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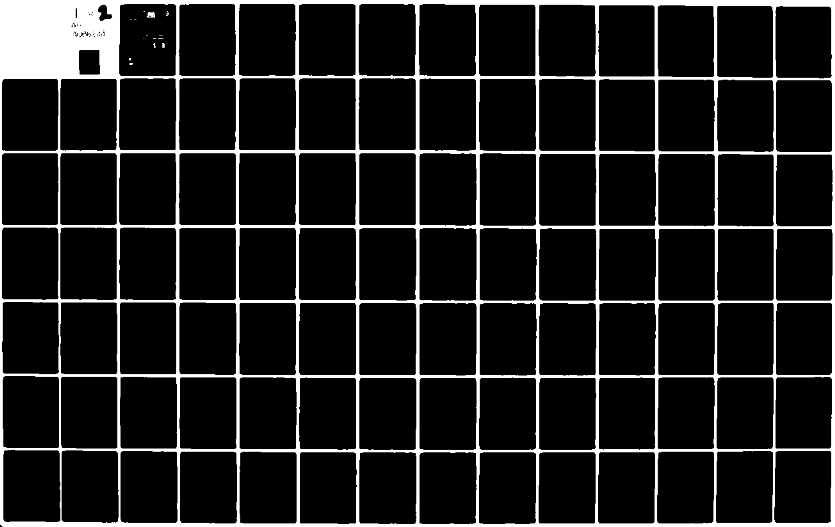

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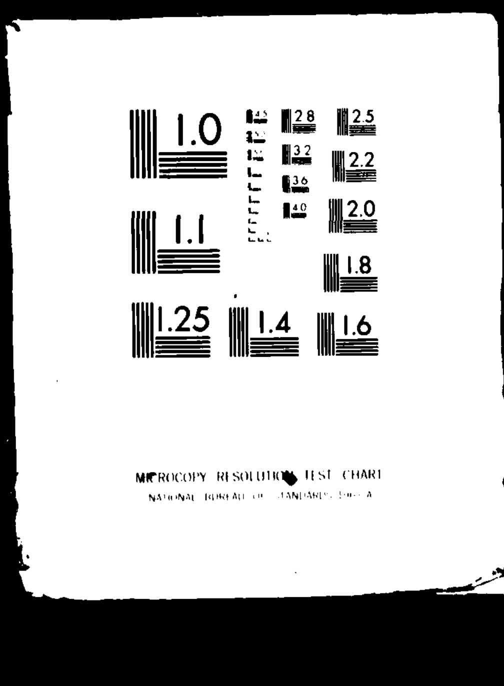

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Detachable Summary

Final Report RTI/1798/00-05F

June 1980

Feasibility and Cost Analysis of Surge Period Shelter Programs

by

Rajeev V. Kamath
Milton D. Wright

for

FEDERAL EMERGENCY MANAGEMENT AGENCY
OFFICE OF MITIGATION AND RESEARCH
Washington, D.C. 20472

under

Contract No. DCPA01-79-C-0233
FEMA Work Unit 1631F

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Summary

I. Introduction

A goal of the Federal Emergency Management Agency (FEMA) is the protection of the civilian population from nuclear attack. In-place protection and protection by relocation to low-risk areas are two types of civilian protection plans under study. In-place protection requires that the entire risk area population be sheltered against the effects of a direct nuclear attack. In the case of protection by relocation, shelter must be provided for the critical work force left behind.

The major objective of this study by the Research Triangle Institute (RTI) was to assess the feasibility and to estimate the costs of providing such protection under various scenarios. The capability of providing shelter spaces and the required amount of cash outlay were the most critical items considered. Variables affecting the feasibility of each type of plan are the surge period length, the number of shelter spaces needed, and the availability of resources — material, labor, and equipment. A surge period is a period of heightened international tensions that may end with a nuclear attack on the United States or an easing of the international tensions.

II. Resource Requirements and Costs

Six single purpose shelter designs were considered in this study and were selected by FEMA. The construction plan for each shelter design was reduced to its elementary components and the required resources, time span, and construction costs were estimated for each component. The major resources needed are materials, labor, and equipment. All costs were estimated on a national basis but factors were provided to convert these national average costs to average costs for each state. Similar estimates were developed for the upgrading of existing buildings, a sheltering option that was subsequently dropped.

III. Resource Availability

The availability of materials depends upon industrial production capacity and the length of the surge period. Two resources — equipment and skilled labor — would have to be diverted from current construction activities to the shelter program. RTI studied in detail the Nation's material production capacity and existing labor force and estimated the availability of these resources under various time constraints. For each required material, the bottlenecks that would make an increase in production capacity diffic 't or impossible were identified.

IV. Analytical Techniques — Approach

The parameters of the shelter building problem were these: an objective to attain, several possible courses of action, and limited resources. RTI determined that linear programming, with its simplicity and versatility, was the most useful method for solving this type of problem.

In order to assess the feasibility of providing shelter spaces, we designed an objective function to maximize the shelter spaces. To develop costs for sheltering selected fractions of the population, another objective function was formulated, which selected a solution to minimize the associated total cost of the shelter program. Both of these formulations were used to analyze selected scenarios created by varying the surge period length, the percentage of available resources, and the fraction of the population to be sheltered. To simulate both the lack of large construction sites in urban areas and the effect of longer lead times for larger shelters, additional constraints were added to the analysis.

V. Results

All analytical results were tabulated to show (1) the capability of providing shelters as a function of the length of surge period and the quantities of resources made available; (2) the minimum costs of shelter programs for various surge period lengths and resource constraints; and (3) the effects of additional constraints that simulate the lack of large construction sites in urban areas and the longer lead times for larger shelters. Tables are also provided that indicate the type and number of each shelter design and the quantities of resources that would be needed in a shelter building program.

VI. Conclusions

1. The critical work force can be sheltered during a surge period as short as 3 months without significant impact on normal production and distribution patterns of resources.

2. Steel is the most critical material and is needed in large enough quantities to possibly disrupt normal usage patterns.

3. In order to provide in-place protection to the entire risk area population, a 6-month surge period length and 50 percent of the nationally produced reinforcement and plate steel would be required.

4. With a 12-month surge period length, the entire risk area population could be sheltered with 25 percent of the reinforcement and plate steel production.

VII. Recommendations

1. Steel and construction labor are the critical elements that limit shelter construction capability. A construction labor shortage could be eased by utilizing labor from other categories or student labor. The production of plate and reinforcement steel is limited by processing capability. Raw steel production can be substantially increased; RTI recommends that detailed additional study be devoted to steel industry capability to provide the plate and reinforcement steel necessary for a risk area shelter program.

2. Another approach for alleviating the steel shortage is to stockpile portions of the needed amount in risk areas, during peace time. RTI recommends further investigation of this option.

3. Lack of land at the places needed could be a great impediment to a shelter program. RTI recommends that the Federal government, perhaps through local civil defense agencies, do extensive compilation of data on potential land for shelter construction and earmark enough land to at least provide the minimum shelter space needs. This would ensure availability of land for shelter construction on short notice.

4. Urban areas, where land is scarce, need the most shelter spaces. We recommend an investigation of the feasibility, practicality, and cost of providing multipurpose shelters in such areas to serve auxiliary purposes (e.g., such as for low income housing, schools, and parking) during peace time.

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Protection of the civilian population from the effects of a nuclear attack is one of the goals of the Federal Emergency Management Agency (FEMA). In-place population protection and protection by relocation are two distinct types of civilian protection plans that are used. The in-place plans demand direct effects protection for the entire risk area population, while in the latter case only a skeleton work force needs to be protected. This report describes the investigation into the feasibility and costs of providing all-effects shelters in risk areas for an in-place shelter plan as well as a population relocation plan.

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RTI estimated the construction costs and resource requirements and assessed the nationwide availability of these resources for each of six shelter designs. Linear programming was used to calculate the capability of providing shelter spaces for various surge period lengths. Minimum costs of providing protection to selected percentages of the population were also computed for the same surge periods. Critical resources that limit shelter building capability were identified and means for improving this capability were suggested.

The results of the study show that the critical workforce can be sheltered under all surge period lenghts. Housing the entire risk area population would require a minimum surge period of 6 months and the diversion of 50 percent of the Nation's reinforcement and plate steel production.

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Dr. John R. Canada of the Industrial Engineering department at North Carolina State University in Raleigh, N.C., collected data and assisted in writing the Chapter on resource availability.

Their efforts and contributions are greatly appreciated.

ABSTRACT

Protection of the civilian population from the effects of a nuclear attack is one of the goals of the Federal Emergency Management Agency (FEMA). In-place population protection and protection by relocation are two distinct types of civilian protection plans that are used. The in-place plans demand direct effects protection for the entire risk area populaton, while in the latter case only a skeleton work force needs to be protected. This report describes the investigation into the feasibility and costs of providing all-effects shelters in risk areas for an in-place shelter plan as well as a population relocation plan.

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I. INTRODUCTION

Protection of the civilian population under nuclear attack conditions is one of the goals of the Federal Emergency Management Agency (FEMA). Plans for providing such protection in the face of a number of attack scenarios are being developed as one of the approaches to achieving this goal. The protection plans can be classified as one of two distinct types: (1) those that provide in-place population protection, or (2) those that depend on population relocation as a means of enhancing protection. Plans of the first type would be implemented in response to an attack that comes with little or no warning, while plans of the second type might be implemented in response to an impending attack with several days warning. Both types of plans require that some fraction of the population that resides in high-risk or target areas be provided with protection against the direct effects of nuclear weapons. In the first type of plan, direct effects protection must be provided for the entire resident population of the risk areas; in the second type of plan, direct effects protection would only be needed for a skeleton workforce that remains behind when population relocation takes place.

Although there are a few buildings and special facilities that in their existing state provide good protection from both fallout and direct weapons effects, their locations may not coincide with the need. Consequently, it is likely that most risk area shelters will have to be provided by (1) expedient modifications in existing buildings to improve their protective capability, (2) the construction of new expedient shelters having the necessary protective capacity, or (3) the construction of new high-quality all-effects shelters. All of these options require substantial quantities of materials and equipment for successful implementation. Identifying sources of these materials and providing for their transportation and distribution require a significant planning effort to insure effective implementation in a period of crisis or increased readiness.

One of the international scenarios to which FEMA is developing a response involves the outbreak of hostilities between other nations, with implications that the United States might eventually become involved. In such a case, FEMA may implement plans for increased activity over a period of time. This time period is generally referred to as a "surge period" and would cover a time interval beginning when some international crisis is recognized and ending either with an attack on the United States or an easing of the international tensions. The length of the surge period may vary from a few weeks to a year or more. Civil defense activities initiated during the surge period would be directed toward increasing the available means of protecting the civilian population, should an attack occur. An important part of this increased activity is the provision of all-effects shelters in the risk areas.

This report describes the results of an investigation into the feasibility and cost of a surge period program to provide all-effects shelters in risk areas for an in-place shelter plan and for a population relocation plan.

II. DEFINITION OF STUDY PARAMETERS

The variables upon which the feasibility and cost of a risk area shelter program depend include: (1) the length of the surge period, (2) the population to be sheltered, and (3) the shelter designs used. This section discusses the methods by which these variables were defined for this study.

A. Surge Period

The period of time during which a shelter construction program can be implemented is a critical element in the determination of the number of shelters that can be constructed. This is true not only because it governs the time available for actual shelter construction but also because it governs the quantities of materials that can be produced and diverted to the shelter program. The variation in surge period length to be considered in this study was dictated by FEMA and is based on its analysis of numerous scenarios. For this study, RTI selected four surge period intervals: 3 months, 6 months, 9 months, and 12 months. To assess the effects that a varying surge period length has on shelter construction, calculations were made using these four discrete time periods. These calculations consisted of separate analyses of the feasibility and cost of sheltering selected fractions of the risk area population.

B. Population Considerations

The risk area population is, of course, the primary factor in determining the number of shelters that must be constructed during a surge period. As mentioned previously, the fraction of the resident population to be sheltered varies depending on the type of plan that is being developed. We investigated both types of plans, and chose as a maximum value the total risk area population, and as a minimum value, the skeleton work force for critical industries. Maximum and minimum values of the population to be sheltered were estimated on a state-by-state basis and the estimates were then summed to give values on a regional and national basis.

Table 1 presents a summary of the population data considered. The information listed in Table 1 was developed using data contained in a publication of the Defense Civil Preparedness Agency (one of the agencies that now comprise FEMA) that is referred to as TR-82 [Ref. 1] and from information contained in the reports on the 1970 census of population [Ref. 2]. TR-82 identifies the areas in each state that are considered to be high risk areas and presents data by which the resident population of these areas can be estimated. This information was used directly as the maximum population for which shelters would be needed and is presented by state in Column (1) of Table 1.

Estimates of the minimum population to be sheltered were slightly more involved, and were made using data from the 1970 census of population. FEMA has estimated that approximately 6 percent of the labor force would be required to maintain critical services and functions in an area that has had its population relocated as a protective measure. This figure was used to estimate the minimum requirement for shelters in a surge period.

The estimates of minimum shelter requirements were derived on a state-by-state basis as follows: (a) The total population of each state was identified and entered in column (2) of Table 1; (b) The total civilian labor force was identified and entered in column (3) of Table 1; (c) column (3) was divided by column (2) to obtain the percentage of the total population that makes up the civilian work force, and this value was entered in column (4) of Table 1; (d) The percentage obtained in column (4) was multiplied by the total risk area population in column (1) to obtain an estimate of the total civilian work force in the risk areas, and this value was entered in column (5) of

TABLE 1. RISK AREA POPULATION AND LABOR FORCE, BY STATE AND REGION

	Risk Area Population	Total Population	Total Labor Force (Civilian)	Labor Force As a Percent of Total Population	Risk Area Labor Force	Critical Work Force
REGION I						
Maine	329,494	993,663	386,466	39	128,503	7,710
Massachusetts	5,437,490	5,689,170	2,416,654	42	2,283,746	137,024
Connecticut	2,946,377	3,032,217	1,309,235	43	1,266,943	76,017
Rhode Island	948,514	949,723	391,729	41	388,891	23,334
New Hampshire	401,152	737,681	309,406	42	168,484	10,109
Vermont	83,093	444,732	177,461	40	33,238	1,995
New Jersey	6,989,341	7,168,164	2,997,172	42	2,935,524	176,132
New York	14,893,510	18,241,266	7,475,760	41	6,106,340	366,381
	32,028,971	37,256,616	15,463,883	41	13,311,669	798,702
REGION II						
Maryland	3,621,849	3,922,399	1,605,609	41	1,484,959	89,098
Delaware	467,748	548,104	221,379	40	187,099	11,226
Dist of Columbia	756,510	756,510	350,536	46	347,995	20,880
Pennsylvania	8,370,751	11,793,909	1,798,906	15	1,255,613	75,337
Virginia	2,802,063	4,648,494	1,781,176	38	1,064,784	63,887
West Virginia	663,733	1,744,237	583,670	33	219,032	13,142
	16,682,654	23,413,653	6,341,276	27	4,559,482	273,570
REGION III						
Alabama	1,685,013	3,444,165	1,259,008	37	623,455	37,408
Florida	4,861,157	6,789,443	2,547,518	38	1,847,240	110,835
Georgia	2,223,830	4,589,575	1,822,215	40	889,532	53,372
Kentucky	1,338,563	3,219,311	1,150,333	36	481,883	28,913
Mississippi	531,094	2,215,912	763,072	34	180,572	10,834
North Carolina	1,843,006	5,082,059	2,070,886	41	755,632	45,338
South Carolina	953,721	2,590,516	1,002,516	39	371,952	22,318
Tennessee	1,763,853	3,924,164	1,538,564	39	687,903	41,274
	15,200,237	31,856,145	12,154,112	38	5,838,169	350,292
REGION IV						
Illinois	8,698,652	11,113,976	4,642,762	42	3,653,434	219,206
Indiana	2,925,710	5,193,669	2,128,790	41	1,199,542	71,973
Michigan	6,703,732	8,875,083	3,498,813	39	2,614,456	156,868
Minnesota	2,070,357	3,805,069	1,555,529	41	848,846	50,931
Ohio	7,660,831	10,652,017	4,278,304	40	3,064,333	183,859
Wisconsin	2,407,461	4,417,933	1,799,280	41	987,059	59,224
	30,466,743	44,057,747	17,903,578	41	12,367,670	742,061

(Continued)

TABLE 1. RISK AREA POPULATION AND LABOR FORCE, BY STATE AND REGION (Continued)

	Risk Area Population	Total Population	Total Labor Force (Civilian)	Labor Force As a Percent of Total Population	Risk Area Labor Force	Critical Work Force
REGION V						
Arkansas	697,666	1,923,295	694,540	36	251,160	15,069
Louisiana	2,083,993	3,643,180	1,234,110	34	708,558	42,514
New Mexico	406,142	1,016,000	347,216	34	138,088	8.285
Oklahoma	1,218,432	2,559,253	980,064	38	463,005	27.781
Texas	7,668,571	11,196,730	4,343,007	39	2,990,743	179,445
	12,074,804	20,338,458	7,598,937	37	4,551,554	273,094
REGION VI						
Colorado	1,612,472	2,207,259	874,179	40	644,989	38,399
Iowa	974,985	2,825,041	1,147,768	41	399,744	23,985
Kansas	1,217,067	2,249,071	889,296	40	486,827	29,210
Missouri	3,156,537	4,677,399	1,864,699	40	1,262,614	75,757
Nebraska	680,820	1,483,791	603,113	41	279,137	16,749
North Dakota	278,708	617,761	218,285	35	97,548	5,853
South Dakota	142,973	666,257	255,351	38	54,330	3,260
Utah	806,924	1,059,273	406,074	38	306,632	18,416
Wyoming	78,659	332,416	132,119	40	31,464	1,888
	8,949,145	16,118,268	6,400,884	40	3,563,285	213,817
REGION VII						
Arizona	1,327,671	1,772,482	650,326	37	491,238	29,474
California	17,766,789	19,953,134	8,071,455	40	7,106,716	426,403
Nevada	383,213	488,738	211,924	43	164,782	9,887
	19,477,673	22,214,354	8,933,705	40	7,762,736	465,764
REGION VIII						
Idaho	112,452	713,008	276,970	39	43,856	2,631
Montana	313,773	694,409	265,083	38	119,234	7,154
Oregon	1,185,266	2,091,385	825,743	39.5	468,181	28,091
Washington	2,396,754	3,409,169	1,358,112	40	958,702	57,523
Alaska	170,406	300,382	167,977	56	95,427	5,726
	4,178,651	7,208,353	2,893,885	40	1,685,400	101,125
GRAND TOTAL	139,058,878	202,463,594	77,690,260	38.37	53,639,965	3,218,425

Table 1; (e) The critical work force in the risk areas was calculated by using a figure of 6 percent of the total civilian work force, and these values were entered in column (6) of Table 1. They represent the minimum requirement for shelter spaces during the surge period. Columns (1) and (6) of Table 1 represent the maximum and minimum values, respectively, of the population to be sheltered in each state and, in sum, for the entire United States. These values were used as the target values in evaluating the feasibility and cost of risk area shelter programs during a surge period.

C. Shelter Designs

The designs of the shelters to be constructed dictate both the types and quantities of resources (i.e., materials, equipment, and labor) that would be needed. The shelter designs considered in this study were all developed under the sponsorship of FEMA or its predecessor agencies that dealt with civil defense planning. The following subsections give brief descriptions of the six shelter designs that were considered.

For computer programming purposes, the six shelters have been numbered Type 1 through Type 6. These are:

Type 1: Reinforced Concrete Rectangular Shelter (500 capacity)

Type 2: Reinforced Concrete Rectangular Shelter (1,000 capacity)

Type 3: Reinforced Concrete Arch Shelter (500 capacity)

Type 4: Steel Arch Shelter (500 capacity)

Type 5: Steel Dome Shelter (20 capacity)

Type 6: Small-Pole Shelter - Lumber Version (12 capacity).

Types 5 and 6 are small expedient shelters, while Types 1 through 4 are large engineered structures.

Initially, we considered a seventh alternative for providing shelters. This alternative consisted of modifications to existing buildings to improve their protective capability. In subsequent analyses and after consultation with FEMA personnel, we concluded that modifications to existing buildings may not be a practical alternative for risk area shelters. At the time the decision was made, that alternative had been studied at length. All the data developed regarding this alternative are presented in tabular form in Appendix A.

1. The Rectangular and Arch Shelters

The rectangular and arch shelters encompass the first four shelter types: two reinforced concrete rectangular shelters, the reinforced concrete arch shelter, and the steel arch shelter. They have a range of shared characteristics and will be described here together. Each was designed to provide 10 square feet of floor space per person for 500 persons. They can be variously situated at ground level, below grade, or semiburied, depending on the terrain. (See Figures 1 and 2 for placement levels). All are most secure and most easily built on flat, lightly wooded land. The three shelters were all designed to protect against nuclear fallout and also against 30 pounds per square inch (psi) of free-field incident overpressures and the associated effects of thermal and prompt nuclear radiation. All of these designs have been successfully tested at 50 psi incident overpressure.

The reinforced concrete rectangular shelter (Type 1) is unique in that it is built in 16-square-foot modules which can be multiplied in number to accomodate 1,000 (Type 2) persons. Figure 3 shows a schematic of its design. Inside, the modules line up in rows of four. A 500-person shelter has 20 modules, spanning a length of 80 feet and a width of 64 feet. The interior walls for each module are 6 inches thick. Around the block of modules is an exterior wall 10 inches thick; the roof is 18 inches thick.

Shelter Types 3 and 4 are structured as arches; Type 3 is made of reinforced concrete and Type 4 of steel. Figure 4 shows their basic design.

