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PLANNING PROTECTIVE ACTION DECISION-MAKING: EVACUATE OR SHELTER-IN-PLACE?

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ACRONYMS AND ABBREVIATIONS

acph	air changes per hour
ALARA	as low as reasonably achievable
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
CSEPP	Chemical Stockpile Emergency Preparedness Program
D2PC	Army atmospheric dispersion code (computer model)
D2-Puff	Army atmospheric dispersion model
DOE	U.S. Department of Energy
EAS	Emergency alert System
FEMIS	Federal Emergency Management Information System
HVAC	heating, ventilation, and air conditioning
lb	pound(s)
min	minute(s)
mph	miles per hour
mps	miles per second
PADRE	Protective Action Dosage Reduction Estimator
PADs	Protective action decisions
PARDOS	partial exposure calculation code (computer model)
PARs	Protective action recommendations

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1.0 INTRODUCTION

Appropriate protective action recommendations or decisions (PARs/PADs) are needed to achieve maximum protection of a population at risk. The factors that affect protective action decisions are complex but fairly well documented. Protective action decisions take into account population distributions, projected or actual exposure to a chemical substance, availability of adequate shelters, evacuation time estimates, and other relevant factors. To choose in-place sheltering, there should be a reasonable assurance that the movement of people beyond their residence, workplace, or school will endanger the health and safety of the public more so than allowing them to remain in place. The decision to evacuate the public should be based on the reasonable assurance that the movement of people to an area outside of an affected area is in the best interest of their health and safety, and is of minimal risk to them.

In reality, an evacuation decision is also a resource-dependent decision. The availability of transportation and other resources, including shelters, may factor heavily in the protective action decision-making process. All strategies to protect the health and safety of the public from a release of hazardous chemicals are explicitly considered during emergency decision making. Each institutional facility (such as hospitals, schools, day care centers, correctional facilities, assisted living facilities or nursing homes) in the community should be considered separately to determine what special protective actions may be necessary.

Deciding whether to evacuate or to shelter-in-place is one of the most important questions facing local emergency planners responding to a toxic chemical release. That such a complex decision with such important potential consequences must be made with such urgency places tremendous responsibility on the planners and officials involved. Researchers have devoted considerable attention to the evacuation/shelter-in-place protection decision. While several decision aids have been developed, no single approach has achieved widespread acceptance based on validity, utility, and effectiveness (Ujihara 1989, Mannan and Kilpatrick 2000). In the absence of an agreed-upon methodology for making this decision, the best strategy for local emergency planners and officials is a thorough understanding of all the components affecting the decision. This paper summarizes what is currently known about the evacuation/shelter-in-place protection decision and points to available literature that more thoroughly explores the individual components of the decision. The next section summarizes the major issues in protective action decision process. This is followed by a discussion of all the factors that may bear on the protective action decision process. The final section address how to make a protective action decision.

2.0 CRITICAL COMPONENTS OF THE PAD PROCESS

Conceptually, the evacuation/in-place protection decision is simple and revolves around two questions (Glickman and Ujihara 1989):

(1) Will shelter-in-place provide adequate protection?
(2) Is there enough time to evacuate?

The answers to these questions indicate the appropriate response. Obviously, if the answer to one, but not both, is 'yes,' the appropriate response has been determined. If the answers to both are 'yes,' then either option is satisfactory, and the issue should be decided on the basis of other considerations (e.g., community disruption or cost). If, however, both questions are answered 'no,' emergency planners and officials face a serious problem and must consider exceptional alternatives (e.g., expedited evacuation, enhanced sheltering, or evacuation of only those persons with access to private vehicles). Measures that may be taken to enhance shelter-in-place protection are discussed in Chester (1988). In many cases a combined response may be called for, with in-place sheltering recommended for some areas close to the release and in the possible path of contamination, and evacuation recommended for other areas which have more time before possible exposure to the chemical. A problem with a combined response strategy is communication with the public (Vogt and Sorensen 1999). Poor communication may lead people to take the action they perceive to be in their best interest regardless of official recommendations. Furthermore, if the recommended protective action is not perceived to be an effective means of protection, people will likely do what they judge to be effective. For example, in the World Trade Center attacks of September 11, 2001, people in the second tower were told to stay in their offices after the first plane hit the other tower; however, many choose to evacuate because they perceived staying in the building was risky.

Some researchers suggest that the public be educated to consider shelter-in-place protection as the first and immediate response on being alerted that a chemical emergency has occurred (Jann 1988, Ujihara 1989). Contra Costa County in California is currently utilizing this approach. They promote a three stage response -- shelter, shut, and listen. The rationale for this approach is that, in addition to providing some protection while authorities assess the situation and develop a response strategy, this approach facilitates communications by getting people inside and tuned to the Emergency Alert System (EAS). If an evacuation is then necessary, authorities can issue detailed instructions via the EAS with some confidence that a large portion of the affected population will quickly hear and understand them.

While the two questions pertinent to the evacuation versus shelter-in-place protection decision are simple, the process involved in answering the questions is much more complicated. The answer to each depends on the interaction of various pieces of information regarding the hazardous chemical and the nature of its release, the affected community, and the meteorological conditions. Some of the necessary information can be gathered by the emergency planning agency before an emergency occurs; other data, for example the meteorological conditions, must be collected during the decision process following notification that a toxic chemical has been (or is likely to be) released. In many cases, there will be uncertainty regarding the interaction of the various types of information, and answers to the two pertinent questions will not be clear-cut. Emergency planners and officials will best be able to deal with this uncertainty if they have a thorough understanding (based on keeping up-to-date with the available literature) of the mechanical, technical, and human aspects of the evacuation and sheltering in-place options.

