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**CHEMICAL PROCESS SYSTEMS  
LABORATORY**

A Goal Oriented Functional Tree  
Structure for Nuclear Power Plant  
Emergency Preparedness

by

Richard V. Calabrese  
Marvin L. Roush

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NUCLEAR POWER PLANT EMERGENCY PREPAREDNESS

Richard V. Calabrese  
Marvin L. Roush

**A CONSTITUENT LABORATORY OF  
THE SYSTEMS RESEARCH CENTER**

**THE UNIVERSITY OF MARYLAND  
COLLEGE PARK, MARYLAND 20742**

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A GOAL ORIENTED FUNCTIONAL TREE STRUCTURE FOR  
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Richard V. Calabrese  
Department of Chemical  
and Nuclear Engineering  
University of Maryland  
College Park, MD 20742

Marvin L. Roush  
Department of Chemical  
and Nuclear Engineering  
University of Maryland  
College Park, MD 20742

**ABSTRACT** Guidelines for development and implementation of emergency response plans do not provide the planner/implementer with an adequate overview of the functions to be achieved or a measure of their relative importance. To provide a framework in which this importance can be recognized, understood and quantified, a logical goal oriented tree structure has been developed which integrates and gives a clear visual representation of the functions required to meet the emergency preparedness objective. The tree considers a spectrum of both high and low probability events which may require mitigation both onsite and offsite.

The ultimate objective: to Minimize the Ill Effects of a Nuclear Power Plant Incident is satisfied by functions concerned with prevention and mitigation of human injury and property damage. A complete and detailed structure which specifies the subfunctions and success paths which satisfy these functions has been developed. Institutional activities such as planning, training, procedure development, monitoring and decision making do not enter the tree directly. Instead, the logic structure defines the extent to which these activities must be considered and the information systems and decision models required for successful implementation of the plan.

The top structure of the tree is presented and a few branches are considered in detail. The impact of institutional activities, information systems, etc. is discussed. Tree quantification is considered.

## I. INTRODUCTION

Numerous documents provide guidance toward development and implementation of nuclear power plant emergency response plans. Most are concerned with the adequacy of personnel, supporting facilities and institutional activities performed in support of the plan. These activities include contingency planning, task organization, procedure development and specification, monitoring and dose projection, and practice drills to aid in plan maintenance and improve-

ment. Unfortunately, such documents do not provide the planner/implementer with a good basis for understanding the functions to be achieved and a clear definition of their overall importance toward attaining the ultimate objective. To provide a framework within which this "importance" can be recognized, understood and quantified, we have developed a logical tree structure which integrates and gives a clear visual representation of the functions required to meet the emergency preparedness objective. Rather than focus solely upon low probability, high consequence events with radiological impact on the public, we consider the spectrum of events which may require mitigation both onsite and offsite.

The goal oriented tree presented herein is an outgrowth of the logic structures defined as part of the Top-Down Integrated Approach to Safe, Reliable, Economic Nuclear Power (e.g., Combustion Engineering, 1982; Technology for Energy Corp., 1982). The approach and results represent refinements of a detailed functional classification performed for the Dept. of Energy (DOE) by these authors (University Research Foundation, 1983) as part of the DOE Information Systems Project. The structure provides an easily understood overview of all required functions and their interrelationships, and a logical framework for quantitative evaluation. It is anticipated that the model can be a useful training tool to allow an individual to view specific parts of a plan in proper context. It might also be useful to provide a contextual overview of regulations to allow a proper perspective of the need for and the contribution of a single regulation to the overall objective, as well as the impact of the regulation upon achievement of other functions.

We have attempted to structure this goal tree according to the following simple guidelines: For each box, one can look "down" in the tree to see how the functional objective is accomplished. One can look "up" in the tree to see why the functional objective is required. Near the top of the tree, each function is specified in a very general way. Subfunctions or components of a higher level goal are then developed at lower levels. The lowest levels

represent one or more success paths by which specific objectives can be accomplished. Effort has been made to address issues in a generic way that is applicable to any plant and to account for all possible contingencies, except sabotage. Therefore, at lower levels not all subfunctions/success paths will be relevant at a specific plant.

## II. OVERVIEW OF TREE STRUCTURE

The top structure, shown in Figure 1, states the ultimate goal of emergency preparedness; that is, to Minimize the Ill Effects of a Nuclear Power Plant Incident that could potentially threaten the health, safety and economic well being of both the public and plant personnel. The objectives to be accomplished are prevention and mitigation of human injury and property damage. The functions which address these objectives can be classified as either preventative (pre-injury) or mitigative (post-injury). Mitigative functions are included since any realistic criteria for success must accommodate some casualties and/or property damage, if only due to the initiating event.

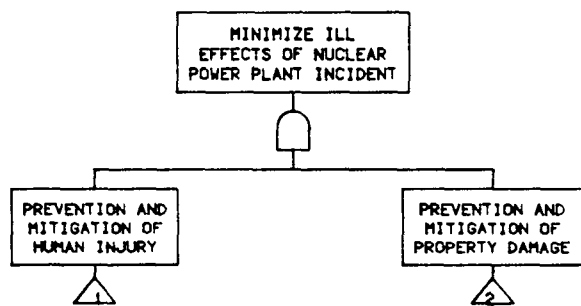


Figure 1 - Top Tree Structure

Portions of the tree that are presented herein are each assigned a number. This number appears inside a triangle located to the left of the top box of that branch. If the lowest boxes of that branch contain a triangle beneath them, then the number inside that triangle specifies the tree number on which it is continued.

The functions that satisfy the ultimate goal are given in Trees 1 and 2. These are:

a) Prevention of Human Injury. Plant personnel and the public must be protected from conventional injury and from exposure to radiation and toxic chemicals.

b) Prevention of Psychological Stress. The psychological impact on the public from an incident of any degree is to be minimized.

c) Human Casualty Control (Mitigation). People injured as a result of conventional accidents and/or exposure to radiation or toxic chemicals must be identified, treated and otherwise cared for both onsite and offsite.

