.5\, e^{96 \times 10^{-7} h}$	$4.8\, e^{72 \times 10^{-7} h}$
300	$7.0\, e^{97 \times 10^{-7} h}$	$7.0\, e^{97 \times 10^{-7} h}$
400	$10.0\, e^{116 \times 10^{-7} h}$	$10.0\, e^{116 \times 10^{-7} h}$
600	$15.1\, e^{126 \times 10^{-7} h}$	$14.6\, e^{137 \times 10^{-7} h}$
800	$20.0\, e^{112 \times 10^{-7} h}$	$17.7\, e^{152 \times 10^{-7} h}$
1000	$25.0\, e^{122 \times 10^{-7} h}$	$21.6\, e^{170 \times 10^{-7} h}$

TABLE II TERMINAL VELOCITY OF FALLOUT PARTICLES

with the initial conditions

$$t = k_1^{-1} k_2^{-1} \left(1 - e^{-k_2(30,000)}\right)$$

$$h = 30,000$$

Solution of the differential equation is

$$t = k_1^{-1} k_2^{-1} \left(1 - e^{-k_2(30 \times 10^3)}\right) + k_3^{-1} k_4^{-1} \left(e^{-k_4(30 \times 10^3)} - e^{-k_4 h}\right)$$

for $h > 30,000$

where again, t is in seconds and h in feet.

Particle Diameter (Microns)	Descent Time (Minutes)	
	$0 < h \leq 30,000$ feet	$h > 30,000$ feet
40	$8,903(1 - e^{-36 \times 10^{-7} h})$	$912 + 8,903(0.89763 - e^{-36 \times 10^{-7} h})$
80	$2,173(1 - e^{-59 \times 10^{-7} h})$	$353 + 4,252(0.91943 - e^{-28 \times 10^{-7} h})$
120	$1,111(1 - e^{-65 \times 10^{-7} h})$	$197 + 1,366(0.85813 - e^{-51 \times 10^{-7} h})$
160	$527(1 - e^{-93 \times 10^{-7} h})$	$128 + 758(0.84030 - e^{-58 \times 10^{-7} h})$
200	$386(1 - e^{-96 \times 10^{-7} h})$	$97 + 482(0.80574 - e^{-72 \times 10^{-7} h})$
300	$245(1 - e^{-97 \times 10^{-7} h})$	$62 + 245(0.74752 - e^{-97 \times 10^{-7} h})$
400	$144(1 - e^{-116 \times 10^{-7} h})$	$42 + 1\ 4(0.70610 - e^{-116 \times 10^{-7} h})$
600	$88(1 - e^{-126 \times 10^{-7} h})$	$28 + 87(0.66299 - e^{-137 \times 10^{-7} h})$
800	$74(1 - e^{-112 \times 10^{-7} h})$	$21 + 62(0.63381 - e^{-152 \times 10^{-7} h})$
1000	$55(1 - e^{-122 \times 10^{-7} h})$	$17 + 45(0.60050 - e^{-170 \times 10^{-7} h})$

TABLE III FALLOUT PARTICLE DESCENT TIME

Table III gives the descent time as a function of altitude for the particle sizes of interest. To use the figure, select a particle size and substitute the altitude of the particle into the appropriate equation which will yield the required descent time in minutes. For example, if a 160 micron particle falls from 20,000 feet, the required time is

$$527(1 - e^{-93 \times 10^{-7}(20 \times 10^{3})}) = 527\,(1 - e^{-.186}) \approx 89 \text{ minutes.}$$

If the same particle fell from 50,000 feet, the descent time would be

$$128 + 758(0.84030 - e^{-58 \times 10^{-7}(50 \times 10^{3})})$$

$$= 128 + 758(0.84030 - e^{-.290})$$

$$= 128 + 758(0.84030 - 0.74826)$$

$$\approx 198 \text{ minutes}$$

Sample calculations were made for various particle sizes falling from several altitudes. The results compare favorably with the times of fall versus altitude given in Glasstone, p. 496 (Reference 4).

Particle Diameter (microns)	Mid Point (microns)	Fraction of Total Radioactivity
< 60	40	0.3607
60 - 100	80	0.1168
100 - 140	120	0.0791
140 - 180	160	0.0580
180 - 220	200	0.0447
220 - 380	300	0.1101
380 - 420	400	0.0178
420 - 780	600	0.0918
780 - 820	800	0.0075
> 820	1000	0.1135

TABLE IV FRACTION OF TOTAL RADIOACTIVITY ASSOCIATED WITH PARTICLE SIZE CLASSES

Fraction of Total Activity

The fraction, F, of the total residual radioactivity associated with each particle size class was obtained from Reference 5* and is shown in Table IV. The fraction of the total activity is assumed to be distributed log normally with the diameter of the particle, μ, and given by

$$F = \frac{1}{\sigma\sqrt{2\pi}} \int_{\phi_1}^{\phi_2} \exp\left[\frac{-(\phi - \bar{\phi})^2}{2\sigma^2}\right] d\phi$$

where for the size class μ_1 to μ_2,

$\phi_1 = \log \mu_1$ $\bar{\phi} = \overline{\log \mu} = 2.053$

$\phi_2 = \log \mu_2$ $\sigma = 0.732$

$\phi = \log \mu$

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* Anderson, ob. cit.

The mean and standard deviation values above are based on tests on Nevada soil but are used for this study, since the soil around the pilot city is not expected to be markedly different than Nevada soil.

The class intervals were chosen so that the particle diameters discussed previously would be midpoints of the particle size class intervals. All particles less than 60 microns in diameter and their associated activity were placed in the 40-micron diameter class. All particles greater than 820 microns in diameter and their associated activity were placed in the 1000-micron diameter class.

The fraction of the total activity associated with the particle size classes does not agree favorably with those presented in Reference 4, p. 496. * The latter were also assumed to be log normally distributed, however the mean and variance were not given.

The computer selects a particle size class and computes the time to fall from the altitude of the midpoint of the lower cloud disk. These computations are then repeated for each of the (N-1) remaining altitude intervals of the cloud. Another particle size class is then taken and the calculations continue until the time to fall has been computed for each particle size class from each cloud altitude layer.

Each time a time-to-fall computation is made the fall time is rounded to the closest time entry of the fall time versus radioactivity table. The radioactivity associated with an altitude layer disk is then multiplied by the fraction of radioactivity in the current particle class to obtain the radioactivity in a particle class subdisk of an initial cloud altitude layer disk. This radioactivity increment is then added to the radioactivity accumulator for the fall time entry computed. The number of fall times considered is the product of the number of cloud altitude disks and the number of particle size classes. The fallout deposition records, which are the only records which must be retained, are the records in the fall time versus radioactivity table. These records are essentially a function of weapon yield only and may be used to obtain fallout patterns for any number of wind values.

Fallout Deposition Diagrams

Fallout deposition diagrams are printed in a matrix format not unlike the large population matrices used in the civil defense countermeasures analysis programs. The reason for this is not only that it seems to be the best format producible by the printer but is also compatible with the analysis programs to which the fallout model has been added. A program input is the scale factor, which is the dimensions of each square element of the grid. Each such element is represented on the output formats by a single character print space. The array, in the checkout version of the program, consists of 57-by-119 characters

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* Glasstone, op. cit.

since this format can be printed on a single output sheet. The detonation point is at 29, 15 so that most of the pattern shown occurs to the right (downwind) of the impact point. Since only the average wind is used, all patterns will be symmetrical about the i equals 29 row.

Another input to the program is the number of fallout deposition diagrams desired. The computer divides the total time interval included in the fall time versus radioactivity table into this number of intervals. The first deposition diagram applies to the time t_0 plus one of these time increments. Only that portion of the fall time versus radioactivity table which occurs at or earlier than this time is used in the construction of the first deposition diagram. The second deposition diagram occurs at time t_0 plus two time increments and a larger portion of the fall time versus radioactivity table is used to compute the diagram. The final diagram corresponds to the time of the last entry in the fall time versus radioactivity table and the entire table is used.

Since the radiation field in an output matrix element can only be represented by a single character, other model inputs describe the coding system which is to be used. Blank spaces, for example, could be used to represent radiation field strengths less than the minimum field of interest, A the interval of minimum fields of interest, B the next and so on with a character, such as E, representing all field strengths greater than the maximum field strength of interest.

While the procedure for computing deposition diagrams has been programmed in a way to insure short computing times, it is essentially as follows. The time to which the diagram applies is determined and the corresponding portion of the fall time versus radioactivity table is found. An output matrix element is then selected. Each of the fall time versus radioactivity records in the selected portion of the table is now considered in turn. Each of these records corresponds to a radioactivity disk on the ground. The position of the disk is found by displacing the center of the disk in the x direction from the impact point by the amount:

$$(t_0 + \text{record fall time})(\text{wind velocity})$$

The routine now tests whether the center of the element is within a cloud radius of the center of the disk If it is, the radioactivity indicated in the current record is added to the value in an accumulator set up for this element. The process is repeated for each record in the applicable portion of the fall time versus radioactivity table.

The accumulated radioactivity value is given by its one hour amount which must be corrected to the time of the output printout. This is accomplished by multiplying by the factor

$$\left(\frac{t_0 + \text{print out time}}{60}\right)^{-1.2}$$

in which the times are in minutes.

The program now compares the corrected radioactivity value with the input radiation levels and selects the proper character. The procedure is repeated for each element of the output matrix and the matrix is printed. It is necessary to store the radiation values of the final deposition diagram as these values are used in computing the decay diagrams.

It is noted that the radiation fields shown on all of the deposition diagrams are the fields resulting from the fallout which has been deposited on the ground up to the time of the printout. There may be a considerable amount of radioactive material in the air in the vicinity of the area included in the output matrix and, while this radioactivity may be expected to add to the fields resulting from the deposited fallout, this contribution to the total field is ignored during computation of the deposition diagrams.

Fallout Decay Diagrams

Fallout decay diagrams resemble deposition diagrams. They are printed on similar formats and use the same output coding scheme. They are concerned with decay only, however, since they occur after fallout of all radioactive material of interest. Inputs controlling the generation of decay diagrams are the number of decay diagrams desired and the time increment between diagrams. Since the radiation fields do not change as rapidly during the decay phase as during the deposition phase, the time between decay diagrams would ordinarily be many hours, perhaps days, while the time spacing between fallout deposition diagrams would be measured in minutes.

Fallout decay diagrams are obtained by correcting the previous fallout decay diagram values (or the final fallout deposition diagram values) to time now using the relation

$$R_{\text{now}} = R_{\text{previous}} \left(\frac{t_{\text{previous}}}{t_{\text{now}}} \right)^{1.2}$$

After the array has been corrected, the values are coded and printed out in the same manner as for the fallout deposition diagrams. The numerical values are retained for use in the computation of the next decay diagram.

The residual nuclear radiation (fallout) used in the Dynamic Analyzer is obtained from the fallout deposition and decay model described above revised to correct for height of burst. The height of burst at which early (local) fallout ceases to be a problem is assumed to be 180 $W^{0.4}$ feet. By assuming 100% of the available residual nuclear radiation activity to be included in the fallout particles for a surface burst and 0% of the activity included in the fallout particles for a burst at or above 180 $W^{0.4}$, and distributed linearly between the two altitudes, the correction for height of burst can be included by correcting the radioactivity associated with each disk in the deposition model. The correction is given by Equation (9).

$$r_N = k \frac{6 \times 10^{10} f W}{\pi N R^2} \qquad \text{Equation (9)}$$

r_N = radioactivity associated with each disk

f = fraction of yield due to fission

W = yield (kilotons)

N = number of disks

R = cloud radius (feet)

$$k = \begin{cases} 1 - \dfrac{H}{180\, W^{0.4}} & 0 \le H < 180\, W^{0.4} \\ 0 & H \ge 180\, W^{0.4} \end{cases}$$

The total radiation dose received by personnel will be the sum of the doses received from initial radiation and from fallout. Exposure to radiations such as X-rays, alpha and beta particles, gamma rays and neutrons, which are capable of producing ionization, can cause injury to living organisms. The consequences of the radiation will depend on the absorbed dose, whether the dose was acute or absorbed over a period of time, and on the region and extent of the exposed body. When the dose is delivered over a large area over a long period of time, the body is able to repair some of the biological damage caused by the radiation and the effective biological dose, EBD, from fallout is given by Equation (10).*

$$\text{EBD} = R_1 \int_{T_F}^{t_2} \left[\alpha t^{-1.2} + (1 - \alpha) t^{-1.2} e^{\beta (t - t_2)}\right] dt \qquad \text{Equation (10)}$$

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* (Ref. 9) Wegner, L. H. , "Some Extensions of the 'Random Bomb Drops' Local Fallout Model of RM-1969", RAND Memorandum RM-2973-PR, March 1962

where

EBD = effective biological dose (rems)

R_1 - dose rate at 1 hour (rem/hr)

T_F = time at which fallout is down or entry into the fallout area (hours)

t_2 = time of departure from the fallout area (hours)

α = irreparable body fraction

β = body repair rate (fraction per hour)

Due to the nature of the fallout deposition model, personnel can be exposed to radiation in several ways. They could be given a dose from initial radiation, then be exposed to increasing radiation fields as the various disks drop on them, then be in a decaying final fallout field after the last disk of interest has landed at their location. By assuming the irreparable fraction of the body, α, and the body repair rate, β, to be applicable for both initial and residual radiation, the total effective biological dose at any time t_2 is given by Equation (11).

$$\text{TEBD} = \alpha D + (1 - \alpha) D e^{-\beta(t_2 - T_F)} + R_1 \int_{T_F}^{t_2} \left[\alpha t^{-1.2} + (1 - \alpha) t^{-1.2} e^{\beta(t - t_2)} \right] dt$$

Equation (11)

where

TEBD = total effective biological dose (rems)

α = irreparable body fraction

D = total dose received from initial radiation and from the disks up until final disk of interest falls (rems)

β = body repair rate (fraction per hour)

T_F = time at which fallout is complete (hours)

t_2 = time of departure from fallout area (hours)

R_1 = dose rate at 1 hour (rem/hour)

Equation (11) was examined in an effort to determine the maximum total effective biological dose analytically as a function of α, β, T_F, and t_2 for use in the evaluation program. However, considerable difficulty was experienced in determining the maximum of the function. Since the integral portion seems to take its maximum somewhere between 72 and 96 hours for an α of 20 percent and a β of 10 percent per day, it has been decided to evaluate Equation (10) for $t_2 = T_F$ and also for $t_2 = 72$ and take the greater of the two values as the maximum biological dose.

The effect of shielding from nuclear radiation can be readily incorporated into the calculations. Protection factors are known for various types of material interposed between personnel and the source of radiation, and the amount of radiation transmitted through the shielding is given by multiplying the unshielded dose rates and doses by $(\text{Protection Factor})^{-1}$. Protection factor as used in this report is defined to be the ratio of the radiation without protection to the radiation with protection. That is, if a shelter has a radiation protection factor of 10, the ratio of the radiation field outside to the radiation field inside is 10, or effectively the radiation inside is 1/10 of the radiation outside. For example, personnel is a designated fallout shelter with a given protection factor at the time of burst, receive a total effective biological dose, which is $(\text{protection factor})^{-1}$ as large as those who are unsheltered for the same length of time at the same location. For personnel unsheltered at the time of burst and who reach a shelter sometime later, either before, during, or after fallout commences, only the radiation received during the time they were sheltered is adjusted for the protection factor.

CALCULATION OF PROBABILITY OF KILL FOR NUCLEAR RADIATION

The relationship between physical dose of ionizing radiation and clinical effect is not completely known, and there is no complete agreement concerning the effect associated with a specific dose or dose range. Equation (12) below has been assumed to be the relationship between effective biological dose and fatality for this study. If the median lethal biological dose is μ and the standard deviation is σ, then the probability of fatality given exposure to an effective biological dose, EBD, is taken to be

$$P(K/EBD) \quad \int_{-\infty}^{\left(\frac{EBD - \mu}{-\sigma}\right)} \frac{1}{\sqrt{2\pi}} \, e^{-\frac{-x^2}{2}} \, dx \qquad \text{Equation (12)}$$

The median lethal biological dose depends on many factors including health and age of exposed personnel. Generally, it has been conceded that values of about 400-500 rem can be taken as the median lethal dose,(*) with a standard deviation of about 75-125 rem. For this study, a median lethal dose of 450 rem with a standard deviation of 75 rem was used. This implies that personnel receiving an effective biological dose of 525 rem have a 84 percent probability of fatality, and those receiving 675 rem have a 99.9 percent probability of fatality.

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* (Ref. 10) Congressional Hearings, Civil Defense - 1961, U.S. Government Printing Office

For radiation dose calculations, the bomb is assumed to detonate at the input altitude above the aim point. The total radiation dose is computed by using Equation (8) to obtain the initial radiation dose and the Fallout Deposition Model to obtain the residual radiation dose rates for inputs to Equation (11) to obtain the total effective biological dose. An alpha of 10% and a beta of 0.1% per hour are used in Equation (11). The maximum total effective biological dose is determined by the method described earlier, and is used in Equation (12) to determine the probability of kill.

When multiple bombs are employed, the radiation effects are assumed to be additive and the maximum total effective biological dose from all bombs is used as input to Equation (12) to determine the probability of kill from radiation.

DYNAMIC ANALYZER

COMPUTER PROGRAM FUNCTIONS

The weapons effects submodels and probability of kill equations and a body of computer programs related to the areas of targeting, weapons effects, and damage assessment which are discussed earlier in this report, form the basis for this computer program. This program is general in nature and provides for many input options to satisfy the requirements of a wide range of situations. Most of the parameters used can be varied at will to adjust to progress in the state of the art and functions internal to the program can be modified to accept improved methods.

The function of the Dynamic CD Countermeasures System Analyzer Program is to calculate and compare the multiple effects survival probabilities of the elements of a given population grid when they are subjected to the blast, thermal and radiation effects of a number of nuclear bombs. The comparison is performed between a system with no shelters available to protect the various population elements and a system with a limited number of shelters available for protection purposes. In general, the operation of the program can be divided into four logical parts.

Part 1 deals with the inputting of control parameters and the calculation of control data.

Part 2 deals with the calculation of survival probabilities in an unsheltered system.

Part 3 deals with the assignment of the population grid elements to specific shelters in a sheltered system, and finally,

Part 4 deals with the calculation of survival probabilities in a sheltered system and with the comparison of results between the two systems.

Survival probability is defined as one minus the kill probability.

Part 1 may be subdivided into four logical segments.

Segment 1 provides for the inputting of the population values in the form of a rectangular grid, the grid scale value, the unsheltered radiation protection factor, the unsheltered blast overpressure factor, the unsheltered thermal factor and the speed with which the population can move from element to element within the grid. The blast overpressure factor is defined as that peak overpressure which determines a range within which the blast survival probability is no more than fifty percent. The thermal factor is defined as the number of calories per square centimeter which determines a thermal survival probability of no more than fifty percent. The generation of the elements of the population grid is described earlier in this report. The program at present can handle a maximum grid size of 35(I) by 65(J).

Segment 2 controls the inputting of the bomb characteristics and the calculation of time down tables for use in the fallout deposition process. For each bomb the values of aim point (i_A, j_A), yield, burst height, aiming error, radiation conversion efficiency and the number of fallout cloud altitude disks to be considered are input. From these values the program computes the radius of the fallout cloud, the total radiation in the cloud, the minimum and maximum altitudes of the cloud and the time of stabilization of the cloud.

In addition, the program calculates what is defined as the time down table which consists of a series of two item entries where one is a one hour radiation dose rate and the other is the time required for that radiation to reach the ground. Fall time is measured from burst time and all bombs are assumed to detonate simultaneously. Burst time is an input parameter and represents the difference in minutes between time zero and the time of the blast. The deposition of fallout and the calculation of the time down table (fall time versus radioactivity) have been described earlier. Ten particle size classes are considered in the computations. However, in this program the actual fall time as well as the radiation dose rate is recorded. Thus, all of the radiation of a cloud is considered as possible local fallout and may fall on any number of the grid elements in the deposition process. The program has the capacity for a maximum of ten bombs, each with a maximum of fifteen cloud altitude disks.

Segment 3 allows for the inputting of a wind velocity which controls the rate and direction with which the various fallout clouds move across the grid. The wind is given in the form of I and J components where a positive I component indicates motion in the direction of decreasing i values and a positive J component indicates motion in the direction of increasing j values.

Segment 4 processes the shelter information which, for each shelter, consists of the location (i_S, j_S), the shelter's radiation protection factor and the shelter's blast overpressure factor. The program can input and process a maximum of five hundred shelters but does not provide for more than one shelter to be located at the same grid element.

Part 2 can be subdivided into two logical segments.

Segment 1 computes the blast/thermal survival probability of the unsheltered grid elements. The total blast/thermal survival probability of a particular grid element is equal to the product of the probabilities of surviving each bomb at that grid element. For each bomb, the program computes both a blast 50% ground radius and a thermal 50% ground radius. The thermal 50% ground radius is defined as:

$$R_{T(50)} = \sqrt{9D^2 - H_B^2}$$

where

H_B = bomb burst height (feet)

D = slant range value (yards) from Equation (2) in which Q is the unsheltered thermal factor.

The blast 50% ground radius is defined by a series of tables relating adjusted burst height to blast peak overpressure and is equal to $R_{B(50)}$ (see Table 1). From these two values a combined radius can be defined as:

$$R = \frac{\text{maximum}\left[R_{T(50)}, R_{B(50)}\right]}{0.83}$$

To compute the blast/thermal survival probability of a particular grid element for a particular bomb, the values of R, σ (aiming error) and d (distance of the grid element from the bomb aim point) are used in Equation (3).

Segment 2 deals with the computation of radiation survival probabilities for the unsheltered grid elements. This calculation is accomplished by first determining the total radiation dose and the total one hour radiation dose rate which occur at each grid element as a result of all fallout clouds. The computation of these values can be described using the following definitions:

Consider a particular grid element (i, j), then the two times t_{1_m} and t_{2_m}, are defined as the local cloud times for the cloud from bomb m as it passes over the grid element under consideration. These two times are the solution of the following quadratic equation:

$$(V_I^2+V_J^2)t^2+2SF\left[V_I(i-i_A) - V_J(j-j_A)\right]t+SF^2\left[(i-i_A)^2+(j-j_A)^2\right] = R_C^2$$

Equation (13)

where

V_I = I wind velocity component (ft/min)

V_J = J wind velocity component (ft/min)

SF = grid scale value (feet)

i, j = location of the grid element under consideration

i_A, j_A = aim point of bomb m

R_C = radius of the fallout cloud for bomb m (feet)

t = time (min.)

It can be shown that Equation (13) has three possible solutions:

1) the cloud is never over grid element i, j, thus

$$t_1 = t_2 = 0$$

2) the cloud is always over grid element i, j, thus

$$t_1 = 0 \quad ; \quad t_2 = +\infty$$

and

3) the cloud is over grid element i, j between two discrete times t_1 and t_2.

Using these two times and the time down table for bomb m, the one hour radiation dose rate at any time t for element i, j may be determined as:

$$r_m(t) = \sum_{t_{1_m}}^{\text{minimum }(t_{2_m},\, t)} r_{TD}$$

where r_{TD} are the radiation values from the time down table whose corresponding fall time entries satisfy the condition that, $t_{1_m} \leq TD \leq$ minimum (t_{2_m}, t). The total one hour radiation dose rate, HDR, from all bombs at grid element i, j is then defined as:

$$HDR(i, j) = r_1(t_{2_1}) + r_2(t_{2_2}) + \ldots + r_m(t_{2_m}) + \ldots + r_B(t_{2_B})$$

The radiation dose rate for bomb m at time t is now defined as:

$$f_m(t) = r_m(t) \left[\frac{60}{t}\right]^{1.2}$$

and the total for all bombs at time t is defined as:

$$F_t = f_1(t) + f_2(t) + \ldots + f_m(t) + \ldots + f_B(t)$$

The total radiation dose , FD, at grid element i, j in the unsheltered system is defined as:

$$FD(i, j) = D_1(i, j) + \left[F_{\Delta T} + F_{2\Delta T} + \ldots + F_t + \ldots + F_T\right] \left[\frac{\Delta T}{60}\right]$$

where

$T = n\Delta T \geq T_F =$ maximum $(t_{2_1}, t_{2_2}, \ldots t_{2_m}, \ldots t_{2_B})$

$T =$ time required for the population to move from one grid element to an adjoining one (min)

$$D_1(i, j) = P_1 + P_2 + \ldots P_m + \ldots + P_B$$

$P_m =$ prompt radiation from bomb m at grid element i, j as given by Equation (8) (defined as $R_{initial}$)

Using the values T_F, R1 = HDR/(unsheltered radiation protection factor) and D = FD/(unsheltered radiation protection factor) in Equations (11) and (12), the unsheltered radiation survival probability for a particular grid element can be calculated. The product of the unsheltered blast/thermal survival probability and the unsheltered radiation survival probability becomes the total unsheltered survival probability.

Part 3 determines the assignment of the elements of the population grid to the various shelter locations. This assignment process implies that at time zero the population will begin to move toward their designated shelters in a sheltered system. The assignment is carried out with a minimum distance criterion.

Part 4 can be subdivided into four logical segments.

Segment 1 calculates the survival probabilities of the various shelters. The computation of the blast survival probability for a particular shelter is identical with that described earlier for the unsheltered system except that only the blast 50% ground radius is used and it is determined using the shelter's blast overpressure factor. Similarly, the calculation of the sheltered radiation survival probability is performed as described for the unsheltered system except that the values of R_1 and D are obtained by dividing HDR and FD respectively by the shelter's radiation protection factor and then using these with the value of T_F in Equations (11) and (12). The radiation survival probability of a particular shelter applies to the people located inside that shelter and not to the structure itself.

Segment 2 deals with those population grid elements which reach their designated shelters before the blast. Both their blast and radiation survival probabilities are equal to those calculated for the shelter itself and the product of the two becomes the total sheltered survival probability of these grid elements.

Segment 3 computes the survival probabilities of those population grid elements which have not reached their shelter locations at the time of the blast. Thus, at the time of the blast, the population from grid element i, j will be located at some new element i_b, j_b. The determination of this grid element location is made by assuming that the population will move in such a way so as to traverse the entire 'I' distance and then the entire 'J' distance from their initial location to the location of their assigned shelter. The unsheltered blast/thermal survival probability of the element i_b, j_b becomes the sheltered blast/thermal survival probability of the population initially located at grid element i, j. The computation of sheltered radiation survival probability is essentially the same as was described earlier for the unsheltered system, with the exception that the total radiation dose is divided into three portions; prompt radiation, radiation obtained before and radiation obtained after reaching the shelter location. The radiation dose obtained prior to reaching the shelter location can be defined as:

$$D_2 = \left[\frac{F_{\Delta T} + F_{2\Delta T}}{2} + \frac{F_{2\Delta T} + F_{3\Delta T}}{2} + \cdots + \frac{F_{S-\Delta T} + F_S}{2}\right]\left[\frac{\Delta T}{60}\right]$$

where each F_t is evaluated at different grid elements as the population moves toward their assigned shelter. $F_{\Delta T}$ is the radiation dose rate at the grid element immediately adjoining the element i_b, j_b and F_S is the radiation dose rate at the shelter location. S is defined as the arrival time which is the time required for the population from a particular grid element to move to their assigned shelter and is equal to $\Delta T|(i-i_S) + (j-j_S)|$. The radiation dose obtained after reaching the shelter location is defined as:

$$D_3 = \left[\frac{F_S + F_{S+\Delta T}}{2} + \frac{F_{S+\Delta T} + F_{S+2\Delta T}}{2} + \cdots + \frac{F_{T-\Delta T} + F_T}{2}\right]\left[\frac{\Delta T}{60}\right]$$

where each F_t is evaluated at the shelter location and $T = n\Delta T \geq$ the T_F at the shelter location. Thus, the total radiation dose for the grid element i, j which is assigned to the shelter located at element i_S, j_S is defined as:

$$FD(i, j) = D_1(i_b, j_b) + D_2 + D_3(i_S, j_S)$$

where D_1 is the sum of the prompt radiations received at element i_b, j_b. In the calculation of sheltered radiation survival probabilities, two situations are considered:

1. The shelter survived the blast and the radiation dose D_3 was obtained inside the shelter. The values used in Equations (11) and (12) to compute the radiation survival probability then become T_F at element i_S, j_S, R_1 = HDR (at element i_S, j_S)/(radiation protection factor of the shelter located at that element) and $D = (D_1 + D_2)$/(unsheltered radiation protection factor) + D_3/(radiation protection factor of the shelter).

2. The shelter was destroyed by the blast and the radiation dose D_3 was obtained unsheltered. The values T_F as defined for situation 1, R_1 = HDR (at the shelter location)/(unsheltered radiation protection factor) and D = FD (from Equation (13))/(unsheltered radiation protection factor) are used in Equations (11) and (12) to compute the radiation survival probability for situation 2.

The total sheltered survival probability becomes the sum of the survival probabilities in situations 1 and 2. The survival probability in situation 1 is the product of the shelter's blast survival probability, the unsheltered blast/thermal survival probability of grid element i_b, j_b, and the radiation survival probability computed for situation 1. The survival probability in situation 2 is the product of one minus the shelter's blast survival probability, the unsheltered blast/thermal survival probability of grid element i_b, j_b and the radiation survival probability computed for situation 2.