In addition, another important decision is when to terminate a protective action. For sheltering to be effective, it may be critical to remove people or ventilate a shelter to prevent exposure after the plume has passed. The worst-case shelter situation is when the toxic material enters the shelter prior to it being closed up and then people remain in the shelter for a long time after the plume has passed. In this situation the exposure to the chemical can be greater than for an outdoor unprotected dosage.

3.0 DETERMINING THE LEVEL OF PROTECTION OFFERED BY PROTECTIVE ACTIONS

The ability of a protective action to adequately protect people in an affected area throughout the duration of the emergency depends on the characteristics of the toxic chemical(s) involved, the size and nature of the release, meteorological conditions, the characteristics of the population affected, and the ability of available structures in the area to provide protection from outdoor chemical concentrations. For shelter-in-place, the emergency planner must be able to predict the outdoor plume concentration of the toxic chemical(s) that will occur in the risk area, estimate the concentration that will occur inside the buildings in which people seek shelter, and calculate the indoor estimated level of exposure. For evacuation, the planner should be able to predict the outdoor concentration of the toxic chemical(s) that will occur in the risk area, estimate when people will leave and when they will reach a safe distance, estimate the concentration that will occur while people are still evacuating, and calculate exposures to those who evacuate in the plume and those who have not left.

Following are suggested steps to help estimate the level of protection for alternative actions.

3.1 STEP 1: DETERMINE THE CHARACTERISTICS OF THE RELEASED CHEMICAL

Characteristics of the chemical influence the nature of the release and are important considerations in determining whether evacuation or in-place sheltering will provide adequate protection. The form (liquid, aerosol, or vapor), the density, and the vapor pressure of the chemical influences the speed and concentration with which it will be released into the atmosphere and how far the plume or cloud will travel before dissipating. These are important factors in determining whether people will have time to evacuate before the arrival of a dangerous chemical concentration.

The nature of the hazard posed by the chemical is a factor in assessing the effectiveness of shelter-in-place protection. Considerations include the degree of health hazard (level of toxicity), the dangerous dosage or concentration, and the nature of the toxic load (peak concentration or time-integrated dosage). In-place sheltering is effective at reducing peak concentrations for a limited time, but may be less effective at reducing the cumulative dose over a longer period (Wilson 1987). In addition, in-place sheltering is unlikely to provide adequate protection for chemicals that are dangerously flammable or explosive in the atmosphere.

3.2 STEP 2: DETERMINE THE CHARACTERISTICS OF THE RELEASE

The amount of chemical released (or expected to be released) into the environment, the rate of release and expected changes in the rate, and the expected duration of the release are important factors in evaluating the effectiveness of shelter-in-place protection. The amount of chemical released and the rate of release are among the determinants of the outdoor concentration that, in turn, is a major determinant of the indoor concentration. The expected duration of the release is significant because shelter-in-place protection is most effective at reducing indoor concentrations associated with a short-term release. For a longer-term release, more of the chemical will seep into the sheltering structures, thus resulting in higher indoor concentrations and longer exposures for people sheltering.

3.3 STEP 3: DETERMINE POTENTIAL METEOROLOGICAL CONDITIONS AT THE SITE

Wind speed and direction are important in determining which areas will be affected and how long it will take the chemical to reach them. In addition, wind speed influences the ability of a structure to provide protection from contamination. The higher the wind speed, the more quickly a chemical vapor will infiltrate a structure and raise concentrations to dangerous levels (Wilson 1988). Temperature is also a consideration; the greater the difference in inside and outside temperatures, the more quickly the chemical will infiltrate the structures providing protection. Inversion conditions may also be important, causing a chemical plume to travel closer to the ground and dissipate less rapidly if not impeded by vegetation.

Planners should analyze historical weather records to develop planning scenarios of potential meteorological conditions during an accident. It is important and helpful to identify the historically worst case meteorological conditions to use in planning protective actions. Worst case is usually defined as light winds under stable atmospheric conditions. By asking the question--what is the longest period of time that E/F stability and low wind speeds (<3 mps) have occurred?--planning is based on credible events and not obscure assumptions. This is particularly important when using a Guassian dispersion model that assumes constant meteorology. Unreasonable assumptions can create unrealistic plume length estimates.

3.4 STEP 4: COLLECT DATA ON STRUCTURES SURROUNDING THE FACILITY

Data gathered during the planning process can be used to assess the protective effectiveness of structures in the area surrounding the chemical facility. Are there mostly older wooden frame buildings or newer more energy efficient (airtight) houses in the area at risk? If the structures surrounding the chemical facility are old and in poor condition, and have not been weatherized, it is likely that they will have high air exchange rates and provide little protection from a chemical vapor release. It may be feasible, however, to recommend evacuation for residents in zones where housing is leaky and in-place sheltering for zones where houses are more airtight. In such situations it is extremely important to convey to the public why two different actions are being recommended.

Air infiltration will be determined not only by the leakiness of the building but by other factors such as wind speed, indoor-outdoor temperature differences, and vegetative cover around the structure.

