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PROTECTIVE ACTION EVALUATOR FOR CHEMICAL EMERGENCIES: A User's Manual (MS-DOS® Version 1.0)

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OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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ENERGY DIVISION

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PREFACE

This user's manual is developed for the first version of the Protective Action Evaluator for Chemical Emergencies (PAECE). This version of PAECE elicits the parameters required to describe a scenario (comprised of an accidental release of agent, its dispersion through the atmosphere, the extant emergency preparedness system(s), and the protective action alternatives) in a serial manner. New versions of PAECE are currently being developed to allow "block-loading" of parameters (e.g., to describe the emergency response system for a given community, or characterize a class of accident), change single parameters on-the-fly, provide help information on an as-needed basis, as well as display the results of individual of parameter selections. Versions of PAECE are also anticipated for several computing platforms, including MacIntosh, DOS and UNIX. Upgrades encompassing these improvements will be made available as soon as practicable, with the first of these revisions being available in late 1990 or early 1991.

The current version(s) of PAECE will be distributed by the Planning Subcommittee of the Chemical Stockpile Emergency Preparedness Program through the Federal Emergency Management Agency. Interested readers should contact co-chairs for further information.

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LIST OF EXHIBITS

ACRONYMS

ACH	air changes per hour
Ct	concentration time integral
D2PC	U.S. Army atmospheric dispersion code (computer model)
DOS	disk operating system
DtW	decision to warn
ECt_{50}	statistically derived concentration-time integral where 50% of reference population are expected to exhibit observable effects
EGA	enhanced graphics adapter
FPEIS	Final Programmatic Environmental Impact Statement
GB	chemical nerve agent (sarin)
H/HD	chemical blister agent (mustard) and chemical blister agent (distilled mustard)
IBM-DOS	DOS for IBM computer only
LCt_{50}	statistically derived concentration-time integral, that is lethal for 50% reference population (Lethal Concentration multiplied by Time)
MB	megabyte(s)
MS-DOS	DOS for IBM compatible computers
NATO	North Atlantic Treaty Organization
PAECE	Protective Action Evaluator for Chemical Emergencies
PARDOS	partial exposure calculation code (computer model)
RAM	random access memory
ToA	time of accident
VX	chemical nerve agent

ABSTRACT

The protective action evaluator for chemical emergencies (PAECE) is a package of computer programs developed to simulate an emergency response to airborne release of chemical agents. This user's manual documents the use of PAECE in the evaluation of chemical agent emergencies in areas potentially affected by the Chemical Stockpile Emergency Planning Program (CSEPP). This research documents the development and use of a method for the evaluation of protective action alternatives in conjunction with potential chemical agent emergencies. The user's manual highlights the development of the PAECE model, the selection of appropriate parameters to represent various scenarios, generate results and interpret them in the analysis of protective action alternatives during the planning and preparedness phases of the CSEPP.

The PAECE model is designed to evaluate protective actions in the context of potential accidents, the emergency management systems required to implement protective actions, and the anticipated consequences for human receptors. The implications and uncertainties of the model are discussed to provide potential users with insight into the use, limitations, and uncertainties associated with evaluating the effectiveness of protective action alternatives. While PAECE represents a unique and powerful tool to evaluate protective actions, the user must exercise caution when interpreting the results to avoid misrepresentation. The expected value interpretation of the PAECE results biases the results toward extreme values. Hence, the PAECE results have to be interpreted in the context exposures similar to those represented by the unprotected exposure and the protection capacity that tend to be associated with people completing the implementation of the required actions later than and earlier than average, respectively.

1. INTRODUCTION

The Protective Action Evaluator for Chemical Emergencies (PAECE) is a package of computer programs developed to simulate an emergency response to airborne releases of chemical agent. PAECE is designed to graphically compare expected exposure to chemical agent without protection (unprotected) with expected exposure to chemical agent in a protected environment (capacity) and the exposure expected when individual and organizational behaviors required to implement a protective action are considered (behaviorally adjusted). These expected exposures are presented in relation to the anticipated human health effects of exposure.

PAECE integrates three bodies of research: (1) on the character of, dispersion of, and protective equipment for chemical agents, (2) on human systems response to emergencies, and (3) on the human health effects of exposure to chemical agents. PAECE allows the user to evaluate the ability of various protective actions to reduce exposure to chemical agent releases in the context of the social, organizational, and individual behavior required to complete the emergency response measures. Moreover, the exposure reductions are presented in the context of the anticipated human health effects of the exposures. Exposure reduction is conceptually a function of the amount of protection a particular action provides and the probability of implementing it during the period.

PAECE was developed as part of the protective action support study for the Joint Federal Emergency Management Agency, Department of the Army Emergency Planning Steering Committee. The development of PAECE and preliminary analysis using PAECE are reported in Rogers et al. (1990a). As with all models, PAECE is a simplified representation of reality. Wherever possible, PAECE incorporates empirical evidence and previous experience with chemical emergencies to provide a realistic basis for the model. Even though this empirical foundation provides realistic elements of the model, each element also has a degree of uncertainty. For example, each of the following elements of the problem have a degree of uncertainty:

1. estimates of the amount of agent released;
2. concentrations reaching various downwind distances;
3. variability in meteorological conditions over time and across various distances;
4. distribution of human receptors at various times of the day, days of the week, and seasons of the year;
5. epidemiological response to a given exposure for various people;
6. capability of warning systems to penetrate routine environs under various conditions;
7. the extent to which the public will respond to those warnings in a timely manner;
8. the amount of time it takes people to implement a given protective action; and
9. the action's effectiveness in reducing exposure.

Some of these uncertainties are understood better than others; some are based on more complete research and data than others. In addition, the effect of combining these elements is not known.

This manual describes PAECE and its use to evaluate accidental releases of chemical agent from a fixed location. Section 2 describes the system requirements, installation, and initialization of PAECE. Section 3 presents a conceptual overview of the program. The specification of the accident and emergency response system are considered in Sects. 4 and 5 respectively. Section 5 also discusses the joint probability output that determines the probability of implementing a given protective action during the first three hours of an emergency. Sections 6, 7, and 8 describe the parameter specification process and resulting exposure output for evacuation, in-place sheltering, and respiratory protection, respectively. Section 9 describes the comparison of PAECE results for various protective action scenarios. Section 10 describes how PAECE can be used to examine combinations of protective action alternatives.

2. GETTING STARTED

PAECE operates on an MS- or IBM-DOS© microcomputer. While PAECE may operate in as little as 409KB of random access memory (RAM) a computer system with 512KB or 640KB of memory will decrease run-time and thereby is preferred. The program will operate on monochrome or color monitors and graphics adaptor cards but will be more legible on an enhanced graphics adapter (EGA) display card and monitor or better. The graphics routine associated with PAECE is most effectively used in conjunction with a mouse, however the user can view the graphs associated with PAECE using default colors, scales, and text without a mouse. To continue on with PAECE from a graphic display without a mouse, the user simply enters an ALT-Q (i.e., hold down the ALT key while pressing the Q key). PAECE was developed for use on an INTEL 80286® based processor, but will run on either the faster INTEL 80386® based processor or the slower INTEL 8088® based processor. PAECE and all its supporting data, programs, and routines can be stored in as little as 2.5 MB, but can run quite efficiently with 4 MB of storage for data files, support programs, and result files. PAECE operations are significantly enhanced by the extent that the program is initialized on a RAM based storage device.

PAECE is not copy protected; hence, the installation of the program is relatively simple. Because PAECE is not particularly developed for completely novice PC users, and the installation is straight-forward, no installation routines have been developed. To install PAECE:

1. select a hard disk or RAM disk on which to install PAECE (e.g., at C:> enter **D:<CR>**),
2. make a directory called ProtAct (e.g., at D:> enter **md\ProtAct<CR>**) on the selected disk,
3. change the current directory to the ProtAct subdirectory (at D:>enter **cd\ProtAct<CR>**),
4. copy all files from PAECE diskettes into the ProtAct subdirectory (at D::> enter **copy A:*.* D:\ProtAct*.*<CR>**).

PAECE operation usually requires long records and therefore will require a record length specification (/r 2700) in the command statement. A batch file has been developed to assist the user. PAECE may be executed running the supplied batch file (PAECE.BAT), or by executing the PAECE.EXE directly with a /r 2700 switch.

3. AN OVERVIEW OF PAECE

Generally, PAECE is interactive. It iteratively presents the user with information designed to assist with parameter selection, solicits the selection of a parameter or set of parameters on which to base the computation of results, and presents the user with the results based on the selected parameters. The guiding principles used in developing PAECE were as follows:

- Flexibility: A system of evaluation must be flexible enough to accommodate the potential situations to be evaluated.
- Empirically based: A system of evaluation must be based on reality; one way to obtain this reality is to build in data, conclusions, and knowledge from existing research.
- Parsimony: A system of evaluation is a representation of the complete process. Such systems focus on the main elements of the situation—those parts of the system that fundamentally alter the outcomes.
- Modularity: A system of evaluation must be able to accommodate changing information, knowledge, and methodologies over a period of time. Modular development allows critical elements to be extracted from the system and replaced with new components as long as the inputs and outputs from the new elements are similar.
- Uncertainty and precision: The precision of an evaluation resulting from a system should be commensurate with the amount of uncertainty in the system and its components.

PAECE achieves flexibility by allowing the user to specify the accident and emergency response scenario from a variety of options. PAECE incorporates empirical data, research, and conclusions by presenting summary information where applicable, and shows the user how to specify appropriate parameters. The parsimony requirement is met by characterizing various functions in terms of their essential components—elements of the problem that fundamentally alter the outcomes. Each fundamental component of PAECE is modular in the sense that it can be replaced as new information, approaches, or methods are developed, as long as the input-output structure is constant. The uncertainty and precision principles are met by not presenting numerical results requiring given levels of numerical precision. In addition, expected exposure results are bounded with graphical information about unprotected people at the upper boundary, and the capacity of the specified protection on the lower boundary.

The overall conceptual model of PAECE is presented in Fig. 1. PAECE is comprised of 12 modules or components. The general flow of PAECE is from specifying the accident to characterizing the emergency response to the accident and ending with the exposure reduction calculation and output of results. Figure 1 depicts the program flow from left to right and top to bottom. A complete example of PAECE input and resulting output is presented in Appendix A.

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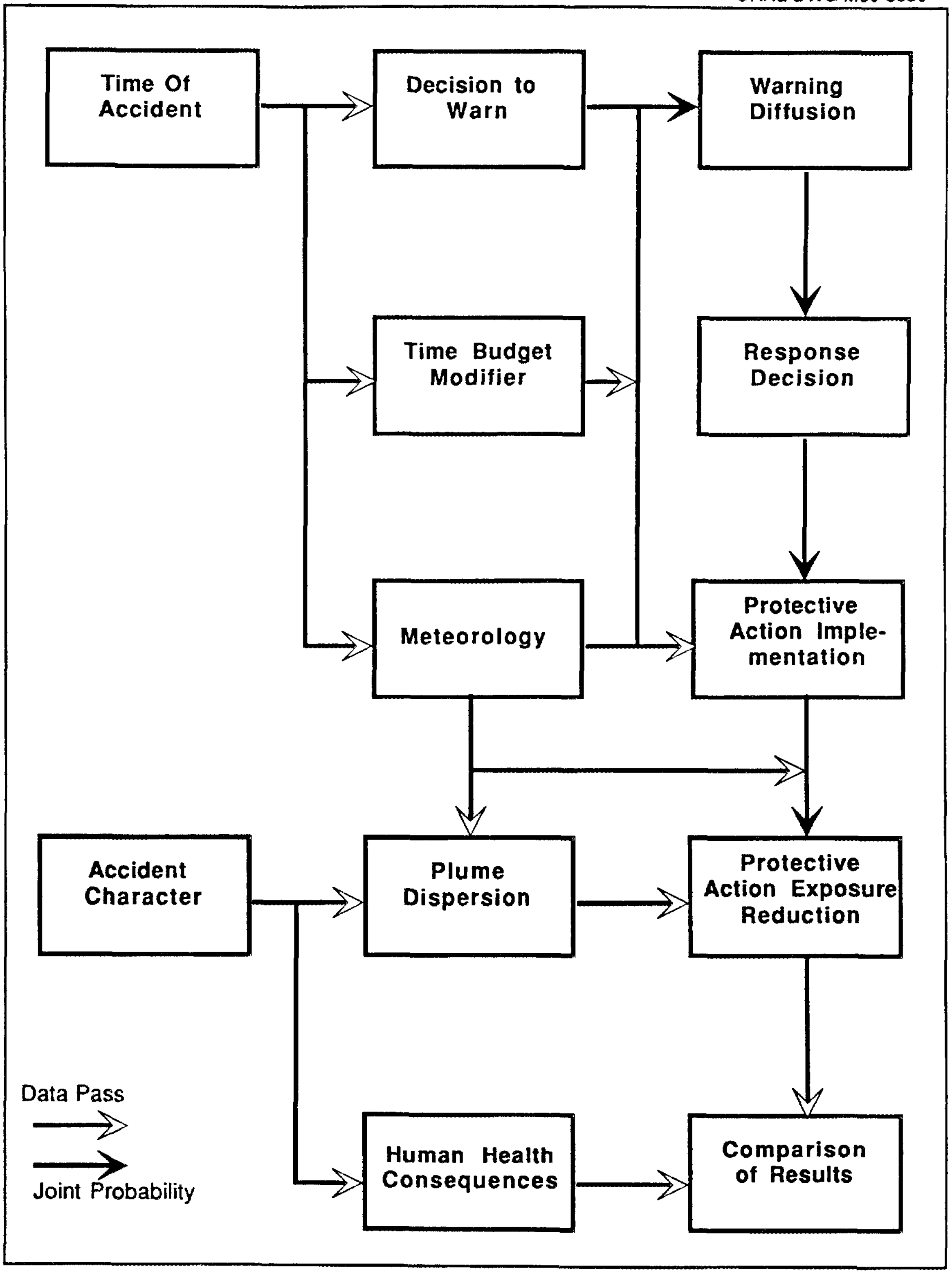

Fig. 1. Conceptual model of protective action evaluation for chemical accidents.

4. ACCIDENT CHARACTERIZATION

4.1 TIME OF ACCIDENT

The time of accident (ToA) can be selected in three fundamentally different ways: (1) via the distribution of recent chemical accidents in the United States, (2) randomly by the hour, and (3) by the user. The distribution of recent chemical accidents is presented in Fig. 2. Basing the ToA on the distribution of accidents, the user may select a most probable ToA or use a stochastic selection. In either case, the user will be prompted to select the desired distribution—either fixed-facility, transportation, or all accidents. The interaction of PAECE with the user is presented in Exhibit 1. The user may select a ToA to the nearest minute; however, PAECE uses hourly data in the specification of meteorological conditions and population location/activity.

The ToA initiates both the accident and emergency response scenario. First, the time of accident provides the initial time at which the chemical release occurs and is the basis for the initial response parameters. Second, PAECE uses the time of accident together with average time budget data (see Appendix B) to establish the expected warning system effectiveness and the extent of anticipated initial protection at that time of day. Finally, PAECE can use the time of accident to estimate the meteorological conditions at the time of accident stochastically.

4.2 RELEASE SCENARIO

The accidental release of chemical agent is specified in terms of the amount of agent released; the extent of vertical (*Z*), crosswind (*Y*) and downwind (*X*) variance involved in defining the plume; the duration of the release; the downwind distance of interest; and the agent involved. Exhibit 2 presents the solicitation screens involved in specifying the accidental release of chemical agent. Specifying the amount of agent released in pounds involves the estimation of the agent's total weight . The risk analysis conducted for the Final Programmatic Environmental Impact Statement (FPEIS) (Fraize et al. 1987) provides one estimate of this amount for specific accidents. Another way to estimate this amount involves knowing the total inventory "with a potential" to be released and making the conservative assumption that all of it is released. Another way that might be available in response to an accident involves observing actual involvement or non-release and then estimating the amount of vapor depending on the amount of agent released and the mode of release. Still another possibility involves the "back-calculation" of amount based on monitored levels of concentration at various distances under the current meteorological conditions.