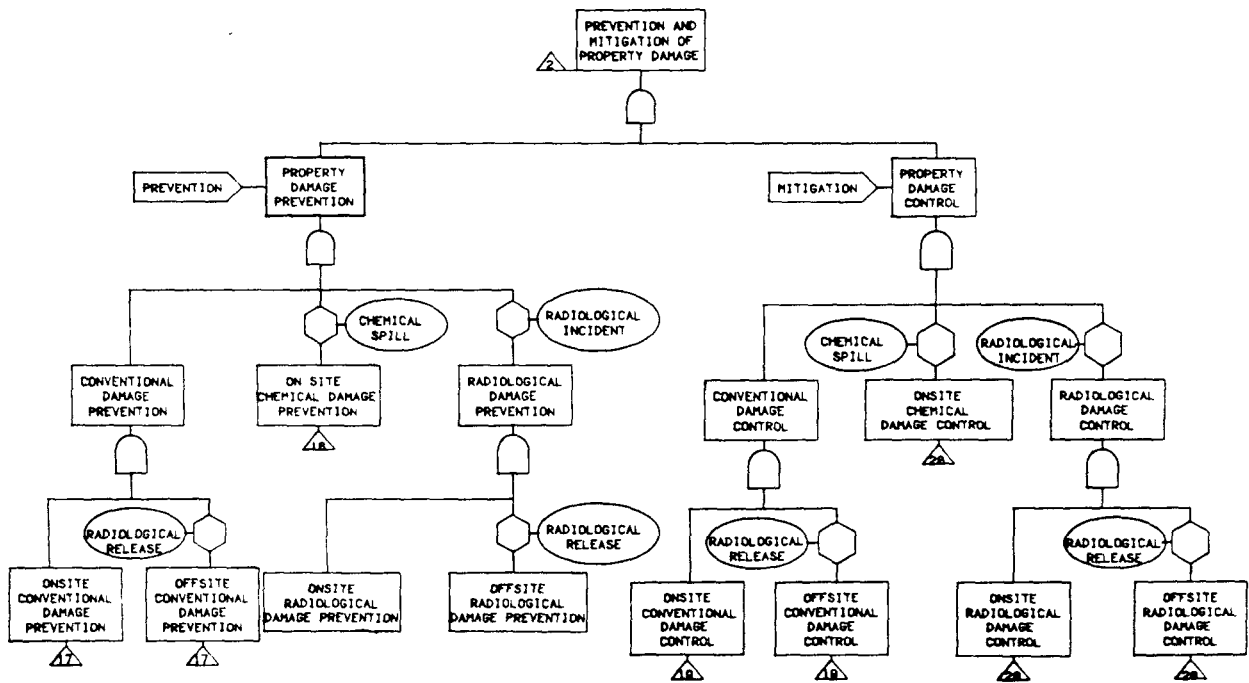
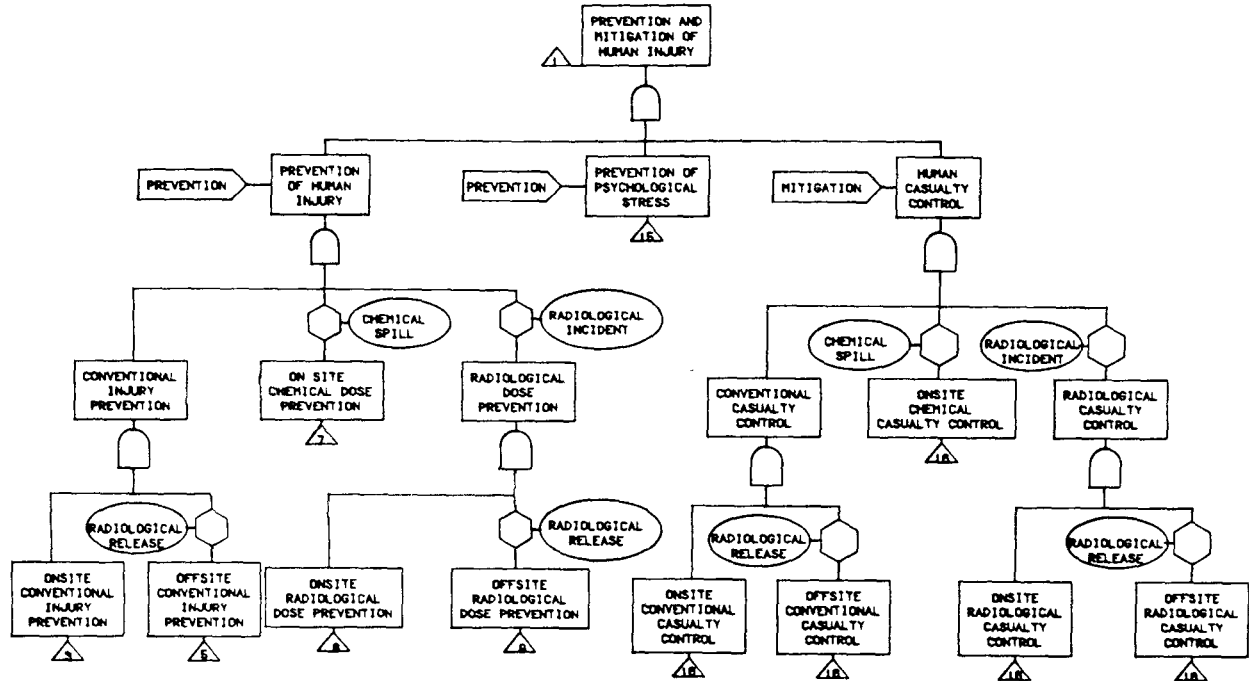
d) Prevention of Property Damage. Damage to plant and public property is to be prevented during an incident.

e) Property Damage Control (Mitigation). Plant and public property suffering conventional damage and/or contamination by radioactivity or toxic (or corrosive) chemicals must be identified, secured, and possibly restored to its pre-incident condition.

Except for Prevention of Psychological Stress, each function is divided into its component parts. These are conventional, radiological and chemical. The conventional and radiological subfunctions are further divided into their onsite and offsite components. Only onsite measures are considered for the case of a chemical spill. The utility is not responsible for the impact of offsite spills on the public. Furthermore, it is unlikely that an onsite spill will impact the public. However, said impact could be included if warranted. The need to consider chemical spills becomes apparent when one considers that release of toxic vapors from the failure of an onsite ammonium hydroxide storage tank or chlorine cylinder can have a higher probability of impacting control room personnel than does a radiological release to the environment. Licensing issues for the proposed Midland Nuclear Power Plant included detailed consideration of the impact of toxic and corrosive chemicals released from nearby chemical plants.

Several conditionals appear in Trees 1 and 2. They serve to identify the conditions for which each subfunction should be considered. Onsite conventional injuries and property damage must be considered for all incidents. The same is true for psychological stress. Offsite functions must only be considered when the potential exists for a radiological release to the environment. The tree is structured to accommodate radiological incidents confined to plant structures and to consider the impact of offsite chemical spills on plant personnel and property.