3.4.1 Why Building Age is Important

One of the best predictors of air exchange rates is the age of the building. Prior to 1965, U.S. building codes did not include energy conservation standards. As in other areas of housing standards, local governments set the requirements for the construction of buildings in the interest of public health, safety, and general welfare. However, in the late 1960s and early 1970s energy conservation became an issue of national concern. Federal and state governments began working together to develop building standards that incorporated energy efficiency. The result was the "Energy Conservation in New Building Design" (ASHRAE 1975). One of the performance standards established was for the exterior envelope of the building. This need to reduce energy consumption in buildings resulted in more stringent weatherization requirements for new construction.

Concern for reducing air infiltration rates has also played a significant role in the U. S. Department of Energy's (DOE) research initiatives. Grot and Clar (1981) examined over 200 dwellings occupied by low-income households in 14 cities across the U.S., representing all major climatic zones. Two types of measures were used: a tracer-gas decay which uses air sample bags to measure natural air infiltration and a fan depressurization test that measures induced air exchange rates (as a measure of the tightness of a building's envelope). The latter method was used as a diagnostic tool to assist weatherization crews in analyzing the leakiness of buildings. The results of the study demonstrated that building weatherization techniques can reduce air infiltration rates significantly.

Gettings et al. (1988) reported on the results of a study on low-income, single-family buildings. The study identified a wide range of air leakage rates. A blower door was used to locate leaks and to measure a house's leakiness in air exchanges per hour. The study found that in addition to leakage around doors and windows, other characteristics of a house add significantly to its infiltration rate. These characteristics include the types of walls and ceilings, number of attic accesses, presence of fireplaces, and insulation of electrical outlets. The study concludes that a 16% reduction in air leakage rates can be achieved by standard infiltration retrofit procedures.

3.4.2 Air Exchange in Residential Buildings

Based on the history of building codes and overall construction practices, homes constructed since the early- to mid-1970s are likely to have significantly lower infiltration rates than homes constructed earlier. Housing built before 1950 will likely be unsuitable for sheltering without weatherization.

A well-constructed energy efficient house may have an air exchange rate of 0.1 acph (air changes per hour) under ideal conditions. This may go as high as 0.8 acph in strong winds and/or a high air temperature differential. An average house may have a minimum rate of 0.3 acph and range as high as 2.4 acph under worst case conditions (high wind speeds and high temperature differential). This is consistent with observations on a house in Canada where the exchange rate varied between 0.1 acph and

0.5 acph during a 1-month period (Wilson and Dale 1985). An older house will have more variability with a rate range between 0.5 and 5 acph being the norm. Overall, the average air exchange rate for housing in the US is around 0.7 to 0.8 acph. Apartment buildings will likely have air exchange rates similar to residential housing (Engelmann 1990, 1992).

3.4.3 Air Exchange in Office Buildings

A limited number of studies have been conducted on the suitability of office buildings and high-rise buildings as shelters. The overall evidence suggests that this category of buildings has lower air exchange rates than single story residential structures (Engelmann 1990, 1992). Often windows in such buildings are permanently sealed. An average air exchange rate for office buildings is estimated to be 0.66 acph and an industrial building to be 0.31 acph with the HVAC system(s) off and doors and windows closed (Engelmann 1990, 1992).

3.4.4 Wind Speed and Temperature Differentials

Air infiltration into a building is also determined by the wind speed. The higher the wind speed, the higher the infiltration rate. The relationship is fairly linear. A house with an air exchange rate of 0.5 acph when winds are calm will have an estimated air exchange of rate of 1 acph at 4 mph, 2 acph at 8 mph and 4 acph at 16 mph.

Temperature differences between outside and inside will also affect infiltration rates. The greater the temperature differential, the greater the infiltration. The relative importance of temperature differential is minor in comparison to other factors affecting infiltration (Engelmann 1990, 1992). Limited data suggest that temperature differential of 20 degrees F will double the infiltration rate, and a differential of 60 degrees may triple or quadruple the infiltration rate.

3.4.5 Air Exchange in Vehicles

Several studies have been conducted on air exchange in both stationary and moving vehicles. The most recent study (Fletcher and Saunders 1994) found that the air exchange in a stationary vehicle with vents closed ranged from 0.5 acph with light wind condition (1 mps) to around 9 acph at high wind speeds (10 mps). This is in accordance with an earlier study that showed an average exchange rate in a stationary vehicle of 0.5 acph (Engelmann et al. 1992). Moving vehicles offer little protection. Fletcher and Saunders (1994) found that air exchange ranged from about 15 acph at 35 mph to over 40 acph at 70 mph. Earlier, Peterson and Sabersky (1975) documented air exchange rates between 18 and 38 acph at speeds between 0 and 55 mph.

3.4.6 Air Replacement Time

The time require to replace air inside a structure (or vehicle) is not a linear function of air exchange. A house with an air exchange rate of 1 acph will not have 100% replacement of air in 1 hour. This is due to interior mixing of the air. Another way to say this is a house with an air exchange of 1 acph that is exposed to a toxic plume for 1 hour will not have the same toxic concentration inside as the outside. Some of the toxic materials that enter the house will also exit the house. Some basic rules of thumb on replacement relationships are shown in Table 1, which is based on calculations made by Fletcher and Saunders (1994). The table shows the length of time required to replace 63% and 95% of the air in structures at different air exchange rates. A house with 0.5 acph will take about 6 hours to exchange 95% of the inside air with outside air. At 32 acph, 95% of the air inside a moving automobile would be replaced in 8 minutes.