The duration may be estimated on the basis of emergency response personnel judgment. For example, if a fire is nearly under control and hazardous materials teams believe that about 10 min will be required to stop the release, a 10-min duration can be used. The selection of the downwind distance of interest may be based on the area of interest for the particular scenario. As presented in Exhibit 2, PAECE uses a series of index numbers to represent downwind distances (e.g., 11 indicates 3 km, 17 indicates 9 km, and 19 indicates 20 km). Finally, the user must specify the agent type for the scenario (i.e., GB, VX, or H/HD).

The amount of vertical, crosswind, and downwind mixing may be estimated from climatology or current meteorological measurements or may be set by other means.

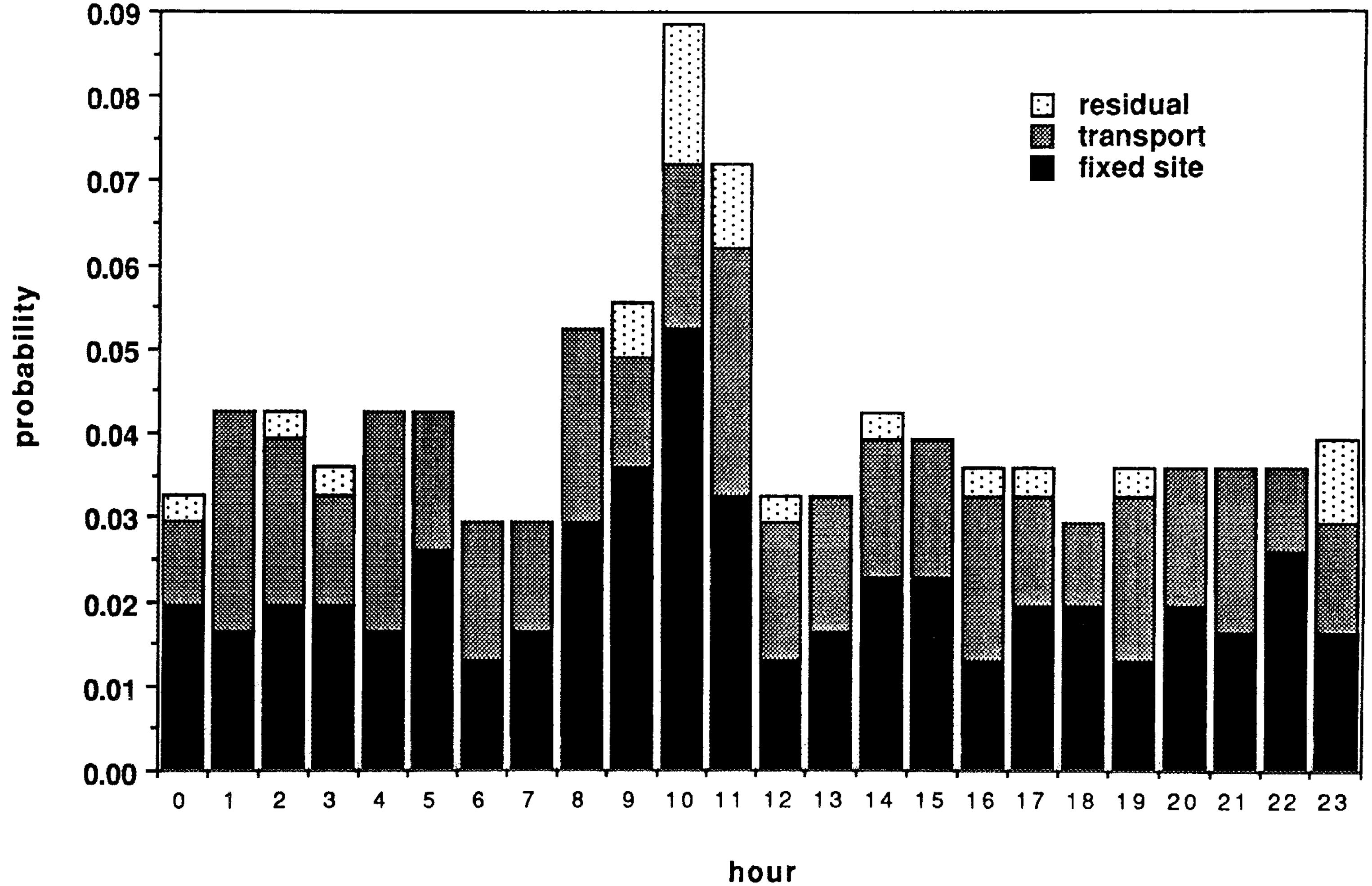

Fig. 2. Distribution of recent chemical accidents in United States.
Source: AP & UPI Reports January 1985 -- September 1988.

Select the mode for determining the Time of Accident (ToA):

1 stochastically derived time
2 Most-Probable time
3 Equi-probable time
4 User selects time.

If 1 or 2 is selected, then

Enter
1 to base ToA on Fixed-facility accident,
2 to base ToA on Transport accident,
3 to base ToA on all (Fixed-facility,Transport,Unknown) accidents

If 3 is selected, time of accident randomly generated.

If 4 is selected then,

Enter the time of the accident [military time - e.g. 2000 = (8PM)]

Exhibit 1. User specification of time of accident.

Enter the released amount, Q, the sigmas (variance)-downwind, crosswind and vertical, and release duration.

INPUT: Q(LBS), SXS(M), SYS(M), SZS(M), RELEASE TIME(MIN)

For example
100 0 0 0 10 or
100,0,0,0,10 both mean 100 lbs of agent, with limited mixing in all directions (i.e., sigma x, y, z, all = 0), over a 10-min period.

Select the distance (indicator) for exposure accumulation:

Enter the desired distance from the following table:

0 —100m	1 —200m	2 —300m	3 —400m
4 —500m	5 —600m	7 —800m	7 —900m
9 — 1km	10 — 2km	11 — 3km	12 — 4km
13 — 5km	14 — 6km	14 — 7km	16 — 8km
17 — 9km	18 —10km	19 —20km	20 —30km
21 —40km	22 —50km		

INPUT: AGENT (1 = GB, 2 = VX, 3 = OTHER)

Exhibit 2. User specification of accidental release.

Setting the variance to zero forces the plume dispersion to be concentrated along the centerline of the plume. Moreover, because PAECE uses only centerline concentration as a conservative "overestimate" of the amount of expected exposure, setting the vertical, crosswind, and downwind variance to zero maximizes the amount of concentration along the centerline.

It is important to understand that the dispersion code for D2PC (Whitacre et al. 1987) accurately represents the atmospheric dispersion in terms of both vapor and aerosol. However, PARDOS (Seigh 1988) represents only the vapor portion of the release for any given agent. Even though the total ending exposure (as based on D2PC) accounts for aerosol depletion, PARDOS does not account for the nature of aerosol dispersion in its partitioning of the exposure for a given downwind distance by time into the event. As a result, the partial exposure results of the dispersion codes employed herein accurately represent the vapor portion of the release. Hence, to the extent that a release of agent is appropriately characterized as vapor, the approach to dispersion modeling employed herein is reasonably accurate. Because GB is volatile [2.2×10^4 mg/m^3 at 25°C (U.S. Department of the Army 1974)] and thereby results in a vapor plume, the atmospheric transport of GB is accurately characterized by PARDOS. However, because VX releases have significant portions of the release appropriately characterized as aerosol, with lower volatility [10.5 mg/m^3 at 25°C (U.S. Department of the Army 1974)] it is less likely to be transported over long distances. Mustard gas is also characterized by reasonably low volatility [925 mg/m^3 at 25°C (U.S. Department of the Army 1974)] and is not likely to be transported for long distances as a vapor. The approach used herein considers the entire release, regardless of agent, to be vapor and thereby overestimates the amount of agent present at any downwind distance at any moment into the release. This estimate of the amount of agent concentration is considered conservative because it overestimates the exposure to be protected from and systematically underestimates the ability of each protective action to protect. Hence, the model most accurately represents the dispersion of GB; it underestimates the level of concentration of VX and H/HD early in the time period at relatively short distances. However, because aerosol droplets are likely to drop out quickly (i.e., probably within 0.5 to 1 km), the exposures are likely to be overestimated by the model at distances greater than 1 km.

4.3 METEOROLOGICAL CONDITIONS

First, PAECE solicits the storage/disposal site of interest from the user. Exhibit 3 presents the solicitation screen for the specification of meteorological conditions. The selection of the site of interest determines what climatology data to use, either for the generation of meteorological data for the scenario or the "verification" of the user-specified conditions. PAECE allows the user to specify meteorological conditions in terms of wind direction, wind speed, and stability class (option 3); or the user can rely on climatology data to select parameters for the most frequently observed (most probable) meteorological condition at the selected time of accident; or PAECE can randomly set these meteorological parameters based on the observed distribution of the climatological data (stochastic).

Enter the site indicator for meterological data:

1 Aberdeen (APG)
2 Anniston (ANAD)
3 Lexington-Bluegrass (LBAD)
4 Newport (NAAP)
5 Pine Bluff (PBA)
6 Pueblo (PUDA)
7 Tooele (TEAD)

Select the mode of meteorological data generation:

Select from the following list:

1. Use the most probable met. conditions during the hour
2. Randomly select met. data weighted by likelihood of occurrence, or
3. Enter your own meteorological data.

If 3, enter own met data selected, then

Enter the wind direction from which the wind is blowing (0-359^{o})

Enter wind speed (m/s)

Enter stability class index (1-6 where AD = 1)

Exhibit 3. User specification of meteorological conditions.

5. SPECIFYING EMERGENCY RESPONSE

5.1 DECISION TO WARN

Figure 3 presents the cumulative distribution of reaching a decision to warn (DtW) the public to take protective action in 14 recent chemical emergencies. The DtW parameters initiate the emergency response process. PAECE requires the user to either determine the amount of time it will take to make a DtW or use the existing distribution as the basis of the probability of reaching a DtW. Exhibit 4 presents the solicitation screen concerning the DtW. PAECE allows the direct entry of DtW parameters; a positive integer indicates the minute after the release when the decision to warn is reached; a negative integer indicates the use of a precautionary warning of up to an hour (i.e., > -60) where emergency managers have an emergency event that has not yet resulted in a release of chemical agent to the atmosphere; and any other entry (e.g., alphanumeric response) results in the use of the probability distribution presented in Fig. 3.

The DtW parameters are used to estimate the independent probability distribution that emergency officials will reach a DtW by lapse-time from the event. Exhibit 4 presents PAECE's solicitation of DtW parameters. If the user selects the displayed distribution, those probabilities at each minute into the event are used. If the user selects a time at which the DtW is reached, the probability is a step probability that is set to zero before that time and unity thereafter.

5.2 EMERGENCY WARNING SYSTEM

Figure 4 presents the estimated cumulative proportion of a population receiving warning by the type of warning system used. They are described by a classic logistic function used to describe diffusion in a social network (Rogers and Sorensen 1988). These systems have been compared with available survey data in conjunction with four chemical accidents including train derailments in Pittsburgh, Pennsylvania; Confluence, Pennsylvania; and Mississauga, Ontario; and a chemical plant fire in Nanticoke, Pennsylvania (Rogers and Sorensen 1989; 1990). The simulated warning receipt curves depict warning receipt reasonably well when matched to the warning system used.

Once the information curves of Fig. 4 are presented, the solicitation screen (Exhibit 5) for selection of a warning system appears. The user is given the complete formulation of the logistic function as well as the specification of the parameters used to simulate each type of warning system. PAECE allows the user to select one of the predefined warning systems or select a new set of parameters that specify a unique warning system. Moreover, PAECE allows the user to select the time at which 100% of the public will receive the warning. This option allows the user to simulate institutional warnings that can be characterized by a direct alert and notification.

The warning system parameters are used to estimate the independent probability distribution that the public will receive warning in terms of lapse-time from the moment the warning system is activated. The probability of warning receipt is adjusted by the likely distribution of people at the hour of the accident (see Appendix B). PAECE estimates the probability of the public's receiving warning independent of the DtW, and of the public's decision to respond to the warning. If a specified time at which 100% of the population receives warning is selected, the probability is a step probability that is set to zero prior to completion and unity thereafter.

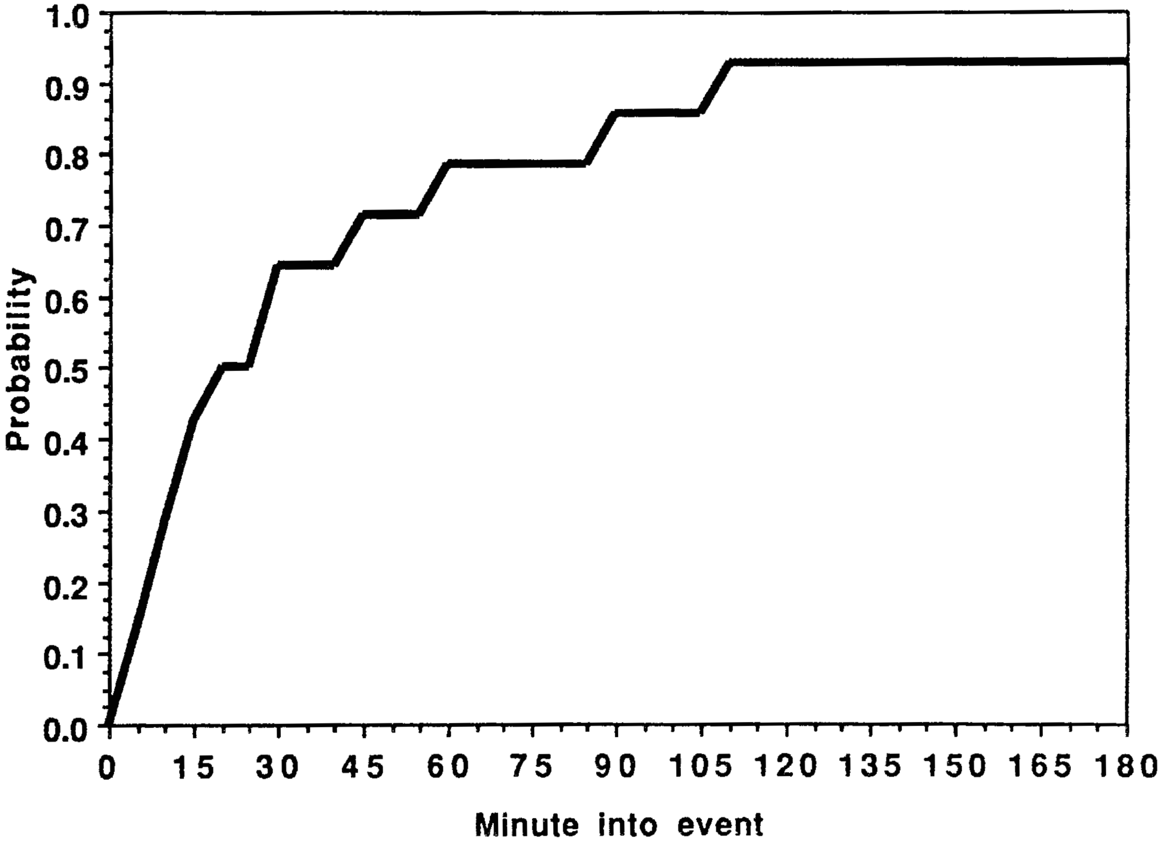

Fig. 3. Probability of decision to warn public by time.

(a) Enter The minute (into the event) when the decision to warn (DtW) is reached, or

(b) Enter Minus the minutes (e.g., -20) before the release when the DtW is reached, or

(c) Enter P to use the probability of a DtW based on the data in the previous graph.

Exhibit 4. User specification of decision to warn.