The functions defined above are accomplished by a complex series of human actions/interactions. Numerous activities must be performed by designated plant personnel and civilians, often under less than ideal conditions. Many require cooperation among plant officials and civilian authorities. Their success is dependent upon proper planning, accurate dissemination of information and an ability to make rational decisions in a timely manner. However, such considerations do not directly enter into the functional classification. Planning, which includes the identification, organization and designation of tasks and the development of implementation procedures to insure that they are accomplished in a timely fashion, is an institutional activity. Each functional activity is best accomplished when a well designed and tested plan exists. Information can only be disseminated in a timely fashion when a well designed communications network is in place. Again, development of such a network and procedures for its use are institutional activities. The functional classification serves to identify



the requisite institutional activities. Each institutional activity could be classified according to a tree structure which parallels the functional tree, once its goals have been properly defined.

The acquisition, analysis and interpretation of data to insure that accurate information

is disseminated and that proper and timely decisions are made are activities which aid in the implementation of the plan. Like institutional activities, decision models and information systems can also be classified according to a parallel tree structure. Furthermore the functional classification serves to identify infor-

mation needs and the decisions which must be made. Separate consideration of institutional activities and Information System/Decision Models also serves to facilitate quantification of the goal oriented tree.

While a detailed functional classification has been carried out, it is too extensive to be presented here. Instead, the major elements of the tree will be presented followed by a discussion of selected individual success paths. As previously noted, the tree super structure presented here represents both a refinement of and a supplement to the tree developed for the DOE Information Systems Project (University Research Foundation, 1983). The work was undertaken to provide a more logical and easily understood representation by emphasizing common features among the various subfunctions and success paths. The lower levels of the tree remain the same and are given in complete detail in the aforementioned report. In this sense, the structures presented here serve as an introduction to and a useful aid in interpreting the more detailed functional classification.

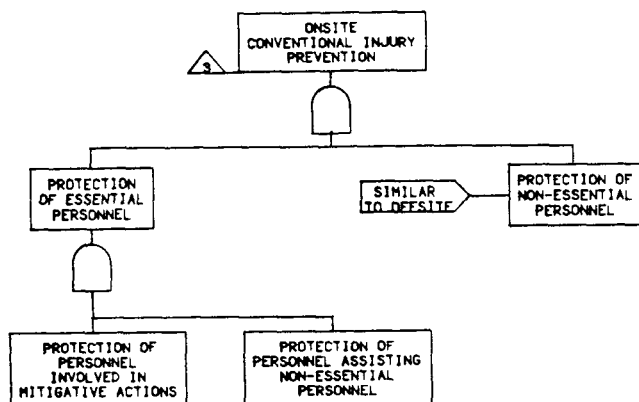
In presenting the logic structures, the impact of institutional activities, data acquisition and decision making will be considered. Emphasis will be given to the function Offsite Radiological Dose Prevention which appears under Prevention of Human Injury. This is satisfied by subfunctions for source mitigation, evacuation, sheltering, etc.

### III. CONVENTIONAL/CHEMICAL INJURY PREVENTION

#### A. Conventional Injury Prevention.

This function is concerned with protecting emergency response workers and the public from conventional injury during the course of their actions.

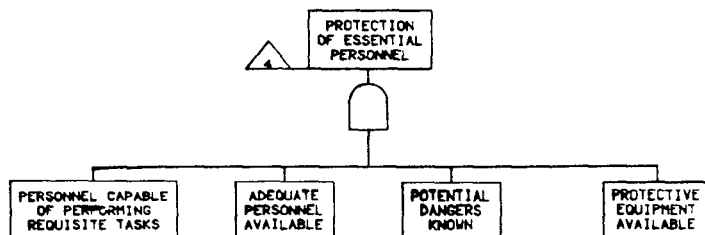
1. Onsite Conventional Injury Prevention. Tree 3 specifies the subfunctions required to meet this goal. Non-essential per-



sonnel must be protected or escorted to the site boundary. The required actions are similar to those taken to protect the public. Two types of essential personnel are identified, simply because the tasks they must perform are quite different. At the next tree level (not shown), specific tasks are identified. These include responding to equipment failures, fires, seismic events, etc., or providing transportation/equipment/supplies to other response teams. For most of these, conventional injuries are prevented by a common type of success path illustrated in Tree 4. Individuals must be capable of performing the task; that is, they must understand all aspects of the task. In order to identify adequate personnel, the magnitude of the task and personnel limitations must be understood. Team members must be aware of potential dangers and the requisite protective equipment (task specific) must be available. This tree is applied in turn to each task with lower tree levels specifying the details of these requirements.

2. Offsite Conventional Injury Prevention. This goal includes protecting the public and emergency response teams assisting them (Tree 5). Protection of essential personnel is satisfied by subfunctions similar to those for the protection of those assisting onsite non-essential personnel. The public is protected by satisfying three general subfunctions. Access to dangerous areas must be restricted. This subfunction is activated only if property damage is caused by initiating events such as earthquakes, tornadoes, etc., or by public panic. Damaged property must be identified and secured and the potential danger must be publicized. Rioting and looting must be controlled by avoiding panic and providing proper deterrents. This is insured by adequate response capability, competent teams and adequate security. Transportation hazards must be minimized on all appropriate types of carriers. A common success path is shown in Tree 6. Traffic congestion and panic tendencies must be minimized. Vehicles must be loaded and operated safely. The needs of special population groups such as the ill and elderly must be accommodated.

