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State of the Art in Evacuation Time Estimate Studies for Nuclear Power Plants

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Operated by
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ABSTRACT

In the event of a major accident at a commercial nuclear power station, exposure of the public to airborne radioactive materials can be prevented or greatly reduced by evacuating the area immediately surrounding the reactor site. Reactor licensees are required to conduct studies to estimate the time needed to evacuate the public from the area surrounding each nuclear power station. The results of such studies are used by regulatory personnel and emergency planners to assess the potential effectiveness of protective responses for the public. The time required to evacuate the public from a 10-mile emergency planning radius is estimated by analyzing the available transportation facilities and other relevant conditions within this radius. To support the analysis, data must be collected and assumptions must be made regarding the transportation facilities, the size and characteristics of the population and other conditions in the planning zone. This report describes standard approaches and provides recommendations regarding the relevant information, assumptions and methods to be used in performing evacuation time estimate studies.

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INTRODUCTION

Evacuation is used as a protective action to remove people from areas potentially affected by wind-borne radioactive materials released from nuclear power plants. To prepare for evacuation, emergency responders can use time estimate studies to develop appropriate protective responses for potential events and to find ways to reduce evacuation time. This report, prepared by the Pacific Northwest Laboratory for the U. S. Nuclear Regulatory Commission (NRC), provides information about what is needed in a useful time estimate study. This report discusses both transportation analysis, the primary concern in a time estimate study, and other considerations, such as populations with special transportation or housing needs.

Before 1980, transportation analysis for natural and technological hazards was rarely done. The determining factors in evacuation times were considered largely qualitative and rarely quantifiable. Techniques for determining evacuation times were devoid of the expertise that existed in transportation analysis. In 1980, the NRC and the Federal Emergency Management Agency (FEMA) issued the *Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants*, NUREG/CR-0654 (NRC 1980a and 1980b). This document established planning standards and evaluation criteria for emergency response plans, including those relating to evacuation. Appendix 4 of NUREG/CR-0654 provided limited guidance on preparing evacuation time estimate studies.

Concurrently, the NRC examined techniques for estimating evacuation times at nuclear power plants with results documented in *Analysis of Techniques for Estimating Evacuation Times for Emergency Planning Zones*, NUREG-CR-1745 (Urbanik et al. 1980). This document made recommendations on how to conduct evacuation time estimates. These recommendations, along with work by FEMA contractors, were included in Revision 1 of NUREG/CR-0654.

Because there may be a wide range of potential accidents, it is impractical to provide time estimates for each of the possible accident and condition possibilities. Thus, it is appropriate to think of evacuation time estimates as part of a planning basis for each site, i.e., as part of the larger plan for responding to a spectrum of possible accidents. (For details about using a planning basis to develop an emergency response plan, see NRC [1980b and 1978].) The standard planning basis includes a plume exposure pathway emergency planning zone (EPZ) of about 10 miles radius; this is the area for which detailed evacuation planning is considered appropriate. Within these spatial limits, evacuation time estimates examine the sensitivity of evacuation times to key variables, including the nature and limits of transportation facilities in the affected area and other factors that may affect evacuation time, such as the public's use of public transportation or need for special transportation (e.g., guarded transportation). Both transportation analysis and ancillary concerns are covered in the following sections.

TRANSPORTATION ANALYSIS CONSIDERATIONS

At the most fundamental level, transportation analysis compares evacuation demand (i.e., the number of evacuating vehicles) with available capacity of evacuation roadways. However, the analysis is complicated by the fact that capacity cannot be stored for future use. That is, if vehicles are delayed in one portion of the roadway network, it is possible that capacity in another portion of the network could be unused.

Simple analysis techniques exist (e.g., see the Transportation Research Board's *Highway Capacity Manual* [1985]) for evaluating operations at various points along a roadway system. Although not specifically intended for estimating evacuation time, the techniques can be used to estimate roadway capacity. However, as the complexity of a roadway network and the number of evacuees increase, the use of computer models becomes attractive.

It is important to note the inappropriateness of using "level-of-service analysis" to do evacuation planning. Level-of-service analysis is predicated on the desire to provide capacity in excess of expected demand. Ensuring that there is sufficient capacity to provide a high level of service during an evacuation is not practical in most cases. Only in very low-population emergency planning zones will a high level of service during evacuations be achievable.

The basic methodology for estimating evacuation times is to compare the evacuation demand (in numbers of vehicles evacuating per hour) with available roadway capacity or transportation service rate. If the transportation service rate (also typically expressed in units of vehicles per hour) is greater than the rate of evacuation demand, no significant traffic-related delays would occur. In such a case, evacuation time is simply the time required by evacuees before beginning to evacuate, plus the time required to drive out of the emergency planning zone. However, if evacuation demand exceeds capacity, additional time is required to account for traffic-related delays. The following sections discuss the key factors affecting evacuation time estimates.

Basic Methodology

The basic method to determine evacuation time is to check whether the time-dependent evacuation demand rate exceeds the available roadway capacity. If the evacuation demand rate is less than available roadway capacity, evacuation time is simply the time required for the last evacuee to begin evacuating, plus the driving time to leave the area. A critical part of evacuation is the trip departure time discussed in below. If the rate of trip departures exceeds available roadway capacity, the time required by the excess vehicle demand must be added to the evacuation time. A simplistic example illustrates the process. If 1000 vehicles attempt to evacuate in a 1-hour period and available roadway capacity is 2000 vehicles per hour, there is no significant roadway-induced delay. Evacuation time is essentially 1 hour plus driving time out of the evacuation area. Alternatively, if 3000 vehicles attempt to evacuate in a 1-hour period and available roadway capacity is 2000 vehicles per hour, the evacuation time for the last vehicle to leave is 1.5 hours (which includes 30-minutes delay time) plus driving time out of the evacuation area.