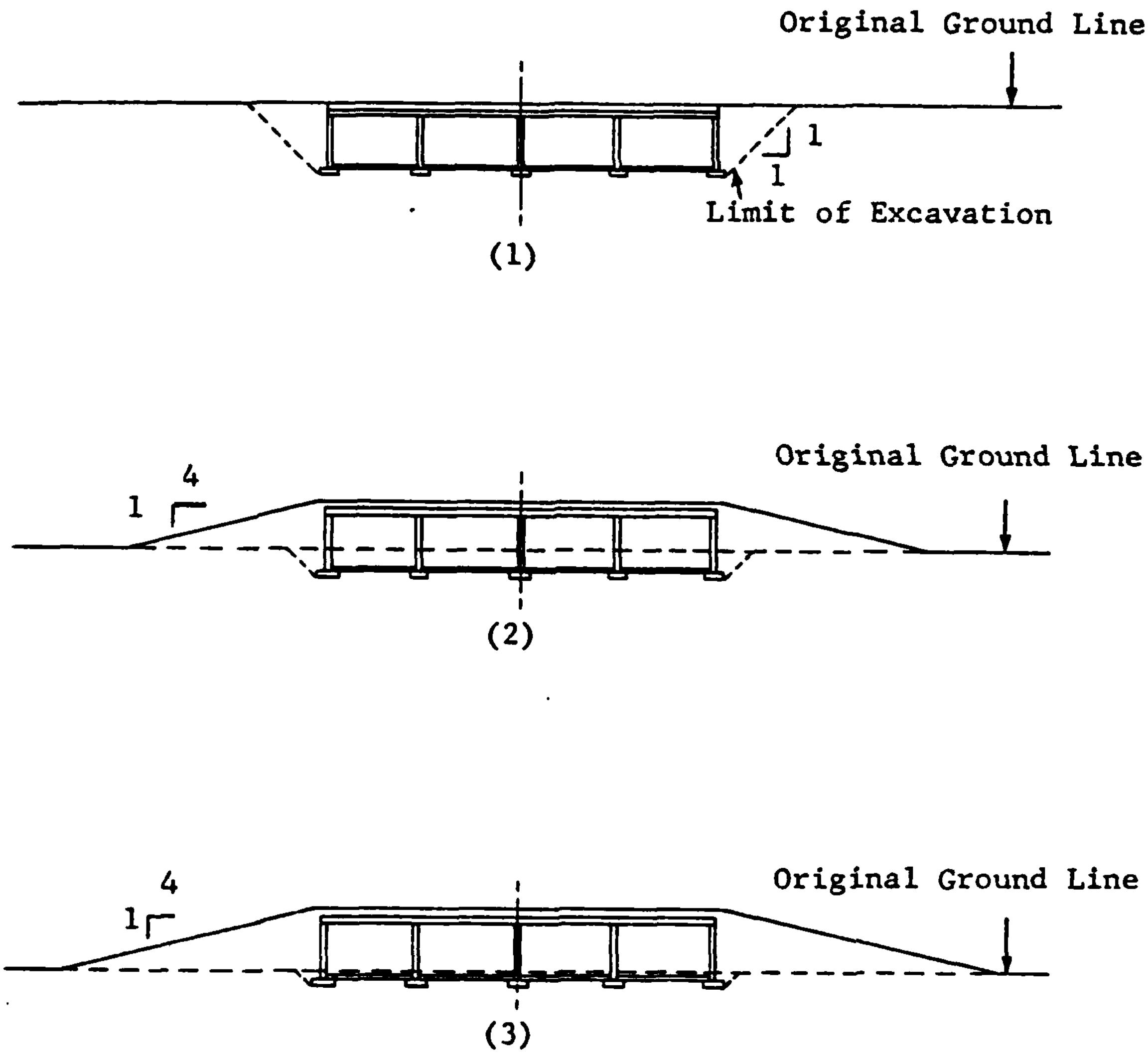


Figure 1. Burial Conditions for Rectangular Shelters

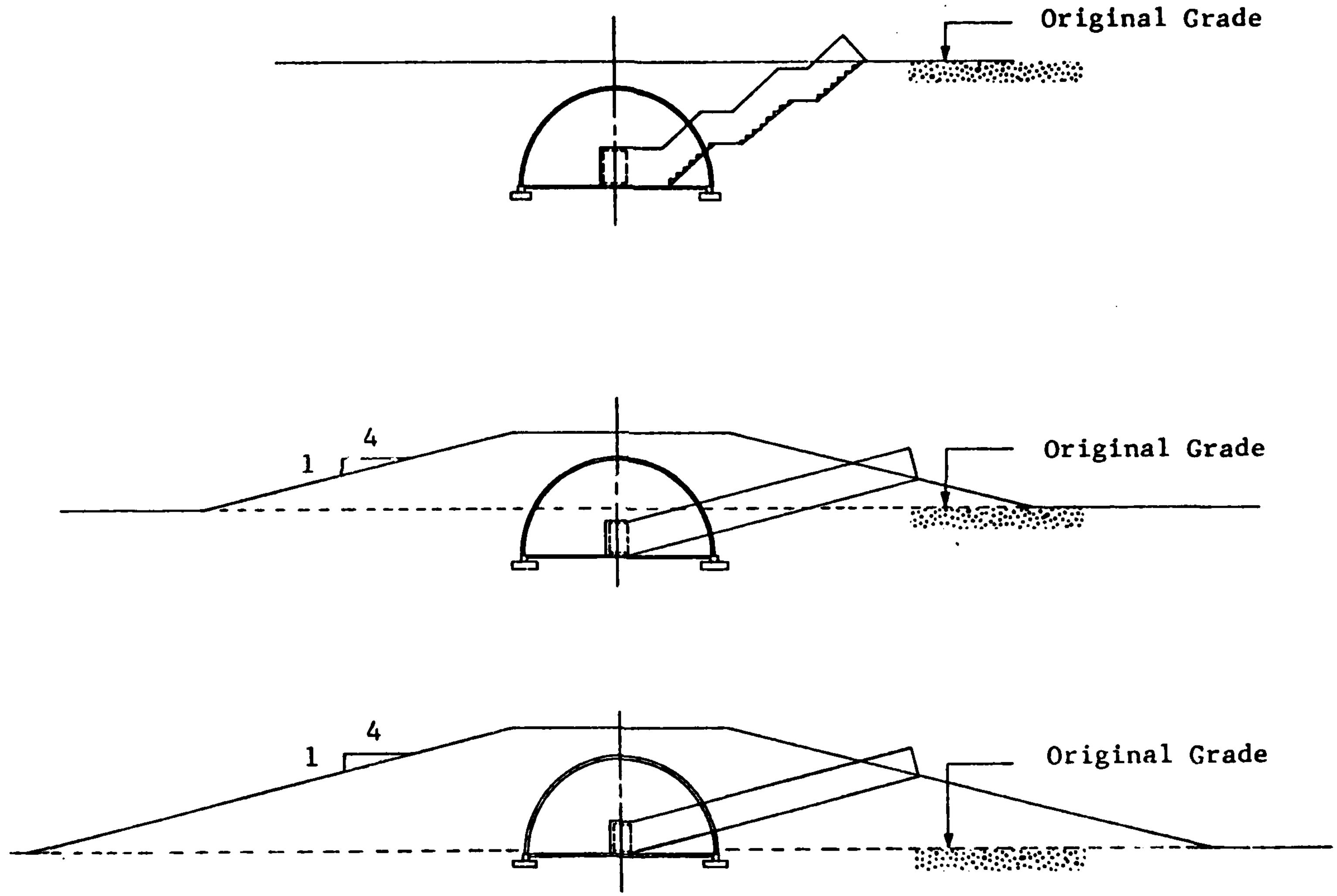


Figure 2. Burial Conditions and Entranceways for Arch Shelters [Ref. 3]

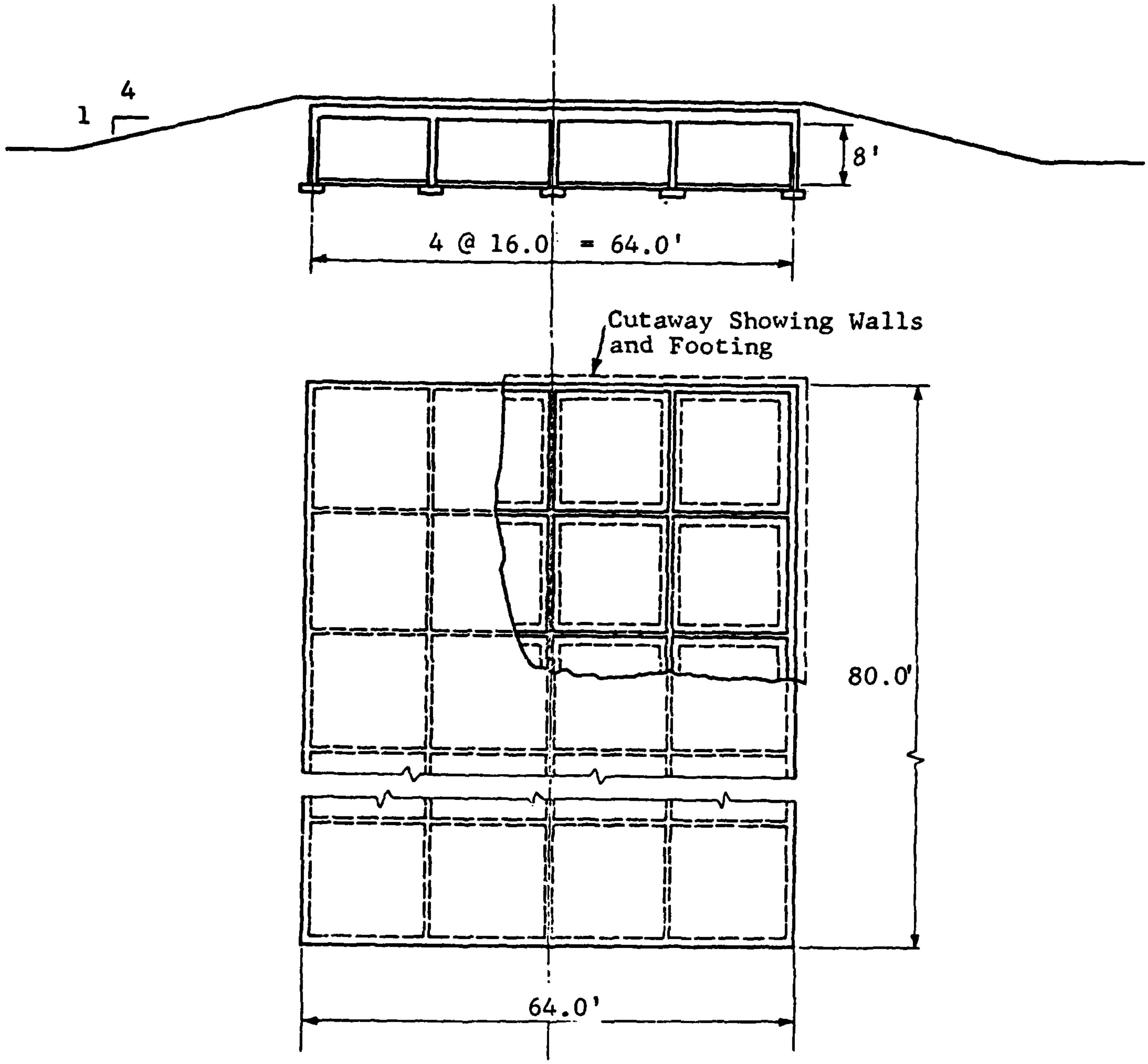


Figure 3. Basic (500-Man) Reinforced Concrete Rectangular Shelter Module [Ref. 3]

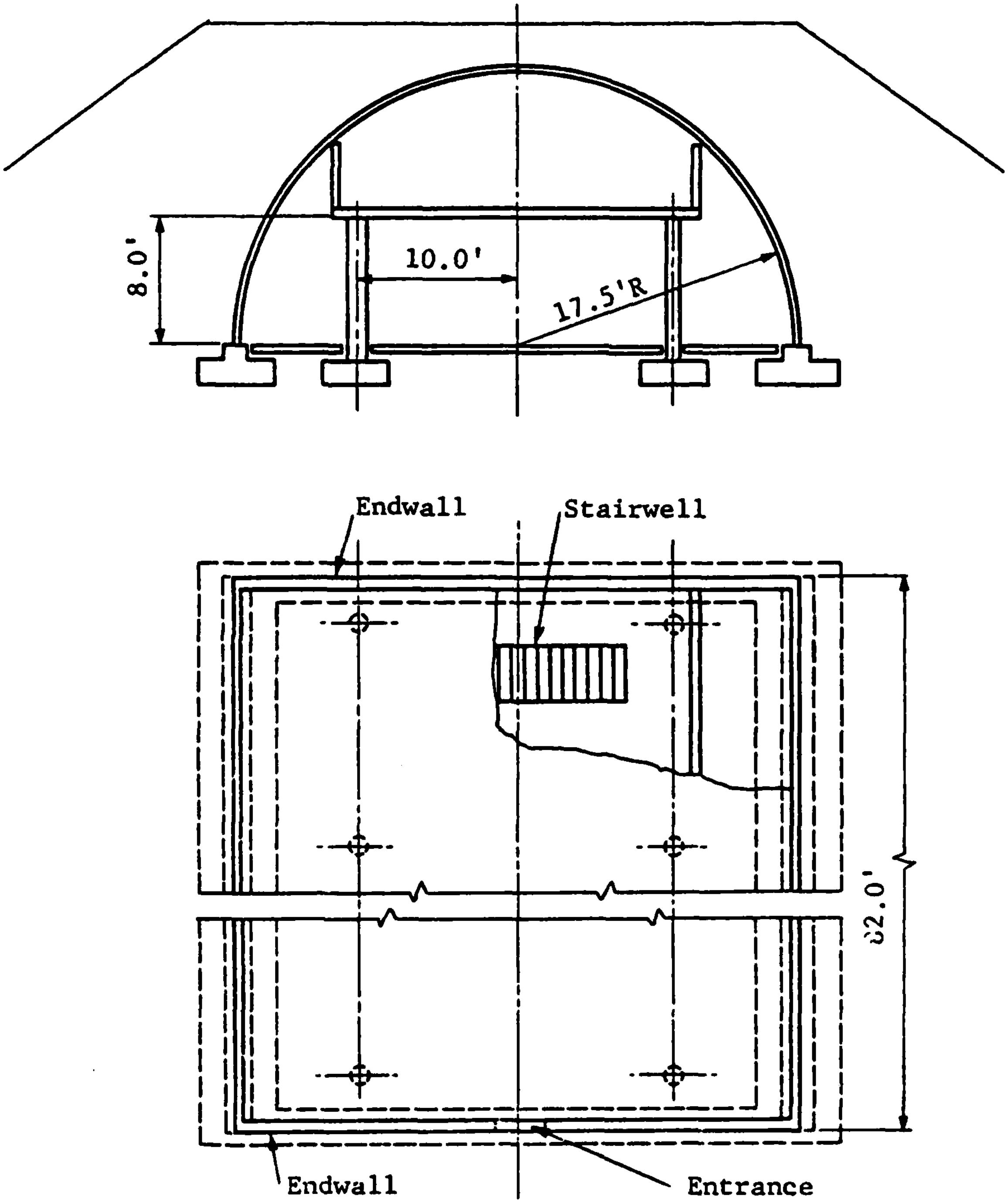


Figure 4. Basic (500-Man) Arch Shelter Module [Ref. 3]

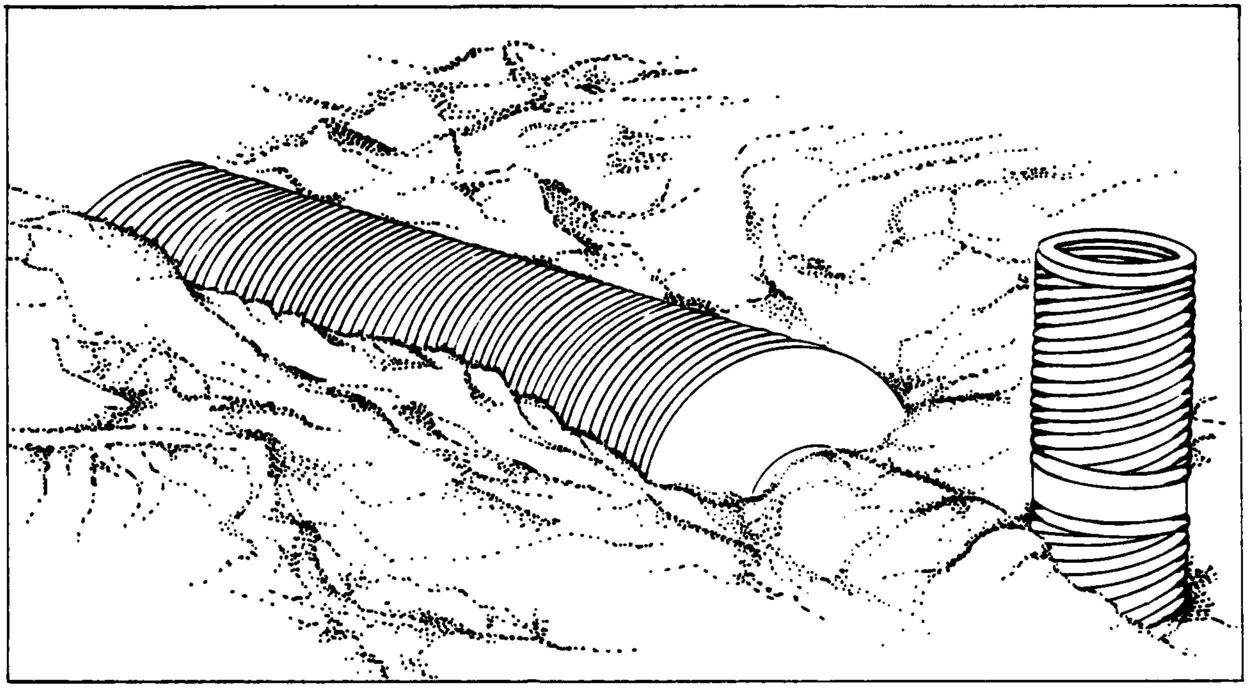
The concrete arch is a 4-inch-thick shell 82 feet long and with an internal radius of 17.5 feet; it is set on arch footings. Within the shell, a second floor (mezzanine) rests on two rows of columns, whose footings are separate from those of the enclosing arch. The endwalls are 10 inches thick and rest on another set of footings.

The shell of the steel arch shelter is one-half inch thick, composed of steel plate. Its endwalls are also 10-inch-thick concrete, and the interior design with its second floor (mezzanine) is like that of the concrete arch.

The four shelters have identical provisions for drainage, waterproofing, ventilation, electricity, and plumbing. Between the excavation bottom and the reinforced concrete floor lies a granular base covered with a 0.004-inch layer of polythelene sheeting that serves as a vapor barrier. Over the tops of the four shelters goes a 0.006-inch polyethelene sheet for rainproofing. For ventilation, it is assumed that each person requires 10 cubic feet of air per minute. To accommodate that need, the shelters can be equipped with a packaged ventilation kit (PVK) which operates by either foot pedal or electrical power. Finally, commercial options exist for various plumbing and electrical systems, ranging from crude to somewhat comfortable.

2. <u>The Steel Dome Shelter</u>

The steel dome shelter (Type 5) is a resilient, high-strength underground system designed to protect a maximum of 20 persons from an overpressure as great as 50 psi. As displayed in Figure 5, it is a tunnel-like corrugated steel shelter buried under 39" of earth. This amount of earth shielding provides adequate protection from the thermal effects of the nuclear blast and reduces the radiation effects by a factor of 2,000, to acceptable levels. Two vertical entrance and exit shafts abut the ends of the shelter barrel. Atop each shaft is a high-strength semielliptic steel dome,



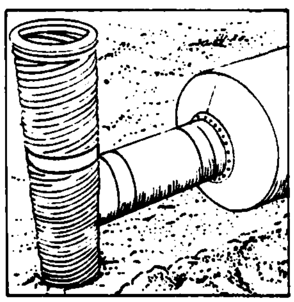


Figure 5. The Steel Dome Shelter

which is equipped with an integral, fast-acting blast valve to limit air pressure build-up in the shelter when it is subjected to abnormal overpressures.

In two tests simulating nuclear blasts, the steel dome shelter proved capable of withstanding 150 psi with less than 5 percent residual distortion, and survived without serious buckling or collapse. The combination of the resilient corrogated shelter wall and the arch effect of the soil cover allows this limited distortion.

The steel dome shelter has the advantages of strength and more than adequate protection against ground blast effects. In addition, it is readily producible and easy to transport and install.

3. <u>The Small-Pole Shelter - Lumber Version</u>

The basic small-pole shelter is designed to house 12 persons, and with adjustments can hold up to 24 people. Made with simple materials, it can be built within one day by those who will occupy it. This underground, box-like structure is especially suited for areas where the earth is not stable enough to make vertical-walled trenches without shoring their walls.

Figure 6 is a drawing of the small-pole shelter without its earth covering. It fits into a trench about 6-1/2 feet deep, 12 feet across, and 23 feet long at surface level (18 feet long at its base). The interior space is composed of an entranceway and a rectangular room. Nine feet of benches and nine feet of overhead bunks line each side of the main room, and a 3-foot-wide overhead bunk stretches across the back end. About one-third of the occupants can sleep in the bunks at any given time, while the remaining two-thirds can sit with plenty of head room.

In the lumber version of the small-pole shelter, the walls and roof consist of a stud framework covered on the outside by plywood sheathing.

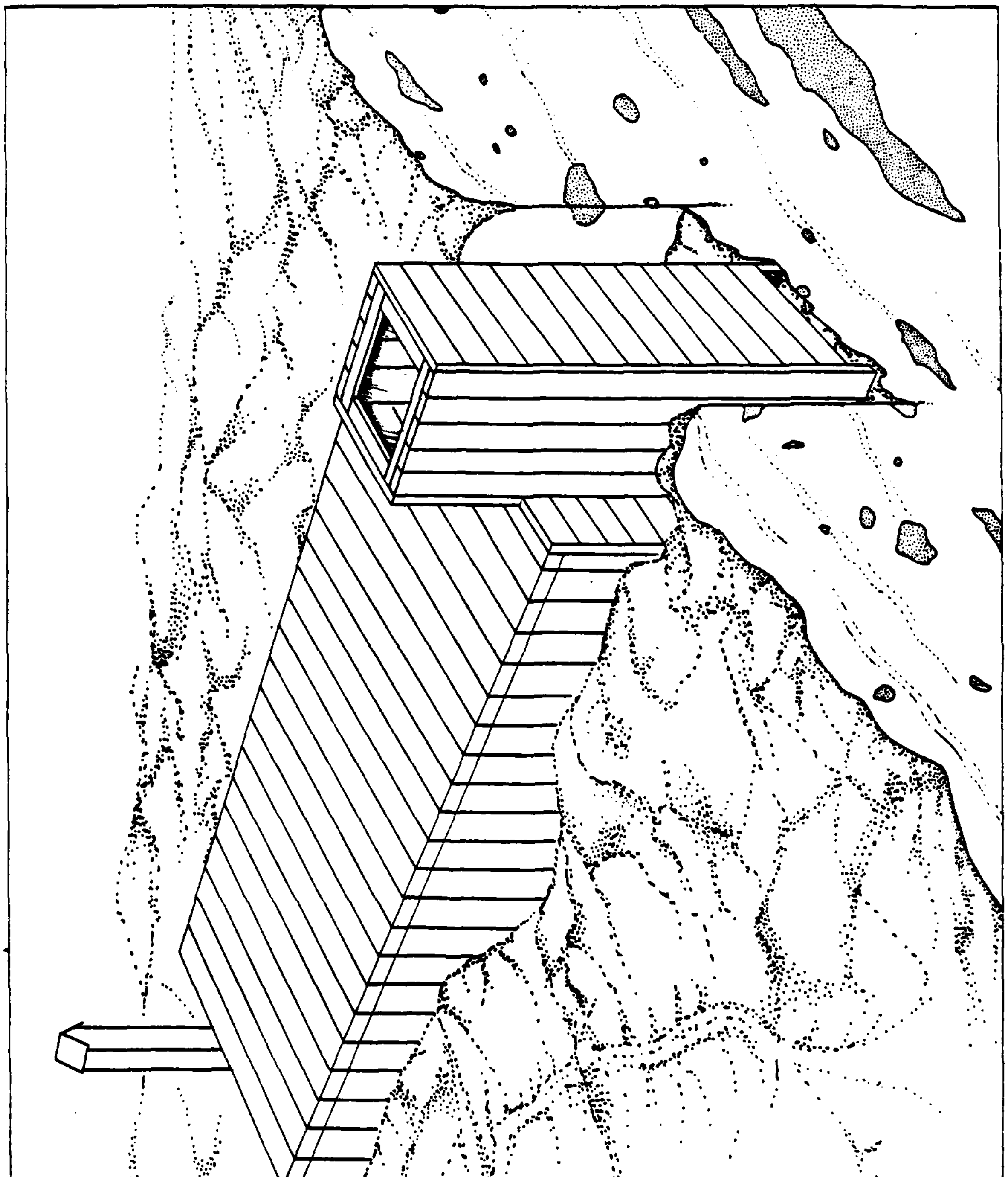


Figure 6. The Small Pole Shelter - Lumber Version

Between these plywood walls and the trench goes a filling of earth. The plywood on the ceiling must be covered with bedsheets, cardboard, or newspaper so that no dirt falls between the cracks. On top of that, dirt is piled in a sloping manner, from a 15-inch-deep center line to a 2-inch-deep level at the edges. This sloping prevents roof leakage and caving if the weather is rainy. On top of the dirt mound goes a layer of rainproofing material, and then at least 2-1/2 feet more of earth. All four sides of the surface require drainage ditches to catch any runoff water.

Within the shelter, several design aspects provide for adequate drainage. The excavation bottom itself grades down toward the entrance and a central drain ditch. In the ditch, sticks covered with porous fabric serve like a crushed-rock drain leading to a sump. The design also provides instruction for building rudimentary lighting and sanitation systems.

Since the carbon dioxide level can become dangerously high in a small underground shelter, the structure must be ventilated. This may be accomplished with a homemade Kearny Air Pump, which is a 36-inch-long by 26-inch-wide device that hangs from the doorway opening between the entrance and main room. When the lower part of the doorway is blocked by a plastic-covered frame, the pump can force through the main room a 36-cubic-feet-per-minute airflow, an essential rate for 12 persons. Especially in hot or humid weather, an efficient pump is necessary to prevent severe headaches. An additional means of ventilation is an air duct that fits through the ceiling of the shelter.

