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**POSTATTACK RECOVERY MANAGEMENT:  
CONCEPTS AND TECHNIQUES  
FOR MODEL DEVELOPMENT**

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STANFORD RESEARCH INSTITUTE

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## CONTENTS

INTRODUCTION . . . . .	1
RECOVERY MODEL SYSTEM . . . . .	5
Weapons Effects and Vulnerability Models . . . . .	5
Economic System Models . . . . .	9
Agricultural Production Models . . . . .	11
Mineral Production Models . . . . .	11
Industrial Processing Models . . . . .	12
Transportation Models . . . . .	12
Storage and Distribution Models . . . . .	13
Utility and Energy Source Models . . . . .	13
Countermeasure Models . . . . .	13
Decontamination and Dose Control Models . . . . .	14
Debris Clearance and Salvage Models . . . . .	17
Damage Repair Models . . . . .	19
Medical Treatment Models . . . . .	19
Evacuation Models . . . . .	22
Preattack Preparation Models . . . . .	22
Civil Defense Organization Models . . . . .	23
Recovery Requirement Models . . . . .	23
Recovery Planning Models . . . . .	23
Recovery Management Models . . . . .	23
Parameter Limits of Models . . . . .	24
GENERAL APPROACH TO MODEL DESIGN AND DEVELOPMENT . . . . .	25
Linear Flow Diagram . . . . .	25
Description of Elements . . . . .	25
Expanded Flow Network . . . . .	25
Operational System Models . . . . .	27
Model Design for Water and Bread Systems . . . . .	27
Water System . . . . .	27
Bread System and Bakery Subsystem . . . . .	36

CONTENTS

RECOVERY MANAGEMENT CONCEPTS AND SOME RELATED MODEL DETAILS . . .	49
Recovery Management Concepts . . . . .	49
Recovery Requirements Model Details . . . . .	50
Consumption and Stockpile Depletion Relationships . . . . .	57
Stockpile Use and Recovery . . . . .	60
Recovery Scheduling Techniques . . . . .	65
SUMMARY AND RECOMMENDATIONS . . . . .	67
REFERENCES . . . . .	69
APPENDIX	
SOME RECOVERY REQUIREMENT MODEL PARAMETERS	
FOR THE FOOD SYSTEM . . . . .	A-1
General Supply, Consumption, and Diet Considerations . . . . .	A-1
Perishable Foods . . . . .	A-10
Nonperishable Foods . . . . .	A-17
APPENDIX REFERENCES . . . . .	A-21

## ILLUSTRATIONS

1	Functional Relationships Among Recovery Models of Table 1 . . . . .	8
2	Functional Relationship of Economic System Models . . . . .	10
3	Decontamination and Dose Control Model . . . . .	16
4	Debris Clearance Model . . . . .	18
5	Damage Repair Model . . . . .	20
6	Medical Treatment Model . . . . .	21
7	Linear Flow Diagram for Utilities . . . . .	26
8	Linear Flow Diagram for Water . . . . .	28
9	Expanded Network for a Water System . . . . .	31
10	Treatment Subsystem Flow Diagram for Water . . . . .	33
11	Linear Flow Diagram for a Bread System . . . . .	37
12	Expanded Network for a Bread System . . . . .	39
13	Bread Subsystem Network for Bakeries . . . . .	43
14	Typical Flow Diagram for Product $i$ Through $l$ Processes . . .	59
15	Inventory Utilization Matrices . . . . .	62
16	Relationships Among $\dot{i}_l$ , Supply and Demand, Inventory $R_{jk}$ In Process, and Recovery Capability for Product $i$ . . . . .	64
A-1	Relationships Among Production Rate, Consumption Rate, and the Stockpile of Single Perishable Crop . . . . .	A-12
A-2	Seasonal Variation of $E_1$ for Nonperishable Food Product $i$ . .	A-19

TABLES

1	Recovery Model System . . . . .	6
2	Functions of Postattack Countermeasure Models . . . . .	15
3	Description of Water System Elements . . . . .	29
4	Per Capita Requirements per Day for Water . . . . .	34
5	Sensitivity of Water System Components to Nuclear Weapons Effects . . . . .	35
6	Sensitivity of Bread System Components to Nuclear Weapon Effects . . . . .	41
7	Estimates of Specific Rates and Capacities for the Input Resources of a Typical Bakery . . . . .	45
8	Nuclear Attack Consequence and Applicable Countermeasures for the Bakery Subsystem . . . . .	47
9	Survival Items . . . . .	51
10	Summary of Recovery Requirement and Industrial Model Parameter Designators . . . . .	53
A-1	Significant Food Consumption Forms . . . . .	A-2
A-2	Estimated Values of $\dot{c}_i$ , $f_{ijk}$ , and $a_{ijk}$ for Significant Food Commodities . . . . .	A-5
A-3	Estimated Food Supply at Various Stages of Distribution . . . . .	A-9
A-4	$\dot{O}_1^m$ and $\dot{C}_1^m$ for Fresh Lima Bean Crops . . . . .	A-16
A-5	Seasonal Variation of Fresh Lima Bean Consumption . . . . .	A-18

## INTRODUCTION

Organized postattack recovery operations can be considered in terms of sequential actions for the restoration of at least minimum operating capabilities of socioeconomic systems needed to ensure continued existence of survivors. The minimum requirements for a scheduled recovery of the systems, in terms of time, type, and amount, will depend on both the subsistence needs of individuals and the number of survivors (injured as well as uninjured). On a national basis, the expenditure of effort and supplies in recovery operations includes consideration of recovery of all systems that contribute directly or indirectly to recovery at the consumer level. The specification of organized postattack recovery operations and their management require information that relates survival needs to system recovery and operation.

At least two steps are entailed in the recovery of the output of a component of an industrial system (i.e., the physical resources of an economic system). The first is the recovery of the use of the components, and the second is the recovery of its productive operations. The actions for each step and their occurrence will depend critically on the post-attack environment in a given geographical area. For areas in which the component is undamaged and received only light deposits of fallout, the first step would not be required, and the achievement of the second step would generally depend only on the availability of inputs (or acceptable substitute inputs) to the component. For areas that are exposed to high levels of blast and thermal effects in which the component is destroyed, both recovery steps are infeasible (at least within the time scale of recovery operations concerned with subsistence needs of survivors following a nuclear attack). In all other geographic areas, both recovery steps would be required, and it is in these areas that the major postattack recovery operations would take place. The postattack environments in this third category of areas would range from those in which moderate levels of fallout occurred (with no physical damage to industrial components from other explosion phenomena) to those in which moderate to heavy levels of physical damage of industrial components occurred.

Although the upper limit of damage for possible recovery of an area might be considered to occur where industrial components are damaged but repairable, the feasible limits for recovery would depend on whether the



subsistence survivor needs (including recovery of their production) could be supplied without interruption on the basis of the capabilities of the survivors (with or without assistance from nearby areas) and the resources available to them.

To establish approximate limits of feasibility for the recovery of industrial components and systems and, for those feasible, to establish requirements (with respect to survivor needs) and planning guidance (with respect to the sequence of recovery operations), quantitative estimates of the recovery process are needed. First, such estimates should provide information on the nature and scope of the recovery problem, including the specification of factors that significantly influence the limits of feasibility mentioned above. Second, the estimates should provide information on potential rates of recovery of production for survival as well as information on how the rates may depend on preattack preparations and the application of postattack countermeasures.

Since there is no experience on recovery from massive nuclear attack, system models offer a means of investigating recovery processes for hypothetical postattack situations. Exercising such models for a range of postattack situations should provide information that can be used in pre-attack development of effective postattack recovery planning procedures and management decision guidance criteria. Both would be difficult to develop extemporaneously after an attack.

Within the scope of this discussion, the objectives of the research in defining postattack recovery activities were:

1. To develop general concepts of models providing methods for controlling and managing postattack recovery operations
2. To describe specific approaches applicable to the development of postattack situation models
3. To indicate the scope and detail required for the development of certain models closely related to Office of Civil Defense responsibility

The approach used to achieve the objectives was to describe a post-attack recovery model system, its scope, and the interrelationships of its submodels. The scope of submodels within the system was defined to ensure that each submodel, developed in detail from future related research effort, will function properly as part of the recovery model system.

The current status of each model of the system is indicated in this report, and its important input and output parameters are described. Typical model development techniques are illustrated by examples. A

relationship between model outputs and management decision guidance criteria for countermeasures of primary interest to OCD are established within the current framework of model development.

## RECOVERY MODEL SYSTEM

A recovery model system consists of four types of models defining a postattack situation and the processes of recovery: weapon effects, economic systems, countermeasures, and civil defense organization to implement countermeasures. A series of submodels for each of the four functional categories of the recovery model system is listed in Table 1, together with estimates of their respective current state of development based on the existing knowledge of the required inputs and the current model capabilities. In some cases, reliable inputs are not available, no model exists, and a poor rating is given. A fair rating indicates either reliable inputs and no model or reliable inputs with some subsequent model development. A good rating is reserved for fully developed models based on reliable inputs, with expected minor improvements in the future. The references listed are neither exhaustive nor exclusive and are intended as a point of departure for seeking information on specific recovery model inputs, outputs, and parameters. In the following paragraphs, the models of the recovery system will be defined and discussed, and relationships between some of the submodel components will be indicated. Functional relationships among the four model types are shown in Figure 1.

### Weapon Effects and Vulnerability Models

To define the nature and magnitude of the postattack recovery problem and to evaluate the relative cost and effectiveness of alternative postattack recovery countermeasures (or systems of countermeasures), the model system must be designed to make estimates of the degree of damage to all elements of the system. The response of the physical parts of the system and the operational parts of the system must be considered. Actually, three submodels and their associated data bases are required:

1. Vulnerability of components (response of physical parts of the system to weapon effects and the geographic location of these parts)
2. Vulnerability of operations (loss of key personnel, delay due to radiation exposure of personnel, delay due to bottlenecks, etc.)
3. Variation in basic vulnerability of components and operations

Table 1

## RECOVERY MODEL SYSTEM

	Model Development			Typical References
	Good	Fair	Poor	
<b>Weapon effects and vulnerability models</b>				
<b>Physical effects</b>				
Air blast	X			1
Ground shock	X			1
Thermal radiation	X			1
<b>Radiological effects</b>				
Radionuclide production	X			2,3,4
Radionuclide condensation	X			2,3,4
Fallout particle formation		X		2,3
Cloud and fallout distribution		X		2,3
Foliar contamination		X		2,3,5,6
Absorbed dose		X		2,7
Beta-gamma dose - plants			X	8
Plant root uptake		X		5,9
<b>Vulnerability</b>				
Physical damage		X		10
Radiation exposure		X		10
Variation with preattack counter- measures			X	10
<b>Economic system models</b>				
Agricultural production		X		11
Mineral production			X	12
Industrial processing			X	12,13
Transportation		X		14,15
Storage and distribution			X	14,15
Utility and energy source		X		14,15
<b>Countermeasure models</b>				
<b>Postattack</b>				
Decontamination and dose control	X			3,16,17
Debris clearance and salvage			X	18
Damage repair			X	19
Medical treatment			X	20
Evacuation	X			21
<b>Preattack</b>				
Stockpiling			X	22
Hardening			X	10
Dispersal			X	23

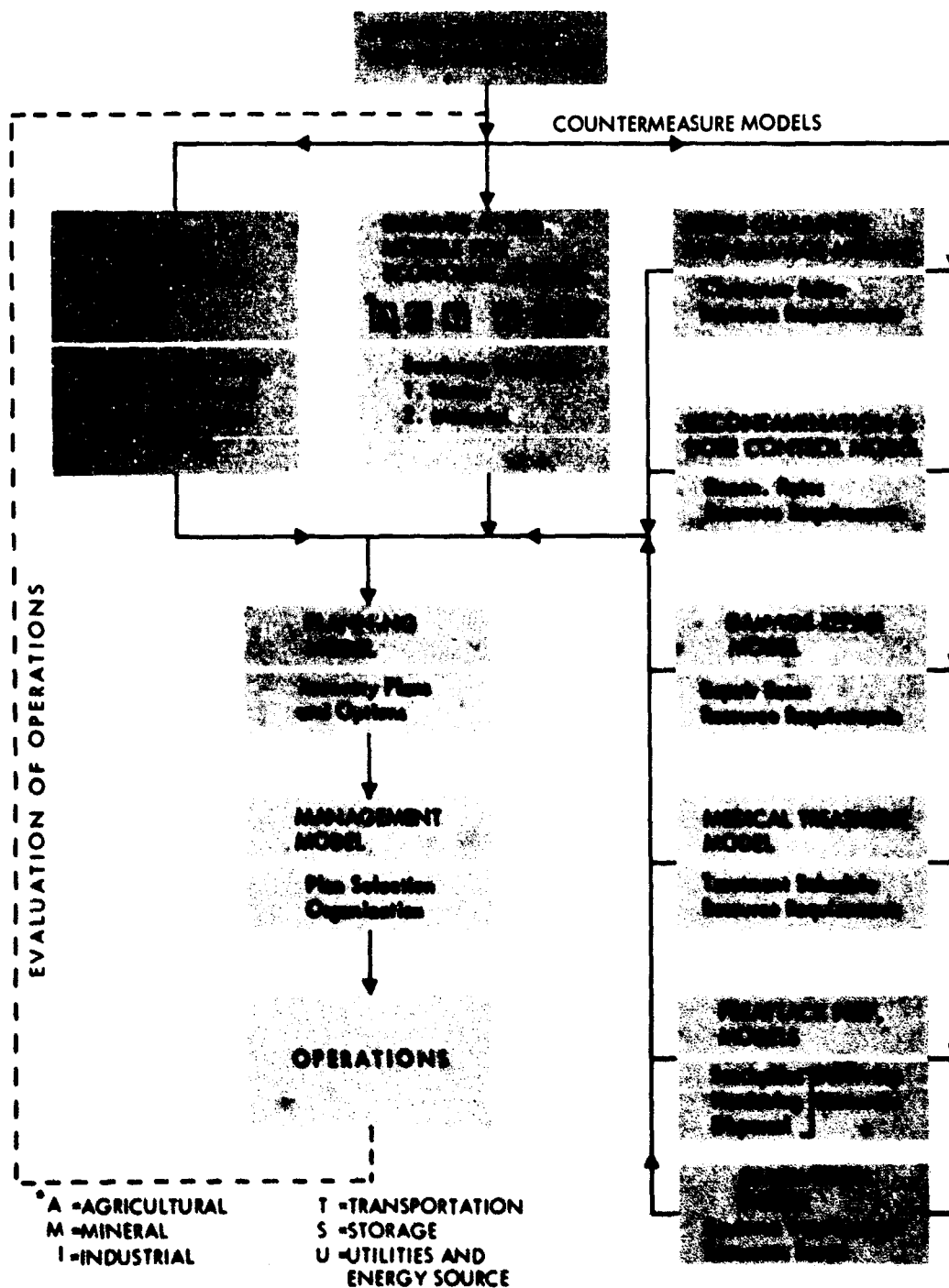
Table 1 (concluded)

	<u>Model Development</u>			<u>Typical References</u>
	<u>Good</u>	<u>Fair</u>	<u>Poor</u>	
Civil defense organization models				
Recovery requirements			X	24
Recovery planning			X	24
Recovery management			X	23

---

Source: Stanford Research Institute

Figure 1  
 FUNCTIONAL RELATIONSHIPS  
 AMONG RECOVERY MODELS OF TABLE 1



SOURCE: Stanford Research Institute.

because of the application of countermeasures (mainly of such preattack preparations as protective measures and stockpiling)

The primary output of these models, when applied in damage assessment studies under hypothetical nuclear war situations, would be a summary of the kinds and amounts of recoverable resources or production capabilities (including humans and their skills) and their locations. The relative effect of the countermeasures would be indicated by the increase in the amount of the recoverable resources when the countermeasures are assumed to be employed. (A more complete evaluation includes the effect of production capability on the time and rate of recovery.)

With a few exceptions, weapon models are well developed. Physical effects models have been derived from well-documented weapon field tests<sup>1</sup> for use in damage assessment studies of hypothetical postattack situations. Radiological effects models have been derived both from weapon field test data and from experimentally simulated weapon effects. Weapon effects and vulnerability models, which provide parametric inputs for the three other model types, have been described elsewhere,<sup>1,2</sup> and will not be discussed further here, except in terms of their outputs.

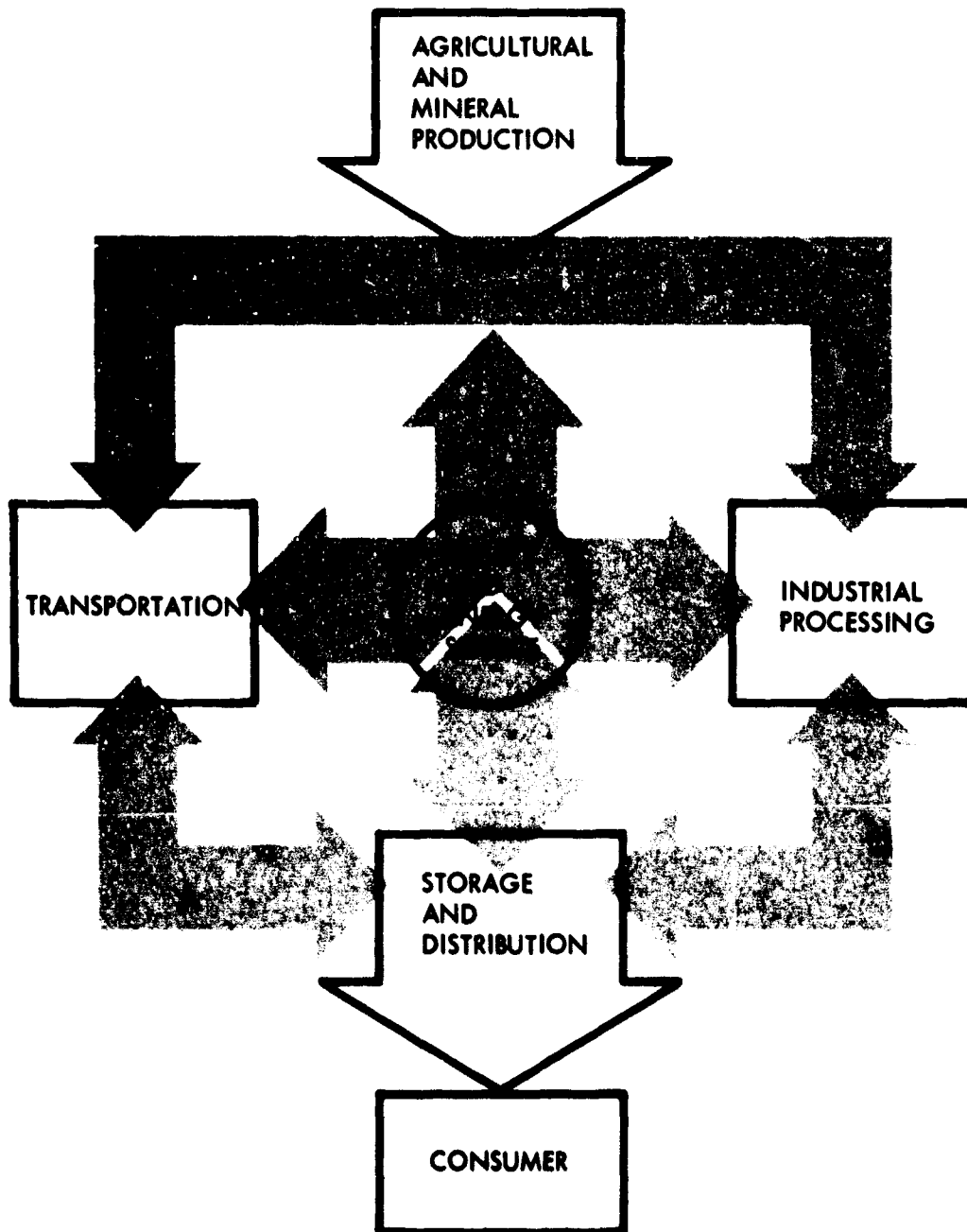
#### Economic System Models

Economic system models, whose functional relationship is shown in Figure 2, describe the current operation of the U.S. economy. The definition and scope of these models are described below to clarify the functional boundaries for further detailed development.

1. Agricultural production--the combination of human resources with material and energy inputs to produce raw materials used as inputs to industrial processing. Processed agricultural production may consist of either food items (packaged, frozen, canned, etc.) or nonfood items (textiles, fibers, chemicals, lumber, etc.).
2. Mineral production--the combination of human resources with material and energy inputs to produce inanimate materials used as inputs to industrial processing. (All raw materials are of either agricultural or mineral origin.)
3. Industrial processing--the combination of human resources with material and energy inputs to produce a product.
4. Transportation--a vehicular system by which people or materials are moved from one location to another.
5. Storage--the retention of a product during or between processes in its production or distribution for consumption.

Figure 2

FUNCTIONAL RELATIONSHIP OF ECONOMIC SYSTEM MODELS



SOURCE: Stanford Research Institute.



6. Distribution--the planned movement of a product to the ultimate consumer.
7. Utility and energy source--an input (electricity, fuel, etc.) essential to all economic systems for conduct of their respective functions.

Within the above defined scope, the outputs of the economic system model must include estimates of degraded postattack production due to the interaction between inputs essential for production for a range of postattack environments. These degraded production capabilities must be known if recovery requirements are to be met through the planned application of countermeasures. Some of the normal inputs, parameters, and damage criteria for the six economic system models of Table 1 are discussed below.

#### Agricultural Production Models

Agricultural production models estimate the production potential of the agricultural industry in the postwar period and, through other related models, to make estimates of the contamination levels of farm produce. Currently available models are rather simplified representations based on average crop yields by county and on average soil properties by county. These models require updating and extension so that other related inputs and parameters can be taken into account in the assessments. Some inputs and parameters are: (1) soil amendments, (2) fuel and electricity, (3) equipment, (4) manpower, (5) fertilizers and insecticides, (6) climatic factors, (7) farm management practices, (8) available shelter for animals and humans, (9) seasonal variation of production, (10) preattack preparations, and (11) alternate cropping sequence. Damage criteria from weapon effects models (fire and lethal or debilitating radiation dose to crops, animals, and humans) and countermeasure requirements (decontamination and repair) must be related to establish postattack work routines (planting, harvesting, and animal husbandry) and for estimating potential agricultural production in the postattack period.