Select the ID number for model parameters used to estimate diffusion of warnings:

where $dn/dt=k[a_1(N-n)]+(1-k)[a_2n(N-n)]^a$

System	k^b	$a_1{}^c$	$a_2{}^d$ Limit	30-min[e] Rate(%)	Release[f]
1 Sirens	0.2	0.2	0.3	0.75	0.3
2 Tone-alert radios	0.4	0.3	0.2	0.90	0.1
3 Media	0.3	0.2	0.25	0.50	0.5
4 Telephones	0.4	0.35	0.2	0.93	0.
5 Sirens and tone-alert	0.4	0.3	0.3	0.95	0.1
6 Siren and telephone	0.4	0.35	0.3	0.95	0.1

7 Other: User specifies new parameters
8 Enter time at which warning is complete

[a]N = population to be warned and n = proportion warned at beginning of period.
[b]k = proportion alerted by broadcast, (1-k) = proportion alerted by contagion.
[c]a_1 summarizes the efficiency of the alerting (broadcast) process.
[d]a_2 summarizes the efficiency of the contagion (birth) process.
[e]30-min limit is a statement constant of first 30 min of warning process.
[f]The rate at which structured constraint is released.

Exhibit 5. User specification of warning system parameters.

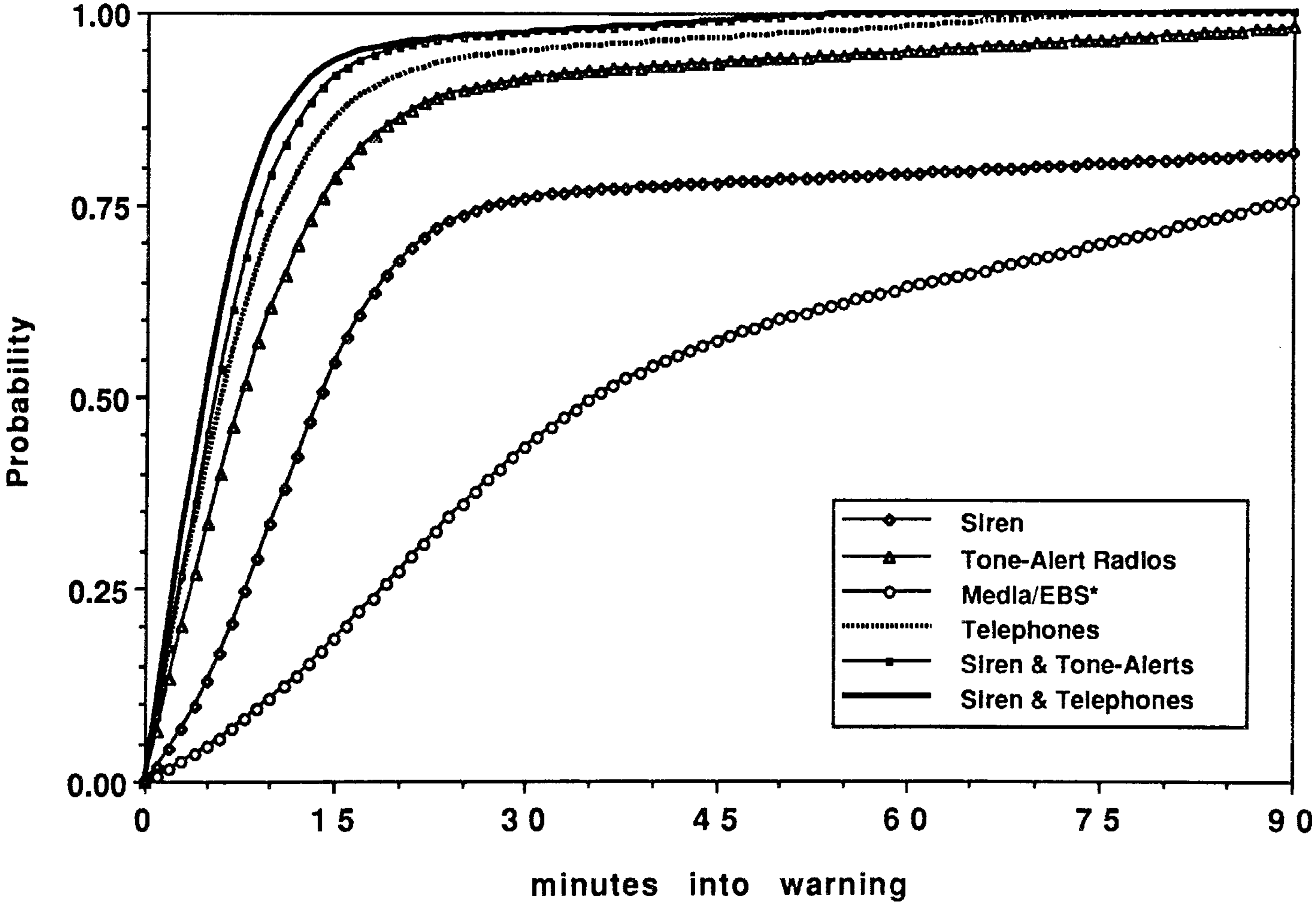

Fig. 4. Probability of receiving warning by warning system by time elapsed since warning decision.

Source: Rogers, G. O. and J. H. Sorensen (1988), "Diffusion of Emergency Warning," The Environmental Professional, Vol. 10, p. 281-294. * Emergency Broadcast System.

5.3 PUBLIC RESPONSE

Public response to the warning is contingent upon the receipt of warning. When the public is warned about the impending danger, people then make decisions about appropriate actions to take in response to that danger. This is sometimes called mobilization. PAECE presents the user with four response curves (Fig. 5) that summarize the public's decision to respond in four chemical emergencies, including three train derailments occurring in Pittsburgh, Pennsylvania; Confluence, Pennsylvania; and Mississauga, Ontario; and a chemical plant fire in Nanticoke, Pennsylvania. The public response in each of these emergencies involved evacuation.

The user selects the cumulative response curve(s) that best represents the anticipated public response for the selected scenario; or the user may select the time at which all people in the area described will be responding. The user specification of public response parameters required by PAECE is presented in Exhibit 6. If the user selects one of the empirically observed mobilization curves, it can then be modified by a scalar to represent better or worse public response than observed in the selected case. For example, if the user feels that response for the selected scenario is likely to be 10% better or 15% worse than the response to a given response curve, it would be modified by the scalar, 1.1, or 0.85, respectively, or it can be used as is by selecting a scalar of 1.0 response. If the user selects more than one public curve, the need to implement weighted average of the selected curves is used as the basis of public mobilization.

The public mobilization curves are used to estimate when the public will respond to the emergency warning by lapse-time from the time of warning. Hence, it estimates the probability of responding to the emergency warning independent of the DtW and the receipt of warning. The selection of the specific time at which all people in the area are responding results in a step probability function that has the value of zero before the mobilization time selected and unity thereafter.

5.4 PROTECTIVE ACTION IMPLEMENTATION

The implementation of a protective action depends largely on the amount of time it takes to accomplish the activities required to complete the actions. The time that it takes depends on both those implementing the action and the structural characteristics of the action. For example, implementing an evacuation is a function of both the person driving the vehicle and the structure of the transportation network in the area to be evacuated in terms of road capacity, type of road, the traffic congestion on the road network, and other variables. The implementation time for various in-place shelters and respiratory protections depends on the skills of those conducting the activity and the actions' structural characteristics. PAECE arbitrarily combines both the structural and behavioral elements of implementation into the probability of completing the protective action, which is independent of the emergency response system context (i.e., DtW, warning system, and public decision to respond or mobilize).

Once the user specifies the protective action (Exhibit 6), PAECE allows the user to select implementation times at 1-min intervals for each protective action. The user's specification of implementation times is presented in Exhibit 7. For evacuation, the implementation is referred to as clearance time because it represents the amount of time required to clear a given area. This clearance can be calculated as a function of the distance

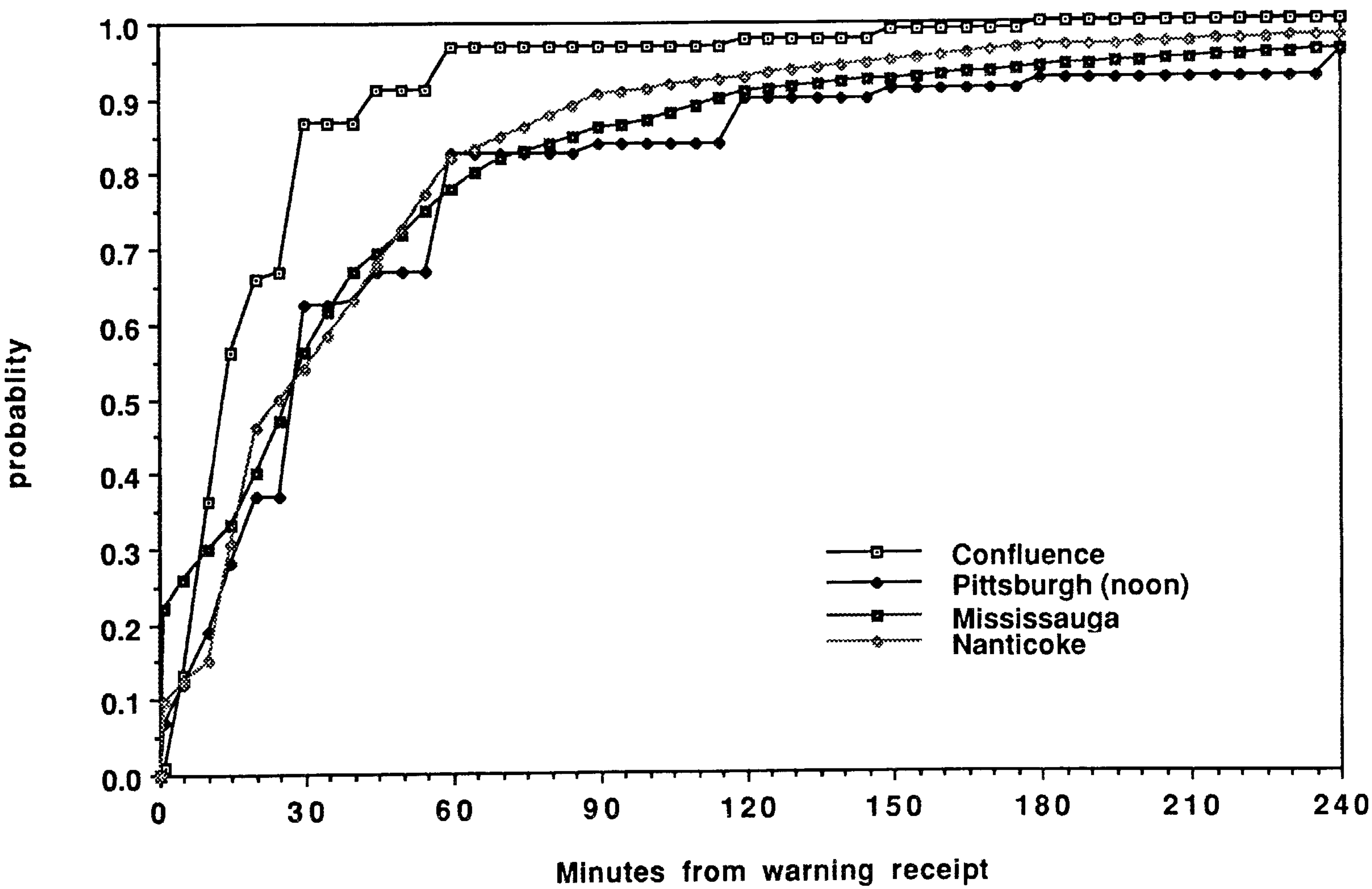

Fig. 5. Response to warning.

Select the protective action indicator:

1 Evacuation
2 In-place
3 Respiratory device

Exhibit 6. User selection of protective action.

If evacuation is selected, then:

Select the indicator for the evacuation mechanism:

1 clearance time (min),
2 evacuation speed.

If clearance time is selected,

Enter the time (min) for complete evacuation.

If evacuation speed selected, the distance from source (in m) is reported and then,

Note: Programmatic IRZ is approximately 10 km,
PAZ is approximately 35 km.

Enter the distance (km) where evacuees will be considered protected (safe)

Enter the average evacuation speed (mph)

If in-place protection selected, then

Select the indicator for in-place shelter implementation:

1 Close doors/windows,
2 Tape/seal,
3 Select time for complete implementation.

Respiratory device

Enter the time (min) required to implement the device

Exhibit 7. User specification of protective action implementation.

to be traveled and the average speed of egress. For in-place shelters, the implementation time can be selected by the user, or it may be treated as a probabilistic function of experimental trials of expedient measures to limit infiltration into residential structures (Rogers et al. in press). For respiratory protection, PAECE allows the user to select the amount of time required to implement the respiratory device.

Once PAECE has the complete specification of the implementation in the context of the emergency response system, the behavioral specification of the emergency response scenario is complete. PAECE calculates the joint probability of completing the selected protective action by iteratively considering each independent probability of the component parts of the emergency response process. For example, people warned in step one have the probability of making a response decision during step one, while people warned in step two have the probability of responding associated with step one, while those who received warning at step one are now characterized by the probability of responding during step

two. At each successive step, the joint probability is calculated by considering the sequence of the response process (Rogers et al. 1990a). When the independent probabilities of each step of the emergency response process are multiplied, the result is the cumulative probability of implementing the selected protective action.

Figure 6 presents an example of PAECE's behavioral summary in terms of the joint probability of the completion of a selected protective action. In this example, the vertical rise of the cumulative probability of receiving warning is lagged 5 min from the event representing a 5-min DtW. Moreover, the parallel spacing between the probability of public response and the completion of the evacuation represents the clearance of the population at a fixed time after the evacuation is initiated (e.g., a 15-min evacuation).

The joint probability output from PAECE summarizes the behavioral components of the emergency response system and the implementation of the selected protective action. It can be used to identify critical components of the emergency response—elements that require improvement and other factors that are operating at or near potential. This output allows the user to identify response system weaknesses that cause exposure.

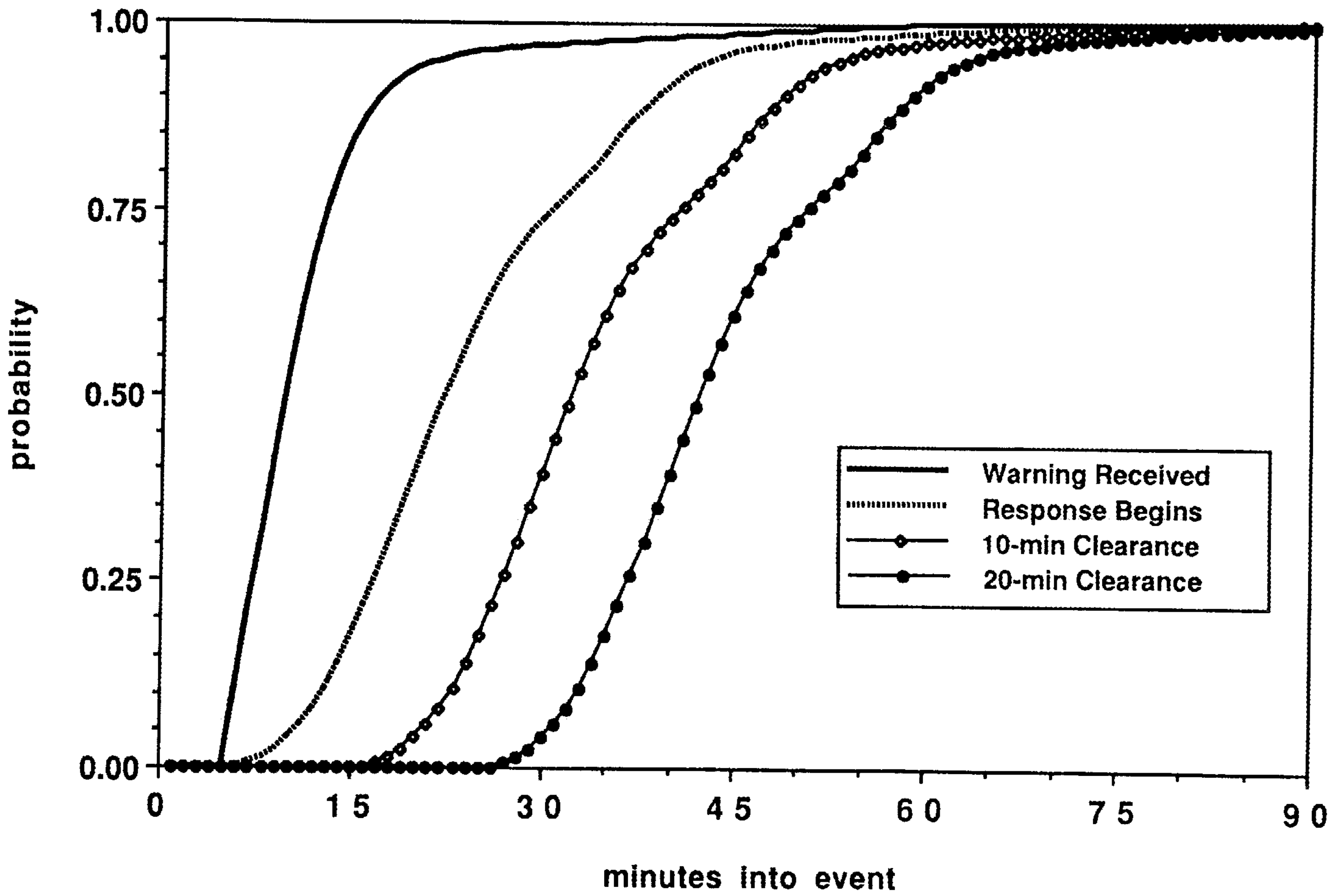

Fig. 6. Probability of completing 10- or 20- min evacuations by time into the event.