Segment 4 handles the comparison of results between the unsheltered system and the sheltered system. The classification of results for each grid element may be conveniently summarized with the following definitions:

1. In the unsheltered system

survivors = $PSB_U PSR_U POP$

casualties from blast/thermal = $(1-PSB_U)PSR_U POP$

casualties from radiation = $(1-PSR_U)PSB_U POP$

casualties from both blast and radiation = $(1-PSB_U)(1-PSR_U)POP$

2. In the sheltered system

a) arrivals before burst (arrival time ≤ burst time)

survivors = $PS_S PSR_S POP$

casualties from blast = $(1-PS_S)PSR_S POP$

casualties from radiation = $(1-PSR_S)PS_S POP$

casualties from both blast and radiation = $(1-PS_S)(1-PSR_S)POP$

b) arrivals after burst (arrival time > burst time)

Situation 1) - shelter survives the blast

survivors = $PS_S PSB_U PSR_{S(1)} POP$

casualties from blast/thermal = $PS_S(1-PSB_U)POP$

casualties from radiation = $PS_S PSB_U(1-PSR_{S(1)})POP$

Situation 2) - shelter destroyed by the blast

survivors = $(1-PS_S)PSB_U PSR_{U(2)} POP$

casualties from blast/thermal = $(1-PS_S)(1-PSB_U)POP$

casualties from radiation = $(1-PS_S)PSB_U(1-PSR_{U(2)})POP$

where

PSB_U = the blast/thermal survival probability at an unsheltered element

PS_S = the blast survival probability of a particular shelter

PSR_U = the radiation survival probability at an unsheltered element

$PSR_{U(2)}$ = the radiation survival probability when all radiation is obtained in an unsheltered condition

PSR_S = the radiation survival probability inside a particular shelter

$PSR_{S(1)}$ = the radiation survival probability when a portion of the radiation is obtained in an unsheltered condition

POP = population of the grid element.

Total results for all grid elements assigned to a particular shelter are maintained for that shelter. In addition, overall system totals (unsheltered versus sheltered) are maintained and outputted. The program also outputs a series of encoded survival probability grids.

DYNAMIC ANALYZER INPUTS

The inputs required to run the Dynamic Analyzer are summarized on the next page.

Unless otherwise indicated, all data cards should punch
blanks in columns 1 - 7
DEC in columns 8 - 10
blank in column 11
data in columns 12 - 72
use appropriate decimal point for each datum
separate data with commas but no blanks
no comma follows last datum.

An exponential form of the datum may also be used. Examples are:
1, 500, 000 punch as 1. 5E6
0. 006 punch as 6. E-3

TRAnsfer cards have same format as DEC cards.

Sample format

1	2	3	4	5	6	7	8 9 10	11	12	13	14	15	16	17	18	. . . . .	72	(Column #)
							DEC		4	.	,	3	.	2				(Data)
							DEC		6	.	E	-	3					(Datum - exponential)
							TRA		2	,	4							(Transfer card)
							BCD		1	A	P	R	I	L				(Month card)
							BCD			I	N	F	O					(Label card)

SUMMARY OF INPUTS FOR DYNAMIC ANALYZER

I. WIND DECK

1st Card	TRA 4, 4
2nd Card	Velocity of north wind (mph), Velocity of east wind (mph)
3rd Card	Month(1)

II. BOMB CATALOG

1st Card	TRA 3, 4
2nd Card	# Bombs(2), Burst time (min.), # Altitude increments(2)
3rd Card(s)(3)	I_A(2), J_A(2), Yield (KT), Height of burst (ft), σ_B = Missile aiming accuracy (ft), f = Radiation conversion efficiency (%)

III. SHELTER CATALOG

1st Card	TRA 5, 4
2nd Card	# Shelters(2)
3rd Card(s)(4)	I_s(2), J_s(2), Overpressure factor (lbs/sq. in.), Radiation protection factor (cal/sq. cm.)

IV. POPULATION DECK

1st Card	TRA 2, 4
2nd Card	Label(5)
3rd Card(s)(6)	# Rows(2), # Columns(2), Scale factor (ft), Mobility (mph), Protection factor, Overpressure (lbs/sq. in.), Q (cal./cm^2), I_i(2), J_i(2), # Non-zero population elements(2)
4th Card(s)	i(2), j(2), Population(2) (Population Deck has one card for each non-zero element)

NOTES

(1) Month Card has BCD in columns 8-10; column 11 must be blank; column 12 has numeral 1 ; columns 13-18 have the month spelled out or abbreviated.

(2) These numbers are integers and decimal must be omitted.

(3) Information for each bomb must be on a separate card.

(4) Information for each shelter must be on a separate card.

(5) Label Card has BCD in columns 8-10; columns 11 and 12 must be blank; columns 13-72 contain any desired identification information.

(6) On this card there should be a zero before other listed parameters for initialization purposes; I_i and J_i should both be zero.

EXAMPLE DYNAMIC ANALYZER OUTPUT FORMATS

INTRODUCTION

This section describes the result of a pilot city (Dallas-Fort Worth) demonstration run and explains the notation and tabulation used in the printed output format.

The figures shown in this report represent only a portion of the total data printed for each analysis case. The computer running time and total cost for each analysis run is primarily determined by two factors: 1) Number of shelters in the system, and 2) average distance the population must travel to reach a shelter. Time does not increase linearly with number of shelters because additional shelters generally decreases the average travel distance. The analysis of a system with 48 shelter locations requires less than 5 minutes of 7090 computer time.

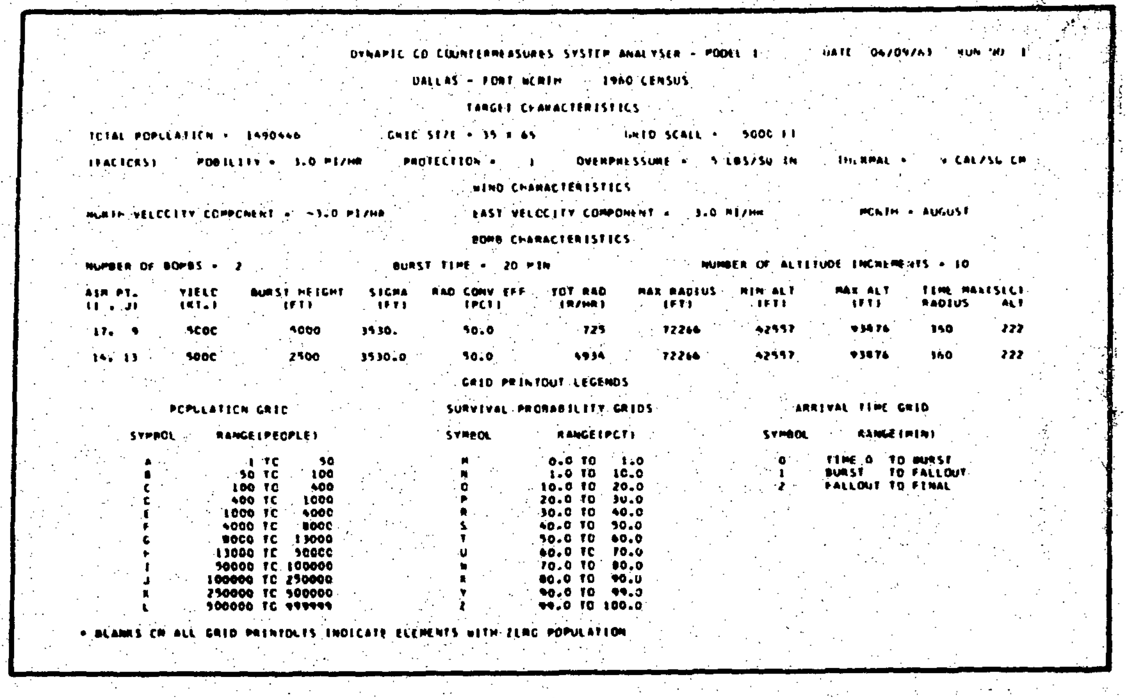
INPUT SUMMARY AND LEGEND (FIGURE 47)

The first page of the printout identifies the run and summarizes the basic input data. TARGET CHARACTERISTICS describes the unsheltered population. The grid method of representing population has been discussed. (FACTORS), MOBILITY is the assumed rate at which the population can move toward shelters, PROTECTION indicates the shielding protection against nuclear radiation. OVERPRESSURE and THERMAL give the effects levels at which the probability of personnel survival is 50%. WIND CHARACTERISTICS show a wind blowing from the northwest at 4-1/4 mph. BOMB CHARACTERISTICS lists and describes the significant characteristics of each bomb up to a limit of 10. BURST TIME is shown here as 20 minutes counted from time 0, the time at which the population receives warning and is instructed to go to shelters. NUMBER OF ALTITUDE INCREMENTS refers to the incremental deposition of the fallout cloud. AIM POINT, YIELD, BURST HEIGHT, SIGMA (weapon delivery accuracy), and RADiation CONVersion EFFiciency are input separately for each bomb. The other characteristics describe the fallout cloud and are computed by the program. TOT RAD (total radiation) is the rems per hour fallout dose rate. The other column callouts indicate the cloud dimensions, altitude of the top and bottom of the cloud, and the time after burst at which these dimensions are reached.

GRID PRINTOUT LEGENDS, shown here for completeness, are also printed on each grid printout where they apply. In each case, the symbol printed refers to the entire population in the element where it appears. These should not be confused with the two-character symbols used to designate shelter assignments.

POPULATION GRID (FIGURE 48)

The manner in which the population grid is prepared has been described. It should be noted that, while the grid printed here shows a population range for each element, all computations done within the program are performed with the specific input populations for each element. Because vertical and horizontal spacings of the printer are not equal, the printouts and map are compressed laterally, and a square area is shown as a 6 x 10 rectangle.



```
                         DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL 1        DATE  04/09/63   RUN NO  1

                                      DALLAS - FORT WORTH     1960 CENSUS

                                          TARGET CHARACTERISTICS

TOTAL POPULATION =  1490446           GRID SIZE = 35 X 65              GRID SCALE =   5000 FT

(FACTORS)    MOBILITY =  3.0 MI/HR      PROTECTION =     1      OVERPRESSURE =   5 LBS/SQ IN     THERMAL =     9 CAL/SQ CM

                                          WIND CHARACTERISTICS

NORTH VELOCITY COMPONENT =  -3.0 MI/HR          EAST VELOCITY COMPONENT =   3.0 MI/HR             MONTH = AUGUST

                                          BOMB CHARACTERISTICS

NUMBER OF BOMBS =  2                   BURST TIME =  20 MIN                    NUMBER OF ALTITUDE INCREMENTS = 10

AIM PT.     YIELD     BURST HEIGHT    SIGMA    RAD CONV EFF   TOT RAD     MAX RADIUS   MIN ALT     MAX ALT    TIME MAX(SEC)
(I , J)     (KT.)        (FT)          (FT)       (PCT)        (R/HR)        (FT)        (FT)        (FT)     RADIUS   ALT

 17,  9     5000         5000        3530.        50.0           725        72266       42557       93876      350     222

 14, 13     5000         2500        3530.0       50.0          4934        72266       42557       93876      360     222

                                          GRID PRINTOUT LEGENDS

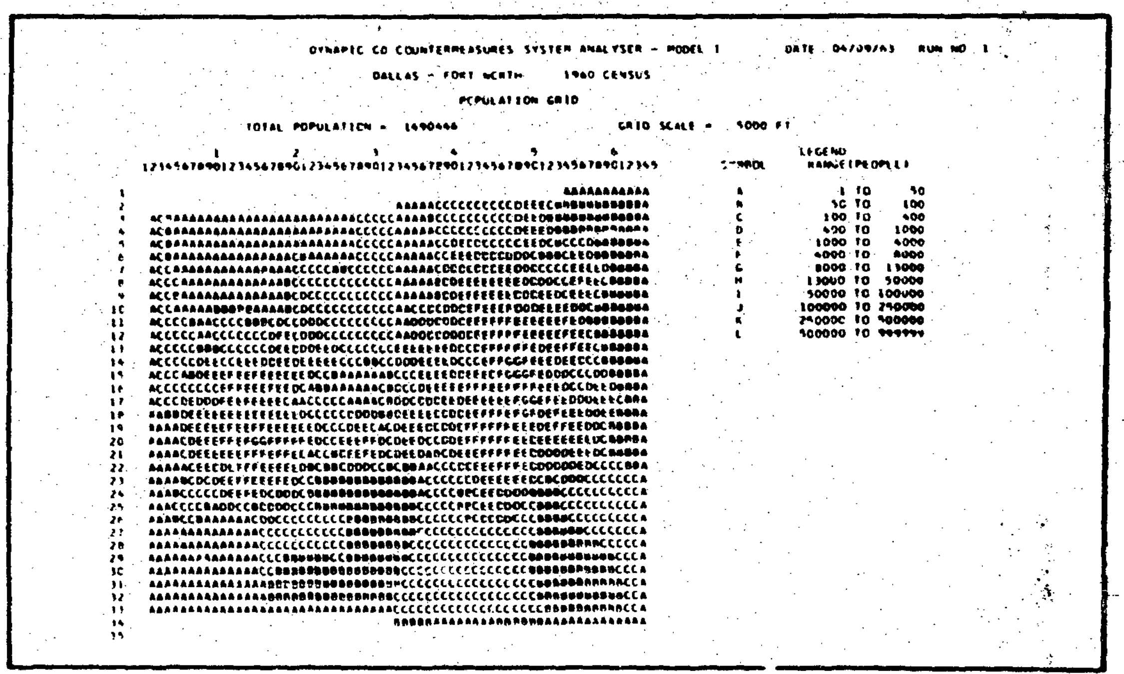
         POPULATION GRID                     SURVIVAL PROBABILITY GRIDS                   ARRIVAL TIME GRID

     SYMBOL      RANGE(PEOPLE)               SYMBOL         RANGE(PCT)                 SYMBOL      RANGE(MIN)

       A              1 TO     50              M          0.0 TO   1.0                  0       TIME 0  TO BURST
       B             50 TO    100              N          1.0 TO  10.0                  1       BURST   TO FALLOUT
       C            100 TO    400              O         10.0 TO  20.0                  2       FALLOUT TO FINAL
       D            400 TO   1000              P         20.0 TO  30.0
       E           1000 TO   4000              R         30.0 TO  40.0
       F           4000 TO   8000              S         40.0 TO  50.0
       G           8000 TO  13000              T         50.0 TO  60.0
       H          13000 TO  50000              U         60.0 TO  70.0
       I          50000 TO 100000              W         70.0 TO  80.0
       J         100000 TO 250000              X         80.0 TO  90.0
       K         250000 TO 500000              Y         90.0 TO  99.0
       L         500000 TO 999999              Z         99.0 TO 100.0

* BLANKS ON ALL GRID PRINTOUTS INDICATE ELEMENTS WITH ZERO POPULATION
```

FIGURE 47 INPUT SUMMARY AND LEGEND



```
                DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL 1        DATE  04/09/63   RUN NO  1

                            DALLAS - FORT WORTH      1960 CENSUS

                                    POPULATION GRID

           TOTAL POPULATION =  1490446                     GRID SCALE =   5000 FT

                                                                                  LEGEND
                                                                     SYMBOL     RANGE(PEOPLE)

                                                                       A            1 TO     50
                                                                       B           50 TO    100
                                                                       C          100 TO    400
                                                                       D          400 TO   1000
                                                                       E         1000 TO   4000
                                                                       F         4000 TO   8000
                                                                       G         8000 TO  13000
                                                                       H        13000 TO  50000
                                                                       I        50000 TO 100000
                                                                       J       100000 TO 250000
                                                                       K       250000 TO 500000
                                                                       L       500000 TO 999999
```

FIGURE 48 POPULATION GRID

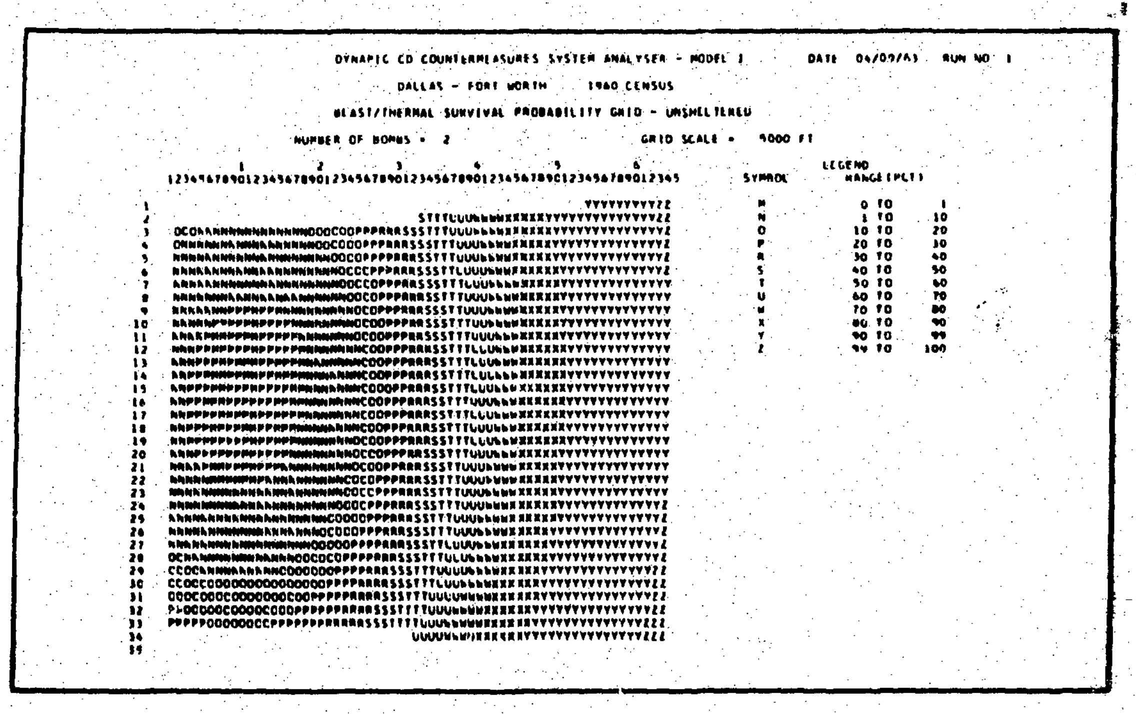
BLAST/THERMAL SURVIVAL PROBABILITY GRID-UNSHELTERED (FIGURE 49)

There is a single, high priority soft military target in the vicinity of Dallas and Fort Worth. The target, Carswell Air Force Base, is located approximately five miles west of the Fort Worth central business district. The attack strategy used against the target in this example uses two 5 MT weapons. Neither of the weapons is aimed directly at the target. The aimpoints were selected to give a high probability of target kill while yielding a maximum bonus kill against population and industrial floor space.

The legend symbol at each printout on this grid represents the probability that the population of that element will survive the effects of blast and thermal radiation. Because the range to which thermal effects are felt by unsheltered population is greater than the range for blast effects for these parameters, the contours shown for the unsheltered case approximate those of thermal alone.

RADIATION SURVIVAL PROBABILITY GRID (FIGURE 50)

The fallout deposition pattern appears here as moving southwest from the two aimpoints. Because the weapons were burst at relatively low altitudes, (one at 2500 feet) the dose rate is such that almost all the population within the fallout pattern are casualties. The area in the vicinity of ground zero where population is killed by initial radiation does not show but is masked by the fallout pattern.



```
DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL 1          DATE  04/09/63   RUN NO  1

                    DALLAS - FORT WORTH      1960 CENSUS

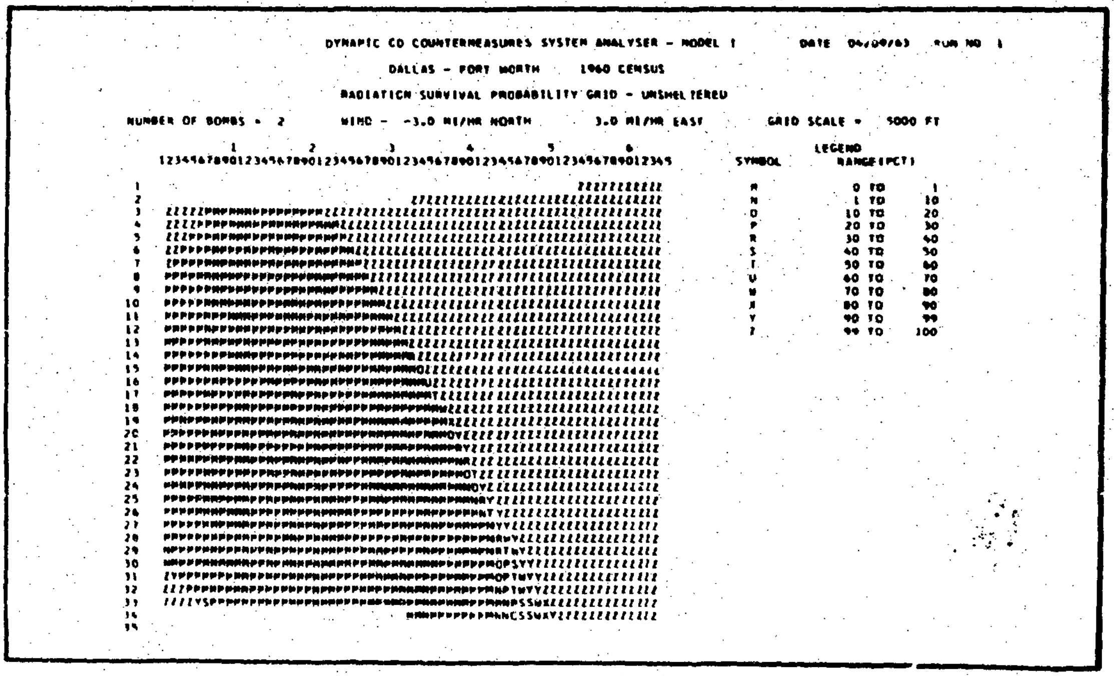
            BLAST/THERMAL SURVIVAL PROBABILITY GRID - UNSHELTERED

        NUMBER OF BOMBS =  2                          GRID SCALE =   5000 FT

          1         2         3         4         5         6                      LEGEND
 12345678901234567890123456789012345678901234567890123456789012345       SYMBOL     RANGE(PCT)

                                                                           M          0 TO    1
                                                                           N          1 TO   10
                                                                           O         10 TO   20
                                                                           P         20 TO   30
                                                                           R         30 TO   40
                                                                           S         40 TO   50
                                                                           T         50 TO   60
                                                                           U         60 TO   70
                                                                           W         70 TO   80
                                                                           X         80 TO   90
                                                                           Y         90 TO   99
                                                                           Z         99 TO  100
```

FIGURE 49 BLAST THERMAL SURVIVAL PROBABILITY GRID



```
DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL 1          DATE  04/09/63   RUN NO  1

                    DALLAS - FORT WORTH      1960 CENSUS

            RADIATION SURVIVAL PROBABILITY GRID - UNSHELTERED

NUMBER OF BOMBS =  2      WIND -  -3.0 MI/HR NORTH       3.0 MI/HR EAST       GRID SCALE =   5000 FT

          1         2         3         4         5         6                      LEGEND
 12345678901234567890123456789012345678901234567890123456789012345       SYMBOL     RANGE(PCT)

                                                                           M          0 TO    1
                                                                           N          1 TO   10
                                                                           O         10 TO   20
                                                                           P         20 TO   30
                                                                           R         30 TO   40
                                                                           S         40 TO   50
                                                                           T         50 TO   60
                                                                           U         60 TO   70
                                                                           W         70 TO   80
                                                                           X         80 TO   90
                                                                           Y         90 TO   99
                                                                           Z         99 TO  100
```

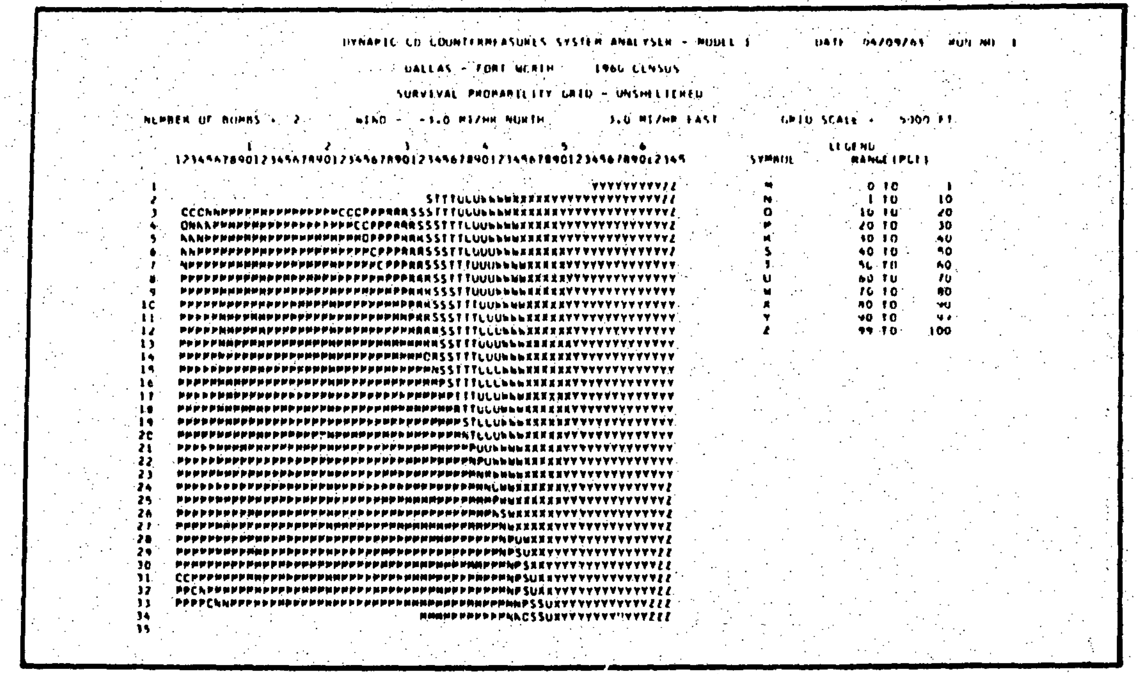
FIGURE 50 RADIATION SURVIVAL PROBABILITY GRID

SURVIVAL PROBABILITY GRID-UNSHELTERED (FIGURE 51)

This shows the probability that the population of each element will survive all three weapon effects. Because of the high intensity of the fallout field and the absence of protection to the population, this appears to be a print of the fallout field superimposed on the Blast/Thermal Probability of Survival Grid.