III. RESOURCE REQUIREMENTS AND COSTS

Each of the alternative shelter designs considered in this study was subdivided into its elementary components to permit an estimation of the total resources (materials, equipment, and labor) required for construction. These requirements were then used in subsequent analyses of the feasibility and costs of surge period shelter programs.

The following paragraphs describe the procedures used to develop the resource requirements for each of the shelter designs and present the results obtained for each design. All data pertaining to productivity and cost were obtained from two primary reference works. R. S. Means Building Construction Cost Data [Ref. 4], and R. S. Means Mechanical and Electrical Cost Data [Ref. 5]. The general procedure followed in estimating the resource requirements and costs of the shelters was as follows:

1. A list was developed of all construction activities required for a shelter.
2. Each construction activity was identified in one of the reference works cited above.
3. The crew size, daily production rate, and costs for each construction activity were extracted and used to obtain a unit cost.
4. The total cost was computed by multiplying the cost per unit by the number of units needed.

All costs were computed as national averages under normal conditions. Factors by which the national cost data can be converted to the costs in a particular state were also developed and are presented in Section VI.

If surge demand for blast shelters is imposed on top of existing normal demand for the resources required, and if normal free market pricing mechanisms are allowed to operate, it seems reasonable to project that prices for most commodities should remain approximately stable for a 5-to 15-percent increase in demand, depending on amount of the underutilized production capacity for each particular resource. However, if the materials resource suppliers and construction contractors knew that the government was definitely going to buy regardless of price, they would be prone to increase the price to maximize profits for the total volume they expect to sell. Hence, it is roughly projected that under free market conditions resource prices will increase 1 percent for each 1 percent increase in total demand for resources up to capacity and beyond, if capacity can be added within the time frame needed. An exception to this would be manpower, for which overtime and staff premiums would have to be paid.

It may be more realistic to assume that a massive surge demand would be met best through a government priority-allocation system to assure resource availability. Such a system would almost have to be accompanied by price controls for at least the affected resources. In this case, it seems reasonable to project stable prices for all resources except manpower, which would require overtime and shift premium payments.

Subsections A., B., C., and D. further describe the assumptions and construction activities that influenced our determination of resource requirements and costs.

A. Reinforced Concrete Rectangular and Arch Shelters

This section deals with shelter Types 1 through 3: two reinforced concrete rectangular shelters, one housing 500 and the other housing 1,000 persons; and the 500-capacity reinforced concrete arch shelter.

Several assumptions underlie the estimates for resource requirements for these shelters. First, each shelter complex is located near an electrical power source and near a transportation route (highway, country road, or railroad). Each complex consists of a group of shelters and an access road. Second, 10 square feet of floor space are designated for each person. Third, concrete for the shelters is mixed at batching plants and material yards and then transported to the sites. Fourth, costs for the land on which shelters are built are not a factor in our estimates. And fifth, the lines for machine excavation extend from the bottom and edges of the footings on a one-to-one slope to the original ground line.

Construction activities for the shelters in this group fall into three basic categories: earthwork, structural, and waterproofing. Earthwork requirements were computed for each of the three burial options.

1. Earthwork

Earthwork encompasses site clearance, granular fill, excavation, and backfill operations. For site clearance, the terrain is assumed to be lightly wooded. The clearing, therefore, is classified as light and includes removal of trees and shrubbery and clearing of stumps. It does not allow for large-scale earth moving or clearing of heavily wooded areas. The ground is prepared by placing 4-1/2 inches of tamped granular fill (crushed stone or gravel) as a base beneath the concrete floor slabs.

As explained in the assumptions listed above, excavation lines would extend 1 foot from the bottom and edges of footings and follow a 1-to-1 slope to the original ground line. RTI assumed the cost for hand excavation to be very low and therefore did not consider it a factor.

Backfill is divided into two operations, hand and machine work. Hand backfill for rectangular shelters includes a fill bounded by a top surface parallel to and 1 foot from the roofline, extending down on a 1-to-4 slope. For arch shelters, hand backfill includes fill in a 90° sector on top of the arch, varying in thickness from 1 foot at the crown to 2 feet at the ends of the section, also extending down on a 1-to-4 slope. Machine backfill accounts for the remaining portions required to suitably cover the shelters.

2. Structural

For the two rectangular shelter alternatives, all structural members are made of reinforced concrete. The volume of concrete needed for the walls was calculated by assuming that there is one door in each interior wall of each room and that there are two exterior doors in each shelter. Footings, walls, and floors are cast in place, while the roof slab (for the rectangular shelter alternatives) and the internal floor (for the arch shelter alternative) are cast and lifted into position.

Data on reinforcements for structural members of arch and rectangular shelters were obtained from Civil Defense Shelter Options: Deliberate Shelters [Ref. 3], Tables A-3 and A-5. Welded-wire fabric with number 6 wires spaced at 6-inch centers is used as reinforcement for the concrete floor slabs.

3. Waterproofing

Polyethelene sheeting serves two functions in preventing water damage to the shelters. Over the dirt fill layer that covers the shelter roof, a 0.006-inch layer of the plastic acts as a rain barrier. A 0.004-inch polyethelene sheet lies between the granular base course and the concrete floor slab as a vapor barrier. To carry ground water away, a 4-inch-diameter vitrified clay drain tile (covered by a 1-by-1 foot section of porous fill) surrounds the shelter.

Detailed breakdowns of the resource requirements for the reinforced concrete rectangular shelters can be found for the 500-person shelter in Table 2 and for the 1,000-person shelter in Table 3. Similar data for the concrete arch shelter appears in Table 4. Definitions of terms and symbols used in the tables are provided in Appendix B.

TABLE 2. RESOURCE REQUIREMENTS FOR REINFORCED CONCRETE RECTANGULAR SHELTER - 500 PERSON CAPACITY†

Activity Description	Burial Option	Unit	Crew Type	Output (Units/Day)	Material/Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Incld. O&P ($)
I. <u>Earthwork</u>														
Site Clearance	1 & 2	Acre	B-7	0.7	535.00E	755.00	1290.00	1650.00	0.5	5	268	378	646	825
	#3	Acre	B-7	0.7	535.00E	755.00	1290.00	1650.00	0.7	8	375	529	904	1,155
Grub & Stump Removal	1 & 2	Acre	B-30	2.0	350.00E	140.00	490.00	580.00	0.5	2	175	70	245	290
	#3	Acre	B-30	2.0	350.00E	140.00	490.00	580.00	0.7	3	245	98	343	406
Granular Fill	1,2 & 3	S.F.	B-14	9000.0	.10E	0.07	0.17	0.21	5,241.0	5	524	367	891	1,101
Excavation	#1	C.Y.	B-10 0	760.0	0.39E	0.20	0.59	0.71	4,028.0	43	1,571	806	2,377	2,860
	#2	C.Y.	B-10 0	760.0	0.39E	0.20	0.59	0.71	2,135.0	23	833	427	1,260	1,516
	#3	C.Y.	B-10 0	760.0	0.39E	0.20	0.59	0.71	666.0	7	260	133	393	473
Back Fill (Machine)	#1	C.Y.	B-10D	510.0	0.75E	0.29	1.04	1.24	1,732.0	27	1,299	502	1,801	2,148
	#2	C.Y.	B-10D	510.0	0.75L	0.29	1.04	1.24	1,607.0	25	1,205	466	1,671	1,993
	#3	C.Y.	B-10D	510.0	0.75E	0.29	1.04	1.24	3,598.0	56	2,699	1,043	3,742	4,462
Back Fill (Hand)	#1	C.Y.	1CLAB	12.0	0	6.95	6.95	9.75	387.0	258	0	2,690	2,690	3,773
	#2	C.Y.	1CLAB	12.0	0	6.95	6.95	9.75	528.0	352	0	3,670	3,670	5,148
	#3	C.Y.	1CLAB	12.0	0	6.95	6.95	9.75	987.0	658	0	6,860	6,860	9,623
Tamping (Air)	#1	C.Y.	B-9	165.0	0.54E	2.55	3.09	4.17	387.0	19	209	987	1,196	1,614
	#2	C.Y.	B-9	165.0	0.54E	2.55	3.09	4.17	528.0	26	285	1,347	1,632	2,202
	#3	C.Y.	B-9	165.0	0.54E	2.55	3.09	4.17	987.0	48	533	2,517	3,050	4,116
II. <u>Concrete and Reinforcements</u>														
(1) Concrete														
Exterior Footing	1,2 & 3	C.Y.	C-14	105.0	47.00M	33.00	80.00	97.00	21.2	2	996	699	1,695	2,055
Interior Footing	1,2 & 3	C.Y.	C-14	105.0	47.00M	33.00	80.00	97.00	23.3	2	1,095	769	1,863	2,259
Lxterior Walls	1,2 & 3	C.Y.	C-14	31.1	66.00M	120.50	186.50	237.50	73.6	19	4,856	8,869	13,725	17,480
Interior Walls	1,2 & 3	C.Y.	C-14	20.0	76.00M	185.50	261.50	331.50	62.8	25	4,773	11,649	16,422	20,818
Walls(Finishing)	1,2 & 3	S.F.	1 CEFI	540.0	0.01E	0.19	0.20	0.27	12,544.0	186	125	2,383	2,509	3,387
Floor System (Casting)	1,2 & 3	C.Y.	C-14	123.0	41.00M	28.00	69.00	84.00	55.9	4	2,292	1,565	3,857	4,696

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

(Continued)

TABLE 2. RESOURCE REQUIREMENTS FOR REINFORCED CONCRETE RECTANGULAR SHELTER - 500 PERSON CAPACITY (Continued)†

Activity Description	Burial Option	Unit	Crew Type	Output (Units/Day)	Material/Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Includ. O&P ($)
Floor System (Finishing)	1,2 & 3	S.F.	C-9	725.0	0.00	0.17	0.17	0.22	5,241.0	58	0	891	891	1,153
Roof Slab (Casting)	1,2 & 3	S.F.	C-11	2400.0	3.13M	0.65	3.78	4.35	5,241.0	18	16,404	3,407	19,811	22,798
Roof Slab (Lifting)	1,2 & 3	S.F.						1.29	5,241.0	2				6,761
(2) Reinforcements														
*Welded Wire Fabric	1,2 & 3	CSF							45.8					
*Walls and Footings	1,2 & 3	Tons							15.9					
Roof Slab	1,2 & 3	Tons	4 Rodman	3.6	345.00M	125.00	470.00	565.00	38.6	86	13,316	4,825	18,141	21,808
III. Water Proofing														
Vapor Barrier	1,2 & 3	CSF	1 CARP	37.0	1.50M	2.85	4.35	5.60	45.8	10	69	130	199	256
Exterior	1,2 & 3	CSF	1 CARP	37.0	2.30M	2.85	5.15	6.50	81.1	18	186	231	417	527
Drain Tile	1,2 & 3	L.F.	B-20	400.0	1.20M	0.81	2.01	2.45	308.0	6	370	250	619	755
Porous Fill	1,2 & 3	C.Y.	B-14	220.0	5.25M	2.85	8.10	9.65	11.4	1	60	33	93	110

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

*Cost included in Section II.

NOTE: See Tables 11, 12, and 13 for details of entranceways, electrical, and mechanical resource requirements.

TABLE 3. RESOURCE REQUIREMENTS FOR REINFORCED CONCRETE RECTANGULAR SHELTER - 1,000 PERSON CAPACITY†

Activity Description	Burial Option	Unit	Crew Type	Output (Units/Day)	Material/Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Includ. O&P ($)
I. Earthwork														
Site Clearance	1 & 2	Acre	B-7	0.7	535.00E	755.00	1290.00	1650.00	0.7	8	375	529	903	1,155
	3	Acre	B-7	0.7	535.00E	755.00	1290.00	1650.00	1.0	11	535	755	1,290	1,650
Grub & Stump Removal	1 & 2	Acre	B-30	2.0	350.00E	140.00	490.00	580.00	0.7	3	245	98	343	406
	3	Acre	B-30	2.0	350.00E	140.00	490.00	580.00	1.0	4	350	140	490	580
Granular Fill	1,2 & 3	S.F.	B-14	9000.0	0.10E	0.07	0.17	0.21	10,414.0	10	1,041	729	1,770	2,187
Excavation	#1	C.Y.	B-10 0	760.0	0.39E	0.20	0.59	0.71	7,198.0	76	2,807	1,440	4,247	5,110
	#2	C.Y.	B-10 0	760.0	0.39E	0.20	0.59	0.71	3,605.0	38	1,406	721	2,127	2,560
	#3	C.Y.	B-10 0	760.0	0.39E	0.20	0.59	0.71	1,277.0	14	498	255	753	907
Back Fill (Machine)	#1	C.Y.	B-10D	510.0	0.75E	0.29	1.04	1.24	2,756.0	43	2,067	799	2,866	3,417
	#2	C.Y.	B-10D	510.0	0.75E	0.29	1.04	1.24	2,715.0	43	2,036	787	2,823	3,367
	#3	C.Y.	B-10D	510.0	0.75E	0.29	1.04	1.24	5,155.0	81	3,866	1,495	5,361	6,392
Back Fill (Hand)	#1	C.Y.	1CLAB	12.0	--	6.95	6.95	9.75	649.0	433	--	4,511	4,511	6,328
	#2	C.Y.	1CLAB	12.0	--	6.95	6.95	9.75	890.0	593	--	6,186	6,186	8,678
	#3	C.Y.	1CLAB	12.0	--	6.95	6.95	9.75	1,395.0	930	--	9,695	9,695	13,601
Tamping (Air)	#1	C.Y.	B-9	165.0	0.54E	2.55	3.09	4.17	649.0	32	350	1,655	2,005	2,706
	#2	C.Y.	B-9	165.0	0.54E	2.55	3.09	4.17	890.0	43	480	2,270	2,750	3,711
	#3	C.Y.	B-9	165.0	0.54E	2.55	3.09	4.17	1,395.0	68	753	3,557	4,310	5,817
II. Concrete and Reinforcements														
(1) Concrete														
Exterior Footing	1,2 & 3	C.Y.	C-14	105.0	47.00M	33.00	80.00	97.00	30.7	2	1,443	1,013	2,456	2,978
Interior Footing	1,2 & 3	C.Y.	C-14	105.0	47.00M	33.00	80.00	97.00	19.9	2	935	657	1,592	1,930
Exterior Walls	1,2 & 3	C.Y.	C-14	31.1	66.00M	120.50	186.50	237.50	104.9	27	6,923	12,641	19,564	24,914
Interior Walls	1,2 & 3	C.Y.	C-14	20.0	76.00M	185.50	261.50	331.50	136.3	55	10,359	25,284	35,643	45,184
Walls(Finishing)	1,2 & 3	S.F.	1 CEFI	540.0	0.01M	0.19	0.20	0.27	23,808.0	353	238	4,524	4,762	6,428
Floor System (Casting)	1,2 & 3	C.Y.	C-14	123.0	41.00M	28.00	69.00	84.00	116.6	8	4,781	3,265	8,046	9,794

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

(Continued)

TABLE 3. RESOURCE REQUIREMENTS FOR REINFORCED CONCRETE RECTANGULAR SHELTER - 1,000 PERSON CAPACITY (Continued)†

Activity Description	Burial Option	Unit	Crew Type	Output (Units/ Day)	Material/ Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/ Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Includ. O&P ($)
Floor System (Finishing)	1,2 & 3	S.F.	C-9	725.0	0.00M	0.17	0.17	0.22	10,414.0	115	0	1,770	1,770	2,291
Roof Slab (Casting)	1,2 & 3	S.F.	C-11	2,400.0	3.13M	0.65	3.78	4.35	10,414.0	35	32,595	6,770	39,365	45,300
Roof Slab (Lifting)	1,2 & 3	S.F.	C-8					1.29	10,414.0	2				13,434
(2) Reinforcements														
*Welded Wire Fabric	1,2 & 3	CSF							95.4					
*Walls and Footings	1,2 & 3	Tons							28.3					
Roof Slab	1,2 & 3	Tons	4 Rodman	3.6	345.00M	125.00	470.00	565.00	75.4	168	26,019	9,427	35,446	42,611
III. Water Proofing														
Vapor Barrier	1,2 & 3	CSF	1 CARP	37.0	1.50M	2.85	4.35	5.60	95.4	21	143	272	415	534
Exterior	1,2 & 3	CSF	1 CARP	37.0	2.30M	2.85	5.15	6.50	145.4	31	334	414	748	945
Drain Tile	1,2 & 3	L.F.	B-20	400.0	1.20M	0.81	2.01	2.45	436.0	9	523	353	876	1,068
Porous Fill	1,2 & 3	C.Y.	B-14	220.0	5.25M	2.85	8.10	9.65	16.2	1	85	46	131	156

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

*Cost included in section II.

NOTE: See Tables 11, 12, and 13 for details of entranceways, electrical, and mechanical resource requirements.

TABLE 4. RESOURCE REQUIREMENTS FOR REINFORCED CONCRETE ARCH SHELTER - 500 PERSON CAPACITY†

Activity Description	Burial Option	Unit	Crew Type	Output (Units/Day)	Material/Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Includ. O&P ($)
I. Earthwork														
Site Clearance	1 & 2	Acre	B-7	0.7	535.00E	755.00	1290.00	1650.00	0.6	7	321	453	774	990
	3	Acre	B-7	0.7	535.00E	755.00	1290.00	1650.00	1.2	14	642	906	1,548	1,980
Grub and Stump Removal	1 & 2	Acre	B-30	2.0	350.00E	140.00	490.00	580.00	0.6	3	210	84	294	348
	3	Acre	B-30	2.0	350.00E	140.00	490.00	580.00	1.2	5	420	168	588	696
Granular Fill	1,2 & 3	C.Y.	B-14	9,000.0	0.10M	0.07	0.17	0.21	1,863.0	2	186	130	316	391
Excavation (Machine)	#1	C.Y.	B-10 O	760.0	0.39E	0.20	0.59	0.71	7,047.0	74	2,748	1,409	4,158	5,003
	#2	C.Y.	B-10 O	760.0	0.39E	0.20	0.59	0.71	4,600.0	48	1,794	920	2,714	3,266
	#3	C.Y.	B-10 O	760.0	0.39E	0.20	0.59	0.71	475.0	5	185	95	280	337
Back Fill (Machine)	#1	C.Y.	B-10D	510.0	0.75E	0.29	1.04	1.24	4,435.0	70	3,326	1,286	4,611	5,498
	#2	C.Y.	B-10D	510.0	0.75E	0.29	1.04	1.24	3,428.0	54	2,571	994	3,565	4,250
	#3	C.Y.	B-10D	510.0	0.75E	0.29	1.04	1.24	15,897.0	249	11,923	4,610	16,533	19,712
Back Fill (Hand)	#1	C.Y.	1CLAB	12.0	--	6.95	6.95	9.75	953.0	635	--	6,630	6,630	9,302
	#2	C.Y.	1CLAB	12.0	--	6.95	6.95	9.75	1,172.0	781	--	8,145	8,145	11,427
	#3	C.Y.	1CLAB	12.0	--	6.95	6.95	9.75	2,351.0	1,567	--	16,340	16,340	22,922
Tamping (Air)	#1	C.Y.	B-9	165.0	0.546E	2.55	3.09	4.17	953.0	46	515	2,430	2,945	3,975
	#2	C.Y.	B-9	165.0	0.546E	2.55	3.09	4.17	1,172.0	57	633	2,989	3,622	4,887
	#3	C.Y.	B-9	165.0	0.546E	2.55	3.09	4.17	2,351.0	114	1,270	5,995	7,265	9,804
II. Concrete and Reinforcements														
(1) Concrete														
Interior Walls	1,2 & 3	S.F.	C-11	464.0	6.40M	1.89	8.29	10.28	648.0	11	4,147	1,225	5,372	6,661
Column Footing	1,2 & 3	C.Y.	C-14	55.2	55.00M	65.00	120.00	145.00	6.35	1	349	413	762	921
Arch Footing	1,2 & 3	C.Y.	C-14	125.0	50.00M	28.00	78.00	95.00	61.4	4	3,070	1,720	4,790	5,833
Endwall Footing	1,2 & 3	C.Y.	C-14	105.0	47.00M	33.00	80.00	97.00	11.7	1	550	386	936	1,135
End Walls	1,2 & 3	C.Y.	C-14	23.7	77.00M	144.00	221.00	283.00	30.4	11	2,341	4,378	6,718	8,603
Floor (Int) Cast.	1,2 & 3	S.F.	C-11	2,400.0	1.85M	0.54	2.39	2.80	1,863.0	7	3,447	1,006	4,453	5,216
Lift.								1.29						2,403
Floor (Int) Finishing	1,2 & 3	S.F.	C-9	725.0	--	0.17	0.17	0.22	1,863.0	21	--	317	317	410

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

(Continued)

TABLE 4. RESOURCE REQUIREMENTS FOR REINFORCED CONCRETE ARCH SHELTER - 500 PERSON CAPACITY (Continued)†

Activity Description	Burial Option	Unit	Crew Type	Output (Units/Day)	Material Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Includ. O&P ($)
Floor System (Casting)	1,2 & 3	C.Y.	C-14	123.0	41.00M	28.00	69.00	84.00	33.9	3	1,390	949	2,339	2,848
Floor System (Finishing)	1,2 & 3	S.F.	C-9	725.0	0.00	0.17	0.17	0.22	2835.0	31	0	482	482	624
Shell (Forms)	1,2 & 3	S.F.	C-2	390.0	0.63	1.35	1.98	2.55	5415.0	111	3,412	7,290	10,702	13,800
Shell (Structure)	1,2 & 3	S.F.	C-16	325.0	1.98	2.69	4.67	6.73	5415.0	134	11,328	14,553	25,881	36,425
Columns	1,2 & 3	C.Y.	C-14	18.7	100.00M	187.00	287.00	365.00	8.1	4	810	1,515	2,325	2,957
(2) Reinforcements														
Welded Wire Fabric	1,2 & 3	CSF	2 Rodman	39.0	11.07M	7.80	18.87	24.00	28.4	6	314	221	535	680
*Deformed Bars	1,2 & 3	Tons							12.8					
*Walls	1,2 & 3	Tons							9.2					
III. Water Proofing														
Vapor Barrier	1,2 & 3	CSF	1 CARP	37.0	1.50M	2.85	4.35	5.60	29.1	6	44	83	127	163
Exterior	1,2 & 3	CSF	1 CARP	37.0	2.30M	2.85	5.15	6.50	55.7	12	128	159	287	362
Drain Tile	1,2 & 3	L.F.	B-20	400.0	1.20M	0.81	2.01	2.45	258.5	5	310	210	520	633
Porous F..l	1,2 & 3	C.Y.	B-14	220.0	5.25M	2.85	8.10	9.65	9.6	1	50	28	78	93

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

*Costs included in Section II.

NOTE: See Tables 11, 12, and 13 for details of entranceways, electrical, and mechanical resource requirements.

B. The Steel Arch Shelter

The major difference between the steel arch (Type 4) and the concrete arch shelter is the construction material for the arch. For resisting an incident overpressure of 50 psi, a 0.5-inch-thick steel plate is used for the shell. The sections are considered to be preformed and strengthened by ribs and longitudinal stiffeners; all connections are assumed to be of the bolted type. The shell is assumed to be mounted on footings with anchors. Considerations regarding earthwork, waterproofing, and concrete and reinforcements for floors, footings, and columns are identical to those for reinforced concrete arch shelters. Table 5 gives the resource requirements and costs for the steel arch shelters.

C. The Steel Dome Shelter

For shelter Type 5, construction activities break down to two major categories: earthwork and structural.

1. Earthwork

Estimates of resource requirements for site clearance, ground preparation, and excavation were based on considerations identical to those for the three concrete shelters. These are described in Section III.A.1. Backfill estimates were computed by subtracting the structure volume from the excavation volume. We assumed that the area just above the steel dome would be covered by hand backfill, and machine backfill would be used for the remaining portion.