6. EXPOSURE COMPARISON

To calculate the expected exposure, PAECE assigns the exposure associated with being unprotected at a given downwind distance to the people who have not yet implemented the given action, and the protected exposure to those people who have completed the protective action, and averages the exposure over the population. For example, if ten people comprise the population of an area at a given downwind distance, and two have been evacuated, those two receive no exposure because they have presumably been evacuated to a safe distance. Eight receive the exposure associated with being unprotected. To continue the example, if the exposure at the given downwind distance is 15 mg-min/m^3, the expected exposure for the population at that distance would amount to 0.8 x 15, or 12.0 mg-min/m^3. Note that no single person in this hypothetical population received 12 mg-min/m^3 exposure; rather, two received no exposure, and eight received 15 mg-min/m^3. Hence, this expected exposure is intended to represent an expected value for a population rather than an accounting of actual exposure. It may be thought of as an average exposure for a population.

PAECE presents various expected exposures for comparison: (1) without protection in an unprotected environment, (2) with the specified protection in the context of the specified emergency response system, and (3) the "structural" protection capacity of the specified protective action. The expected unprotected exposure is estimated using a combination of the results from D2PC (Whitacre et al. 1987), which estimates the total exposure for a given downwind distance, and PARDOS (Seigh 1988), which partitions the total exposure into the amount of concentration anticipated at each minute into the release. The unprotected exposure estimate represents the concentration of chemical agent on the centerline of the plume and postulates no protection associated with emergency response. The exposure expected among people protected by the specified action takes into account the probability of completing a protective action given the emergency response system specified. The protection capacity associated with the selected protective action represents the structural ability of the action to provide protection independent of the specified emergency response system required to implement the action. The protection capacity thus represents the maximum exposure reduction possible for a given accident scenario using the selected protective action.

PAECE also reports the relationship between protected and unprotected exposures. The overall exposure reduction compares the exposure associated with the selected protective action with the unprotected exposure in the context of the described emergency response system. The overall exposure reduction is best suited to compare protective actions of different types (i.e., evacuation vs in-place shelters vs respiratory protection) or protective action effectiveness under various emergency response systems, or for a variety of scenarios. The overall exposure reduction simultaneously compares the protected exposure with the unprotected exposure and the protection capacity of the selected protective action. The relative exposure reduction compares the effect of similar protective actions—i.e., from the same accident and having the same capacity to protect, but resulting in different expected exposures (e.g., under various emergency response systems). The relative exposure reduction is used to examine the effect of various emergency response parameters on exposure. For example, relative exposure can be used to examine the effect of warning system characterization on an evacuation with a specific clearance time.

These three expected exposure results are presented over the first three hours (180 min) of the release or up to four hours of the emergency response (i.e., including up to an hour before the release). The cumulative expected exposure curves represent the concentration-time integral (Ct) in mg-min/m^3 and summarize the human health effects associated with such exposures, including the exposures where 50% of the population are expected to die (LCt_{50}) for adult males and infants and exposures where 50% of population segments exhibit observable effects (ECt_{50}). This representation is intended to remind the user of the anticipated human health consequences associated with the expected exposures. In addition, a summary of the accident, meteorology scenarios, the emergency response system, and protective action specification is listed. The summary helps the user keep track of the assumptions underlying an individual result.

7. EVALUATING EVACUATION SCENARIOS

Evacuation scenarios within PAECE are characterized in terms of the time it takes to evacuate an area, or clearance time. Clearance time is a function of both the individual driver or vehicle behavior and the structural characteristics of the road network.

When calculating the protection capacity of a specified evacuation, PAECE artificially reports the clearance as if it were strictly a structural parameter. In reality, those who complete evacuation before exposure to the plume completely avoid harm. However, because clearance is partly a function of structural characteristics (e.g., road capacity, bottlenecks, and present load), the capacity of an evacuation to protect includes the amount of time it takes to clear an area.

Once the clearance time is specified, an evacuation is completely specified, because those who have completed the action avoid exposure. Like all protective actions, clearance time specifies both the amount of protection provided (exposure reduction) and the length of time it takes to achieve the protection (implementation).

Evacuation exposure output, like all exposure outputs, is composed of an unprotected exposure, a protected exposure, and a capacity to protect. Figure 7 presents an example of output from PAECE for an evacuation scenario. The unprotected exposure, the curve farthest from the *x* axis, represents the amount of exposure that would be expected among individuals without protection. The capacity to protect, the curve closest to the *x* axis, represents the amount of exposure anticipated as a function of clearance time. The protected exposure, depicted by the curve between the unprotected curve and the protection capacity curve, represents the amount of exposure anticipated among those evacuating within the clearance time of the specified emergency response system.

To the extent that the evacuation clearance time is less than the amount of time required for the plume to traverse the selected downwind distance, the protection capacity associated with that evacuation will be complete protection (no exposure). The results displayed on the screen include a numeric indicator of the extent to which the selected protective action is completed when the plume arrives [i.e., labeled "P(Impl. PA) @ Plume arv."]. The value represents the extent to which the exposure is a function of the selected action or the behavior of the emergency response system, and the implementation of the action. When the probability of implementing the selected action by the time the plume arrives is low, behavior plays a large role in the associated exposure. Conversely, when the probability of completing a selected action by the time the plume arrives is high, the resulting exposure is largely determined by the ability of the selected protective action to reduce exposure.

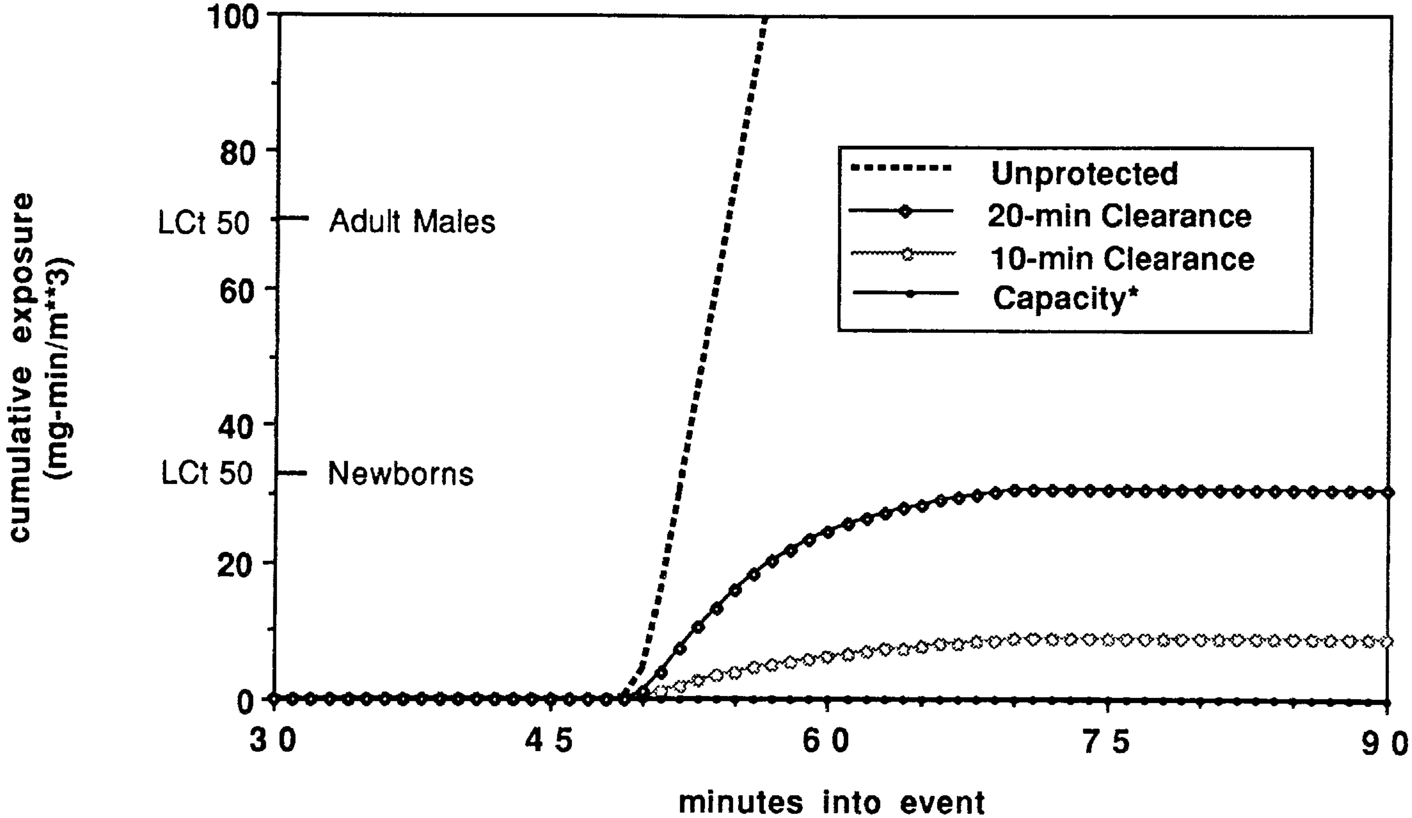

Fig. 7. Evacuation scenarios (10- & 20- min) at 3 km distance for GB class III events when 1 m/s winds prevail.

Note: LCt 50 = concentration-time integral, lethal for 50% of reference population.
* All evacuation clearance time are capable of complete protection in this scenario.

8. EVALUATING IN-PLACE SHELTER SCENARIOS

The specification of an in-place sheltering scenario requires two fundamental parameters that specify implementation and the amount of protection afforded by the action. PAECE first displays the implementation curves (Fig. 8) that are based on a limited number of experimental trials (Rogers et al. 1990b, Rogers et al. in press). The data represented in these empirical curves summarize the time it takes to complete the tasks required to provide shelter within existing structures. There are two basic sets of activities required; the simplest set of activities requires people to close the structure's doors and windows and turn off central heating or cooling systems. Infiltration is further reduced by taping and sealing a room within the "closed-up" structure. Hence, the implementation of the latter requires the implementation of the former along with the additional activities (taping and sealing). Closing up a structure by closing the doors and windows and turning off the central heating and cooling system is representative of (passive) normal sheltering and enhanced sheltering. PAECE allows the user to adjust implementation of "passive" in-place activities to accommodate current locations (see Appendix B). PAECE allows the user to specify which set of activities comprise the implementation of in-place shelters, or to simply set the amount of time it takes to implement in-place protection.

Second, the user specifies the amount of protection in terms of the number of air changes per hour (ACH). Exhibit 8 presents some preliminary estimates of the number of ACH for several types of shelters. Because the United States housing stock is characterized by 0.5 to 1.5 ACH, normal sheltering (which is achieved simply by closing the doors and windows and turning off the central heating and cooling) may be characterized by approximately 1.5 ACH. Weatherized homes would be more typical of the other end of the distribution. Hence, enhanced shelter characterized by 0.5 ACH could be achieved by taking advantage of existing weatherized housing in the threatened area, or by implementing a program of weatherization before the emergency. Expedient shelter trials have shown that taping and sealing a room can result in between 0.1 and 0.3 ACH. Moreover, when the "double-barrier" of the outside structure is taken with the more tightly sealed interior room, expedient shelters can be represented by 0.15 ACH. Finally, pressurized shelters are represented as 0 ACH because they achieve an exfiltration from the internal room to the outside by forcing filtered air into the room.

Exposure output for in-place protection has the same basic form as the evacuation output, containing an unprotected and protected exposure as well as the protection capacity of the specified shelter (Fig. 9). Outputs from reduced infiltration shelter scenarios are characterized by a "split" in the curves representing the protected exposure and protection capacity. This represents the minimum and maximum exposures associated with "near-perfect" ventilation of the shelter and failure to ventilate the shelter after the plume has passed, respectively. The vacated or ventilated curve represents the ventilation of the shelter when the unprotected concentration is lower than the concentration inside the shelter.

The pressurized shelter option produces output similar to evacuation scenarios—characterized by three curves and human-health-effect indicators. Like evacuation results, pressurized shelter scenarios produce exposure results that are bounded by the unprotected exposure curve maximum, which is farthest from the x axis, and the protection capacity curve minimum, nearest the x axis. Like the evacuation scenarios, pressurized shelters are characterized by protected exposure curves that are between the unprotected exposure and protection capacity curves. However, reduced infiltration shelters may be characterized by "protected" exposures that exceed the unprotected exposure when the shelters are not ventilated or vacated after the plume passes.

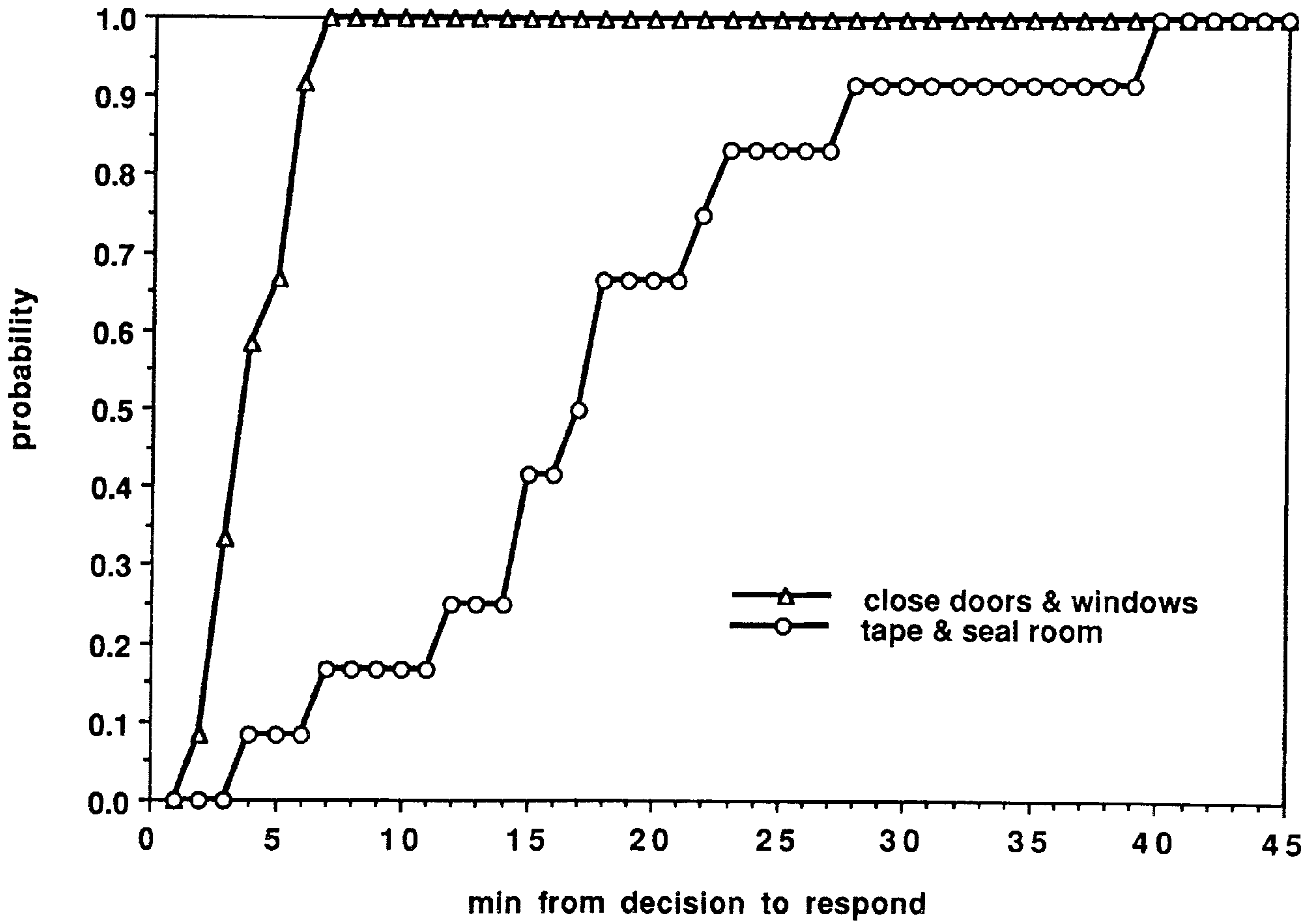

Fig. 8. Implimentation of in-place shelter activities.