#### Mineral Production Models

Mineral production models are used to assess the production potential of raw materials other than agricultural production in the postattack period. Little has been done to develop these models, although much input data are available. Some input and parameters for these models are: (1) fuel and electricity, (2) equipment, (3) manpower, (4) explosives, and (5) preattack preparations. Mineral production operations are frequently located in remote areas and some are underground. Thus, except for

possible shortages of some external inputs such as fuel, electricity, and explosives, these operations should be more readily recoverable than many others. Underground facilities could also be used to provide fall-out protection to operators and to workmen and their families. The characteristics of mineral production do not include the problems of spoilage before consumption, as is the case with agricultural products. Some mineral fuels (petroleum, coal, natural gas) are vital inputs to other systems and, indirectly, to themselves.

#### Industrial Processing Models

Industrial processing models are used to assess the effects of nuclear attack and civil defense countermeasures and operations on the postwar production potential of vital industries. Although industries are similar in many respects (men, materials, and equipment combining to produce a product), individual differences in these inputs must be defined in the model for each industry with respect to (1) system description giving input-output rates for all materials, services, and energy (including manpower); (2) vulnerability functions for all vital system components and variations in those functions because of protective measures; (3) preattack preparations such as component hardening, stockpiling of spare parts and materials, and the like; (4) applicable post-attack recovery procedures; and (5) the data base for the current and future systems.

Some of these models have been designed to describe the normal functioning of the economy, and preliminary simple designs for recovery models have been developed.<sup>11,12,13,15</sup> However, the major portion of the recovery model development remains to be accomplished. Further development of these models, especially for the case of targeted urban areas, is probably the most important consideration in postattack research for the future. Without objective assessments of the postattack recovery potential of the industrial base, assuming that agricultural production could be achieved more readily if the minimum required industrial base were recoverable, no realistic evaluation can be made of postattack recovery processes and the role of postattack countermeasures in these processes.

Because of the importance of industrial processing in the U.S. economy, a general approach to the development of models of these industries will be given later in this section.

#### Transportation Models

The transportation models assess the postattack potential of these systems to transport vital goods and people from one location to another

at the times and places required in support of postattack operations and other recovery processes. All modes of transportation are included in the assessment. As individual systems, transportation models would be treated in much the same way as the industrial processing models discussed above.

Movement of goods and people can be considered in terms of flow potentials across boundaries of designated geographic areas (census tracts, counties, states, and so forth) per unit of time, with each area being a sink or source for a specific product or manpower. Allowance for delay times in transit across the area, or for internal processing, and serial addition of these times, as weighted by the flow potential, should provide a basis for estimating when specific products would reach the consumer-- for example, when flour made from wheat grown in a given county in Minnesota would appear at a city in the state of New York.

#### Storage and Distribution Models

Storage and distribution models fulfill the same function as the industrial processing models. However, these models are generally simpler in that no change in the products occurs within the models. Storage locations and distribution points would be sources of stockpiles of various materials and products. Little formal treatment of these models has been accomplished, except for some stockpile development and a few investigations of local food distribution systems. 15,25

#### Utility and Energy Source Models

The function of the utility and energy source models is the same as that of the industrial processing models. Although many of these systems (such as water) produce or deliver vital products for use and consumption by humans, most also serve as support systems for other industrial processing systems and provide vital inputs to them. These systems have received more attention than have other systems, mainly on the premise that without availability and recovery of the systems (fuel, electricity, water, communication, etc.), no other system would be operable.

#### Countermeasure Models

The countermeasure models listed in Table 1 that are functionally related to other types of model systems in Figure 1 are a primary interest and responsibility of the Office of Civil Defense. These models are required for the development of civil defense organization models, and their output will generally serve either as inputs to, or restraints on, other

system models for the purpose of estimating the variation in rate of production from other systems during the postattack period.

Each countermeasure model has a similarity of functional relationships between inputs, internal computations, and outputs. Inputs of situation assessment and surviving countermeasure capabilities are related by model computation to establish the cost-effectiveness of possible alternative procedures or applications of the given countermeasure. Each countermeasure model has a characteristic set of physical units that describe it within the outline of model functions given in Table 2.

Some of the models are well developed (for example, decontamination and dose control) whereas others require clearer definition of input parameters and development of internal mathematical procedures for estimating useful output information. In many instances, useful outputs have not been defined, because virtually no research has gone into defining quantitative relationships among countermeasures systems parameters that apply to various postattack environments. As a first step toward a quantitative description of a countermeasure system, inputs, internal computation parameters, and outputs for some countermeasure models will be described below in greater detail. The order of description is by decreasing current state of model development; no attempt to rank these models according to their importance in postattack recovery investigations has been made because any combination of countermeasures, as a system, may be required in a given postattack situation.

#### Decontamination and Dose Control Models

Decontamination and dose control models are used to estimate the effectiveness and effort entailed in carrying out radiological countermeasures in the postattack period. These models must have a means (1) to identify the postattack environments in which decontamination is both applicable and required, (2) to estimate the amount of resources consumed, and (3) to estimate the operational effectiveness in terms of advanced recovery times, decrease in exposure dose, or in increased production rates at a given time. A flow diagram of a model to perform these functions is shown in Figure 3.

Key elements of this model are decontamination scheduling and target analysis. Techniques for performing the internal model computation functions of these elements are currently developed to a state where they can be used. Additionally, most of the inputs to the decontamination and dose control model can be obtained from related models or from research findings.

Table 2

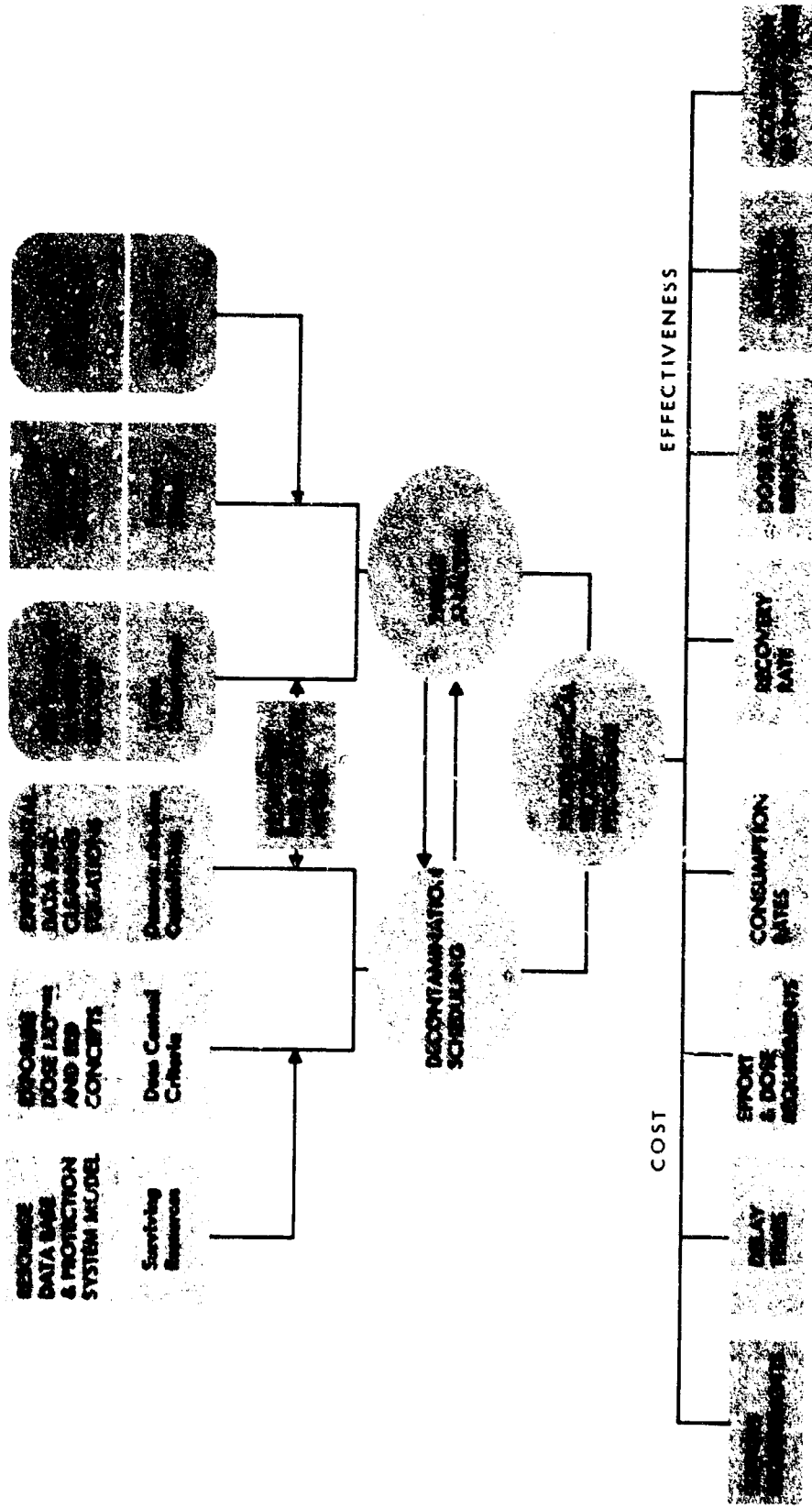
**FUNCTIONS OF POSTATTACK COUNTERMEASURE MODELS**

- I Inputs**
  - A. Situation Assessment**
    - 1. Preattack description of system components
    - 2. Vulnerability functions for system components
    - 3. Survivor requirements
  - B. Countermeasure Capabilities**
    - 1. Personnel required
    - 2. Equipment and materials required
    - 3. Postattack capabilities
- II Internal Computations (for Postattack Situation)**
  - A. Countermeasure Costs**
    - 1. Personnel requirements - manhours, dose, skills, locations
    - 2. Equipment and material requirements - amounts, types, locations
  - B. Countermeasure Effectiveness**
    - 1. Lives saved
    - 2. Recovery time saved
    - 3. Radiation dose conserved
    - 4. Production rate achieved
- III Output**
  - A. Alternative feasible countermeasures procedures and sequences**
  - B. Cost of procedures for recovery management use**
  - C. Effectiveness of procedures for recovery management use**

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Source: Stanford Research Institute

Figure 3  
 DECONTAMINATION AND DOSE CONTROL MODEL



SOURCE: Stanford Research Institute.

### Debris Clearance and Salvage Models

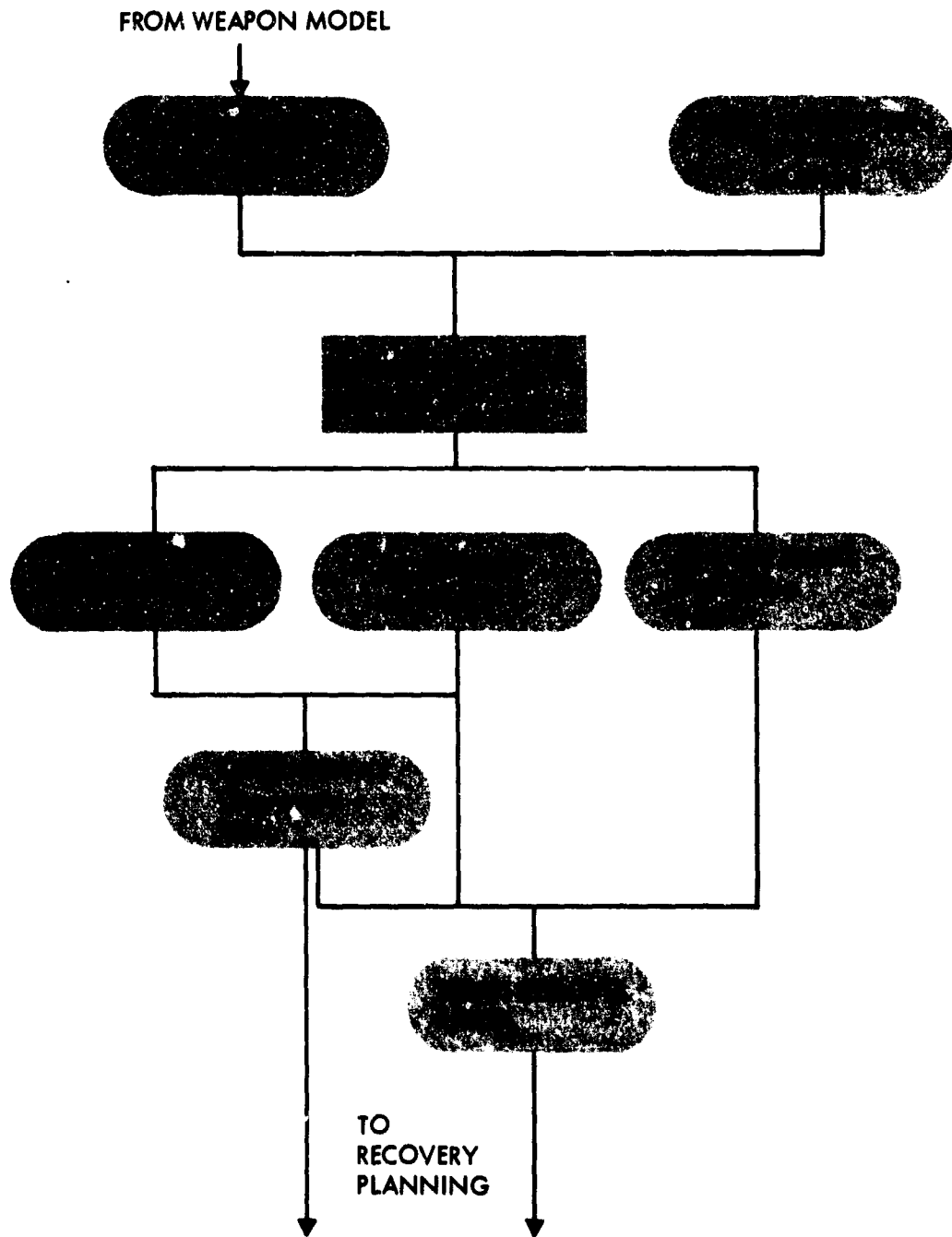
The debris clearance model is used to estimate the effectiveness and effort entailed in carrying out debris clearance operations in target areas exposed to the immediate effects (blast and thermal) of nuclear explosions. Three general types of debris clearance operations need to be considered in the postattack period: (1) early-time clearance of transportation routes, (2) early-time clearance of access ways to vital facilities, and (3) later removal and disposal of debris.

Only limited information has been developed on the formation and distribution of debris from blast and fire effects and on procedures for debris clearance. Target vulnerability functions and debris production submodels describing the type and distribution of debris are needed to provide inputs to the debris clearance model. These inputs must be consistent with the normal sequence and characteristics of events, with respect to debris production following weapon detonation. These events, relative to a structure, are: (1) the structure is bathed in a thermal flux; (2) ignition may occur at this time; (3) the blast wave envelops the structure; (4) ignited materials may or may not continue to burn; (5) the structure is damaged by the blast wave and the degree of collapse and the type and distribution of debris depend on the blast pressure and the type of structure; (6) the debris or the structure may continue to burn, be ignited, or be reignited; (7) upon ignition, burning may cause further structure collapse; (8) additional debris may be cast into the street; and (9) the volume of the debris may be reduced by further burning.

Debris clearance and debris removal effort depends on the amount and nature of the debris and on available clearance and removal equipment. In general, debris that has been reduced to rubble is the easiest to remove whereas large steel members of semicollapsed structures are the most difficult. The location of debris (on site or off site) is important in estimating effort requirements for early-time debris clearance activities and is a basic parameter of the internal model computations. The characteristics of a debris clearance model are shown in the flow diagram of Figure 4.

Salvage models apply to useful material and equipment in damaged areas and the removal of this material and equipment to other areas of need. Salvaged materials and equipment obtained from debris clearance activities may expedite or make possible the repair or replacement of damaged critical items. The salvage model would provide estimates of the effort required (men, materials, equipment) to use surviving materials and equipment at the same site or another site to help meet the requirements of damage repair.

Figure 4  
DEBRIS CLEARANCE MODEL



SOURCE: Stanford Research Institute.



### Damage Repair Models

Damage repair models are used to estimate the manpower, equipment, and supplies needed to repair damaged facilities. Structural repair requirements may be similar for many facilities in the same sense that decontamination and debris clearance are widely applicable. However, repair requirements for recovery of industrial production are facility- or industry-oriented and depend on operational characteristics of components in terms of their sensitivity to the effects of nuclear weapons. Operational characteristics of facilities and industries vary so widely that weapon effects vulnerability functions are needed for specific facility, component, and equipment.

Some industries have been assessed for their vulnerability to weapon effects, but many more must be considered before the postattack production potentials of even a limited number of essential survival items can be evaluated. A flow diagram for a damage repair model is shown in Figure 5. This presentation of the model functions is in general terms, recognizing that facility-oriented models in much greater detail will be needed.

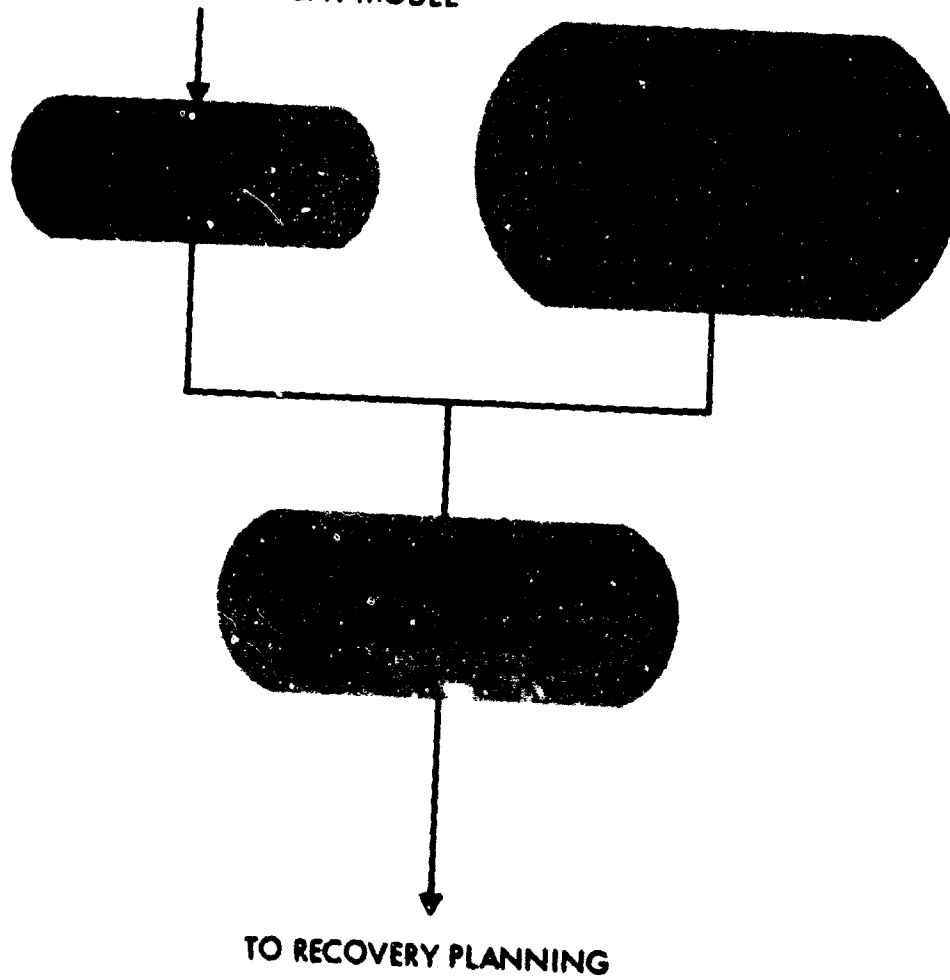
### Medical Treatment Models

Medical treatment models provide estimates of the effectiveness and effort of countermeasures for administering medical treatment to the survivors in the postattack period. Treatment for specific weapon effects injuries is well understood, and if treatment capabilities are available, the methods can be effectively given to a limited number of patients. However, in the early postattack period, when the patient-to-doctor ratio may be very high in some areas, it is possible that the management of medical treatment could be improved through the use of models for estimating medical treatment requirements. Some input, output, and other parameters for these models are: (1) injury from direct weapon effects on people, (2) injury from environmental damage (structure collapse, missiles, fire), (3) injury from radiation exposure, (4) illness and injury not related to the attack, (5) resource requirements (skills, supplies, facilities) for treatment of injured survivors, (6) resources (medical supply stockpiles, hospitals) available to meet needs of survivors, and (7) degraded treatment procedures and triage techniques to permit the most timely use of surviving resources.