2. Structural

One cost estimate for the steel dome shelter appears in Blast Shelter Concept II [Ref. 6], and is shown in Table 6. RTI contacted a steel fabricator to obtain a separate estimate for the total manufacturing cost of the end caps and obtained independent estimates of the other costs from the

TABLE 5. RESOURCE REQUIREMENTS FOR STEEL ARCH SHELTER - 500 PERSON CAPACITY†

Activity Description	Burial Option	Unit	Crew Type	Output (Units/Day)	Material/Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Includ. O&P ($)
I. Earthwork														
Site Clearance	1 & 2	Acre	B-7	0.7	535.00E	755.00	1290.00	1650.00	0.6	7	321	453	774	990
	3	Acre	B-7	0.7	535.00E	755.00	1290.00	1650.00	1.2	14	642	906	1,548	1,980
Grub and Stump Removal	1 & 2	Acre	B-30	2.0	350.00E	140.00	490.00	580.00	0.6	3	210	84	294	348
	3	Acre	B-30	2.0	350.00E	140.00	490.00	580.00	1.2	5	420	168	588	696
Granular Fill	1,2 & 3	C.Y.	B-14	9,000.0	0.10M	0.07	0.17	0.21	1,863.0	2	186	130	316	391
Excavation (Machine)	#1	C.Y.	B-10 O	760.0	0.39E	0.20	0.59	0.71	7,047.0	74	2,748	1,409	4,158	5,003
	#2	C.Y.	B-10 O	760.0	0.39E	0.20	0.59	0.71	4,600.0	48	1,794	920	2,714	3,266
	#3	C.Y.	B-10 O	760.0	0.39E	0.20	0.59	0.71	475.0	5	185	95	280	337
Back Fill (Machine)	#1	C.Y.	B-10D	510.0	0.75E	0.29	1.04	1.24	4,435.0	70	3,326	1,286	4,611	5,498
	#2	C.Y.	B-10D	510.0	0.75E	0.29	1.04	1.24	3,428.0	54	2,571	994	3,565	4,250
	#3	C.Y.	B-10D	510.0	0.75E	0.29	1.04	1.24	15,897.0	249	11,923	4,610	16,533	19,712
Back Fill (Hand)	#1	C.Y.	1CLAB	12.0	--	6.95	6.95	9.75	953.0	635	--	6,630	6,630	9,302
	#2	C.Y.	1CLAB	12.0	--	6.95	6.95	9.75	1,172.0	781	--	8,145	8,145	11,427
	#3	C.Y.	1CLAB	12.0	--	6.95	6.95	9.75	2,351.0	1,567	--	16,340	16,340	22,922
Tamping (Air)	#1	C.Y.	B-9	165.0	0.546	2.55	3.09	4.17	953.0	46	515	2,430	2,945	3,975
	#2	C.Y.	B-9	165.0	0.546	2.55	3.09	4.17	1,172.0	57	633	2,989	3,622	4,887
	#3	C.Y.	B-9	165.0	0.546	2.55	3.09	4.17	2,351.0	114	1,270	5,995	7,265	9,804
II. Concrete and Reinforcements														
(1) Concrete														
Interior Walls	1,2 & 3	S.F.	C-11	464.0	6.40M	1.89	8.29	10.28	648.0	11	4,147	1,225	5,372	6,661
Column Footing	1,2 & 3	C.Y.	C-14	55.2	55.00M	65.00	120.00	145.00	6.35	1	349	413	762	921
Arch Footing	1,2 & 3	C.Y.	C-14	125.0	50.00M	28.00	78.00	95.00	61.4	4	3,070	1,720	4,790	5,833
Endwall Footing	1,2 & 3	C.Y.	C-14	105.0	47.00M	33.00	80.00	97.00	11.7	1	550	386	936	1,135
End Walls	1,2 & 3	C.Y.	C-14	23.7	77.00M	144.00	221.00	283.00	30.4	11	2,341	4,378	6,718	8,603
Floor (Int) Cast. Lift.	1,2 & 3	S.F.	C-11	2,400.0	1.85M	0.54	2.39	2.80 1.29	1,863.0	7	3,447	1,006	4,453	5,216 2,403
Floor (Int) Finishing	1,2 & 3	S.F.	C-9	725.0	--	0.17	0.17	0.22	1,863.0	21	--	317	317	410

(Continued)

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

TABLE 5. RESOURCE REQUIREMENTS FOR STEEL ARCH SHELTER - 500 PERSON CAPACITY (Continued)†

Activity Description	Burial Option	Unit	Crew Type	Output (Units/Day)	Material Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Includ. O&P ($)
Floor System (Casting)	1,2 & 3	C.Y.	C-14	123.0	41.00M	28.00	69.00	84.00	33.9	3	1,390	949	2,339	2,848
Floor System (Finishing)	1,2 & 3	S.F.	C-9	725.0	0.00	0.17	0.17	0.22	2,835.0	31	0	482	482	624
Shell	1,2 & 3	each	S-2	10.17	756.32M	251.41	1007.73	1108.62	71.2	56	53,850	17,900	71,750	78,935
Columns	1,2 & 3	C.Y.	C-14	18.7	100.00M	187.00	287.00	365.00	8.1	4	810	1,515	2,325	2,957
(2) Reinforcements														
Welded Wire Fabric	1,2 & 3	CSF	2 Rodman	39.0	11.07M	7.80	18.87	24.00	92.0	19	1,018	718	1,736	2,208
*Deformed Bars	1,2 & 3	Tons							9.1					
*Walls	1,2 & 3	Tons							9.2					
III. Water Proofing														
Vapor Barrier	1,2 & 3	CSF	1 CARP	37.0	1.50M	2.85	4.35	5.60	29.1	6	44	83	127	163
Exterior	1,2 & 3	CSF	1 CARP	37.0	2.30M	2.85	5.15	6.50	55.7	12	128	159	287	362
Drain Tile	1,2 & 3	L.F.	B-20	400.0	1.20M	0.81	2.01	2.45	258.5	5	310	210	520	633
Porous Fill	1,2 & 3	C.Y.	B-14	220.0	5.25M	2.85	8.10	9.65	9.6	1	50	28	78	93

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

*Costs included in Section II.

NOTE: See Tables 11, 12, and 13 for details of entranceways, electrical, and mechanical resource requirements.

TABLE 6. MATERIALS AND COSTS FOR STEEL DOME SHELTER (CAPACITY 20)

Material	Pounds
Shelter Shell	2,250
End Caps	470
Access Tunnels	200
Vertical Shafts	570
Accessories	220
Blast Valves	150
TOTAL MATERIALS	3,860

Costs	Dollars
Material Cost	1,110
Labor, Burden G & A (except charges for plant and equipment)	490
Distribution	250
Fixed Charges: Plant & Equipment fully Absorbed	33
Excavation	420
TOTAL COSTS	2,303

standard reference texts. A summary of the resource requirements and their costs as estimated by RTI for the steel dome shelter is given in Table 7. These costs are substantially higher than the costs given in Table 6 but are felt to be much more representative of the true construction costs.

D. The Small Pole Shelter - Lumber Version

Construction activities for the small pole shelter were divided into four basic categories: earthwork, structural, waterproofing, and ventilation. The resource requirements and costs associated with each of these categories were then computed using the procedure outlined at the beginning of this chapter. Calculations were made under the assumption that all shelters of this type would be constructed in the fully buried condition. The estimates of resource requirements and costs are given in Table 8.

1. Earthwork

The earthwork for this shelter consists of site clearance, excavation, and backfill. For estimation purposes, it was assumed that the terrain for the shelter sites would be lightly wooded. Site clearance work was therefore classified as light and includes removal of trees and shrubbery and clearing of stumps. It does not allow for large-scale earth moving or clearing of heavily wooded areas. Both excavation and backfill for this shelter was considered to be accomplished by hand.

2. Structural

All structural members of this shelter design are lumber. Prices were estimated based on the use of treated lumber.

3. Waterproofing

All waterproofing is to be accomplished by the use of polyethylene sheeting. Rainproofing over the shelter consists of a 0.006-inch polyethylene sheet and in addition, a 0.004-in. vapor barrier is placed beneath the lumber floor of the shelter.

TABLE 7. RESOURCE REQUIREMENTS FOR STEEL DOME SHELTER - 20 PERSON CAPACITY†

Activity Description	Burial Option	Unit	Crew Type	Output (Units/Day)	Material/Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Includ. O&P ($)
I. Earthwork														
Site Clearance	#1	Acre	B-7	0.7	535.00E	755.00	1,290.00	1650.00	0.14	2	75.00	105.00	180.00	231.00
Grub and Stump Removal	#1	Acre	B-30	2.0	350.00L	140.00	490.00	580.00	0.14	1	49.00	20.00	69.00	82.00
Excavation	#1	C.Y.	B-10 O	760.0	0.39E	0.20	0.59	0.71	171.00	2	67.00	34.00	101.00	121.00
Back Fill (Machine)	#1	C.Y.	B-10D	510.0	0.75L	0.29	1.04	1.24	85.00	1	64.00	25.00	89.00	105.00
Back Fill (Hand)	#1	C.Y.	1CLAB	12.0	0	6.95	6.95	9.75	39.00	26	0	271.00	271.00	380.00
Tamping (Air)	#1	C.Y.	B-9	165.0	0.54L	2.55	3.09	4.17	39.00	2	21.00	100.00	121.00	163.00
II. Components														
Shell (1)	#1	L.F.	B-13	30.0	59.00ME	20.00	79.00	92.00	30.00	8	1,770.00	600.00	2,370.00	2,760.00
End Caps (2)	#1	lbs							470.00				300.00	350.00
Access Tunnel (2)	#1	L.F.	B-21	120.0	10.50M	3.55	14.05	16.30	6.67	1	70.00	24.00	94.00	109.00
Vertical Shafts (2)	#1	L.F.	B-13	120.0	11.00M	7.65	18.65	21.58	22.17	2	244.00	170.00	414.00	492.00

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

TABLE 8. RESOURCE REQUIREMENTS FOR LUMBER SHELTER - 12 PERSON CAPACITY†

Activity Description	Burial Option	Unit	Crew Type	Output (Units/Day)	Material Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Includ. O&P ($)
I. <u>Earthwork</u>														
Site Clearance	#1	S.Y.	1CLAB	280.00	0	0.30	0.30	0.42	42.0	1.2	0	13	13	18
Excavation (Hand)	#1	C.Y.	1CLAB	4.00	0	21.00	21.00	29.00	32.0	64.0	0	672	672	928
Back Fill (Hand)	#1	C.Y.	1CLAB	12.00	0	6.95	6.95	9.75	66.7	45.0	0	464	464	651
Tamping (Hand)	#1	C.Y.	1CLAB	20.60	0	4.05	4.05	5.65	66.7	26.0	0	270	270	377
II. <u>Structure</u>														
Roof	#1	S.F.	F-2	250.00	2.25M	0.88	3.13	3.70	86.0	3.0	194	76	270	318
Joist	#1	MFBM	F-2	1.40	450.00M	160.00	610.00	710.00	0.13	1.0	59	21	80	93
Sills	#1	MFBM	F-2	0.78	395.00M	285.00	680.00	825.00	0.03	0.4	13	10	23	28
Frame	#1	MFBM	F-2	1.05	445.00M	210.00	655.00	780.00	0.14	1.0	61	29	90	107
Walls	#1	S.F.	F-2	250.00	2.25M	0.88	3.13	3.70	394.45	13.0	888	347	1235	1460
Studs	#1	MFBM	F-2	1.05	445.00M	210.00	655.00	780.00	0.41	3.0	184	87	271	323
Benches														
Frame	#1	MFBM	F-2	0.70	360.00M	315.00	675.00	830.00	0.17	2.0	61	54	115	141
Platform	#1	MFBM	F-2	1.25	390.00M	175.00	565.00	670.00	0.10	0.6	39	18	57	67
III. <u>Waterproofing</u>														
Exterior	#1	CSF	1CARP	37.00	2.30M	2.85	5.15	6.50	4.19	1.0	10	12	22	27
Vapor Barrier	#1	CSF	1CARP	37.00	1.50M	2.85	4.35	5.60	0.99	0.2	2	3	5	6
IV. <u>Ventilation</u>														
Kearny Air Pump	#1	Each		16.00	60.77M	12.50	73.27	80.60	1.00	0.5	61	13	74	81

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

4. Ventilation

Ventilation for this shelter can be provided by a single Kearny pump, which is a manually powered air pump that can be built of generally available materials. The resource requirements for this device are included in Table 8.

E. Additional Data

Four tables provide further data on resources for the various shelters and their costs. Table 9 shows entranceway components and the costs for the materials and labor to build them. These requirements vary with the burial condition of the shelter. Table 10 gives similar data for all the electrical items needed to supply a 500-person shelter. The mechanical equipment breakdown (for ventilation and plumbing) for a 500-capacity shelter appears in Table 11 and a final summary of shelter costs for the six shelters has been compiled in Table 12. These total cost figures are the ones that were used to compute the cost of surge period shelter construction.

The construction time for each shelter type was calculated by drawing critical path diagrams. To shorten critical activity times to reasonable lengths, we assumed that multiple sets of standard construction crews would be employed. The total time required to build each shelter was calculated for both single-shift and three-shift operations. Allowances were made for lower efficiency during a three-shift operation. The construction time data are given in Table 13.

TABLE 9. RESOURCE REQUIREMENTS FOR ENTRANCEWAYS

Activity Description	Burial Option	Unit	Crew Type	Output (Units/Day)	Material/Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Includ. O&P ($)
Passageway	#1	Lin.Ft	B-13	30.00	32.00M	28.75	60.75	71.00	34	9	1,088	978	2,066	2,414
	#2 & 3	Lin.Ft	B-13	30.00	32.00M	28.75	60.75	71.00	29	7	928	834	1,762	2,059
Steel Stairs (Incld. Treads, Risers, Carriers, & Metal Pipe Handrails)	#1	Lin.Ft	E-4	30.00	60.00M	10.85	70.85	83.00	15	4	900	163	1,063	1,245
Interior Door	1,2 & 3	Each	2CARP	4.30	110.00M	49.00	159.00	190.00	1	2	110	49	159	190
Bulkhead	1,2 & 3	Each							1					1,100
Exterior Door	1,2 & 3	Each	2SSWK	1.50	220.00M	98.00	318.00	380.00	1	5	220	98	318	380
Blast Door	1,2 & 3	Each	2SSWK	1.50	500.00M	150.00	650.00	750.00	1	5	500	150	650	750

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

TABLE 10. ELECTRICAL ITEMS FOR 500 MAN SHELTER†

Activity Description	Unit	Crew Type	Output (Units/ Day)	Material Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/ Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Includ. O&P ($)
I. <u>Lighting</u>													
(a) Sleeping area													
100W incandescent fixture	Each	1Elec	8.00	25.00	14.85	39.85	48.00	6.00	6.00	150.00	89.10	239.10	288.00
Wiring, 200 ft. 2 #12,	CLF	1Elec	11.00	3.30	9.15	12.45	16.45	2.00	1.46	6.60	18.30	24.90	32.90
0.5 in. conduit and	LF	1Elec	100.00	0.48	1.19	1.67	2.20	200.00	16.00	96.00	238.00	334.00	440.00
switches	Each	1Elec	16.00	4.25	7.45	11.70	15.00	6.00	3.00	25.50	44.70	70.20	90.00
(b) Administrative area													
40W Fluorescent fixture	Each	1Elec	5.70	30.00	21.00	51.00	62.00	2.00	2.81	60.00	42.00	102.00	124.00
Wiring 50 ft. 2 #12,	CLF	1Elec	11.00	3.30	9.15	12.45	16.45	0.50	0.37	1.65	4.58	6.23	8.23
0.5 in. conduit and	LF	1Elec	100.00	0.48	1.19	1.67	2.20	50.00	4.00	24.00	59.50	83.50	110.00
switches	Each	1Elec	16.00	4.25	7.45	11.70	15.00	2.00	1.00	8.50	14.90	23.40	30.00
(c) Living area													
100W incandescent fixture	Each	1Elec	8.00	25.00	14.85	39.85	48.00	6.00	6.00	150.00	89.10	239.10	288.00
Wiring 180 ft. 2 #12,	CLF	1Elec	11.00	3.30	9.15	12.45	16.45	1.80	1.31	5.94	16.47	22.41	29.61
0.5 in. conduit and	LF	1Elec	100.00	0.48	1.19	1.67	2.20	180.00	14.40	86.40	214.20	300.60	396.00
switches	Each	1Elec	16.00	4.25	7.45	11.70	15.00	6.00	3.00	25.50	44.70	70.20	90.00
(d) Storage & Toilet area													
100W incandescent fixture	Each	1Elec	8.00	25.00	14.85	39.85	48.00	4.00	4.00	100.00	59.40	159.40	192.00
Wiring, 200 ft. 2 #12,	CLF	1Elec	11.00	3.30	9.15	12.45	16.45	2.00	1.45	6.60	18.30	24.90	32.90
0.5 in. conduit and	LF	1Elec	100.00	0.48	1.19	1.67	2.20	200.00	16.00	96.00	238.00	334.00	440.00
switches	Each	1Elec	16.00	4.25	7.45	11.70	15.00	4.00	2.00	17.00	29.80	46.80	60.00
II. <u>Outlets</u>													
(a) Food warming outlets	Each	1Elec	20.00	0.55	5.95	6.50	8.95	3.00	1.20	1.65	17.85	19.50	26.85
(b) Wiring, 300 ft. #12	CLF	1Elec	11.00	3.30	9.15	12.45	16.45	3.00	2.19	9.90	27.45	37.35	49.35
(c) Conventional outlets and	Each	1Elec	20.00	0.55	5.95	6.50	8.95	5.00	2.00	2.75	29.75	32.50	44.75
wiring, #12	CLF	1Elec	11.00	3.30	9.15	12.45	16.45	0.50	0.37	1.65	4.58	6.23	8.23
III. <u>Wiring for Mech Equip</u>.													
(a) Power wiring for 2 to 5 HP	Each	1Elec	3.30	8.00	36.00	44.00	59.00	1.00	2.43	8.00	36.00	44.00	59.00
motors and disconnect switches	Each						85.00	2.00					170.00

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

(Continued)

TABLE 10. ELECTRICAL ITEMS FOR 500 MAN SHELTER (Continued)†

Activity Description	Unit	Crew Type	Output (Units/Day)	Material Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs.)	Material/Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Includ. O&P ($)
IV. Service													
(a) Wiring, 25 ft., 2 Sets of 4-300 MCM in 2-3 in. Conduit	CLF	1 Elec	2.70	57.00	44.00	101.00	125.00	0.5	1.50	28.50	22.00	50.50	62.50
and service leads	LF	1 Elec	35.00	2.60	3.39	5.99	7.60	50.0	11.43	130.00	169.50	299.50	380.30
(b) Power Service Switchboard	Each	1 Elec	0.50	930.00	240.00	1,170.00	1,350.00	1.0	16.00	930.00	240.00	1,170.00	1,350.00
			0.75	210.00	160.00	370.00	455.00	1.0	10.67	210.00	160.00	370.00	455.00
(c) Lighting panel, 18 Circuit panel	Each	1 Elec											
Feeder	L.F.	1 Elec					6.5	40.0	2.0				260.00
V. Additional Wiring for Duct Heater													
(a) Power wiring for 130 kW duct heater, power panel (14-60 amp	L.F.	1 Elec	190.00	3.60M	0.63	4.23	4.85	30.0	1.26	108.00	19.00	127.00	146.00
switches and 4-60 amp blanks in panel)	Each	1 Elec	0.75	210.00M	160.00	370.00	455.00	1.0	10.67	210.00	160.00	370.00	455.00
								1.0					
(b) 14 disconnect switches	Each	1 Elec	2.30	31.00M	52.00	83.00	105.00	14.0	48.70	434.00	728.00	1,162.00	1,470.00
(c) Wiring front panel to heater, 40 ft.	L.F.	1 Elec	190.00	3.60M	0.63	4.23	4.85	40.0	1.68	144.00	25.00	169.00	194.00

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

TABLE 11. MECHANICAL EQUIPMENT FOR 500 MAN SHELTER†

Activity Description	Unit	Crew Type	Output (Units/Day)	Material/Equipment Cost ($/Unit)	Labor Cost ($/Unit)	Total Cost ($/Unit)	Total Cost Incld.O&P ($/Unit)	Quantity Required (Units)	Time Reqd. (Crew Hrs)	Material/Equipment Cost ($)	Labor Cost ($)	Total Cost ($)	Total Cost Incld. O&P ($)	Index
I. **Ventilation**														
a. 5 H.P. Forced Air Supply Fan with filter section	Each	Q-20	2.8	1,420.00M	96.00	1,516.00	1,700.00	1	2.86	1,420.00	96.00	1,516.00	1,700.00	
b. Supply air duct work	Lot					1,100.00*		1				2,318.00	2,898.00	2.107
c. Diffusers and registers	Lot					400.00*		1				843.00	1,059.00	2.107
d. Air filters	Lot					75.00*		1				158.00	198.00	2.107
e. Fresh air intake with exhaust hatch	Lot					2,000.00*		1				4,214.00	5,268.00	2.107
f. H.P. forced exhaust fan	Each	Q-20	3.4	1,250.00M	79.00	1,329.00	1,475.00	1	2.35	1,250.00	79.00	1,329.00	1,475.00	
g. Forced exhaust fan duct work	Each					500.00		1				1,054.00	1,317.00	2.107
II. **Plumbing**														
a. Chemical Toilets	Each					1,600.00*		10				3,371.00	4,214.00	2.107
b. Cast iron vent with 6" diameter vent capacity	Each					600.00*		1				1,264.00	1,580.00	2.107
c. Drain tile, 4 in. diameter 260'	Lot					900.00*		1				1,896.00	2,370.00	2.107
d. Water storage tank 1,750 gal. with 0.5" pipe and fittings	Each	Q-7	3.0	665.00M	150.00	815.00	945.00	1	2.67	665.00	150.00	815.00	945.00	
e. Double drain steel sink	Each	Q-1	1.2	175.00M	175.00	350.00	440.00	1	6.67	175.00	175.00	350.00	440.00	
f. Drinking fountain wall hung cast iron, enameled	Each	1 Plum	4.0	180.00M	29.00	209.00	240.00	1	2.00	180.00	29.00	209.00	240.00	
g. Septic tank, concrete, 5,000 gal.	Each	B-21	1.7	1,600.00M	250.00	1,850.00	2,100.00	1	4.71	1,600.00	250.00	1,850.00	2,100.00	

†See Appendix B for definition of symbols used and for tables of costs for Standard Crews.