SURVIVAL PROBABILITY GRID-SHELTERED (FIGURE 52)

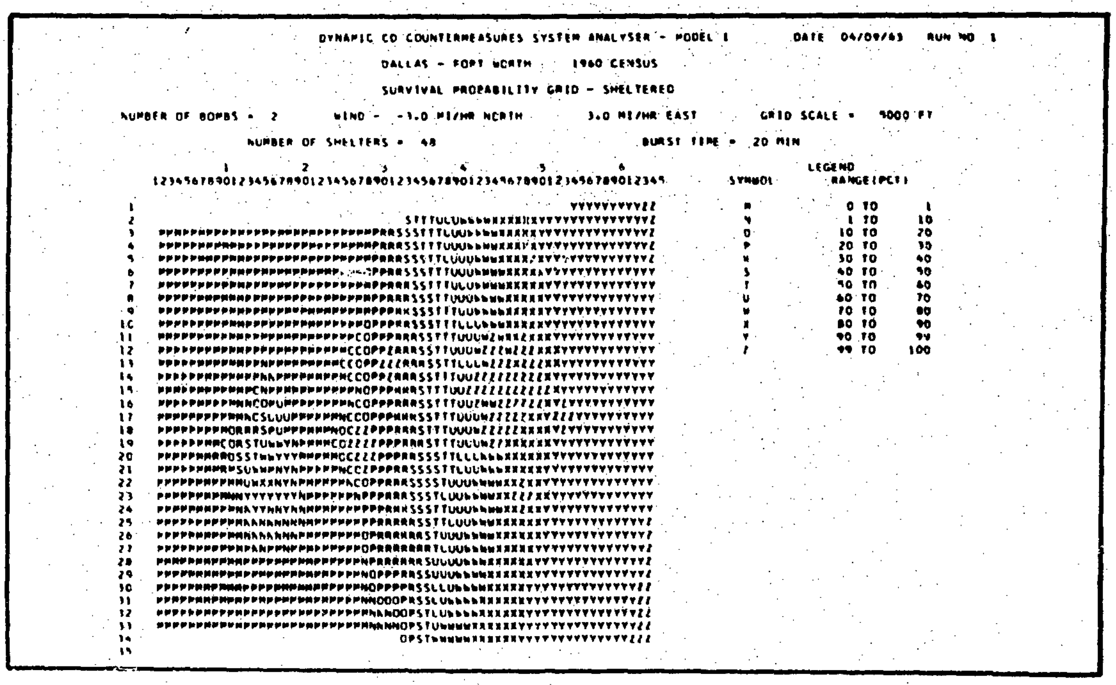
This figure shows the probability of surviving this attack for the population in each element when provided with the protection defined for the existing Dallas-Fort Worth fallout shelter system. Most of the survival improvement is shown in two areas, one of them south of the Fort Worth central business district where the shelters were far enough from the blast to survive and the population was close enough to the shelters to reach protection before the blast. The other area is in the south central area where those surviving the blast outside of the shelter were able to reach radiation protection before the downwind fallout arrived. A comparison of the two grids shows that the shelter system actually decreased the probability of survival for population in the northwest and southwest corners of the grid. This is because their nearest shelters were closer to the burst point or they were required to travel through regions of heavier fallout or both. A detailed printout of this effect is given in the next figure.



```
DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL 1        DATE 04/09/63   RUN NO 1
                DALLAS - FORT WORTH      1960 CENSUS
           SURVIVAL PROBABILITY GRID - UNSHELTERED
NUMBER OF BOMBS = 2     WIND -  -3.0 MI/HR NORTH     3.0 MI/HR EAST     GRID SCALE =  5000 FT

                                                             LEGEND
                                                   SYMBOL    RANGE(PCT)
                                                     M        0 TO    1
                                                     N        1 TO   10
                                                     O       10 TO   20
                                                     P       20 TO   30
                                                     R       30 TO   40
                                                     S       40 TO   50
                                                     T       50 TO   60
                                                     U       60 TO   70
                                                     W       70 TO   80
                                                     X       80 TO   90
                                                     Y       90 TO   99
                                                     Z       99 TO  100
```

FIGURE 51 SURVIVAL PROBABILITY GRID - UNSHELTERED



```
DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL 1        DATE 04/09/63   RUN NO 1
                DALLAS - FORT WORTH      1960 CENSUS
           SURVIVAL PROBABILITY GRID - SHELTERED
NUMBER OF BOMBS = 2     WIND -  -3.0 MI/HR NORTH     3.0 MI/HR EAST     GRID SCALE =  5000 FT
          NUMBER OF SHELTERS = 48                   BURST TIME = 20 MIN

                                                             LEGEND
                                                   SYMBOL    RANGE(PCT)
                                                     M        0 TO    1
                                                     N        1 TO   10
                                                     O       10 TO   20
                                                     P       20 TO   30
                                                     R       30 TO   40
                                                     S       40 TO   50
                                                     T       50 TO   60
                                                     U       60 TO   70
                                                     W       70 TO   80
                                                     X       80 TO   90
                                                     Y       90 TO   99
                                                     Z       99 TO  100
```

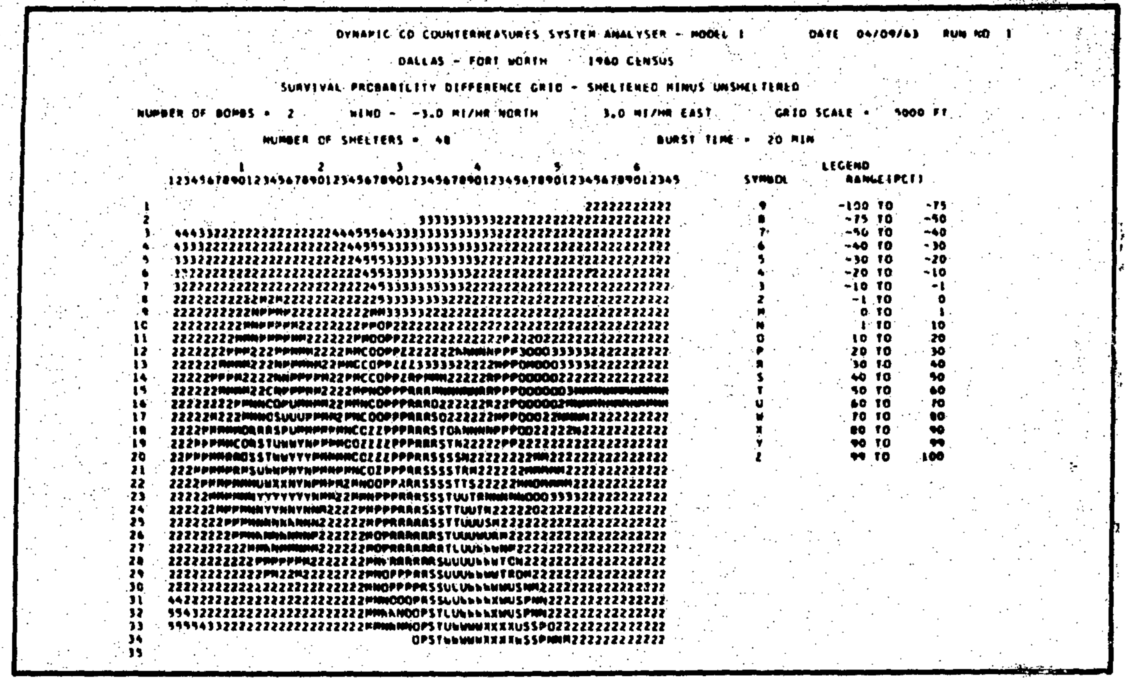
FIGURE 52 SURVIVAL PROBABILITY GRID - SHELTERED

SURVIVAL PROBABILITY DIFFERENCE GRID-SHELTERED MINUS UNSHELTERED (FIGURE 53)

This matrix shows the value of this shelter system to each population element in terms of survival. It is generated by differencing the probability of survival in the two preceding figures. Alphabetical symbols printed in an element indicate an improved survival probability attributable to the existence and use of the countermeasures system. Numerical symbols indicate elements of population for whom use of the shelter system actually decreased the probability that they would survive the attack. For those whose survival probability decreased, this is simply a matter of running the wrong way, generally toward a shelter that was not close enough. For a large portion of the population, those with symbols 2 or M, it appears to make little difference whether they proceed toward assigned shelters or stay home.

ARRIVAL TIME GRID (FIGURE 54)

As an aid in analyzing the problems and significance of shelter location and population mobility, an arrival time grid is printed. For the 20 minute warning time used, all population in elements marked with a 0 were able to reach a shelter before the burst. Those with a 1 were caught in the open at the time of burst and if they survived the immediate effects, were able to reach their assigned shelter before any fallout arrived in any of the elements through which they passed. Those marked with a 2 were subjected to not only the immediate effects of the burst, but, if they were able to proceed to their shelter, passed through the fallout field, although the element at which they originated and the shelter element to which they went may not have received any fallout.



DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I DATE 04/09/63 RUN NO 1

DALLAS - FORT WORTH 1960 CENSUS

SURVIVAL PROBABILITY DIFFERENCE GRID - SHELTERED MINUS UNSHELTERED

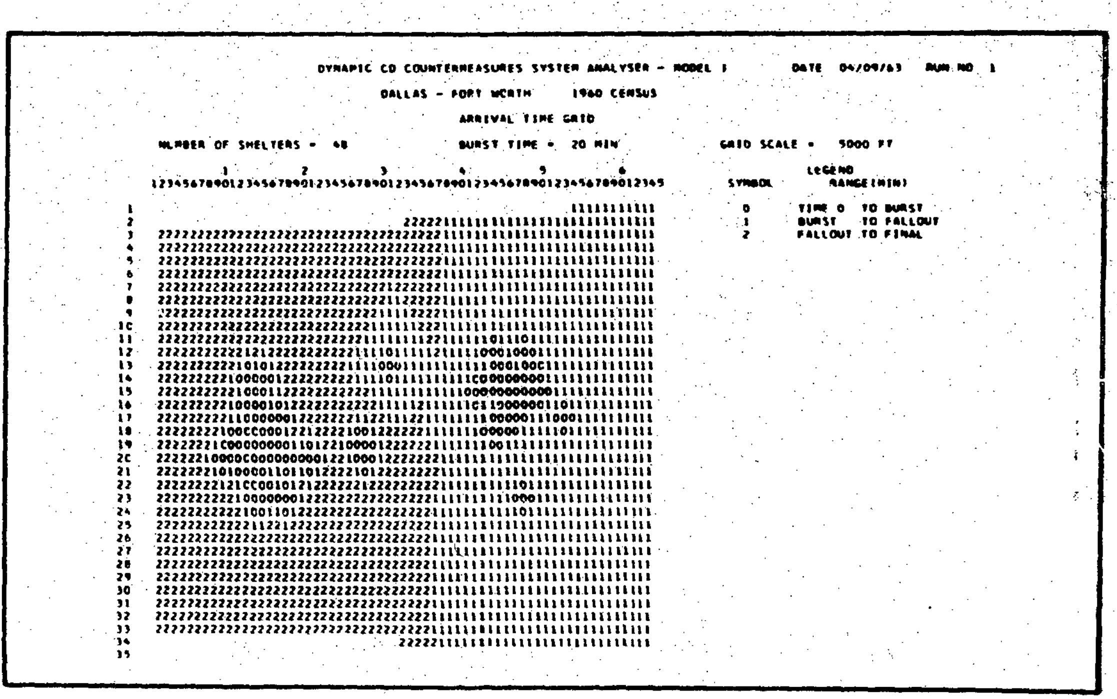
NUMBER OF BOMBS = 2 WIND - -3.0 MI/HR NORTH 3.0 MI/HR EAST GRID SCALE = 5000 FT

NUMBER OF SHELTERS = 48 BURST TIME = 20 MIN

LEGEND

SYMBOL	RANGE(PCT)
9	-100 TO -75
8	-75 TO -50
7	-50 TO -40
6	-40 TO -30
5	-30 TO -20
4	-20 TO -10
3	-10 TO -1
2	-1 TO 0
M	0 TO 1
N	1 TO 10
O	10 TO 20
P	20 TO 30
R	30 TO 40
S	40 TO 50
T	50 TO 60
U	60 TO 70
W	70 TO 80
X	80 TO 90
Y	90 TO 99
Z	99 TO 100

FIGURE 53 SURVIVAL PROBABILITY DIFFERENCE GRID



DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I DATE 04/09/63 RUN NO 1

DALLAS - FORT WORTH 1960 CENSUS

ARRIVAL TIME GRID

NUMBER OF SHELTERS = 48 BURST TIME = 20 MIN GRID SCALE = 5000 FT

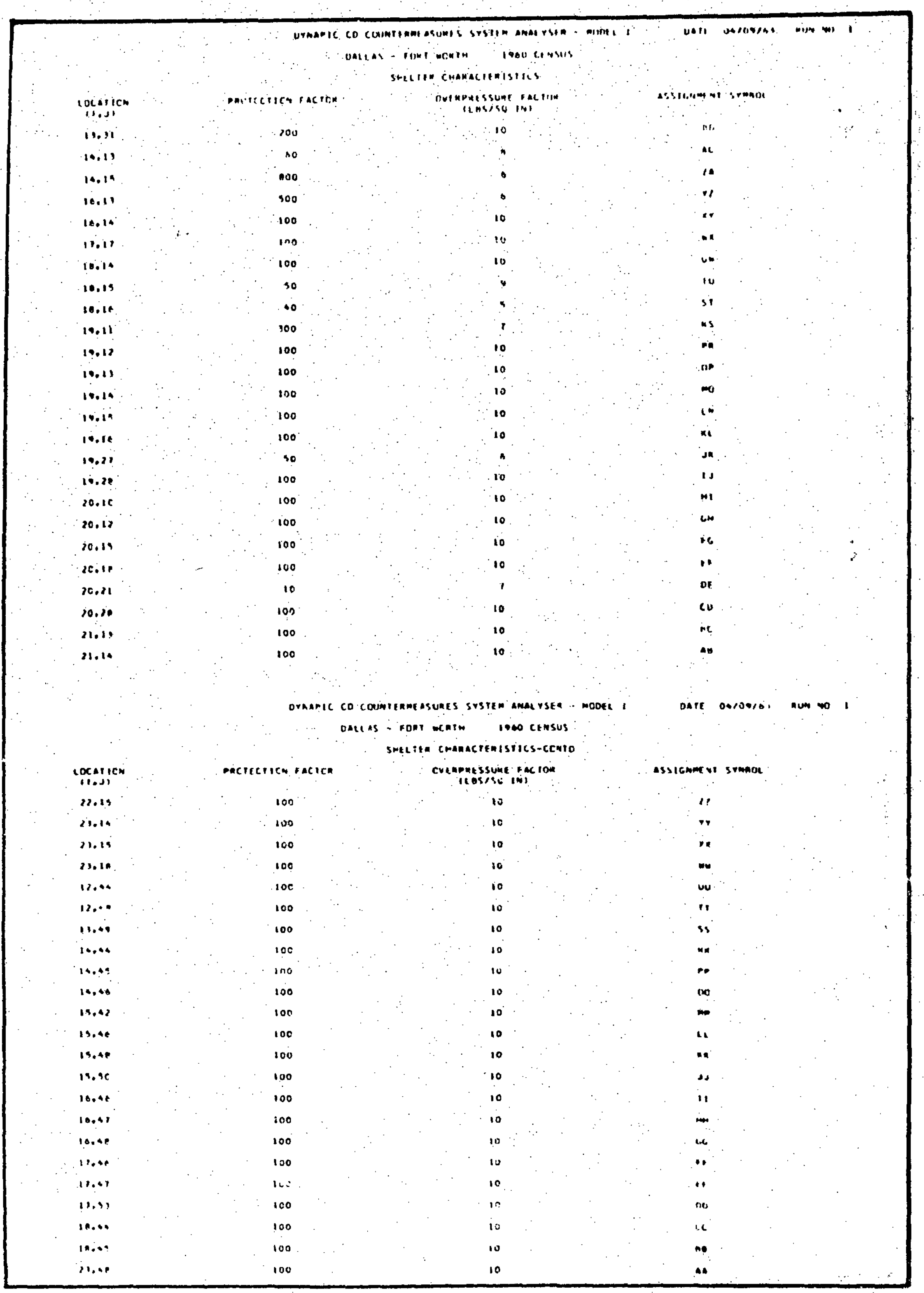
LEGEND

SYMBOL	RANGE(MIN)
0	TIME 0 TO BURST
1	BURST TO FALLOUT
2	FALLOUT TO FINAL

FIGURE 54 ARRIVAL TIME GRID

SHELTER CHARACTERISTICS (FIGURE 55)

A complete listing of all the shelters in the system is given. For each shelter the i, j coordinate location is given with the protection factor and resistance to overpressure. In order to test the system's sensitivity to these parameters and to show the parameter selection option, some of the values were varied from their actual values for this run. Each shelter is given a unique assignment symbol. This is used in the following figure to identify each population element which is assigned to that shelter. The use of a two letter symbol permits separate identification of approximately 500 shelters.



```
                    DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE  04/09/64   RUN NO  1

                              DALLAS - FORT WORTH      1960 CENSUS

                                   SHELTER CHARACTERISTICS

  LOCATION            PROTECTION FACTOR          OVERPRESSURE FACTOR              ASSIGNMENT SYMBOL
   (I,J)                                             (LBS/SQ IN)

   13,31                    200                         10                              DG
   14,13                     80                          8                              AC
   14,15                    800                          6                              ZA
   16,13                    500                          6                              YZ
   16,14                    100                         10                              XY
   17,17                    100                         10                              WX
   18,14                    100                         10                              UW
   18,15                     50                          9                              TU
   18,16                     40                          5                              ST
   19,11                    300                          7                              RS
   19,12                    100                         10                              PR
   19,13                    100                         10                              OP
   19,14                    100                         10                              MO
   19,15                    100                         10                              LM
   19,16                    100                         10                              KL
   19,27                     50                          8                              JK
   19,28                    100                         10                              IJ
   20,10                    100                         10                              HI
   20,12                    100                         10                              GH
   20,15                    100                         10                              FG
   20,18                    100                         10                              EF
   20,21                     10                          7                              DE
   20,28                    100                         10                              CD
   21,13                    100                         10                              BC
   21,14                    100                         10                              AB


                    DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE  04/09/64   RUN NO  1

                              DALLAS - FORT WORTH      1960 CENSUS

                                   SHELTER CHARACTERISTICS-CONTD

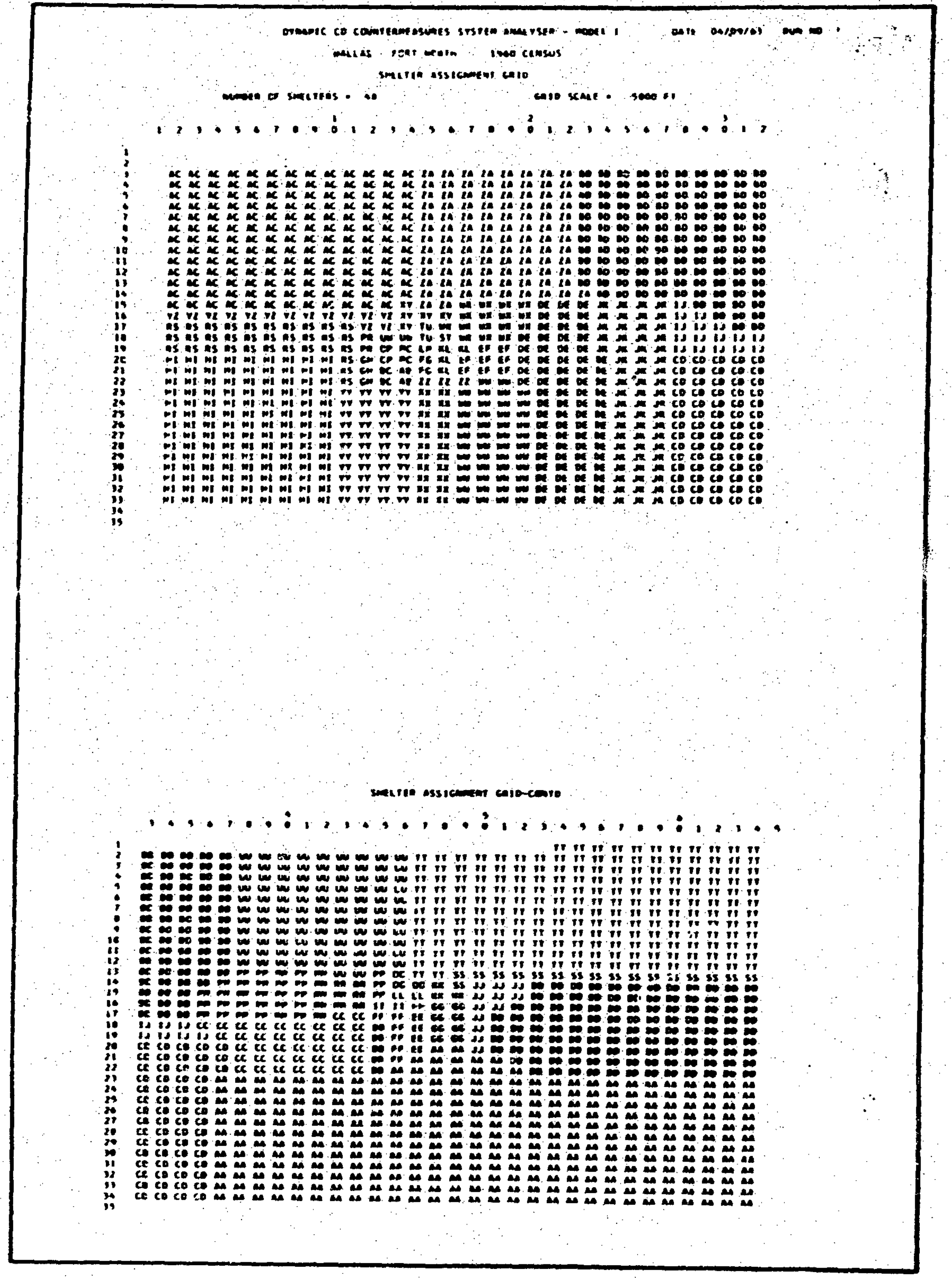
  LOCATION            PROTECTION FACTOR          OVERPRESSURE FACTOR              ASSIGNMENT SYMBOL
   (I,J)                                             (LBS/SQ IN)

   22,15                    100                         10                              ZZ
   23,14                    100                         10                              YY
   23,15                    100                         10                              XX
   23,18                    100                         10                              WW
   12,44                    100                         10                              UU
   12,49                    100                         10                              TT
   13,49                    100                         10                              SS
   14,44                    100                         10                              RR
   14,45                    100                         10                              PP
   14,46                    100                         10                              OO
   15,42                    100                         10                              NN
   15,46                    100                         10                              LL
   15,48                    100                         10                              KK
   15,50                    100                         10                              JJ
   16,46                    100                         10                              II
   16,47                    100                         10                              HH
   16,48                    100                         10                              GG
   17,46                    100                         10                              FF
   17,47                    100                         10                              EE
   17,53                    100                         10                              DD
   18,44                    100                         10                              CC
   18,45                    100                         10                              BB
   23,48                    100                         10                              AA
```

FIGURE 55 SHELTER CHARACTERISTICS

SHELTER ASSIGNMENT GRID (FIGURE 56)

The shelter identification symbols from Figure 55 are used here to show the population element areas assigned to each particular shelter. Because three print spaces are needed to show each element, the grid is expanded laterally so that the left and right halves of the gird matrix are printed on separate sheets. The actual location of each shelter could not be shown without losing the identity of shelters to which only one element is assigned. However, i, j coordinate locations from Figure 55 can be used to locate particular shelters of interest. As can be seen here, a particular weakness of this shelter system is the large areas assigned to some of the shelters and the great distance some of the population must travel. It is significant, however, that the largest assignment areas are in the region of least population density.



```
DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE  04/09/63   RUN NO [illegible]
                     DALLAS - FORT WORTH  -  1960 CENSUS
                          SHELTER ASSIGNMENT GRID
NUMBER OF SHELTERS =  40                          GRID SCALE =  5000 FT
```

```
                            SHELTER ASSIGNMENT GRID-CONTD
```

FIGURE 56 SHELTER ASSIGNMENT GRID

SURVIVAL CONDITIONS FOR SHELTER AC (FIGURE 57)

The program computes and prints a complete analysis similar to this figure for each shelter in the system. This example gives the conditions for the shelter located at i, j = 14, 13 for both the shelter and for all the population assigned to that shelter whether they survive to reach the shelter or not. This particular shelter is at an aimpoint during the run and has a blast survival probability of only 2.3 percent. This value is greater than zero because of the weapon sigma (aiming accuracy).

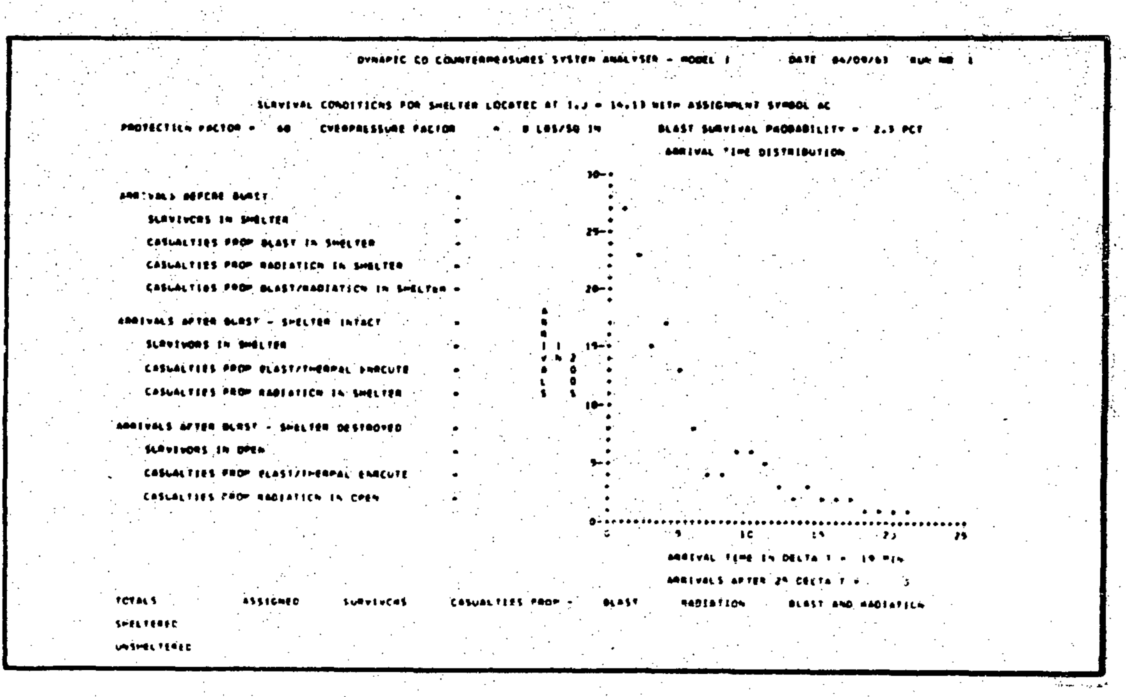
The population assigned to this shelter is divided into two main categories, those who arrive before the burst and those who arrive after the burst or who would arrive if they survived the initial weapon effects. The late arrivals are further divided into two probabilistic groups - those who may expect to find that their shelter had survived the blast, and those who may expect to find their shelter destroyed. This is computed as the number of arrivals after the burst times the probability that the shelter will either survive or be destroyed. Among the 7022 who are in the shelter before the burst, there are no survivors. It is also indicated that there are no casualties from blast in the shelter although the probability that the shelter survives the blast is only 2.3 percent. This simply means that there are no casualties due to blast alone. Casualties from radiation in the shelter shows that 164 survived the blast but were killed by initial radiation. The rest of the shelter occupants were killed by both blast and radiation, i.e., either effect would have been sufficient to kill them.

There were also no survivors associated with those who would have arrived after burst to find the shelter intact. Most of them were killed by blast and/or thermal enroute and did not arrive. Those few who survived blast and thermal received a lethal radiation dose either before they reached the shelter or a combined lethal dose of radiation received before and after they reached the shelter. The four casualties from radiation in the shelter may not actually have arrived or were effectively dead on arrival. In determining casualties for arrivals after the burst, radiation casualties are computed and shown only for those surviving blast/thermal, while in the arrivals before burst case, the effects are considered separately to determine specific shelter inadequacies.

Totals are given at the bottom of the figure for both the sheltered and unsheltered case. SHELTERED here refers to the number of people assigned to this particular shelter whether they reach the shelter or not. UNSHELTERED refers to the same segment of the population but without the population moving to a shelter. An interesting comparison here shows that if the 30,758 persons move toward the assigned shelter there are no survivors;

but if they remain in place, 91 will survive without special protection. This is reasonable because the shelter is located at an aimpoint. The casualties from the various effects for the sheltered case is summed from the ARRIVALS breakdown above. However, the value given under BLAST, which refers to the combined effects of blast and thermal, and under BLAST AND RADIATION are misleading because population killed by blast and thermal enroute to the shelter are not considered when radiation kill is computed as it is for the arrivals before the burst. The totals tabulated for the unsheltered case show 919 who were killed by the blast/thermal but would have survived radiation, 151 who would have survived blast/thermal but were killed by radiation, and 29,597 who would have been killed by either effect.

The right hand of the figure shows a plot of arrival time distribution of people arriving at this shelter after warning is given. Note the scale factor ARRIVAL TIME IN 200s. This factor is computed for improved readability and may change from shelter printout to printout. This plot shows that 7 x 200 plus 27 x 200 or approximately 6,800 people arrived before one delta T which is 19 minutes or just one minute before burst. This corresponds to the 7022 arrivals before burst. Delta T is the time required for people to cross one grid element and is calculated from the input population mobility factor. Arrivals after 25 Delta T is an overflow term used when travel distance is greater than 25 elements.



```
                    DYNAPIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE  04/09/63   RUN NO  1

             SURVIVAL CONDITIONS FOR SHELTER LOCATED AT I,J = 14,13 WITH ASSIGNMENT SYMBOL AC
PROTECTION FACTOR =   40     OVERPRESSURE FACTOR     =  8 LBS/SQ IN        BLAST SURVIVAL PROBABILITY =  2.3 PCT
                                                                               ARRIVAL TIME DISTRIBUTION

ARRIVALS BEFORE BURST                          =
    SURVIVORS IN SHELTER                       =
    CASUALTIES FROM BLAST IN SHELTER           =
    CASUALTIES FROM RADIATION IN SHELTER       =
    CASUALTIES FROM BLAST/RADIATION IN SHELTER =

ARRIVALS AFTER BURST - SHELTER INTACT          =
    SURVIVORS IN SHELTER                       =
    CASUALTIES FROM BLAST/THERMAL ENROUTE      =
    CASUALTIES FROM RADIATION IN SHELTER       =

ARRIVALS AFTER BURST - SHELTER DESTROYED       =
    SURVIVORS IN OPEN                          =
    CASUALTIES FROM BLAST/THERMAL ENROUTE      =
    CASUALTIES FROM RADIATION IN OPEN          =

                                                                        ARRIVAL TIME IN DELTA T =  19 MIN
                                                                        ARRIVALS AFTER 25 DELTA T =     3
TOTALS          ASSIGNED     SURVIVORS     CASUALTIES FROM -     BLAST     RADIATION     BLAST AND RADIATION
SHELTERED
UNSHELTERED
```

FIGURE 57 SURVIVAL CONDITIONS FOR SHELTER AC

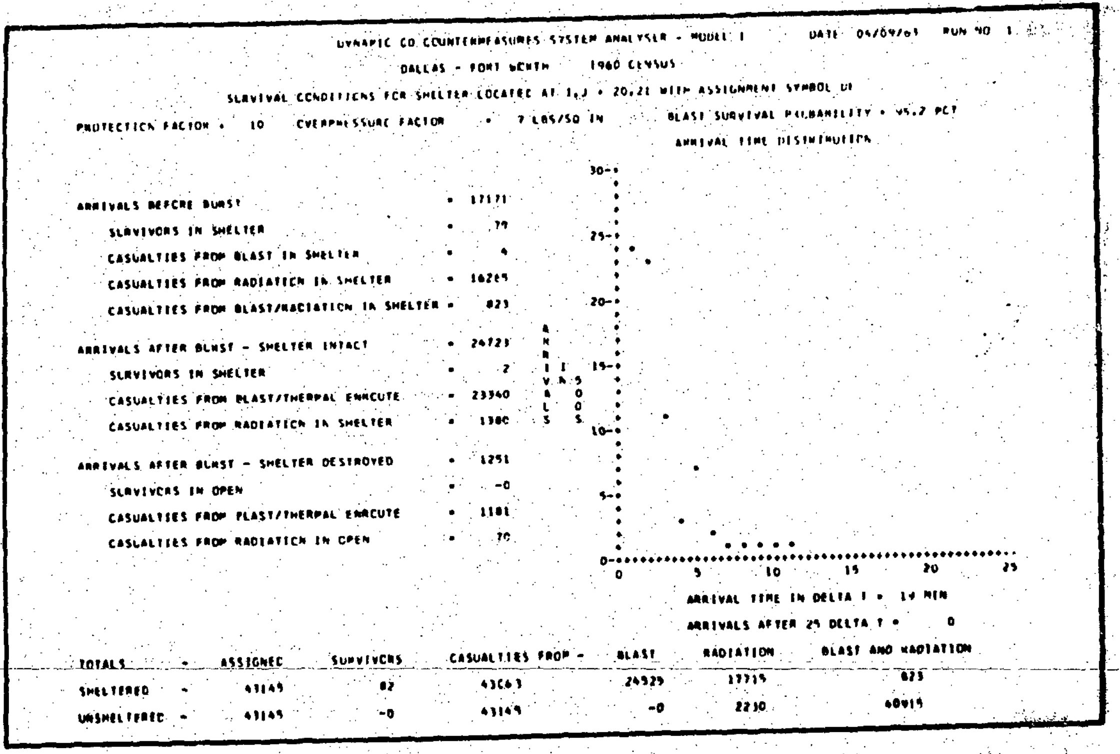
SURVIVAL CONDITIONS FOR SHELTER DE (FIGURE 58)

The protection factor and overpressure factors of this shelter were arbitrarily made small to test the sensitivity of the analysis to these parameters. In this case, the blast survival was good but most of the shelter occupants were not adequately protected from radiation. Over half of the population assigned to this shelter were killed enroute because the shelter was too far away, some not arriving until almost three hours after the burst. Had they arrived in time, the improvement in survival probability would have been negligible. The unsheltered total shows that most of the assigned population would have been double kills, i.e., either blast/thermal or radiation alone would have killed them. Protection is required here against all effects.