Table 1. Air replacement times

Percent of air replaced	Air changes per hour (acph)			
	0.25	0.5	1.0	2.0
63%	4 h	2 h	1 h	0.5 h
95%	12 h	6 h	3 h	1.5 h

3.5 STEP 5: ESTIMATING THE TIME AVAILABLE BEFORE THE AREA IS CONTAMINATED

The characteristics of the release and weather conditions largely determine the amount of time available before an area becomes contaminated. The timing of the release--when it occurred or is expected to occur--and the distance of the release from the inhabited area are the principal release characteristics affecting the time available before contamination reaches the area. These factors, along with wind direction and wind speed, indicate which areas are likely to be contaminated by a release and how long the chemical will take to reach a specific area. In addition, the emergency planner should consider the amount of chemical released and the rate of release to estimate the expected variation in concentration over time. Computer models are available to forecast the dispersion of contamination from a chemical release. In the Chemical Stockpile Emergency Preparedness Program (CSEPP), D2PC/PARDOS, D2-Puff, or the Protective Action Dosage Reduction Estimator (PADRE) can be used to estimate the plume arrival time and outdoor concentrations over time.

3.6 STEP 6: ESTIMATING THE TIME REQUIRED FOR IMPLEMENTING PROTECTIVE ACTIONS

3.6.1 Evacuation

Evacuation is a complex undertaking requiring the coordination of a wide variety of factors. Estimating the time that would be required to evacuate an area affected by a release of toxic chemical makes use of various types of information, many of which can be collected beforehand. Adequate time must be allowed for all phases of the evacuation, including: 1) reaching an official decision to evacuate, (2) mobilizing community evacuation resources, (3) communicating appropriate protective action instructions to the public, (4) individual mobilization of resources to leave the area at risk, and (5) Completing the physical evacuation of people occupying the affected area.

The time required to reach a decision and to mobilize resources depends, to a large extent, on the quality of emergency response pre-planning, although planners and decision makers will certainly have to deal with unique aspects of the situation at-hand. Research indicates that, once a decision is made to protect the public, a considerable amount of time (up to one to two hours using conventional warning practices) may elapse before most people in the affected area hear, absorb, and decide to respond to the instructions (Sorensen, et al. 1987, Sorensen 1988). Innovative design of the alert/warning system along with an effective public education program will minimize, but not eliminate, the delay. The CSEPP warning system guidelines have been developed to help assure a timely warning issuance.

The time required to accomplish the evacuation once the physical movement of people is underway depends on the characteristics of the area and on the available evacuation resources. Pertinent characteristics of the area include the size and density of the population to be evacuated, the presence of people requiring special attention (e.g., hospitals, nursing homes, prisons, handicapped, elderly, children, and transients), and the geometry and capacity of the transportation network (considering current weather conditions and time of day). Research indicates that, contrary to popular belief, warning and evacuation times do not necessarily increase with population size and density, because, as these factors increase, so does the capacity of the infrastructure (e.g., street system, public transportation resources) necessary for moving people out of the area (Vogt and Sorensen 1992).

Transportation network geometry, however, may be of great significance. A community with an open network characterized by a grid of streets and roads will be easier to evacuate than a community with a closed network where there are a limited number of egress paths. Suburban areas with subdivisions and gated communities may be particularly difficult to evacuate. This was experienced in the Oakland wildfires when the rapid spread of the fire blocked egress on the single road out of the area. In addition, although rural areas may not experience traffic congestion, limited roads may constrain egress by requiring movement toward the source of the hazard.

Crucial evacuation resources include appropriate modes of transport for evacuees, personnel to guide the evacuees and facilitate the flow of traffic, and safe destinations for the evacuees. Private automobiles will be the prevalent mode of transportation in most situations, but buses, taxis, and ambulances may also often be required.

Quantitative evacuation studies can aid in estimating the time required to evacuate an area (Southworth, 1990). OREMS or the Oak Ridge Evacuation Modeling System has been developed for use in CSEPP and is available as a stand-alone application or as a component of FEMIS. It should be recognized that 100% of the people told to evacuate will not do so. Evacuation compliance rates in hazardous material accidents, however, will likely be high, probably as high as 98% (Sorensen and Mileti, 1989).

3.6.2 Shelter-in-Place

One of the major problems with the analyses and frameworks that have been used to evaluate shelter-in-place is that they ignore the fact that time is required to implement sheltering as well as evacuation. Sheltering does not occur without a warning. Warnings require time. People do not respond instantly to a warning. Rather people tend to seek additional information from multiple sources including friends, relatives, and the media. Furthermore, sheltering takes time to implement as people may need to go inside, close windows and doors and shut off HVAC systems. Expedient shelter takes additional time to tape and seal a room. Thus a real potential exists for exposure to an outdoor concentration prior to reaching a shelter environment or for an outdoor concentration of chemical to enter a structure before it is closed up. Several analyses suggest that it will take 5 to 10 minutes on average to implement shelter-in-place, once a sheltering decision is made by a household. Expedient shelter will take a longer time. Data from a limited set of trials indicate that the time it takes to tape and seal a room is likely to average 17 min, with a minimum of 3 min and a maximum of 39 min (Rogers et. al. 1990).