*Estimated total costs for year 1968

TABLE 12. SUMMARY OF SHELTER COSTS

Shelter Type	Reinforced Concrete									Steel				
	Rectangular						Arch			Arch			Dome	Lumber
Capacity (Persons)	500			1,000			500			500			20	12
Burial Option	1	2	3	1	2	3	1	2	3	1	2	3	1	1
1. Site Preparation ($)	891	891	1,247	1,246	1,246	1,780	1,068	1,068	2,136	1,068	1,068	2,136	249	13
2. Shelter														
Excavation ($)	2,377	1,260	393	4,247	2,127	753	4,158	2,714	280	4,158	2,714	280	101	672
Earthwork ($)	6,578	7,864	14,543	11,152	13,529	21,136	14,502	15,648	40,454	14,502	15,648	40,454	481	734
Structural ($)	85,876	85,876	85,876	162,009	162,009	162,009	66,307	66,307	66,307	102,675	102,675	102,675	3,178	2,242
Mechanical ($)	21,187	21,187	21,187	42,374	42,374	42,374	21,187	21,187	21,187	21,187	21,187	21,187	848	509
Electrical ($)	5,938	5,938	5,938	11,876	11,876	11,876	5,938	5,938	5,938	5,938	5,938	5,938	238	143
Shelter (Total) ($)	121,956	122,125	127,937	231,658	231,915	238,148	112,092	111,794	134,166	148,460	148,162	170,534	4,846	4,300
3. Entranceway $)	5,173	3,806	3,806	10,038	7,304	7,304	5,019	3,652	3,652	5,019	3,652	3,652	*	*
4. Total Cost ($)	128,020	126,822	132,990	242,942	240,465	247,232	118,179	116,514	139,954	154,547	152,882	176,322	5,095	4,313
5. Total Cost Including Overheads and Profits ($)	157,140	156,000	164,265	298,205	295,760	304,830	154,940	153,390	183,675	185,177	183,629	213,912	6,135	5,430
6. Gross Floor Area (S.F.)	5,120	5,120	5,120	10,240	10,240	10,240	4,644	4,644	4,644	4,644	4,644	4,644	120	65
7. Usable Floor Area (S.F.)	4,872	4,872	4,872	9,704	9,704	9,704	4,636	4,636	4,636	4,636	4,636	4,636	120	65
8. Usable Area per Shelter Space (S.F./Shelter Space)	9.74	9.74	9.74	9.70	9.70	9.70	9.27	9.27	9.27	9.27	9.27	9.27	6.0	5.42
9. Cost (including Overheads and Profits) per square foot of usable area ($/S.F.)	32.25	32.02	33.72	30.73	30.48	31.41	33.42	33.09	39.62	39.94	39.61	46.14	51.13	83.54
10. Cost (Including Overheads and Profits) per Shelter Space ($/Shelter Space)	314.28	312.00	328.53	298.21	295.76	304.83	309.88	306.78	367.35	370.35	367.26	427.82	306.75	452.5

*Included in shelter costs

TABLE 13. MINIMUM CONSTRUCTION TIME, BY SHELTER TYPE AND SHIFTS OF OPERATION

Shelter Type	Capacity (Persons)	Time if 1 Shift (Days)	Time if 3 Shifts (Days)
1. Reinforced Concrete Rectangular	500	28	15
2. Reinforced Concrete Rectangular	1,000	39	20
3. Reinforced Concrete Arch	500	25	12
4. Steel Arch	500	27	13
5. Steel Dome	20	3	2
6. Small-Pole Lumber	12	8	4

IV. AVAILABILITY OF RESOURCES

The most critical constraints on the construction of large numbers of blast shelters in a short time are the availability of the large quantities of materials, equipment, and labor required. The availability of land in highly urbanized areas may also be critical, but this will not be treated here.

Projections of resource availabilities for blast shelter construction can be approached best by determination of existing levels of total U.S. resource production, stockpiling, and employment, as well as the capability for expansion upon demand. The proportion of total U.S. resources of the type needed which can be allocated to blast shelter construction depends upon national priorities in the case of a massive surge in demand, and upon market supply-demand price mechanisms in case of a moderate, yet long-term surge in demand without government control of resources. The former--a massive surge in demand--is assumed to be the case in this study. Existing production and expansion capabilities and constraints for each major resource are summarized in Table 14 and are discussed below. Unless otherwise indicated, all estimated production figures are for the United States in 1979.

A. Concrete

In 1979, some 236 million cubic yards of ready-mixed concrete were produced in the United States. Approximately 90 percent of this was trucked to the using location. The industry has some 60,000 trucks averaging 8 cubic yards capacity, which would enable production of at least 50 percent more than the above level (on a round-the-clock basis). However, it is constrained by the availability of portland cement material. The portland cement industry produced 80 million tons in 1979 and has a total capacity of 97 million tons. This would indicate that the industry could produce an additional 21 percent;

TABLE 14. SUMMARY OF 1979 OUTPUTS AND ESTIMATED CAPABILITY TO PRODUCE FOR SURGE DEMAND: RESOURCE-PRODUCING INDUSTRIES

Resource	1979 Output	Estimated Capability to Produce for Surge Demand (% Increase Over 1979 Output)
Concrete	236 million cubic yards	20% now; 30% or more when portland cement capacity added
Steel (raw)	136 million tons	15% with existing plants; >15% if old plants recommissioned
Plate	8.6 million tons	Great increase possible if product-equipment mix is changed
Reinforcing bars	4.0 million tons	Great increase possible if product-equipment mix is changed
Lumber (softwood)	29.7 billion board feet (+9.8 billion board feet imported)	15%
Plywood	19.7 billion sq. ft. (3/8" thick)	7%
Gravel	1.0 billion tons	40%
Drain pipe plaster	1.0 billion tons	40%
Polyethelene sheet	4,018 million pounds (3% of which was for construction. Approx. 38,000 sq. yd. of 6 mil thick)	Great increase possible

nevertheless, there were shortages west of the Mississippi (particularly in California and Arizona), and imports in 1979 were 7 percent of the total supplies compared to 4 percent in a typical year. Additional portland cement manufacturing capacity takes several years of lead time. For the intermediate term, approximately 11 million tons of new capacity are slated to become available (all west of the Mississippi) within the next 5 years. [Refs. 7,8]

A conclusion that can be drawn from the above is that the concrete industry, because of portland cement availability limitations, should not be expected to produce more than 20 percent to 30 percent (depending on imports and cross-country transportation) above its 1979 level.

B. Steel

In 1979, some 136 million tons of raw steel were produced. The industry has the capacity to produce at least 15 percent more than this; and with sufficient demand, could recommission some inefficient old plants to significantly add to the capacity. Raw steel is converted into many finished forms upon demand. Capabilities to produce steel plate and concrete reinforcing bars are reflected below.

1. Steel Plate - The industry produced about 8.6 million tons of plate in 1978 and has the capability to greatly increase this level by diverting the production of lighter sheet steel to hot strip mills, thus freeing up the heavy plate mills to produce plate only. As of early 1980, the existing inventory of plate was insignificant.

2. Reinforcing Bars - The industry produced about 4.0 million tons of concrete reinforcing bars in 1978, and has the capacity to greatly increase this by readily converting mills that roll more complex structural shapes into bar mills. As in the case of plates, there was an insignificant inventory of reinforcing bars in early 1980.

In conclusion, the steel industry has a significant quantity of underutilized capacity and has the flexibility to convert production to the products needed for blast shelter construction on a fairly fast surge demand basis. [Refs. 9,10,11]

C. Lumber

In 1979, approximately 29.7 billion board feet of softwood lumber were produced in the United States by approximately 7,500 sawmills. The major constraint on increasing this for surge demand is the availability of the infrastructure for the supply of logs. It is estimated that the industry is now capable of increasing its production to 33.8 billion board feet (a 14 percent increase). In addition, the United States imported a net of 9.8 billion board feet in 1979, for a total of 39.5 billion board feet available that year. [Ref. 12]

It should be noted that if there is to be a significant increase in lumber consumed, then public lands will have to be opened for more harvesting. At present, 51 percent of U.S. timber is on public lands, but only 25 percent of all harvesting is permitted to be from public lands.

D. Plywood

In 1979, some 19.7 billion square feet of plywood (with 3/8" nominal thickness) was produced in the United States. It is estimated that the industry is now capable of increasing its production to only 21 billion feet (a 7 percent increase), because most plants now work on a round-the-clock basis. There were no significant net imports of plywood in 1979. [Ref. 12]

E. Gravel

In 1979, the total gravel produced in the United States was 1.0 billion tons. It is estimated that this could be increased by approximately 40 percent, with the greatest limiting factor being the time required to excavate new sources.

While the total gravel available in the country is probably adequate for blast shelter construction needs, transportation to point of use may become a binding constraint for areas of the country with insufficient sources. The gravel industry depends primarily on rail and contract truck haulers which serve the construction industry in general. To indicate the importance of transportation, a rough average cost of gravel is $3.00/ton free on board (FOB) + $0.10/ton/mile transported. [Ref. 13]

F. Drain Pipe and Tile

Because corrugated plastic pipe and drain tile can be used interchangeably for most drainage purposes, it is projected that availability of these resources will not be a constraint to blast shelter construction. In 1978 some 340 million pounds of corrugated polyethelene pipe was produced. [Ref. 14]

G. Polyethelene Sheet

It is also projected that polyethelene sheet film availability will not be a constraint to blast shelter construction. In 1978 about 7,111 million pounds of polyethelene was produced, of which 4,018 million pounds was for sheet film. Of the sheet film produced, only 3 percent was for construction (a total of approximately 38,000 square yards of 6-mil film), but the vast majority was for packaging. Because the production process is continuous, we concluded that its total output under surge demand could not be increased significantly, but we also concluded that it is possible to convert to the production of construction sheet film in place of some types of packaging sheet film with reasonable ease. [Ref. 14]

H. Construction Resources

As of 1976, 3.94 million persons were employed in the construction industry, which represented almost 5 percent of the total nonagricultural employment in the United States. Table 15 is a breakdown of these workers according to skill categories [Refs. 15,16]. In addition to workers, approxiamtely 400,000 people were employed as management/staff support in the construction industry. Not included above but also relevant is the fact that there are about 176,000 air conditioning, refrigeration, and heating mechanics out of approximately 3.0 million mechanics and repairers (including telephone) in the United States.

Employment in the construction industry is highly volatile. Many people move in and out of construction employment as well as among various skill categories within the industry. During the period 1948-76, the unemployment rate for the construction industry averaged 11 percent, while for all industries it was only 5 percent. [Refs. 17,18]

In perspective, because of the flexible characteristics of construction employment, and because most blast shelter construction work will be highly repetitive and thus susceptible to rapid training for new recruits in most skill categories, it is projected that the availability of manpower will not be a major problem for reasonable surge demand conditions. One cannot assume a similar availability of sufficient management/staff support to handle the inherent problems of a massive, intense shelter building program. It is recognized that such a program would require a disproportionate increase in management/staff to carry out the programs with efficiency.

There is some question concerning the availability of sufficient heavy construction equipment (excavators, bulldozers, cranes, derricks, etc.) to meet surge demands. Definitive estimates of the availability of such

TABLE 15. AVAILABILITY OF LABOR, BY SKILL CATEGORY (1979)

Skill	Number (in thousands)	Percent of Total
Carpenters	1,010	25.6
Painters & paperhangers	425	10.8
Excavating, grading, & bulldozing operators	420	10.7
Crane, derrick, & other equipment operators	165	4.2
Plumbers & pipefitters	385	9.8
Electricians	260	6.6
Structural & ornamental drainworkers	71	1.8
Laborers	715	18.1
Cement masons & terrazzo workers	71	
Drywall, dustall, & fin workers	45	
Elevator constructors	20	
Floor covering installers	85	
Glazers	10	
Insulation installers	30	12.4
Lathers	20	
Plasterers	24	
Roofers	90	
Sheet metal workers	65	
Tilesetters	30	
TOTALS	3,941	100.0

equipment were not identified, but it is thought that the items of equipment can be tied to the 420,000 excavating, grading, and bulldozing operators and the 165,000 crane, derrick, and other construction equipment operators (cited in Table 15). In a previous study by RTI, the availability of heavy equipment in host areas was found to be adequate in most cases. Because of these findings, the availability of heavy equipment was not considered to be a constraint on shelter construction.

V. ANALYTICAL TECHNIQUES

The primary objective of this research program was to assess the feasibility and cost of constructing risk-area shelters for selected fractions of the resident population within specified constraints on time and resources. The resources needed to attain this objective are materials, labor, and equipment. A shelter construction plan would have to compete with the existing construction industry for resources because the capacity of the material-producing industries is limited, as is the existing inventory of equipment and labor. As a result, the supply of materials, labor, and equipment to the shelter plan will be far from unlimited and the capability to provide shelter spaces will depend on the resource availability constraints.

There are six types of shelters under consideration, each needing a different set of resources. Permutations and combinations of these shelter types form the different courses of action available to attain the objective. It was observed that the objective function as well as all the constraints can be expressed in terms of linear functions. Numerous mathematical programming methods are available to identify the optimum solution to this type of problem under given circumstances. Linear programming is perhaps the simplest and decidedly the most versatile of these methods. It has been very widely used and has three quantitative components:

1. An objective function,
2. Alternative methods or processes for attaining the objectives, and
3. Resource or other restrictions.

Considering the existence of these components is surge demand analysis, RTI concluded that such a problem could best be approached by using linear programming techniques. The use of this approach permits great flexibility in the types of analyses conducted and numerous programs are available for processing this type of problem on computing machinery. After settling on the type of analysis to be done, RTI proceeded to develop a linear programming model to describe the sheltering problem.

A. Formulation of the Model

To facilitate the development of the linear programming model, the conditions under which the shelters are to be supplied were carefully defined. Shelters are to be constructed within specified intervals of time in any one of six designs, each of which has certain requirements for resources. These resources consist of materials, equipment, and labor. The availability of the needed materials is limited by the capacity of the industries that produce the materials and the amount of time allowed for construction. The availability of equipment and labor is limited by the existing supply of these resources and again by the time span available for construction.

Considering the conditions under which the problem is set, RTI elected to analyze the problem from two perspectives. From the first perspective, the objective is to determine the maximum number of shelter spaces that can be provided within each of the time intervals considered and within selected constraints on the availability of resources. From the second perspective, the objective is to determine the minimum cost of providing shelters for selected fractions of the resident population within the same constraints on the availability of resources. For both these objectives, the optimum solution would indicate the combination of shelter types that would optimize the value of the objective function. With the above objectives in mind, mathematical functions were written to define the two approaches and each of the constraint conditions.

The first objective function was written as follows:

$$\text{Maximize} \quad z = \sum_{i=1}^{n} C_i x_{i,t}$$

Subject to:

$$\sum_{i=1}^{n} a_{i,j} x_{i,t} \leq M_{j,t}$$

$$\sum_{i=1}^{n} b_{i,j} x_{i,t} \leq L_{j,t}$$

$$\sum_{i=1}^{n} d_{i,j} x_{i,t} \leq E_{j,t}$$

$$x_{i,t} \geq 0$$

Where

z = Total number of shelter spaces

C_i = Capacity of shelter type i

$x_{i,t}$ = Number of shelters of type i built in time period t. (the decision variable)

n = Number of shelter types

$a_{i,j}$ = Amount of material of type j required for a unit of shelter of type i

$b_{i,j}$ = Labor hours of type j required for a unit of shelter of type i

$d_{i,j}$ = Equipment hours of type j required for a unit of shelter of type i

$M_{j,t}$ = Amount of material of type j available in time period t

$L_{j,t}$ = Labor hours of type j available in time period t

$E_{j,t}$ = Equipment hours of type j available in time period t

t = Time period.

The second objective function was written as follows:

$$\text{Minimize} \quad z_1 = \sum_{i=1}^{n} c_i x_{i,t}$$

Subject to:

$$\sum_{i=1}^{n} a_{i,j} x_{i,t} \leq M_{j,t}$$

$$\sum_{i=1}^{n} b_{i,j} x_{i,t} \leq L_{j,t}$$

$$\sum_{i=1}^{n} d_{i,j} x_{i,t} \leq E_{j,t}$$

$$\sum_{i=1}^{n} C_{i}, x_{i,t} \geq P$$

$$x_{i,t} \geq 0$$

Where

z_1 = Total cost of shelter program

c_i = The cost of a unit of shelter of type i

P = The population to be sheltered

All the remaining symbols are as defined for the first objective function.

B. Capabilities of the Model

With the first objective function defined above, the maximum number of shelter spaces that can be built under any combination of constraints on time and resources can be estimated. When the problem is solved in this fashion, the result indicates the maximum number of shelter spaces that can be built, the types of shelters that should be built to obtain this maximum value, the quantity of each resource needed, and the total cost of the construction program. Sensitivity analyses can be conducted by solving the problem repeatedly using different constraints on the availability of time and resources. Additional constraint conditions can be added or any of the existing constraints can be lifted.

With the second objective function defined above, the minimum cost of constructing a specified number of shelter spaces can be determined under any selected combination of constraints on the availability of time and resources. If by working within the time and resource constraints, the specified number of shelters could not be built, the results of the analysis will indicate that no solution to the problem is feasible. If a solution is feasibile, the program will indicate the combination of shelter types that could provide the specified number of shelter spaces at the least cost. It will also identify the number of shelters to be built of each type, the quantity of each resource needed, and the associated total cost of the shelter program. Constraints can be added, deleted, or modified as desired to determine their impacts on the shelter construction program.

VI. RESULTS

This section describes the results obtained from four series of analyses that were made using the linear programming model described in Section V. The first two series of analyses were for the purpose of estimating the maximum number of shelter spaces that can be constructed under specified conditions of resource availability. The remaining two series of analyses were for the purpose of computing the minimum cost of providing a specified number of shelter spaces within the same conditions of resource availability. All of the analyses were made under the following set of conditions and assumptions:

1. The total costs of the large shelter designs (Types 1 through 4) were computed by assuming that 20 percent of the shelters would be fully buried, 35 percent would be semiburied, and 45 percent would be above ground.

2. No costs were assigned for identifying shelter sites or for using the land.

3. No credit was given for the use of the existing inventory of materials.

4. No costs were assigned for the planning and administration of a shelter construction program.

5. No engineering or architectural costs would be incurred.

6. The supply of drain tile and polyethylene would not be a constraint on shelter construction.

7. Resource availability varies linearly with the length of the surge period.

A. Shelter Maximization Analysis

The first series of computer runs using the linear programming model was for the purpose of determining the maximum number of shelter spaces that can be provided under various conditions of surge period length and resource availability. These analyses were made using the first objective function defined in Section V. Separate calculations were made for each combination of surge period length and resource availability. This amounted to a total of 28 solutions to the problem, using four surge period lengths and seven levels of resource availability. Table 16 shows the results of the 28 analyses in terms of the maximum total number of shelter spaces that can be provided and the fraction of the total risk area population that the number represents.

In seeking the optimum solution to the problem, the computer model analyzes all combinations of the six shelter designs and selects the combination that produces the largest number of shelter spaces with the resources made available for shelter construction. The percentage figures, given in Table 16 to represent the resources available, refer to the percent of total production of each resource that may be used to construct shelters over the time span of the surge period. The model stops creating shelter spaces and assumes a maximum has been reached when the balance of the resources available are not adequate to construct additional shelters.

The computer model produces a listing of the types of shelters that are selected to provide the maximum number of shelter spaces and a listing of the actual quantitites of each resource that would be needed to construct these shelters. All of these data are contained in Tables 17 through 21 and are supportive of the information contained in Table 16.

In selecting the percentage of resources to make available for shelter construction, a lower value of 10 percent of production was chosen on the basis of the information presented in Section IV of this report. Data given in Section IV indicate that production of all materials except plywood could be increased by at least 15 percent without adversely affecting the normal distribution and price of the products. Therefore, 10 percent of normal production was chosen as a lower bound on the supply of resources to make available, because this value would identify the number of spaces that could be constructed with little or no impact on the existing market structure of

TABLE 16. MAXIMUM SHELTER SPACES WITH SPACE CONSTRAINTS (IN MILLIONS)

Surge Period	3 Months		6 Months		9 Months		12 Months	
Percent Resources	Shelter Spaces	Percent of Total	Shelter Spaces	Percent of Total	Shelter Spaces	Percent of Total	Shelter Spaces	Percent of Total
10%	15.6	11.2	31.2	22.4	46.8	33.6	62.3	44.8
15%	23.4	16.8	46.8	33.6	70.1	50.4	93.5	67.3
20%	31.2	22.4	62.3	44.8	93.5	67.3	124.7	89.7
25%	39.0	28.0	77.9	56.0	116.9	84.1	155.9	112.1
30%	46.8	33.6	93.5	67.3	140.3	100.9	187.0	134.5
40%	62.3	44.8	124.7	89.7	187.0	134.5	249.4	179.3
50%	77.9	56.0	155.9	112.1	233.8	168.1	311.7	224.2

Range of Risk Area Population To Be Sheltered

100%	139,058,878
75%	104,294,150
50%	69,529,439
25%	34,764,720

Risk Area Labor Population: 53,639,965 Percent of Total: 38.57

Critical Work Force (i.e., 6% of Risk Area Labor Population): 3,218,425 Percent of Total: 2.31

TABLE 17. NUMBER OF SHELTERS, BY TYPE, FOR SHELTER-SPACE MAXIMIZATION SOLUTION: 3-MONTH SURGE PERIOD

Shelter Type	Capacity	Percent of Resources Made Available						
		10	15	20	25	30	40	50
1. Reinforced Concrete Rectangular	500							
2. Reinforced Concrete Rectangular	1,000	491	737	982	1,227	1,473	1,964	2,454
3. Reinforced Concrete Arch	500							
4. Steel Arch	500	2,638	3,957	5,276	6,594	7,913	10,551	13,188
5. Steel Dome	20	688,808	1,033,212	1,377,616	1,722,020	2,066,424	2,755,232	3,444,040
6. Small Pole	12							

TABLE 18. NUMBER OF SHELTERS, BY TYPE, FOR SHELTER-SPACE MAXIMIZATION SOLUTION: 6-MONTH SURGE PERIOD

Shelter Type	Capacity	Percent of Resources Made Available 10	15	20	25	30	40	50
1. Reinforced Concrete Rectangular	500							
2. Reinforced Concrete Rectangular	1,000	982	1,473	1,964	2,454	2,945	3,927	4,908
3. Reinforced Concrete Arch	500							
4. Steel Arch	500	5,276	7,913	10,551	13,188	15,826	21,101	26,376
5. Steel Dome	20	1,377,616	2,066,424	2,755,232	3,444,040	4,132,848	5,510,464	6,888,080
6. Small Pole	12							

TABLE 19. NUMBER OF SHELTERS, BY TYPE, FOR SHELTER-SPACE MAXIMIZATION SOLUTION: 9-MONTH SURGE PERIOD

Shelter Type	Capacity	Percent of Resources Made Available						
		10	15	20	25	30	40	50
1. Reinforced Concrete Rectangular	500							
2. Reinforced Concrete Rectangular	1,000	1,473	2,210	2,946	3,681	4,419	5,892	7,362
3. Reinforced Concrete Arch	500							
4. Steel Arch	500	7,914	11,871	15,828	19,782	23,739	31,653	39,564
5. Steel Dome	20	2,066,424	3,099,636	4,132,848	5,166,060	6,199,272	8,265,696	10,332,120
6. Small Pole	12							

TABLE 20. NUMBER OF SHELTERS, BY TYPE, FOR SHELTER-SPACE MAXIMIZATION SOLUTION: 12-MONTH SURGE PERIOD

Shelter Type	Capacity	Percent of Resources Made Available						
		10	15	20	25	30	40	50
1. Reinforced Concrete Rectangular	500							
2. Reinforced Concrete Rectangular	1,000	1,964	2,945	3,927	4,909	5,890	7,854	9,817
3. Reinforced Concrete Arch	500							
4. Steel Arch	500	10,551	15,826	21,101	26,376	31,652	42,202	52,752
5. Steel Dome	20	2,755,232	4,132,848	5,510,464	6,888,080	8,265,696	11,020,928	13,776,160
6. Small Pole	12							

TABLE 21. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR MAXIMIZATION ANALYSIS: ALL SURGE PERIOD LENGTHS

	Percentage of Resources Made Available						
Resource	10	15	20	25	30	40	50
Concrete	2.09	3.13	4.17	5.21	6.25	8.34	10.42
Gravel	.11	.16	.21	.26	.32	.42	.52
Lumber	.33	.49	.65	.82	.98	1.31	1.63
Plywood	.25	.38	.50	.63	.75	1.00	1.25
Reinforcing Steel	10.00	15.00	20.00	25.00	30.00	40.00	50.00
Structural Steel	10.00	15.00	20.00	25.00	30.00	40.00	50.00
Building Laborer	10.00	15.00	20.00	25.00	30.00	40.00	50.00
Carpenter	.27	.40	.54	.67	.81	1.08	1.34
Cement Finisher	.07	.10	.14	.17	.21	.27	.34
Electrician	4.70	7.04	9.39	11.74	14.08	18.78	23.47
Equipment Operator	3.40	5.10	6.80	8.50	10.20	13.60	17.00
Supervisory	4.75	7.12	9.50	11.87	14.25	18.99	23.74
Maintenance	8.87	13.30	17.73	22.16	26.59	35.46	44.32
Plumber	.39	.58	.78	.97	1.17	1.55	1.94
Steel Worker	6.91	10.36	13.82	17.27	20.73	27.63	34.54

the industries that produce the resources of interest in this study. The upper bound of 50 percent of production was chosen on the basis of qualitative considerations and discussions with a university economist who is knowledgeable in the field. This value was acknowledged, by consensus, to be the maximum quantity of materials that could be diverted from normal use patterns without creating catastrophic impacts on other segments of the U.S. economy. Intermediate values were selected for convenience.