Some of the relationships that need to be established among weapon effects injuries, communicable diseases, chronic ailments, and treatment requirements are shown in Figure 6. The model must be able to estimate stochastic medical treatment requirements, mostly for weapon effects injuries at early postattack times and for control of epidemics of

Figure 5  
DAMAGE REPAIR MODEL

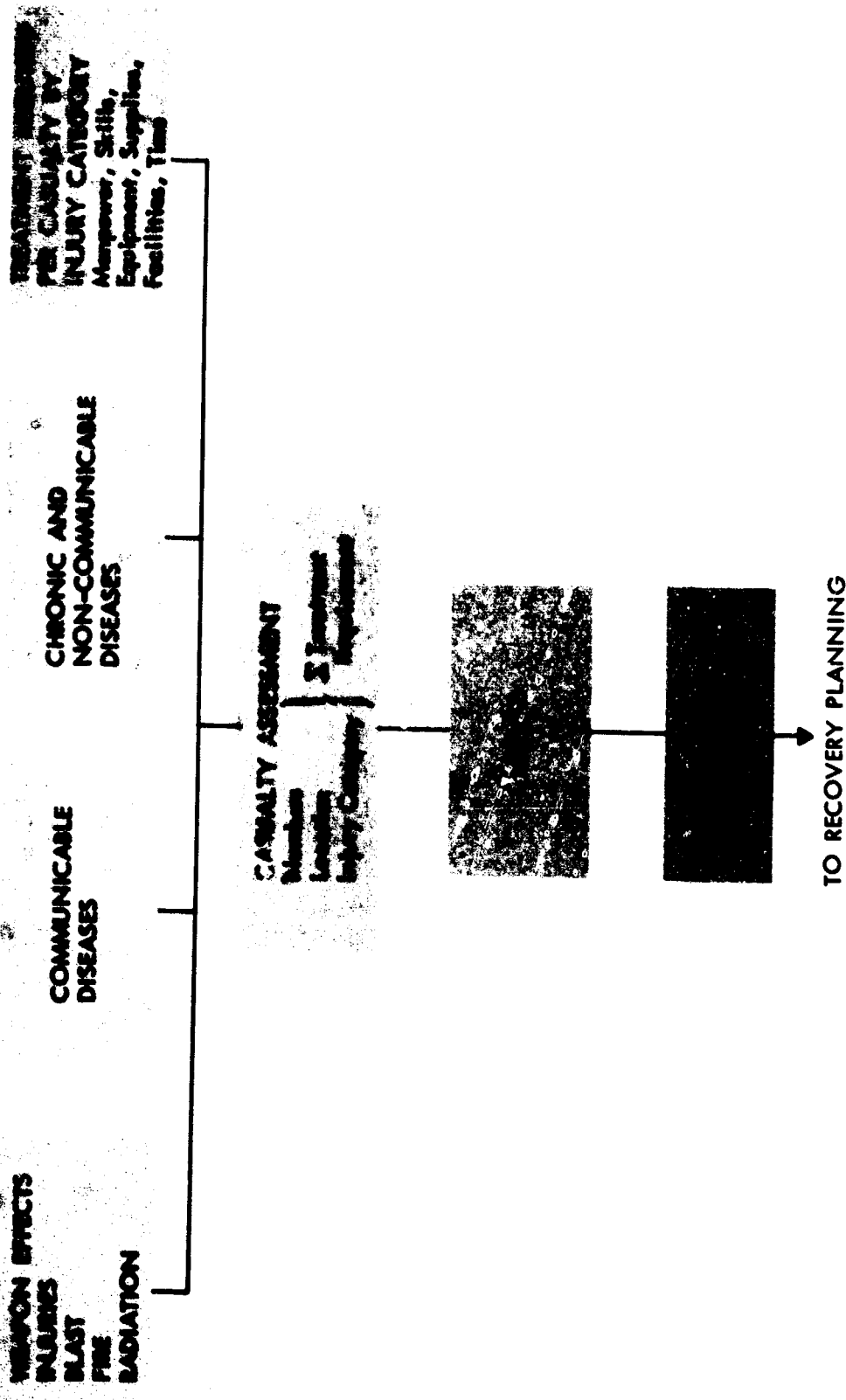
FROM DAMAGE ASSESSMENT MODEL



SOURCE: Stanford Research Institute.

Figure 6

MEDICAL TREATMENT MODEL



SOURCE: Stanford Research Institute.

communicable diseases at later times while providing chronic or routine treatment to the extent possible at all times.

#### Evacuation Models

Evacuation models are used to examine the cost-effectiveness of operations in which human or material resources are moved. Evacuation of people may be for their initial survival; however, this action also includes the sustenance of the evacuees as well as their integration into the surviving economic and social structure at their destination.

Studies of evacuation (or remedial movement) have been made for several phases of nuclear attack. These studies have been concerned with specific time periods before, during, and after attack without consideration of later activities of the evacuees. Some inputs and parameters of these models are: (1) location and types of threats to the surviving population, such as fire, radiation, starvation and thirst, exposure to elements, sickness, and injury; (2) surviving evacuation capabilities, such as personnel, equipment, and supplies available; and (3) destination requirements for short term needs, such as medical treatment, feeding, and housing, or long term integration of evacuees, such as manpower utilization for recovery and continued production, economic self-support, and social coalescence.

Expected outputs of these models are: (1) alternative evacuation procedure costs, (2) number of evacuees at old and new locations, and (3) cost-effectiveness of alternative evacuation procedures (materials or man-hours per life saved or unit of increased production - or all).

#### Preattack Preparation Models

Preattack preparation models provide quantitative estimates for pre-attack preparation requirements for stockpiling, hardening, and dispersing material resources that may be in short supply in the early postattack period. These models would be used to examine the requirements and effectiveness of these countermeasures in recovery processes and, where feasible, to provide cost-effectiveness information for preattack planning. The model details would consider reductions in vulnerability and the consequent increase in resources for these countermeasures.

The preattack preparation models should also provide information on the character and size of the organization needed to manage the countermeasures.

## Civil Defense Organization Models

Civil defense organization models consist of the recovery requirement models, recovery planning models, and recovery management models. These three models are used to coordinate the outputs of all other recovery system models and to supply feedback information on operational constraints. The scope of these models is defined briefly below.

### Recovery Requirement Models

Recovery requirement models identify the systems that must be recovered and provide estimates of the minimum production requirements, including the latest time after attack when the system must be operable. The criteria, or model constraints, include individual and aggregate needs for continued survival of the population (healthy people and casualties) as minimum requirements and those imposed for support of national goals (for example, military requirements).

Typical inputs and parameters are number, location, and status of survivor groups; essential survival items and their necessary and desirable consumption rates; and surviving stockpiles of these items.

### Recovery Planning Models

The functions of the recovery planning models are to estimate the feasibility of recovery operations, to develop alternative plans and schedules for feasible operations, and to provide operating information for use in selection of plans by management.

Formalized recovery planning methods have been developed only for radiological recovery operations (as decontamination manuals, and so forth). Similar formalizations are needed for other postattack recovery operations and for postattack countermeasure systems. The detailed methods, however, may require some degree of alteration and adjustment to accept inputs from the recovery requirement models. The recovery planning models are concerned with the details of data processing that would be carried out as staff functions of a civil defense organization concerned with operational planning. The original inputs consist of damage assessment data that would be obtained from damage assessment models for research, but under attack conditions would be obtained from observation reports.

### Recovery Management Models

Recovery management models are used to assess the relative effectiveness of alternative postattack recovery plans and operations and to develop

decision guidance and organizational characteristics for the management of postattack operations. These models will accept inputs from all other models and exercise them, using various assumed kinds and weights of attack and assumed postures of alternative feasible postattack countermeasure systems.

Outputs from these models should lead to sets of production rate curves for assessing the relative effectiveness of recovery routines, the gross cost of postattack countermeasures relative to the cost of other countermeasures, the gross size and composition of a postattack recovery force, support requirements for countermeasure systems (information, communications, equipment, supplies, and manpower), command and control requirements, description of system bottlenecks, and requirements of pre-attack preparations for making the recovery of specified postattack situations feasible.

#### Parameter Limits of Models

Each model described above is functionally limited in scope by its interface with associated supporting models as shown in Figure 1. The principal reason for this defined limitation is to permit a systematic development of each specific model without carrying postattack research to an unmanageable degree of complexity in which every parameter depends on all others with no limit of variability.

Within any model, each parameter has limiting values. For economic system models and preattack preparation models, these limits are related to the physical characteristics of system components that determine the overpressure at which either destruction or no damage occurs, the thermal radiation flux at which fires start, or the exposure dose at which operations are either unrestricted or impossible at a given time. Postattack countermeasure model parameters describing performance characteristics are also limited by physical effects on men, equipment, and materials. These limitations, in turn, limit the recovery that may be achieved in a given time. On the other hand, a conservative application of postattack countermeasures would tend to be limited by the scheduling requirements for production recovery. The scheduling of production recovery for economic system components and operations is therefore a major concern in postattack recovery planning and management.

## GENERAL APPROACH TO MODEL DESIGN AND DEVELOPMENT

One approach to the design of recovery system models (with special reference to the industrial processing models) is discussed in this section. The model development techniques that include linear flow diagrams, description of elements, and expanded flow network lead to models of operational systems. As examples, water and bread systems are outlined and described by using these techniques. A flow diagram for utilities, an important if not essential input to all industrial process models, is shown in Figure 7.

### Linear Flow Diagram

The initial representation of any given system for model development is a simplified flow diagram. Such a diagram consists of a series of boxes that illustrate the linear sequence of flow of major elements (materials, products, energy, and so forth) along the main path of movement through the system. Each box carries the title of a major element or a major process that may or may not be composed of several minor elements and processes.

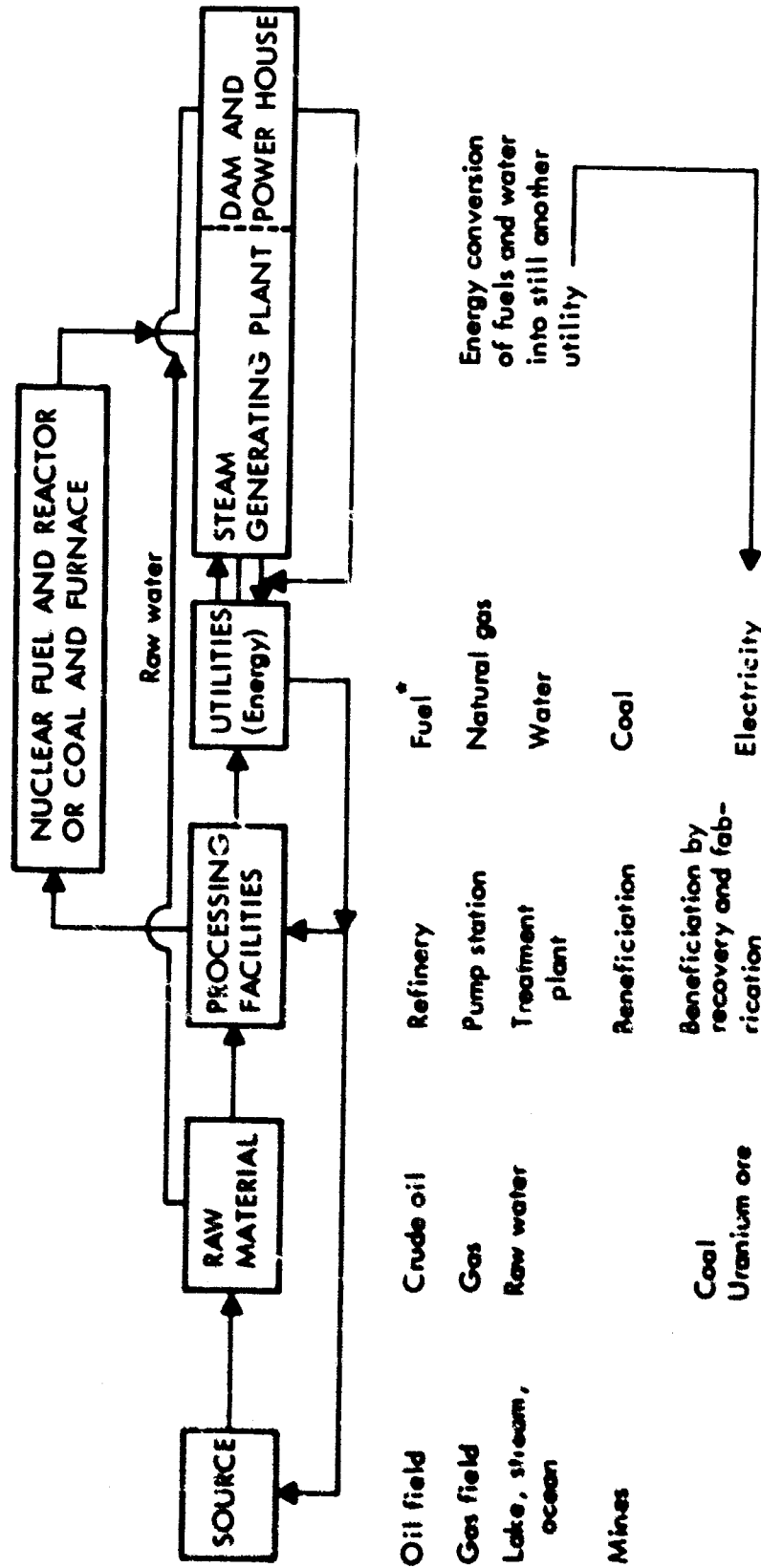
### Description of Elements

Major elements and processes for each box in the flow diagram, as well as the composition of minor elements, are identified and described as to kind, amount, properties, specifications, flow rate from box to box, delay times, exchange rates (in terms of entry into the system), and other factors considered important in the operation of the system.

### Expanded Flow Network

The simplified flow diagram and the description of elements provides the basic framework for developing a system network that links all the various elements into a continuous working system. The expansion includes subsystem and subelement networks required to illustrate the processes and their supporting systems.

Figure 7  
 LINEAR FLOW DIAGRAM FOR UTILITIES



SOURCE: Stanford Research Institute



## Operational System Models

The major system models consist of mathematical descriptions of the operations and the logistical aspects of each element of the system. Essentially, this effort includes the collection and reconstitution of data required for description of the elements, as given above. The descriptions are formulated so that vulnerability functions can be applied in damage assessment computations for making estimates of changes in various input and output parameters, in addition to the loss in capacity itself given above.

In practice, the operational models are developed for a given type of system with "open" inputs and outputs to resources, support systems, or other systems. These inputs are closed when other models are developed in sequence or by damage assessment data when an attack condition is applied.

## Model Design for Water and Bread Systems

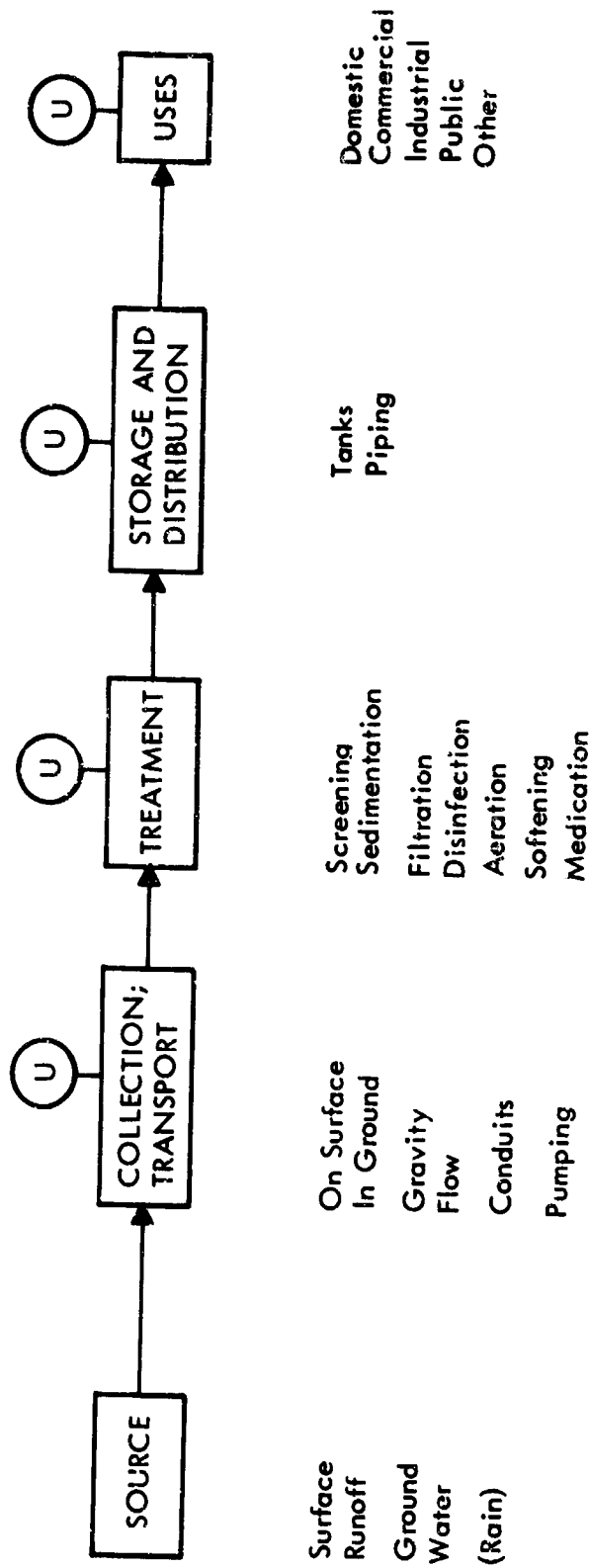
Processing model flow diagrams have been outlined for two systems--water and bread. The bakery element, as a subsystem to the bread network, is described in some detail as part of the second example.

### Water System

A linear flow diagram for the major functional elements of a water system is shown in Figure 8, with a listing of component minor elements whose specific functions are described in Table 3. An expanded system network for water, showing the source of minor elements, is given in Figure 9. A typical water treatment subsystem network is shown in Figure 10, and daily per capita requirements for water are given for normal and emergency conditions in Table 4. These figures and tables define the operating characteristics of the normal water system on which the effects of a nuclear attack can be superimposed.

Vulnerability models for the water system components can be generated from information on the sensitivity of the water system component to nuclear weapon effects such as that given in Table 5. Vulnerability functions in the case of blast damage would consist of the overpressure at which specific components fail. For a specified attack, the overpressures at all water system component locations could be computed from weapon effects models. The type and number of undamaged, damaged, and destroyed components may then be summarized, and the recovery requirements may be estimated in terms of repaired or replaced components, with associated inputs of material, labor, and equipment.

Figure 8  
LINEAR FLOW DIAGRAM FOR WATER



NOTES:

1. Major elements (or classes of elements) for the system are contained in the boxes with lesser elements listed beneath.
2. A circled U signifies utilities required.
3. Excludes brackish and salt water (see Figure 9).

SOURCES: Stanford Research Institute and Reference 25.

Table 3

DESCRIPTION OF WATER SYSTEM ELEMENTS

Source

Surface: Runoff from rain and snow melt--lakes, reservoirs  
Ground: Natural springs, wells, infiltration galleries  
Rain: Not widely used--domestic systems

Collection; Transport

On Surface: Lakes, conduits, pumping stations, reservoirs-dams  
In Ground: Wells, pumps--6- to 24-inch diameter, 50 to 3,000 gpm  
Transmission: Canals, tunnels, pipes  
Pumping stations: Electric motors, automatic operation

Treatment

Screens: Bars for coarse materials  
Plain Sedimentation: 1 to 10 hours for 50 to 80 percent suspended  
solid removal  
Chemical Sedimentation: Flocculating agents--alum  
Filtration: Bacteria-free water--sand filters, anthracite filters  
Disinfection: Chlorine  
Aeration: Taste and odor removal--spraying, charcoal absorption  
Softening: Zeolite--hardness removal  
Medication: Fluoridation

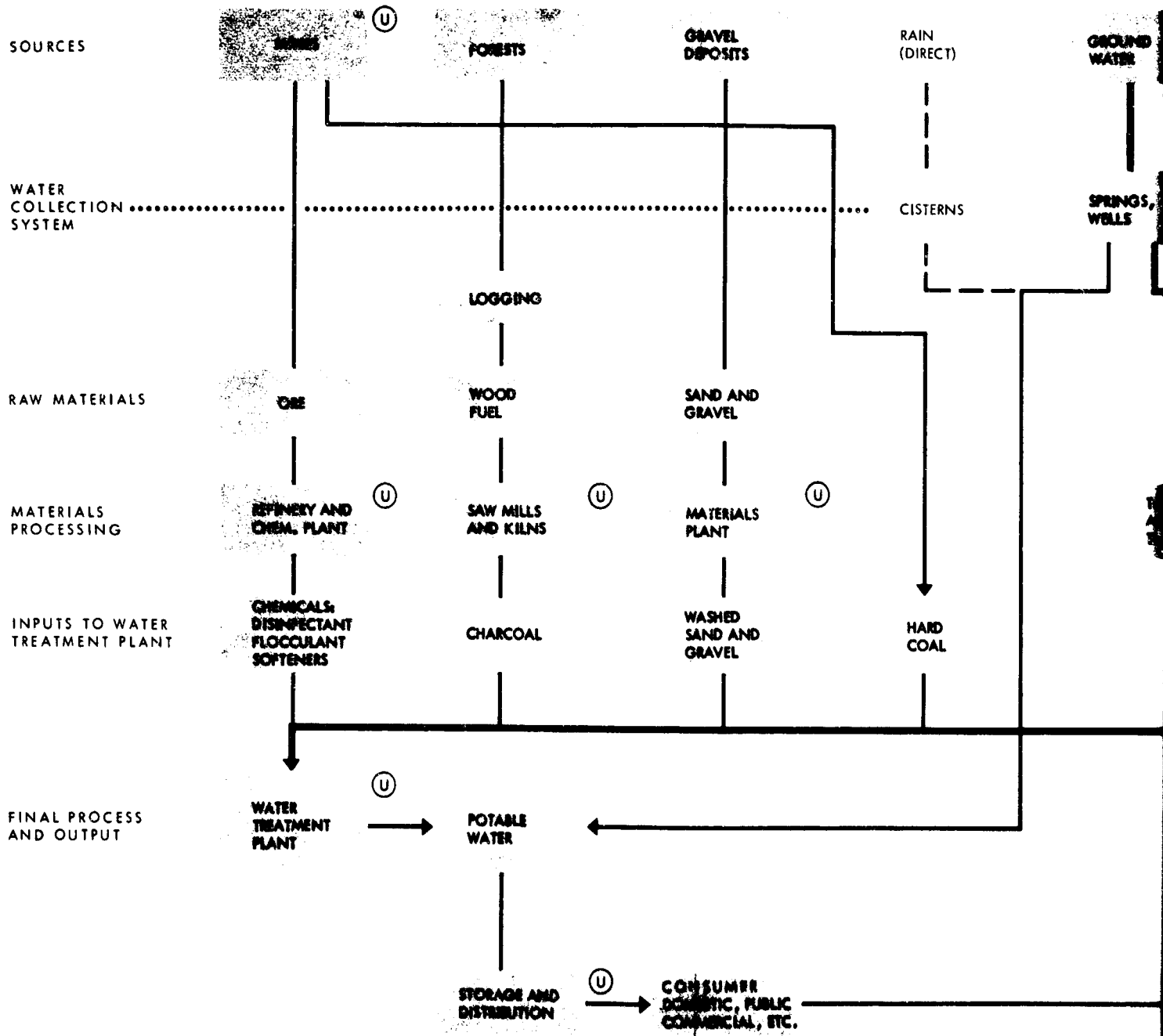
Storage and Distribution

Tanks--elevated and ground storage  
Piping system--low pressure, high pressure  
Demand and pressure control