If in-place protection, then

Enter the number of air changes/hour for the in-place shelter

normal (leaky) house has	1.5 ACH,
weatherized house has	0.5 ACH,
expedient shelter has	0.15 ACH,
pressurized shelter set	0.0 ACH

Exhibit 8. User specification of in-place shelter.

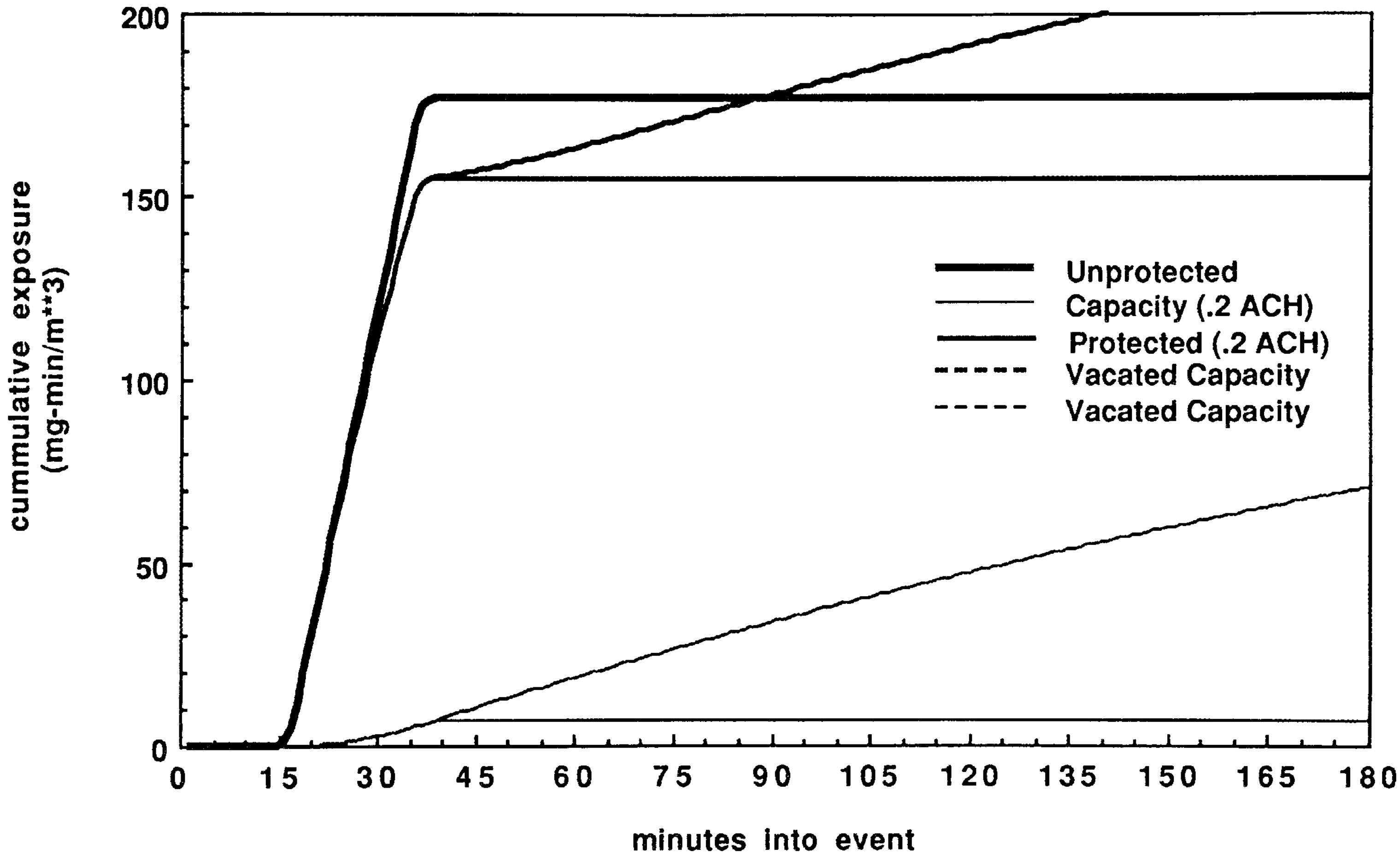

Fig. 9. In-place shelter scenario at 3-km distance for GB class V event when 3 m/s winds prevail.

9. EVALUATING RESPIRATORY PROTECTION SCENARIOS

Like the specification of in-place protection, specifying respiratory protection requires both the specification of the timing of implementation and the amount of protection afforded by respiratory protection. Unlike the parameter specification of in-place protection, parameters for the amount of protection associated with respiratory protection require the specification of two alternative "pathways" of exposure: through the filter (breakthrough) and around the filter mechanism (leakage). Exhibit 9 summarizes the user specification of the parameters required to examine a respiratory protection scenario. Breakthrough may be thought of as the amount of agent that can be absorbed by the filter material available in the respiratory device (e.g., civilian masks meeting the NATO standard for absorption are capable of eliminating up to 1500 mg-min/m^3 of GB in two exposures).

Respiratory protection options produce output similar to evacuation and pressurized shelter scenarios. They are characterized by three curves and human-health-effect indicators (Fig. 10). They all produce exposure results that are bounded by the unprotected exposure curve maximum, which is farthest from the x axis, and the protection capacity curve minimum, which is nearest the x axis. The respiratory protection scenarios are characterized by protected exposure curves that are between the unprotected exposure and protection capacity curves.

The protected exposure and protection capacity curves represent respiratory protection with a clear visual sequence: the first consisting of the proportion of people experiencing leakage (i.e., a constant fraction of the unprotected exposure that yields a near-linear exposure curve), and the second comprising the unprotected concentrations accumulated after filter breakthrough is reached. The result is an exposure curve characterized by leakage until breakthrough is reached and the unprotected concentration occurring thereafter. Should unprotected exposures remain below the breakthrough standard of a particular scenario, the protected exposure and protection capacity are solely a function of the proportion of people experiencing leakage with the hypothesized device.

If respiratory protection, then

Define the characteristics of the respiratory device:
Note: Breakthrough standards for
respiratory protection

Chemical industry—GB = 230,000 mg-min/m**3,
Chemical agent workers—GB/VX = 159,000 mg-min/m**3,
NATO—GB = 3000 mg-min/m**3,
NATO—VX = 1000 mg-min/m**3,

Select the breakthrough standard (numerical value in mg-min/m3).**

Select a leakage rate of the respiratory device:

Note: 7% of the adult population wear beards, 58% wear eyeglasses, 10-20% have chronic bronchitis, almost 4% fail minimum weight requirements for military service. These factors and others may reduce the ability of respiratory devices to protect people (e.g., 0 means no leakage, 0.15 means people receive 15% of outside concentration.)

Enter the desired leakage rate

Exhibit 9. User specification of respiratory protection.

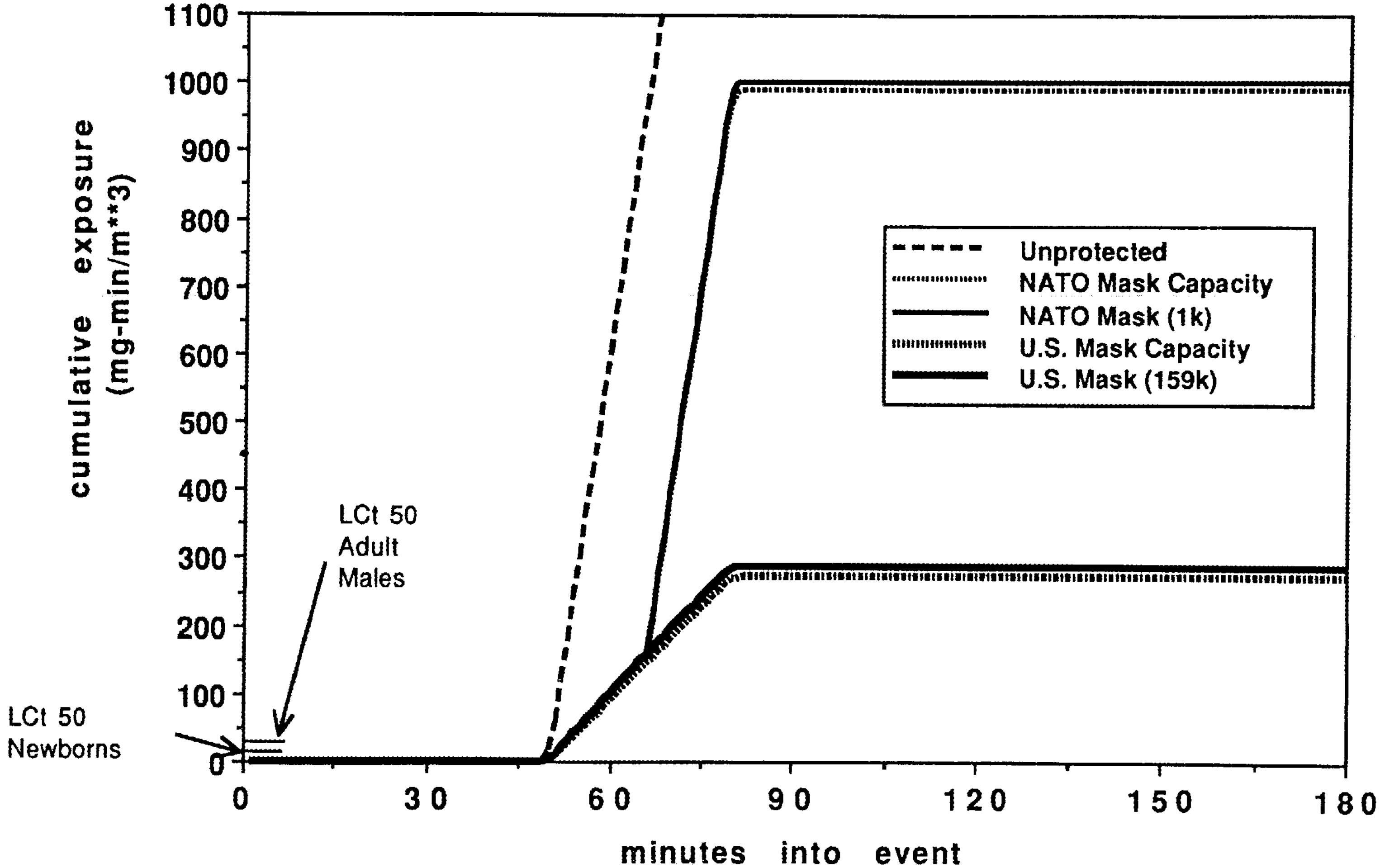

Fig. 10. Respiratory protection scenarios at 3 km distance for VX class IV events when 1 m/s winds prevail.
Note: LCt 50 = concentration-time integral, lethal for 50% of reference population.

10. COMPARING PROTECTIVE ACTIONS

PAECE displays a single protective action strategy with each run. However, the user can iteratively run PAECE and import the numeric results (contained in the file named PLBOTH.res) into a spreadsheet or graphics application. To compare the effectiveness of various protective action alternatives, the same accident (i.e., ToA, accidental release, meteorological condition, and downwind distance), and emergency response system (i.e., DtW, warning system, and public response parameters) should be selected. To compare the effectiveness of a single protective action under various emergency response systems, the user can vary emergency response system parameters (e.g., the DtW or warning system parameters). Alternatively, to compare emergency response system effectiveness for various accident scenarios, the user can vary the accident parameters (e.g., time of accident, wind speed, or size and duration of release).

Figures 11 and 12 compare several protective action alternatives for a single release and emergency response system scenario. The general preference for options that exhibit greater exposure reduction is well founded and for the most part correct. However, the user must be aware of several aspects of the situation that are not easily represented as single exposure curves. When comparing alternatives, the relationship of both alternatives to the anticipated human health consequences is important. Even if a particular protective action alternative reduces exposure better than another, there can be no clear preference if the chances of survival are not improved. For example, given the same accident and emergency response system, a faster evacuation might seem better than a slower evacuation in terms of reducing exposure. However, if neither evacuation is completed before the plume's arrival (i.e., the joint probability of completing evacuation given emergency response system is zero), both evacuations will be equally ineffective. Conversely, if both evacuations are complete when the plume arrives, the alternatives are equally effective. Even large reductions of expected exposures can result in exposures well above the LCt_{50} for most people at a given downwind distance. This clearly would not be an acceptable protective action alternative because it fails to protect, even though it drastically reduces exposure. The user must consider the relationship of all alternatives in view of the human health consequences associated with exposure at those levels.

Another factor that should be considered when comparing alternatives is the structural capacity of the protective action being examined. For example, if the expected exposures achieved by a pair of protective action alternatives are similar, but the protection capacity of one alternative is clearly preferable to the other, the user will probably want to give preference to the alternative with greater protection capacity. In some circumstances (e.g., precautionary emergency responses), even slight advantages in expected protection may be overshadowed by clear disadvantages in terms of protection capacity. Hence, in comparing protective action alternatives for a given accident and emergency response system scenario, the user must consider not only the expected protection associated with an alternative but also the protection capacity.