SURVIVAL CONDITIONS FOR SHELTER WX (FIGURE 59)

The first shelter discussed proved to be inadequate for protection against either blast or radiation at that location. The second shelter analyzed above provided effective protection against blast but permitted a large percent of radiation casualties in the shelter. The shelter in this figure provides 100 percent survival protection against radiation for persons arriving before the blast, but bears a high blast casualty rate. The major cause of casualties associated with this shelter is late arrivals.

In this situation it appears that there is a significant correlation between blast resistance and radiation protection required for a given shelter. For example, it may be meaningless to provide a shelter with a high radiation protection factor if, in the region where it will be exposed to this level of effect, it would be destroyed by blast.



```
                         DYNAPIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE 04/09/63   RUN NO 1
                                        DALLAS - FORT WORTH     1960 CENSUS
                   SURVIVAL CONDITIONS FOR SHELTER LOCATED AT I,J = 20,21 WITH ASSIGNMENT SYMBOL DE
PROTECTION FACTOR =  10    OVERPRESSURE FACTOR     =  7 LBS/SQ IN        BLAST SURVIVAL PROBABILITY = 95.2 PCT
                                                                               ARRIVAL TIME DISTRIBUTION

ARRIVALS BEFORE BURST                              =  17171
    SURVIVORS IN SHELTER                           =     79
    CASUALTIES FROM BLAST IN SHELTER               =      4
    CASUALTIES FROM RADIATION IN SHELTER           =  16265
    CASUALTIES FROM BLAST/RADIATION IN SHELTER =        823

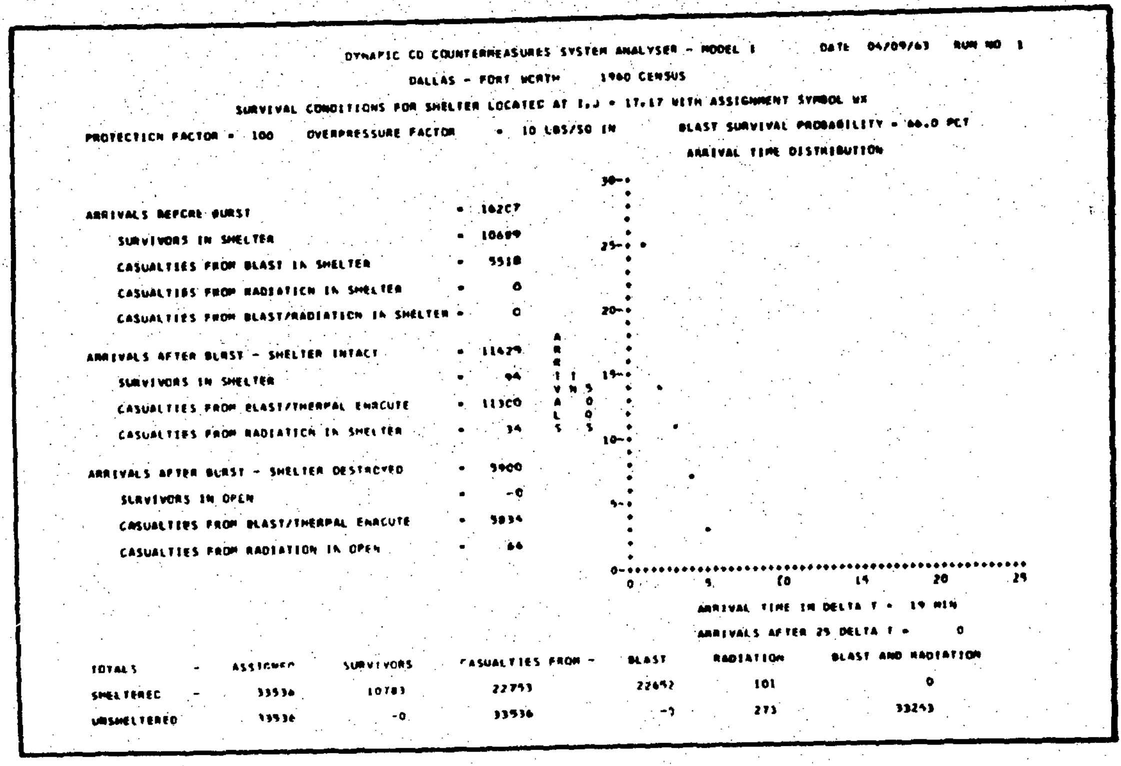
ARRIVALS AFTER BLRST - SHELTER INTACT              =  24723
    SURVIVORS IN SHELTER                           =      2
    CASUALTIES FROM BLAST/THERMAL ENRCUTE          =  23340
    CASUALTIES FROM RADIATION IN SHELTER           =   1380

ARRIVALS AFTER BLRST - SHELTER DESTROYED           =   1251
    SURVIVORS IN OPEN                              =     -0
    CASUALTIES FROM BLAST/THERMAL ENRCUTE          =   1181
    CASUALTIES FROM RADIATION IN OPEN              =     70

                                                                           ARRIVAL TIME IN DELTA T =  19 MIN
                                                                           ARRIVALS AFTER 25 DELTA T =     0

TOTALS      -    ASSIGNED     SURVIVORS      CASUALTIES FROM -    BLAST    RADIATION    BLAST AND RADIATION
SHELTERED   -      43145          82              43063           24525      17715              823
UNSHELTERED -      43145          -0              43145              -0       2230            40915
```

FIGURE 58 SURVIVAL CONDITIONS FOR SHELTER DE



```
                         DYNAPIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE 04/09/63   RUN NO 1
                                        DALLAS - FORT WORTH     1960 CENSUS
                   SURVIVAL CONDITIONS FOR SHELTER LOCATED AT I,J = 17,17 WITH ASSIGNMENT SYMBOL WX
PROTECTION FACTOR =  100    OVERPRESSURE FACTOR     =  10 LBS/SQ IN       BLAST SURVIVAL PROBABILITY = 66.0 PCT
                                                                               ARRIVAL TIME DISTRIBUTION

ARRIVALS BEFORE BURST                              =  16207
    SURVIVORS IN SHELTER                           =  10689
    CASUALTIES FROM BLAST IN SHELTER               =   5518
    CASUALTIES FROM RADIATION IN SHELTER           =      0
    CASUALTIES FROM BLAST/RADIATION IN SHELTER =          0

ARRIVALS AFTER BLRST - SHELTER INTACT              =  11429
    SURVIVORS IN SHELTER                           =     94
    CASUALTIES FROM BLAST/THERMAL ENRCUTE          =  11300
    CASUALTIES FROM RADIATION IN SHELTER           =     34

ARRIVALS AFTER BURST - SHELTER DESTROYED           =   5900
    SURVIVORS IN OPEN                              =     -0
    CASUALTIES FROM BLAST/THERMAL ENRCUTE          =   5834
    CASUALTIES FROM RADIATION IN OPEN              =     66

                                                                           ARRIVAL TIME IN DELTA T =  19 MIN
                                                                           ARRIVALS AFTER 25 DELTA T =     0

TOTALS      -    ASSIGNED     SURVIVORS      CASUALTIES FROM -    BLAST    RADIATION    BLAST AND RADIATION
SHELTERED   -      33536       10783              22753           22652        101                0
UNSHELTERED        33536          -0              33536              -0        273            33263
```

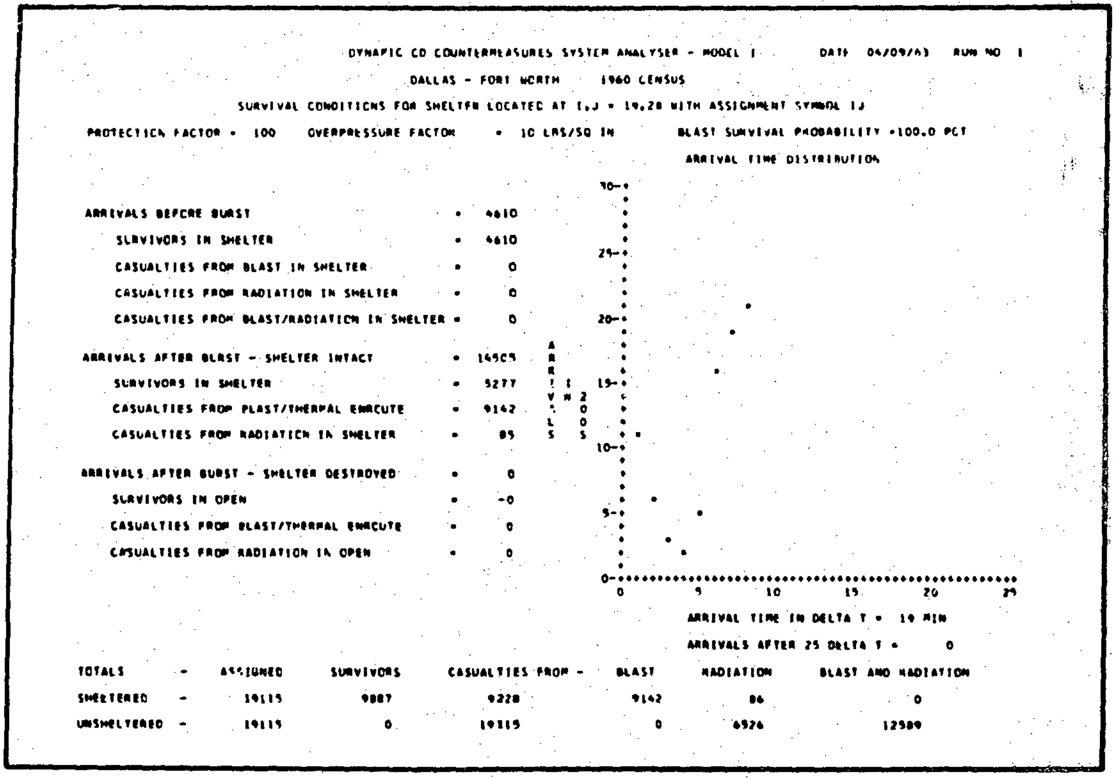
FIGURE 59 SURVIVAL CONDITIONS FOR SHELTER WX

SURVIVAL CONDITIONS FOR SHELTER IJ (FIGURE 60)

Of the four shelters discussed in this section, this is the only one that offers complete survival protection for personnel inside the shelter at the time of burst. However, there is a 50 percent casualty rate among those assigned this shelter because of late arrival. Arrivals after burst is noted as 14, 505.

SUMMARY OF SURVIVAL CONDITIONS FOR ALL SHELTERS (FIGURE 61)

Provided with the system analyzed, approximately 35% of the pilot city would be casualties in the event of the postulated threat. With no system, casualties would be about 50%. For this case, the system saves approximately one quarter of a million lives. A major fault of the system which accounts for most of the casualties is that there are not enough shelters located where people can reach them in time.



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                    DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE  04/09/63   RUN NO  1
                                 DALLAS - FORT WORTH      1960 CENSUS
              SURVIVAL CONDITIONS FOR SHELTER LOCATED AT I,J = 19,28 WITH ASSIGNMENT SYMBOL IJ
PROTECTION FACTOR =  100    OVERPRESSURE FACTOR     =  10 LBS/SQ IN        BLAST SURVIVAL PROBABILITY =100.0 PCT
                                                                           ARRIVAL TIME DISTRIBUTION

ARRIVALS BEFORE BURST                              =   4610
    SURVIVORS IN SHELTER                           =   4610
    CASUALTIES FROM BLAST IN SHELTER               =      0
    CASUALTIES FROM RADIATION IN SHELTER           =      0
    CASUALTIES FROM BLAST/RADIATION IN SHELTER     =      0

ARRIVALS AFTER BLAST - SHELTER INTACT              =  14505
    SURVIVORS IN SHELTER                           =   5277
    CASUALTIES FROM BLAST/THERMAL ENROUTE          =   9142
    CASUALTIES FROM RADIATION IN SHELTER           =     85

ARRIVALS AFTER BURST - SHELTER DESTROYED           =      0
    SURVIVORS IN OPEN                              =     -0
    CASUALTIES FROM BLAST/THERMAL ENROUTE          =      0
    CASUALTIES FROM RADIATION IN OPEN              =      0

                                                                           ARRIVAL TIME IN DELTA T =  10 MIN
                                                                           ARRIVALS AFTER 25 DELTA T =      0
TOTALS       -    ASSIGNED    SURVIVORS    CASUALTIES FROM -    BLAST    RADIATION    BLAST AND RADIATION
SHELTERED    -      19115        9887           9228             9142        86                0
UNSHELTERED  -      19115           0          19115                0      6526            12589
```
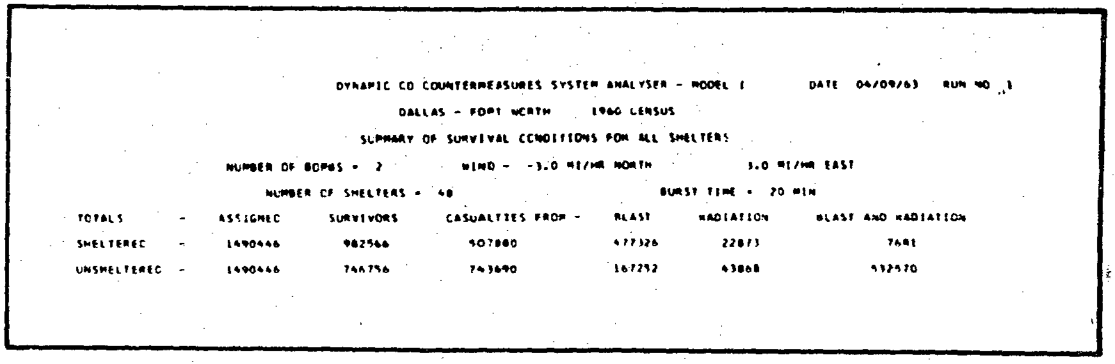

FIGURE 60 SURVIVAL CONDITIONS FOR SHELTER IJ