Table 16 shows that if 10 percent of the resources produced for a 3-month period are made available for shelter construction, approximately 15 million shelter spaces can be built during that time. This is equal to about 11 percent of the risk area resident population and is substantially greater than the approximately 3.2 million critical industry workers who account for approximately 2.31 percent of the risk area population. The 3.2 million figure represents the lower bound on the number of shelter spaces that would be needed during a surge period. On the basis of this result, it is concluded that risk area shelters for critical industry workers can be constructed in the shortest surge period length considered (3 months) without having any significant economic impacts and with little or no impact on product prices.

Table 21, which lists the actual quantities of resources that would be used for shelter construction, indicates that steel and construction labor are the only resources that are exhausted for all surge period lengths. These items, therefore, are the ones that limit the numbers of shelters that can be constructed. These same limits are reached for all of the combinations of surge period length and availability of resources. The information presented in Tables 17 through 20 explain the reason why the same resources constitute the limits for all cases analyzed. As can be seen, only three types of shelters are chosen for construction and the same three are chosen for each case analyzed.

Referring back to Table 16, it can be observed that if shelters are to be built for the entire risk area population, the shortest feasible surge period length is 6 months. At this surge period length, a commitment of up to 50 percent of the resources produced would be required. It must be remembered, however, that only steel and some types of labor are completely depleted in the situations analyzed. All other resources are used at rates that are well below the levels at which a noticeable impact would occur.

Other feasible solutions for sheltering the entire risk area population were found for a 9-month surge period with a commitment of up to 30 percent of the resources produced, and for a 12-month surge period with a commitment of up to 25 percent of the resources produced.

Given these results of the first analysis, and being aware of the unique characteristics of linear programming, we decided that further analysis using different constraints was merited. Linear programming is a computational procedure that determines the best course of action for achieving a specified objective when there are many alternative courses of action available. The selection of the best course of action is made by considering all of the available choices and imposed constraint conditions. Quantification of the objective function in numerical terms and formulation of the constraints is of extreme importance to the outcome of the analysis and must be carefully done to ensure that the desired analysis is carried out. It is also important to remember that only explicitly defined constraints will be considered in the analysis, which highlights the necessity of making sure that all of the desired constraints are defined.

Because the initial runs in this study selected only three of the six available shelter designs, and because the sole reason for the choice of these designs was that they resulted in the maximum number of shelter spaces from the available resources, additional study was devoted to determining if there might be other reasons for using more of the shelter designs or for using designs different from those chosen by the initial linear programming analysis. The result of this additional study was that there are, in fact, other factors that should be considered in the selection of the shelter designs used. The calendar time that is required to construct a large 500-person or 1,000-person shelter is much greater than that required to construct a small 12-person or 20-person shelter. Because all of the shelters needed during a surge period cannot be built simultaneously, initiation of the construction of new shelters must be spread out over the entire surge period.

Because partially completed shelters would be of no benefit, there comes a point in time during the surge period after which shelters that take a long time to construct (i.e., large shelters) should not be started. A similar point occurs that pertains to the smaller shelter, but that point is much nearer the end of the surge period. In view of these considerations, RTI concluded that for the shorter surge period lengths, greater emphasis should be placed on the construction of smaller shelters, while for the longer surge period lengths, a greater fraction of the needed shelter spaces could be supplied by large shelters.

After a careful evaluation of the time requirements for construction of each of the shelter designs and through consultation with the Contracting Officer's Technical Representative (COTR) for this project, a preferred mix of shelter designs was formulated for each surge period length. These preferences are given in Table 22 and show an increasing fraction of shelter spaces being provided by the larger shelters as the surge period length increases. One additional constraint was included to simulate lack of large land sites in urban areas. This constraint ensures that the total population

TABLE 22. PREFERRED SHELTER MIX BY SURGE PERIOD LENGTH

Surge Periods (Months)	3	6	9	12
Shelter Type				
Reinforced Concrete Rectangular, 500				
Reinforced Concrete Rectangular, 1,000	50%	65%	75%	85%
Reinforced Concrete Arch, 500				
Steel Arch, 500				
Steel Dome, 500	30%	25%	15%	10%
Lumber, 12	20%	10%	10%	5%

housed in reinforced concrete rectangular shelters is shared equally by the 500- and 1,000-person capacity shelters. The reason for including this condition is that the 1,000-person shelter is slightly less costly than the 500-person shelter. Therefore, it seemed logical that if any of the reinforced concrete rectangular shelters were to be selected in the analysis, the 1,000-person shelter would always be chosen. Since the 1,000-person shelter requires a relatively large land area (1.7 acres), which may not be abundant in highly urbanized areas, RTI felt that a portion of these shelters should be built in the smaller 500-person version with its smaller requirement for land. This constraint does not force the use of rectangular shelters at all, but if this shelter type is selected in the analysis, the land area constraint will cause both sizes of the shelter to be used.

By comparing the preferred distribution of shelters contained in Table 22 with the distributions that the model recommends in Tables 17 through 20, it can be seen that the distribution derived by the model relies far more on the smaller shelters than does the preferred distribution. In Table 22, more emphasis was placed on the smaller shelters for the 3-month surge period to prevent the initiation of new large shelters near the end of the surge period. The fact that the maximization analysis uses fewer large shelters than permitted in Table 22 negates the need to further restrict the number of large shelters at the shorter surge period lengths. The model analysis also relies heavily on the smaller shelters at the longer surge period lengths for which Table 22 indicates greater reliance on the larger shelters. Because there may be advantages (relative to care and feeding) to having people sheltered in large groups, additional computer runs were made with the constraints on the mix of shelter types included. The results of these analyses are presented in Table 23, and supporting information describing the types of shelters and the quantities of resources used are given in Tables 24 through 31.

TABLE 23. MAXIMUM SHELTER SPACES WITH SHELTER CONSTRAINTS

Surge Period	3 Months		6 Months		9 Months		12 Months	
Percent Resources	Shelter Spaces	Percent of Total	Shelter Spaces	Percent of Total	Shelter Spaces	Percent of Total	Shelter Spaces	Percent of Total
10%	4,795,802	3.45	7,378,157	5.31	9,599,605	6.90	11,284,241	8.11
15%	7,193,703	5.17	11,067,236	7.96	14,387,407	10.35	16,926,361	12.17
20%	9,591,605	6.90	14,756,315	10.61	19,183,209	13.80	22,568,481	16.23
25%	11,989,506	8.62	18,445,393	13.26	23,979,011	17.24	28,210,602	20.29
30%	14,387,407	10.35	22,134,472	15.92	28,774,814	20.69	33,852,721	24.34
40%	19,183,209	13.80	29,512,629	21.22	38,366,418	27.59	45,136,962	32.46
50%	23,979,011	17.24	36,890,787	26.53	47,958,023	34.49	56,421,203	40.57

Range of Risk Area Population To Be Sheltered

100%	139,058,878
75%	104,294,150
50%	69,529,439
25%	34,764,720

Labor Population:	77,522,283	Percent of Total:	55.75
Risk Area Labor Population:	53,639,965	Percent of Total:	38.57
Critical Work Force (i.e., 6% of Risk Area Labor Population):	3,218,425	Percent of Total:	2.31

TABLE 24. NUMBER OF SHELTERS, BY TYPE, FOR SHELTER-SPACE MAXIMIZATION SOLUTION WITH SHELTER CONSTRAINTS: 3-MONTH SURGE PERIOD

Shelter Type	Capacity	Percent of Resources Made Available						
		10	15	20	25	30	40	50
1. Reinforced Concrete Rectangular	500							
2. Reinforced Concrete Rectangular	1,000							
3. Reinforced Concrete Arch	500	2,269	3,404	4,539	5,673	6,808	9,077	11,346
4. Steel Arch	500	2,527	3,790	5,053	6,316	7,580	10,106	12,633
5. Steel Dome	20	71,937	107,906	143,874	179,843	215,811	287,748	359,685
6. Small Pole	12	79,930	119,895	159,860	199,825	239,790	319,720	399,650

TABLE 25. NUMBER OF SHELTERS, BY TYPE, FOR SHELTER-SPACE MAXIMIZATION SOLUTION WITH SHELTER CONSTRAINTS: 6-MONTH SURGE PERIOD

Shelter Type	Capacity	Percent of Resources Made Available						
		10	15	20	25	30	40	50
1. Reinforced Concrete Rectangular	500							
2. Reinforced Concrete Rectangular	1,000							
3. Reinforced Concrete Arch	500	4,539	6,808	9,077	11,346	13,615	18,154	22,692
4. Steel Arch	500	5,053	7,580	10,106	12,633	15,159	20,213	25,266
5. Steel Dome	20	92,227	138,341	184,454	230,567	276,681	368,908	461,135
6. Small Pole	12	61,485	92,227	122,969	153,712	184,454	245,939	307,423

TABLE 26. NUMBER OF SHELTERS, BY TYPE, FOR SHELTER SPACE-MAXIMIZATION SOLUTION WITH SHELTER CONSTRAINTS: 9-MONTH SURGE PERIOD

Shelter Type	Capacity	Percent of Resources Made Available 10	15	20	25	30	40	50
1. Reinforced Concrete Rectangular	500							
2. Reinforced Concrete Rectangular	1,000							
3. Reinforced Concrete Arch	500	6,808	10,212	13,615	17,019	20,423	27,231	34,039
4. Steel Arch	500	7,580	11,370	15,159	18,949	22,739	30,319	37,899
5. Steel Dome	20	71,937	107,906	143,874	179,843	215,811	287,748	359,685
6. Small Pole	12	79,930	119,895	159,860	199,825	239,790	319,720	399,650

TABLE 27. NUMBER OF SHELTERS, BY TYPE, FOR SHELTER-SPACE MAXIMIZATION SOLUTION WITH SHELTER CONSTRAINTS: 12-MONTH SURGE PERIOD

Shelter Type	Capacity	Percent of Resources Made Available 10	15	20	25	30	40	50
1. Reinforced Concrete Rectangular	500							
2. Reinforced Concrete Rectangular	1,000							
3. Reinforced Concrete Arch	500	9,077	13,615	18,154	22,692	27,231	36,308	45,385
4. Steel Arch	500	10,106	15,159	20,213	25,266	30,319	40,425	50,531
5. Steel Dome	20	56,421	84,632	112,842	141,053	169,264	225,685	1,438,741
6. Small Pole	12	47,018	70,527	94,035	117,544	141,053	188,071	1,598,601

TABLE 28. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR MAXIMIZATION ANALYSIS WITH SHELTER CONSTRAINTS: 3-MONTH SURGE PERIOD

	Percentage of Resources Made Available						
Resource	10	15	20	25	30	40	50
Concrete	3.60	5.39	7.19	8.99	10.79	14.38	17.98
Gravel	.10	.16	.21	.26	.31	.41	.51
Lumber	6.56	9.84	13.12	16.40	19.67	26.23	32.79
Plywood	.22	.33	.44	.55	.66	.88	1.10
Reinforcing Steel	10.00	15.00	20.00	25.00	30.00	40.00	50.00
Structural Steel	10.00	15.00	20.00	25.00	30.00	40.00	50.00
Building Laborer	4.64	6.96	9.27	11.59	13.91	18.55	23.19
Carpenter	.90	1.35	1.80	2.25	2.70	3.61	4.51
Cement Finisher	.14	.20	.27	.34	.41	.54	.68
Electrician	1.28	1.92	2.57	3.21	3.85	5.13	6.41
Equipment Operator	.83	1.24	1.66	2.07	2.49	3.31	4.14
Supervisory	.95	1.43	1.90	2.38	2.86	3.81	4.76
Maintenance	1.10	1.66	2.21	2.76	3.31	4.41	5.52
Plumber	.08	.11	.15	.19	.23	.30	.38
Steel Worker	6.60	9.90	13.20	16.51	19.81	26.41	33.01

TABLE 29. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR MAXIMIZATION ANALYSIS WITH SHELTER CONSTRAINTS: 6-MONTH SURGE PERIOD

	Percentage of Resources Made Available						
Resource	10	15	20	25	30	40	50
Concrete	3.60	5.39	7.19	8.99	10.79	14.38	17.98
Gravel	.10	.16	.21	.26	.31	.42	.52
Lumber	2.71	4.07	5.43	6.79	8.15	10.86	13.58
Plywood	.22	.33	.44	.55	.66	.88	1.10
Reinforcing Steel	10.00	15.00	20.00	25.00	30.00	40.00	50.00
Structural Steel	10.00	15.00	20.00	25.00	30.00	40.00	50.00
Building Laborer	2.77	4.15	5.54	6.92	8.31	11.08	13.85
Carpenter	.52	.77	1.03	1.29	1.55	2.06	2.58
Cement Finisher	.14	.20	.27	.34	.41	.54	.68
Electrician	.97	1.46	1.94	2.43	2.92	3.89	4.86
Equipment Operator	.71	1.07	1.43	1.78	2.14	2.85	3.56
Supervisory	.77	1.16	1.55	1.94	2.32	3.10	3.87
Maintenance	.78	1.17	1.55	1.94	2.33	3.11	3.89
Plumber	.06	.09	.13	.16	.19	.25	.31
Steel Worker	3.29	5.26	13.14	16.43	19.72	26.29	32.86

TABLE 30. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR MAXIMIZATION ANALYSIS WITH SHELTER CONSTRAINTS: 9-MONTH SURGE PERIOD

Resource	Percentage of Resources Made Available						
	10	15	20	25	30	40	50
Concrete	3.60	5.39	7.19	8.99	10.79	14.38	17.98
Gravel	.10	.16	.21	.26	.31	.42	.52
Lumber	2.40	3.59	4.79	5.99	7.19	9.58	11.98
Plywood	.22	.33	.44	.55	.66	.88	1.10
Reinforcing Steel	10.00	15.00	20.00	25.00	30.00	40.00	50.00
Structural Steel	10.00	15.00	20.00	25.00	30.00	40.00	50.00
Building Laborer	2.34	3.52	4.69	5.86	7.03	9.37	11.72
Carpenter	.48	.73	.97	1.21	1.45	1.93	2.42
Cement Finisher	.14	.20	.27	.34	.41	.54	.68
Electrician	.82	1.23	1.65	2.06	2.47	3.29	4.12
Equipment Operator	.61	.92	1.23	1.53	1.84	2.45	3.07
Supervisory	.63	.95	1.26	1.57	1.89	2.52	3.15
Maintenance	.50	.75	.99	1.24	1.49	1.99	2.49
Plumber	.05	.08	.10	.13	.15	.20	.26
Steel Worker	6.55	9.82	13.09	16.37	19.64	26.19	32.73

TABLE 31. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR MAXIMIZATION ANALYSIS WITH SHELTER CONSTRAINTS: 12-MONTH SURGE PERIOD

	Percentage of Resources Made Available						
Resource	10	15	20	25	30	40	50
Concrete	3.60	5.39	7.19	8.99	10.79	14.38	17.98
Gravel	.10	.16	.21	.26	.31	.42	.52
Lumber	1.23	1.85	2.24	3.08	3.70	4.93	6.16
Plywood	.22	.33	.28	.55	.66	.88	1.11
Reinforcing Steel	10.00	15.00	20.00	25.00	30.00	40.00	50.00
Structural Steel	10.00	15.00	20.00	25.00	30.00	40.00	50.00
Building Laborer	1.75	2.63	3.50	4.38	5.25	7.00	8.75
Carpenter	.37	.55	.73	.92	1.10	1.47	1.83
Cement Finisher	.14	.20	.27	.34	.41	.54	.68
Electrician	.77	1.07	1.43	1.79	2.15	2.87	3.58
Equipment Operator	.57	.85	1.14	1.42	1.71	2.28	2.84
Supervisory	.56	.84	1.13	1.41	1.69	2.25	2.81
Maintenance	.37	.56	.74	.93	1.12	1.49	1.86
Plumber	.05	.07	.09	.11	.14	.18	.23
Steel Worker	6.53	9.80	13.07	16.43	19.60	26.14	32.67

It becomes obvious upon comparing Table 23 with Table 16 that the addition of the constraints on the mix of shelter types greatly reduces the maximum number of shelter spaces that can be constructed. The maximum number of spaces that can be constructed in the longest time period (12 months) and with maximum resources available (50 percent) amounts to only about 40 percent of the risk area residents. Because of the obvious, marked decrease in the number of shelter spaces that can be provided under the specified conditions of constraint, little additional study was given to these results. It is interesting to note that with no more than 10 percent of the resources available, shelters could be provided for the critical workforce in the shortest surge period length considered (3 months). Should there be legitimate reasons for constructing large shelters instead of small ones, that alternative is feasible and would require the resources listed in Tables 28 through 31.

B. Minimum Cost Analysis

Following the two series of analyses using the first objective function, attention was turned to the second objective function, the minimum cost function. In this analysis, a discrete number of shelter spaces is specified as being required and the model determines the combination of shelter designs that will provide the specified spaces at the least cost. The model then displays the total number of each type of shelter needed and the associated costs. To conduct this analysis, the national average cost of each of the required resources was included in the data inputs. Independent analyses were conducted for space requirements, ranging from a minimum value equal to the critical work force to a maximum value equal to the entire risk area population.

In the first minimum cost analysis, no constraints were imposed on the types of shelters that could be utilized. The results of the maximization analysis given in Table 16 were used as guidance in selecting the number of shelter spaces, the surge period length, and the available resources for which analyses would be requested. This, in fact, was one of the important reasons for conducting the maximization analysis. By using Table 16 as a guide, we were assured that analyses would not be requested for conditions that did not have a feasible solution.

Population figures (i.e., the shelter spaces required) were selected to coincide with the nearest 5 percentile below the maximum value given in Table 16. For example, for the 3-month surge period, analyses were conducted for 10 percent resource availability and 10 percent of the population to be sheltered; for 15 percent resource availability and 15 percent of the population to be sheltered; and so on for the remaining values.

In addition to the values selected on the basis of Table 16, another analysis was carried out to determine the minimum cost of providing shelters for the critical workforce, which is equivalent to approximately 2.31 percent of the resident population. For this latter analysis, a surge period length of 3 months and a resource availability of 10 percent was specified. Table 32 shows the results obtained from the minimum cost analysis. The X's identify the conditions for which the analyses were made and the right hand column displays the cost of the shelter program in millions of dollars. Tables 33 through 40 present the types and numbers of shelters selected to be built and the quantities of resources used for each of the cases analyzed.

It can be seen in Table 32 that the estimated cost of a nationwide shelter program to house the critical workforce is about $0.98 billion and the estimated cost of a nationwide shelter program for the entire risk area population is $42.6 billion. These costs are based on national averages and do not include any increase in prices due to the additional demand of the

TABLE 32. MINIMUM COSTS FOR SHELTERING SELECTED PERCENTAGES OF THE POPULATION AT DIFFERENT SURGE PERIODS AND RESOURCE LEVELS, WITH RESOURCE CONSTRAINTS ONLY*

Length of Surge Period	Percent Resources Made Available	Percent of Population To Be Sheltered†													Cost# ($ Millions)
		2.31	10	15	20	25	30	40	50	60	70	80	90	100	
3 Months	10%	X													981
	10%		X												4,260
	15%			X											6,390
	20%				X										8,235
	25%					X									10,650
	30%						X								12,780
	40%							X							17,040
	50%								X						21,300
6 Months	10%				X										8,235
	15%						X								12,780
	20%							X							17,040
	25%								X						21,300
	30%									X					25,560
	40%											X			34,080
	50%													X	42,600
9 Months	10%						X								12,780
	15%								X						21,487
	20%									X					25,560
	25%											X			34,083
	30%													X	42,975
12 Months	10%							X							17,040
	15%								X						25,560
	20%											X			34,080
	25%													X	42,600

*Assumes government price controls.
†X's indicate the percentage of the population that could feasibly be sheltered at the indicated surge period and resource level.
#Shelter costs at the 30, 80, and 100 percent levels vary with surge period length because different combinations of shelter designs are selected.

TABLE 33. NUMBER OF SHELTERS, BY TYPE, FOR COST-MINIMIZATION SOLUTION:
3-MONTH SURGE PERIOD

			Percent of Resources Made Available							
			10	10	15	20	25	30	40	50
				Percent of Risk Area Population To Be Sheltered						
	Shelter Type	Capacity	2.31	10	15	20	25	30	40	50
1.	Reinforced Concrete Rectangular	500								
2.	Reinforced Concrete Rectangular	1,000		986	1,479	1,972	2,465	2,958	3,943	4,929
3.	Reinforced Concrete Arch	500	986							
4.	Steel Arch	500								
5.	Steel Dome	20	111,634	646,008	969,011	1,239,327	1,615,019	1,938,023	2,584,031	3,230,038
6.	Small Pole	12				87,815					

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FEASIBILITY AND COST ANALYSIS OF SURGE PERIOD SHELTER PROGRAMS.(U)
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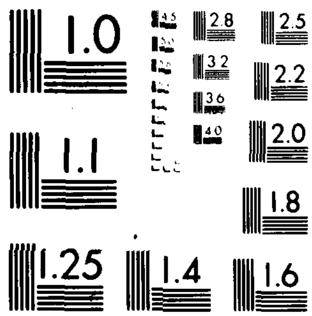

MICROCOPY RESOLUTION TEST CHART
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TABLE 34. NUMBER OF SHELTERS, BY TYPE, FOR COST-MINIMIZATION SOLUTION: 6-MONTH SURGE PERIOD

		Percent of Resources Made Available						
		10	15	20	25	30	40	50
		Percent of Risk Area Population To Be Sheltered						
Shelter Type	Capacity	20	30	40	50	60	80	100
1. Reinforced Concrete Rectangular	500							
2. Reinforced Concrete Rectangular	1,000	1,972	2,958	3,943	4,929	5,915	7,886	9,858
3. Reinforced Concrete Arch	500							
4. Steel Arch	500							
5. Steel Dome	20	1,239,327	1,938,023	2,584,031	3,230,038	3,876,046	5,168,061	6,460,076
6. Small Pole	12	87,815						

TABLE 35. NUMBER OF SHELTERS, BY TYPE, FOR COST-MINIMIZATION SOLUTION: 9-MONTH SURGE PERIOD

		Percent of Resources Made Available				
		10	15	20	25	30
		Percent of Risk Area Population To Be Sheltered				
Shelter Type	Capacity	30	50	60	80	100
1. Reinforced Concrete Rectangular	500					
2. Reinforced Concrete Rectangular	1,000	2,958	3,674	2,958	7,394	7,348
3. Reinforced Concrete Arch	500					
4. Steel Arch	500		4,062			8,123
5. Steel Dome	20	1,938,023	3,191,249	1,938,023	5,192,704	6,382,497
6. Small Pole	12					

TABLE 36. NUMBER OF SHELTERS, BY TYPE, FOR COST-MINIMIZATION SOLUTION: 12-MONTH SURGE PERIOD

		Percent of Resources Made Available			
		10	15	20	25
		Percent of Risk Area Population To Be Sheltered			
Shelter Type	Capacity	40	60	80	100
1. Reinforced Concrete Rectangular	500				
2. Reinforced Concrete Rectangular	1,000	3,943	5,915	7,886	9,858
3. Reinforced Concrete Arch	500				
4. Steel Arch	500				
5. Steel Dome	20	2,584,031	3,876,046	5,168,001	6,460,076
6. Small Pole	12				

TABLE 37. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR COST MINIMIZATION: 3-MONTH SURGE PERIOD

	Percentage of Resources Made Available							
	10	10	15	20	25	30	40	50
	Percentage of Risk Area Population To Be Sheltered							
Resource	2.31	10	15	20	25	30	40	50
Concrete	1.92	1.92	2.88	3.84	4.80	5.76	7.68	9.60
Gravel	.09	.09	.14	.19	.24	.28	.38	.47
Lumber	.39	.39	.58	7.63	.96	1.16	1.54	1.93
Plywood	.33	.33	.50	.67	.83	1.00	1.34	1.67
Reinforcing Steel	10.00	10.00	15.00	20.00	25.00	30.00	40.00	50.00
Structural Steel	.62	.62	.94	1.25	1.56	1.87	2.50	3.12
Building Laborer	1.77	9.00	13.50	20.00	22.50	27.00	36.00	45.01
Carpenter	.24	.24	.35	1.16	.59	.71	.95	1.18
Cement Finisher	.08	.08	.13	.17	.21	.25	.34	.42
Electrician	.93	4.23	6.34	8.40	10.56	12.68	16.90	21.13
Equipment Operator	.58	2.98	4.47	5.72	7.45	8.94	11.91	14.89
Supervisory	.79	4.25	6.37	8.17	10.62	12.74	16.99	21.24
Maintenance	1.50	8.26	12.39	15.86	20.65	24.78	33.04	41.31
Plumber	.07	.35	.53	.68	.88	1.06	1.41	1.76
Steel Worker	1.19	1.81	2.71	3.56	4.52	5.43	7.23	9.04