Compliance rates for sheltering have not been extensively documented. In situations where both shelter and evacuation have been advised, compliance with sheltering has not been very high (Vogt and Sorensen 1999).

4.0 PROTECTIVE ACTION DECISION MAKING

The simple determination of whether people should be sheltered or evacuated depends on the answers to two questions:

(1) Will the chemical plume reach the area before people evacuate?
(2) Will shelters prevent people from receiving a harmful exposure to the chemical?

A successful evacuation removes people from the affected area and avoids exposing them to a harmful concentration of the toxic chemical. An inappropriate decision to evacuate, on the other hand, can have negative consequences if it results in the population of the affected area being caught outdoors or in their vehicles when contamination enters the area. Sheltering can be worse than evacuation if shelters are leaky, people are not told when to come out of the shelter, or the release continues for a long time.

The planning process can help pre-determine situations for which either evacuation or sheltering is clearly preferred. Several approaches to doing have been developed with the aid of computer models (see Rogers et. al. 1990, Alberta Public Safety Services 1992, SSI 1998). If such an exercise results in ambiguous cases, then a procedure is needed to make a final choice of actions based on the conditions at the time of the emergency.

In addition to technical considerations pertaining to the evacuation/shelter-in-place protection decision, local emergency planners and officials must also consider sociological aspects: How will the public react to the officials' recommended action? In particular, research indicates that a recommendation to seek shelter-in-place protection may be met with skepticism by the public and may lead them to take actions that are counter to their safety (Glickman and Ujihara 1989). Limited evidence supports this hypothesis. In a study in West Helena, Arkansas, where part of a community was told to evacuate and another part to shelter in response to an organophosphate pesticide accident, most of those told to shelter evacuated instead (Vogt and Sorensen 1999). There was no evidence, however, of prior public information explaining the reasons for sheltering. Several explanations have been offered for this potential problem with sheltering. The option of shelter-in-place protection is much less familiar than evacuation, and people are thus reluctant to believe that it will be effective. The public may lack faith in the official making the recommendation. In addition, people may perceive that sheltering is not an effective strategy for protection. More fundamentally, they may be obeying a basic psychological force that tells them to take action by fleeing from an environmental hazard over which they have no control rather than passively seeking protection (Wilson 1987).

4.1 DECISION MAKING AIDS

Several methods to help make protective action decisions include checklists, decision matrices, decision trees or decision tables. Checklists present various attributes of a decision problem and allow for systematic consideration of each attribute. Decision matrices frame decision outcomes by 2 or 3 key attributes of the decision. Decision trees and tables pose a series of yes/no questions or sets of criteria which lead decision makers down branches of the tree or cells of the table to a desired outcome. In this section we will apply both a checklist and a decision tree approach to further explore decision-making options.

4.2 CHECKLISTS

Table 2 illustrates a checklist approach to the evacuation/sheltering decision. The first column lists various decision attributes. The second and third columns list the attribute values that favor either shelter or evacuation.

Table 2. Protective action checklist

Attribute	Shelter	Evacuation
Infiltration	Tight housing	Leaky housing
Plume duration	Short	Long
Time of day	Night	Day
Population density	High	Low
Road Geometry	Closed	Open
Road conditions	Poor	Good
Population mobility	Immobile	Mobile
Traffic flow	Constrained	Unconstrained
Public perception of shelter effectiveness	High	Low
Toxic load	High	Low

For some of the attributes more quantitative values could be assigned. For example, one might shelter with an expected plume duration of less than 30 minutes and evacuate with an expected plume duration of over 120 minutes. The middle ground of 30 to 120 minutes is a "gray area" where the decision outcome is unclear.

The advantage of this approach is that it is relatively easy to do. Among the disadvantages are that it will not lead to a clear-cut decision in every planning case, it may not optimize the safety of the public, and the relative influence of each checklist item is not accounted for.

4.3 DECISION TREES

Several sample decision trees for deciding between shelter-in-place and evacuation are found in Appendix A. Decision trees pose a series of Yes/No questions to the user. Answers to these questions lead to a path through the tree to an ending outcome. The protective action decision trees discussed here have three outcomes:

• evacuate,
• shelter, or
• conduct a detailed analysis.

The latter outcome is necessary because, under certain conditions, yes/no questions cannot lead to the identification of a preferable option.

More than one decision tree has been prepared because the trees will differ depending on the goals and objectives of protective action planning. Examples of different, but not necessarily mutually exclusive, goals are

• avoid fatalities,
• minimize total population exposure,
• minimize number of people exposed,
• minimize fatalities,
• minimize expected population risk,
• reduce exposure below a threshold level (i.e. no deaths exposure), or
• reduce exposure to “As Low As Reasonably Achievable” (ALARA).

Example decision trees for the first 2 goals are provided in Appendix A. The choice of goals is essentially a public policy decision involving difficult tradeoffs. For example, policy makers must decide whether it is better to (1) minimize fatalities by having a large percent of the population exposed to a sublethal, but harmful, level of chemical or (2) minimize the number of people exposed by choosing to avoid exposure for most people, while allowing a few to be exposed to a potentially fatal level of the chemical.

4.4 DETAILED ANALYSIS

A detailed analysis will likely require the use of one or more computer models and a structured approach to the analysis. One model developed in CSEPP to assist planners in protective action decision making is PADRE. The following discussion of PADRE is intended to illustrate the logic behind conducting a detailed analysis and is not an endorsement of the particular model. PADRE is an emergency planning tool that allows planners to assess the expected dosage reduction from implementing alternative protective actions under different scenarios. PADRE evaluates three protective actions: evacuation, sheltering, and respiratory protection. Scenarios can be specified with respect to the accident size, meteorological conditions, and emergency response system.