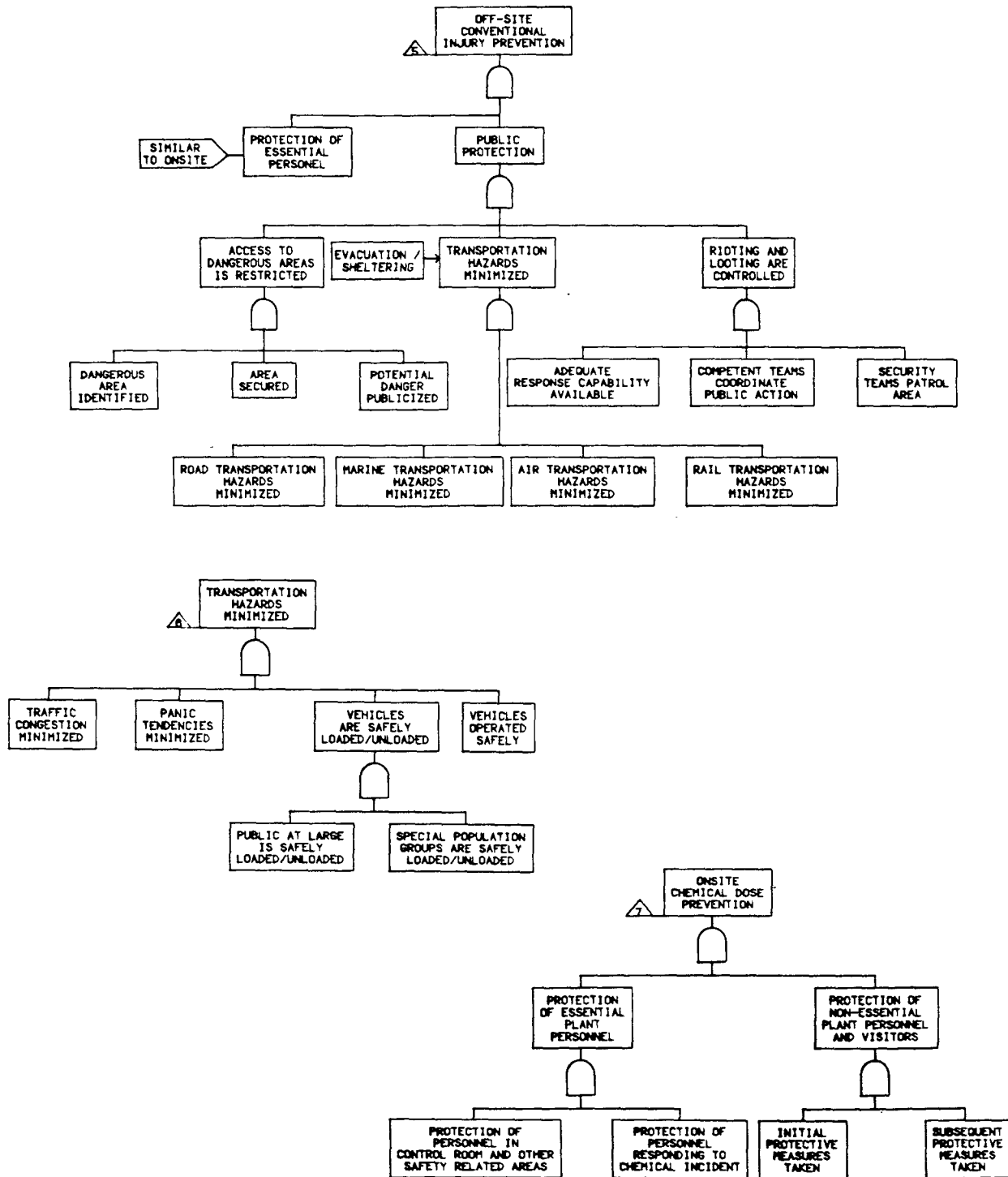
Lower levels of the Offsite Conventional Injury Protection tree identify specific items/population groups that must be considered and



detail the specific tasks and facilities (including communications) that are required. This is common to the success paths for all major functions.

B. Onsite Chemical Dose Prevention.  
Tree 7 reveals that the top tree struc-

ture for this function is similar to that for Onsite Conventional Injury Prevention. Since workers must be protected from overexposure the general subfunctions are quite similar to those for Onsite Radiological Dose Prevention to be discussed subsequently. Of course, specific tasks and equipment requirements will differ.



#### IV. RADIOLOGICAL DOSE PREVENTION

The onsite component of this function is defined to include monitoring teams and those assisting the public.

##### A. Onsite Radiological Dose Prevention.

Like the other onsite "prevention" functions, the radiological function involves protection of both essential and non-essential personnel (Tree 8). Essential personnel are divided into those involved in emergency response outside plant buildings and those who remain inside the plant. Those outside plant buildings include monitoring teams and those assisting non-essential personnel. Their safety is insured by adequate knowledge of environmental hazards, and use of protective clothing/equipment and/or shift rotation to avoid overexposure. Personnel within the plant must be protected from radiation sources within the plant and from radioisotopes released to the atmosphere. The former corresponds to the protection of workers entering high radiation areas. This subfunction has not been developed since it is more the concern of health physicists than emergency planners. The latter subfunction is satisfied by success paths which insure the habitability of the control room, emergency response center and other safety related areas.

Initial and subsequent measures are taken to insure the safety of non-essential personnel. Initial measures include identifying, notifying, accounting for and sheltering these individuals. Subsequent measures include sheltering or evacuation and possibly the use of blocking agents.

##### B. Offsite Radiological Dose Prevention.

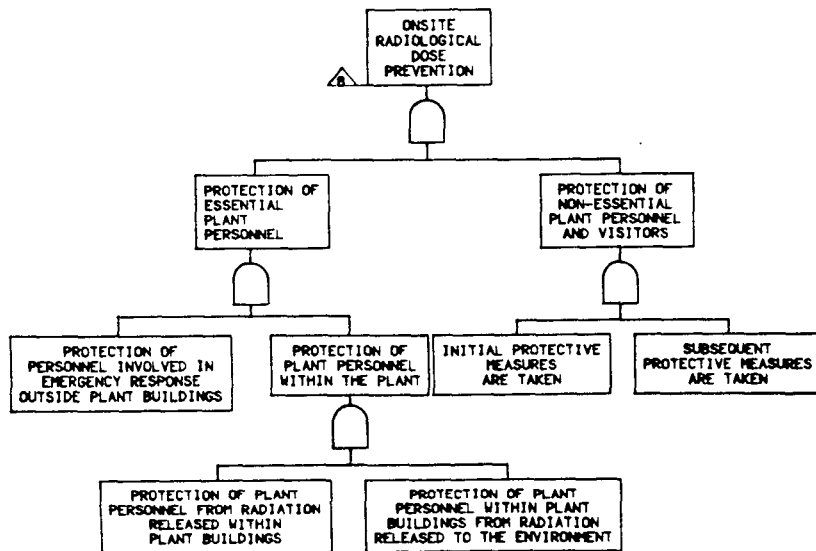
To protect the public, two subfunctions are required as shown in Tree 9. Both acute and chronic exposure pathways must be controlled. Acute pathways are those to which the public is