TABLE 38. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR COST MINIMIZATION: 6-MONTH SURGE PERIOD

	Percentage of Resources Made Available					
	10	15	20	25	30	40
	Percentage of Population To Be Sheltered					
Resource	20	30	40	50	60	80
Concrete	1.92	2.88	3.84	4.80	5.76	7.68
Gravel	.10	.14	.19	.24	.28	.38
Lumber	3.82	.58	.77	.97	1.16	1.54
Plywood	.34	.50	.67	.84	1.00	1.34
Reinforcing Steel	10.00	15.00	20.00	25.00	30.00	40.00
Structural Steel	.63	.94	1.25	1.56	1.87	2.50
Building Laborer	10.00	13.50	18.00	22.51	27.00	36.00
Carpenter	.58	.36	.48	.59	.71	.95
Cement Finisher	.09	.13	.17	.21	.25	.34
Electrician	4.20	6.34	8.45	10.57	12.68	16.90
Equipment Operator	2.86	4.47	5.96	7.45	8.94	11.91
Supervisory	4.09	6.37	8.50	10.62	12.74	16.99
Maintenance	7.93	12.39	16.52	20.66	24.78	33.04
Plumber	.34	.53	.71	.88	1.06	1.41
Steel Worker	1.78	2.72	3.62	4.52	5.43	7.23

TABLE 39. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR COST MINIMIZATION: 9-MONTH SURGE PERIOD

	Percentage of Resources Made Available				
	10	15	20	25	30
	Percentage of Population to Be Sheltered				
Resource	30	50	60	80	100
Concrete	1.92	2.96	3.84	4.80	5.93
Gravel	.09	.15	.19	.24	.29
Lumber	.39	.55	.77	.96	1.09
Plywood	.33	.46	.67	.83	.92
Reinforcing Steel	10.00	15.00	20.00	25.00	30.00
Structural Steel	.62	5.75	1.25	1.56	11.50
Building Laborer	9.00	15.00	18.00	24.07	30.00
Carpenter	.24	.37	.47	.59	.74
Cement Finisher	.08	.12	.17	.21	.24
Electrician	4.23	7.03	8.45	11.28	14.05
Equipment Operator	2.98	5.01	5.96	7.97	10.02
Supervisory	4.25	7.10	8.49	11.37	14.20
Maintenance	8.26	13.62	16.52	22.12	27.24
Plumber	.35	.59	.71	.94	1.17
Steel Worker	1.81	5.41	3.62	4.66	10.83

TABLE 40. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR COST MINIMIZATION: 12-MONTH SURGE PERIOD

	Percentage of Resources Made Available			
	10	15	20	25
	Percentage of Population To Be Sheltered			
Resource	40	60	80	100
Concrete	1.92	2.88	3.84	4.80
Gravel	.10	.14	.19	.24
Lumber	.39	.58	.77	.96
Plywood	.34	.50	.67	.83
Reinforcing Steel	10.00	15.00	20.00	25.00
Structural Steel	.63	.94	1.25	1.56
Building Laborer	9.00	13.50	18.00	22.50
Carpenter	.24	.36	.47	.59
Cement Finisher	.09	.13	.17	.21
Electrician	4.23	6.34	8.45	10.56
Equipment Operator	2.98	4.47	5.96	7.45
Supervisory	4.25	6.37	8.50	10.62
Maintenance	8.26	12.39	16.52	20.65
Plumber	.35	.53	.71	.88
Steel Worker	1.81	2.72	3.62	4.52

shelter program on the available resources. The cost estimates would probably be realistic only if government price controls are implemented to maintain then current price levels. If such an action is not taken, product prices would be expected to increase.

The results presented in Table 32 can be used to estimate the cost of a shelter program at the state or regional level. Table 41 contains factors by which national average costs can be transformed to state costs. These factors would include variations in transportation and other cost elements for each of the resources used in the shelter construction program. The fraction of the total risk area population that resides in each state is also given in Table 41. The cost factors are presented in two ways. A single average factor is shown and individual factors are given for each shelter design. A rough estimate of the cost of providing shelters for individual states can be obtained using the average cost factor, and a more accurate cost estimate can be obtained by using the factors for each individual shelter.

To illustrate the procedure for using these factors, the cost of a shelter program for the state of New York to house the critical work force is calculated as follows:

1. Obtain the cost of a national program from Table 32 ($981 million).
2. Obtain the fraction of the total risk area population that is in New York from Table 41 (10.72 percent).
3. Obtain the average cost factor from Table 41 (1.019).
4. Multiply the national cost by the population fraction in New York and by the cost factor for New York.

$$\text{New York Cost} = \$981\ (10^6)(.1072)(1.019)$$

$$= \$107.2 \text{ million.}$$

From this calculation, a rough estimate of the cost of the shelter program for the state of New York would be $107.2 million. To obtain a more

TABLE 41. FACTORS FOR CONVERTING U.S. NATIONAL AVERAGE COSTS* TO STATE AVERAGE COSTS, BY SHELTER TYPE

	PERCENT OF NATIONAL RISK AREA POPULATION RESIDING IN STATE	REINFORCED CONCRETE RECTANGULAR (500)	REINFORCED CONCRETE RECTANGULAR (1,000)	REINFORCED CONCRETE ARCH	STEEL ARCH	STEEL DOME	SMALL POLE	OVERALL
REGION I								
MAINE	0.24	98.2	98.6	95.7	100.7	99.1	94.0	97.7
MASSACHUSETTS	3.92	100.5	100.6	100.2	99.7	99.3	102.8	100.5
CONNECTICUT	2.12	99.0	99.7	99.5	99.2	98.3	98.8	99.2
RHODE ISLAND	0.69	99.5	99.7	98.3	102.9	103.1	96.6	100.0
NEW HAMPSHIRE	0.29	95.0	95.4	93.5	95.9	94.5	93.3	94.6
VERMONT	0.06	94.6	95.1	93.6	95.6	94.3	89.9	93.9
NEW JERSEY	5.03	104.9	104.8	104.3	104.5	104.4	107.1	105.0
NEW YORK	10.72	101.6	101.5	101.3	101.8	101.9	103.0	101.8
REGION II								
MARYLAND	2.61	96.0	96.3	95.2	94.5	92.2	92.6	94.5
DELAWARE	0.34	101.5	101.3	102.6	102.0	103.1	102.4	102.2
DISTRICT OF COLUMBIA	0.55	98.3	98.4	97.9	97.9	97.4	98.9	98.1
PENNSYLVANIA	6.02	100.5	100.5	100.6	99.8	99.6	101.5	100.4
VIRGINIA	2.02	92.9	93.3	91.7	90.8	87.9	87.0	90.6
WEST VIRGINIA	0.48	101.0	101.1	100.3	100.5	100.3	100.7	100.7
REGION III								
ALABAMA	1.22	93.3	93.6	93.1	93.1	92.1	90.5	92.6
FLORIDA	3.50	92.8	93.1	93.3	92.7	92.1	91.3	92.6
GEORGIA	1.60	91.9	92.4	91.2	93.7	92.1	84.3	90.9
KENTUCKY	0.97	97.0	97.1	97.5	94.6	93.3	100.2	96.6
MISSISSIPPI	0.39	92.0	92.4	91.7	92.4	91.1	86.5	91.0
NORTH CAROLINA	1.33	89.6	90.2	89.4	89.3	86.6	84.6	88.3
SOUTH CAROLINA	0.69	88.5	89.3	87.1	89.9	87.0	80.6	87.1
TENNESSEE	1.27	92.7	93.2	91.9	93.3	92.0	88.2	91.9
REGION IV								
ILLINOIS	6.26	99.2	99.2	98.7	98.3	97.8	100.0	98.9
INDIANA	2.11	100.0	100.1	99.7	100.0	99.7	101.5	100.2
MICHIGAN	4.83	99.0	99.0	98.9	97.1	96.3	103.0	98.9
MINNESOTA	1.49	99.5	99.7	98.4	100.5	100.0	97.2	99.2
OHIO	5.51	101.6	101.6	101.6	101.2	101.3	104.3	101.9
WISCONSIN	1.74	98.1	98.1	98.6	97.7	98.0	99.7	98.4

(Continued)

*U.S. national average costs equal 100 percent.

TABLE 41. FACTORS FOR CONVERTING U.S. NATIONAL AVERAGE COSTS* TO STATE AVERAGE COSTS, BY SHELTER TYPE (Continued)

	PERCENT OF NATIONAL RISK AREA POPULATION RESIDING IN STATE	REINFORCED CONCRETE RECTANGULAR (500)	REINFORCED CONCRETE RECTANGULAR (1,000)	REINFORCED CONCRETE ARCH	STEEL ARCH	STEEL DOME	SMALL POLE	OVERALL
REGION V								
ARKANSAS	0.51	90.9	91.3	91.7	88.1	86.2	89.8	89.7
LOUISIANA	1.50	94.4	94.7	94.2	94.3	93.1	89.5	93.4
NEW MEXICO	0.30	102.0	102.2	100.0	104.5	104.1	96.8	101.6
OKLAHOMA	0.86	98.7	98.9	98.1	99.7	99.9	100.7	99.3
TEXAS	5.52	93.1	93.4	93.0	93.4	92.3	88.3	92.2
REGION VI								
COLORADO	1.16	98.4	98.5	98.0	98.0	97.4	96.8	97.8
IOWA	0.71	98.3	98.5	97.9	97.7	96.9	97.7	97.8
KANSAS	0.88	98.0	98.2	98.1	97.7	97.3	99.9	98.2
MISSOURI	2.27	99.5	99.4	100.2	99.5	100.4	102.2	100.2
NEBRASKA	0.49	98.5	98.7	97.6	98.0	97.1	98.1	98.0
NORTH DAKOTA	0.21	92.7	93.1	91.6	92.7	90.6	87.9	91.4
SOUTH DAKOTA	0.11	97.4	97.7	96.7	100.5	100.2	91.8	97.4
UTAH	0.59	95.9	96.1	96.2	94.7	93.9	94.8	95.3
REGION VII								
WYOMING	0.06	99.8	99.8	100.3	97.8	96.8	101.4	99.3
ARIZONA	0.96	107.1	106.6	108.7	107.8	109.5	109.1	108.1
CALIFORNIA	12.78	104.0	103.7	105.1	104.8	104.8	102.2	104.1
REGION VIII								
NEVADA	0.28	97.0	97.1	97.6	98.3	98.7	92.5	96.9
IDAHO	0.09	97.1	97.3	97.0	96.9	96.2	93.2	96.3
MONTANA	0.23	102.3	102.1	103.1	102.3	102.9	100.1	102.1
OREGON	0.86	101.4	101.3	102.0	101.5	101.7	99.6	101.3
WASHINGTON	1.73	132.9	131.8	132.0	127.0	127.2	135.8	131.1
ALASKA	0.13	110.3	110.1	108.3	108.3	107.7	117.7	110.4

*U.S. national average costs equal 100 percent.

detailed estimate, the average cost factor would be replaced by a weighted average of the cost factors for the specific shelter types to be built.

A second series of minimum cost analyses was performed based on the maximization results contained in Table 23. For these analyses, the constraints pertaining to the types of shelters to be constructed were included. The results of the second series of analyses are given in Table 42 and supporting information pertaining to the types of shelters to be constructed and the quantities of resources needed is provided in Tables 43 through 50. As was stated previously, the results of these analyses may not be very useful unless there are reasons for increasing the number of shelter spaces provided by large shelters. It is interesting to note that the cost of a shelter program for the critical workforce increases from $981 million to $1,115 million when constraints on shelter type are included in the analysis. This is an increase of approximately 14 percent.

TABLE 42. MINIMUM COSTS FOR SHELTERING SELECTED PERCENTAGES OF THE POPULATION AT DIFFERENT SURGE PERIODS AND RESOURCE LEVELS WITH SHELTER CONSTRAINTS

Length of Surge Period	Percent Resources Made Available	Percent of Population To Be Sheltered*							Cost ($Millions)
		2.31	5	10	20	25	30	40	
3 Months	10%	X							1,115
	15%		X						2,504
	30%			X					5,008
6 Months	10%		X						2,414
	20%			X					4,827
	40%				X				9,655
	50%					X			12,068
9 Months	10%		X						2,380
	15%			X					4,973
	30%				X				9,947
	40%					X			11,896
	50%						X		14,249
12 Months	10%		X						2,293
	15%			X					4,672
	25%				X				10,036
	40%					X			11,636
	40%						X		14,266
	50%							X	20,072

*X's indicate the percentage of the population that could feasibly be sheltered at the indicated surge period and resource levels.

TABLE 43. NUMBER OF SHELTERS, BY TYPE, FOR COST-MINIMIZATION SOLUTION WITH SHELTER CONSTRAINTS: 3-MONTH SURGE PERIOD

		Percent of Resources Made Available			
		10	15	30	
		Percent of Risk Area Population To Be Sheltered			
Shelter Type	Capacity	2.31	5	10	20
1. Reinforced Concrete Rectangular	500	462			
2. Reinforced Concrete Rectangular	1,000	231			
3. Reinforced Concrete Arch	500	2,295	4,598	9,196	
4. Steel Arch	500		2,355	4,710	
5. Steel Dome	20	48,277	104,294	208,588	
6. Small Pole	12	53,641	115,882	231,765	

TABLE 44. NUMBER OF SHELTERS, BY TYPE, FOR COST-MINIMIZATION SOLUTION WITH SHELTER CONSTRAINTS: 6-MONTH SURGE PERIOD

		Percent of Resources Made Available					
		10	20	40	50		
Shelter Type	Capacity	Percent of Risk Area Population To Be Sheltered					
		5	10	20	25	30	40
1. Reinforced Concrete Rectangular	500						
2. Reinforced Concrete Rectangular	1,000						
3. Reinforced Concrete Arch	500	7,280	14,560	29,119	36,399		
4. Steel Arch	500	1,759	3,518	7,036	8,795		
5. Steel Dome	20	86,912	173,824	347,647	434,559		
6. Small Pole	12	57,941	115,882	231,765	289,706		

TABLE 45. NUMBER OF SHELTERS, BY TYPE, FOR COST-MINIMIZATION SOLUTION WITH SHELTER CONSTRAINTS: 9-MONTH SURGE PERIOD

		Percent of Resources Made Available					
		10	15	30	40	50	
		Percent of Risk Area Population To Be Sheltered					
Shelter Type	Capacity	5	10	20	25	30	40
1. Reinforced Concrete Rectangular	500	1,076			126	1,202	
2. Reinforced Concrete Rectangular	1,000	538			63	600	
3. Reinforced Concrete Arch	500	8,278	13,794	27,587	51,895	60,173	
4. Steel Arch	500		7,065	14,131			
5. Steel Dome	20	52,147	104,294	208,588	260,735	312,883	
6. Small Pole	12	57,941	115,882	231,765	289,706	347,647	

TABLE 46. NUMBER OF SHELTERS, BY TYPE, FOR COST-MINIMIZATION SOLUTION WITH SHELTER CONSTRAINTS: 12-MONTH SURGE PERIOD

		Percent of Resources Made Available					
		10	15	25	40	40	50
		Percent of Risk Area Population To Be Sheltered					
Shelter Type	Capacity	5	10	20	25	30	40
1. Reinforced Concrete Rectangular	500	2,270	1,038		4,345		
2. Reinforced Concrete Rectangular	1,000	1,135	519		2,173		
3. Reinforced Concrete Arch	500	7,281	21,565	26,055	50,410	65,135	52,110
4. Steel Arch	500			21,225		5,785	42,451
5. Steel Dome	20	34,765	69,530	139,059	173,824	208,588	278,118
6. Small Pole	12	28,971	57,941	115,882	144,853	173,824	231,765

TABLE 47. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR COST MINIMIZATION WITH SHELTER CONSTRAINTS: 3-MONTH SURGE PERIOD

	Percentage of Resources Made Available		
	10	5	10
	Percentage of Risk Area Population To Be Sheltered		
Resource	2.31	15	30
Concrete	3.47	6.10	12.20
Gravel	.10	.15	.30
Lumber	4.56	9.55	19.10
Plywood	.30	.36	.72
Reinforcing Steel	10.00	15.00	30.00
Structural Steel	1.02	10.11	20.22
Building Laborer	3.12	6.84	13.68
Carpenter	.67	1.31	2.61
Cement Finisher	.15	.25	.49
Electrician	.86	1.86	3.72
Equipment Operator	.51	1.21	2.43
Supervisory	.58	1.38	2.76
Maintenance	.75	1.60	3.20
Plumber	.05	.11	.22
Steel Worker	1.74	7.48	14.96

TABLE 48. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR COST MINIMIZATION WITH SHELTER CONSTRAINTS: 6-MONTH SURGE PERIOD

	Percentage of Population To Be Sheltered			
	5	10	20	25
	Percentage of Resources Made Available			
Resource	10	20	40	50
Concrete	4.41	8.82	17.64	22.05
Gravel	.10	.20	.39	.49
Lumber	2.61	5.21	10.43	13.04
Plywood	.25	.51	1.01	1.26
Reinforcing Steel	10.00	20.00	40.00	50.00
Structural Steel	4.38	8.77	17.53	21.92
Building Laborer	2.74	5.49	10.97	13.71
Carpenter	.49	.97	1.94	2.43
Cement Finisher	.19	.37	.74	.93
Electrician	.92	1.83	3.66	4.58
Equipment Operator	.69	1.37	2.74	3.43
Supervisory	.73	1.46	2.92	3.65
Maintenance	.73	1.46	2.93	3.66
Plumber	.06	.12	.24	.29
Steel Worker	3.79	7.59	15.18	18.97

TABLE 49. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR COST MINIMIZATION WITH SHELTER CONSTRAINTS: 9-MONTH SURGE PERIOD

	Percentage of Population To Be Sheltered				
	5	10	20	25	30
	Percentage of Resources Made Available				
Resource	10	15	30	40	50
Concrete	3.78	6.10	12.20	19.25	23.03
Gravel	.96	.15	.30	.38	.48
Lumber	1.88	3.51	7.03	8.98	10.86
Plywood	.29	.36	.71	1.08	1.38
Reinforcing Steel	10.00	15.00	30.00	40.00	50.00
Structural Steel	1.10	10.11	20.22	5.51	6.61
Building Laborer	1.75	3.51	7.03	9.29	11.05
Carpenter	.40	.70	1.40	1.76	2.16
Cement Finisher	.17	.25	.49	.84	1.01
Electrician	.60	1.19	2.39	2.98	3.58
Equipment Operator	.41	.90	1.80	2.30	2.72
Supervisory	.41	.91	1.83	2.28	2.69
Maintenance	.36	.72	1.44	1.80	2.17
Plumber	.04	.07	.15	.19	.22
Steel Worker	1.83	7.40	14.80	9.09	10.93

TABLE 50. ACTUAL PERCENTAGE OF RESOURCES USED IN A SHELTER PROGRAM FOR COST MINIMIZATION WITH SHELTER CONSTRAINTS: 12-MONTH SURGE PERIOD

	Percentage of Population To Be Sheltered					
	5	10	20	25	30	40
	Percentage of Resources Made Available					
Resource	10	15	25	40	40	50
Concrete	3.16	6.50	9.49	16.15	18.67	18.98
Gravel	.10	.14	.26	.38	.38	.51
Lumber	.94	1.68	3.07	4.30	4.81	6.13
Plywood	.31	.42	.57	1.15	1.05	1.14
Reinforcing Steel	10.00	15.00	25.00	40.00	40.00	50.00
Structural Steel	.94	1.87	21.56	46.79	10.47	43.11
Building Laborer	1.05	2.36	4.40	5.76	7.17	8.79
Carpenter	.30	.49	.90	1.28	1.36	1.81
Cement Finisher	.14	.28	.37	.71	.81	.74
Electrician	.44	.88	1.77	2.21	2.65	3.53
Equipment Operator	.29	.69	1.41	1.68	2.18	2.82
Supervisory	.28	.66	1.39	1.60	2.08	2.78
Maintenance	.24	.46	.92	1.16	1.38	1.84
Plumber	.03	.06	.11	.14	.17	.23
Steel Worker	1.56	3.09	14.63	7.73	11.54	29.27

VII. CONCLUSIONS AND RECOMMENDATIONS

On the basis of the analyses described in the preceding sections, a number of conclusions may be drawn. The following are included:

1. A risk area shelter program for the critical workforce is feasible for any of the surge period lengths considered in this study without a significant impact on the normal production and distribution of resources.

2. A minimum surge period length of 6 months and the use of 50 percent of the plate and reinforcing steel produced nationally would be required to implement a risk area shelter program for in-place sheltering of the entire resident population.

3. An in-place shelter program for the entire risk area population can be implemented with 25 percent of the production of plate and reinforcing steel, if the surge period length is increased to 12 months.

4. Steel is the only material that is needed in quantities sufficiently large to disrupt the normal pattern of usage.

Below are several recommendations developed as a result of the experience gained during the performance of this study.

1. Steel and construction labor appear to be the only resources that limit the construction of risk area shelters. It is RTI's opinion that the labor shortage can be alleviated by using more skilled labor from other labor groups or student labor. The steel shortage may be more difficult to alleviate, but our preliminary investigation of the steel industry indicates that raw steel production can be increased significantly. The question that remains unanswered is whether or not this increased raw steel production can be processed into plate and reinforcing steel. RTI recommends that additional study be devoted to the ability of the steel industry to provide the steel needed for risk area shelter construction.

2. A second means of alleviating the shortage of steel would be to purchase a portion of the amount that would be needed and store it in the risk areas. RTI recommends that an investigation be made to determine the feasibility and cost of such a program.

3. It is recognized that probably the greatest impediment to expeditious construction initiation would be the identification and securing of land at locations where shelters are needed. Regardless of how soon the shelters might be built, if at all, it is recommended that the Federal Government, perhaps through civil

defense agencies in each state, undertake extensive compilation of data on land potentially available to meet needs. Further, it is recommended that the government at least obtain options on likely land to meet minimum initial shelter space needs so that land may be secured for construction on very short notice.

The greatest number of blast shelter spaces will be needed in the most urbanized areas, where land is least available. We therefore, recommend that consideration be given to designing and locating shelters to serve auxiliary purposes, such as for low-income housing, schools, and parking, during normal times.

In addition to the above items, RTI recommends the following areas for further research.

1. Perform case studies of shelter construction programs for small areas such as cities, counties, and counterforce areas to take into into consideration unique characteristics such as soil conditions and the local availability of material, labor, and equipment.

2. Perform a Project Evaluation and Review Technique (PERT) type of analysis, incorporating all the activities pertaining to shelter construction programs. A combination of simulation and PERT analyses could provide further insight into the problems of shelter planning and construction, by taking into consideration any limitations on shelter building capability that might result from scheduling of equipment and labor.

3. Construct prototype shelters to validate time and cost estimates.

4. Conduct methods-improvement and value-engineering studies on the design and construction of the selected shelter types. This would result in the determination of optimum shelter designs, crew size, and construction methods and procedures.

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APPENDIX A

UPGRADING EXISTING STRUCTURES

APPENDIX A
UPGRADING OF EXISTING SHELTERS

One of the options initially earmarked for study along with the six shelter types was the expedient upgrading of existing structures. However, a literature search in this field revealed that with the exception of caves, subway stations, tunnels, and mines, all other structures cannot withstand a blast overpressure of more than 10 psi and possibly cannot be upgraded to withstand 50 psi overpressure (see Table A-1). Caves, subway stations, and tunnels were not considered in the scope of this study.