---

Sources: Stanford Research Institute and Reference 26

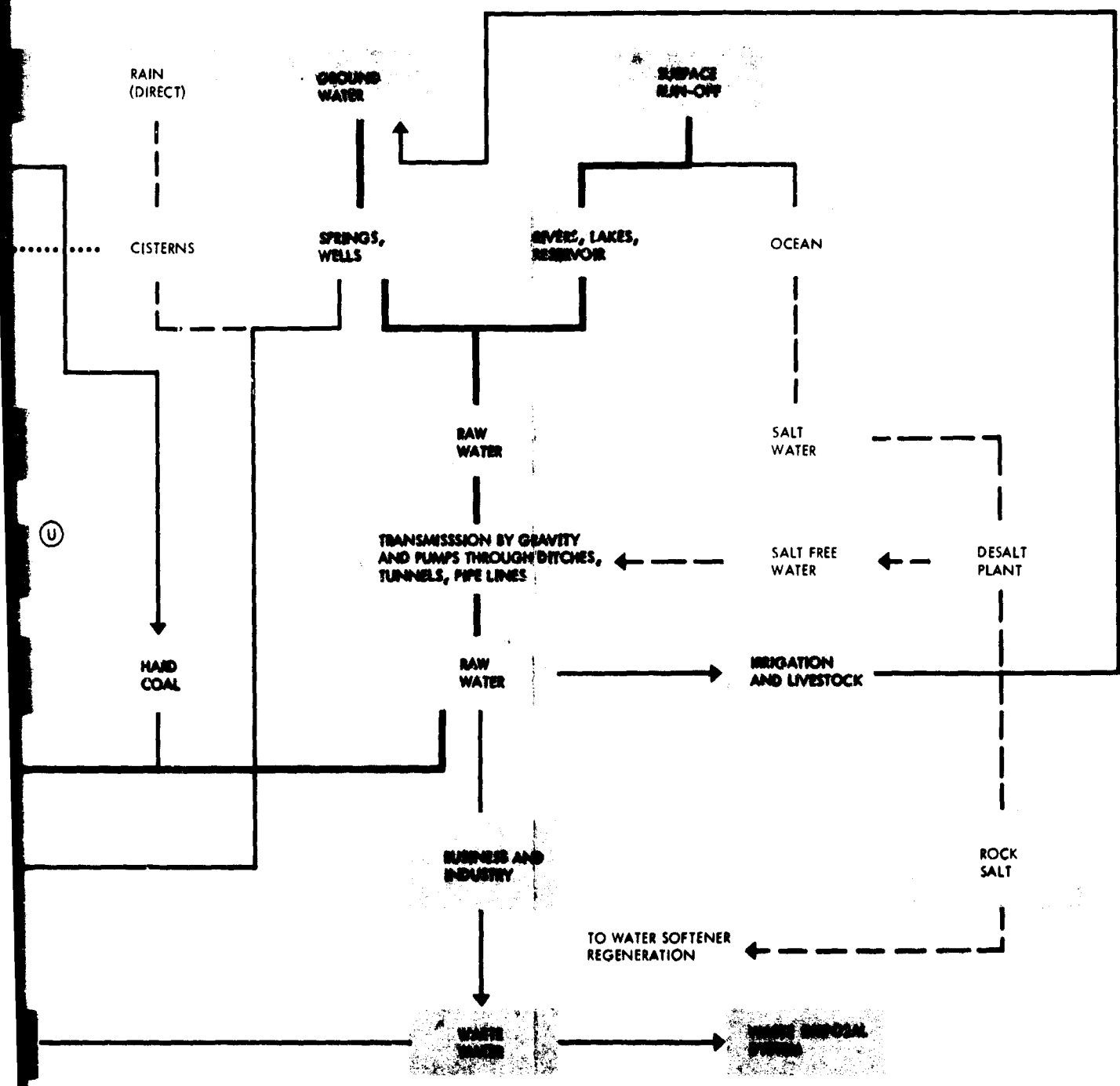
Figure 9  
EXPANDED NETWORK FOR A WATER SYSTEM



NOTE: (U) SIGNIFIES UTILITIES REQUIRED

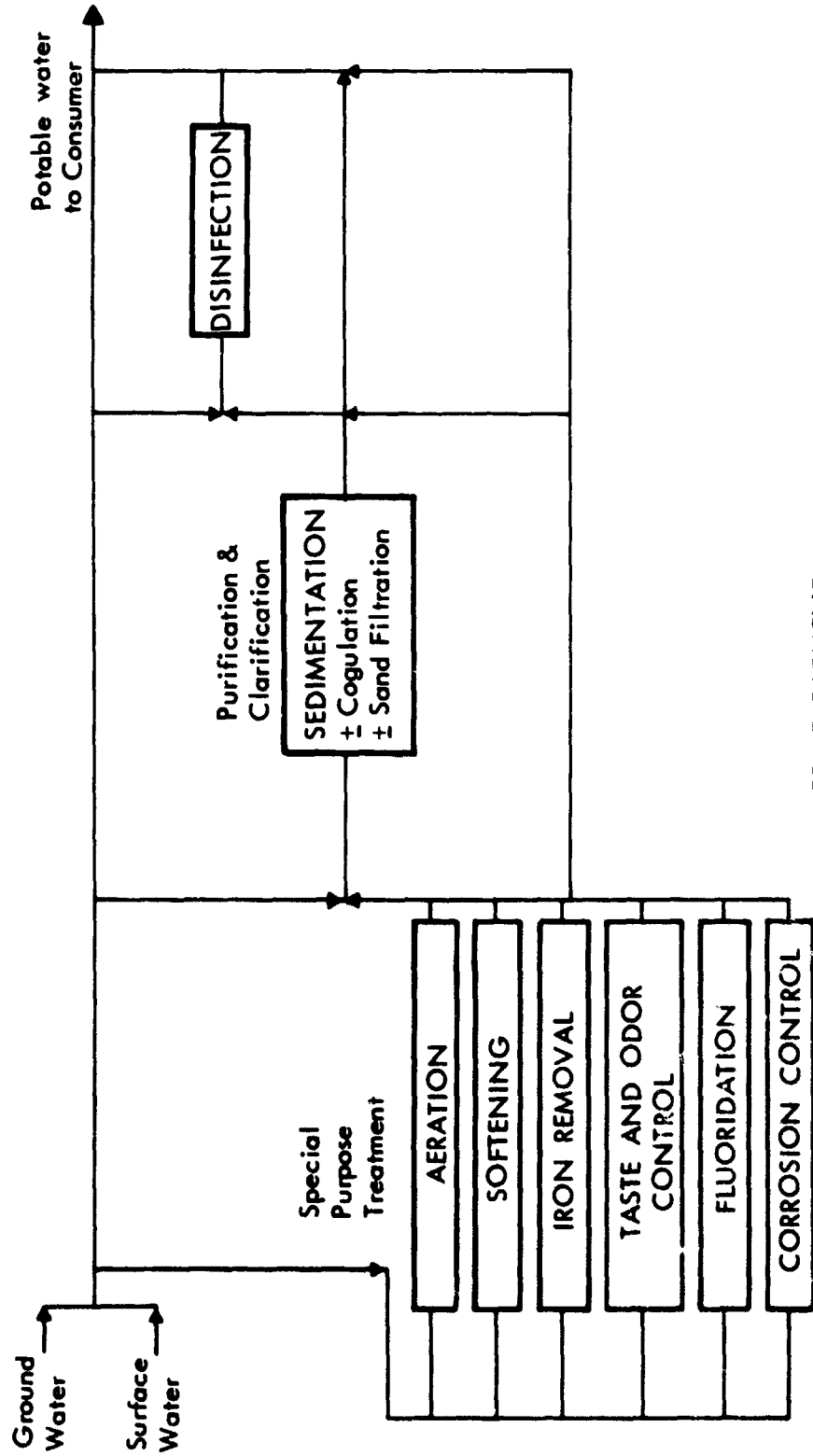
SOURCE: Stanford Research Institute.

A



B

Figure 10  
TREATMENT SUBSYSTEM FLOW DIAGRAM FOR WATER



WATER TREATMENT  
COMBINATION OF PROCESSES

SOURCE: Reference 26.

Table 4

PER CAPITA REQUIREMENTS PER DAY FOR WATER

<u>Water Use</u>	<u>Consumption</u> <u>(gal/man-day)</u>	
	<u>Normal</u>	<u>Emergency</u>
Drinking and cooking	4	4
Laundry	6	1
Bathing	5	1
Toilet	5	2
Other domestic	<u>40</u>	<u>2</u>
Total	60	10 <sup>a</sup>

---

a ≈ 1/6 normal total

Source: Reference 26

Table 5

SENSITIVITY OF WATER SYSTEM COMPONENTS  
TO NUCLEAR WEAPON EFFECTS

	Blast	Fire (Thermal)	Fallout
More Sensitive ↑	1 psi	Structures	Operators
	Elevated tank roofs	Equipment	Water contamination
	Glass chlorinator chambers	Supplies	
	Chlorine feeder components	Forests	
	2 psi		
	Elevated tanks		
	Tower-type aerators		
	Chemical storage and feeding equipment		
	3 psi		
	Structures housing equipment		
	Home service connections		
	Pumps, motors, and controls damaged by flying debris		
	4 psi		
	Tanks, standpipes overturned		
	Coagulation equipment		
	Grit conveyers and supports		
	6 psi		
	Ground storage tank roofs		
	Filters		
	15 psi		
	Chlorine storage cylinders		
	Heavy pumping equipment		
	Ion exchange equipment		
	Ground-level tanks		
Less Sensitive ↓	25 psi		
	Underground sand-filter galleries		

Sources: Stanford Research Institute and Reference 26



Vulnerability functions for fire damage to water system would relate the thermal flux computed from weapons effects models to the fire susceptibility of system components (principally structures) at a given location. However, because of the probabilistic nature of fire ignition and spread, vulnerability functions for fire damage could not be as consistently defined as blast damage. Vulnerability functions for fallout effects on the water system would relate fallout characteristics at a given location estimated from a fallout model to water contamination and exposure doses to operators.

#### Bread System and Bakery Subsystem

An important reason for studying the bread system and its recovery in the early postattack period is the potential use of bread as a dietary expedient. About a pound of bread, three times the normal daily per capita consumption, could provide the energy, protein, and carbohydrate requirements shown below.

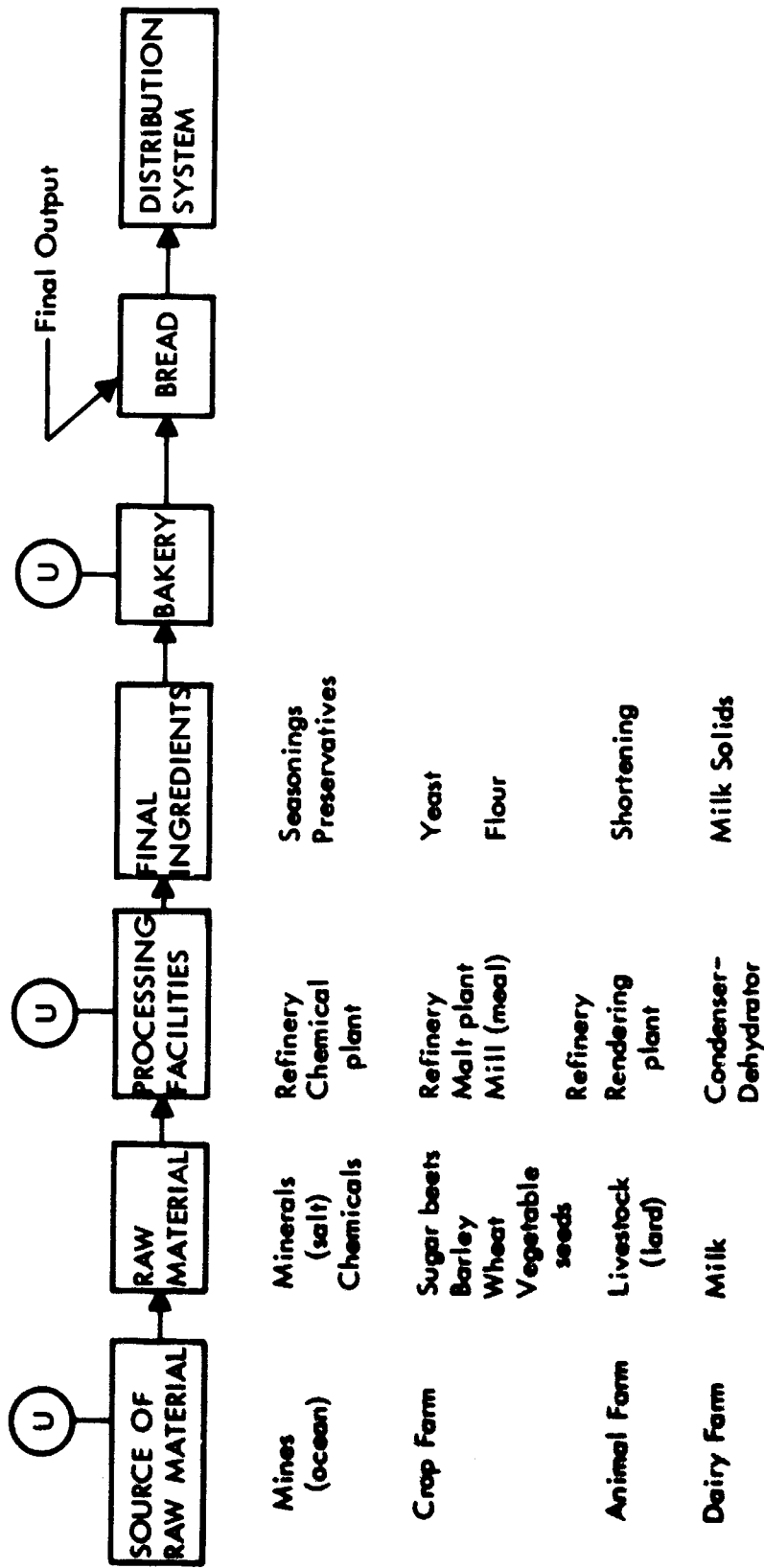
<u>Energy</u> (calories)	<u>Percent of Daily Requirement</u>		
	<u>Protein</u>	<u>Calcium</u>	<u>Carbohydrate</u>
1,300	67	67	100

The normal preattack operating characteristics of the bread system are given in Figures 11 and 12. Vulnerability models and functions are derived from the component sensitivity listing in Table 6 in the manner described for water systems.

Normal characteristics of the operation of a bakery are illustrated by the flow diagram in Figure 13. A modern bakery of average capacity produces 100,000 pounds of bread a day, which provides the normal daily bread consumption for about 365,000 people. Significant input resources are raw and processed materials, labor, facilities, and utilities. The quantities of ingredients used are approximately proportional to the quantity of bread produced, and to the number of man-hours required in most labor categories.

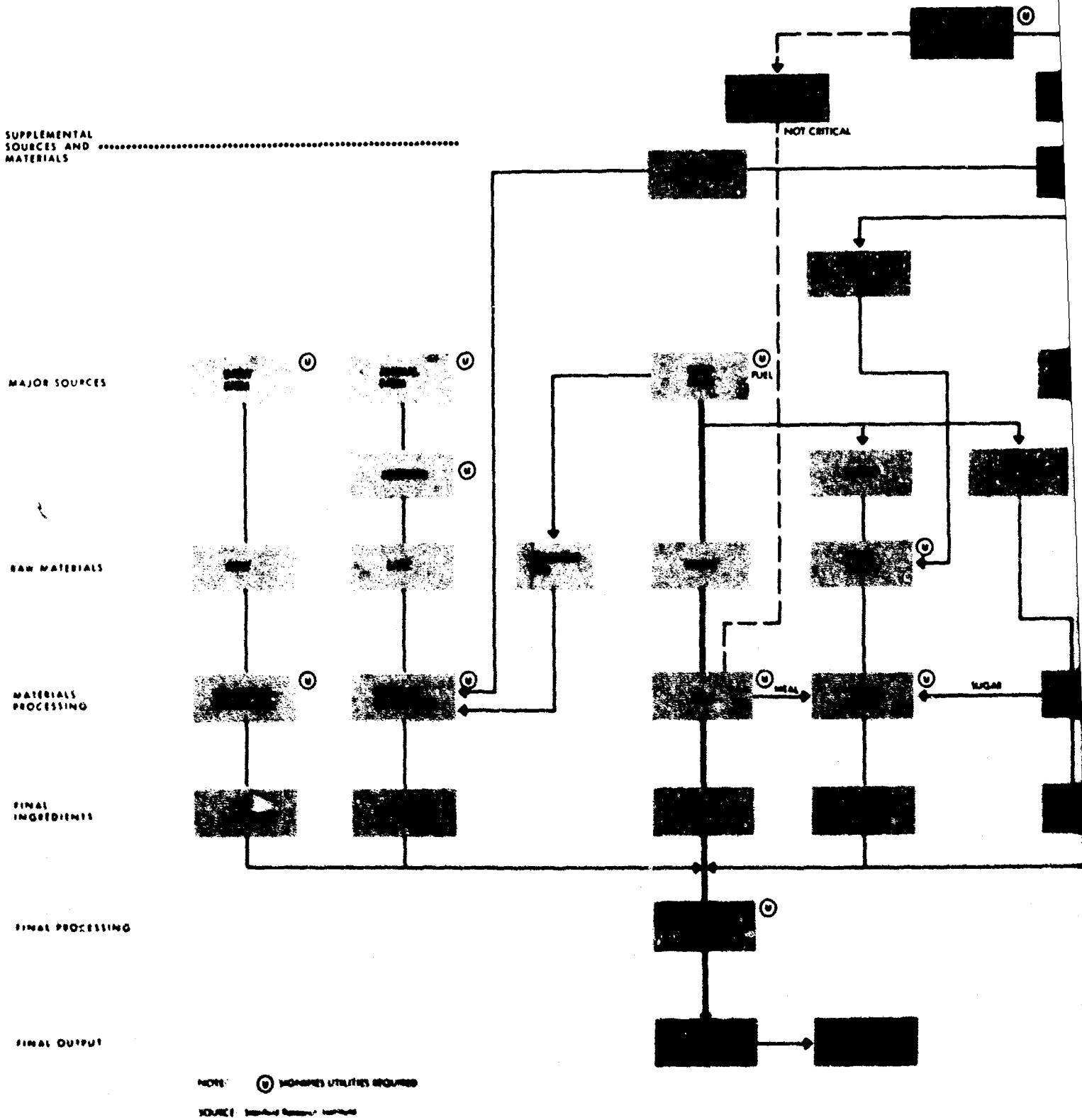
Estimates of specific rates and capacities for the input resources to a bakery are given in Table 7 on the basis of unit output and an assumed output capacity of 100,000 pounds of bread a day. The nature of the processing equipment requires a larger specific input rate for utilities for less than normal capacity production. Larger specific input rates would occur in situations where any production process of the system does not operate at its normal capacity. (An extreme case would be the use of a 50,000-pound capacity oven to bake one loaf of bread.)

Figure 11  
 LINEAR FLOW DIAGRAM FOR BREAD A BREAD SYSTEM



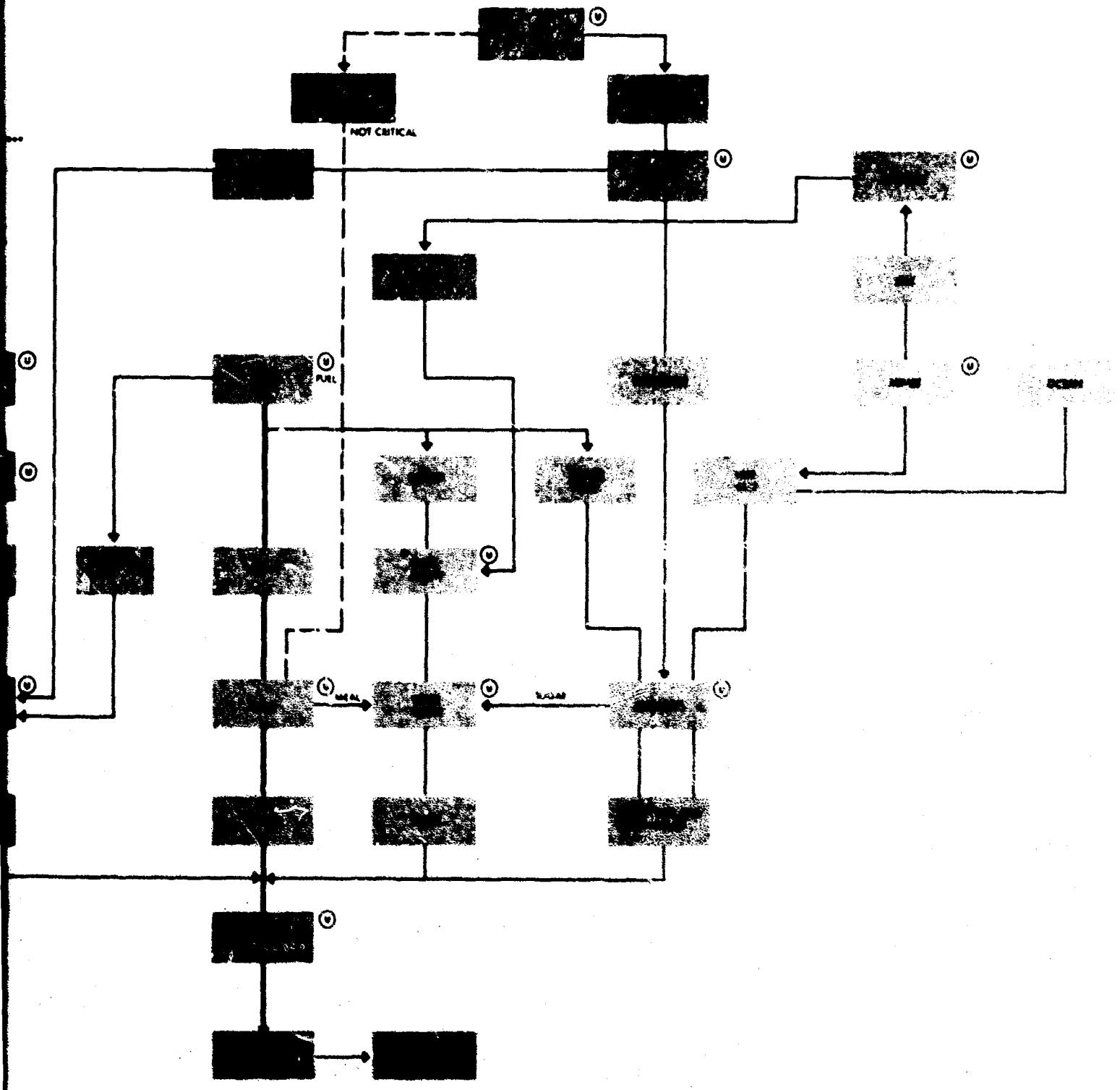
NOTE: A Circled U Signifies Utilities Required.  
 SOURCES: Stanford Research Institute and Reference 27.