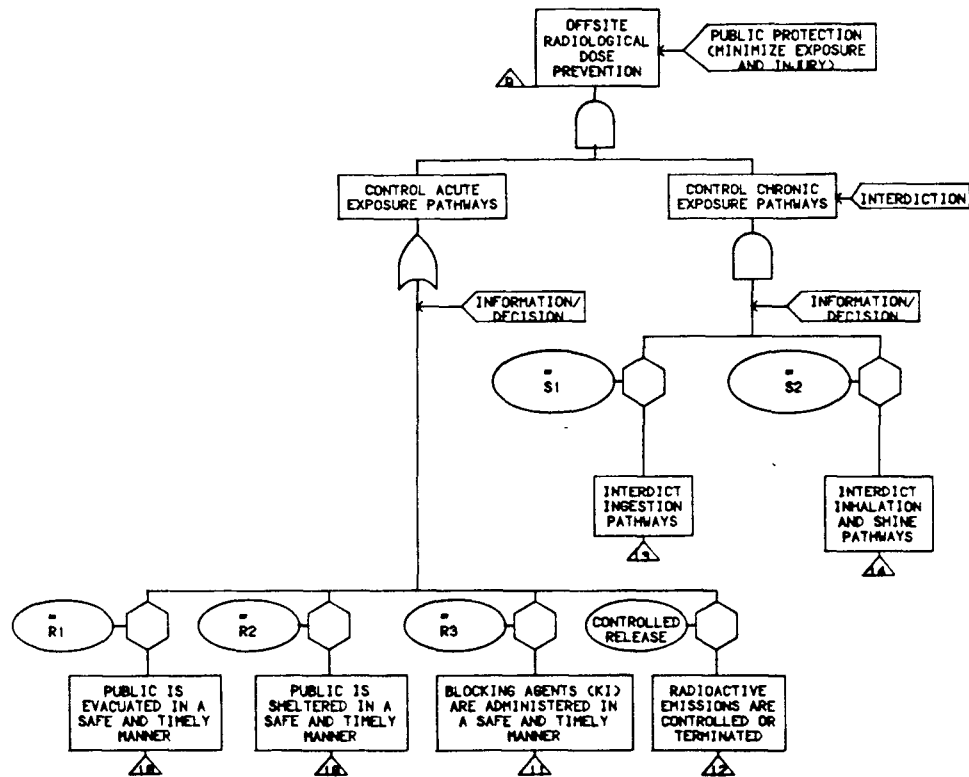
exposed during and immediately after a release of radioactivity to the environment. These include inhalation, cloud shine, and short-term ground shine. Chronic exposure pathways are longer term pathways of concern during the period of days (or possibly years) after the incident. These include longer term ground shine, inhalation of resuspended material, and ingestion of contaminated foodstocks.

##### 1. Control Acute Exposure Pathways.

Methods currently accepted for controlling public exposure to radioactivity are evacuation and sheltering. However, the use of blocking agents such as potassium iodide (KI) is included for completeness. Each of these methods may be used alone or in conjunction with one or both of the others. For instance, it may not be practical or desirable to evacuate the entire population. During a severe incident it is possible that the people residing in areas to which the radioactive plume is carried by the winds will be evacuated and those in surrounding areas will be sheltered. Blocking agents may be distributed to evacuees and those sheltered in areas adjacent to those under evacuation. Evacuees may be directed to engage in mobile sheltering techniques such as breathing through wet towels while en route to their cars and keeping their car windows and air intake vents closed to avoid the influx of contaminated air. Furthermore, it may be recommended that only particularly susceptible members of the population, such as pregnant women, be evacuated and all others be sheltered or given blocking agents. It may only be possible to evacuate the mobile population requiring sheltering for immobile persons, such as bedridden individuals and the like. It may be desirable to evacuate the general public but not institutionalized individuals.

The decision as to which of the aforementioned methods should be employed, and where, when, and to whom is a complex one requiring plant, monitoring and weather data. As pre-





viously mentioned, the decision process with its requisite information is not included as part of the functional classification presented here. The output of the decision process is represented by conditionals placed on the subfunctions "Evacuation," "Sheltering" and "Blocking Agents" displayed as R1, R2 and R3, respectively, in Tree 9.

In principle, the area surrounding the plant can be divided into several sectors, the size and number depending upon population density, road network, meteorology, terrain features, etc. The decision to evacuate, shelter, use KI or to use a combination of these can be made for each sector and population group and for various time periods. The conditionals therefore represent a matrix of decisions. The matrix coefficients prioritize and define the requisite subfunctions. For instance, a coefficient of 0 can be used to define the associated subfunction as unnecessary for the sector/population group/time period it represents, a 1 can define it as a primary success path, a 2 as an alternate success path, etc. Depending upon the situation, two or more of the conditionals may have the same coefficient for a common element. For example, sheltering with ingestion of KI may be the primary success path. Again, the coefficients of the matrices are the output of the decision process.

We have defined an Information System/Decision Model whose output in the form of conditional matrices specifies the particular success paths that should be utilized. Such models enter the goal tree at many locations and a

sample model will be presented later. The need for particularized decisions becomes apparent in areas of high population density during inclement weather, when the road network cannot accommodate a full scale evacuation or when the presence of water bodies and terrain features could force some evacuees to travel through the radioactive plume.

The role of evacuation, sheltering, use of blocking agents and the output of the decision model can be modified to account for an additional success path under certain circumstances. A controlled release (note the conditional displayed in Tree 9) is defined as one that can be reduced in emission rate or terminated for a period of time, or permanently. Consider a situation where the containment building contains substantial airborne radioactivity and the pressure is rising but has not yet reached an unsafe level. Plant authorities may wish to vent the containment to prevent its rupture. If the wind direction is shifting away from population centers, the decision may be made to wait, if possible, until the wind shift occurs. If the wind is steady, the decision may be made to evacuate in the direction of the wind but to hold off completely or vent slowly until the evacuation is well underway or until the public can be safely sheltered.