For the purpose of comparison, a few estimates were made regarding the number of supports needed, backfill required, and the total cost of upgrading basements and first floors of typical structures. The estimates were prepared by using information from reference 1, Upgrading Basements for Combined Nuclear Weapons Effects: Expedient Options, by Stanford Research Institute. The following protective measures were presumed as the basis for the estimates:

1. prevention of air blast entry,
2. air blast loading reduction on exterior surfaces,
3. air blast structural strengthening, and
4. provision of radiation protection.

The major variables affecting the resources and cost of upgrading a structure are:

1. dimensions,
2. appertures in the building,
3. height of exposed walls,
4. length of unsupported beams, and
5. amount of backfill needed.

RTI's Statistical Classification Report [Ref. 2] which classifies the National Fallout Shelter Survey (NFSS) inventory of buildings, was used to identify the most commonly occuring types of structures. For convenience, each structure was assumed to have a square floor plan. The capacity of each structure was calculated by allocating 10 square feet per person. Apperture percentages were chosen from the most common ones found in structures. Similarly, the most commonly occuring percentage of exposed lower-story walls was selected from the Statistical Classification Report. Six sizes of buildings, six apperture percentages, three wall exposure heights, and six sets of numbers of midspan supports were considered in these estimates. The average cost for providing a unit of midspan support, for closing a unit of apperture, and for providing a unit volume of backfill were calculated. The cost estimates for individual structures were developed by using these unit costs. The estimates are given in Table A-2.

TABLE A-1. RELATIVE BLAST PROTECTION IN CONVENTIONAL STRUCTURES

Structure Category	Blast Code	MLOP psi (kPa)	MIOP psi (kPa)
1. Subway stations, tunnels, mines and caves.	A	>35 (241.32)	>10 (68.95)
2. Basements and subbasements of massive (monumental) masonry buildings.	B	10 (68.95)	7 (48.26)
3. Basements and subbasements of large, fully engineered structures having any floor system over the basement other than wood, concrete flat plate, or band beam support.	C	10 (68.95)	7 (48.26)
4. Basements of wood frame and brick veneer structures including residences.	D	10 (68.95)	4 (27.58)
5. First three stories of buildings with "strong" walls, less than 10 aboveground stories, and less than 50 percent apertures.	E	8 (55.16)	2 (13.79)
6. Fourth through ninth stories of buildings with "strong" walls, less than 10 aboveground stories, and less than 50 percent apertures.	F	8 (55.16)	2 (13.79)
7. Basements and subbasements of buildings with a flat plate or band beam supported floor system over the basement.	G	5 (34.47)	2 (13.79)
8. First three stories of buildings with "strong" walls, less than 10 aboveground stories, and greater than 50 percent apertures; or first three stories of buildings with "weak" walls and less than 10 aboveground stories.	H	5 (34.47)	2 (13.79)
9. All aboveground stories of buildings having 10 or more stories. Fourth through ninth stories of buildings having "weak" walls.	I	5 (34.47)	2 (13.79)

TABLE A-2. RESOURCE REQUIREMENTS FOR UPGRADING EXISTING STRUCTURES

	Capacity (Persons)	Dimensions (feet)	Apertures (Percent)	Exposed Height (Percent)	No. of Midspan Supports	Aperture Area (S.Y.)	Backfill (C.Y.)	COSTS ($)				
								Midspan Supports	Closing Apertures	Backfill	Total	Total Incld. O&P
1	3,750	194x194x9	15%	100%	200	744	3,184	14,000	26,784	3,311	44,095	52,575
	3,750	194x194x9	15%	50%	200	744	1,592	14,000	26,784	1,656	42,440	50,602
	3,750	194x194x9	15%	25%	200	744	796	14,000	26,784	828	41,612	49,614
	3,750	194x194x9	25%	100%	200	1,239	3,184	14,000	44,604	3,311	61,915	73,822
	3,750	194x194x9	25%	50%	200	1,239	1,592	14,000	44,604	1,656	60,260	71,848
	3,750	194x194x9	25%	25%	200	1,239	796	14,000	44,604	828	59,432	70,861
	3,750	194x194x9	5%	100%	200	248	3,184	14,000	8,928	3,311	26,239	31,285
	3,750	194x194x9	5%	50%	200	248	1,592	14,000	8,928	1,656	24,584	29,312
	3,750	194x194x9	5%	25%	200	248	796	14,000	8,928	828	23,756	28,324
	3,750	194x194x9	35%	100%	200	1,735	3,184	14,000	62,460	3,311	79,771	95,112
	3,750	194x194x9	35%	50%	200	1,735	1,592	14,000	62,460	1,656	78,116	93,138
	3,750	194x194x9	35%	25%	200	1,735	796	14,000	62,460	828	77,288	92,151
	3,750	194x194x9	45%	100%	200	2,231	3,184	14,000	80,316	3,311	97,627	116,401
	3,750	194x194x9	45%	50%	200	2,231	1,592	14,000	80,316	1,656	95,972	114,428
	3,750	194x194x9	45%	25%	200	2,231	796	14,000	80,316	828	95,144	113,441
	3,750	194x194x9	55%	100%	200	2,727	3,184	14,000	98,172	3,311	116,023	138,335
	3,750	194x194x9	55%	50%	200	2,727	1,592	14,000	98,172	1,656	114,368	136,362
	3,750	194x194x9	55%	25%	200	2,727	796	14,000	98,172	828	113,540	135,375
2	2,000	141x141x9	15%	100%	104	416	2,055	7,280	14,976	2,137	24,393	29,084
	2,000	141x141x9	15%	50%	104	416	1,028	7,280	14,976	1,069	23,325	27,810
	2,000	141x141x9	15%	25%	104	416	514	7,280	14,976	535	22,791	27,174
	2,000	141x141x9	25%	100%	104	693	2,055	7,280	24,948	2,137	34,365	40,974
	2,000	141x141x9	25%	50%	104	693	1,028	7,280	24,948	1,069	33,297	39,700
	2,000	141x141x9	25%	25%	104	693	514	7,280	24,948	535	32,763	39,063
	2,000	141x141x9	5%	100%	104	139	2,055	7,280	5,004	2,137	14,421	17,194
	2,000	141x141x9	5%	50%	104	139	1,028	7,280	5,004	1,069	13,353	15,921
	2,000	141x141x9	5%	25%	104	139	514	7,280	5,004	535	12,819	15,284
	2,000	141x141x9	35%	100%	104	970	2,055	7,280	34,920	2,137	44,337	52,863
	2,000	141x141x9	35%	50%	104	970	1,028	7,280	34,920	1,069	43,269	51,590
	2,000	141x141x9	35%	25%	104	970	514	7,280	34,920	535	42,735	50,953
	2,000	141x141x9	45%	100%	104	1,247	2,055	7,280	44,892	2,137	54,309	64,753
	2,000	141x141x9	45%	50%	104	1,247	1,028	7,280	44,892	1,069	53,241	63,480
	2,000	141x141x9	45%	25%	104	1,247	514	7,280	44,892	535	52,707	62,843
	2,000	141x141x9	55%	100%	104	1,525	2,055	7,280	54,900	2,137	64,317	76,686
	2,000	141x141x9	55%	50%	104	1,525	1,028	7,280	54,900	1,069	63,249	75,412
	2,000	141x141x9	55%	25%	104	1,525	514	7,280	54,900	535	62,715	74,776

(Continued)

TABLE A-2. RESOURCE REQUIREMENTS FOR UPGRADING EXISTING STRUCTURES (Continued)

	Capacity (Persons)	Dimensions (feet)	Apertures (Percent)	Exposed Height (Percent)	No. of Midspan Supports	Aperture Area (S.Y.)	Backfill (C.Y.)	COSTS ($)				
								Midspan Supports	Closing Apertures	Backfill	Total	Total Incld. O&P
5	350	59x59x9	15%	100%	53	93	720	3,710	3,348	749	7,807	9,308
	350	59x59x9	15%	50%	53	93	360	3,710	3,348	374	7,432	8,861
	350	59x59x9	15%	25%	53	93	180	3,710	3,348	187	7,245	8,638
	350	59x59x9	25%	100%	53	156	720	3,710	5,616	749	7,807	9,308
	350	59x59x9	25%	50%	53	156	360	3,710	5,616	374	7,432	8,861
	350	59x59x9	25%	25%	53	156	180	3,710	5,616	187	7,245	8,638
	350	59x59x9	5%	100%	53	31	720	3,710	1,116	749	7,807	9,308
	350	59x59x9	5%	50%	53	31	360	3,710	1,116	374	7,432	8,861
	350	59x59x9	5%	25%	53	31	180	3,710	1,116	187	7,245	8,638
	350	59x59x9	35%	100%	53	218	720	3,710	7,848	749	7,807	9,308
	350	59x59x9	35%	50%	53	218	360	3,710	7,848	374	7,432	8,861
	350	59x59x9	35%	25%	53	218	180	3,710	7,848	187	7,245	8,638
	350	59x59x9	45%	100%	53	280	720	3,710	10,080	749	7,807	9,308
	350	59x59x9	45%	50%	53	280	360	3,710	10,080	374	7,432	8,861
	350	59x59x9	45%	25%	53	280	180	3,710	10,080	187	7,245	8,638
	350	59x59x9	55%	100%	53	343	720	3,710	12,348	749	7,807	9,308
	350	59x59x9	55%	50%	53	343	360	3,710	12,348	374	7,432	8,861
	350	59x59x9	55%	25%	53	343	180	3,710	12,348	187	7,245	8,638
6	6,250	250x250x9	15%	100%	289	1,192	4,603	20,230	42,912	4,787	67,929	80,992
	6,250	250x250x9	15%	50%	289	1,192	2,302	20,230	42,912	2,394	65,536	78,139
	6,250	250x250x9	15%	25%	289	1,192	1,151	20,230	42,912	1,197	64,339	76,712
	6,250	250x250x9	25%	100%	289	1,986	4,603	20,230	71,496	4,787	67,929	80,992
	6,250	250x250x9	25%	50%	289	1,986	2,302	20,230	71,496	2,394	65,536	78,139
	6,250	250x250x9	25%	25%	289	1,986	1,151	20,230	71,496	1,197	64,339	76,712
	6,250	250x250x9	5%	100%	289	397	4,603	20,230	14,292	4,787	67,929	80,992
	6,250	250x250x9	5%	50%	289	397	2,302	20,230	14,292	2,394	65,536	78,139
	6,250	250x250x9	5%	25%	289	397	1,151	20,230	14,292	1,197	64,339	76,712
	6,250	250x250x9	35%	100%	289	2,781	4,603	20,230	100,116	4,787	67,929	80,992
	6,250	250x250x9	35%	50%	289	2,781	2,302	20,230	100,116	2,394	65,536	78,139
	6,250	250x250x9	35%	25%	289	2,781	1,151	20,230	100,116	1,197	64,339	76,712
	6,250	250x250x9	45%	100%	289	3,575	4,603	20,230	128,700	4,787	67,929	80,992
	6,250	250x250x9	45%	50%	289	3,575	2,302	20,230	128,700	2,394	65,536	78,139
	6,250	250x250x9	45%	25%	289	3,575	1,151	20,230	128,700	1,197	64,339	76,712
	6,250	250x250x9	55%	100%	289	4,369	4,603	20,230	157,284	4,787	67,929	80,992
	6,250	250x250x9	55%	50%	289	4,369	2,302	20,230	157,284	2,394	65,536	78,139
	6,250	250x250x9	55%	25%	289	4,369	1,151	20,230	157,284	1,197	64,339	76,712

TABLE A-2. RESOURCE REQUIREMENTS FOR UPGRADING EXISTING STRUCTURES (Continued)

Capacity (Persons)	Dimensions (feet)	Apertures (Percent)	Exposed Height (Percent)	No. of Midspan Supports	Aperture Area (S.Y.)	Backfill (C.Y.)	COSTS ($)				
							Midspan Supports	Closing Apertures	Backfill	Total	Total Incld. O&P
3 750	87x87x9	15%	100%	42	178	1,120	2,940	6,408	1,165	10,513	12,535
750	87x87x9	15%	50%	42	178	560	2,940	6,408	582	9,930	11,840
750	87x87x9	15%	25%	42	178	280	2,940	6,408	291	9,639	11,493
750	87x87x9	25%	100%	42	297	1,120	2,940	10,692	1,165	14,797	17,643
750	87x87x9	25%	50%	42	297	560	2,940	10,692	582	14,214	16,948
750	87x87x9	25%	25%	42	297	280	2,940	10,692	291	13,923	16,601
750	87x87x9	5%	100%	42	59	1,120	2,940	2,124	1,165	6,229	7,427
750	87x87x9	5%	50%	42	59	560	2,940	2,124	582	5,646	6,732
750	87x87x9	5%	25%	42	59	280	2,940	2,124	291	5,355	6,385
750	87x87x9	35%	100%	42	416	1,120	2,940	14,976	1,165	19,081	22,750
750	87x87x9	35%	50%	42	416	560	2,940	14,976	582	18,498	22,055
750	87x87x9	35%	25%	42	416	280	2,940	14,976	291	18,207	21,708
750	87x87x9	45%	100%	42	535	1,120	2,940	19,260	1,165	23,365	27,858
750	87x87x9	45%	50%	42	535	560	2,940	19,260	582	22,782	27,163
750	87x87x9	45%	25%	42	535	280	2,940	19,260	291	23,073	27,510
750	87x87x9	55%	100%	42	654	1,120	2,940	23,544	1,165	27,649	32,966
750	87x87x9	55%	50%	42	654	560	2,940	23,544	582	27,066	32,271
750	87x87x9	55%	25%	42	654	280	2,940	23,544	291	27,357	32,618
4 1,250	112x112x9	15%	100%	68	276	1,576	4,760	9,936	1,165	16,222	19,416
1,250	112x112x9	15%	50%	68	276	763	4,760	9,936	763	15,459	18,432
1,250	112x112x9	15%	25%	68	276	382	4,760	9,936	382	15,078	17,978
1,250	112x112x9	25%	100%	68	460	1,576	4,760	16,560	1,165	22,846	27,240
1,250	112x112x9	25%	50%	68	460	763	4,760	16,560	763	22,083	26,330
1,250	112x112x9	25%	25%	68	460	382	4,760	16,560	382	21,702	25,876
1,250	112x112x9	5%	100%	68	92	1,576	4,760	3,312	1,165	9,598	11,444
1,250	112x112x9	5%	50%	68	92	763	4,760	3,312	763	8,835	10,534
1,250	112x112x9	5%	25%	68	92	382	4,760	3,312	382	8,454	10,080
1,250	112x112x9	35%	100%	68	645	1,576	4,760	23,220	1,165	29,506	35,180
1,250	112x112x9	35%	50%	68	645	763	4,760	23,220	763	28,743	34,271
1,250	112x112x9	35%	25%	68	645	382	4,760	23,220	382	28,362	33,816
1,250	112x112x9	45%	100%	68	829	1,576	4,760	29,844	1,165	36,130	43,078
1,250	112x112x9	45%	50%	68	829	763	4,760	29,844	763	35,367	42,168
1,250	112x112x9	45%	25%	68	829	382	4,760	29,844	382	34,986	41,714
1,250	112x112x9	55%	100%	68	1,013	1,576	4,760	36,468	1,165	42,754	50,976
1,250	112x112x9	55%	50%	68	1,013	763	4,760	36,468	763	41,991	50,066
1,250	112x112x9	55%	25%	68	1,013	382	4,760	36,468	382	41,610	49,612

(Continued)

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APPENDIX B

DEFINITIONS OF TERMS AND ABBREVIATIONS

APPENDIX B

DEFINITIONS OF TERMS AND ABBREVIATIONS

This appendix provides an alphabetical listing of abbreviations and symbols used in tables in this report. Also provided below is a tabular presentation of the standard construction crews cited in the "Crew Type" columns of Tables 4 through 14.

Burial options: 1 - Fully Buried
2 - Semiburied
3 - Above Ground

CARP. - Carpenter

CLAB. - Common Laborer

C.L.F. - Hundred Linear Feet

C.S.F. - Hundred square Feet

C.Y. - Cubic Yards

E - Equipment

ELEC. - Electrician

Incl. - Including

LBS. - Pounds

L.F. or Lin. Ft. - Linear Feet

M - Material

M.F.B.M. - Thousand Feet Board Measure

O&P - Overheads and Profits

Reinf. - Reinforcements

S.F. - Square Feet

Sswk. - Structural Steel Worker

Struct. - Structural

Subs. - Subcontractors

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TABLE B-1. INDIVIDUAL LABOR RATES FOR SELECTED LABOR CATEGORIES*

	Bare Costs		Incl. Subs. O & P	
	Hr.	Daily	Hr.	Daily
1 Building Laborer	$ 10.40	$ 83.20	$ 14.60	$ 116.80
1 Carpenter	13.20	105.60	18.25	146.00
1 Electrician	14.85	118.80	20.80	166.40
1 Rodman (reinf.)	14.15	113.20	20.85	166.80
1 Struct. Steel Workers	14.20	113.60	22.00	176.00

TABLE B-2. STANDARD CREWS*

Crew No.	Bare Costs		Incl. Subs. O & P	
Crew B-7	Hr.	Daily	Hr.	Daily
1 Foreman	$ 10.90	$ 87.20	$ 15.30	$ 122.40
4 Building Laborers	10.40	332.80	14.60	467.20
1 Equip. Oper. (med.)	13.40	107.20	19.20	153.60
1 Chipping machine		82.25		90.50
1 Front End Loader		292.80		322.10
48 M.H., Daily Total		$902.25		$1155.80

Crew B-10 [A-U]	Hr.	Daily	Hr.	Daily
1 Equip. Oper. (med.)	$ 13.40	$107.20	$19.20	$153.60
.5 Building Laborer	10.40	41.60	14.60	58.40
Add equip. costs below				
12 M.H., Daily Total (labor only)		$148.80		$212.00

Crew	Equipment	Dly. Bare Cost	Dly. Incl. O&P
B-10A	1 Roller compactor, 2000 lb.	$49.80	$54.80

B-10D	1 Dozer, 180 H.P.	$333.80	$367.20
	1 Sheepsfoot roller, towed	49.40	54.30
	Daily Total	$383.20	$421.50

(Continued)

TABLE B-2. STANDARD CREWS (Continued)*

Crew	Equipment	Dly. Bare Cost	Dly. Incl. O&P
B-10 0	F.E. Loader T.M., 2 1/2 C.Y.	$292.80	$322.10

Crew No.	Bare Costs		Incl. Subs. O & P	
Crew B-15	Hr.	Daily	Hr.	Daily
Crew B-10		$148.80		$ 212.00
2 Truck Drivers	$ 10.75	172.00	$ 15.00	240.00
2 Trucks Heavy		334.00		367.40
1 Dozer, 180 H.P.		333.80		367.20
28 M.H., Daily Total		$988.60		$1186.60

Crew B-20	Hr.	Daily	Hr.	Daily
1 Foreman	$ 15.20	$121.60	$ 21.40	$ 171.20
1 Plumber	14.70	117.60	20.70	165.60
1 Building Laborer	10.40	83.20	14.60	116.80
24 M.H., Daily Total		$322.40		$ 453.60

(Continued)

TABLE B-2. STANDARD CREWS (Continued)*

Crew No.	Bare Costs		Incl. Subs. O & P	
Crew B-21	Hr.	Daily	Hr.	Daily
1 Foreman	$ 15.20	$121.60	$ 21.40	$ 171.20
1 Plumber	14.70	117.60	20.70	165.60
1 Building Laborer	10.40	83.20	14.60	116.80
0.5 Equip Oper.(crane)	13.80	55.20	19.80	79.20
0.5 Self-prop Crane, 5 ton		50.00		55.00
28 M.H., Daily Total		$427.60		$ 587.80

Crew C-6	Hr.	Daily	Hr.	Daily
1 Labor Foreman	$ 10.90	$ 87.20	$ 15.30	$ 122.40
4 Building Laborers	10.40	332.80	14.60	467.20
1 Cement Finisher	12.85	102.80	17.55	140.40
2 Gas eng. vibrators		32.00		35.20
48 M.H., Daily Total		$554.80		$ 765.20

Crew No.	Bare Costs		Incl. Subs. O & P	
Crew C-7	Hr.	Daily	Hr.	Daily
Crew C-6 from above		$ 554.80		$ 765.20
1 Building Laborer	$ 10.40	83.20	$ 14.60	116.80
1 Equip. Oper. (med.)	13.40	107.20	19.20	153.60
1 Crane or Pump		449.20		494.10
64 M.H., Daily Total		$1194.40		$1529.70

(Continued)

TABLE B-2. STANDARD CREWS (Continued)*

Crew No.	Bare Costs		Incl. Subs. O & P	
Crew C-8	Hr.	Daily	Hr.	Daily
1 Labor Foreman	$ 10.90	$ 87.20	$ 15.30	$ 122.40
3 Building Laborers	10.40	249.60	14.60	350.40
2 Cement Finishers	12.85	205.60	17.55	280.80
1 Equip. Oper. (med.)	13.40	107.20	19.20	153.60
1 Conc. pump (small)		172.60		189.85
56 M.H., Daily Total		$822.20		$1097.05

Crew C-14	Hr.	Daily	Hr.	Daily
15 Carpenters	$ 13.20	$1584.00	$ 18.25	$2190.00
7 Building Laborers	10.40	582.40	14.60	817.60
6 Rodmen (reinf.)	14.15	679.20	20.85	1000.80
1 Cement Finisher	12.85	102.80	17.55	140.40
1 Equip. Oper. (med.)	13.40	107.20	19.20	153.60
1 Crane & power tools		440.90		485.00
240 M.H., Daily Total		$3496.50		$4787.40

Crew E-4	Hr.	Daily	Hr.	Daily
1 Struct Steel Foreman	$ 14.70	$117.60	$ 22.75	$ 182.00
3 Struct Steel Workers	14.20	340.80	22.00	528.00
1 Gas Welding Machine, 300 A		30.25		33.25
32 M.H., Daily Total		$488.65		$ 743.25

TABLE B-2. STANDARD CREWS (Continued)

Crew No.	Bare Costs		Incl. Subs. O & P	
Crew F-2	Hr.	Daily	Hr.	Daily
2 Carpenters	$ 13.20	$ 211.20	$ 18.25	$ 292.00
Power Tools		9.90		10.90
16 M. H., Daily Total		$ 211.20		$ 302.90

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Crew No.	Bare Costs		Incl. Subs. O & P	
Crew S-2	Hr.	Daily	Hr.	Daily
11 Struct Steel Workers	$ 14.70	$1,293.80	$ 22.75	$2,002.00
2 Equp. Oper (Med.)	13.40	214.40	19.20	307.20
1 Hydraulic Crane 55 Ton		417.20		458.90
1 Air Compressor, 160 C.F.M.		64.60		71.10
2 Impact Wrenches; pneumatic		32.00		35.20
104 M. H. Daily Total		$2,021.80		$2,874.40

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FEMA Contract No. DCPA01-79-C-0233
Feasibility and Cost Analysis of Surge Period Shelter Programs
Kamath, R. V., and M. D. Wright
June 1980 (UNCLASSIFIED) 135 pages

Protection of the civilian population from the effects of a nuclear attack is one of the goals of the Federal Emergency Management Agency (FEMA). In-place population protection and protection by relocation are two distinct types of civilian protection plans that are used. The in-place plans demand direct effects protection for the entire risk area populaton, while in the latter case only a skeleton work force needs to be protected. This report describes the investigation into the feasibility and costs of providing all-effects shelters in risk areas for an in-place shelter plan as well as a population relocation plan.

The major variables affecting the feasibility and costs of providing shelter spaces are the time available, the population to be sheltered, the shelter design used, and the resource requirements and availability.

RTI estimated the construction costs and resource requirements and assessed the nationwide availability of these resources for each of six shelter designs. Linear programming was used to calculate the capability of providing shelter spaces for various surge period lengths. Minimum costs of providing protection to selected percentages of the population were also computed for the same surge periods. Critical resources that limit shelter building capability were identified and means for improving this capability were suggested.

The results of the study show that the critical workforce can be sheltered under all surge period lengths. Housing the entire risk area population would require a minimum surge period of 6 months and the diversion of 50 percent of the Nation's reinforcement and plate steel production.

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