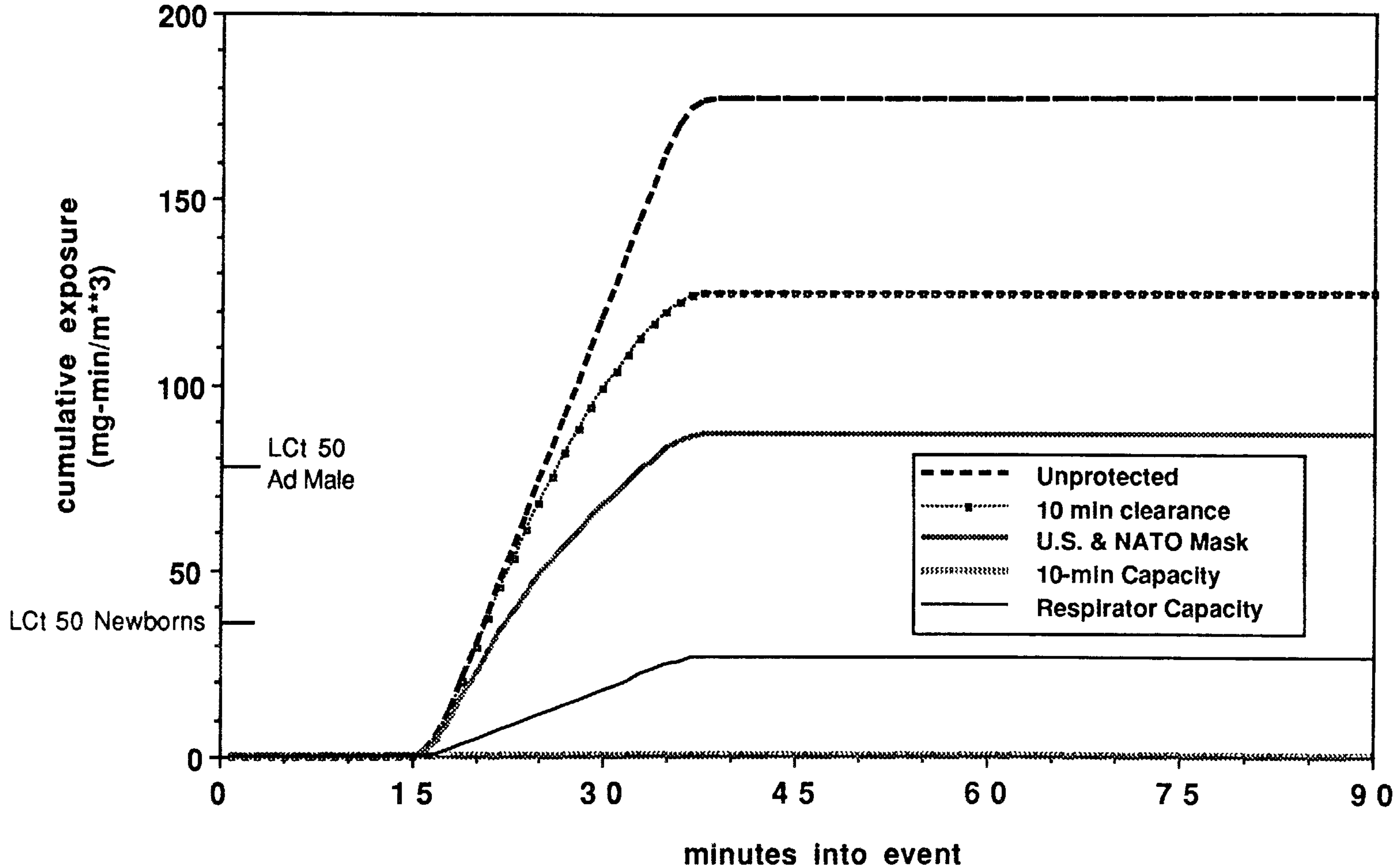

Fig. 11. Comparison of evacuation and respiratory protection scenarios at 3 km distance for GB class V events when 3 m/s winds prevail.

Note: LCT 50 = concentration-time integral, lethal for 50% of reference population.

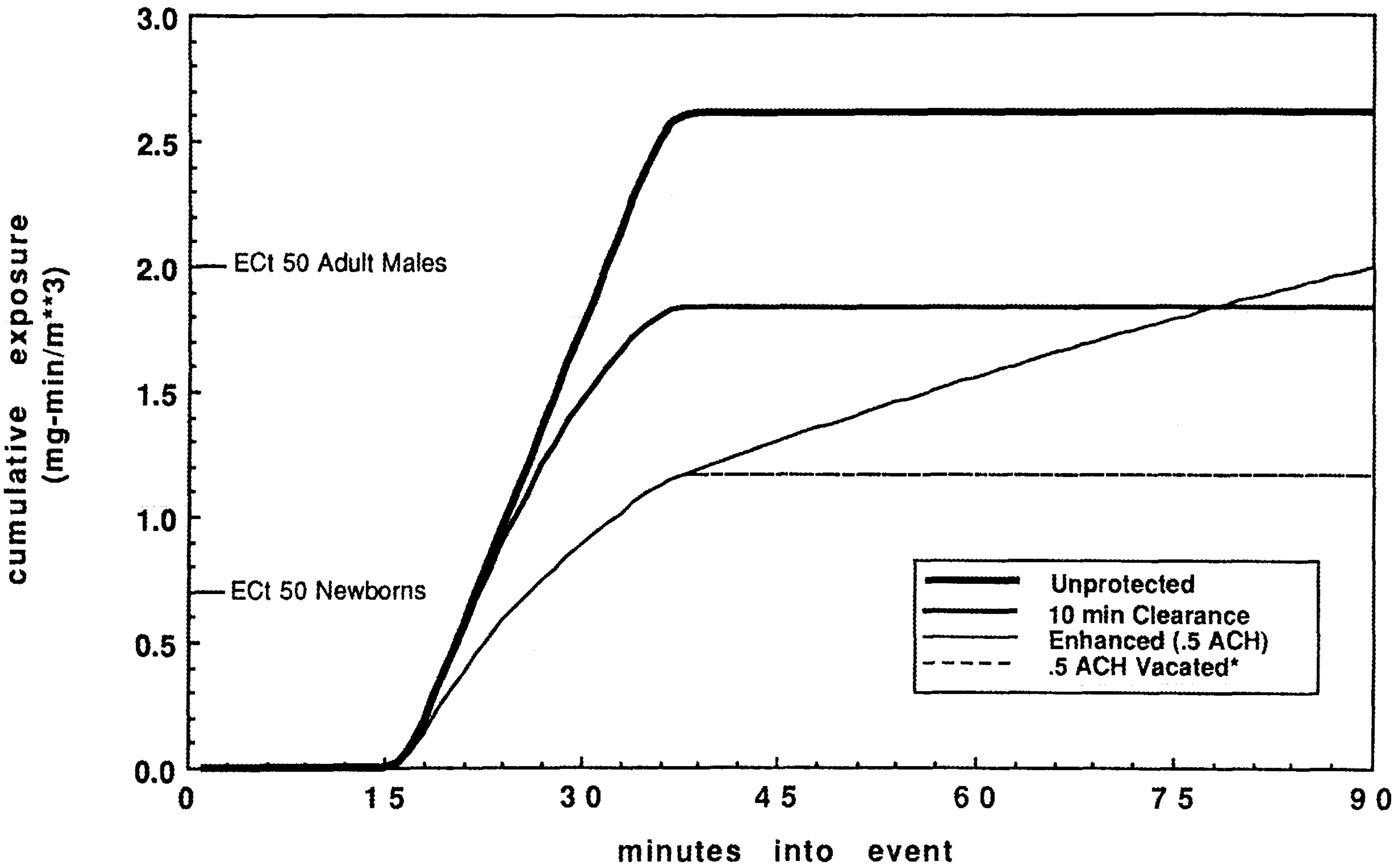

Fig. 12. Comparison of evacution and in-place scenarios at 3 km distance for GB class II events when 3 m/s winds prevail.

Notes: ECt 50 = concentration-time integral, where 50% of reference population are expected to exhibit observable effects. ACH = Air Changes / Hour. * Exposure curve is flat after the plume passes because the shelter is vacated when the concentration outside is less than that inside.

11. EVALUATING COMBINATIONS OF PROTECTIVE ACTIONS

Although PAECE was designed to examine a specific single protective action, it also allows the user to examine combinations of protective actions as long as the combination can be characterized as a shift from one set of actions to another. For example, the user can examine the combination of respiratory protection with evacuation. Results can be combined by first executing PAECE and renaming the file containing the data arrays behind the graphic representations of each curve (e.g., C:>rename plboth.res evac10.res), and then rerunning PAECE for the other desired scenario. Once both sets of arrays are contained in DOS files, they can be transferred into a spreadsheet or graphics package (e.g., Lotus 123©, Excel©). The user should exercise extreme care to assure that the same accidental release is postulated by directly comparing the unprotected exposures associated with each scenario.

If the same accident has been specified in each PAECE run, the user then can either numerically or graphically combine the resulting arrays. Numerically, the resulting combined exposure is the accumulation of the minimum *de minimus* minute-by-minute concentrations representing the evacuation and respiratory protection. To combine the results graphically requires a more conceptual approach than combining results numerically. The combination of evacuation with respiratory protection is comprised of the exposure resulting from respiratory protection until the population has evacuated the area to a safe distance. Hence, graphically the combined result traces the minimum protected curve—following the respiratory protection curve until it exceeds the specified evacuation curve, and then following the resulting evacuation curve.

Figure 13 presents the combination of an evacuation with respiratory protection in the context of both alternatives used separately. The *de minimus* approach estimates the exposure when combining respiratory protection with other alternatives when, and only when, the concept of combination is sequential. That is, when the respiratory protection is intended to protect people until other protective action(s) can be completed, the *de minimus* approach is appropriate. However, when respiratory protection is intended to be used in conjunction with another alternative on an on-going basis, the *de minimus* approach overestimates exposure. The resulting underestimation of protection occurs because, taken independently, the postulated respiratory protection device is reducing the unprotected exposure—but when used in conjunction with reduced infiltration shelters the device would actually reduce the exposure from the already reduced exposures associated with in-place protection.

Hence, when two alternative protective actions are to be used in conjunction, an interactive method is required. These conjunctive measures require that the exposure be reduced twice, once for each action. In this case, the unprotected exposure is reduced to reflect the in-place sheltering and then further reduced to reflect the respiratory protection.

For example, the combination of respiratory protection and in-place sheltering may be estimated within reason by modifying in-place protection exposures by the proportion of people expected to experience respirator leakage. To examine such a scenario, the user would simply run an in-place protection scenario but would allow extra time to don the respiratory equipment in the response times (e.g., adding additional minutes to the DtW), and then reduce the exposure associated with the in-place protection by the desired leakage fraction. Because in-place sheltering over relatively short durations (e.g., several hours) is likely to reduce overall exposure enough to avoid breakthrough, it is probably not

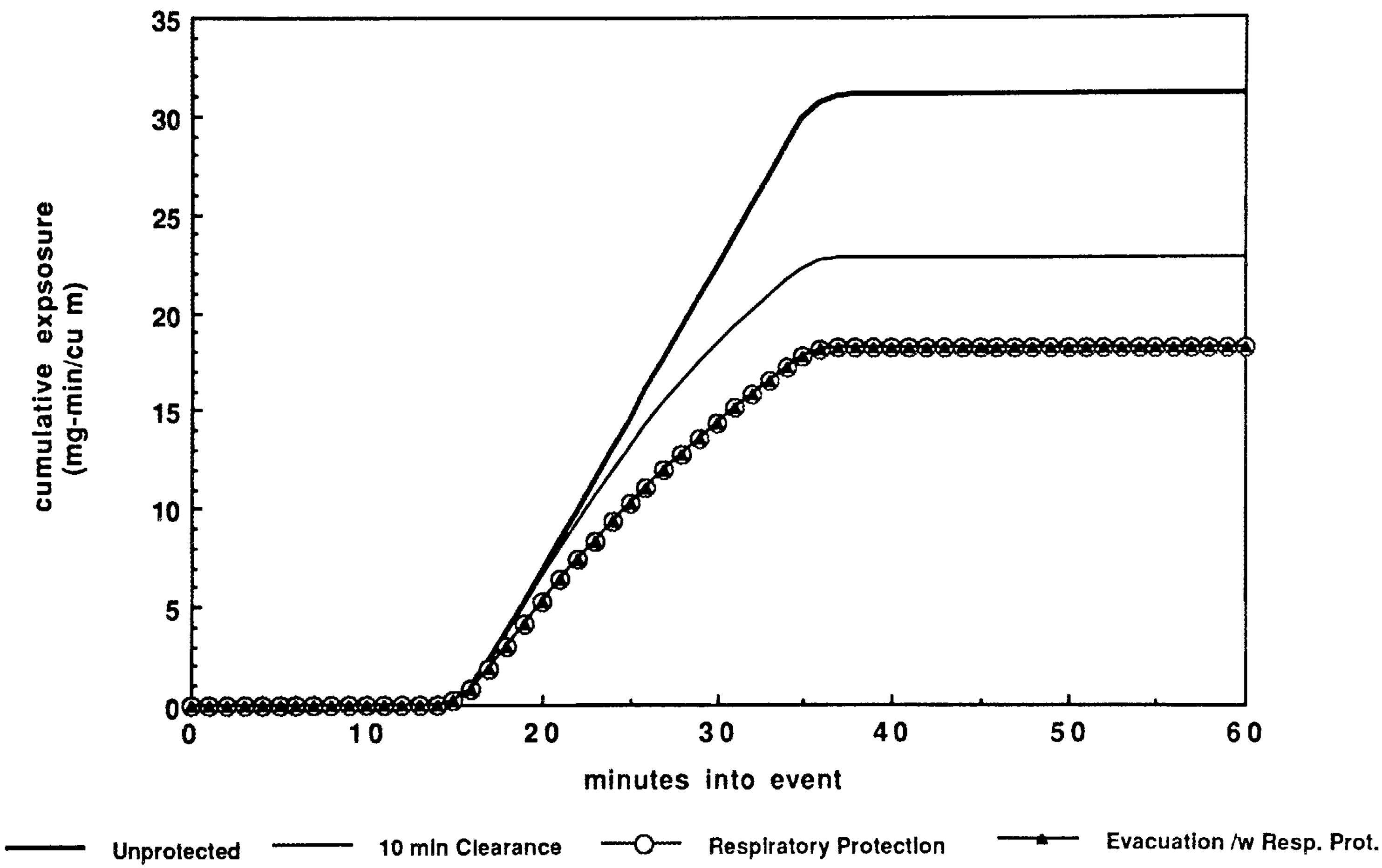

Fig 13. Combination of evacuation and respiratory protection using de minimus method.

necessary to consider the potential for device failure. Figure 14 presents an example of such a modification in comparison with either of the options alone.

The user should be aware that this relatively simple approach to iterative combinations does not adequately reflect more complex iterative problems. One example is the inability of this simple approach to represent the iterations required for combining in-place sheltering—closing windows and doors and turning off central heating and cooling systems (i.e., whole structure infiltration)—and taping and sealing a room within that sealed structure (i.e., expedient reduction of infiltration into a room). This more complex iterative problem involves both iterative probabilities of implementation and iterative protection. Although the iterative methodology is capable of handling both of these iterative problems, both the implementation probabilities and the protection afforded are not simple mathematical functions easily represented in a standard spreadsheet application.