```
                     DYNAMIC CD COUNTERMEASURES SYSTEM ANALYSER - MODEL I        DATE  04/09/63   RUN NO  1
                                DALLAS - FORT WORTH      1960 CENSUS
                          SUMMARY OF SURVIVAL CONDITIONS FOR ALL SHELTERS
              NUMBER OF BOMBS =  2          WIND -  -3.0 MI/HR NORTH          3.0 MI/HR EAST
                 NUMBER OF SHELTERS =  48                            BURST TIME =  20 MIN
TOTALS       -    ASSIGNED    SURVIVORS    CASUALTIES FROM -    BLAST    RADIATION    BLAST AND RADIATION
SHELTERED    -    1490446      982566        507880            477326      22873             7681
UNSHELTERED  -    1490446      746756        743690            167252      43868           532570
```

FIGURE 61 SUMMARY OF SURVIVAL CONDITIONS

SECTION III

DETAILED PROGRAM DESCRIPTION - MULTIPLE EFFECTS WEIGHTED STRATEGY SHELTER OPTIMIZER

INTRODUCTION

Civil Defense literature includes the result of many research activities concerned with weapons effects and the effectiveness of particular Civil Defense countermeasures for particular situations. We are aware, however, of no attempt to use the information which is now available to determine most desirable Civil Defense countermeasure systems to protect actual populated areas against a realistic threat other than the Soft Target Study. Section I describes a computer program, called the Multiple-Shelter Type Mix and Location Optimizer, which established the feasibility of quantitatively considering the composition of optimal Civil Defense countermeasure systems. In some respects this program was aptly named. The program inputs include a shelter catalog, and the program optimization process results in the identification of both the mix and deployment of shelters for the system of best cost effectiveness against some specified threat.

In other respects the title does not suggest the true utility of the program. The program, for example, accepts the actual distribution of population over the area of interest at the time of an attack. Analysis procedures which have been devised elsewhere, on the other hand, ordinarily employ some idealized population distribution or attempt to evaluate the worth of a particular Civil Defense countermeasure without considering the population distribution at all. Moreover, the demonstrated feasibility of the procedure for treating the area distribution of population suggests similar procedures might be used for other area distributions which are important. These factors include terrain details and the characteristics of the unsheltered population.

We have received the comment that the consideration of optimal Civil Defense countermeasures is not a useful activity because the threat cannot be known with certainty. It is true the pay-off is greater if a specific threat can be postulated. This is not to say, however, that optimization has no meaning if the threat is uncertain. What cannot be done is to define meaningful and quantitative measures of Civil Defense countermeasure system effectiveness if nothing whatever is assumed about the threat. An important though limited feature of the original program is that the attack definition may consist of aim points rather than impact points so that the effect of uncertainties in this aspect of the problem may be studied. A major objective of the program herein described is to provide an improved capability for studying the usefulness of Civil Defense planning, when the nature of an enemy attack, should one occur, or the conditions at the time of the attack cannot be predicted with precision.

The most significant feature of the program is the form of the results. The Reference 1* paper on Systems Analysis in Civil Defense states that the Civil Defense countermeasures systems analyst should not be expected to recommend that a particular level of investment be selected. The program results are presented in the form most convenient for those whose responsibility it is to consider the level of investment problem. The routine automatically generates the curve of system effectiveness as a function of total system cost such that for each cost the effectiveness of the system is maximum. The shelter mix and deployment at desired intervals along the curve are also displayed. Section I of Reference 1* concludes with a description of a repetitive process by which a Civil Defense countermeasures systems analysis may be accomplished. While the program does not remove the desirability of considering several possible threat situations, the analysis procedure is enormously simplified over what it would be if only a program for computing the effectiveness of a specific shelter system design were available.

While the program has demonstrated the feasibility of the method and has brought out many features of the problem, it has limitations which restrict its practical utility. There are other uncertainties present besides the impact points of the enemy weapons. Weapons effects other than blast may also be important. The program uses a fixed 21 by 21 element population distribution matrix since this is the largest size for which numerical values of the elements may be conveniently printed on a single output sheet. Since the model bookkeeping procedure has been designed for this matrix size only, it can not easily be increased and program modifications would result in both per operation, as well as total running time, time increases. In order to alleviate these restrictions, to more completely realize the potential utility of the method and to extend the program into areas not now considered, the program has been completely redesigned and rewritten. The mathematical concepts of Inverse Cost Effectiveness (ICE) and conversion inverse cost effectiveness (CICE), which are used to compute optimal mix and deployments, have been retained.

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* Devaney, op. cit.

The new program employs a variable size population distribution matrix which is limited by restrictions which appear to result in the absolute maximum size matrix which may be used by a reasonably fast running program. The way in which the matrix is used in the program permits a larger geographic area to be considered during one computer run if the population centers are widely distributed over the area than if the area population density is greater. This has been accomplished by not using computer fast access storage for zero population matrix elements except in a memory conserving way. Moreover, an optimal system over the area of any number of population matrices may easily be determined manually by a procedure which is essentially merging the individual results by matching at corresponding ICE or CICE levels and accumulating total cost and survivors added.

The program, as before, will accept a catalog consisting of any reasonable number of shelter types. It is now necessary, however, to describe the performance of each shelter type in protecting occupants against thermal radiation, prompt nuclear radiation and fallout as well as blast. Shelter is here used in a broad sense and may merely mean some kind of modification to existing structures such as the expenditure of money (cost) to improve the fire resistance of a residence (effectiveness).

The nature of an attack against targets in the area of interest, given that an attack will occur, would not ordinarily be known. Several alternatives would be found reasonable but with varying likelihood. In order to determine what can be done to optimize a shelter system for such an uncertain threat situation, any number of attack plans, called strategies, and the estimated probability of occurance of each may be used as program inputs. The program computes the shelter system mix and deployment which maximizes the expected number of survivors for each total cost level. The aim points included in the strategies need not be elements of the population matrix since the range of some weapon effects may be so great that remote aim points are important.

Fallout is a significant hazard for strategies involving low altitude detonations. The fallout contours resulting from an attack depend on the winds at the time of the attack. These winds cannot be known at the time a shelter system is chosen. The new program takes this uncertainty into account. Inputs to the program may include any number of wind seasons, and, for each season, the fractional part of a year (probability) for the season and parameters indicating the distribution of winds.

Weather may affect the destruction and loss of life resulting from an enemy attack in an important way. The wind model herein described is considered the first step toward the development of a weather submodel which will permit study of the operational significance of this parameter.

The vulnerability of the target to weapon effects is also a function of atmospheric transmissivity, relative humidity, temperature, and other factors which might be profitably considered in future studies.

The vulnerability of the unsheltered population to the combined weapon effects is dependent upon the interaction of environmental factors. The original program defined the environment in terms of hardness to overpressure, thermal hardness of unsheltered population and a single, deterministic wind. The pre-shelter environment was assumed to be uniform throughout the entire target area. In the present program the environment is defined separately for each population element and includes a probabilistic wind model. In this manner, population living in elements composed of well maintained, quality structures would be assigned higher environmental protection factors than those in substandard slum structures. The environment of each element is defined in terms of its vulnerability to each of the weapon effects and identifies the shelter types which are not applicable. For example, basement fallout shelters are applicable only to houses having basements.

The program begins by selecting a shelter type from the shelter catalog and an element from the population distribution array such that no other shelter type assigned anywhere in the population matrix has a lower ICE. This is the first point on the cost vs effectiveness curve. This shelter system would have low effectiveness, low cost and the best cost effectiveness possible. The program continues by assigning shelters to previously unprotected elements by minimum ICE or by modifying shelter assignments according to the CICE values until the system of maximum effectiveness is obtained. (Effectiveness is the expected number of survivors added which is computed by taking into account all of the uncertainties of the situation and the weapons effects - blast, thermal radiation, prompt nuclear radiation and fallout.) At each total cost level, the effectiveness is the greatest value possible with the Civil Defense countermeasure components available in the shelter catalog. The mix and deployment corresponding to any point on the curve may be determined by following the assignment and reassignment operations indicated in the output listing or the program will automatically output coded shelter deployment arrays at desired ICE/CICE levels. The system cost, effectiveness and shelter mix and deployment for areas described by any number of population distribution arrays may be determined by merging the output listing by ICE/CICE levels or a simple program may be written to automatically perform these operations.

Considerable effort has been expended on the program bookkeeping and logic to achieve a program which will require very little computer time for a problem of this magnitude. Tape storage is, of course, required. The program has, however, been considered to consist of several sequential phases or segments. Information may be transferred to or from tape between phases although all of the operations for one phase involve fast access storage only. The mathematical operations have also been studied to achieve solutions which can easily be handled by the computer. This work has resulted in the idea of a shelter vector, which replaces the old probability of survival matrix for each shelter type, the procedure for applying the optimization operations to only one vector at a time and then appropriately combining the results and a unique mathematical formulation for considering the effect of fallout with distributed winds.

GENERAL PROGRAM DESCRIPTION

THE POPULATION MATRIX

The original Shelter Mix and Location Optimizer considered the region of interest to be a square area subdivided into an array of 21 by 21 square elements. The population of each non-zero element was an input to the program. The data was stored in the computer as a 21 by 21 numerical array. The size of an element determined the accuracy of the program which, in turn, determined the size of the region of interest which could be considered during a program run. If the number of shelter types in the shelter catalog was small, part of the computer fast access memory would not be used but this would not increase the permissible size of the population matrix. The consideration which led to the original choice of matrix size was the number of numerical values which could be neatly printed on a single printout sheet.

The new program employs a rectangular, though not necessarily square, population distribution matrix. Both the number of elements per row and per column are variable. The maximum number of elements in a row is limited by the number of useable print spaces in the printer, which is slightly greater than 130. It is necessary to code the element values by population intervals, each represented by a single character, if the population matrix is to be printed as an output array. The maximum number of elements per column depends on the number of elements per row, the fraction of zero population elements in the area of interest and the number of shelter types in the catalog. This procedure will permit making full use of the computer fast access memory even though the shelter catalog may be small.

Population matrices for adjacent regions may also be pasted together to form a population map of the total area of interest for some study. All of the output matrices of whatever type are compatible in this sense except for the total cost vs total survivors added curve, which is obtained by summing the cost and survivors added data in the individual output listings as will be explained.

THE PHASE I PROGRAM (PROBABILITY OF SURVIVAL SHELTER VECTORS)

One of the operations of the original program was to construct a probability of survival matrix for the unsheltered population and for each shelter type in the catalog. These matrices were stored as 21 by 21 element arrays. Zero elements consumed storage space in the computer memory.

An extensive study of the storage and running time problem has resulted in the concept of probability of survival shelter vectors. The computer calculates the probability of survival at a particular non-zero population element using the vulnerability characteristics of the unsheltered population and the characteristics of each shelter in the catalog. Each of these probabilities of survival represents a component of the probability of survival vector. This process is continued until a vector is obtained for each non-zero element in the population matrix. These vectors need not be stored in fast access memory since the set, as such, is not involved in subsequent computations. The program bookkeeping has been set up in this way since the Phase I routine, which takes into account all weapon effects and problem uncertainties, is expected to be the largest of the routines and will therefore occupy the most fast access memory. The shelter vectors are stored on tape for use by later phases of the program. The shelter vectors are stored as vectors although they contain all of the information required to form probability of survival matrices.

The idea of a shelter vector is more than a different point of view from the original procedure. The concept will, in general, result in conservation of memory since no spaces are used for zero elements. If many zero elements are present, the convenience with which the program is used would be greatly increased. If all of the population matrix elements contain at least the minimum population of interest, the two procedures are approximately equivalent. The most important reason for adopting the shelter vector procedure is that it is much easier to perform all of the calculations for one element at a time than to compute many complete matrices a shelter at a time. The original program was simple enough so that the probability of survival grids could be retained in a form suitable for output printing.

The new program, which represents an enormous increase in complexity, requires highly efficient bookkeeping and computational procedures if the program is to be a practical aid in Civil Defense countermeasures research.

THE PHASE I' PROGRAM (PROBABILITY OF SURVIVAL MATRICES)

The Phase I' routine is an optional program which may be used if a display of the probability of survival matrix for the unsheltered population and for population protected by each shelter in the catalog is desired. The program begins by reading and storing the shelter vectors. It is necessary that all the vectors be stored. This is not expected to be a limiting situation, however, since the program is expected to be relatively short. The program reads all of the probability of survival values for some shelter type. These values are coded by intervals, each interval being represented by a single output character. The matrices are assembled and read out for printing a line (row) at a time so that only a small amount of working storage is required. After a matrix has been assembled, the index number is changed, causing the program to assemble another probability of survival matrix based on a different entry in the shelter vectors. The Phase I' program is complete when the number of probability of survival grids printed equals the number of entries in a shelter vector.

The probability of survival grids printed by the program are composite matrices which take into account all weapons effects and all problem uncertainties. Arrays for particular effects or situations may be obtained, however, by proper use of the program inputs.

THE PHASE II PROGRAM (ICE/CICE VECTORS)

The Phase II program converts the probability of survival shelter vectors to ICE/CICE shelter vectors. This is equivalent to applying the optimization process to one population matrix element at a time. The results are then merged to develop the shelter assignment and reassignment sequence.

The program begins by reading a probability of survival shelter vector, converting the vector to an ICE/CICE vector and storing the vector in the computer fast access memory. This process is continued until the vector for each non-zero population matrix element has been stored.

The process of converting the vector consists of first computing an inverse cost effectiveness (ICE) for each shelter type at that location. The ICE value computed for a shelter type is a function of the probability of survival if protected by the shelter type (a shelter vector entry), the probability of survival of unprotected population (a shelter vector entry) and the per person cost of the countermeasure (a program input). The countermeasure corresponding to minimum ICE (best cost effectiveness) is identified as the initial shelter assignment for that location. The ICE values for the remaining types are then converted to conversion inverse cost effectiveness (CICE) values. A CICE value is a function of the per occupant costs of the last countermeasure type assigned and the shelter for which the CICE is being computed and the probability of survivals for the same shelters. The shelter type of minimum CICE is identified as the next assignment and the CICE values for the remaining types, based on the last assignment, are computed. ICE and CICE values are only computed for those countermeasure types which can be ordered by both increasing per person cost and probability of survival. Shelter types not so orderable are marked "not useable at this location". The remaining types may not all be used and these are eliminated by the relative ordering of their CICE values. When all of the countermeasure types have been assigned or eliminated, the vector is complete. The initial assignment is the shelter of best cost effectiveness. The final assignment is the countermeasure affording highest probability of survival without regard to cost. The intermediate assignments are optimal with respect to decreasing cost effectiveness and increasing effectiveness. The fact that a particular shelter type does not appear in the optimal assignment sequence does not necessarily mean that it would not appear elsewhere if the effects of the threat are different.

The requirement that all of the shelter ICE/CICE vectors must be stored in the computer fast access memory at the same time is the consideration which limits the size of the largest population matrix which may be used on a single run. There is an entry in each vector for every shelter or countermeasure type in the catalog. There is no entry for the unsheltered situation. At least one other word is necessary to achieve a fast running program. This word, in three parts, indicates the i and j numbers for the location of the vector in the matrix and the location of the minimum ICE/CICE value within the vector. The limiting condition is that the product of the number of shelter types in the catalog plus 1 and the number of non-zero elements in the population matrix must not exceed the number of fast access storage words allocated for these data. The number of spaces available is about 25 thousand words. The remainder of the memory is used for the system, the master control, the program for converting and processing the ICE/CICE vectors and a small working memory.

The program processes the vectors by selecting the minimum ICE value in any of the vectors and assigning the corresponding shelter type to that location. The value is essentially marked "used" and the next lowest value is found, which may be an ICE or a CICE for the location already assigned a shelter type. The process continues until all of the useable vector entries have been considered in the assignment and reassignment process and the system of maximum effectiveness is obtained.

An assignment is made by generating an output record which indicates the ICE/CICE level, (which increases from record to record), the i and j numbers for the matrix element where the assignment is made, the previous shelter type (if any) and the new shelter type. The first record is the single assignment of best cost effectiveness. The effect of all records is to define the system of greatest effectiveness although the cost effectiveness may be poor. The assignments and reassignments up to some intermediate record defines the optimal system at that ICE/CICE level or the system which achieves the greatest possible expected number of total survivors added. The total cost cannot be included in the shelter assignment records since the population matrix cannot be maintained in memory without either reducing the size of the largest population matrix which can be used during a single run or successively scanning tape which is a time consuming operation.

THE PHASE III PROGRAM (FINAL REPORT DETAILS)

This program reads the population matrix, which is available on tape, and stores the numerical array in memory. The shelter assignment records which have been generated by the Phase II program are then read and amended by adding total system cost and survivors added. These quantities are a function of the population in that element, the shelter costs, the ICE/CICE level and the values of these quantities for the last record. The amended records are again stored on tape.

A listing of the Phase III Program output records may be used to plot total system cost as a function of suvivors added for the shelter mix and deployment which yields the greatest possible expected number of survivors at that total cost level. The corresponding system cannot be determined without noting the shelter assignments and reassignments in all previous records however.

THE PHASE IV PROGRAM (SHELTER ASSIGNMENT GRIDS)