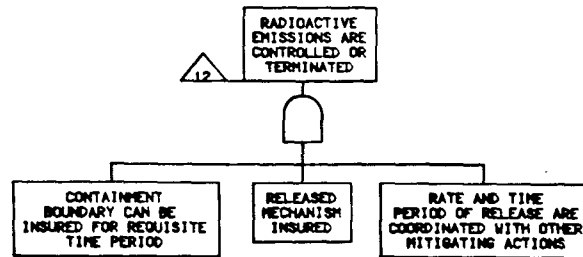
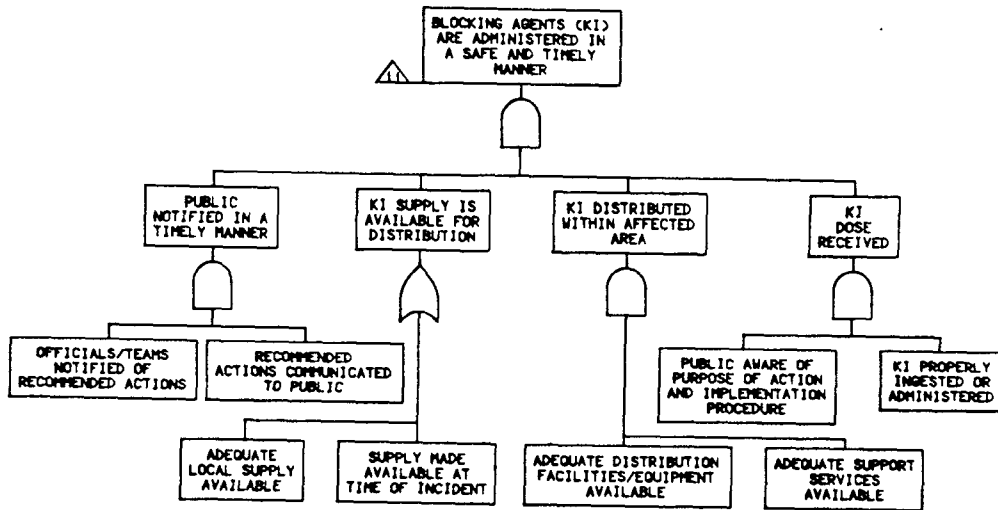
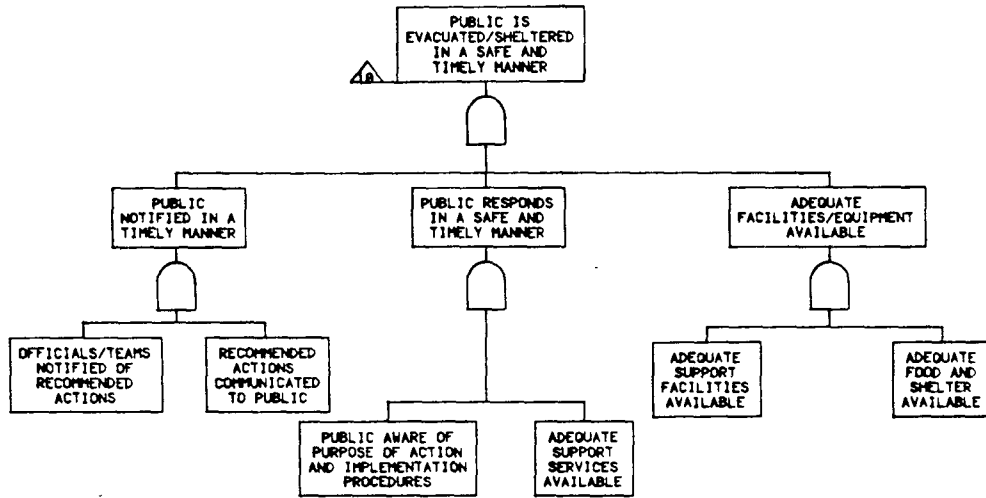
The other extreme of a controlled release is the situation that existed in the TMI-2 containment after the plant was under control. The containment pressure level was safe but venting was necessary. Radioactivity was released at a well-controlled rate during optimal meteorolog-

ical conditions to maintain acceptably small levels of radioactivity in the environment. Evacuation, sheltering, or use of blocking agents were not required.

Tree 10 provides the elements common to successful evacuation and sheltering. Lower levels of the tree (not shown) identify and specify the specific tasks/facilities/equipment needed to achieve each goal. Tree 11 is a similar structure for administering blocking

agents. Tree 12 applies to a controlled release. By Release Mechanism Insured we mean that the venting aperture will function properly. It is evident that lower levels of this tree are intimately linked to knowledge of plant status and other emergency response measures.

2. Control Chronic Exposure Pathways. This function is accomplished by interdiction as noted on Tree 9. Again, an Information System/



Decision Model impacts the tree. This model uses weather and monitoring data and analytical predictions to locate contaminated areas and to determine the proper course of action. Lower levels of this tree are specified in Trees 13 and 14. Again, the success paths (not shown) specify the specific means to accomplish each goal.

V. OTHER FUNCTIONS

A. Prevention of Psychological Stress.

It is not our intention to imply that the utility is responsible for the psychological well being of the public. Rather, we note that the probability of success is enhanced when panic is avoided and the public demonstrates a cooperative spirit. It is evident from Tree 15 that this is accomplished through education, by competent response efforts and by accurate and timely dissemination of information. In other words, this function is satisfied by a successful plan.

B. Human Casualty Control.

Tree 1 reveals that consideration of conventional, chemical and radiological issues for both onsite and offsite areas involves five separate functions to accomplish this goal. All have a similar top tree structure. This is shown in Tree 16. At lower levels of the tree (not shown), detailed success paths for each have been developed. Except for degree of injury/overexposure, onsite and offsite considerations are similar. The success paths give the