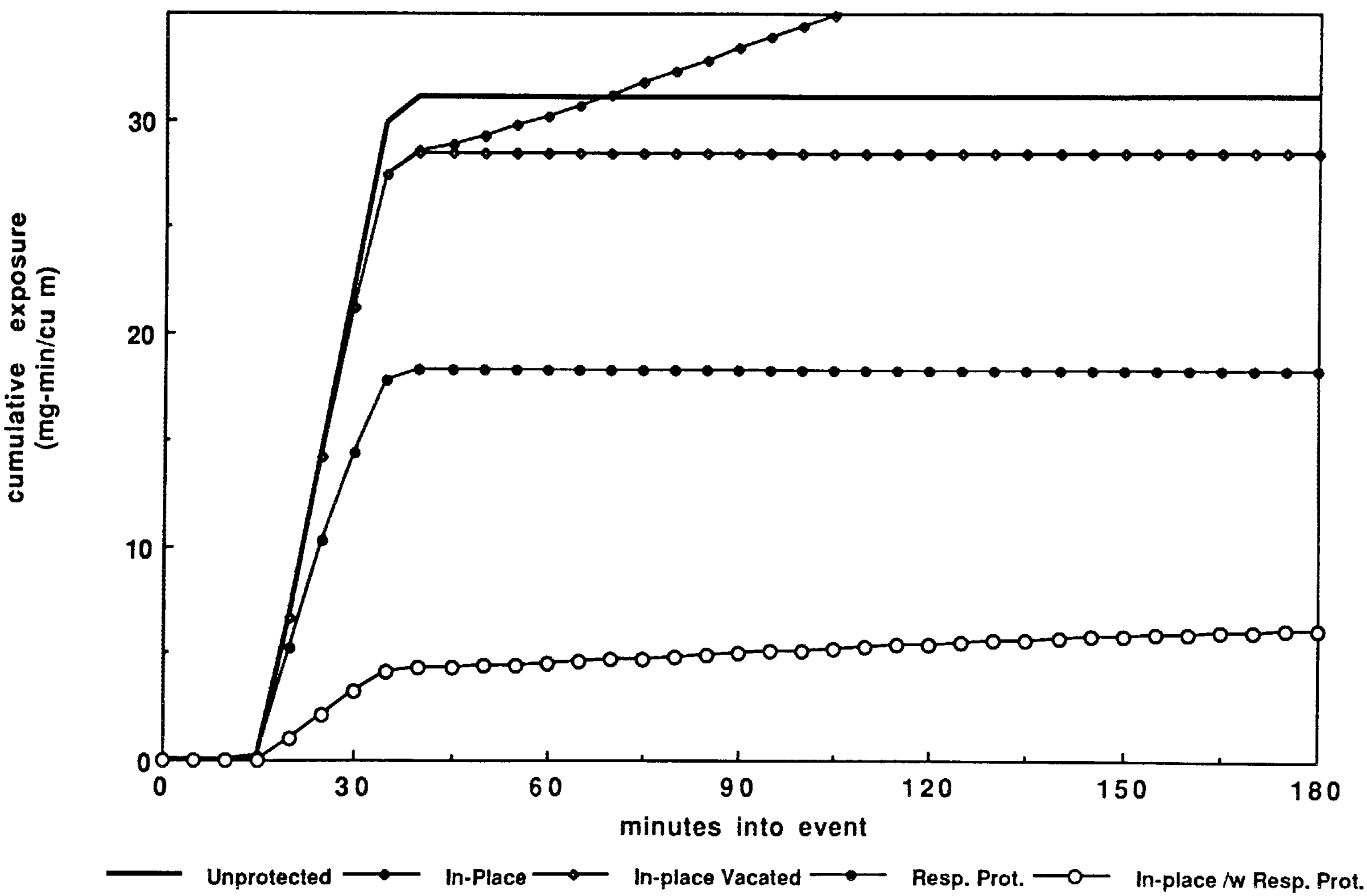

Fig. 14. Combination of in-place and respiratory protection using combined effect method.

12. USE AND LIMITATIONS OF PAECE

PAECE simulates an accident, its consequences, and the emergency response system to compare the degree of protection afforded by protective action alternatives. PAECE is an evaluation tool intended to systematically examine the alternative means of protection. The concepts involved are relatively simple and PAECE represents an accident-emergency-response scenario as a simplification of what might actually occur. Despite its simplicity, PAECE provides a powerful analytic tool for the evaluation of protective action alternatives. There are limits, however, to the utility of PAECE in determining the number of lives saved or the expected effectiveness of various protective action alternatives.

One key limitation involves the stochastic nature of the estimated expected exposure. Because PAECE uses a stochastic estimate of the joint probability of reaching a DtW, receiving a warning, deciding to respond, and implementing the protective action, it may be interpreted as an expected value. People who implement the protective action early would have lower exposures than the expected value, and people who implement protective measures late would receive exposures greater than expected. Thus, the expected exposure is an average or typical exposure given the distribution of warning, response, and implementation times from the beginning of the event. Depending on the distribution itself, people who implement the protective measure either before or early into the release are more likely to achieve protection near the capacity of that protective action—the exposure reduction capacity. On the other end of the distribution, people who implement the protective action late in the sequence are more likely to receive exposures similar to the unprotected exposure. Therefore, these analyses are to be interpreted as a distribution of results with an expected value estimate in the "middle" of that distribution rather than as a deterministic value that represents absolute exposure levels or exposure limits.

Perhaps a more important implication of this general limitation on interpretating expected exposure results concerns the absolute exposure and the exposure reduction achieved. Results can indicate that a particular protective action drastically reduces the expected exposure, when compared with the unprotected exposure (e.g., 90 or 95% reductions), but that the absolute exposures remain well above the LCt_{50} for adult males. Such a case indicates that even though vast exposure reductions can be achieved, protection is limited. The converse is also true; even though the results indicate that given the particular protective measure, the expected exposure remains below the LCt_{50} for infants, this cannot be interpreted to mean no deaths will occur. In fact, some people may not survive (e.g., people who implement protective measures late, sensitive people, people who implement measures improperly, or people caught in pockets of accumulated agent).

Finally, the user should be aware that uncertainty permeates PAECE at every juncture: at best, the dispersion model predicts the expected exposure within ±50%; the DtW assumptions are based on limited cases; the receipt of warning is based on extrapolations and interpolations of limited data; public response is estimated on a basis of a limited number of previous chemical accidents; and implementation of in-place shelter techniques is based on a limited number of trials. Any particular numerical result of the model is sensitive to these uncertainties; however, the relative effectiveness of various protective actions is not affected by either the individual uncertainties or the combined uncertainty. Moreover, the greater the difference in effectiveness between one protective action and another, the more likely that the relative effectiveness is in the predicted direction. These uncertainties do not reduce PAECE's effectiveness as a way of systematically comparing protective action alternatives, but must be recognized to avoid misinterpreting the results.

In short, PAECE results are not substitutes for sound human judgment. If the expected exposures associated with alternative protective actions are similar, a recommendation of one alternative over another will have to be based on other factors, such as the ease of implementation or capacities to protect. PAECE is designed to assist emergency managers in reaching considered recommendations regarding protective action alternatives, but does not substitute for dynamic human decision-making processes.

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APPENDIX A

SAMPLE PAECE DIALOGUE AND RESULTS

APPENDIX A

SAMPLE PAECE DIALOGUE AND RESULTS

This section contains a listing of the interactive session through a sample case. The resultant probability (Fig. A.1) and exposure plots (Fig. A.2) are also shown in this appendix.

STEP 1

Select the mode for determining the time of accident (ToA):

1	Stochastically derived time;	**(Set the**
2	Most-probable time;	**time of**
3	Equi-probable time;	**accident)**
4	User selects time.	**4**

Enter the time of the accident [military time—e.g. 2000 (8 p.m.)]	**1100**

STEP 2

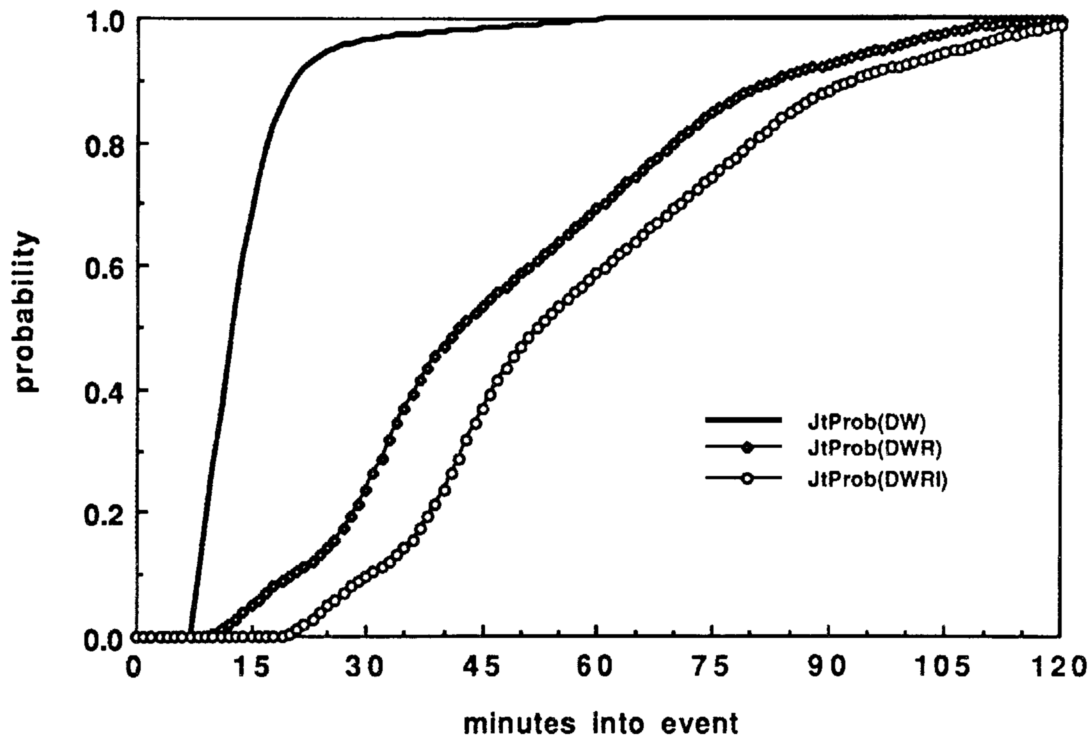
Enter the indicator for meteorological data:

1	Aberdeen	
2	Anniston	
3	Lexington-Blue Grass	
4	Newport	
5	Pine Bluff	
6	Pueblo	
7	Tooele	
8	Umatilla	
9	Non-specific site (i.e., user specifies meteorological data).	**9**

STEP 3

Enter weather condition:

Enter the wind direction from which the wind is blowing (0-359.99°)	**12**
Enter the wind speed (m/s)	**1**
Enter the stability class index (1–6 where A = 1)	**5**
Enter the mixing height (m > 0)	**1000**



D=Decision to warn W=Warning received R=Public response I=Implement protective action

Fig A.1. Joint probability plot for sample PAECE run.

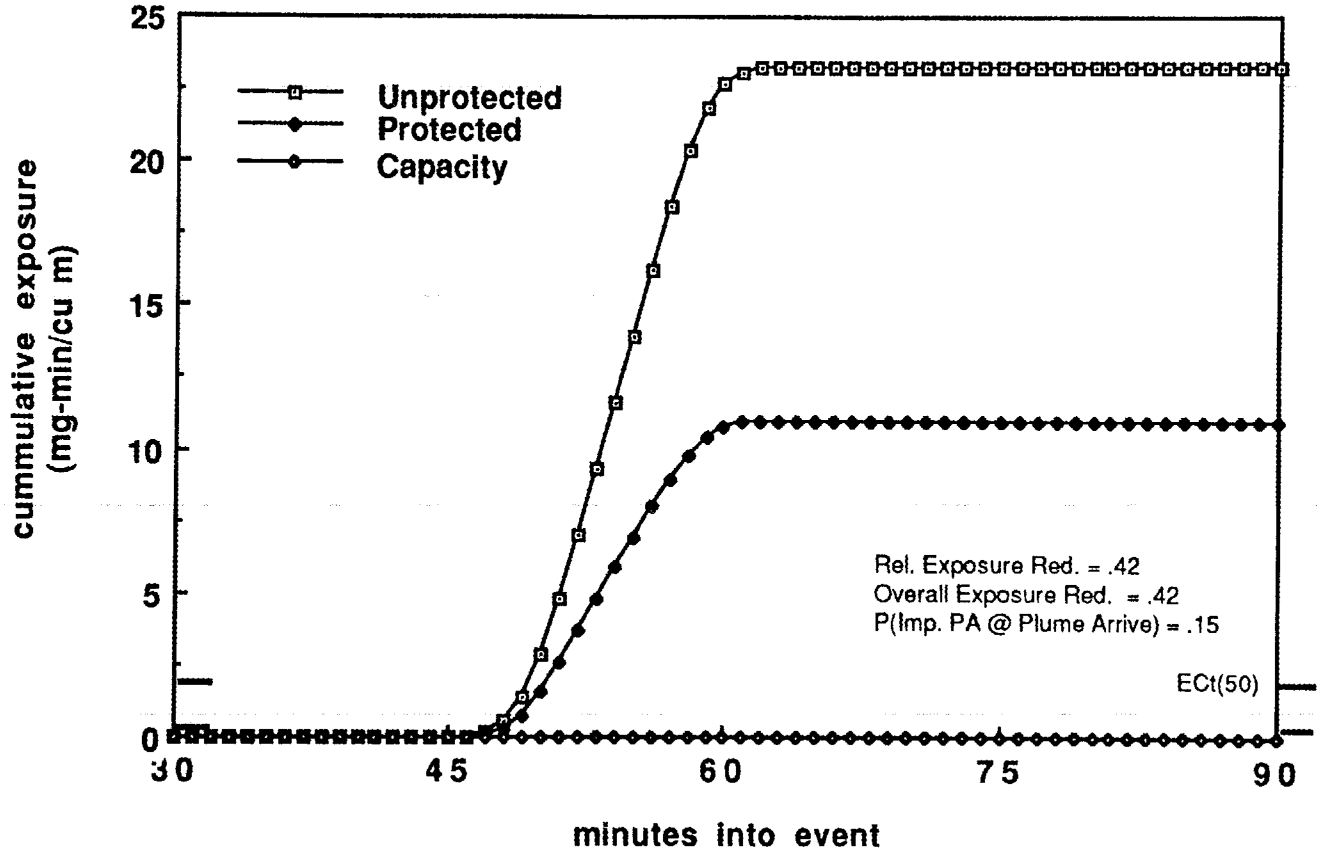


Fig A.2. Exposure plot for sample PAECE run.

STEP 4

Enter the released amount Q, the sigmas (variances), downwind, crosswind, and vertical, and release duration:

INPUT: Q(LBS), SXS(M), SYS(M), SZS(M),
RELEASE TIME(MIN) **100,0,0,0,10**

STEP 5

Select the distance indicator for exposure accumulation:

Select the desired distance (m) from the following table:

0–100	1–20	2–300	3–400	4–500
5–600	7–800	8–900	9–1000	10–2000
11–3000	12–4000	13–5000	14–6000	15–7000
16–8000	17–9000	18–10000	19–20000	20–30000
21–40000	22–50000			

11

STEP 6

Select Agent type:

INPUT: Agent type (1 = GB, 2 = VX, 3 = Other) **1**

(At this point output from D2PC and PARDOS appears on screen.)

STEP 7

Set the decision to warn parameter. (Empirically based curve is displayed here to assist the user in making choices.):

Please enter the decision to warn (DtW) parameter:

a Enter the minute (into the event) when the DtW is reached; or
b Enter the minutes (e.g., -20) before the release when the DtW is reached; or
c Enter P to use the probability of a DtW based on the data in the previous graph. **10**

STEP 8

Select the identification number for model parameters used to estimate diffusion of warnings:

where dn/dt=k[a1(N-n)]+(1-k)[a2n(N-n)]

Number	System	k	a1	a2	30-min limit	Release rate(%)
1	Sirens	0.2	0.2	0.3	0.75	0.3
2	Tone-alert radios	0.4	0.3	0.2	0.90	0.1
3	Media	0.3	0.2	0.25	0.50	0.5
4	Telephones	0.4	0.35	0.2	0.93	0.1
5	Sirens and tone-alert	0.4	0.3	0.3	0.95	0.1
6	Siren and telephone	0.4	0.35	0.3	0.95	0.1
7	Other (User specifies new parameters)					

(Select the warning diffusion curve) **5**

Enter the number of other curves to show.
0 means none; 7 means all. **0**

(Results of selection are displayed here.)

STEP 9

Select Response Curve(s) to use. (Empirically based curve displayed here to assist the user in making choices):

1 means Confluence curve;
2 means Pittsburgh curve;
3 means Mississauga curve;
4 means Nanticoke curve;
5 means User-Specified Response Time.

(Select the response curve) **4**

Note: number 2 means use only Pittsburgh curve; numbers 2, 3,and 4 means use average of Pittsburgh, Mississauga, and Nanticoke curves.

Enter a scale factor (> 0.0) for the response curve.
1 means no modification. **1.1**

(Results of selection are displayed here.)

STEP 10

Select the type of protective action:

1 Evacuation; 2 In-place; 3 Respiratory device.	**(Select the type of protective action)** **1**

STEP 11

Select the evacuation mechanism:

1 Clearance time (min); 2 Evacuation speed.	**(Select the type of evacuation mechanism)** **1**
Enter the time (min) for complete evacuation.	**10**

APPENDIX B

TIME BUDGET

APPENDIX B

TIME BUDGET

The location of people at various times of the day impacts two important aspects of emergency response: the ability of warning systems to penetrate to people in various locations and the inherent protection provided by the current locations. The former deals with the ability of warning systems to alert and notify people in various locations, while the latter characterizes various locations by the protection they offer.