Figure 12  
EXPANDED NETWORK FOR A BREAD SYSTEM



A

# A BREAD SYSTEM



B

Table 6

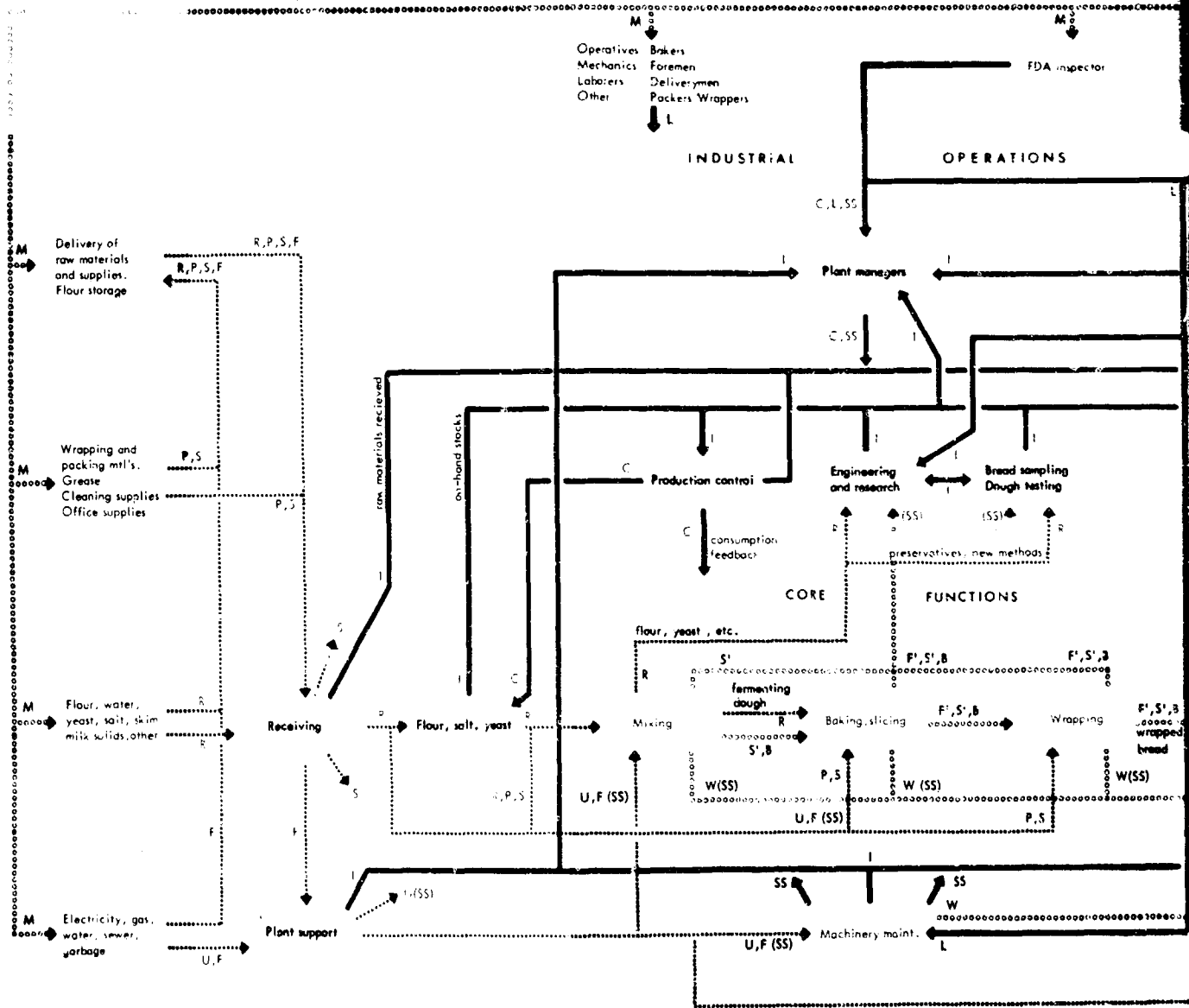
SENSITIVITY OF BREAD SYSTEM COMPONENTS  
TO NUCLEAR WEAPONS EFFECTS

<u>Blast</u>	<u>Fire (Thermal)</u>	<u>Fallout</u>
Structures	Structures	People
Equipment	Equipment	Animals
Fixtures	Supplies	Crops
Supplies	Animals	
Utilities	Crops	
Transportation		

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Source: Stanford Research Institute

Figure 13  
BREAD SUBSYSTEM NETWORK FOR BAKERIES

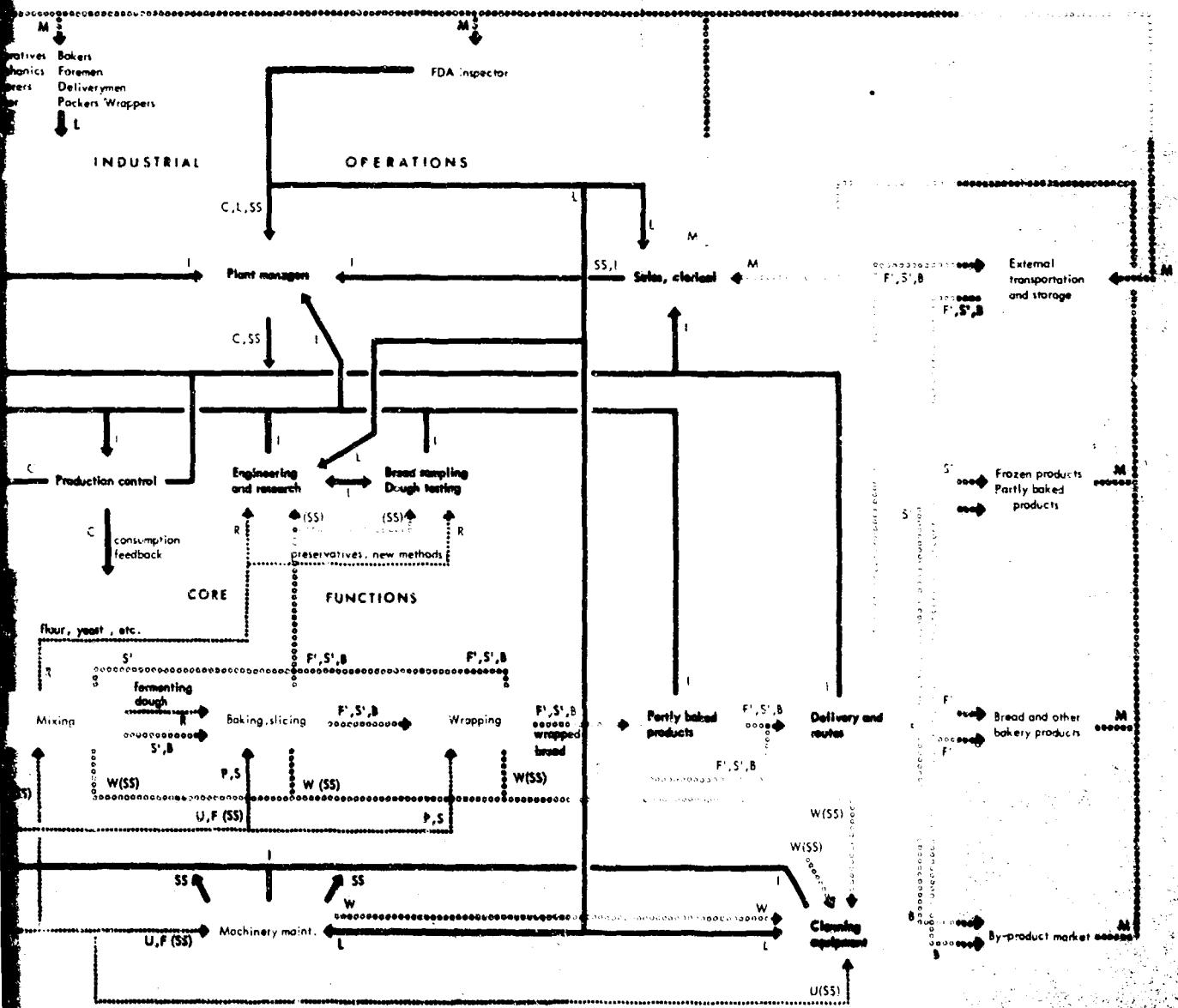


- |                                  |                                  |                        |
|----------------------------------|----------------------------------|------------------------|
| <b>INPUTS</b>                    | <b>OUTPUTS</b>                   | <b>HUMAN RESOURCES</b> |
| R - raw materials                | F' - finished products           | C - command links      |
| P - process materials            | S' - semi processed materials    | L - labor supply       |
| S - supplies                     | B - by-products                  | I - information links  |
| U - utilities                    | W - waste products               | SS - support service   |
| F - fuel                         | M - money                        |                        |
| (SS) - support service connected | (SS) - support service connected |                        |

SOURCE: Stanford Research Institute

A

# BAKERIES



B

Table 7

ESTIMATES OF SPECIFIC RATES AND CAPACITIES FOR  
THE INPUT RESOURCES OF A TYPICAL BAKERY

Input	Pounds of Bread per Pound of Input	Pounds Needed per 10 <sup>6</sup> Pound Bread
<b>Materials</b>		
Flour	1.85	54,000
Water	2.78	36,000 (~4,500 gal)
Yeast	100.	1,000
Salt	100.	1,000
Sugar	33.3	3,000
Skim milk solids	33.3	3,000
Other ingredients	33.3	3,000
	Pounds of Bread per Man-Day	Workers per 10 <sup>6</sup> Pound Bread
<b>Labor<sup>a, b</sup></b>		
Bakers	825	121
Foremen	4,970	20
Delivery men	918	110
Packers and wrappers	2,210	45
Operatives <sup>c</sup>	1,460	68
Laborers <sup>c</sup>	6,640	15
Truck drivers	5,220	19
Mechanics	7,440	14
Other workers	516	190
Total		602
	Pounds of Bread per Unit Day	Units per 10 <sup>6</sup> Pound Bread
<b>Facilities</b>		
Floor area		
Bakery	--	100,000 sq ft
Warehouse	--	25,000 sq ft
Pneumatic flour bins <sup>d</sup>	--	15
Mixers <sup>b</sup>	50,000	2
Kneading, shaping, and panning machines <sup>b</sup>	72,000	2
Ovens <sup>b</sup>	50,000-100,000	1-2
Slicers and wrappers <sup>b</sup>	50,000	2
<b>Utilities<sup>e</sup></b>		
Water (cooling, heating, and humidifying)		
Electricity (machinery motors and lighting)		
Gas (ovens)		

a These workers also produce perhaps another 100,000 pounds of nonbread bakery products.

b Sixteen-hour day of two shifts is assumed.

c Not elsewhere classified.

d Storage of perhaps 750,000 pounds of flour, or about a 15-day supply.

e Rates not known in detail but must operate above facilities.

Sources: Stanford Research Institute and Reference 27.



Qualitative descriptions of damage or hazards from nuclear weapon effects and potential countermeasures for use against these effects are presented in Table 8 for a number of bakery subsystem components. The quantitative detail needed for planning and implementing the countermeasures would be part of the input data used in the development of the recovery model system.

Table 8

NUCLEAR ATTACK CONSEQUENCE AND APPLICABLE COUNTERMEASURES FOR THE BAKERY SUBSYSTEM

	Blast	Thermal and Primary Ignition	Secondary Ignition and Fire Spread	Fallout	Rapid No Shutdown	Countermeasures
<b>Facilities</b>						
<b>Structures</b>						
Process	Direct damage		Direct	Denial		Hardening; decon;
Bakery	Missiles & debris		Direct Damage			Debris clearance
Office (if separate)	Missiles & debris		Direct Damage	Denial		Debris clearance
Warehousing						
Flour storage	Missiles & debris		Direct Damage	Denial		Debris clearance
<b>Process equipment</b>						
<b>Continuous</b>						
Knending, shaping, & panning						Alternate method
Ovens						Harding
Slicers	Minor missile damage		Warped machines	Cleanup problem		Alternate method
Wrappers						Alternate method
<b>Batch</b>						
Mixers						Alternate method
<b>Support equipment</b>						
<b>Materials</b>						
<b>Inputs</b>						
<b>Unprocessed raw materials</b>						
Water (see under utilities)						
<b>Semiprocessed raw materials</b>						
Flour		Dust explosion		Contamination	Growth & spoilage	Closed containers
Yeast						
Salt				Contamination		Closed containers
Sugar				Contamination		Closed containers
Skim milk solids						
Other ingredients						
<b>Utilities</b>						
Electricity	Break drops		Short circuits		Hot wires	Shutdown
Gas	Break drops		Ignition of leaks		Leaks	Shutdown
Water	Break drops				Leaks	Shutdown
<b>Fuel</b>						
<b>Process materials</b>						
Grease			Grease fire			Cleanup
<b>Supplies</b>						
Office supplies						
Cleaning supplies						
<b>Outputs</b>						
<b>Finished products</b>						
Bread (loaf)						
Other bakery products						
<b>Semiprocessed products</b>						
Partly baked products						
By-products						
Waste products						
Defective product						
Usual wastes						
<b>People</b>						
<b>Employees</b>						
Bakers	Wounds	Burns	Burns	Radiation sickness		Shelter, training exchangeable jobs
Deliverymen						
Foremen						
Packers & wrappers						
Other operatives						
Mechanics						
<b>Nonemployees</b>						
FDA inspector						

(above notes apply to all people)

Source: Stanford Research Institute

## RECOVERY MANAGEMENT CONCEPTS AND RELATED MODEL DETAILS

### Recovery Management Concepts

The information derived from applying the models to a range of attack situations and alternative countermeasure systems is needed to develop specific definitions of management functions and requirements. These functions and requirements are:<sup>23</sup> (1) situation assessment, (2) communications, (3) data processing, (4) specification of recovery requirements, (5) development of recovery plans and schedules, (6) decision guidance on plan selection, and (7) supervision and control of the recovery operations. The design features of the three civil defense organization models previously described include the consideration of these requirements and functions. Further, the models are so constructed that each functional representation corresponds to the actual operational functions of management. For example, in the research case, the situation assessment data would be supplied by other model computations, whereas in an operational case, the situation assessment data would be obtained from observation and status reports to the management organization.

The sequence of model application to describe postattack recovery starts with the situation assessment from the output of a damage assessment model, which provides computed indications of the status of survivors in terms of numbers and locations. The recovery requirements model uses these data in conjunction with machine-stored data on (1) all essential survival items and their expected consumption rates (physical units per day per survivor) and (2) stockpile-consumption relationships to make estimates of the times at which the production of essential items must be recovered. The recovery planning model also uses damage assessment data, which are combined with information (as a data base) on various countermeasures to generate alternative preattack preparation and postattack recovery plans. The outputs from both models are then used to select the feasible alternatives for implementation decisions by management.

The decision guidance information that can be derived from the recovery management model would be based on the results of feasibility analyses of the various recovery plans. The cost-effectiveness analyses would consider costs in terms of capital investments and maintenance for

the preattack preparations and in terms of other units of measure, such as manpower (number, skills, man-hours), equipment (amount, type, equipment-hours), materials (amount and type), and radiation dose (to both countermeasure and mission personnel) for the postattack recovery period.

The effectiveness of a postattack countermeasure system, while generally related to its capability for improving the environment or the feasibility of recovery, may be measured in physical performance units for specific countermeasures and in such terms as lives saved, reduction in radiation dose, reduction in recovery time, and increase in the rate at which the production of goods is recovered for a countermeasure system. It is conceivable that, for the possible range in postattack environments and recovery situations, combinations of the two will result in some cases where the recovery is cost-limited and effectiveness-limited. In other cases, the cost-effectiveness ratios may be used for direct comparison and selection of the best available set of countermeasures and consistent (and compatible) procedures for allocating available resources.

A recovery management model can be developed functionally from a range of outputs of the recovery planning model. Selection of a recovery plan, based on feasibility and cost-effectiveness, must meet the recovery requirements derived from the outputs of the requirements and planning models (in which the major constraints are the operational limitations of the countermeasures, the production rate of essential commodities needed to sustain survivors, and the capabilities of the survivors to recover and operate the facilities at the indicated levels). The scope and detail of the organizational structure required to implement the selected (or derived) plan can also be determined from the functional requirements of the recovery task.

#### Recovery Requirements Model Details

As the first step in developing the three models that will describe a civil defense organization, some of the equations for the internal computations of the recovery requirements model have been derived and applied to the food system. The following discussion focuses on the model functions that describe the basic relationships among consumption rates of essential survival commodities, stockpiles, production recovery times, and countermeasure scheduling.

The items essential for survival have been designated by the Office of Emergency Planning under seven major categories and are listed in Table 9. Systems that produce and distribute these items would be included in the model systems for deriving recovery requirements for the early postattack period. The list of survival items may show items that

Table 9

**SURVIVAL ITEMS**

1. Health supplies and equipment
  - a. Pharmaceuticals
  - b. Blood collecting and dispensing supplies
  - c. Emergency surgical instruments and supplies
  - d. Biologicals
  - e. Surgical textiles
  - f. Laboratory equipment and supplies
2. Food
  - a. Milk group
  - b. Meat and meat alternate group
  - c. Vegetable-fruit group
  - d. Grain products
  - e. Fats and oils
  - f. Sugars and syrups
  - g. Food adjuncts
3. Body protection and household operations
  - a. Clothing
  - b. Personal hygiene items
  - c. Household equipment
4. Electric power and fuels
  - a. Electric power
  - b. Petroleum products
  - c. Gas
  - d. Solid fuels
5. Sanitation and water supply
  - a. Water
  - b. Water supply materials
  - c. Chemical, biological, and radiological (CBR) detection, protection, and decontamination items
  - d. Insect and rodent control items
  - e. General sanitation
6. Emergency housing and construction materials and equipment
7. General use items

---

Source: Reference 28

are not required for simple survival. It can be shortened if the capability to produce becomes limited after attack, or to emphasize certain types of items.

To indicate how the recovery requirements model parameters are related to those of the industrial models, some of the parameters and basic relationships for the industrial models are discussed in the following paragraphs. A summary of the parameter designators used in the discussion is given in Table 10.\*

The average or instantaneous rate of change in any of the parameters is designated with a dot over the designator; thus  $dO_i/dt$  is represented by  $\dot{O}_i$ . For any defined industrial system, a finite number of parameters and relationships exist; thus, there are  $m$  survival items or commodities,  $n$  resources or materials,  $p$  processes or types of equipment, and  $r$  inputs other than people or materials. In general, it is convenient to number the processes in reverse order of occurrence (i.e., from last to first). According to the notation, each of several forms of a commodity (e.g., fresh milk, dried milk, skim milk, etc.) would be given a separate  $i$  number (or  $j$  number if it is an input to a process). The designations may be expanded for application to specific conditions; thus the output rate of commodity  $i$  from process  $k$  would be designated  $\dot{O}_{ik}$ .

$$\dot{O}_{ik} = a_{ijk} \dot{R}_{jk} \quad (1)$$

$$\dot{O}_{ik} = b_{ik} \dot{N}_k \quad (2)$$

$$\dot{O}_{ik} = e_{ikl} \dot{i}_{lk} \quad (3)$$

$$\dot{O}_{ik} = \epsilon_{ik} \dot{P}_k \quad (4)$$

in which  $a_{ijk}$ ,  $b_{ik}$ ,  $e_{ikl}$ , and  $\epsilon_{ik}$  are production coefficients for normal operating conditions of the system. For small variations in the parameters, the coefficients may be considered as constants. Since all four equations

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\* See Brown<sup>13</sup> and Billheimer<sup>15</sup> for comparison as to notation

TABLE 10

SUMMARY OF RECOVERY REQUIREMENT AND  
INDUSTRIAL MODEL PARAMETER DESIGNATORS

i	Commodity or survival item in the specific form in which it is consumed (e.g., fresh milk, dried milk, canned peas, gasoline, etc.)
j	Material resource input to a process: raw, semi-processed, or a consumer commodity i
k	Process or equipment required as one step in the production of commodity i
l	Input other than a material resource or people
m	Arbitrarily selected number of commodities i
n	Number of resources or materials
p	Number of processes or types of equipment k involved in the production of commodity i
r	Number of inputs l involved in the production of commodity i
$O_i$	Magnitude of the output of commodity i
$R_j$	Magnitude of the input of resource (material) j
$P_k$	Capacity level for process or equipment
$N_k$	Number of people associated with process k
$I_l$	Magnitude of an input l other than a material resource or people
$C_i$	Amount of commodity i that is consumed
$c_i$	Amount of commodity i consumed per person
$N_i$	Total number of people or consumers of commodity i
$E_i$	Inventory of the ith commodity at any time

Production coefficients relating four production limiting parameters to the production rate,  $\dot{O}_i$ , of commodity i:

$a_{ijk}$	for physical material inputs $\dot{R}_{jk}$
$b_{ik}$	for the number of people $N_k$
$c_{ikl}$	for inputs $I_{lk}$ other than material or people
$c_{ik}$	for the capacity level $\dot{P}_k$ of process or equipment k

Table 10 (concluded)

$N_1^0$	Number of overhead or non-operative persons associated with the production of commodity i
$\alpha_{ik}$	Number of overhead persons per operating person for process k
$\beta_{lk}$	Excess of input $I_l$ per unit of input $I_{lk}$ normally associated with process k
$O_1^*$	Potential final output of commodity when all inventory in process is used
$t_1$	Consumption delay time (raw material to consumer)
$t_{ik}$	Production time for commodity i in process k
$t_{id}$	Distribution or delay time for commodity i
$t_{is}$	Storage time for commodity i
$\bar{T}_1$	Average consumption delay time
$E_1^0$	Inventory of commodity i at the start of the postattack period
$\tau_1$	Time after start of the postattack period
$T_1^0$	Time after start of the postattack period when $E_1^0 = 0$

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Source: Stanford Research Institute



must be satisfied before a value of  $O_{ik}$  or  $\dot{O}_{ik}$  is realized, the value of  $\dot{R}_{jk}$ ,  $N_k$ ,  $\dot{i}_{jk}$ , and  $\dot{P}_k$  giving the lowest value of  $\dot{O}_{ik}$  in reality establishes the maximum value  $\dot{O}_{ik}$ .