The Phase IV Program sets up a blank matrix in memory which is the same size as the initial population matrix. The shelter assignment records of the Phase II or III programs are then read, record by record. As each record is read, the shelter assignment described by that record is recorded by writing the shelter type, indicated by a single output character, into the array element corresponding to the i, j values in the record. The deployed system, as indicated by the shelter assignment matrix, is expanded and changed to shelter types affording greater protection as additional assignment and reassignment records are read. The matrix is printed at input ICE/CICE levels.

The assignment grids are printed at specified ICE/CICE levels since optimal systems for several regions, each separately optimized by a program run, are correctly assembled by matching at corresponding ICE/CICE levels, not a corresponding total cost levels.

The number of shelters and countermeasures which can be included in the catalog is limited by the number of different output characters available for printing the shelter assignment grids. This number is somewhat greater than 40.

GENERAL PROGRAM ORGANIZATION

A flow diagram which indicates the function of each of the program phases and how they are interrelated is shown on Figures 62a - 62e. The Phase I and Phase II programs require additional explanation and are discussed in detail in subsequent sections. The operation of the Phase I', Phase III, and Phase IV programs are straightforward.

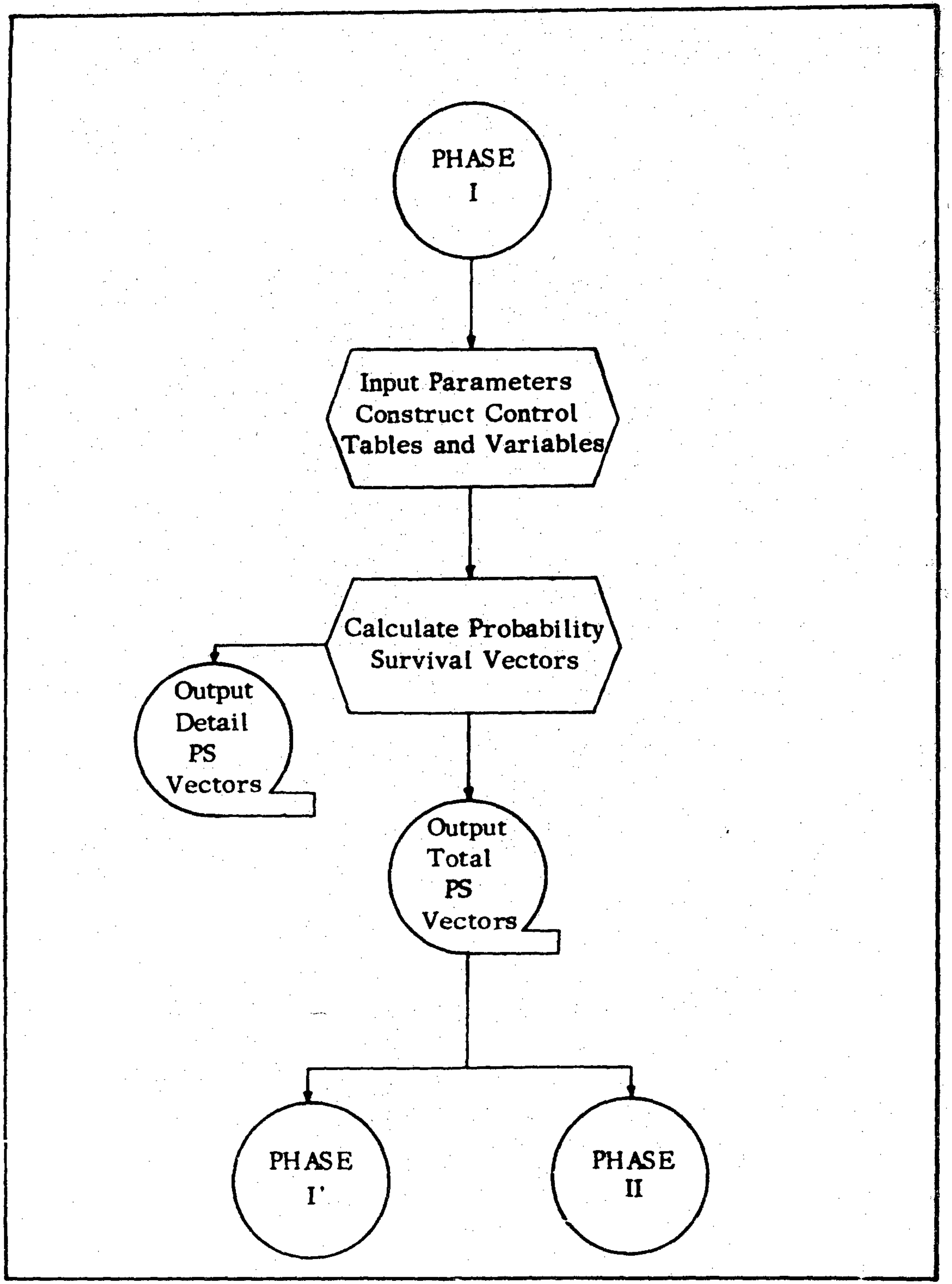


FIGURE 62a GENERAL PROGRAM ORGANIZATION

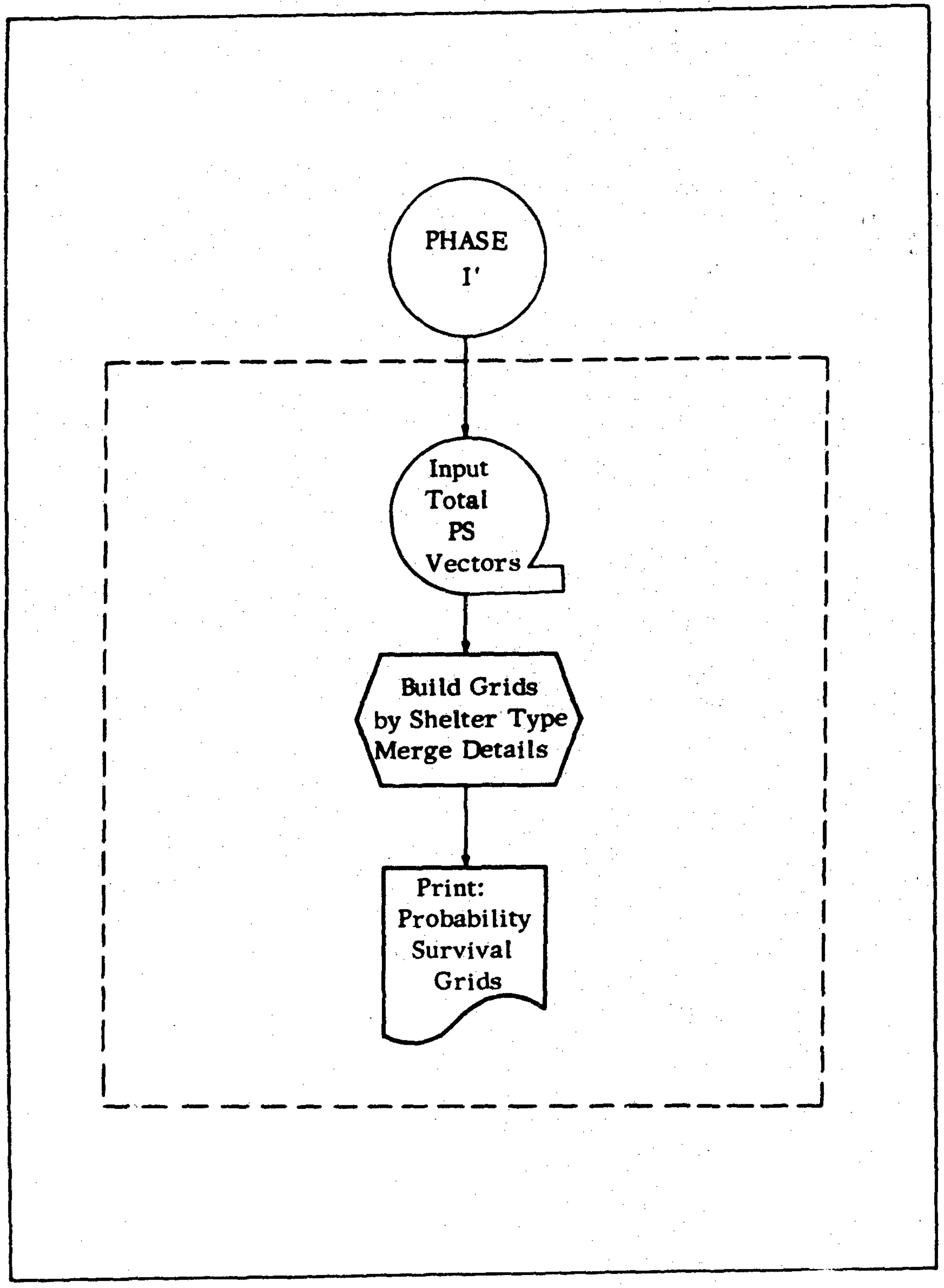


FIGURE 62b GENERAL PROGRAM ORGANIZATION

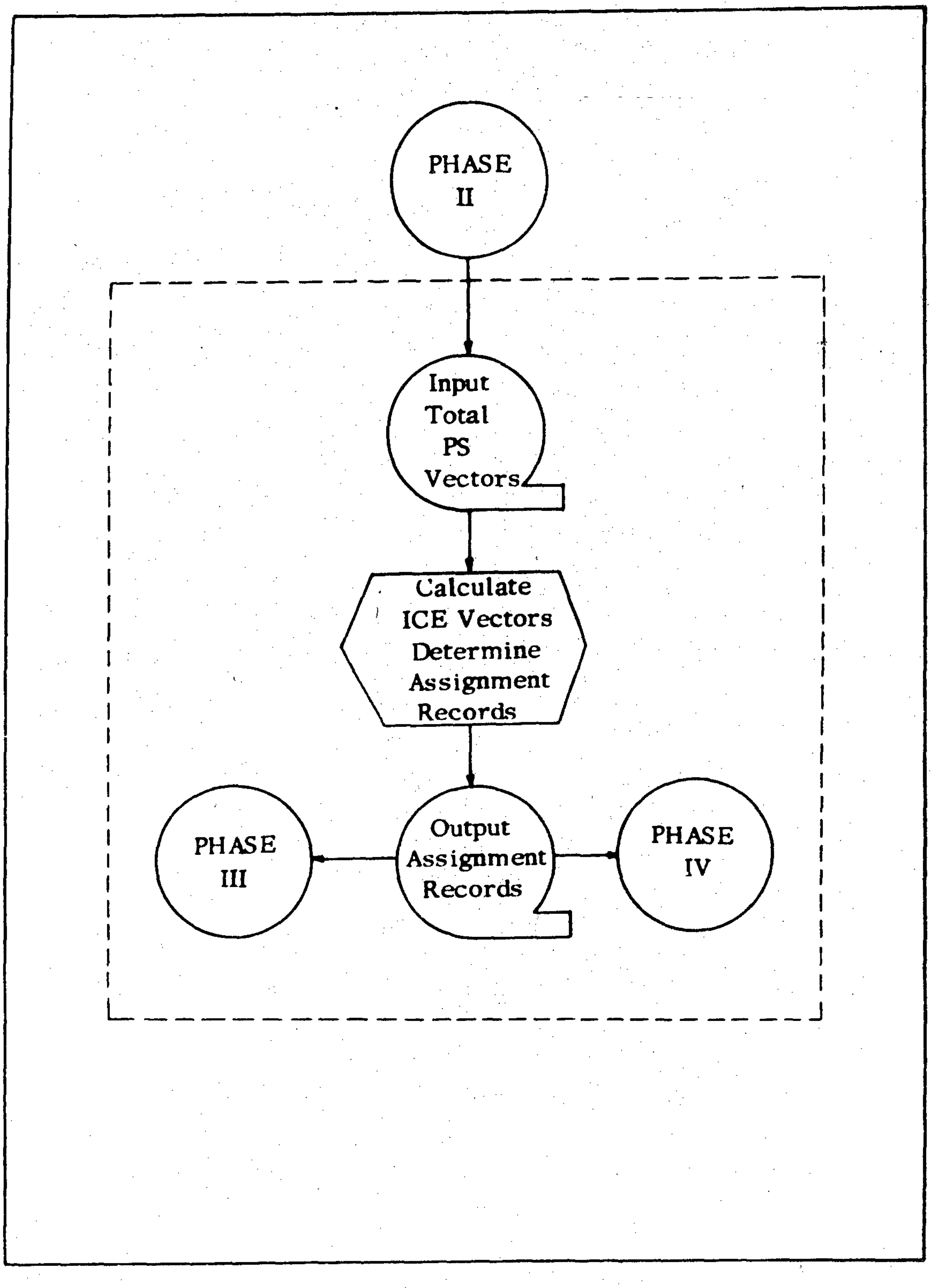


FIGURE 62c GENERAL PROGRAM ORGANIZATION

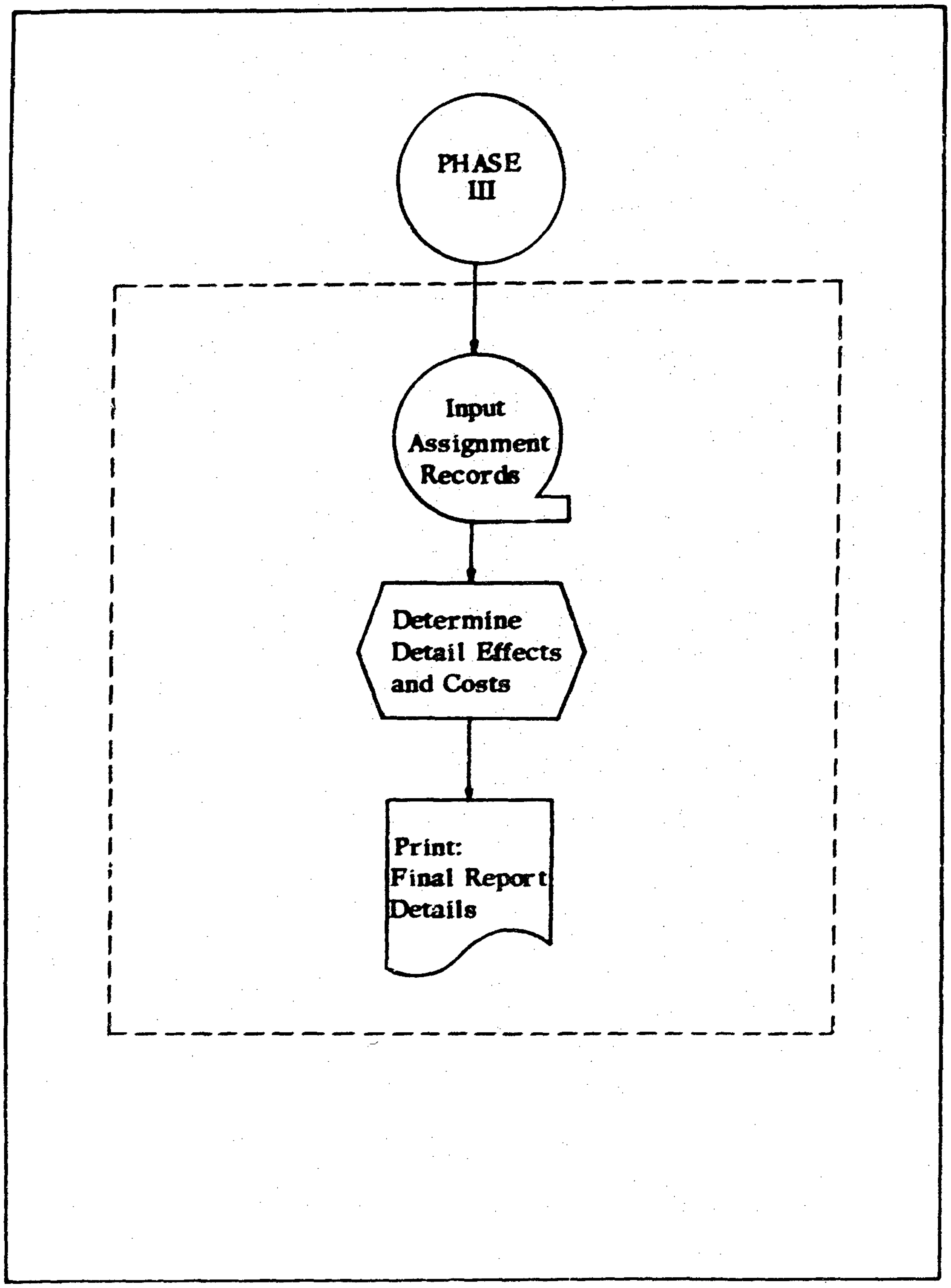


FIGURE 62d GENERAL PROGRAM ORGANIZATION

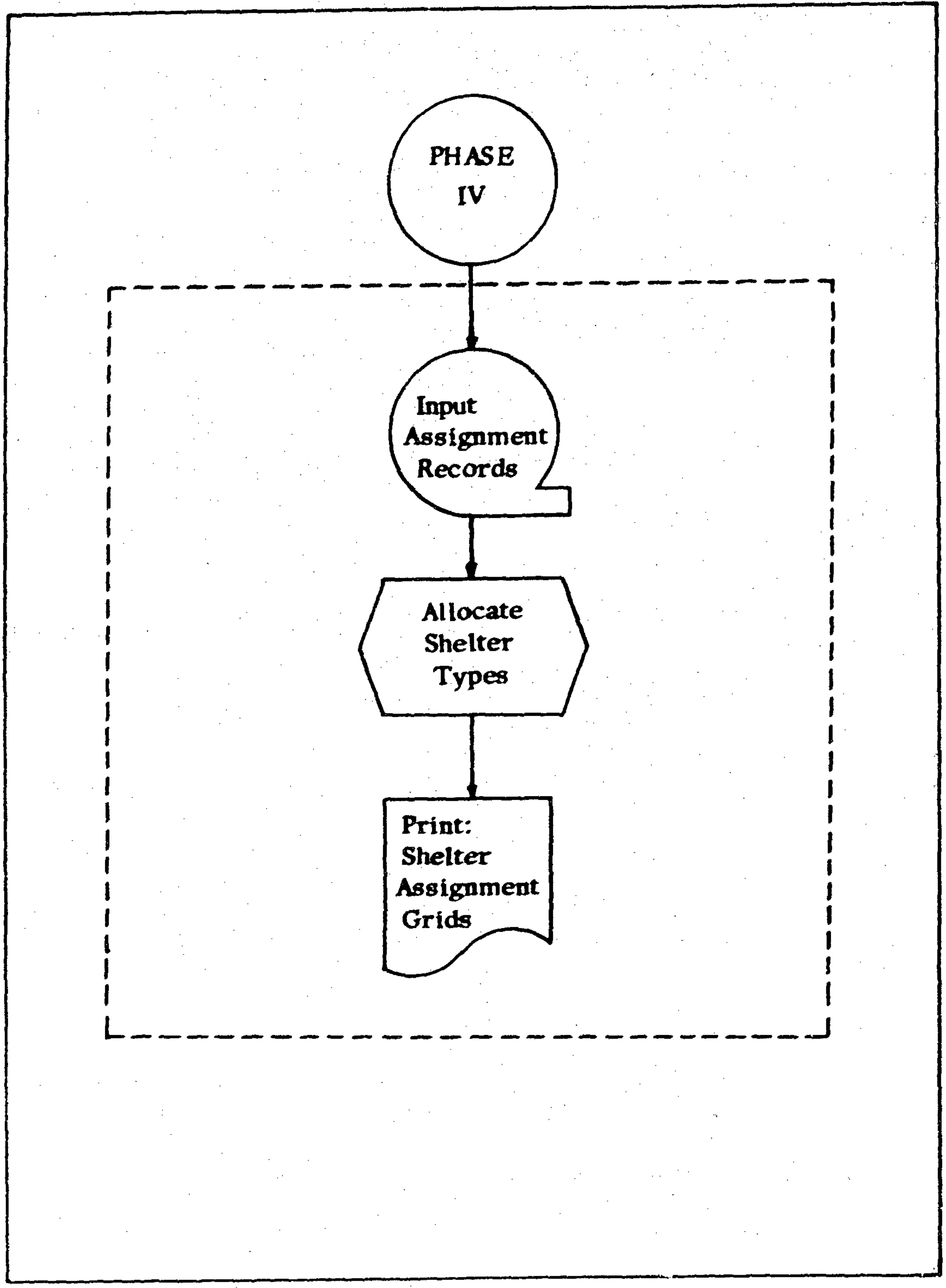


FIGURE 62e GENERAL PROGRAM ORGANIZATION

DETAILED PROGRAM DESCRIPTION

PHASE I

A flow diagram for the Phase I Program is shown beginning on Figure 63. The numbering of paragraphs in this discussion corresponds to the numbers on the general operation descriptions in the flow diagram.

1. Inputs to the program include the shelter and countermeasure catalog, the attack strategies, the wind seasons and the attack weapons. The shelters and countermeasures in the catalog are defined by parameters which determine the vulnerability of persons protected by that shelter or countermeasure and the per person cost. Each strategy is specified by a list of aimpoints, a bomb number and a delivery error standard deviation for each aimpoint, and the probability that strategy will be used. The weapon characteristics for a strategy are determined by correlating the bomb number with characteristics in a bomb table to avoid duplicate computations if identical weapons are used in the same or different strategies. The wind seasons are described by the fraction of the year the season applies (probability), the mean wind components and the vector standard deviation of the wind during the season. If an attack is more likely during one wind season than another, the probability of the season may be adjusted to take this fact into account. A weapon type is defined by yield, burst altitude and radiation conversion efficiency. A weapon type need only be input once regardless of how often it is used in the strategies. The sum of the probabilities of the strategies and the sum of the probabilities of the wind seasons should both be unity.

2. For each weapon in the bomb list, the program increments the stabilized, cylindrical cloud into altitude layers. Each layer is then incremented by particle size. The resulting disks of approximately the same time down are then combined. The disks are described by a table which indicates the cloud

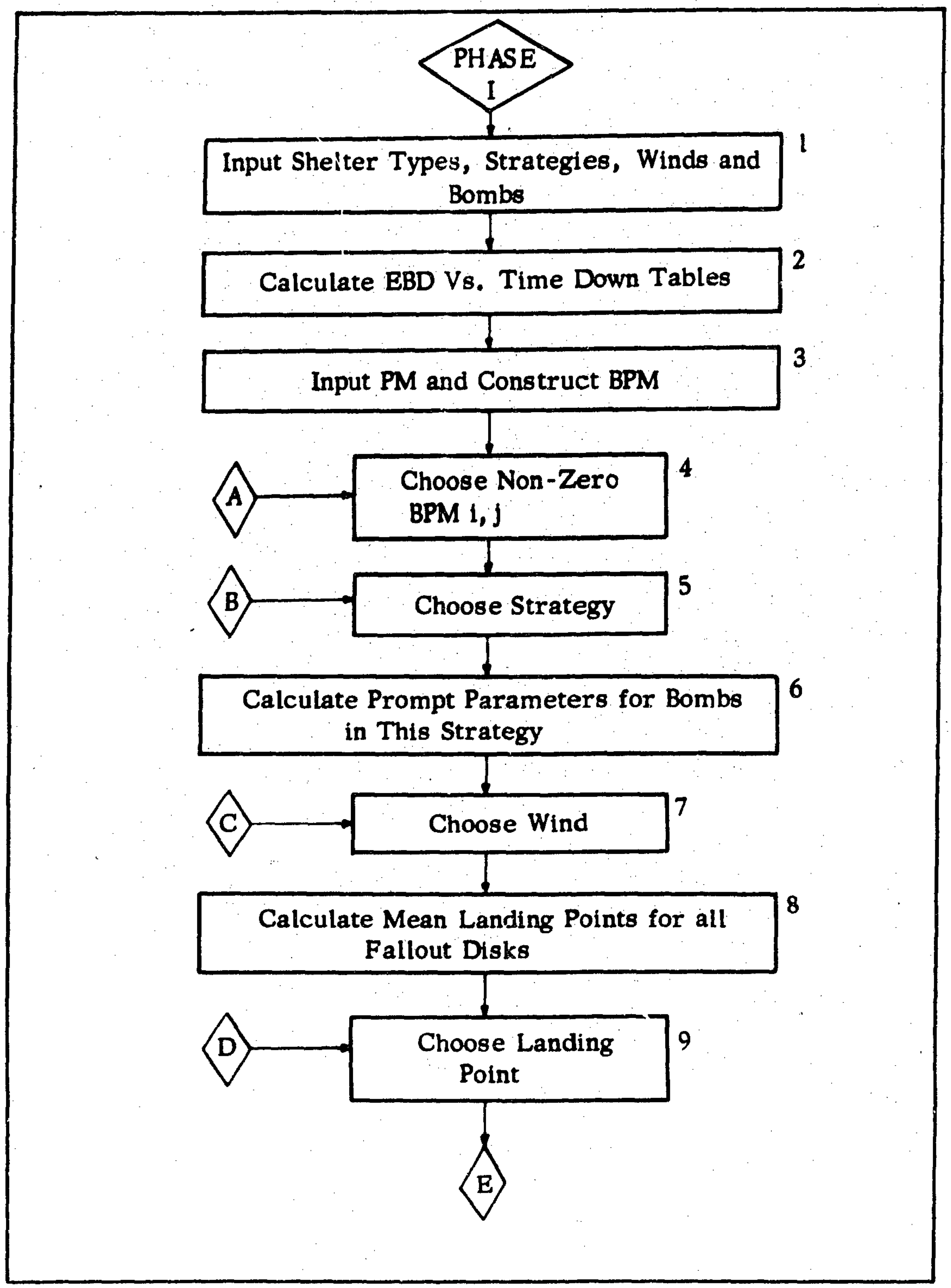


FIGURE 63 PHASE I FLOW DIAGRAM

radius, time to fall for each disk and the effective biological dose (EBD) which is obtained by integrating the decaying radiation field component caused by the disk from the time down to an appropriate later time. The validity of this procedure is discussed elsewhere. The program generates an EBD vs time to fall table for each low altitude burst point weapon in the input bomb table.

3. The numerical population matrix (PM) is a program input. The routine computes a binary population matrix (BPM) in which a 0 or 1 indicates whether a population value has been input at that i, j. The BPM requires only 1/36th the memory storage of the PM. The PM is stored on tape for use during the Phase III program while the BPM is stored in the fast access memory. The program computes a probability of survival shelter vector for each element for which a 1 appears in the BPM.

4. The routine selects a non-zero element in the BPM and proceeds to compute a vector for that element. The routine then transfers back to this instruction, as shown by the "A" connector, picks up the next non-zero element and continues until a probability of survival vector has been computed for each non-zero element in the BPM.

5. The probability of survival vectors take into account all of the possible strategies. The routine picks a strategy, adds the contribution of the strategy into the working values of the vector and then loops back, via the "B" connector, to pick the next strategy. When all of the strategies have been considered, the working values in the vector are the desired final probability of survival values for that vector which is then output by the program.

6. At this point, the weapon aimpoints (the strategy) and shelter location are known so that parameters relating to the probability of surviving prompt weapon effects may be computed. The computations are discussed elsewhere.

7. The routine now prepares to make fallout computations by selecting a wind season. After the computations for this wind season have been made, the next wind season is selected by transferring back to this instruction through connector "C". A wind season is defined by a probability, the mean wind components W_N and W_W and the vector standard deviation σ_W.

8. The weapon aim points, fallout disk tables and the wind are now known. The routine computes the mean landing point for the center of each disk in each time down table. The relations used are of the form

$$X_L = X_A - W_N t_d$$

$$Y_L = Y_A + W_W t_d$$

where A refers to an aim point, N and W to North and West as the directions from which the wind components come and t_d is the time to fall for this disk. The standard deviation of the distance from the center of a disk to its mean position depends on the time to fall.

$$\sigma_d = \sigma_W t_d$$

9. The routine now selects one of the disks for more detailed computations. After the disk has been processed, another disk from the same or different weapon is selected by transferring back to this instruction via the "D" connector.

10. The Phase I Program flow diagram is continued on Figure 64. At this point the routine has established a shelter location, a mean landing point for the center of a disk and a disk radius which depends on the cloud from which the disk was taken. The standard deviation in x and y for the landing point is

$$\sigma_L^2 = \sigma_d^2 + \sigma_B^2$$

where the standard deviation of the bomb impact point with respect to the aim point is part of the input strategies. The program now assumes a bivariate normal distribution for the disk landing point and computes the probability that the shelter location will be within a disk radius of the disk landing point. This is an application of what has been called the bomb coverage function. This computation is discussed in another section.

11. This instruction is in a loop which considers each fallout disk from every weapon in a particular strategy. The purpose of the loop is to compute the distribution of fallout at a particular location during a particular wind season. The assumption is made that the distribution is normal. Each of the fallout disks is characterized by the probability, P_L, that the disk will cover the center of the element under consideration and a dose, (EBD), that unsheltered population would receive given that the disk does cover the element. The mean dose is

$$\sum P_L \text{ (EBD)}$$

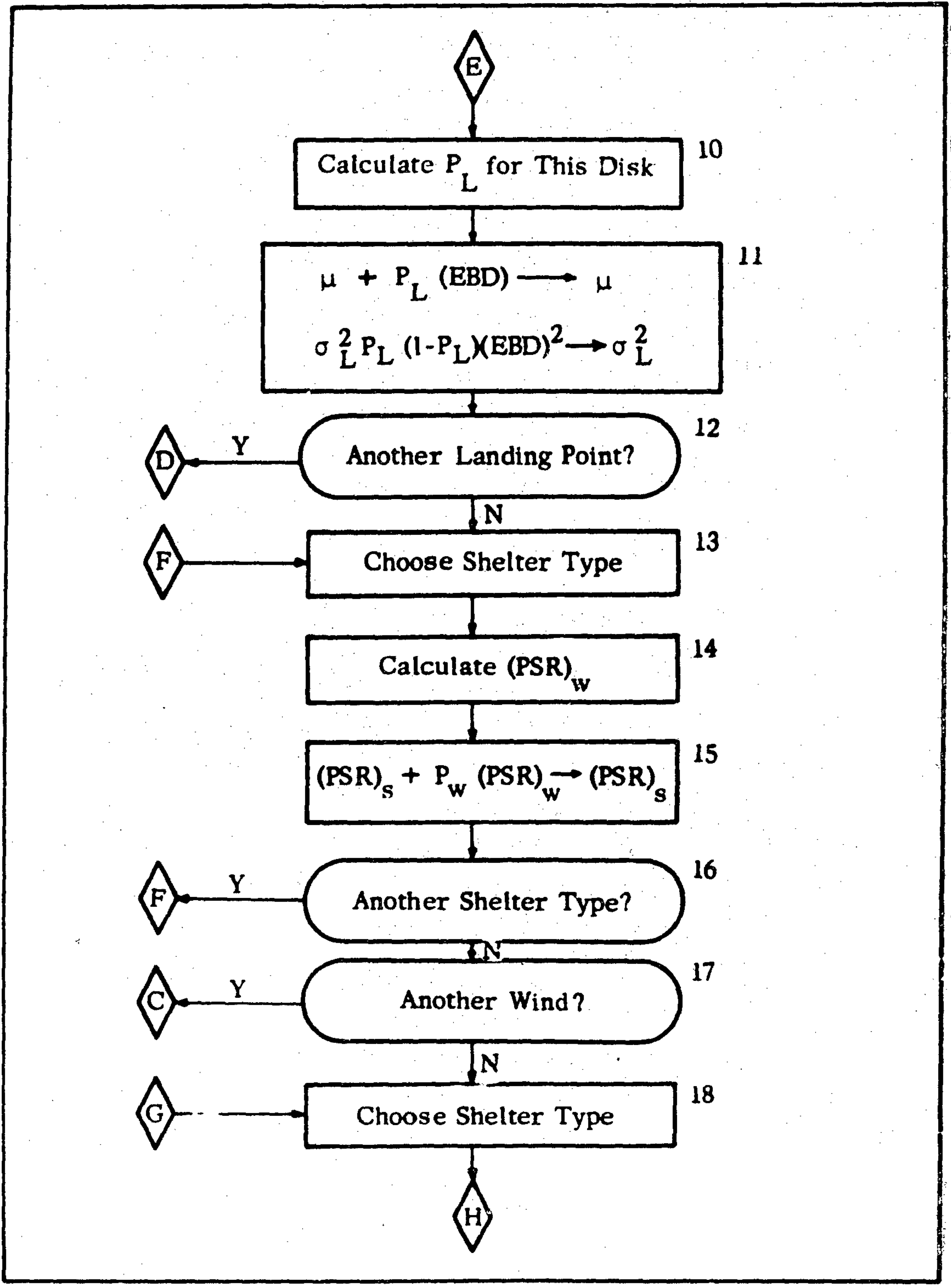


FIGURE 64 PHASE I FLOW DIAGRAM (CONTINUED)

The variance is

$$\sum P_L (1 - P_L)(EBD)^2$$

These sums are formed by initializing mean and variance accumulators to zero whenever Operation 9, Figure 63, is entered from the Operation 8 direction. Each pass through the landing point loop augments these accumulators as shown to account for the effects of another fallout disk.

12. When the contributions of a fallout disk to the mean and variance accumulators have been added, the program tests whether there is another disk to consider. If there is, the routine transfers back to an earlier operation by way of the "D" connectors. If all of the disks of all of the weapons of the strategy have been considered, the values in the accumulators are the desired quantities. The parameters determine the distribution of fallout for a specified location, strategy and wind season.

13. The program selects a shelter from the catalog for which probability of surviving nuclear radiation computations are to be made.

14. The program now computes the probability of surviving radiation given the wind season, strategy and shelter. The radiation absorbed by shelter occupants has two components, prompt and fallout. The prompt parameters were computed in Operation 6 of Figure 63 since only the shelter location and strategy are needed for this computation and the results apply to a particular wind season. The parameters for the composite distribution are

$$\mu = \frac{(\mu)_p}{(PF)_p} + \frac{(\mu)_{fo}}{(PF)_{fo}}$$

$$\sigma^2 = \frac{\sigma_p^2}{(PF)_p^2} + \frac{\sigma_L^2}{(PF)_{fo}^2}$$

In these relations separate protection factors for a particular shelter type are used for prompt and fallout nuclear radiation. The values are input as part of the catalog. The program then computes the probability of surviving radiation at this location given the wind season and shelter. The procedure involves an input probability of survival vs EBD table and the normal probability density function of radiation dose which is a function of μ and σ. The procedure is discussed in another section.

15. This instruction computes the probability of surviving radiation by taking all wind seasons into account. Separate probabilities are computed for each shelter type. The probabilities apply to the strategy selected under Operation 5, Figure 63. The computations are made by setting up an accumulator for each shelter type and initializing these words to zero. These operations are part of Instruction 7 of Figure 63 when approaching from the Operation 6 direction. Instruction 15 is in a shelter loop which is part of a larger wind season loop. Instruction 14 computes the probability of survival for a particular shelter and wind season. Instruction 15 multiplies this value by the probability of the wind season and adds the product to the previous value in the accumulator for this shelter type.

16. This operation is to test whether all the shelters have been considered for a particular wind season. If they have not, the program transfers back to Instruction 13 via connector "F". The routine then considers the next shelter type in the catalog.

17. If all the shelters have been considered, the routine tests whether all the wind seasons have been taken into account. If they have not, the program transfers back to Instruction 7 via the "C" connectors. The routine then proceeds to add the contribution of the new wind season to the probability of surviving nuclear radiation of each shelter type. If all the wind seasons have been considered, the probability for each shelter is correct for this strategy.

18. The program now sets up another shelter loop which computes the probability of surviving the other weapon effects and the overall probability of survival for each shelter. These computations apply to one strategy.

19. This operation is shown on Figure 65. The instruction computes the probability of surviving blast when protected by this shelter type at this location given that this strategy occurs. The procedure is discussed in a separate weapons effects section.

20. This instruction computes the probability of surviving thermal radiation if protected by a shelter of this type. The procedure is also discussed in a separate weapons effect section.

21. Part of Operation 4, Figure 63 consists of setting up an overall probability of survival accumulator for the unsheltered population at this location and for persons protected by each shelter type in the catalog. Operation 21 includes the computation of the overall probability of survival for this location, shelter type and strategy. The computation is made by forming the product of the independent probabilities of surviving prompt and fallout nuclear radiation, blast and thermal radiation. This product is then multiplied by the likelihood of this strategy and the new sum is added to the overall probability of survival for this shelter type.

22. If all shelter types have not been considered, the routine transfers back to Operation 18 via connector "G" and the overall probability of survival accumulator for a new shelter is corrected for the current strategy.

23. If the effects of all strategies have not been included in the overall probability of survival accumulators, the routine transfers back to Operation 5, of Figure 63 and the procedure described is repeated for another strategy.

24. When all of the strategies have been taken into account, the contents of the overall probability of survival accumulators are the desired shelter vector. There is one element of the vector for the unsheltered population at this location and another for each of the shelter types in the catalog. Since one vector is not used to compute another vector at a different location, the computed vector is merely stored on tape.

25. The program now continues to search the BPM. If another non-zero element is found, the operations are repeated for the new location using the same core addresses. If no such elements are found, the shelter vector tape is completed and may be listed or used as input to the Phase I' or Phase II programs.

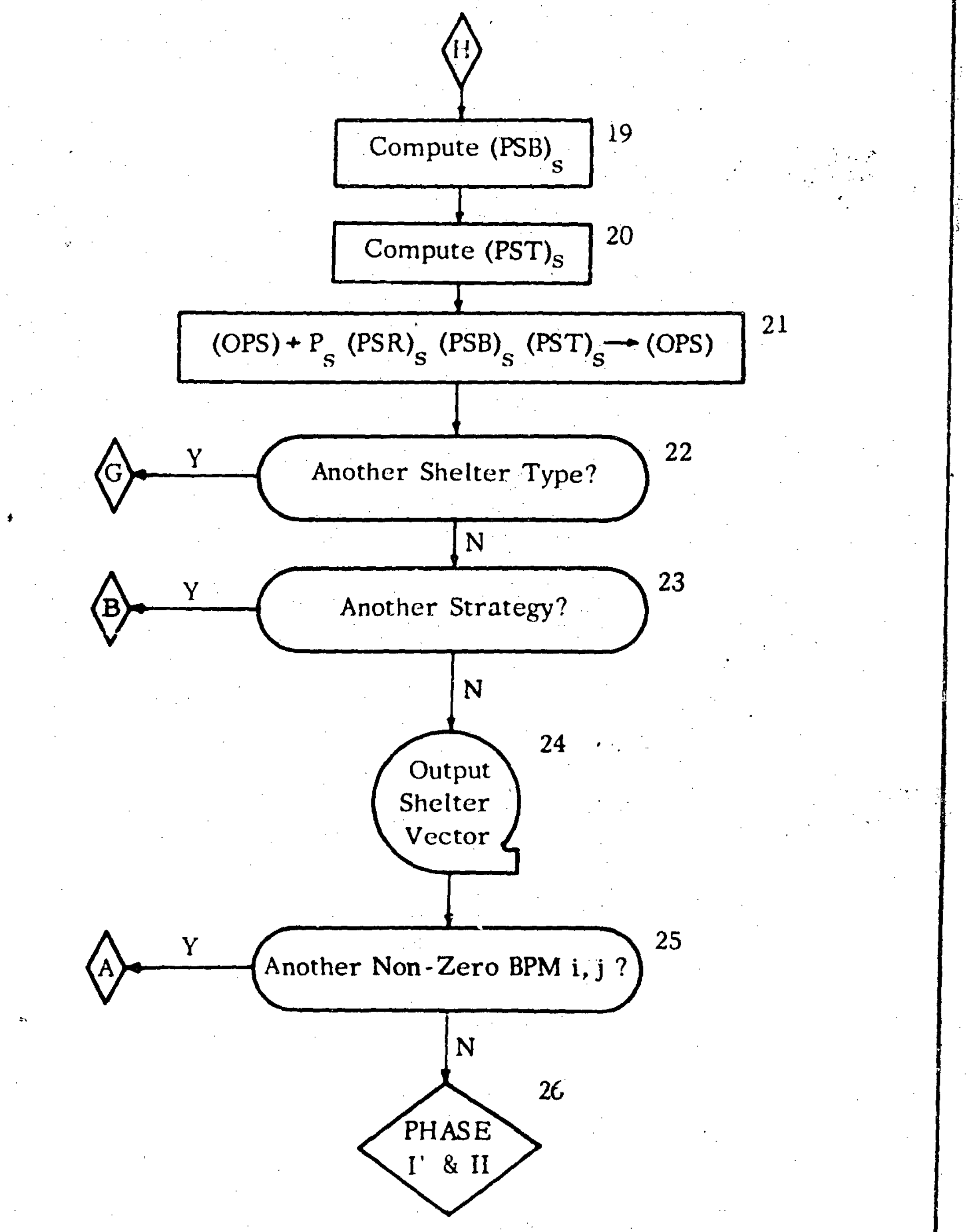


FIGURE 65 PHASE I FLOW DIAGRAM (CONCLUDED)

PHASE II

This program may be considered to consist of two parts. The first part reads the shelter probability of survival vectors from tape, one at a time. The vector is essentially converted to a vector of inverse cost effectiveness (ICE) and conversion inverse cost effectiveness (CICE). The procedure followed develops the optimal assignment sequence for the single location. The converted vector is then stored in the computer fast access memory. The first part of the program is complete when an ICE/CICE vector for every non-zero element of the population matrix has been stored. The second part of the program operates on the ICE/CICE vectors to generate the optimal shelter assignment sequence for the array. The assignment sequence is stored on tape and is used as input to the Phase III and IV programs.

The basic flow diagram is shown beginning on Figure 66. The procedure is quite simple although some of the required bookkeeping operations may make the diagram difficult to follow without the accompanying text. The validity of the ICE/CICE procedure for generating the optimal shelter assignment sequence for a single location and for the entire array is discussed in another section.

1. The routine reads a shelter vector from tape. This vector includes the probability of survival of the unsheltered population at the location for this vector and a probability of survival for each shelter type in the catalog. The program computes a modified ICE/CICE vector which contains an entry for each shelter type, information indicating which shelters of the catalog appear in the optimal assignment sequence for this location and what this sequence is. The ICE/CICE vector is then stored in the fast access memory. The routine then tests whether there is another shelter vector on tape. If there is, the program transfers back to Operation 1 via the "A" connector.

2. There are several working numbers required by the program bookkeeping. These numbers will be described as they are used by the program. One of the operations at this point is to set the shelter number counter, i, to 1.

3. The program sets up working values of the ICE/CICE vector. This vector has an entry for each shelter type in the catalog but no entry for the unsheltered population. The values in this vector will be called WICE to indicate that they are working values of quantities related to ICE and CICE and which contain all of the information of the real ICE and CICE values. The initial WICE are set to zero. It is also imagined that the WICE may be specially marked in two independent ways. One of these marks will be called "infinity" and the other a "flag". The actual computer operations to which these marks correspond are not of interest in this discussion. The initial zero values of the WICE are unflagged.

4. The program now selects shelter type i. The quantities of interest are $WICE_i$, the shelter vector entry PS_i and the bookkeeping variables. After the operations for this shelter type are completed, the program, in general, returns to this instruction via connector "B".

5. The routine tests whether the WICE for shelter type i is flagged. If it is, the routine transfers via connector "C" and proceeds to test for another shelter type. On the first pass through the shelter numbers, all WICE are unflagged and the answer to this query is no.

6. The next operation is a conditional transfer depending on the relative magnitudes of the probability of survival given shelter i and PS. One of the operations of Instruction 2 is to set PS equal to the probability of survival of the unsheltered population, given in the shelter vector, and the quantity remains at this value during the first pass through the shelter numbers. Each time a new shelter assignment in the optimal sequence is made, however, PS is appropriately increased. In the first pass through the shelter list, each shelter type, since it appeared promising enough to justify machine analysis, would be expected to afford greater security than no shelter or special countermeasure and the program would transfer to "D" of Figure 67.

7. If the probability of survival afforded by shelter type i is not greater than PS, the WICE is set to a flagged infinity. This indicates that shelter i is not in the optimal assignment sequence for this location.

8. This procedure is shown on Figure 67. One of the operations of Instruction 2, Figure 66, is to set PSH to unsheltered. In general, during

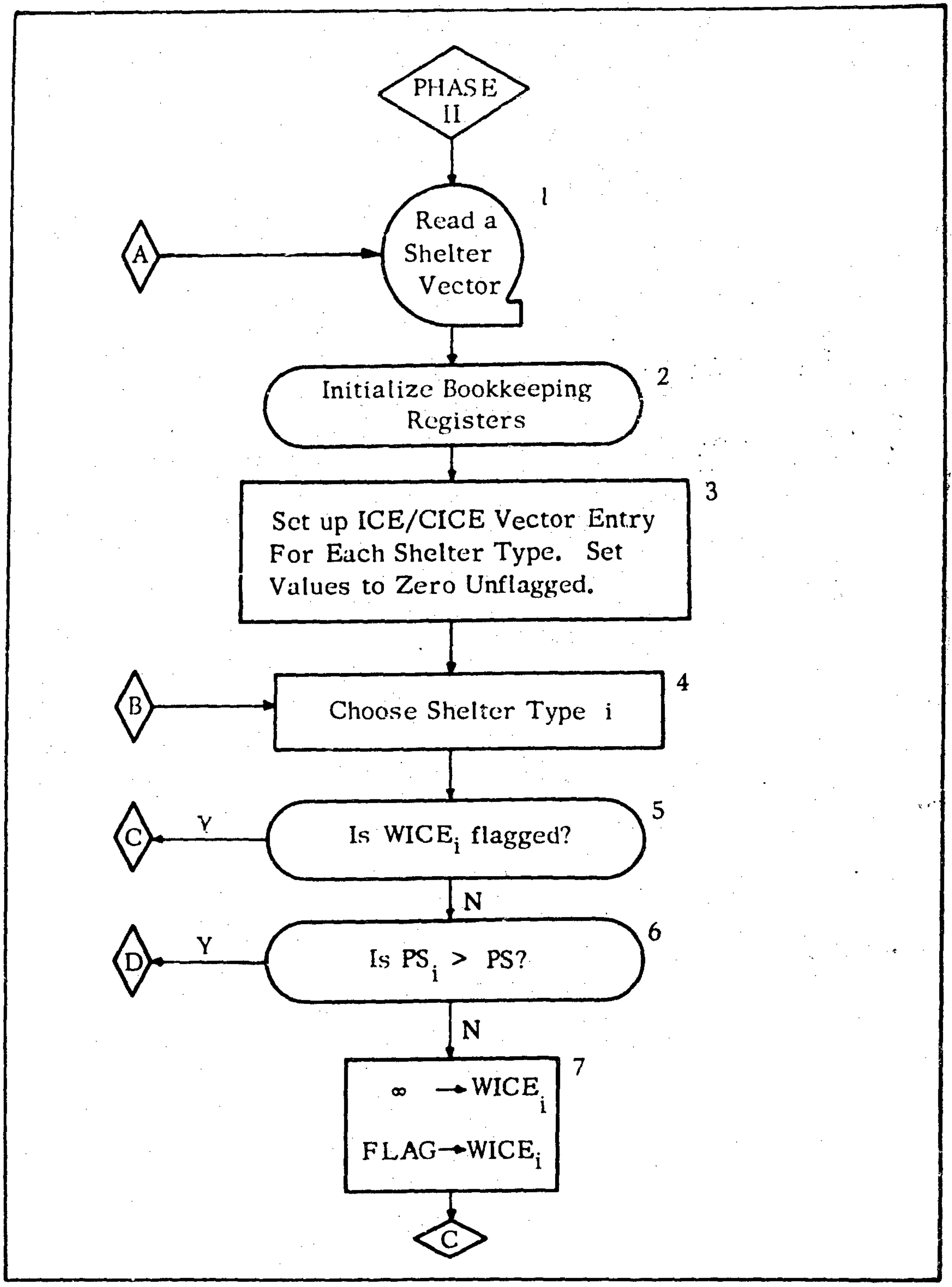


FIGURE 66 PHASE II FLOW DIAGRAM

a pass through the shelter numbers which seeks to identify the next assignment in the optimal assignment sequence, PSH is set to the number of the last shelter type assigned which is the reference point for the new computations. If PSH is unsheltered, the per person cost of this countermeasure is zero and the probability of survival is that for the unsheltered situation. Under these conditions, Operation 8 computes the ICE for shelter i. In the general case, the instruction computes the CICE for a conversion from shelter type PSH to shelter type i. The probability of survival for shelter type PSH is always equal to the quantity PS of Instruction 6, Figure 66. The redundant symbols could be removed from the flow diagram.

9. During a pass through the shelter types, the routine not only computed a new WICE for each shelter type which has not yet been assigned (flagged) or discarded (set to flagged infinity) but also remembers the minimum WICE computed. This is accomplished by setting a number MIN to infinity during Operation 2 of Figure 66. Each time a new WICE is computed, it is compared with the current MIN value. If WICE is the larger, the routine transfers to the logic which selects the next shelter type via connector "C".

10. If ICE is smaller, which means its cost effectiveness is better than MIN, the WICE for shelter i replaces some previous WICE as the new value for MIN. The shelter number i also replaces the previous value of SH which is the shelter number to which the WICE in MIN applies.

11. The program now compares i with the number of shelters in the catalog. If they are equal, this pass through the shelters is complete and the program transfers to "E".

12. If all of the shelters have not been taken into account, the program selects the next greater shelter number and transfers back to "B" of Figure 66.

13. Whenever the program reaches this point it has completed a pass through all of the shelters of the catalog. During the first pass, any shelter which affords less protection than is naturally provided the unsheltered population is discarded by setting its WICE to flagged infinity. An ICE for all remaining shelters has been computed and stored in the WICE for the shelter type. The minimum ICE, which is the best inverse cost effectiveness provided by the available shelter types at this location, has been identified and stored in MIN. The shelter number corresponding to MIN is stored in SH.

During any pass through the shelter types after the first, any shelter which affords less protection than the last shelter type which has been included in the optimal assignment sequence is discarded by setting its WICE to flagged infinity. A CICE for all remaining unflagged shelters has been

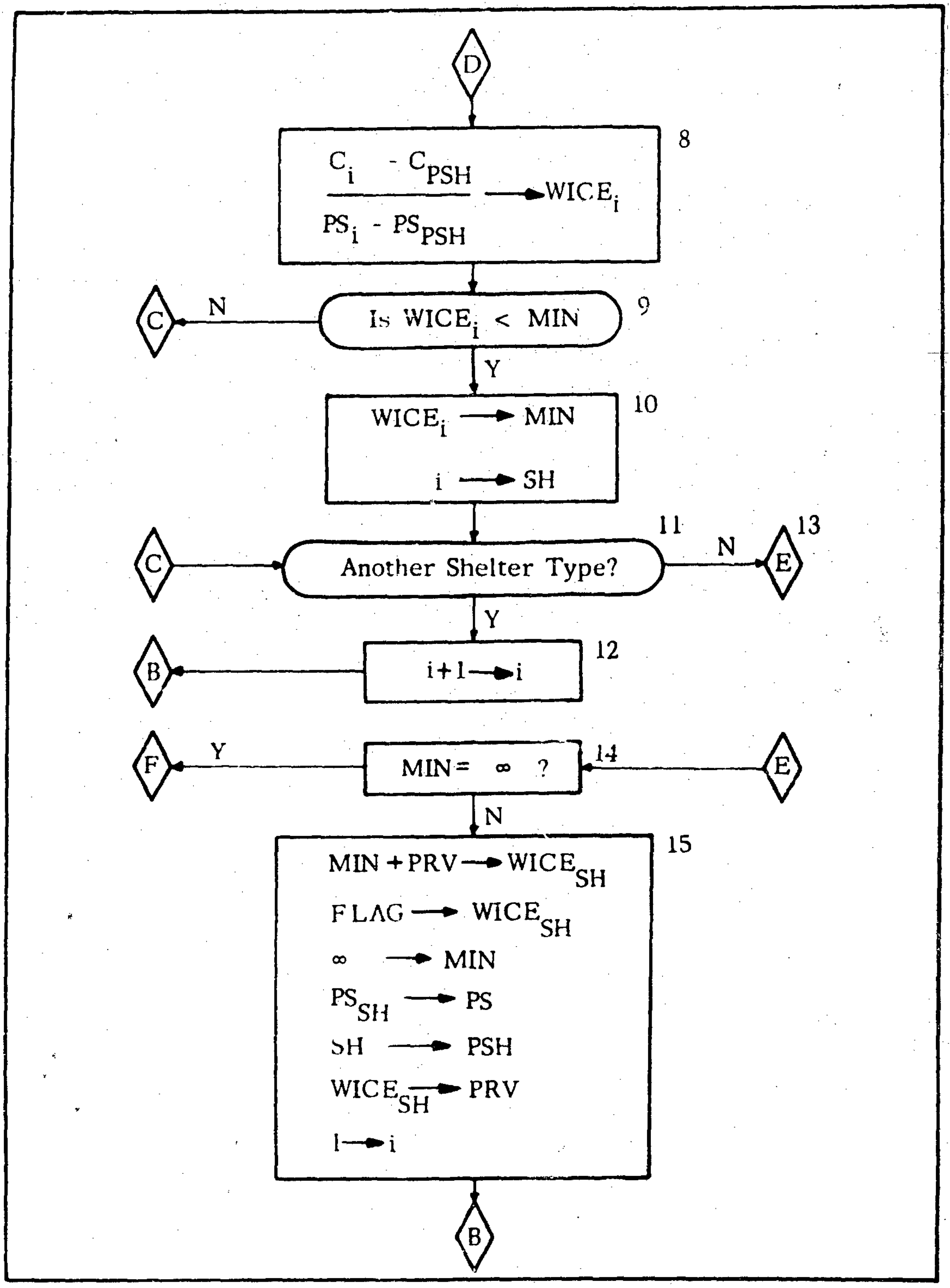


FIGURE 67 PHASE II FLOW DIAGRAM (CONTINUED)

computed, based on the last shelter assignment, and stored in the WICE for the shelter type. The minimum CICE, which is the best conversion cost effectiveness provided by the remaining (not discarded or assigned) shelter types at this location, has been identified and stored in MIN. The shelter number corresponding to MIN is stored in SH.

14. When, after a pass through the shelter types, MIN is still set at infinity, all of the shelter types which should appear in the optimal shelter assignment sequence for this location have been assigned. The routine proceeds to the final operations for this vector by way of connector "F".

15. If, after a pass through the shelter types, a minimum WICE has been computed, shelter type SH is the next type in the optimal assignment sequence. The assignment is noted by entering the sum of MIN (which is the minimum WICE computed on the last pass through the shelter types) and the quantity PRV in place of the WICE for shelter type SH (the shelter type corresponding to the CICE in MIN). The quantity is then flagged. It is seen that a flagged infinity for some WICE entry indicates that shelter type has already been assigned and also need not be considered on later passes through the shelter type. The quantity PRV is the value stored as a WICE for the last shelter assigned. This procedure is a device to permit the order of the shelter assignments to be reconstructed from the order of the magnitudes of the flagged WICE without committing additional fast access memory to record this information.

The number MIN is reset to infinity so that it may again be used to record the minimum CICE on the next pass through the shelter types. The probability of survival for shelter type SH is stored in PS. The number of the current sheltered assignment, SH, is stored as the number of the previous shelter assigned, PSH. It is remembered that the operations shown are redundant inasmuch as the probability of survival for shelter type PSH is equal to PS. The number stored as a flagged WICE for shelter type SH is stored as PRV for use during the next shelter assignment. The routine now sets the shelter number i to 1 and transfers to "B" of Figure 66 for another pass through the shelter types.

16. This operation is shown on Figure 68. At this point all of the values in the WICE vector have been flagged. The flagged infinities correspond to the shelter types which do not appear in the optimal shelter assignment sequence at this location. The other values consist of an ICE and modified CICE values. The routine unflags all WICE not set at infinity.

17. The program now examines each WICE of the vector and determines the shelter number, j, corresponding to the minimum WICE. The j value

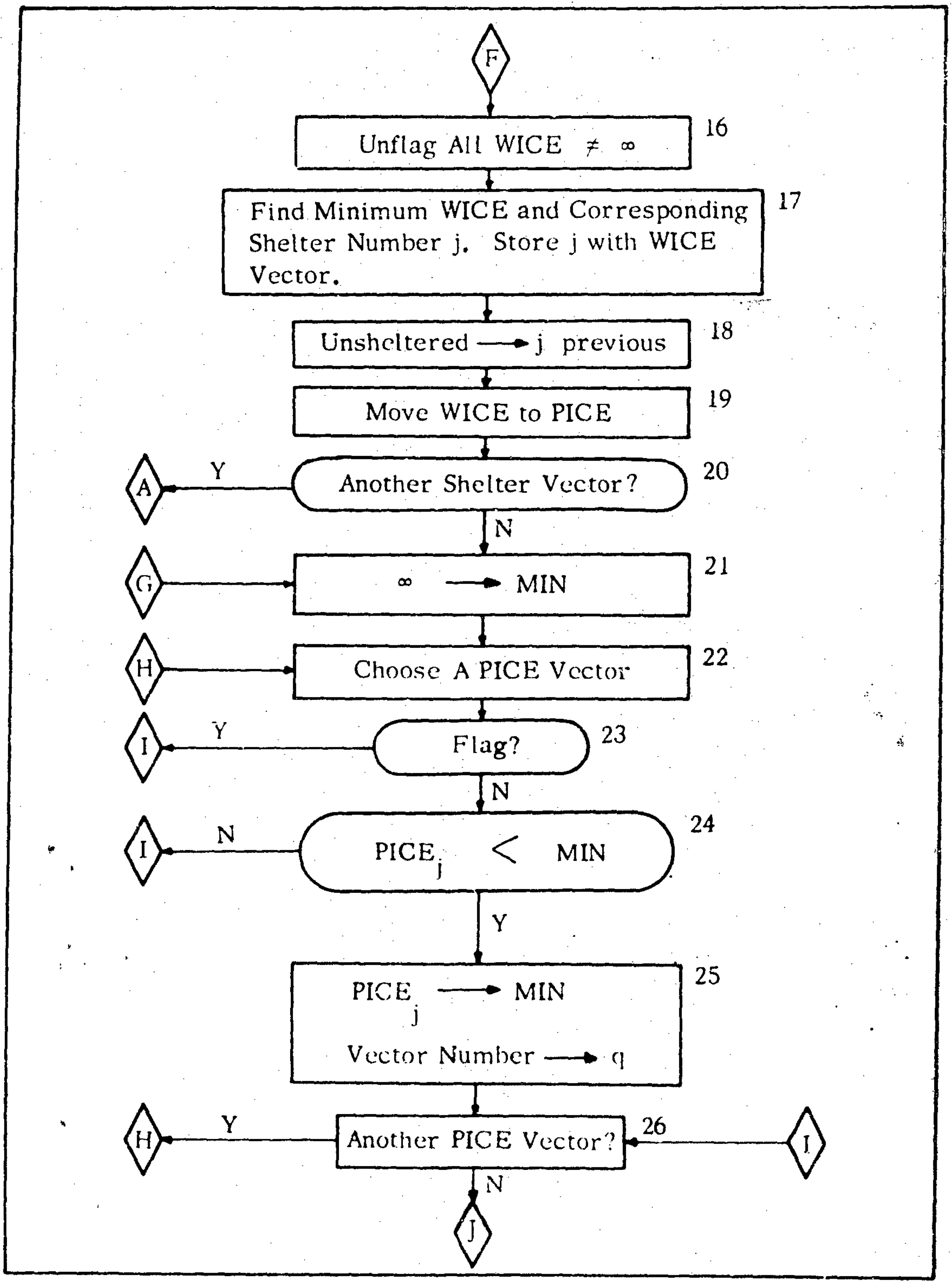


FIGURE 68 PHASE II FLOW DIAGRAM (CONTINUED)

is stored in the one additional word associated with the vector. The word contains the i, j numbers which locate the vector in the population matrix, the j which identifies the shelter type of minimum WICE and one other fact. The word may also be flagged.