B.1 WARNING PENETRATION ADJUSTMENTS

Warning systems generally are characterized by their ability to alert people and transfer information. The penetration of the emergency warning systems varies for people in different locations and engaged in different activities. Each warning system has a different penetration capability in five fundamental locations/activities: (1) home asleep, (2) indoors at home or in the neighborhood, (3) outdoors in neighborhood, (4) in transit, and (5) working or shopping. In addition, two activities are allowed to override the other locations/activities, that is, watching television and listening to the radio. Such electronic-media-exposed activities are relevant for warning because some of the waring systems depend on these forms of media. Figure B.1 summarizes the average percentage of the population in these location/activity categories during a 24-h period starting with 12 midnight (Juster et al. 1983). Table B.1 provides estimates of the percentage of the population reached by each warning system while engaged in the different activities. The following discussion provides the basis of these estimates.

Home Asleep. One of the most vulnerable positions, at least in terms of perception, occurs when people are at home asleep. In a regional survey, Nehnevajsa (1985) asked people what kinds of things awaken them at night, for example, between 2 a.m. and 4 a.m. The results indicated that 69.1% of the residents in southwestern Pennsylvania are aroused from sleep by sirens in their area, and 93.3% reported that telephone calls wake them up. These empirical data are used as estimates of the penetration rate for the siren and alarm and the telephone ring-down systems, respectively. Because tone-alert radios are similar to telephones but may or may not be physically located in the bedroom, as many phones are, the penetration rate for tone-alert radios is estimated at 85%. Furthermore, because media and the emergency broadcast system are relatively dependent on having either a radio or a television on at the time of warning and because most people do not sleep with them on, the penetration rate is assumed to be zero for media/Emergency Broadcast System (EBS) warning systems.

Indoors at home or in neighborhood. Residential indoor locations are categorized together. This includes nonsleeping activities in residential locations in the area at risk. The penetration rates are assumed to resemble the pattern for sleeping conditions but to be somewhat higher for nonsleeping activities. However, when people are awake, even though they may not be watching television or listening to the radio, they may be warned by others. For this reason, the media/EBS warning system is assumed to be 40% effective.

Outdoors in neighborhood. Siren systems are very effective in reaching people in outdoor environments, although some people will not hear sirens because of background noises. Overall, it is estimated that 90% of the people outdoors will hear the

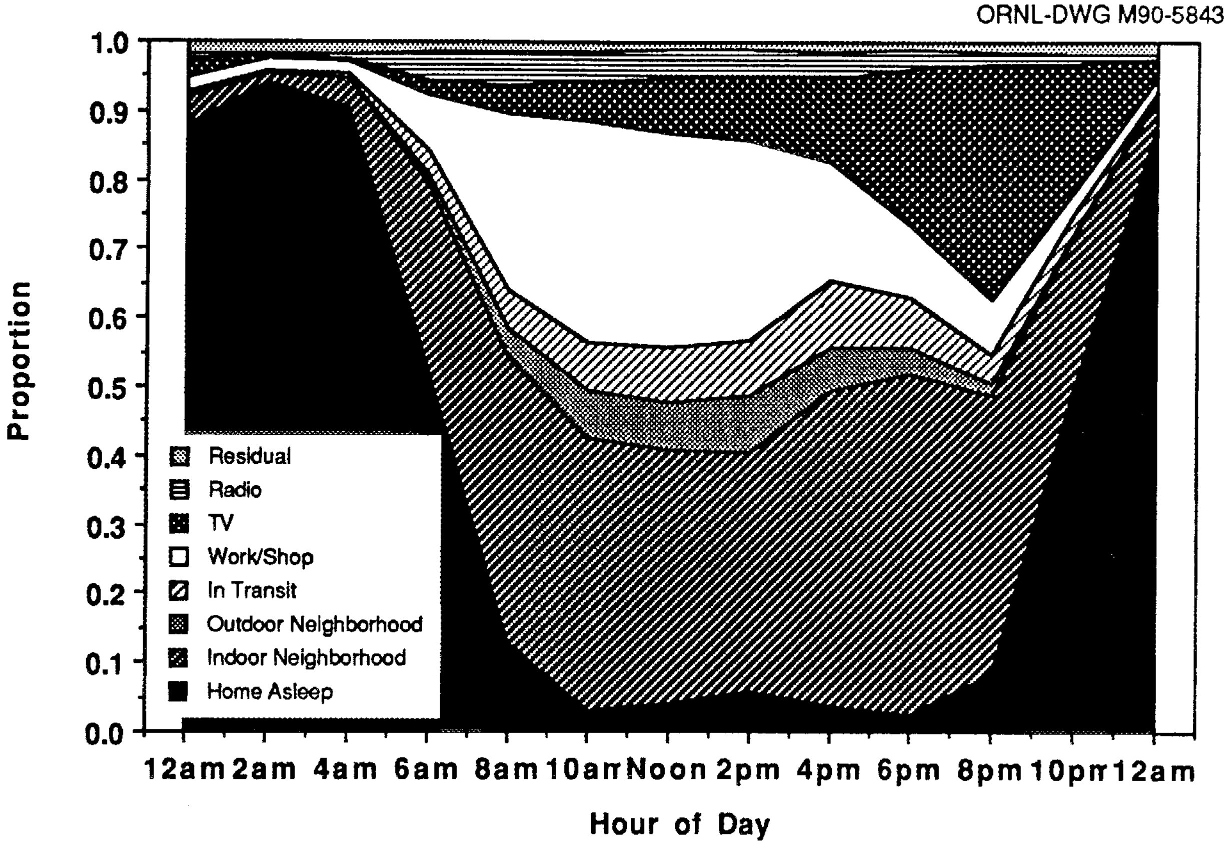


Fig B.1. Average U. S. time budget with secondary media activities overriding. Source: Juster et al., 1983, 1975-1981 Time use Longitudinal Panel Study, Survey Research Center, Univ. of Michigan, Ann Arbor, MI.

Table B.1. Warning systems effectiveness by location and activity

Locations/ activities	Alternative warning system: Sirens and alarms	Alternative warning system: Tone-alert radios	Alternative warning system: Auto-dial telephones	Siren and alarm systems combined with: EBS[a] and media	Siren and alarm systems combined with: Tone-alert radios	Siren and alarm systems combined with: Auto-dial telephones
Home asleep[b]	0.691	0.85	0.933	0.0	0.90	0.933
Indoors at home or in neighborhood	0.80	0.90	0.95	0.40	0.90	0.95
Outdoors in neighborhood	0.90	0.0	0.0	0.20	0.90	0.90
In transit	0.90	0.0	0.0	0.20	0.90	0.90
Working or shopping	0.60	0.70	0.80	0.10	0.70	0.80
Watching television	n/a	n/a	n/a	1.0	n/a	n/a
Listening to the radio	n/a	n/a	n/a	1.0	n/a	n/a
Time-adjusted warning system effectiveness						
Annual average	0.665	0.685	0.745	0.287	0.784	0.826

[a]EBS is Emergency Broadcast System.

[b]Reported arousal by sirens and telephones is derived from a survey by the University of Pittsburgh, Center for Social and Urban Research, in 1985, from Nehnevajsa 1985.

Source: Rogers, G. O. and J. H. Sorensen 1988, "Diffusion of Emergency Warning," *The Environmental Professional*, **10**, 281–94.

siren. Because people outdoors are very unlikely to hear an indoor-based warning system, it is assumed that no one outdoors hears a warning when tone-alert or auto-dial telephone systems are being considered. The effectiveness of media will also be low for people outdoors. However, it is likely that some people will be listening to the radio while engaged in other activities. This is conservatively estimated at 25%.

In transit. Most people in vehicles are likely to hear a siren within a warning zone (Towers et al. 1982); therefore, the portion receiving the alert is estimated to be 90%. No one in a vehicle is able to hear either the tone alert or the telephone warning. A portion of those in transit will be listening to the radio; hence, this fraction is defined as 20%.

Working or shopping. Sirens will have a lower effectiveness in alerting people who are working or shopping, because of background noise and poor attenuation of sound into buildings housing those activities. It is estimated that about 60% will hear the warning. Shops and places of employment can be provided with tone-alert radios and telephone warning systems. However, the penetration of warning through these systems is likely to be lower than for home environments. In addition, the telephone systems are likely to be more effective than tone-alert systems because people in shopping and work locations are more likely to answer their phones than to be near a tone-alert radio. Few people engaged in shopping or work will receive a media-disseminated warning unless they are listening to a radio station at the time.

Watching television and listening to radio (primary and secondary). It is assumed that 100% of the people engaged in activities involving exposure to the media, such as watching television or listening to the radio, will receive a warning.

Time budget surveys

In 1975, the Survey Research Center at the University of Michigan administered a time budget survey to a national probability sample of U.S. households (Robinson 1977). The same households participated in a second panel of the same survey in 1981 (Juster et al. 1983). Although some panel attrition occurred between the 1975 and 1981 portions of the study, a comparison of the two studies indicates that the attrition in sample sizes caused little, if any, bias in the results. Controlling for demographic variables indicates that the time budgets of U.S. households were amazingly stable over this period of time (Hummon et al. 1987). The results in this study are from an analysis of the 1981 panel data.

Respondents were asked to construct a 1-d (24-h) log of their activities during the previous day. The two weekdays and two weekend days of data for each survey year are combined and weighted to estimate how Americans spend time over an annual average week—a "synthetic week" (Stafford and Duncan 1980; Stafford 1980). However, the synthetic week approach does not provide enough details about the daily schedules of people for risk analysis and emergency management (Hummon et al. 1987). This analysis uses a daily schedule data structure.

Each type of warning system is evaluated in terms of the likelihood that people in the different locations will be warned; the locational capabilities of each system are mapped onto the probability that people will be in these locations at various times of the day. This mapping of locational system effectiveness on the likelihood of the presence of people in these locations provides a relative effectiveness in terms of the likelihood that people will be engaged in various activities in various locations (Table B.1).

The warning dissemination process is adjusted to account for time-dependent activities by multiplying the location activity adjustment factor in Table B.1 by the average portion of the population engaged in each activity in a 24-h period. This value represents the portion of the population in each activity assumed to receive the warning. Second, this is summed for each warning system to achieve the time-adjusted warning system effectiveness score. This score is then used to weight the original alerting parameter (a_1) in the diffusion model. This weighting reduces the influence that the initial alert has on diffusion according to the average distribution of people in various activities who would not receive an initial alert. This procedure was used to produce time-specific curves to reflect the locations/activities of the population for any 2-h period.

B.2 PROTECTIVE ACTION IMPLEMENTATION ADJUSTMENTS

The average time budget data also are used to adjust the amount of "natural" protection various locations provide. This adjusts initial exposures to account for the fact that some environments that people frequent provide minimal protection. The most important of these are indoor locations. Being indoors, particularly in cool or cold weather, buildings already would be closed up and would provide protection commensurate with the amount of infiltration associated with that building. On the one hand, complete maximum protection cannot be achieved passively; however, just because people are already in enclosed environments, they are not completely unprotected.

The current evaluation of protective actions for chemical emergencies takes advantage of the protection afforded by indoor locations by initializing the implementation of in-place shelters with the probability of being located in a partially protected location at the time of release. Hence, for relatively passive in-place sheltering techniques (e.g., normal and enhanced shelters) during periods of the year when doors and windows would be closed naturally, the shelter is already implemented for people in those buildings. The degree of protection in these partial shelters is accounted for by higher infiltration rates.

The implementation of an in-place shelter is initialized at the probability of being located indoors (Fig. B.2). This means that the proportion of people implementing the action is initiated at more than 90% for accidents at 2 a.m., while initial midday implementation of normal and enhanced shelters is about 50%.

For in-place protective actions where the activities required to implement are relatively passive (i.e., people would achieve protection without taking significant actions), the user is asked if time budget adjustments to the implementation times are to be used. If the user responds yes, a series of location/activities (e.g., home asleep, indoors in neighborhood) are presented for the user to select as "protected" location/activities. Then the user specifies the proportion of people in these locations that considered "protected". This allows the user to consider the proportion of people likely to have doors and windows closed at a particular time of the day or during a certain period of the year. These data are combined to augment initial implementation of in-place protection. For example, if 50% of the people are in the selected indoor locations, and 50% are expected to achieve the protection (e.g., have their doors and windows closed), then the implementation of the action would be augmented by 25%. The user may choose to skip these implementation adjustments by responding "no" to the initial solicitation. Note that if time budget augmentation is used, the level of protection, specified in air changes per hour (ACH), should be appropriately increased.

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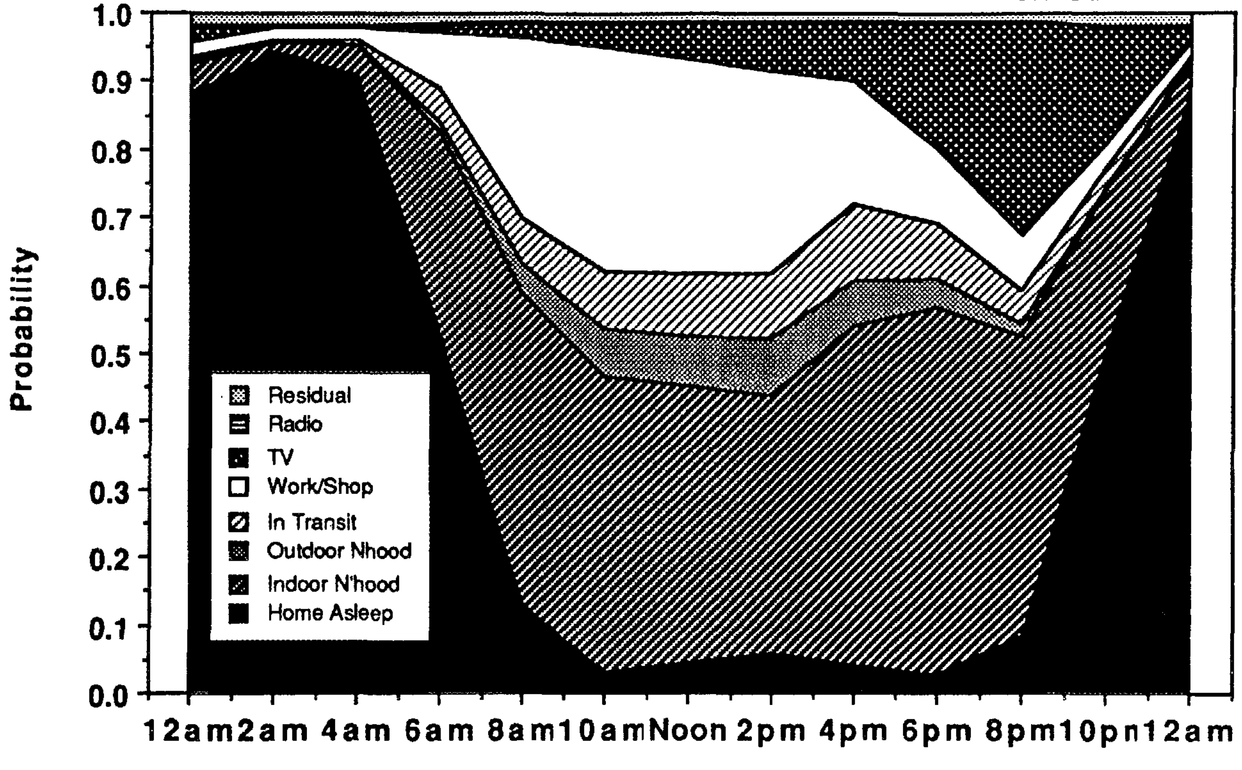

Fig B.2. Average U. S. time budget of primary activities. Source: Juster et al., 1983, 1975-1981 Time Use Longitudinal Panel Study, Survey Research Center, Univ. of Michicgan, Ann Arbor, MI.

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