PADRE allows the user to generate an emergency response scenario. With PADRE the user can incrementally change a single factor in the scenario and almost instantaneously see the effect on the expected dose given that scenario. For example, one can compare the effectiveness of evacuating in a given accident scenario if the wind speed is 1 mps, 2 mps, 3 mps, or 4 mps. Likewise one can compare the effectiveness of sheltering given a 10 lb. release versus an 800 lb. release.

An overview of PADRE is presented in Fig. 1. PADRE begins with the specification of the initiating events in terms of the time and nature of the accident resulting in a release. The time of the release determines (1) the time at which the emergency response begins, (2) the distribution of people in various locations, and (3) the likelihood of the occurrence of various meteorological conditions. Each module of PADRE characterizes another step in the emergency response process. The warning-diffusion module characterizes warning system effectiveness in terms of the probability of receiving warning at various times in the warning process. The response-decision module characterizes the public's decision to respond to the warning message in terms of public response to previous chemical emergencies. The protective-action-implementation module characterizes the implementation of various protective actions in terms of probability of completion once the decision to respond is made.

The probability of a completed protective action is the joint probability of (1) public officials deciding to warn, (2) the public receiving the warning, (3) the population at risk deciding to respond, and (4) the population at risk implementing the protective measure. Such a joint probability must account for the period of time at which each previous step is achieved. For example, if warning is not received until minute three, the probability of response before minute three is essentially zero. On the first iteration, the probability of the decision to warn and warning receipt are multiplied to form a joint probability of a decision to warn and warning receipt. On the second iteration, the joint probability of a decision to warn and warning receipt and the probability of response produces the joint probability of reaching a decision to warn, receiving it, and responding to the warning message. Finally, combining that joint probability with the probability of completing implementation of the protective action produces an estimate of the final joint probability of achieving the protection action for each time period, "t".

Accident characterization, particularly the type and amount of chemical agent released, together with the meteorological characterization, allows estimation of plume dispersion for given downwind distances. These data alone determine concentrations of agent in the unprotected environment. In addition, the type of chemical agent allows the modeler to select the appropriate anticipated human health impacts for comparing the estimated unprotected and protected exposures.

Finally by integrating the probability of protection, with the dosage reduction from the selected protective action, one can calculate the expected dosage for that scenario-specific application of the protective action. By comparing evacuation with sheltering one can determine the expected dosages and health consequences to the population at risk, allowing a selection of the appropriate PAR.