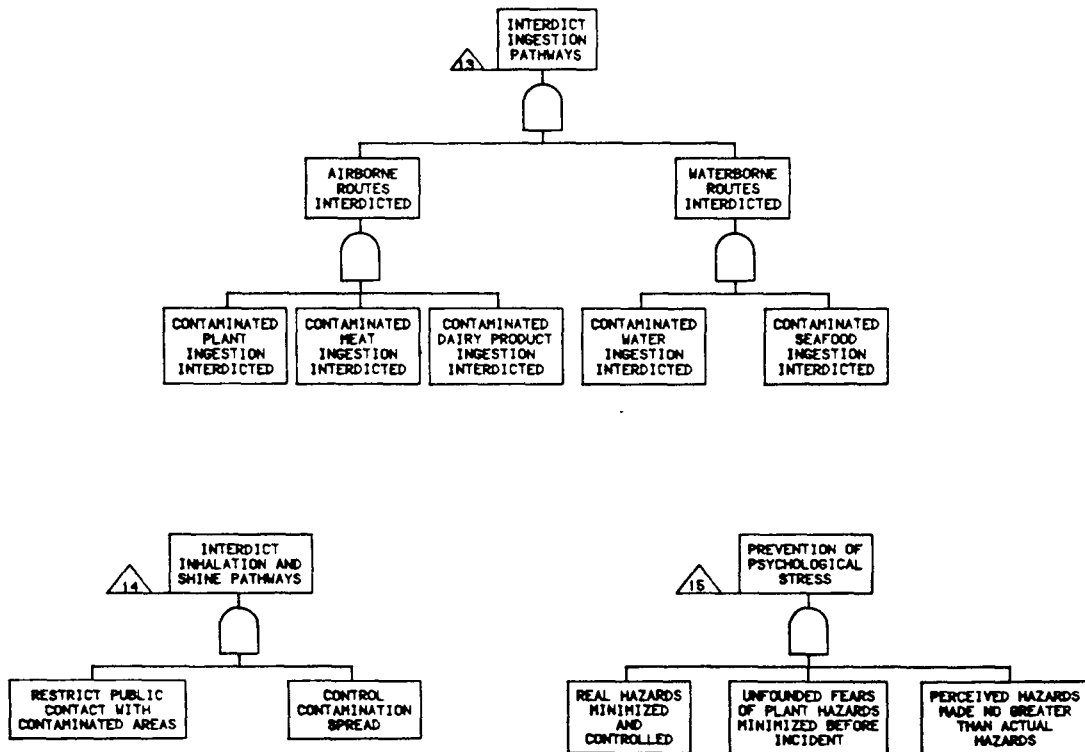
means by which casualties are identified and diagnosed, first aid is administered and subsequent treatment is obtained. Transportation considerations include use of road, air and possibly marine transportation, depending upon the site. Specific treatment facilities are identified. Alternate success paths include facilities committed in advance and at the time of the incident.

C. Property Damage Prevention.

The functions/success paths which insure that property damage is prevented have many elements in common with those which insure the prevention of human injury. While certain tasks are specific to damage prevention others will be implemented by the same teams responsible for human safety. These latter tasks are included in the property tree for completeness and to emphasize to implementers the dual nature of their responsibilities. The top tree structure for conventional property damage prevention is given in Tree 17. It applies (in turn) both onsite and offsite. That for onsite chemical property damage prevention is given in Tree 18. Structures for radiological damage prevention are not given. These have not been developed in detail since the requisite subfunctions are intimately linked to termination of the incident. The offsite branch of this tree does contain provisions for sheltering of farm animals and the like.

D. Property Damage Control

This function is concerned with the



mitigation of property damage caused by the incident, the initiating event and emergency response actions. During the actual emergency, the subfunctions which satisfy conventional property damage control (Tree 19) are concerned with controlling fires and securing areas to prevent further damage. The subfunction dealing with other initiators is taken to include damage to structures caused as a result of emergency response actions. A separate subfunction deals with damaged equipment (e.g., motor vehicles) that must be moved to prevent interference with other emergency actions. Subfunctions which deal with the restoration of conventionally damaged property have not been developed since this is usually not the responsibility of emergency plan implementers.

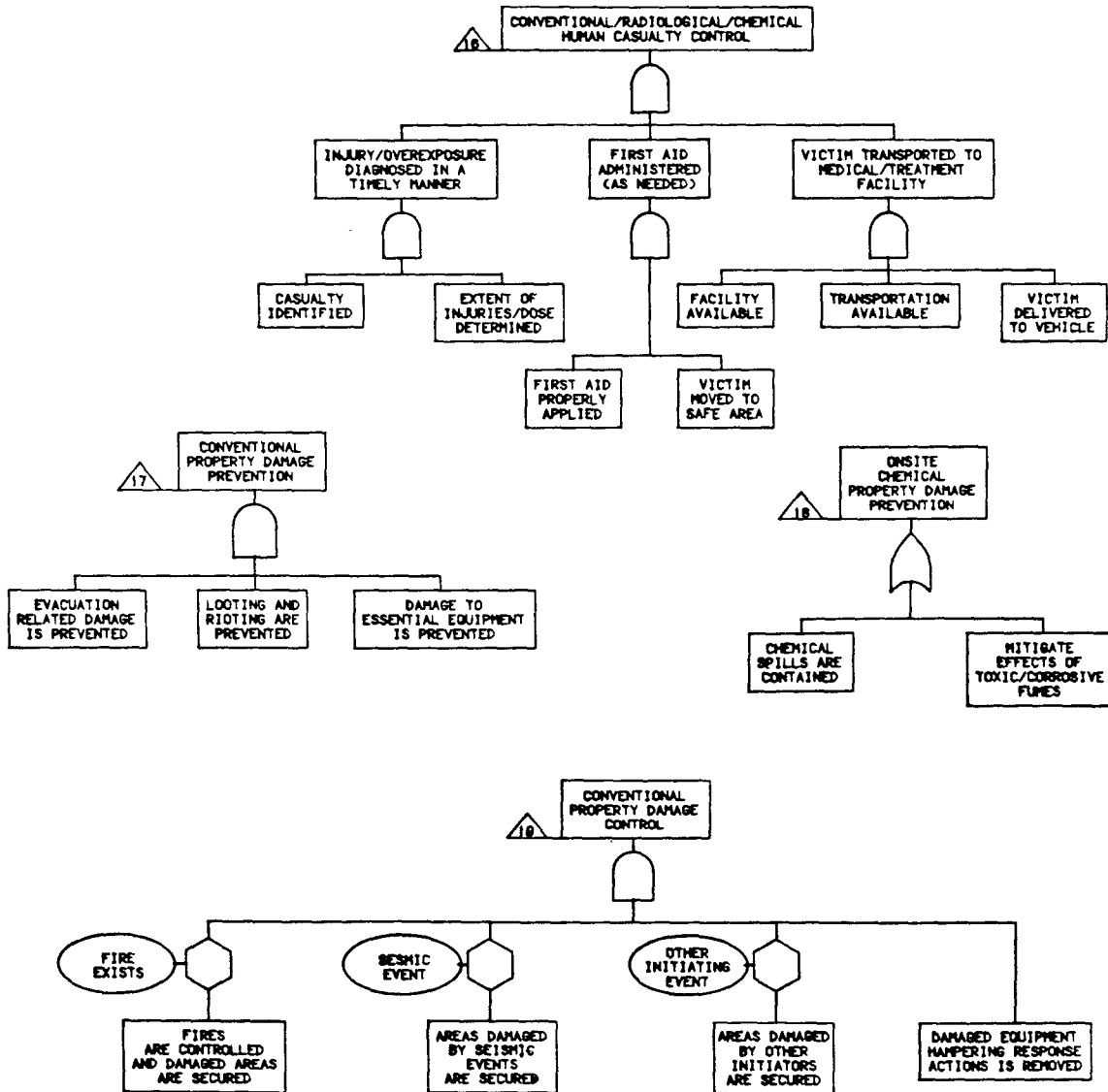
The radiological (onsite and offsite) and onsite chemical property damage control functions are concerned with decontamination and/or

disposal of contaminated materials and property. Their common top structure is shown in Tree 20. The need for an Information System/Decision Model to locate contaminated areas and determine the proper course of action is noted. Of course the success paths for radiological and chemical decontamination are quite different.