For a 40-hour week operation without breakdown, the value of  $\epsilon_{ik}$ , by definition, would be 40/168 or 0.24; its average value might be less where occasional breakdowns occurred and repair time interrupted production. The maximum potential output for continuous operation would thus be controlled by Equation (4) with an  $\epsilon_{ik}$  value of one. This equation could also control the maximum potential output under postattack conditions. If the facility equipment is destroyed,  $\dot{P}_k$  is zero and  $\dot{O}_{ik}$  is zero. If the equipment is damaged but is reparable, then the value of  $\epsilon_{ik}$  is reduced (and may be zero until some degree of repair is achieved).

Under normal operating conditions, the number of people associated with the production of a commodity in one or more processes is larger than those associated with the processes; it is convenient to relate the number of these overhead persons,  $N_i^o$ , in proportion to the number of operating people so that:

$$N_i^o = \sum_{k=1}^P \alpha_{ik} N_k \quad (5)$$

where  $\alpha_{ik}$  is a proportionality constant for a given process. The total number of people for normal operation is then given by:

$$N_i = \sum_{k=1}^P (1 + \alpha_{ik}) N_k \quad (6)$$

In postattack or other situations of manpower shortage, consideration can be given to decreasing the overhead staff to make better use of the facilities.

Also, in most operations, some of the utility inputs are larger than those required for production. Again, it is convenient to consider these excess inputs as fractional increases over the amounts required for productive needs. The total input requirement of  $i$  is then given by:

$$i_i = \sum_{k=1}^P (1 + \theta_{ik}) i_{ik} \quad (7)$$

in which  $\beta_{lk}$  is a proportionality constant for a given process (and input).

In many production systems of more than one process, the output of one process becomes an input to a successive process; if the commodity  $i$  numbering system is in order of the processes, then  $R_{jk}$  for one process is equal to  $\dot{O}_{(i+1)(k+1)}$  of the previous process (otherwise  $i = i' + x$  and  $k = k' + y$  where  $x$  and  $y$  are matrix translation numbers from one system to another).

The potential final output of commodity  $i$  at a given time from a series of processes where the output of one is an input to a succeeding process is given by:

$$O_i = \sum_{k=1}^P O_{ik} \quad (8)$$

$$O_i^* = \sum_{k=1}^P a_{ijk} R_{jk} \quad (9)$$

The inventory (stockpile) of the material or resource inputs at any time is defined by  $R_j$  or, if the same resource is used in more than one process, by:

$$R_j = \sum_{k=1}^P R_{jk} \quad (10)$$

The inventory (stockpile) of the commodity  $i$  (an input) at any time is defined by:

$$E_i = O_i - C_i \quad (11)$$

The above two inventory definitions were selected to facilitate accommodation to the recovery requirements model. The inventory of the resource  $j$  would indicate, through integration of Equation (1), the maximum potential output of commodity  $i$  if the other inputs are provided and the inventory is not replaced. The inventory for the commodity  $i$  probably could also be defined as  $O_i$  but since a time delay between production and consumption occurs, it is convenient to define the inventory as the amount available for consumption at a given time. In other words, the inventory

$R_j$  would represent the stockpiles directly available for processing, whereas the inventory  $E_i$  would represent the stockpiles in the distribution chain or supply system between the points of production and consumption.

If the production times,  $t_{ik}$ , time of delivery (or transport),  $t_{id}$ , and the storage time,  $t_{is}$ , for a commodity are known, the product delivery lead time (or consumption delay time),  $t_i$ , can be estimated from:

$$t_i = \sum_{k=1}^p t_{ik} + t_{id} + t_{is} \quad (12)$$

In general,  $t_i$  would have a range of values mainly because of the possible variations in  $t_{id}$  and  $t_{is}$ . Maximum values of  $t_i$  would be expected to be limited by the storage life of perishable goods or by the marketing cycle of goods. Minimum values of  $t_i$  would be expected to be limited by the time required to transport the commodity to consumers with a minimum of storage time. An overall average value of  $t_i$  for the delivery lead time of the commodity  $i$  that is being produced and consumed at a constant rate ( $\dot{E}_i = 0$ ) for an area may be estimated from:

$$t_i = \frac{O_i + E_i}{C_i} \quad (13)$$

#### Consumption and Stockpile Depletion Relationships

Per capita consumption rates for survival items can be determined in two ways: (1) by prorating the preattack annual production over the population and (2) by analyzing individual survivor requirements. The first is useful for investigating recovery potential on a national basis and testing whether items can be supplied at normal consumption rates as a desirable goal. The second would be used to evaluate recovery sequences at the minimum feasibility level of production.

If Equation (11) is evaluated at the end time of a nuclear war (or at the start of the postattack period) under the simplified condition that  $\dot{O}_i$  is zero, then  $O_i$  in that equation is a constant, say  $E_i^0$ . Equation (11) can be rewritten as:

$$E_i = E_i^0 - N_i \dot{c}_i \tau_i \quad (14)$$

in which  $\dot{c}_i$  is assumed to be constant and  $\tau_i$  is the time after attack. Another way of stating the rewrite of Equation (11) is that at  $\tau_i$  equal

zero, the total consumption,  $C_1$ , is zero so that  $O_1$  at that time is equal to  $E_1$  (and designated  $E_1^0$ ), the inventory of commodity  $i$ . The time  $T_1$  at which  $E_1$  becomes zero for a given number of consumers (i.e., survivors) may be represented by:

$$T_1^0 = \frac{E_1^0}{N_1 \dot{c}_1} \quad (15)$$

If the area considered is large enough, it should be expected that, for some commodities, the output from undamaged facilities could be realized from the stockpiles  $R_j$ . And, where this production took place such that  $T_1^0 \geq t_1$ , then the potential consumption time would be represented by:

$$T_1^0 = \frac{E_1^0 + O_1}{N_1 \dot{c}_1} \quad (16)$$

where

$$O_1 = \sum_{k=1}^p a_{ijk} R_{jk} \quad (17)$$

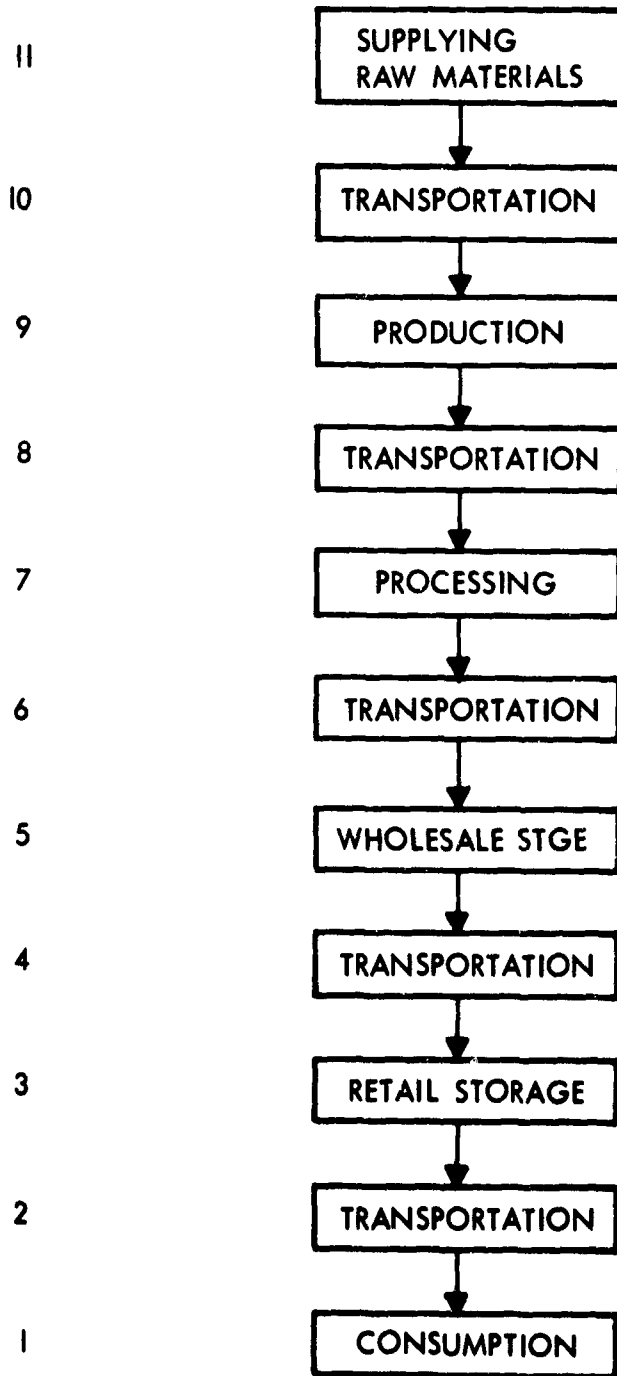
The production system for a given survival item can be illustrated by a flow diagram that designates the steps or processes through which a raw material passes to the consumer. A generalized flow diagram that applies for many survival items from raw material to consumption is shown in Figure 14. Equations (16) and (17) represent the initial stages of the recovery process where the production from undamaged facilities is resumed even though at the initial stages the contribution from these facilities is considered only in terms of extending the potential consumption (or survival) time.

The value of  $T_1^0$  by Equation (16) is valid only if the entire inventory in the process chain can be depleted by consumption through supplying the inputs to the  $p$  processes. In recovery planning, where a number of survival items are competing for a supply-limited production input, the input may have to be allocated among the items (at least initially). This allocation may either eliminate some of the potential supplies from the earlier processing steps or decrease the amounts processed or both. Degrada-tions in supplies and production capabilities resulting from weapon effects would be included in the estimate of the  $R_{jk}$  values. The recovery-degraded consumption-time is also represented by Equations (16) and (17), where  $p$  is the number of processes (starting with the last one in the chain) actually used. The value of  $R_{1k}$  may be less than for normal operations because the allocation of an input  $l$  to the  $k$ th process is reduced. The value of  $R_{jk}$  is zero if the production capability of any process after the  $k$ th process (i.e., the process numbered  $k-1$ , counting from the last one in the chain) is zero. In other words, the output constraints set by Equation (1) through (4) still hold.

Figure 14

TYPICAL FLOW DIAGRAM FOR PRODUCT i THROUGH 11 PROCESSES

Process k



SOURCE: Stanford Research Institute.

### Stockpile Use and Recovery

The full use of the stockpiles of all commodities, as indicated by Equations (16) and (17), would require the allocation of available inputs (some of which may also be commodities). In addition, the facilities for the indicated processing steps must be available. The recovery requirements model thus must include procedures for identifying the required facilities, the times when their production capability should be recovered, the time when the inputs should be recovered or made available, and a summary of the allocation requirements for the inputs.

The potential supply of commodity  $i$ , as represented by  $R_{jk}$  in Equation (17), can only be obtained by supplying resource inputs (man-hours, kwh, and so forth) to inventories in each process  $k$  in sufficient quantities to carry the product through  $p$  processes to the consumer. (At this point, the problem is one of recovery rather than only of survival.) The magnitude of the input  $l$  required to complete the process  $k$  in the production of the commodity  $i$  is given by Equation (3). In the case of food, the coefficient  $e_{ikl}$  will be physical units of the consumable edible product  $i$  in process  $k$  per unit of input  $l$ .

The total input requirements for the full use of the inventory  $R_{ij}$  for  $m$  survival items distributed among  $p$  processes is:

$$I_l = \sum_{i=1}^m \sum_{k=1}^p \frac{a_{ijk}}{e_{ikl}} R_{jk} \quad (18)$$

In the case where the inventory for the input  $l$  is less than  $I_l$  from Equation (18), then, where  $a_{ijk}$ ,  $e_{ikl}$ , and  $m$  are fixed, either  $p$  or  $R_{jk}$  (or both) must be reduced to conform to the available value of  $I_l$ . Or, an additional capacity of  $I_l$  must be recovered.

The rate at which the input  $l$  must be supplied to maintain the commodity stockpiles from all processes and at the level  $O_{ij}$  is given by:

$$\dot{i}_l = \sum_{i=1}^m \sum_{k=1}^p \frac{a_{ijk}}{e_{ikl}} \dot{R}_{jk} \quad (19)$$

which is simply the differential of Equation (18) with respect to time.

In general, a given number of inputs are required in the  $k$  processes to produce each commodity. Thus, a matrix of  $I_l$  or  $\dot{i}_l$  parameters exists for each set of the  $k$  processes. And, for any combination or series of

processes and inputs where  $I_l$  or  $\dot{i}_l$  is zero, no product will be obtained from the  $k$ th process [as specified by Equation (3)]. Hence, if  $r$  inputs are needed, all must be supplied or the process cannot be carried out.

A three dimensional matrix for the production variables among inputs, products, and processes (designated as an inventory utilization matrix) is shown in Figure 15. As each form of the final product  $i$  across the front face moves vertically through processes  $k$ , inputs  $j$  and  $l$  must be supplied at each process. The matrix can be expanded to include feedback loops and exchanges for cases where products are inputs to processes or where an input product could pass through process  $k$  with required inputs from itself.

In the early postattack period, the actual survival time on a national scale without recovery efforts is represented by Equation (15) or Equations (16) and (17) for  $k=1$ . In general, the readily available stockpiles of the survival items would probably be used to recover inputs for the final processing step ( $k=2$ ) of the items, since this step should require the minimum expenditure of supplies and energy to increase the apparent stockpile. Further, the last step process would always be required before the product would be available to consumers. Thus, the recovery of the inputs and facilities should proceed over time in reverse order of the processing steps (i.e., in order of increasing  $k$  numbers). The priority in order of recovery could be established on the basis of the  $T_i^0$  values from Equation (15), the processing times (or lead times from the  $k$ th process), and the facility recovery time. The minimum input capacity of each kind for all survival items that needs to be recovered to sustain the  $N_1$  consumers is given by:

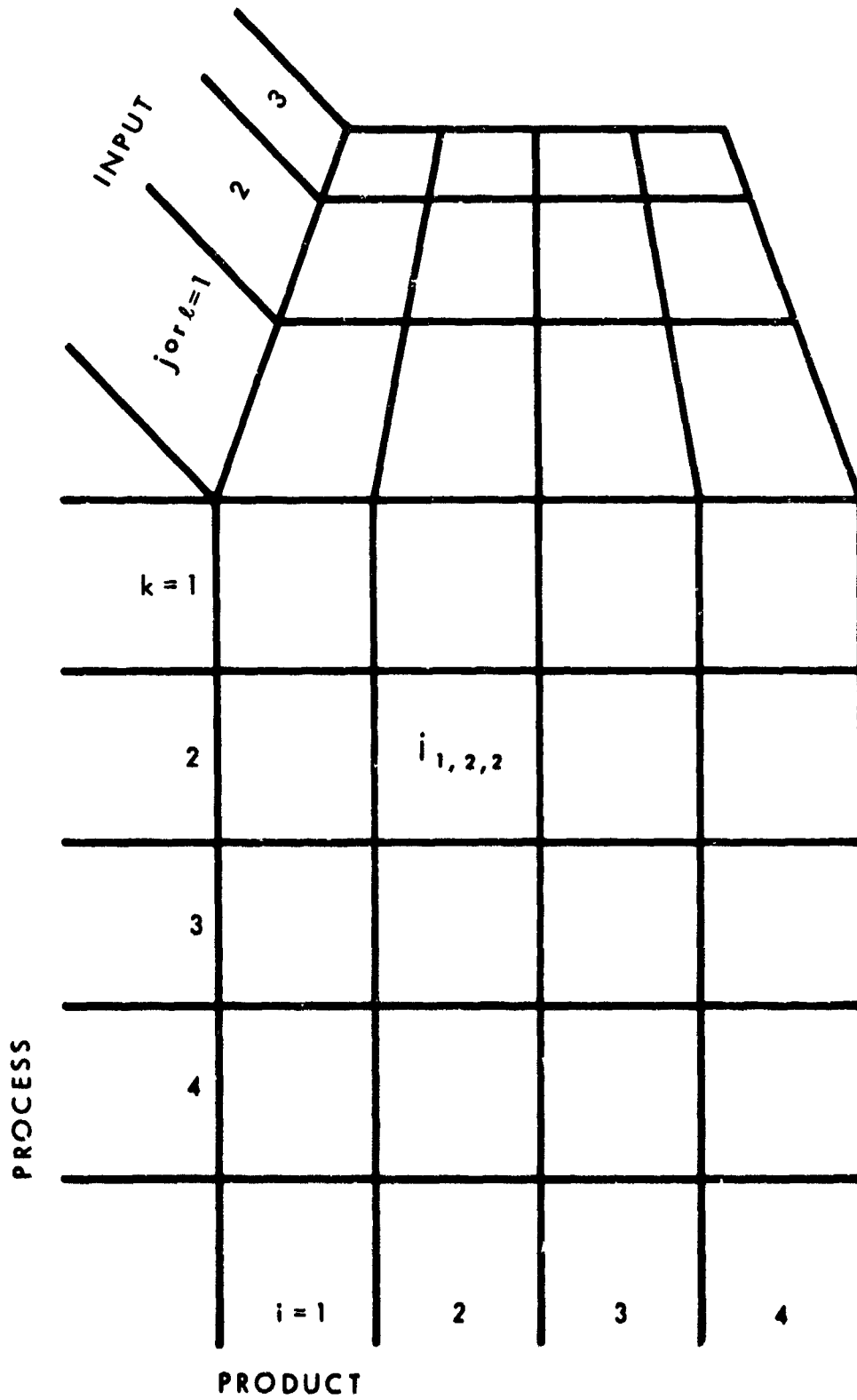
$$\dot{i}_l = \sum_{i=1}^m \sum_{k=1}^p \frac{N_1 \dot{c}_i}{c_{ikl}} \quad (20)$$

where Equation (20) represents the minimum equilibrium supply rate for each input in the  $k$  processes for all survival commodities that is consistent with the survival requirements defined by:

$$\dot{O}_i = N_1 \dot{c}_i, \quad \tau_i \geq T_i^0 \quad (21)$$

If the sums indicated by Equation (20) are evaluated in increasing order of the  $k$  values for each  $i$  and in the order of the  $i$  values according to the order of the  $T_i^0$  values from Equation (15), the order of recovery requirements of each input  $l$  may be estimated. The accumulated sums would indicate the input needs during the initial stages of recovery for each

Figure 15  
 INVENTORY UTILIZATION MATRICES



SOURCE:  
 Stanford Research Institute.



commodity and process; for each increasing value of  $k$  (for a given commodity), the evaluation of Equation (20) should provide a stepwise requirement for the recovery of the input  $l$ .

The minimum product delivery lead time for each successive step is given by Equation (12). When facility (or transport) recovery must be achieved to meet production and distribution needs, however, an additional delay may result from radiological recovery operations or repair of damaged facilities. These recovery needs will be evidenced by lack of inputs in resources, manpower, utilities, and facilities. If the maximum additional delay resulting from any cause other than processing, transport, and storage is designated as  $\Delta t_{ikl}$ , then the maximum recovery lead time for each successive stage in the recovery of the output from the  $k$  processes (because of lack of inputs) is given by:

$$T_i = t_i + \sum_{l=1}^r \sum_{k=1}^p \Delta t_{ikl} \quad (22)$$

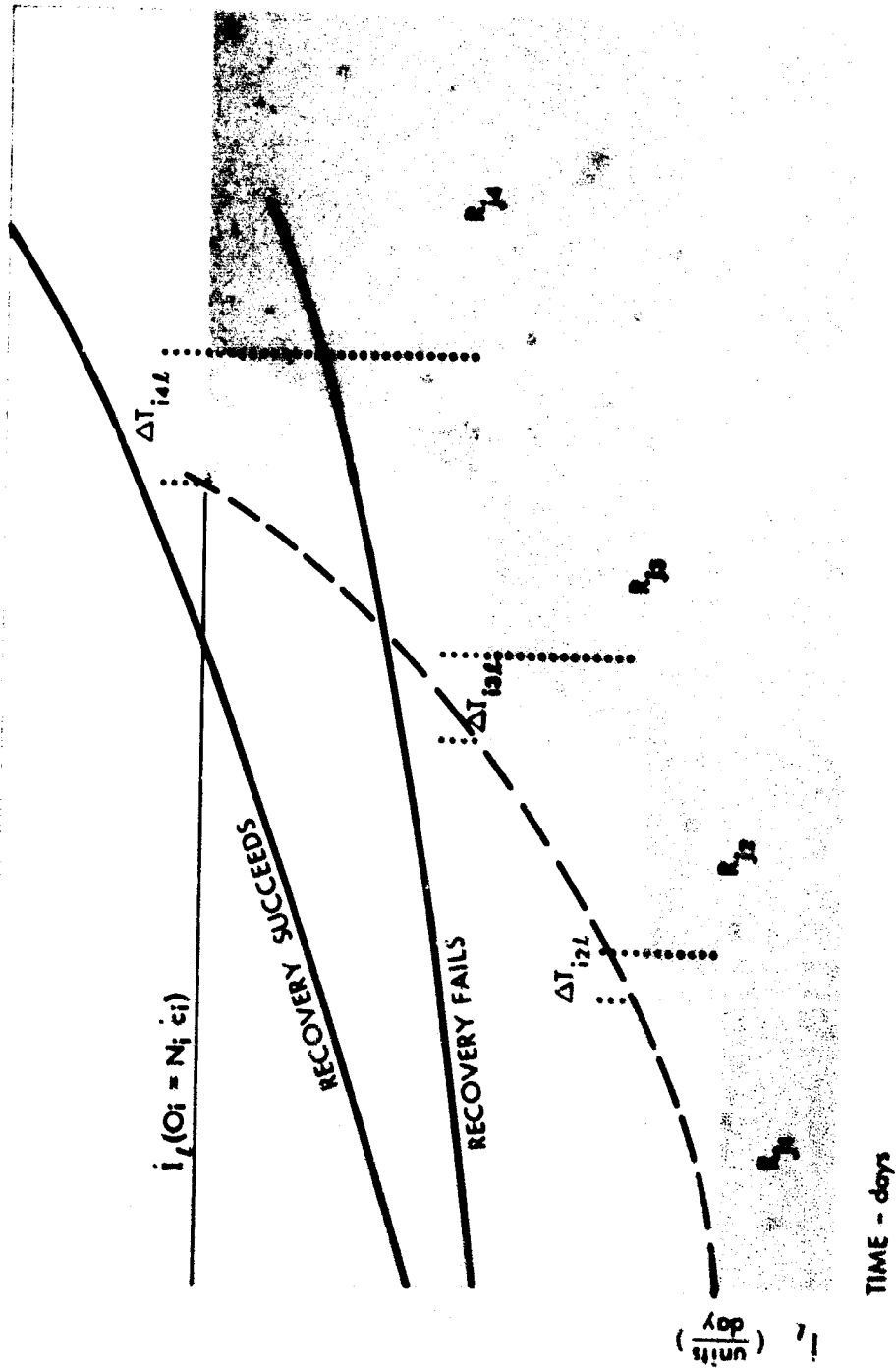
The double sum is given in Equation (22) to indicate a maximum delay time for the case in which the processes and inputs are recovered in sequence. This situation would probably not be a general case where several recovery countermeasures are carried out simultaneously by different groups of people. The real values of  $\Delta t_{ikl}$  would be estimated from the recovery planning models; however, the minimum delay time requirements would be established by comparing estimates from Equation (15) or perhaps Equations (16) and (17) to determine feasible limits for the second term of Equation (22).