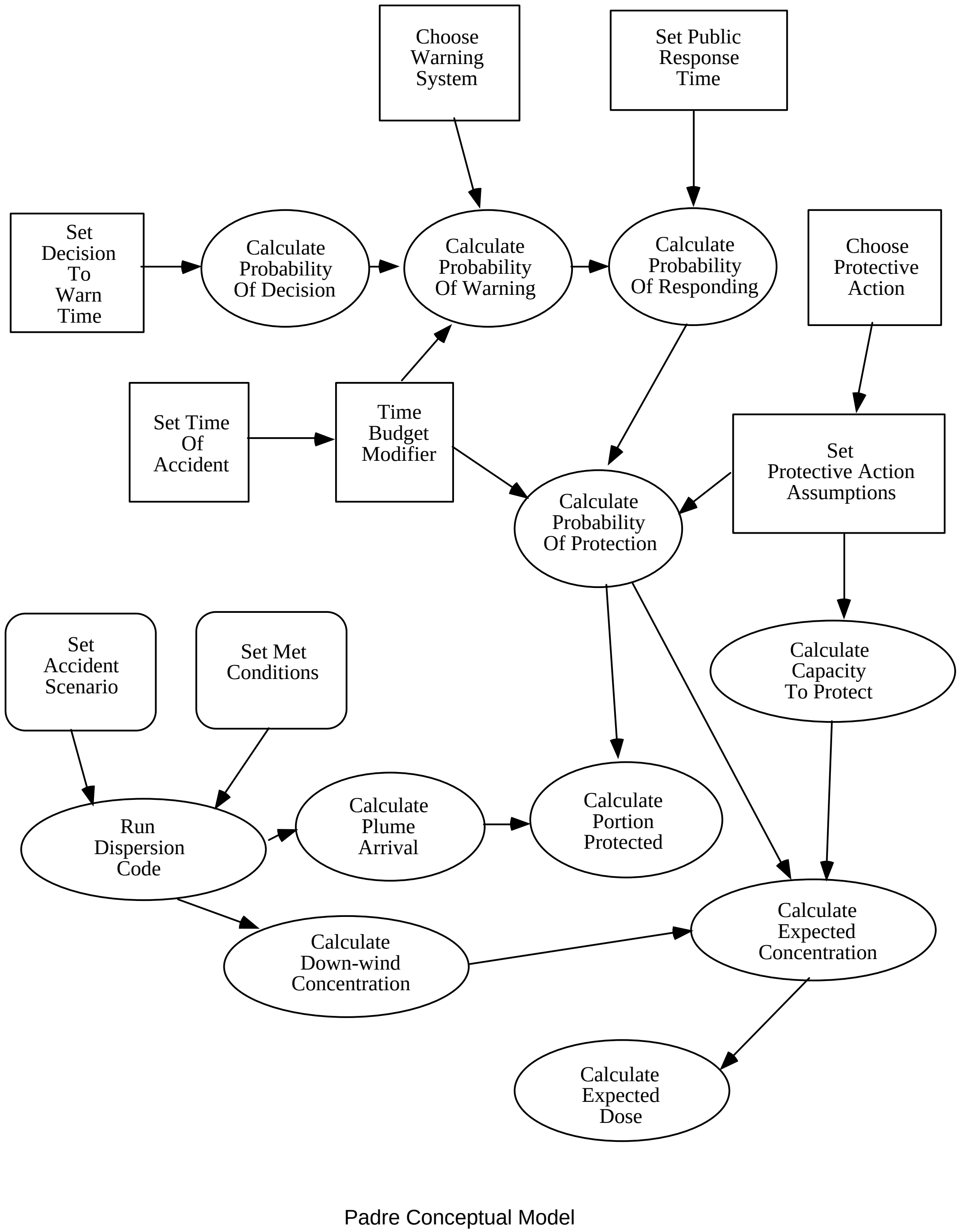

Figure 1. Flow diagram of PADRE

5.0 CONCLUSIONS

In making decisions to protect people's lives, we look for simple yet robust solutions with a high degree of certainty. Unfortunately, a simple technical decision making method for choosing protective actions does not exist. Simple rules do not work under all circumstances, or even for a large set of circumstances. A checklist approach is useful but likely will not result in an optimal decision. Furthermore the decision cannot be a seat-of-the-pants effort or based on intuition or hunches without preplanning.

The decision trees in Appendix A illustrate that this type of decision aid can help in some cases, but not all, and perhaps not in many. In addition, using a decision tree will involve a great amount of analysis which needs to occur in a planning and not in a response mode.

There are a few clear case situations in which either evacuation or sheltering is clearly preferred. These include the following cases:

- when no fatalities are expected, either protective action is feasible,
- when people can be evacuated before plume arrival, evacuation is preferable,
- when conditions make evacuation impossible, shelter is preferable
- when releases are extremely short, sheltering is preferable,
- when releases are extremely long, evacuation is preferable, and
- when the public may refuse to take an action, the choice may be limited to one alternative.

In most cases, detailed analysis may be required to determine if one action is more effective in protecting the public than another. Computer simulation models may be necessary to support these detailed analyses because the problem is too complex or has too many dimensions to analyze on paper. If models are utilized, it is important that the analyst and people using the results of the analysis are familiar with the assumptions of the model(s), understand the general nature of how the model works, and understand the limits and uncertainty of the model and its results. This includes the person(s) legally responsible for making the protective action recommendation and decision. If this decision maker(s) does not understand or trust the analyses that were performed during planning, an inappropriate recommendation could result.

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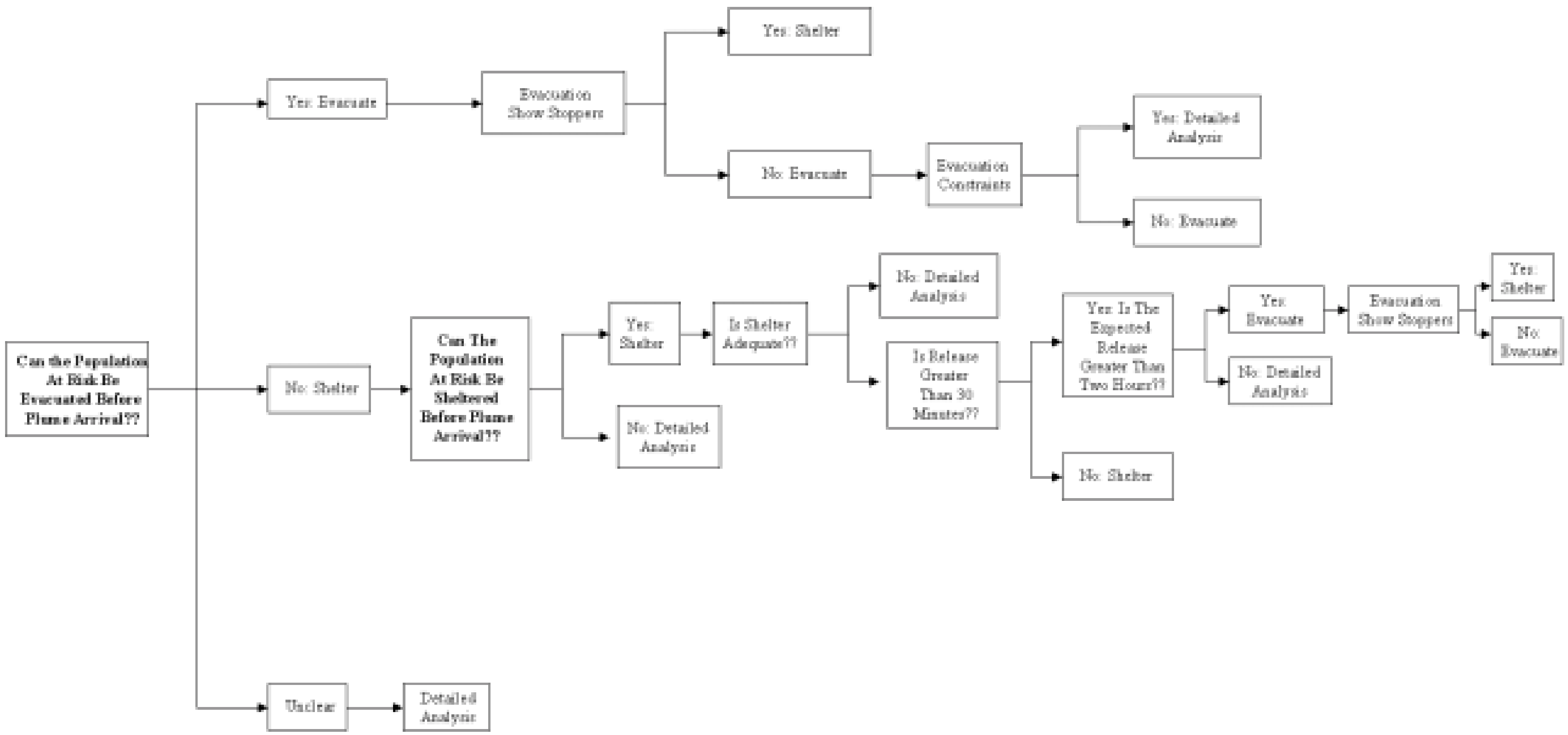
APPENDIX A