18. The other fact in the data word associated with the vector is the number of the previous shelter assigned which, at this point, is set to unsheltered.

19. The working WICE vector is now complete and is transferred to its permanent location in the fast access storage. It is now referred to as a PICE vector.

20. The program tests whether a PICE vector has been assembled for every non-zero element of the BPM. If this is not the case, a new vector is computed, using the working WICE storage, for another location by transferring back through connector "A".

21. Upon first reaching this point in the program, the optimal assignment sequence for each non-zero element of the BPM has been determined. The program now prepares to merge these results to obtain the assignment sequence for all of the non-zero elements of the population matrix. The program sets MIN to infinity. This counter is used in the operations which result in the identification of the location and shelter type of best cost effectiveness.

22. The program now prepares for a pass through the PICE vectors to find the minimum PICE. The routine selects the first vector in memory. After performing the required operations, the routine returns to this instruction by way of connector "H", picks up the next vector, and so on.

23. The first operation on the vector is to test the data word for a flag. The presence of a flag would indicate all of the useable shelter types at this location have been assigned.

24. If the flag has not been set, the program compares the minimum PICE with MIN. This value is not found by scanning the PICE vector but rather by reading the value directly after noting the corresponding shelter type in the data word. If the best cost effectiveness at this location is inferior to the cost effectiveness of some shelter type somewhere else, the program considers the next PICE vector by transferring to point "I".

25. If the best cost effectiveness at this location is superior to the best previous value found on this pass through the PICE vectors, the value of

the best PICE, which is a correct CICE and applies to shelter type j, replaces the previous value in MIN. The vector number q is also stored.

26. If this is not the last PICE vector in memory, the routine considers the next vector by transferring back to point "H".

27. This operation is shown on Figure 69. Whenever the program reaches this point, a pass through the PICE vectors has been completed. If MIN is still set at infinity, no new shelter assignment has been found and the output optimal shelter assignment sequence tape is complete. This tape is input to the Phase III and IV Programs.

28. If a new MIN has been found, the routine sets up a record for the output shelter assignment tape. MIN is the correct current ICE/CICE level at which the assignment is made. The value of this quantity, which is the cost per survivor added for the assignment or reassignment, increases from record to record. The i, j numbers which indicate the location where the assignment is made, the previous shelter type and the type currently being assigned are found in the data word for PICE vector q. The increase in cost per person sheltered is

$$C_j - C_{j \text{ previous}}$$

The increase in survivors added per person sheltered is

$$\frac{C_j - C_{j \text{ previous}}}{\text{MIN}}$$

29. The assembled record is output on the optimal shelter assignment sequence tape.

30. The routine now prepares for another pass through the PICE vectors to determine the next shelter assignment. The PICE for shelter j of vector 1 is set to a flagged infinity. This shelter type will not again be considered at this location.

31. The program subtracts MIN from each unflagged PICE of vector q. The minimum PICE is now a correct CICE although the other PICE are still artificially augmented to establish the same numerical ordering as the optimal shelter assignment sequence at that location.

32. The binary digits of the data word of PICE vector q which indicate shelter type j are now moved and replace the digits indicating type j previous.

33. The program now searches PICE vector q and locates the new minimum PICE. The shelter number corresponding to this PICE is stored as a new j in the data word. If no unflagged PICE are found, all of the useable shelter types at this location have been assigned and the data word for the vector is flagged. The routine transfers to "G" and begins another pass through the PICE vectors.

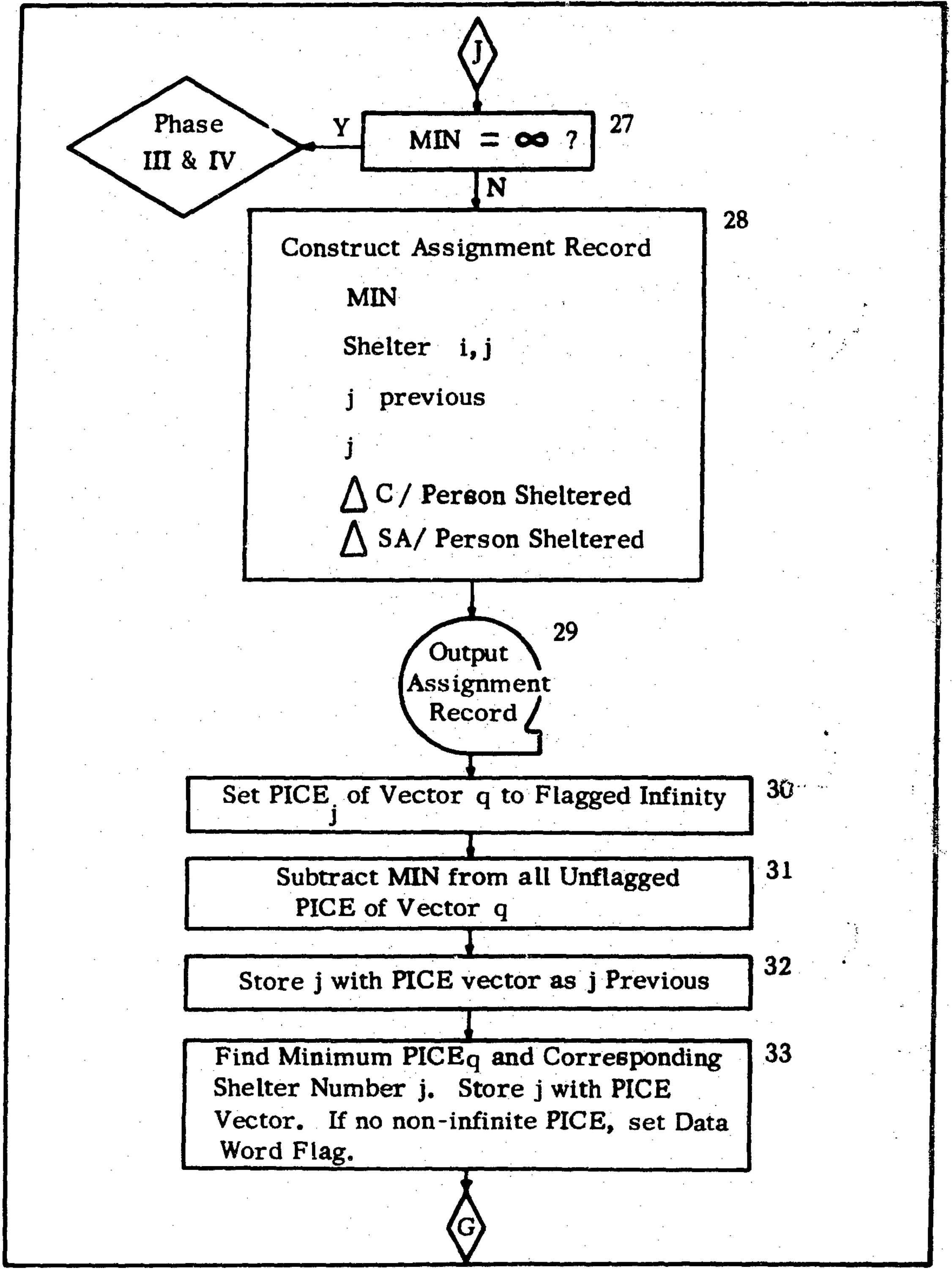


FIGURE 69 PHASE II FLOW DIAGRAM (CONCLUDED)

EXTENDED PROGRAM CAPABILITIES

The program has two capabilities which are not described in the previous flow diagram discussions. These are

- The variation of the protection afforded the unsheltered population in the different areas of the region by existing buildings
- The suitability of a given countermeasure type at a particular location

The inputs which control the use of these program features are discussed in detail later in this report. They are

- Shelter catalog
- Existing conditions catalog
- Shelter correlation input matrix

The shelter catalog defines the possible countermeasure types in terms of resistance to the different weapon effects and per occupant cost. If shelter provisions are defined in this way, the same provision may appear more than once. The cost of a specially constructed neighborhood shelter, for example, may depend on whether the land is free, inexpensive or costly. Some shelter provisions may not be possible. An example of this is the incorporation of shelters in new school designs for established communities in which the schools have already been built.

The existing conditions catalog defines types of existing conditions by the resistance of the unsheltered population to the different weapon effects in that location and also by the ability of that location to accept particular countermeasure provisions. If, for example, one of two neighborhoods containing well maintained homes of good construction had a park or school, both neighborhoods would have the same vulnerability characteristics but only one could accept a shelter type for which the cost had been based on the availability of public land. In this situation two existing conditions states would be defined although the vulnerability inputs would be the same for both.

The existing condition type number is included on each input card of the population matrix. It is remembered that the cost effectiveness of a shelter type at some location depends not only on the cost and hardness of the shelter but on the threat and unsheltered population vulnerability as well.

The columns of the shelter correlation input matrix correspond to the existing condition numbers. The rows correspond to the shelter type numbers. The matrix entries are binary indications of whether a particular countermeasure type should be considered at a location characterized by a particular local conditions type.

The means by which the program uses these inputs are

- Binary population matrix
- Packed existing conditions table

The binary population matrix is the same size as the population distribution matrix. Each entry is a binary indication of whether or not the population in that element is greater than zero. Since only one bit is required for each element of the population matrix, the binary population matrix requires only 1/36 as many words in fast access memory as the actual population distribution matrix.

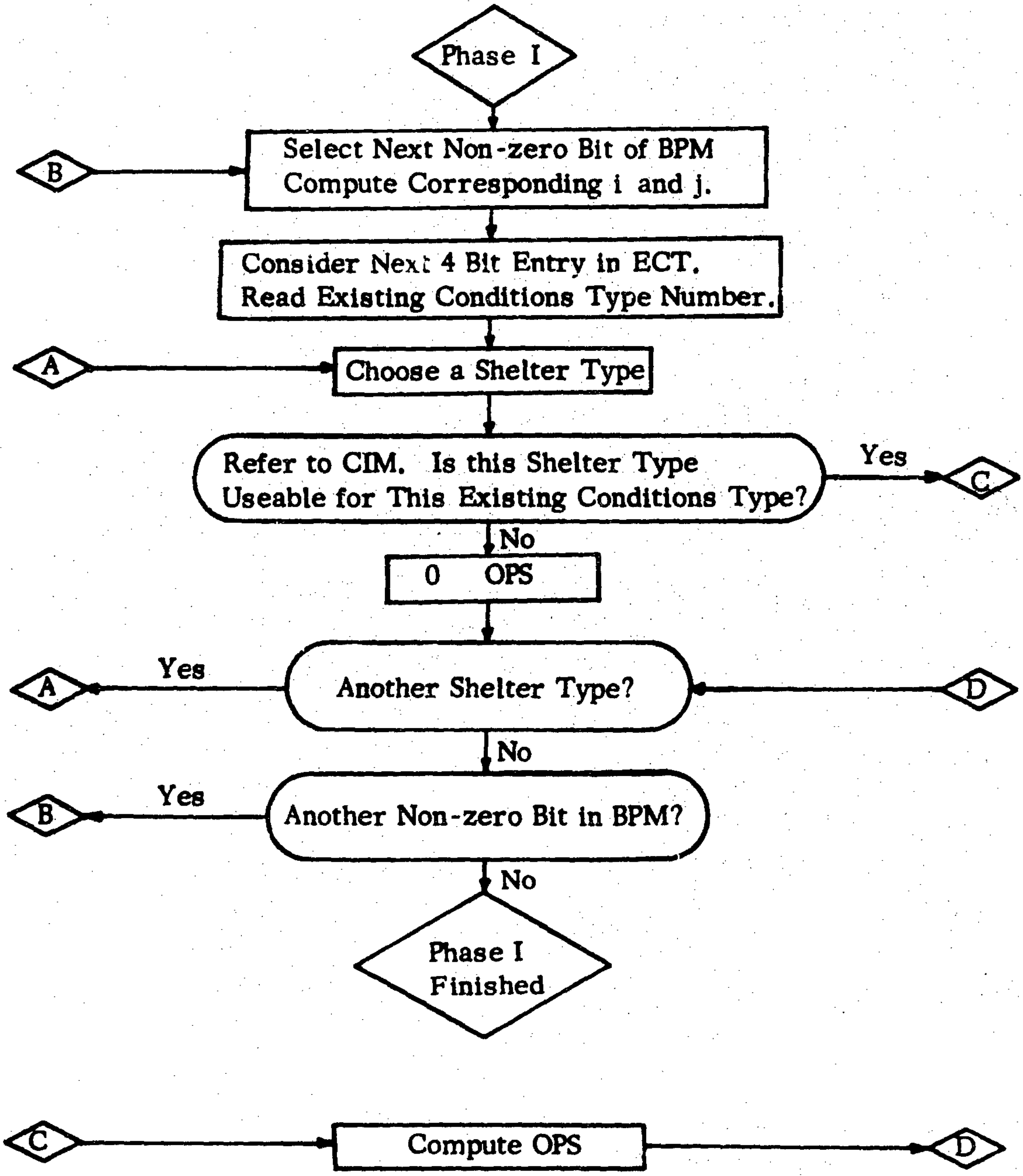
The packed existing conditions table contains an entry for each non-zero element of the population matrix. Each entry is the existing conditions type number for that location. Four bits are used to store the number. The table is packed in the sense that the numbers are not stored for the zero population matrix elements. The table is therefore a distorted area representation in the computer memory and cannot be used directly for computations in which spatial relationships are important. The number of words required to store the table is 1/9 (4/36) the number of non-zero elements in the population matrix.

In general, the program associates an entry in the packed existing conditions table with a particular non-zero bit of binary population matrix. The location of the non-zero bit in the undistorted binary population matrix implies the i and j values of the population matrix element under consideration. The next computation is made by considering the next four bits of the packed existing conditions table. The program then tests the bits, one at a time, of the binary population matrix until the next non-zero bit is found. This procedure maintains the correlation between the distorted existing conditions table and the undistorted binary population matrix.

The next four bits of the existing conditions table is found by shifting the current word four places between computations. The active bits always appear in the same location within the word. The program determines whether all the entries in a word have been considered by testing for zero in the active bits location. This procedure limits the number of existing condition types to 15(1 + 2 + 4 + 8). If another type is required, the program could be changed to count the number of shifts. If more than 16 are required, it would be necessary to change the model bookkeeping by using fewer than 9 entries per word of memory.

The Phase I program computes a shelter probability of survival vector for each non-zero element of the population matrix. Each vector has an element for every shelter type in the shelter catalog. For shelters which are not useable at this i, j, the overall probability of survival is set to zero. The programming by which this is accomplished is shown on the following simplified flow diagram. (See page 3-44)

The Phase II program consists of two parts. The first part converts each probability of survival vector to a vector of ordered cost effectiveness values. The zero probability of survival values which appear for shelter types which are not useable at this location are converted to flagged infinites in the resulting ordered cost effectiveness vector. The second part of the program considers the entire set of cost effectiveness vectors and generates the optimal shelter assignment and reassignment sequence. Shelters never appear in this sequence at locations where their use is not permitted by the program inputs.



BPM = Binary Population Matrix
ECT = Packed Existing Conditions Table
CIM = Shelter Correlation Input Matrix
OPS = Overall Probability of Survival

FIGURE 70 SIMPLIFIED EXTENDED CAPABILITY PHASE I FLOW DIAGRAM

WEAPON EFFECT SUBMODELS

BLAST AND SHOCK

The probability of survival from blast and shock phenomena was considered previously in conjunction with the probability of survival from thermal radiation effects since the interaction of the blast and thermal effects on personnel is not well defined. A single radius was considered within which the probability of kill from either blast or thermal effects or both was represented. The radius was taken to be the larger of the two radii corresponding to the critical peak overpressure and thermal radius values which were model inputs.

To permit more flexibility in the analysis so that the effectiveness of particular countermeasures can be evaluated, a separate probability of survival for blast effects and for thermal effects is now calculated by assuming the blast and thermal effects on personnel to be independent. The assumption of the independence of the blast and thermal effects on personnel, although unrealistic, was made to permit continued progress on the evolution of countermeasure analysis and optimization programs. Reference 11* appears to contain the most realistic probability of target kill as a function of distance from detonation point data presently available. Fitting analytic expressions to this data is considered to be a useful growth item for the program.

The calculation of the probability of kill from blast effects is now computed in the same manner as described earlier in this report.

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* Ref. 11 "Prediction of Urban Casualties from the Immediate Effects of a Nuclear Attack," Final Report, the Dikewood Corporation, DC-FR-1028, April 1963 (Confidential)

THERMAL RADIATION

As described in the preceding topic, the calculation of the probability of surviving thermal radiation has been separated from the calculation of the probability of surviving blast. In addition, a change has been made in the calculation of the probability of survival of personnel in designated shelters. Previously, personnel in designated shelters at the time of detonation were assumed to have a 100% probability of surviving the primary and secondary thermal effects. This assumption implies that the shelters were completely fireproof and would remain so regardless of the initial thermal radiation impinging on the shelter and the resulting fire storms and conflagrations, if any. This assumption is unrealistic and the present program allows for a decreased probability of survival from thermal radiation for sheltered personnel by incropoprating a concept of a thermal factor for each shelter type. The thermal factor is based on a 1 KT yield and is a thermal radiation value, calories per square centimeter, such that if the shelter receives that thermal radiation value, the probability of the shelter surviving is 50%. As before, the probability of personnel in the shelter surviving is taken to be the probability of the shelter surviving. The thermal factor for a particular shelter is a function of the building material of the shelter, its manner of construction, etc. The thermal radiation value for 50% probability of survival for yields greater than 1 KT can be obtained for each shelter by multiplying the thermal factor by the eighth root of the yield in kilotons. For example, a shelter which has a thermal factor of 50 cals/cm^2 would have a 50% probability of surviving if it received $50(10,000)^{1/8} = 158$ cal/cm^2 from a 10 MT yield. The scaling factor $W^{1/8}$ seems to describe the yield dependency of critical ignition values quite adequately and was obtained by examination of the empirical data relating critical ignition energy with yield and type of combustible material.

The calculation of the probability of survival of sheltered personnel can be computed in the same manner as unsheltered personnel by use of the thermal factor to determine the radius corresponding to the 37% probability of kill and using this radius in the bomb damage function.

Although the use of the thermal factor permits the calculation of a probability of survival for sheltered personnel and is an improvement over the manner in which thermal radiation effects were previously considered, the effects of fire storms and conflagrations have not as yet been directly included. The survival of the shelter and personnel depends not only on the primary thermal radiation but also upon meterological factors, fuel characteristics and other environmental characteristics in the immediate vicinity of the shelter location in the target area. Several documents have been received (References 12* and 13**) and have been perused for relative information upon which a model of fire storm or other secondary thermal effects can be based.

NUCLEAR RADIATION

Several changes and additions have been made to the manner in which the initial and residual nuclear radiation effects are calculated and included in the analyses.

Initial Nuclear Radiation

The equation for determining the initial nuclear radiation dose as a function of slant range, height of burst, and yield was derived earlier in this report. The range of the scaling factor, W', was increased so that yields up to 20 MT could be incorporated in the analyses. The additional scaling factor ranges are:

$$W' = \begin{cases} 4.57\, W^{2.26} \times 10^{-5} & 10,000 < W \leq 15,000 \\ 1.44\, W^{3.58} \times 10^{-10} & 15,000 < W \leq 20,000 \end{cases}$$

where W is the yield in kilotons.

Another change was made in the inclusion of nuclear radiation protection factors. Previously, a single protection factor was used to describe the attenuation of nuclear radiation by a shelter. The protection factor was the same for both initial radiation and fallout. However, the protection factor of a shelter will generally differ for the two forms of nuclear radiation due to the greater energy of the initial gamma rays. Therefore, two protection factors are now used in the programs, one for the initial nuclear radiation, the other for residual nuclear radiation (fallout).

The biggest improvement in the program has been in the inclusion of bomb aiming errors in the determination of the dose due to initial nuclear radiation. While the probability of survival from blast and thermal effects have always included aiming errors in their calculation, previous initial nuclear radiation dose calculations considered the bomb to detonate directly above the aim point.

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* Ref. 12 "Prediction of Fire Spread Following Nuclear Explosions," U.S. Forest Service Research Paper, PSW-5, 1963.

** Ref. 13 "A Study of Mass Fires and Conflagrations," U.S. Forest Service Research Note, PSW-N22, 1963.

Assuming reasonably small aiming errors, and ignoring higher moments, the biological dose due to prompt radiation is assumed to have a normal distribution. The mean value is:

$$R_i = \frac{10^9 k}{D^2}\left[3.2\,W' e^{-D/360} + 15.5\,W e^{-D/210}\right]$$

where

R_i = initial nuclear radiation dose (rems)

D = slant range (yards)

W = yield (kilotons)

and W' and k are functions of yield and/or height of burst. The variance of the prompt dose is

$$\sigma_p^2 = \left[3.2\,W'\left(\frac{1}{360} + \frac{2}{D}\right) e^{-D/360} + 15.5\,W\left(\frac{1}{210} + \frac{2}{D}\right) e^{-D/210}\right]^2 \times \left[\frac{10^9 k}{D^2}\right]^2 \left[1 + (H/D)^2\right] \sigma_B^2 ,$$

where

H = height of burst

σ_B^2 = variance of weapon aiming error.

Residual Nuclear Radiation

Previous calculations of the residual nuclear radiation dose considered the bomb to detonate at a specified altitude above the aim point and the fallout was deposited through the action of a constant velocity, completely deterministic wind which was a model input. The present program provides for a probabilistic wind, which is characterized by a vector having a mean velocity and a standard deviation. The concept of a vector standard deviation will not only permit a more realistic wind environment, but will allow for bomb aiming errors to be incorporated into the calculations of the probability of surviving nuclear and radiation.

To facilitate inclusion of bomb aiming errors and probabilistic winds, a different process is utilized in determining the Effective Biological Dose than has been previously described. The previous program considered the residual dose received at a particular location to be divided into two parts, the dose received up until the final fallout disk landed at the location and the subsequent dose from all the landed disks at some later time which was taken to be 72 hours. In building the Effective Biological Dose up until the last disk of interest fell on the location, the one hour dose rate of the disks that had landed by a time, t, was adjusted to the time t by the factor $t^{-1.2}$ and this dose rate was assumed constant for the time interval until the next disk landed. This process was repeated until the last disk landed. The model was programmed in this way to facilitate calculations of the radiation dose received by personnel passing through elements on their way to shelter locations.

The Effective Biological Dose is now determined for each disk and is defined to be

$$\text{Effective Biological Dose (rems)} = r_1 \int_{t_1}^{t_2} \left[\alpha t^{-1.2} + (1 - \alpha) t^{-1.2} e^{\beta (t - t_2)} \right] dt$$

where

r_1 = dose rate at 1 hour for the disk (rem/hr)

t_1 = time at which the disk landed or entry into the fallout area (hours)

t_2 = time of departure from fallout area (hours)

α = irreparable body fraction

β = body repair rate (fraction per hour)

In most cases, more than one disk will cover any location and the Effective Biological Dose will be the sum of the Effective Biological Doses of the disks covering the location. As was the case previously, the integral is assumed to take its maximum value at $t_2 = 72$ and this maximum value is used in the analyses.

The landing position of an arbitrary fallout disk has not only the uncertainty induced by the random wind, but also the uncertainty of the weapon detonation point. The combined effect is to produce a circular normal distribution of the landing point of the center of the fallout disk. The mean central landing point is the weapon aim point displaced by the product of the time down and the mean wind velocity. The landing point variance is

$$\sigma_L^2 = \sigma_W^2 \, t_D^2 + \sigma_B^2 \quad ,$$

where σ_B^2 is the variance of the weapon detonation point.

Knowing the radius R of a specific fallout disk, its mean landing point and its variance, σ_L^2, it is possible to compute the probability of this disk covering an arbitrary point. This probability is defined in Reference 14* as the circular coverage function

$$P_L = e^{-r^2/2\sigma_L^2} \int_0^{R/\;L} e^{-t^2/2} \, I_o(rt/\sigma_L) \, dt$$

where r is the distance from the arbitrary point in question to the mean landing point of the disk, t is a dummy variable, and $I_o(z)$ is the modified Bessel function of order zero.

The integral equation for P_L has been expanded into a series approximation which converges with reasonable speed for all values of interest. This series is

$$P_L = e^{-x} \sum_{n=0}^{k} \frac{x^n}{n!} \left[1 - e^{-y} \sum_{m=0}^{n} \frac{x^m}{m!} \right]$$

where

$$x = r^2/2\,\sigma_L^2 \quad , \qquad y = R^2/2\,\sigma_L^2 \; .$$

Since

$$P_L < 10^{-4} \quad \text{for} \quad r > R + 3.62\,\sigma_L,$$

it is assumed that P_L is zero in this case. In other words, it is assumed that any disk whose mean landing point is more than $R + 3.62\,\sigma_L$ from the point in question cannot cover that point.

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* Ref. 14* "The Circular Coverage Function," H. H. Germond, Rand Corp., RM-330, 29 January 1950.

The effective biological dose (EBD) contributed at a point by an arbitrary disk is seen to be a random variable. The value of this dose is the EBD of the disk, if the disk covers the point. On the other hand, if the disk does not cover the point, the contributed dose is zero. The dose contributed by the disk consequently has a Bernoulli distribution with probability P_L and value EBD. The mean of this dose is

$$P_L\,(\text{EBD})$$

and the variance is

$$P_L(1 - P_L)(\text{EBD})^2.$$

Since there are a large number of disks, each having a different EBD and P_L relative to a particular point, it is desirable to obtain an expression for the distribution of the total fallout EBD at the point. Unfortunately, no simple exact expression exists for the distribution of the sum of several Bernoulli distributed variables having different parameters. Because of the large number of disks, however, we can make use of the central limit theorem which allows the total dose to be approximated by a normal distribution whose mean is

$$\sum P_L(\text{EBD})$$

and whose variance is

$$\sum P_L(1 - P_L)(\text{EBD})^2$$

Radiation Survival Probability

At each non-zero population element, the probability of surviving radiation is computed from the distribution of the effective biological dose due to both prompt and fallout radiation. The combined biological dose is normally distributed with mean given by

$$U = \frac{R_i}{(PF)_p} + \frac{u_{fo}}{(PF)_{fo}}$$

and variance given by

$$\sigma^2 = \frac{\sigma_p^2}{(PF)_p^2} + \frac{\sigma_{fo}^2}{(PF)_{fo}},$$

where

R_i = mean biological dose from initial radiation

u_{fo} = mean effective biological dose from fallout radiation

σ_p^2 = variance of initial radiation dose

σ_{fo}^2 = variance of fallout radiation dose

$(PF)_p$ = shelter protection factor against prompt radiation

$(PF)_{fo}$ = shelter protection factor against fallout radiation

As in the Dynamic Analyzer Model, this model makes use of the conditional probability of survival, given an effective biological dose. Unlike the previous model, the present model assumes the conditional survival probability to be a stairstep function which is evaluated at equal increments of probability. The increments of biological dose are, in general, not uniform, but depend upon the nature of the function. The cumulative normal function is used, although other functions can easily be substituted. Figure 71 illustrates a 20 point approximation to the cumulative normal survivability function which is presently used.