The results from Equations (20) and (12) or Equation (22) may be combined to establish a single product or commodity production requirement (or output) curve as a function of time. The true curve for a local area, as mentioned above, would be a step function reflecting discrete increases in inputs and outputs as the facilities are recovered and process inventories are brought into the production chain. On a national scale, the step functions would probably approach the form of a smooth curve.

The above concepts are illustrated in Figure 16 for a single input and product. The recovery of the supply rate of input  $l$  is indicated by two arbitrarily drawn solid line curves; neither is conservative with respect to requirements. The third curve (broken line) is conservative with respect to the amount recovered and time of recovery. In the figure, the recovery rate curve that falls in the gray area represents failure after successful recovery of the output from three processes. It should

Figure 16

RELATIONSHIPS AMONG  $i_t$ , SUPPLY AND DEMAND, INVENTORY  $R_{jk}$  IN PROCESS, AND RECOVERY CAPABILITY FOR PRODUCT  $i$



be noted that the recovery of the production from any number of successive processes and their inventories less than the total number of processes in the chain is equivalent to increasing the original stockpile and, if feasible, increases the survival time. On the other hand, the recovery of the production from all processes in the chain constitutes recovery of the industry to the degree required to sustain production at the survival level. This achievement would, in general, satisfy the first basic objective of a postattack recovery system.

#### Recovery Scheduling Techniques

As stated above, ultimate and sustained recovery will require the continuing operation of all related survival systems, including systems that provide raw materials. Therefore, it is important that recovery requirements of all systems, both individually and collectively, be projected as far as necessary into the postattack period for identifying problems of input shortages and for identifying countermeasures for solving these problems. Longer term problems such as these may require long lead times to resolve but, if anticipated, certain recovery variables could be altered. Alterations in variables that could lead to alternative recovery plans and procedures include: (1) revision of schedules for the supply of product  $i$ ; (2) deletion, substitution, or reduction in consumption rate  $\dot{c}_i$ ; (3) reduction in product quality; and (4) possible increase or substitution of inputs.

The steps for determining postattack recovery requirements and scheduling can be summarized as follows:

1. Determine the number of survivors ( $N_i$ ).
2. Estimate a normal or minimum consumption rate,  $\dot{c}_i$ , for selected survival items, including acceptable substitute relationships among items.
3. Estimate the available and potentially consumable inventories,  $R_i$  and  $R_{ij}$ , of each survival item from preattack statistics and damage assessment summaries.
4. Estimate the potential consumption or survival times for each survival commodity--Equations (15) and (16).
5. Use the three-dimensional matrix (see Figure 15)--based on preattack economy data--the  $R_{ij}$  data, and damage assessment summaries of available inputs  $I_i$  to estimate the total input capacities and production potentials required to maintain or regenerate the stockpile--Equations (18) and (19).
6. Estimate the requirements of input  $I_i$  capacities for continued survival--Equation (7)--and compare these with results from Step 5.

7. Use Equations (8), (9), and (10) to develop a minimum requirement for the recovery of input  $I_j$  (Figure 16) for  $r$  inputs and  $p$  processes to each of  $m$  survival items; cumulate the rate of input and estimate the allowed process delay times--Equation (20).
8. Sum the daily requirements for each input  $I_j$  in Step 6 to obtain the total rate required as a function of time and repeat estimate of allowed delay times.
9. Compare the results of Steps 4, 6, and 7 to determine whether any input  $I_j$  requirement exceeds availability at the minimum lead time, to enumerate bottleneck inputs, and to establish allocation priorities for the inputs.
10. If recovery is possible in Step 9 ( $T_1(n)$  is greater than  $T_1$ ), recovery scheduling and planning can proceed. Alternative recovery plans and schedules may be tested to evaluate those having the minimum delay times [these, by definition, should give the most rapidly rising curves for the variation of production (supply of  $R_1$ )] with time after attack.

Some of these steps are superficially applied to the food system in the appendix to indicate how available data can provide data bases for postattack recovery requirement and scheduling information.

## SUMMARY AND RECOMMENDATIONS

A list of postattack recovery model systems was given under the four general categories of weapon effects and vulnerability, economic systems, countermeasures, and civil defense organization. A series of specific models in each general category was discussed briefly in terms of inputs, internal computational parameters, and outputs. The functional scope of each model as part of a recovery model system was described and the current state of development of each was indicated. A general approach to model design and development was given, using water and bread systems as detailed examples.

Some countermeasure models, which are a primary interest and responsibility of OCD, were outlined and discussed. Decontamination and dose control models, currently the most highly developed countermeasure models, were presented in the greatest detail. The inputs, internal computations, outputs, and parameter limits (from referenced associated research) were reasonably well defined. Other countermeasure models were diagrammed in terms of inputs, internal computation, and outputs, but computation procedures and parameter relationships and the ranges of applicable parameter values are yet to be defined.

Postattack management functions and requirements were discussed in parametric terms in model form for evaluating recovery requirements, recovery planning, and management operations. The theory of the recovery requirements model was developed in detail with a series of procedural steps for evaluating recovery requirements as a function of time. These steps, some of which were applied to the food system as an example, were based on concepts that should be applicable to essential survival items as well as to the recovery of the entire economy. However, the effort required to generate input data bases in the detail needed may limit initial application to selected essential survival items or to small regions.

The primary functions of the civil defense organization models for recovery requirements, planning and management are to develop feasible production recovery schedules from the recovery model system--and to develop recovery schedules that are designed to meet the needs of survivors. Except for the few recovery requirement model details developed as examples in this report, no quantitative methods are available for estimating postattack recovery requirements on a national scale.

Individual models of the recovery model system should be developed to the point where the model system can be tested. A rapid development of the system would require initial estimates of all major parameters and basic relationships. Later, these estimates could be replaced through more detailed research on each model. Testing the model system through sensitivity analyses could indicate where research effort to gain detailed information on each model should be concentrated. This approach is being used in continuing research on recovery model systems in the further development of models that can be applied to the study of organization and management requirements for a range of postattack situations.

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Appendix

SOME RECOVERY REQUIREMENT MODEL PARAMETERS FOR THE FOOD SYSTEM

## Appendix

### SOME RECOVERY REQUIREMENT MODEL PARAMETERS FOR THE FOOD SYSTEM

Production and distribution of food in a postattack environment will play an important part in postattack survival and recovery. Because of its importance and the large number of detailed statistics available, the food chain of selected dietary items has been investigated as an example of the application of the theory and concepts discussed under "Recovery Management Concepts and Related Model Details."

Statistics on national production have been used to derive model parameter relationships to illustrate and describe the development of the recovery requirements model. Although application of data from national averages to local areas of different sizes can lead to misrepresentation, the application is suitable for demonstrating the types of input and output parameters required in the treatment and the internal data processing techniques that might be applied to local data bases.

#### General Supply, Consumption, and Diet Considerations

The agricultural products that are consumed as food are itemized by group under Item 2 of Table 9. Within each group are several products that, unprocessed or processed, are eaten in different forms, such as fresh, frozen, or canned. Data on normal eating habits and trends are summarized by U.S. Food Consumption<sup>1</sup> in terms of supply and consumption rates; the summaries include data on the annual per capita weight consumption of many foods according to the form in which they are retailed. These data were used to determine the specific foods that are most important in the national diet (on a consumption basis). A list of the food forms that are consumed in significant amounts and for which the recovery requirements model is applied in the example is given in Table A-1.

The normal daily consumption rate,  $\dot{c}_i$ , of the edible portion of each food form can be determined from per capita consumption data<sup>1-4</sup> or estimated from annual production figures<sup>4-7</sup> prorated over the contemporary population. This method evaluating  $\dot{c}_i$  assumes that annual production and consumption are equal and that the consumption is spread evenly over the year.

Table A-1

SIGNIFICANT FOOD CONSUMPTION FORMS

<u>Food</u>	<u>Form</u>						
	<u>Fresh</u>	<u>Frozen</u>	<u>Canned</u>	<u>Dried</u>	<u>Cured</u>	<u>Juice</u>	<u>Processed</u>
<b>Milk Group</b>							
Whole Milk	x	x	x	x			
Cheese	x						
Cottage Cheese	x						
<b>Meat and Meat Alternate Group</b>							
Beef	x	x	x	x	x		
Pork	x	x	x	x	x		
Lamb, Mutton	x	x	x				
Chicken	x	x	x				
Turkey	x	x	x				
Eggs	x	x			x		
Fish	x	x	x	x			
<b>Vegetable-Fruit Group</b>							
Potatoes	x	x	x	x			
Tomatoes	x		x			x	x
Sweet Corn	x	x	x				
Snap Beans	x	x	x				
Field Beans			x	x			
Lima Beans	x	x	x				
Lettuce	x						
Cabbage	x		x				
Peas	x	x	x				
Onion					x		
Carrot	x	x	x				
Cantaloupe	x						
Watermelon	x						
Orange	x	x	x			x	
Grapefruit	x	x	x			x	
Peach	x	x	x	x			
Apple	x	x	x	x			
Almond	x						
Pecan	x						
Walnut	x						

Table A-1 (concluded)

<u>Food</u>	<u>Form</u>					
	<u>Fresh</u>	<u>Frozen</u>	<u>Canned</u>	<u>Dried</u>	<u>Cured</u>	<u>Juice Processed</u>
<b>Grain Products</b>						
Wheat Flour						x
Wheat Cereal						x
Rye Flour						x
Rice	x					
Corn Meal						x
Corn Cereal						x
Corn Starch						x
Oats						x
Barley						x
<b>Fats and Oils</b>						
Lard						x
Butter						x
Margarine						x
Shortening						x
Edible Oils						x
<b>Sugar and Syrups</b>						
Cane Sugar						x
Beet Sugar						x
Corn Sugar						x
<b>Food Adjuncts</b>						
Coffee						x
Tea						x
Cocoa						x

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Source: Reference 1 and Stanford Research Institute

If the inputs to the food production process (i.e., farming or ranching) are not considered, then the outputs (farm products) either go directly to consumers without change in form or are inputs to a process where the form may be changed. Many of the farm products arrive at the consumer level in several forms. The fractional distribution of the farm output of a given commodity among several processes where it is an input in the preparation of another commodity (or another form of the original commodity) may be represented by:

$$\dot{R}_{jk} = f_{ijk} \dot{O}_{(1+x)(k+y)} \quad (A-1)$$

in which  $f_{ijk}$  is the fraction of the farm output that becomes an input  $j$  to the  $k$ th process in the production of commodity  $i$ . The output of the commodity is then represented by:

$$\dot{O}_{ik} = f_{ijk} a_{ijk} \dot{O}_{(1+x)(k+y)} \quad (A-2)$$

The value of the production coefficient,  $a_{ijk}$ , for any input-output combination depends on the units of measure of the two quantities. Thus, weight changes, partitioning of the input (more than one product can result in a given process), or combination with other inputs may result; but in general,  $a_{ijk}$  would be a pure number representing weight, volume, or number change.

Estimated values of  $\dot{c}_i$ ,  $f_{ijk}$ , and  $a_{ijk}$  for significant food commodities are summarized in Table A-2 as obtained from data reported in Reference 3 to 11 (References 9 and 11 were particularly useful for this tabulation). In this table,  $\dot{c}_i$  is a 1960 per capita retail food form consumption figure;  $f_{ijk}$  is the fraction of farm production (input  $j$ ), which is allocated to processes  $k$  to produce food form  $i$  and is computed with the assumption that all of input  $j$  is accounted for in the food forms listed. The process dependent production coefficient  $a_{ijk}$  is the weight change factor that gives the number of pounds of farm production required to produce one pound of food form  $i$  at retail ( $k = 0 \dots n$  and  $a_{ijk} = 1.00$  when  $k = 0$ ).

A check on the adequacy of the daily diet given by the sum of these  $\dot{c}_i$  from Table A-2 shows that approximately 2,650 calories are provided when the food energy values derived by Merrill and Watt<sup>12</sup> are applied. Daily caloric requirements vary with individuals and the activities in which they are engaged--ranging from 50 calories per pound for infants to 4,500 calories for male adults doing heavy manual labor.

Several studies<sup>13-16</sup> have been made of the potential supply of food at various stages in the production and distribution system. The results of one of these studies<sup>16</sup> are summarized in Table A-3 on a national basis.

Table A-2

ESTIMATED VALUES OF  $\hat{c}_i$ ,  $f_{ijk}$  AND  $a_{ijk}$  FOR SIGNIFICANT FOOD COMMODITIES

Food Form $i$	$\hat{c}_i$		$f_{ijk}$		$a_{ijk}$	
	lb/day/ Person at Retail	lb/day/ Person at Retail	Farm Production Fraction	lb. Farm Production/ lb. Retail	Farm Production Fraction	lb. Farm Production/ lb. Retail
Milk						
Fresh	0.8823	0.465	0.465	1.00	0.541	8.00
Frozen	0.0501	0.040	0.040	1.50		
Canned	0.0499	0.053	0.053	2.00		
Dried	0.0200	0.084	0.084	8.00	0.684	2.43
Cheese	0.0227	0.085	0.085	7.14	0.088	2.43
Cottage Cheese	0.0129	0.038	0.038	5.56	0.228	3.26
Butter	0.0206	0.235	0.235	21.70		
Beef						
Fresh	0.0672	0.507	0.507	1.93	0.735	2.04
Frozen	0.0112	0.084	0.084	1.93	0.184	2.04
Canned	0.0224	0.227	0.227	2.59	0.081	2.88
Dried	0.0056	0.091	0.091	4.14		
Cured	0.0056	0.091	0.091	4.14		
Pork						
Fresh	0.0407	0.212	0.212	1.60	0.467	2.00
Frozen	0.0088	0.035	0.035	1.60	0.467	2.00
Canned	0.0136	0.118	0.118	2.68	0.066	2.88
Dried	0.0034	0.047	0.047	4.29		
Cured	0.0034	0.047	0.047	4.29		
Eggs						
Fresh	0.0987	0.851	0.851	1.00		
Frozen	0.0056	0.048	0.048	1.00		
Dried	0.0027	0.027	0.027	4.33		

Pork (con'd)

Table A-2 (continued)

Food Form i	c <sub>i</sub>		f <sub>ijk</sub>		a <sub>ijk</sub>		Food Form i	c <sub>i</sub>		f <sub>ijk</sub>		a <sub>ijk</sub>	
	lb/day/ Person at Retail	lb/day/ Person at Retail	Farm Production/ Fraction	lb. Farm Production/ lb. Retail	Farm Production/ Fraction	lb. Farm Production/ lb. Retail		Food Form i	lb/day/ Person at Retail	Farm Production/ Fraction	lb. Farm Production/ lb. Retail		
<b>Fish</b>													
Fresh	0.0055	0.214	0.214	1.50	0.214	1.50	Snap Beans	0.0063	0.484	0.0063	0.484	1.00	1.00
Frozen	0.0085	0.302	0.302	1.38	0.302	1.38	Fresh	0.0019	0.154	0.0019	0.154	1.06	1.06
Canned	0.0110	0.402	0.402	1.42	0.402	1.42	Frozen	0.0059	0.362	0.0059	0.362	0.68	0.68
Cured	0.0016	0.082	0.082	2.00	0.082	2.00	Canned						
<b>Potato</b>							<b>Field Beans</b>						
Fresh	0.2487	0.756	0.756	1.00	0.756	1.00	Canned	0.0192	0.277	0.0192	0.277	0.34	0.34
Frozen	0.0059	0.018	0.018	1.00	0.018	1.00	Dried	0.0170	0.723	0.0170	0.723	1.00	1.00
Canned	0.0009	0.002	0.002	0.82	0.002	0.82							
Dried	0.0133	0.224	0.224	5.57	0.224	5.57	Lima Beans						
							Fresh	0.0004	0.053	0.0004	0.053	1.00	1.00
<b>Tomato</b>							Frozen	0.0021	0.760	0.0021	0.760	2.72	2.72
Fresh	0.0311	0.222	0.222	1.00	0.222	1.00	Canned	0.0008	0.187	0.0008	0.187	1.79	1.79
Canned	0.0078	0.039	0.039	0.69	0.039	0.69							
Juice	0.0132	0.145	0.145	1.54	0.145	1.54	Lettuce						
Catsup	0.0104	0.181	0.181	2.44	0.181	2.44	Fresh	0.0370	1.000	0.0370	1.000	1.00	1.00
Paste	0.0104	0.413	0.413	5.56	0.413	5.56							
							<b>Cabbage</b>						
<b>Sweet Corn</b>							Fresh	0.0216	0.840	0.0216	0.840	1.00	1.00
Fresh	0.0080	0.261	0.261	1.00	0.261	1.00	Canned	0.0038	0.160	0.0038	0.160	1.09	1.09
Frozen	0.0017	0.150	0.150	2.69	0.150	2.69							
Canned	0.0097	0.589	0.589	1.86	0.589	1.86							



Table A-2 (continued)

Food Form i	$\dot{c}_i$ lb/day/ Person at Retail	$f_{ijk}$		$\dot{c}_i$ lb/day/ Person at Retail	$f_{ijk}$		$a_{ijk}$ lb. Farm Production/ lb. Retail	$a_{ijk}$ lb. Farm Production/ lb. Retail
		Farm Production Fraction	Production Fraction		Farm Production Fraction	Production Fraction		
<b>Peas</b>								
Fresh	0.0002	0.008	1.00	0.0059	0.031	2.00		
Frozen	0.0045	0.450	2.37					
Canned	0.0077	0.542	1.68					
<b>Onion</b>								
Fresh	0.0295	1.000	1.00					
<b>Carrot</b>								
Fresh	0.0114	0.826	1.00	0.0021	0.386	8.00		
Frozen	0.0009	0.080	1.24					
Canned	0.0011	0.094	1.14	0.0007	0.037	2.27		
<b>Cantaloupe</b>								
Fresh	0.0140	1.000	1.00					
<b>Watermelon</b>								
Fresh	0.0217	1.000	1.00					
<b>Orange</b>								
Fresh	0.0344	0.089	1.00	0.0419	0.604	1.00		
Canned	0.0096	0.024	0.97	0.0022	0.029	0.89		
Frozen				0.0104	0.183	1.22		
Juice	0.0413	0.856	8.00	0.0016	0.184	8.00		

Table A-2 (concluded)

Food Form i	$\dot{c}_i$ lb/day/ Person at Retail	$f_{ijk}$ Farm Production Fraction	$a_{ijk}$ lb. Farm Production/ lb. Retail	Food Form i	$\dot{c}_i$ lb/day/ Person at Retail	$f_{ijk}$ Farm Production Fraction	$a_{ijk}$ lb. Farm Production/ lb. Retail
Almond	0.0006	1.000	1.00	Margarine	0.0258	1.000	2.86
Pecan	0.0011	1.000	1.00	Shortening	0.0345	1.000	2.86
Walnut	0.0010	1.000	1.00	Oils	0.0315	1.000	2.86
Wheat Flour	0.3233	0.982	1.37	Cane Sugar	0.1943	1.000	10.00
Cereal	0.0074	0.018	1.08	Beet Sugar	0.0767	1.000	7.14
Rye Flour	0.0033	1.000	1.25	Coffee	0.0364	1.000	1.19
Rice	0.0167	1.000	1.50	Tea	0.0016	1.000	1.00
Corn Meal	0.0195	0.253	1.12	Cocoa	0.0079	1.000	1.25
Cereal	0.0049	0.149	2.63				
Starch	0.0049	0.090	1.59				
Syrup	0.0279	0.486	1.50				
Sugar	0.0101	0.022	1.85				
Oats	0.0096	1.000	1.67				
Barley	0.0027	1.000	1.41				

Table A-3

ESTIMATED FOOD SUPPLY AT  
VARIOUS STAGES OF DISTRIBUTION  
1963

	<u>Days</u> <sup>a</sup>	<u>Cumulative</u> <u>Days</u>
Home	9.0	9.0
Retail Food Stores	11.6	20.6
Wholesale Warehouses	11.7	32.3
Other <sup>b</sup>	52.3 ± 10.0	84.6 ± 10.0

---

a Based on 2650-calorie diet

b Includes unprocessed and surplus food stocks whose quantities fluctuate seasonally as well as from year to year

Source: Reference 16

In all of the studies, the supply was computed by dividing total calories of stored food by an assumed daily caloric requirement of the population. A balanced diet including specific food items was not considered.