PROTECTIVE ACTION DECISION TREES

Protective Action Decision Tree: Minimize Exposure



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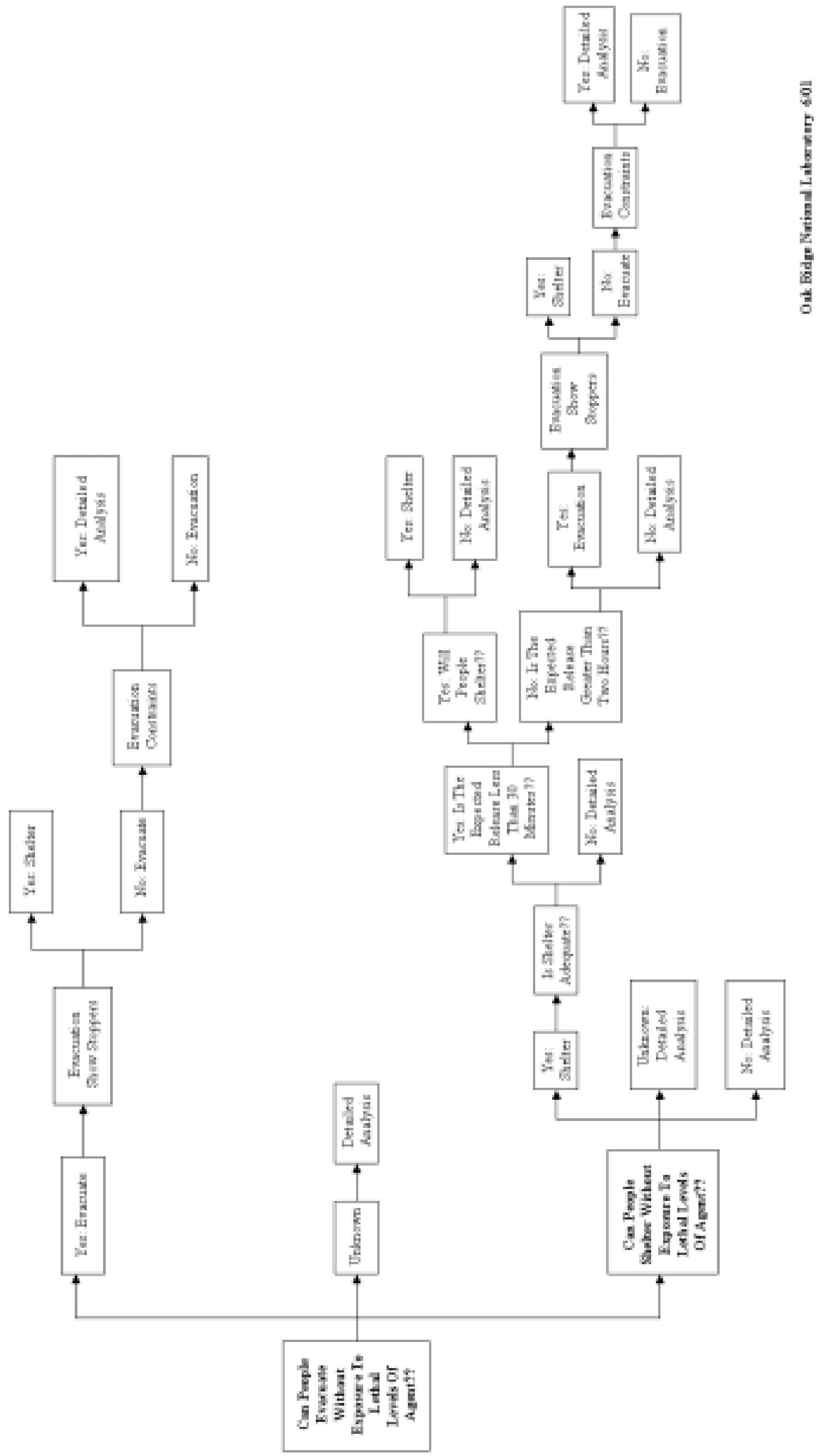
Protective Action Decision Tree: Avoid Fatalities



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