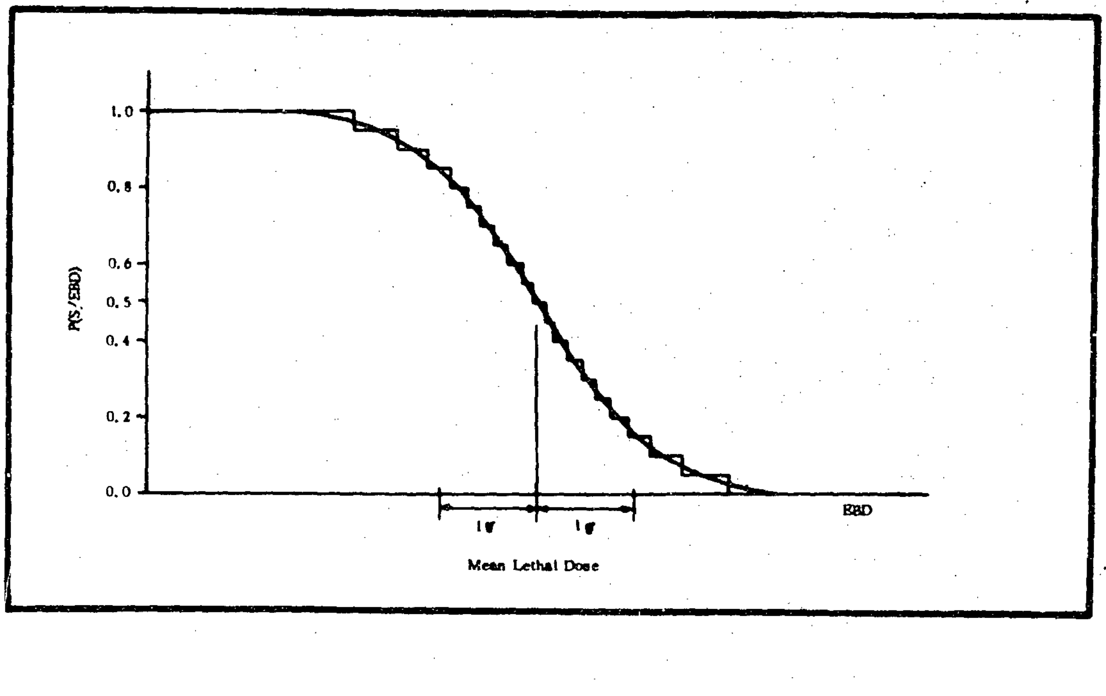

FIGURE 71 PROBABILITY OF SURVIVING RADIATION

The radiation survivability must be evaluated over the statistically distributed biological dose that is received. The following equation is used:

$$P(S) = \frac{1}{n} \sum_{m=0}^{n} F(E_m)$$

where

$$F(E_m) \quad \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{E_m - u}{\sigma}} e^{-x^2/2} \, dx$$

$F(E_m)$ = the probability of EBD being less than E_m.

E_m = the tabulated values of EBD for equal survivability increments

n = the number of increments in the survivability function.

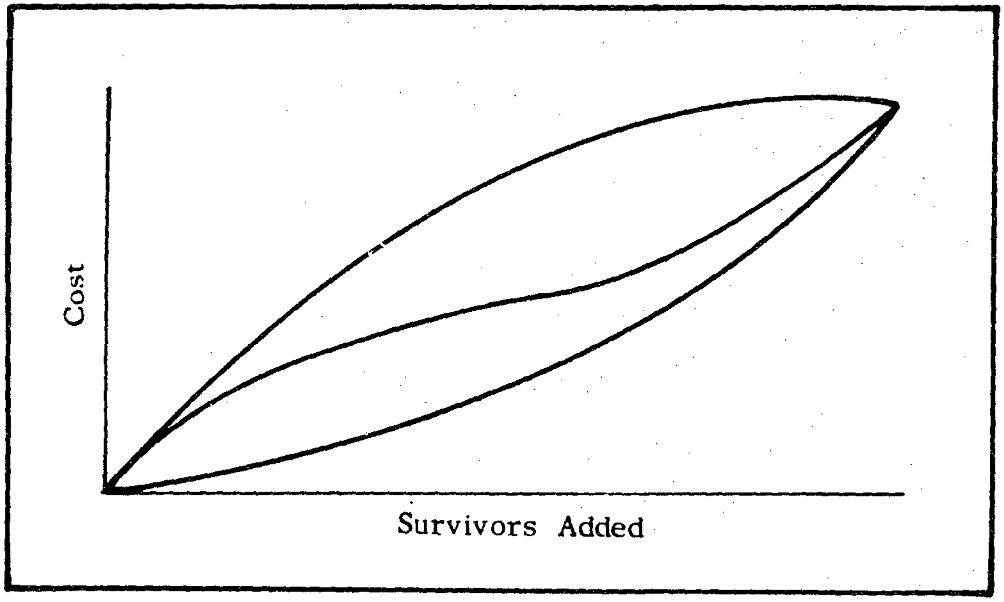

FIGURE 72 EFFECT OF SHELTER DEPLOYMENT

OPTIMUM SHELTER ASSIGNMENT

In general, it is desirable to build shelters of a type and in locations such that the most benefit is obtained per dollar spent. The previous shelter optimization programs assigned and/or reassigned shelters on the basis of decreasing cost effectiveness for consecutive assignments. This technique is described and verified in the following paragraphs.

A curve of total shelter system cost versus the expected number of survivors added by the system of shelters is highly useful in the development of an optimal shelter deployment scheme. Having generated such a curve, the operating point can be determined. Otherwise, the desired expenditure or some other parameter defining the operating point would be required as an input. As previously discussed, this would be unacceptable.

A number of curves of cost versus survivors added can be generated as illustrated in Figure 72. In general, such curves will depend upon the shelter deployment at each cost level. Clearly, the optimum set of shelter assignments is the one adding the greatest number of survivors at each cost level, i.e., the shelter assignment and re-assignment sequence producing the right-most curve of cost versus survivors added. A technique for generating this sequence will now be discussed.

The assumption is made that by some method, as yet undetermined, an optimum set of shelters has been selected and emplaced. This allows a point on the optimum cost effectiveness curve to be determined. In order to obtain additional points on the optimum curve, it is necessary to determine the effect of increasing expenditures. Since the most efficient expenditure is desired, those which decrease the expected number of survivors will not be considered.

Starting with the optimum set of shelters at the initial cost level, additional expenditures can be made in two optional ways:

1. Plan additional shelters for previously unsheltered population.

2. Replace some of the previously planned shelters with more expensive (and more effective) shelters at the same location.

The most effective expenditure will be the one which adds the greatest number of survivors for the money expended. In other words, the better of the two options is the one for which

$$\text{slope} = \frac{d\,(\text{cost})}{d(\text{survivors added})}$$

is a minimum.

Considering Option 1 first, let C_i be the cost per person sheltered with a type i shelter. P_{ia} is the probability of survival with this shelter at location a, N_a is the population at element a, and P_{ua} is the probability of survival without shelter at this location. The cost of sheltering n people is

$$\text{cost} = nC_i .$$

The expected number of survivors with n people sheltered is

$$S = nP_{ia} + (N_a - n)\,P_{ua},$$

and, in the absence of shelters, the expected number of survivors is

$$S_u = N_a P_{ua} .$$

The number of survivors added by sheltering n people is consequently

$$SA = S - S_u = n(P_{ia} - P_{ua}).$$

Differentiating with respect to n,

$$\frac{d\,(\text{cost})}{dn} = C_i$$

and

$$\frac{d\,(SA)}{dn} = P_{ia} - P_{ua}$$

so

$$\text{slope} = \frac{d\,(\text{cost})}{d\,(SA)} = \frac{C_i}{P_{ia} - P_{ua}} = (\text{ICE})_i .$$

The slope for Option 1 is simply the quantity which has been defined as the inverse cost effectiveness or ICE. When assigning shelters at previously unsheltered locations, the optimum shelter type and location is the combination having the smallest ICE.

Considering Option 2 next, let the entire population of element a be initially sheltered by type i shelter. The cost of replacing the type i shelters by the more effective type j shelters for n people in this element is

$$\text{cost} = n(C_j - C_i) \ .$$

The expected number of survivors is

$$S = nP_{ja} + (N_a - n)P_{ia} .$$

The expected number of survivors using only type i shelters is

$$S_i = N_a P_{ia} \ .$$

The number of survivors added by the replacement process is consequently

$$SA = S - S_i = n(P_{ja} - P_{ia}) \ .$$

Differentiating with respect to n,

$$\frac{d\,(\text{cost})}{dn} = C_j - C_i$$

and

$$\frac{d\,(SA)}{dn} = P_{ja} - P_{ia}$$

so

$$\text{slope} = \frac{d\,(\text{cost})}{d\,(SA)} = \frac{C_j - C_i}{P_{ja} - P_{ia}} = \text{CICE}_{j-i} \ .$$

The slope for Option 2 is simply CICE as defined earlier. The optimum replacement of shelters is the one which yields the smallest CICE.

The most effective shelter to replace a previously assigned shelter is not necessarily the shelter having the smallest value of ICE. For example, Figure 73 illustrates a graph of the cost versus the survivors added by using three different shelter types at a single location. Lines OA, OB, OC are generated by providing shelter types A, B, and C, respectively, to part of the population. Points A, B, and C are reached when all of the population is sheltered. For expenditures less than C_A, it is most efficient to use only type A shelters.

For higher expenditures, line AB is generated by a mixture of type A and type B shelters. Similarly, line AC is generated by using both type A and type C shelters. If the choice of a shelter to replace type A shelters were based on the ICE value, type B shelters would be used, since the slope of OB (the ICE value of shelter type B) is <u>less than</u> the slope of OC (the ICE for shelter type C). The CICE value of shelter type B (the slope of line AB) is <u>greater than</u> the value of CICE for shelter type C (the slope of line AC), however. Examination of Figure 73 shows that path AC represents a more efficient expenditure than path AB. Consequently, the use of CICE rather than ICE appears to be justified.

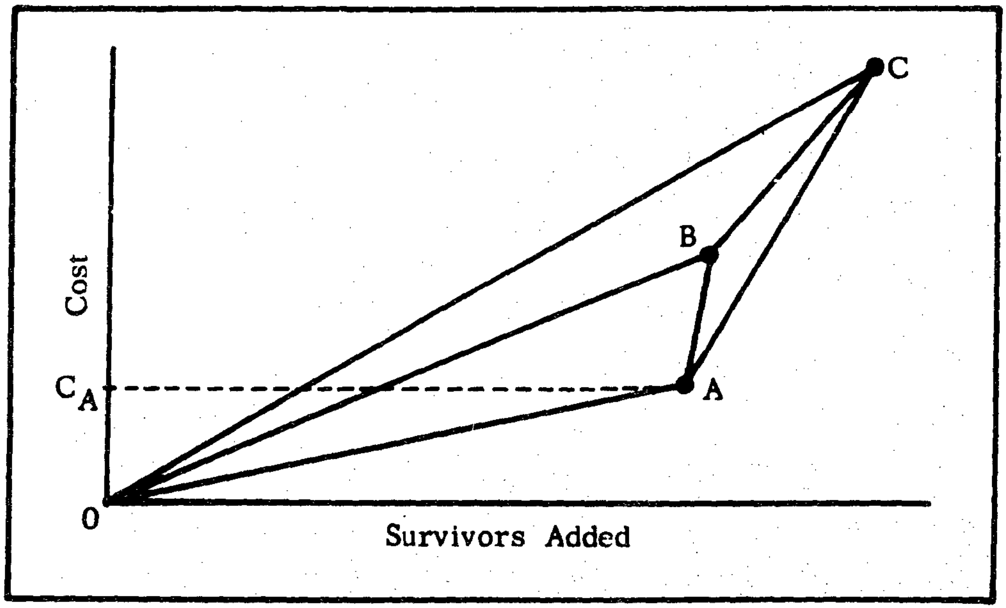

FIGURE 73 SHELTER ASSIGNMENT SEQUENCE

The replacement of shelters at one location with more efficient, more expensive shelters at another location is always an inefficient procedure. For example, it is assumed that n_a type i shelters have been employed at position a. These are to be removed from the shelter plan and replaced by n_b type j shelters at position b. The cost of this transaction is

$$\text{cost} = n_b C_j - n_a C_i \; .$$

The number of survivors added is

$$SA = n_b S_{jb} - n_a S_{ia}$$

where

$$S_{jb} = P_{jb} - P_{ub}$$

and

$$S_{ia} = P_{ia} - P_{ua} \; .$$

Consequently the value of CICE for the replacement is

$$\text{CICE} = \frac{n_b C_j - n_a C_i}{n_b S_{jb} - n_a S_{ia}}$$

The value of ICE for building the shelters at position a is

$$\text{ICE}_a = \frac{C_i}{S_{ia}}$$

and the value of ICE for building the shelters at position b is

$$\text{ICE}_b = \frac{C_j}{S_{jb}}$$

Since the shelters at position a were assigned initially on the basis of least ICE,

$$\text{ICE}_a < \text{ICE}_b,$$

so

$$\frac{C_i}{S_{ia}} < \frac{C_j}{S_{jb}}$$

or

$$-aC_iS_{jb} > -aC_jS_{ia},$$

and

$$S_{jb}(bC_j - aC_i) > C_j(bS_{jb} - aS_{ia}) .$$

Consequently,

$$\frac{bC_j - aC_i}{bS_{jb} - aS_{ia}} > \frac{C_j}{S_{jb}},$$

or

$$\text{CICE} > \text{ICE}_b .$$

It is consequently more efficient to plan a few additional shelters at location b and to leave the previously planned shelters at location a than to plan any replacement of shelters at a by more efficient shelters at b.

OPTIMIZATION PROGRAM INPUT OPTIONS

This section describes the various input options available for use in the Multiple Effects, Weighted Strategy Optimizer Program. The program is written in a manner which permits a generally unrestricted amount of data to be used with any particular option. However, the total amount of data which the computer can handle is necessarily limited. Thus, a large number of shelter types in the shelter catalog necessarily limits the number of non-zero elements which can be used in the population matrix and/or reduces the number of threat strategies which can be employed.

THREAT STRATEGIES

It is argued that it is not possible to design an optimum countermeasures system because the exact nature of the enemy's threat strategy cannot be known in advance of an attack. However, it is true that certain strategies appear to be more desirable to the enemy than others for particular target or target area and mission objectives. In order to make possible a meaningful definition of an optimum countermeasures system at any level of cost, the program incorporates an option which permits the analyst to define and use a number of strategies for the optimization procedure, each identified with the probability (given that an attack occurs) that that strategy is the strategy which will be used.

Strategy Design Options

There is no limit, other than program running time, on the number of strategies which may be used for a single program run for a given target-population situation.

Weapon Catalog

All of the strategies for a single run may use only weapons listed in the weapon catalog. The weapon catalog is an input option and may be different for each run to conform to the characteristics of the target of interest. Each weapon is defined in terms of yield, radiation conversion efficiency, detonation altitude, number of altitude increments (for use by fallout model), CPE, and an identification word or name to simplify comparison when the same weapon is used for more than one run. An example weapon catalog is shown in Table V.

Weapon Designation	Yield MT	Conversion Efficiency %	Detonation Altitude K Feet	Altitude Increments	CPE Feet
AAA	1	80	0	10	1000
BBB	5	60	0	20	1000
CCC	5	60	15	15	3000
DDD	10	50	0	20	2000
EEE	10	50	25	15	4000
FFF	20	50	30	15	5000

TABLE V WEAPON CATALOG

Strategy Definition

Any number of strategies necessary to define the nuclear threat to a target area may be defined. Any number of weapons may be selected from the weapon catalog to define each strategy. Weapons may be used in any combination and each weapon may be used as many as five times. Each weapon is assigned a specific target aimpoint and more than one weapon may be assigned to the same aimpoint. There is no specific restriction on strategies and aimpoints and any conceivable strategy which can be made up of weapons from the input catalog will be accepted by the program. It should be noted, however, that weapon yields in the sense that they are used here are not additive. That is, two five megaton weapons cannot be used with a single aimpoint to simulate the effect of a ten megaton weapon, but would be considered by the program to be two independent bursts. An example threat strategy table using the weapons from the catalog in Table V is shown in Table VI. The aim point designations shown under each weapon are the i, j coordinates of the target area population matrix. While these coordinates do correspond to possible aimpoint for various missions against the Dallas-Ft. Worth area, they are given as examples only and it is not the purpose of this report to argue the validity or accuracy of the choice of aimpoints or the relative probability of employment of the strategies.

Strategy Designation	Probability	Weapon Aim Points					
		AAA	BBB	CCC	DDD	EEE	FFF
1	.1		14,6 15,48 20,15				
2	.25				14,6		
3	.05	14,6			5,10 5,30		
4	.1			10,16 26,16 10,48 26,48		14,6	
5	.2					14,6	15,48
6	.3					14,6	

TABLE VI EXAMPLE THREAT STRATEGY

WIND MODEL

In a target area characterized by prevailing winds which blow almost invariably from the same direction and with a relatively constant force, it might be possible to directly determine the areas where fallout is a hazard and the degree of protection required. However, in most areas where the wind varies greatly in both direction and velocity, the probability of hazard from fallout for a given attack is not so obvious and requires some method of taking into account the total probabalistic wind environment for the time frame during which an attack might be expected. One method is to choose a large number of wind vectors and assign to each of these a probability of occurrence. For a program of the type herein described, a model of this type would make the computer running time prohibitively long (three velocity vectors for each 10 degrees of azimuth would require over 100 winds) and would introduce errors in that some areas of the target area would incorrectly be designated as never being downwind from a given burst point.

The wind model used here permits the use of one or more wind vectors to adequately describe the statistical winds for a year or other appropriate time frame of interest. The number of vectors required is dependent upon the wind variation characteristic for the target location and the desired degree of fidelity with which the wind environment is represented. Each wind vector used is described by its mean velocity, mean direction, vector standard deviation and the probability of occurrence at the time of an attack.

In the case where an attack at any time during the year is considered equally likely, the probability of a wind vector occurring at the time of an attack would be the probability of the wind season occurring. In the sample case (see Table VII) which uses one vector for each of four seasons of equal length, the probability assigned to each wind vector is 0.25. If, however, it is determined to be more likely that an attack will be launched during one season than another, the probability of attack occurring during each season may be weighted accordingly.

	Mean Direction Clockwise from North	Mean Speed Knots	Vector Standard Deviation	Probability
Spring	082	31.5	20.4	0.25
Summer	282	03.7	13.2	0.25
Fall	095	16.5	20.7	0.25
Winter	085	37.8	22.3	0.25

TABLE VII SEASONAL WIND MODEL FOR FT. WORTH

TARGET AREA ENVIRONMENT AND SHELTER CHARACTERISTICS INPUT OPTIONS

For the purpose of this study, any measure, other than evacuation, which decreases the degree to which any of the effects of a nuclear detonation are felt by an individual can be considered to be a shelter. Thus, a particular building or a particular physical location designated as providing some measure of protection is a shelter in the same sense as an elaborately conceived reinforced concrete underground vault. The difference is in the incremental cost involved in elevating the protective element to the status of a designated shelter and the degree to which weapons effects are attenuated.

POPULATION MATRIX INPUT DATA

The population distribution matrix is described elsewhere in this report. Each element of the population matrix was described by i, j, coordinate location and total element population. In the new program, in order to make more efficient use of computer memory capacity, only elements with a non-zero population are input. Each element is also described by a word which identifies the class of existing shelter conditions in that element at the beginning of the optimization procedure.

EXISTING CONDITIONS

With no defined shelter system there still exists some level of protection which is incidental to the ordinary working/living environment of the population. Generally, the incidental protection against thermal and nuclear radiation exceeds that found in a completely unprotected environment but the probability of blast casualties may be greater in built-up areas due to building collapse and flying debris. Incidental protection is considered to include actual existing CD shelters at the beginning of the optimization procedure. Incidental protection varies from one area to another as a function of the general class of buildings and the level of Civil Defense preparation in the area.

At the beginning of the shelter optimization procedure cost free shelters of some type do exist for each element of the population and what is generally called an unsheltered population is actually a population in an incidental shelter environment which exists at no cost chargeable to a Civil Defense Improvement Program.

The original program considered all elements of the population to be equally vulnerable to weapons effects. The new version of this program accepts as an input a catalog of existing shelter conditions. Each of a selected set of existing conditions is described in terms of its resistance to weapons effects in much the same manner as the shelter catalog except that there is no cost entry. Each existing condition is identified by a code number and the appropriate number is included as part of the population matrix input data for each non-zero population element. An example of existing conditions catalog is shown in Table VIII. The actual number of entries is not specifically limited but is related to the total amount of data used for the various input options and population matrix size. In order to optimize the use of the program and conserve computer running time, this table can be tailored for specific target area situations and new information relating to vulnerability to weapon effects. While the entries in this table are actual shelters, they are not available to optimization program routines in the sense that an ineffective shelter in this catalog cannot be replaced by a better shelter or shelter condition from this same catalog. However, the actual shelter catalog may include shelters with characteristics identical to some of those in the existing conditions catalog.

	Blast P.S.I.	Thermal cal/cm^2	Prompt P. F.	Residual P. F.	Description
1	3	5	1.5	2.3	Slum - unpainted frame, trash, etc.
2	4	15	1.5	2.3	Below average residence
3	5	15	1.5	2.3	Good, well maintained residence
4	8	40	7.5	100	Commercial, industrial, existing fallout shelters
5	5	15	6	20	Type 3 with basement
6	5	15	1.5	2	Type 3 with free school land
7	5	15	1.5	2	Type 3 with new school building construction projected

TABLE VIII EXISTING CONDITIONS CATALOG

SHELTER CATALOG

A basic input to the program is a catalog of shelter types which might be used in an optimum shelter system. As many as 40 shelter types specifically selected as applicable to the target area of interest may be listed for a single optimization run. An example shelter catalog prepared for the Dallas-Ft. Worth area is shown in Table IX. Some of the shelters listed are nothing more than a general maintenance activity, some involve building modification, some involve incorporation of shelter space in new construction and others are new structures exclusively for shelters. This table is given as an example and is not intended to represent a complete catalog applicable to the target area of interest.

	Blast p.s.i.	Thermal cal/cm^2	Prompt p.f.	Residual p.f.	Cost/Occupant	Description - Application
A	5	60	1.5	2.3	10	Thermal coating on windows Paint exterior trim
B	3	30	1.5	2.3	50	Slum clean up, paint up, etc.
C	4	45	1.5	2.3	25	Improve below average residence
D	10	250	10	150	20	New school construction to incorporate shelter protection
E	15	10,000	30	1000	75	New shelter on free school land
F	15	10,000	30	1000	100	New shelter including site costs
G	30	10,000	30	1000	100	New shelter on free school land
H	30	10,000	30	1000	125	New shelter including site costs
J	50	10,000	30	1000	125	New shelter on free school land
K	50	10,000	30	1000	150	New shelter including site costs
L	100	10,000	100	10,000	150	New shelter on free school land
M	100	10,000	100	10,000	175	New shelter including site costs
N	15	100	12	200	35	Improve existing fallout shelters

TABLE IX SHELTER CATALOG

Note that shelters E and F are identical except for cost. The difference in cost reflects the difference in the cost of land and associated siting expenses. The less expensive shelter is considered to be built on free public land. This is used as an example case but it is possible to include incremental land/siting costs for all types of shelters. This is discussed in the shelter correlation input section. The shelter types in this catalog are not ordered in any particular way because both the effectiveness and ICE are a function of the element location and the nature of the attack.

Shelter Parameters

The parameters used in the shelter catalog are based on the following considerations and assumptions:

1. Blast. Structural resistance to blast is that overpressure at which the probability of survival for the occupants is 0.5.

2. Thermal. Protection of personnel against direct exposure to thermal effects is, in all cases, considered to be absolute. Thermal protection is defined as that thermal exposure to the structure for which there is a 0.5 probability of survival for the occupants.

3. Nuclear Radiation. Because radiation shieldings are not equally effective against prompt and residual, separate protection factors are listed for each effect.

4. Shelter Costs. Shelter costs are determined as the cost per occupant to provide a protective structure with the assigned protective characteristics. The cost does not necessarily represent the total cost of the structure or even that portion of the structure used as a shelter but may be the incremental cost of converting an existing structure to improve its protective qualities. A shelter cost might be the total cost of excavating and constructing an underground concrete vault or simply the cost of installing metal shutters on the windows of a residence to minimize the probability of interior materials being ignited by thermal radiation.

SHELTER CORRELATION INPUT MATRIX

It is apparent that all the shelters which might be included in the shelter catalog as being useful in the total system might not be applicable for every element of the target matrix. For example, construction of a fallout shelter in the basement of a residence is appropriate only in elements where basements exist. Similarly, incorporation of shelter space in new school construction is a possible countermeasure only for elements in which new school structures are to be built. Thus, the applicability of a particular shelter type must be correlated with the existing conditions of the element for which it is considered. This is handled in the form of a Shelter Correlation Input Matrix of the type shown in Table X. In the table identifying numbers for each of the existing conditions entered in the Existing Conditions Catalog, Table VIII, are listed across the top of the matrix. Identifying letters for each of the shelters from the catalog in Table IX are listed in the column at the left. In use, the program determines from the population matrix input data, the existing conditions for a specific element. The program then accepts, as possible countermeasures for that element, only those shelter types for which there is an entry under that existing situation column. For example, under existing Condition 1 (slum conditions) only shelter types B, F, H, K, and M are available as possible countermeasures. Countermeasure B, which is slum cleanup, is not available as a possible measure for any of the other conditions. Shelter type N, improvement of existing fallout shelters is applicable only to existing Condition 4 which is elements with existing fallout shelters.

Cost of land for shelter locations can be included in the optimization procedure. In the example Table X, all of the shelter types available to elements with existing Condition 3 are also available to elements with existing Condition 6. In addition, Condition 6 elements can also be provided with identical new shelter types at a lower cost because the cost of land is not included when the shelters are built on school sites. It is obvious that the more expensive shelter types F, H, K, and M need not be included in the matrix for Condition 6 because they will never be used in place of their less expensive, otherwise identical counterparts.

Shelter Type	Original Existing Condition						
	1	2	3	4	5	6	7
A			X		X	X	X
B	X						
C		X					
D							X
E						X	X
F	X	X	X	X	X	X	X
G						X	X
H	X	X	X	X	X	X	X
J						X	X
K	X	X	X	X	X	X	X
L						X	X
M	X	X	X	X	X	X	X
N				X			

TABLE X SHELTER CORRELATION INPUT MATRIX

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