A recovery requirements model must be able to account for each food product inventory in greater detail than the summation of available calories of all foods used to generate Table A-3. Each food form  $i$  is a separate system that must be understood in detail if the total system is to operate or is to be recovered in a postattack environment. A simplified approximation such as:

$$E_i^O = N_i \dot{c}_i T_i^O \quad (A-3)$$

does not account for seasonal or regional variations in quantity of a specific food form  $i$ , particularly a fresh perishable food, even though the total caloric content of all foods stored in homes, retail, and wholesale locations remains about constant throughout the year. Unprocessed surplus food stocks have seasonal variations in both composition and quantity.

Equation A-3 is based on a consumption rate established by prorating the production of each food form uniformly over the time it is available. Adequate distribution is assumed, and each person has a daily (constant or seasonably variable) consumption rate  $\dot{c}_i$  of each food form, whatever the size of the portion may be. Realistically, this apportionment of the food would be impractical and probably would not produce a balanced diet for individuals throughout the year because of the seasonal variation in supply. The Department of Agriculture has proposed national emergency food consumption standards that set forth food allowances per person per week, acceptable substitutes, and substitution rates for canned and concentrated foods.<sup>17</sup> Such standards can be used to apportion available foods among survivors at the local level to approximate balanced but not identical diets from available foods. These local variations of equivalent diets can be considered when the detail of the recovery requirements model is extended beyond the national level of the current example; further, the diets must be based on the stockpiles available at the time of an attack, so that some items will not be included if the attack occurs near harvest time. These detailed analyses will also indicate (1) how the consumption of various foods can be combined to follow the general guidance set forth by the USDA<sup>17</sup> and (2) whether that guidance is consistent with the feasibility of recovery of the food system.

#### Perishable Foods

Important factors in planning the most efficient consumption schedule for a perishable food crop are (1) harvest starting and completion dates

and period of maximum harvest activity or production rate, (2) delay time from production to consumption, (3) storage time without loss by spoilage, (4) total production of the crop, and (5) a spoilage factor. Simplified relationships among the first four factors in relation to harvest rate, consumption rate, and the stockpile size of a single perishable crop (with no processing steps) are shown in Figure A-1.

The output rates represented by Figure A-1a are:

$$\dot{O}_1 = \frac{\dot{O}_1^m (t - t_0)}{(t_1 - t_0)} \quad , \quad t_0 \leq t \leq t_1 \quad (\text{A-4})$$

$$\dot{O}_1 = \dot{O}_1^m \quad , \quad t_1 \leq t \leq t_2 \quad (\text{A-5})$$

and

$$\dot{O}_1 = \dot{O}_1^m \left[ 1 - \frac{(t - t_2)}{(t_3 - t_2)} \right] \quad , \quad t_2 \leq t \leq t_3 \quad (\text{A-6})$$

where  $t$  is the day of the year,  $t_0$  is the first day of harvest,  $t_1$  is the first day of maximum harvest activity,  $t_2$  is the last day of maximum harvest activity,  $t_3$  is the last day of harvest, and  $\dot{O}_1^m$  is the production rate during the period of maximum harvest activity.

The cumulative output (independent of the destination of the harvested crop) during the harvest period is represented by:

$$O_1(t) = \frac{\dot{O}_1^m (t - t_0)^2}{2(t_1 - t_0)} \quad , \quad t_0 \leq t \leq t_1 \quad (\text{A-7})$$

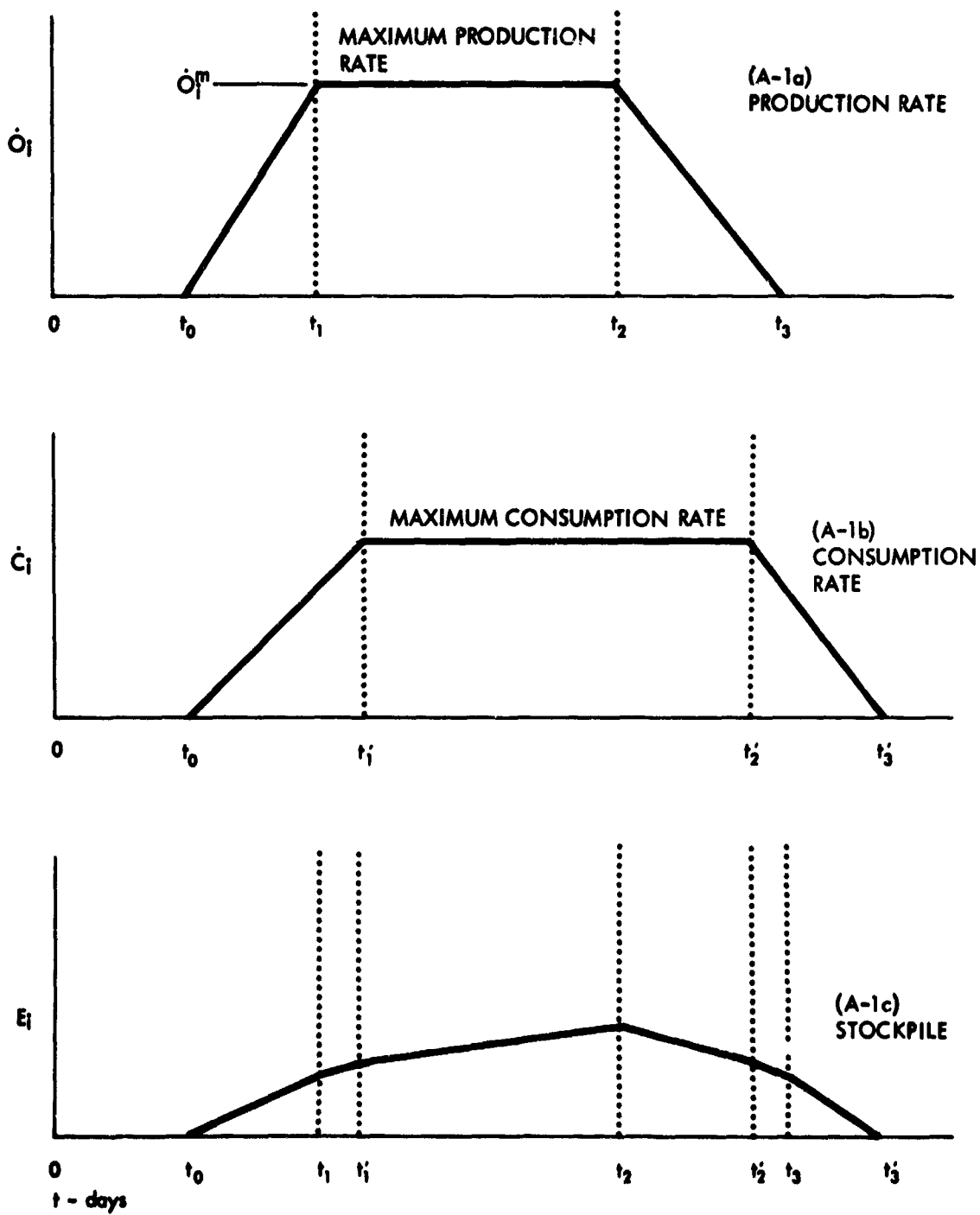
$$O_1(t) = \dot{O}_1^m \left[ t - \frac{(t_0 + t_1)}{2} \right] \quad , \quad t_1 \leq t \leq t_2 \quad (\text{A-8})$$

and

$$O_1(t) = \frac{\dot{O}_1^m}{2} \left\{ (t - t_2) \left[ 1 - \frac{(t - t_2)}{(t_3 - t_2)} \right] + 2t_2 - t_0 - t_1 \right\} \quad , \quad t_2 \leq t \leq t_3 \quad (\text{A-9})$$

Figure A - 1

RELATIONSHIPS AMONG PRODUCTION RATE, CONSUMPTION RATE,  
AND THE STOCKPILE OF A SINGLE PERISHABLE CROP



SOURCE: Stanford Research Institute.

The total production is obtained by setting  $t$  equal to  $t_3$  in Equation (A-9); it is given by:

$$O_1(t_3) = \frac{\dot{O}_1^m}{2} (t_2 + t_3 - t_0 - t_1) \quad (\text{A-10})$$

Generally, consumption begins at the same time as the harvest for areas adjacent to the production sites. However, the consumption rate over the country (or a large area) will not reach a plateau until some time after the production rate becomes constant and output is delivered to the farthest market. The same time delay in the maximum consumption rate would be expected after the harvest rate begins to decline. And finally, the consumption rate must vanish at a time after production stops, determined by the maximum storage time before spoilage occurs. The above assumptions and the consumption-rate pattern given by Figure A-1b are represented by:

$$\dot{C}_1 = \frac{\dot{C}_1^m (t - t_0)}{(t'_1 - t_0)} \quad , \quad t_0 \leq t \leq t'_1 \quad (\text{A-11})$$

$$\dot{C}_1 = \dot{C}_1^m \quad , \quad t'_1 \leq t \leq t'_2 \quad (\text{A-12})$$

$$\dot{C}_1 = \dot{C}_1^m \left[ 1 - \frac{(t - t'_2)}{(t'_3 - t'_2)} \right] \quad , \quad t'_2 \leq t \leq t'_3 \quad (\text{A-13})$$

where  $t'_1$  is the first day of maximum consumption rate,  $t'_2$  is the last day of maximum consumption rate,  $t'_3$  is the last day of consumption, and  $\dot{C}_1^m$  is the maximum consumption rate.

The cumulative amounts of the crop consumed are given by:

$$C_1(t) = \frac{\dot{C}_1^m (t - t_0)^2}{2(t'_1 - t_0)} \quad , \quad t_0 \leq t \leq t'_1 \quad (\text{A-14})$$

$$C_1(t) = \dot{C}_1^m \left[ t - \frac{(t_0 + t'_1)}{2} \right] \quad , \quad t'_1 \leq t \leq t'_2 \quad (\text{A-15})$$

and

$$C_1(t) = \frac{\dot{C}_1^m}{2} \left\{ (t - t'_2) \left[ 1 - \frac{(t - t'_2)}{(t'_3 - t'_2)} \right] + 2t'_2 - t_o - t'_1 \right\},$$

$$t'_2 \leq t \leq t'_3 \quad (A-16)$$

According to the above discussion, the time delays for delivery and storage (or spoilage) result in the following relationships among the time parameters:

$$t'_1 = t_{id} + t_1 \quad (A-17)$$

$$t'_2 = t_{id} + t_2 \quad (A-18)$$

and

$$t'_3 = t_{is} + t_3 \quad (A-19)$$

where  $t_{id}$  is the maximum delivery time (for delivery to farthest significant consumer group) and  $t_{is}$  is the maximum storage time (i.e., storage time at which spoilage occurs). Thus, for a perishable commodity,  $t_{id}$  must always be less than  $t_{is}$  for full utilization of the output. Substitution of Equations (A-17), (A-18), and (A-19) for Equation (A-16) and evaluation at  $t_3$  gives:

$$C_1(t'_3) = \frac{\dot{C}_1^m}{2} (t_2 + t_3 + t_{is} - t_o - t_1) \quad (A-20)$$

If  $f_{ijk}$  is the fraction of the harvested crop that is utilized in perishable form, then  $C_1(t'_3)$  is equal to  $f_{ijk} O_1(t_3)$  and, from Equations (A-10) and (A-20), the production and consumption parameters are related by:

$$\dot{O}_1^m = \frac{\dot{C}_1^m (t_2 + t_3 + t_{is} - t_o - t_1)}{f_{ijk} (t_2 + t_3 - t_o - t_1)} \quad (A-21)$$

If  $\dot{c}_1$  is evaluated in terms of the average daily consumption of the commodity over a year's time, then the output required to supply  $N_1$  people is given by:

$$O_1(t_3) = \frac{365 N_1 \dot{c}_1}{f_{ijk}} \quad (A-22)$$



The inventory at any time between  $t_0$  and  $t_3'$  is given by:

$$E_1(t) = O_1(t) - C_1(t) \quad (A-23)$$

where  $O_1(t)$  for  $t$  greater than  $t_3$  is equal to  $O_1(t_3)$ .

If more than one cropping or harvesting of the same commodity occurs in one year, then the output  $O_1(t)$  and consumption  $C_1(t)$  are redesignated as  $O_{ix}(t)$  and  $C_{ix}(t)$ , respectively, for each of the harvests. The total output for the yearly harvest is then given by:

$$O_1(t) = \sum_{x=1}^z O_{ix}(t) \quad (A-24)$$

where  $z$  is the total number of croppings. The total amount consumed is given by:

$$C_1(t) = \sum_{x=1}^z C_{ix}(t) \quad (A-25)$$

In the case of several croppings, the equality stated by Equation (A-21) is not required; however, if it holds for each cropping, then the yearly crop is consumed. The requirement stated by Equation (A-21) becomes:

$$O_1(365) = \frac{365 N_1 \dot{c}_1}{z_{ijk}} \quad (A-26)$$

The production and consumption characteristics must be computed separately for each cropping to ensure that the inventories are not mixed and that  $t_{id}$  is less than  $t_{is}$  for each harvest. Thus, several croppings can contribute to the stockpile only if the difference in their respective values of  $t_0$  is less than  $t_{is}$ .

As an example of concurrent consumption of several croppings of a fresh perishable food, lima bean consumption is analyzed on a national basis. The pertinent factors of Equations (A-4) through (A-21) are given in Table A-4, together with the computed values for  $O_1^{an}$  and  $C_1^{an}$  illustrated in Figure 1. The seasonal variation of the concurrent consumption of fresh lima beans, on a national basis, where the number of crops contributing to consumption varies from none to nine, grown throughout the year,

Table A-4

$O_1^m$  AND  $C_1^m$  FOR FRESH LIMA BEAN CROPS

Time	State	Crop	$t_0$ day	$t_1$ day	$t_2$ day	$t_3$ day	$t_1^a$ day	$t_2^b$ day	$t_3^c$ day	$t_2^c$ day	$t_3^d$ day	$O_{1x}(t_3)$ $10^3$ cwt	$O_{1x}^m$ cwt/day	$C_{1x}^m$ cwt/day
Winter	Fla.	1	-16	1	90	90	4	93	102	6	62	58		
Spring	S.C.	2	140	166	196	212	169	199	224	42	824	737		
	Fla.	3	91	91	151	166	94	154	178	42	622	571		
Summer	N.Y.	4	213	213	273	304	216	276	316	26	344	319		
	N.J.	5	191	196	243	304	199	246	316	61	763	709		
	Md.	6	182	182	243	273	185	246	285	20	263	244		
	N.C.	7	161	161	212	222	164	215	234	50	893	806		
	Ca.	8	140	152	243	304	155	246	316	122	957	914		
	Ala.	9	140	152	243	304	155	246	316	80	627	599		

NOTES:

- a Reference 19, page 2
- b Assumed  $t_1 + 3$  days ( $t_{1d}=3$ )
- c Assumed  $t_2 + 3$  days ( $t_{2d}=3$ )
- d  $t_3 + 12$  days ( $t_{3d}=12$ ) Reference 18, page 18-02
- e Reference 4, Table 312, 1960

is given in Table A-5. Intermediate values of  $\dot{C}_1$  can be obtained by straight-line interpolation.

### Nonperishable Foods

Food forms that can be stored until the start of the next harvest period have a seasonal variation of their stockpile  $E_1$  as shown in Figure A-2. Unlike fresh perishable crops, all crops can contribute concurrently to the consumption rate throughout the year so that the rate is:

$$\dot{C}_1 = N_1 \dot{c}_1 \quad (\text{A-27})$$

and the total consumption up to any time is:

$$C_1(t) = N_1 \dot{c}_1 t, \quad 0 \leq t \leq 365 \quad (\text{A-28})$$

The total consumption for the year is then  $365 N_1 \dot{c}_1$ . If only one cropping occurs, production or harvest parameters for minimum production requirements are specified by:

$$\dot{O}_1^m = \frac{730 N_1 \dot{c}_1}{(t_2 + t_3 - t_0 - t_1)} \quad (\text{A-29})$$

For the case where more than one cropping occurs, the minimum production requirement is given by:

$$O_1 = \sum_{x=1}^z O_{1x} = \frac{365 N_1 \dot{c}_1}{f_{ijk}} \quad (\text{A-30})$$

The above requirements, as derived on the basis of the  $\dot{c}_1$  values for each crop, may be adjusted (as mentioned previously) to some degree on the basis of total dietary needs and substitutions of one food for another (although the sums over the  $i$  products are not indicated here). Over any period of time, the costs associated with the output production at the level  $\dot{O}_1^m$  may be the controlling factor in the selection of the diet items and the crops to be grown in a postattack environment. The above equations indicate only how the production outputs can be related to diet requirements, to their delivery times, and to the food stockpile.

Table A-5

## SEASONAL VARIATION OF FRESH LIMA BEAN CONSUMPTION

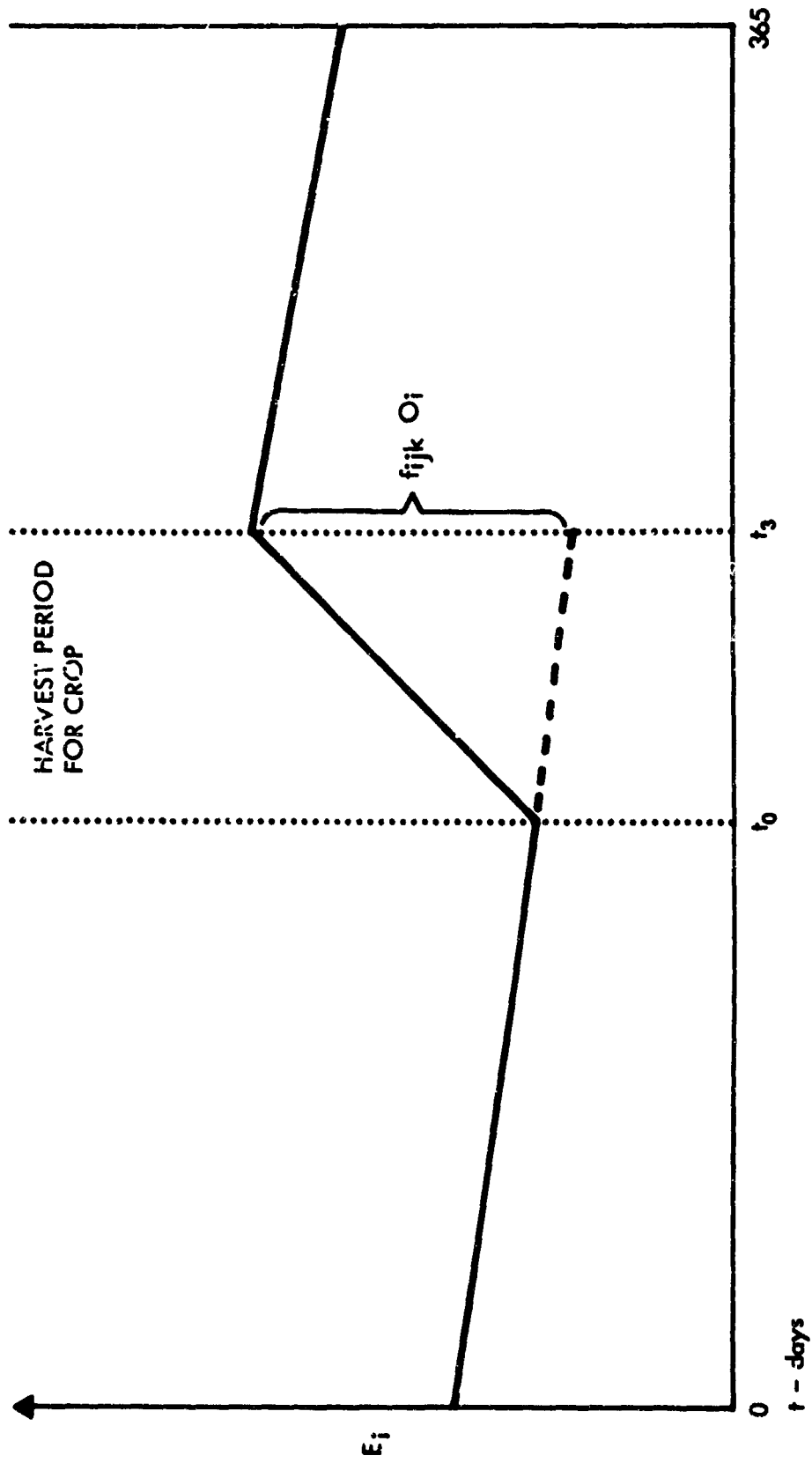
t day	Crop x <sup>a</sup>									C <sub>1</sub> <sup>b</sup> cwt/day
	1	2	3	4	5	6	7	8	9	
0	X									46
4	X									58
91	X		X							58
93	X		X							439
94	X		X							629
102			X							571
140		X	X					X	X	571
154		X	X					X	X	2339
155		X	X					X	X	2441
161		X	X				X	X	X	2451
164		X	X				X	X	X	3262
169		X	X				X	X	X	3270
178		X					X	X	X	3056
182		X				X	X	X	X	3056
185		X				X	X	X	X	3300
191		X			X	X	X	X	X	3300
199		X			X	X	X	X	X	4009
213		X		X	X	X	X	X	X	3596
215		X		X	X	X	X	X	X	3750
216		X		X	X	X	X	X	X	3785
224				X	X	X	X	X	X	3209
234				X	X	X		X	X	2785
246				X	X	X		X	X	2785
276				X	X	X		X	X	1644
285				X	X			X	X	1231
316										0
349	X									0
365	X									46

a See Table A-4

b National consumption of concurrent crops

Source: Stanford Research Institute

Figure A - 2  
 SEASONAL VARIATION OF  $E_i$  FOR NON-PERISHABLE FOOD PRODUCT  $i$



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