## VI. DISCUSSION

### A. Task Implementation/Institutional Activities.

The lowest levels of the goal tree detail the specific tasks that must be implemented and the mechanisms for their accomplishment. Figure 2 illustrates the elements common to implementation of many tasks. It is at this level that institutional activities have their greatest impact on the tree. Table 1 gives the institutional activities that insure successful



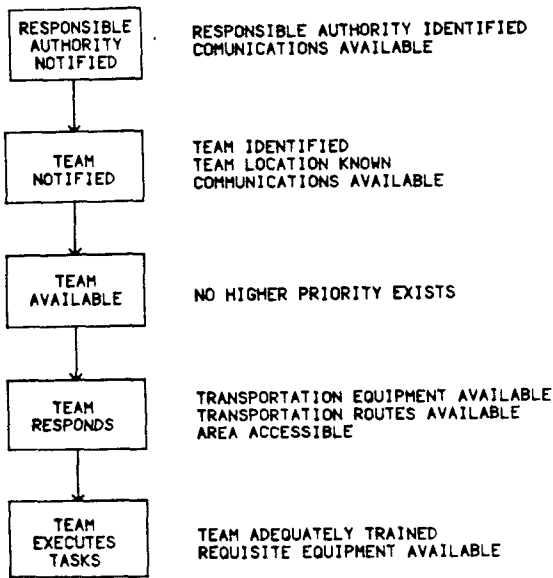
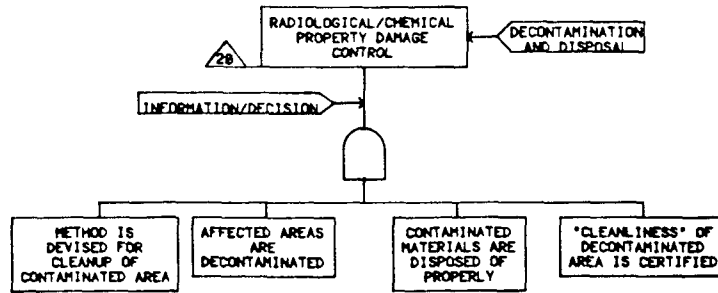


Figure 2 - Elements Common to Task Implementation

Table 1

Institutional Activities for Task Performance

1. Task Implementation Requirements
  - A. Task Designation
  - B. Implementation Procedures
  - C. Auxiliary Procedures  
(Communications, Notification, Assembly)
  - D. Training  
(Programs and Exercises)
2. Equipment Requirements
  - A. Task Specific Equipment/Facilities
    1. Specification and Procurement
    2. Storage, Installation or Construction
    3. Maintenance
  - B. Peripheral Equipment  
(Communications and Transportation)  
See 2.A.1 to 2.A.3
3. Disseminate Information to Users
  - A. Identification of Responsible Authorities and How to Contact Them
  - B. Notification and Response Procedures
  - C. Equipment/Facility Availability and Location

task performance.

B. Information System/Decision Model.

Figure 3 illustrates a typical Information System/Decision Model to aid in the control of acute exposure pathways (Section IV.B.1 and Tree 9). The decision model considers the availability of specific success paths at a particular time. For instance, the evacuation success path would not be available to all if certain roads were not passable. The adequacy of such a model is crucial to the success of the entire emergency plan. The model itself can be classified according to a functional/goal tree structure. The need for institutional activities in support of the Information System/Decision Model is apparent. Other information systems which enter the tree have many elements in common with that of Figure 3.

C. Tree Quantification.

The very nature of emergency response defies quantification since there is no clearly

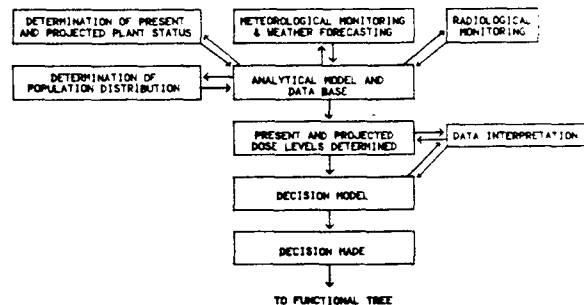


Figure 3 - Information System/Decision Model for Control of Acute Exposure Pathways

defined measure of overall success. However, it is possible to define quantitative measures of success at lower levels of the tree to test alternate success paths. For instance, a measure of success for the subfunction Control Acute Exposure Pathways (Tree 9) can be the total or maximum dose to the population for a given accident scenario. Consequence models such as CRAC and CRACIT can thus be employed to test alternate sheltering, evacuation and controlled release strategies. Proposed modifications in the Information System/Decision Model and the success paths can thereby be assessed. For instance, different evacuation paths, speed and distance scenarios can be considered. The impact of decision time can be related to warning and delay time.

#### D. Summary.

A goal oriented tree structure has been developed which provides a clear visual representation of the functions that must be performed to insure successful emergency preparedness. In addition to employing it as a training tool, the structure has several other potential uses. For instance, the particular information needs, implementation procedures and regulations which apply to each success path can be noted on the tree to provide a contextual overview of their importance. The adequacy of present capabilities can thereby be assessed. The tree structure can be customized to meet specific needs. Success paths that are not relevant at a particular site can be deleted. Civilian authorities and planners can delete onsite functions and those only responsible for onsite measures can remove the offsite functions.

#### VII. ACKNOWLEDGEMENTS

The lower branches of the tree were developed at the University of Maryland by a task group under the direction of the first author. The team members were George Harrison, Don Marksberry, Christine Reilly and Bob Starrett. Special thanks to Niall Hunt and Malcolm Patterson of Baltimore Gas and Electric Co. and Joe Braun of Combustion Engineering for many useful discussions concerning the tree structure.

#### VIII. DISCLAIMER

Any opinions expressed or implied herein are solely those of the authors. Several controversial functions and success paths appear on the goal tree for the purpose of completeness. The presence in no way implies that the use is supported or condoned by any other persons or agencies associated with this work.

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