Obviously, a real example is more involved due to the complexities of vehicles leaving many different areas at many different times over many different roads under a variety of weather conditions. Nevertheless, the methodology simply requires an analysis of all the routes and any delay because of evacuation demand rates exceeding the capacity of the roadways.

Emergency Planning Zones

A plume exposure emergency planning zone of about 10-miles radius is required for the area covered by evacuation planning (see NRC 1980b and 1978). The EPZ boundary is often increased or decreased slightly to conform to the characteristics of a particular site. Factors considered in determining an EPZ are demography, topography, natural barriers, land characteristics, access routes, and local jurisdictional boundaries.

Sectors are sub-areas of the EPZ. The sectors, usually 90 degrees and sub-divided at 2 and 5 miles, provide a convenient frame of reference within which to carry out partial evacuation of the EPZ based on wind direction. The prevailing wind direction at the time of a radiological release determines the affected sectors. The sector boundaries are also based on demography, topography, land characteristics, access routes, and local jurisdictional boundaries.

Scenarios

Scenarios are the alternative sets of input variables that represent combinations of conditions that might occur at the time of a nuclear power plant accident. For purposes of evacuation time estimating, key variables are typically population and roadway capacity. It is desirable for the evacuation time estimate study to provide a range of evacuation times based on the likely ranges of conditions. The evacuation time for any set of conditions not specifically analyzed in the study can be inferred, based on an understanding of how evacuation time is affected by each of the variables.

For a given geographic area, the population to be evacuated is highly time-dependent. For example, scenarios to be analyzed should reflect different seasons of the year, days of the week, and times of day. Likewise, roadway capacity is highly dependent on weather conditions. Weather conditions to be considered should include both good conditions (clear) and adverse conditions (rain, fog, or snow). Adverse weather reduces vehicle speeds. (See page 5, below.)

The purpose of formulating several different scenarios is to determine if certain combinations of conditions cause evacuation demand to exceed roadway capacity. A range of possible combinations should be considered; however, it is not useful to analyze illogical or mutually exclusive combinations of conditions, such as a large daytime beach population and snow-covered roads. The analyst should attempt to identify that combination of conditions likely to generate the highest typical demand on a recurring basis. Scenarios to be analyzed should also include periodic events or conditions that generate a large, temporary population in the EPZ.

There is a relationship between evacuation time and the advisability of certain protective action decisions. Overestimating evacuation time, for instance, is not desirable because such an estimate might lead the decision-maker not to order evacuation as a protective action when it is actually the best alternative. It is also not necessary or desirable to determine a "worst case" evacuation time. The worst case would nearly always be one in which evacuation is simply not possible.

Demand Estimation

One of the key aspects of the methodology is to define the number of evacuees. Although the object of evacuation is to remove people from the EPZ, it is the number of evacuating *vehicles* that determine if any transportation-related delays are likely. An estimate of the number of evacuating vehicles can be based on several possible data sources. In most cases, the number is estimated *after* estimating the number of evacuees. Occasionally, it is more appropriate to estimate the number of evacuating vehicles directly. For example, it may be more accurate to determine the number of vehicles at a beach by counting them in the parking lots than to count or estimate the number of individuals on the beach.

Databases may be used to estimate of the number of evacuating vehicles. The evacuating population is typically subdivided into three groups: permanent residents, transients and special facility populations. Some individuals may be members of more than one group.

Permanent residents are those persons who live in the EPZ year-round. The permanent resident population is typically estimated from census data (often updated for local growth).

Transients are visitors, including tourists and daily employees, who live outside the EPZ. Transient populations are usually derived from other local sources of data. In some cases, special field studies, such as counting the numbers of tourists' vehicles, may be conducted in specific areas in order to develop better estimates of those areas' transient populations.

Special facility populations, including school and prison populations, are estimated on a facility-by-facility basis because the transportation needs are determined by individual facility characteristics. Some special-facility populations may require buses, and others ambulances. Therefore, consideration of individual facilities is necessary because of the need to identify the specific vehicle requirements. Evacuation time for special-facility populations is determined by the vehicle needs, mobilization time, loading time, and travel time. For example, if enough buses are available to evacuate schools in a single trip, evacuation time depends primarily on mobilization time of the buses, loading time, and travel time out of the emergency planning zone. If multiple trips are required due to vehicle limitations, the analysis is more complicated (see "Other Considerations" on populations depending on public transportation).

The issue of double counting makes careful analysis necessary. In some cases, double counting is necessary and does not cause significant problems. For example, school children are counted both as permanent residents and as special facility populations. This is because in some cases the school children may evacuate from school (on weekdays in the winter and in the daytime) and in others from home (e.g., in the summer or an evening). The school children are counted separately in order to determine vehicle needs for a direct evacuation from schools. This particular type of double counting has no adverse effect on evacuation time estimates; however, care should be taken to avoid inappropriate double-counting.

Returning commuters are permanent residents who work outside the EPZ and return home before evacuating as a family group. Returning commuters move in a direction opposite to the general evacuation during the early portion of an evacuation while the public is preparing to evacuate. Trip generation time includes the returning commuter trips. Returning commuters are not considered evacuation trips for purposes of estimating evacuation time.

Voluntary evacuation covers those who decide to evacuate without being advised to evacuate. The terms "spontaneous evacuation" and "shadow evacuation" are also applied to this phenomenon. Voluntary evacuees can be individuals living within the planning zone but not within the sector(s) where evacuation has been advised, or those living *outside*, but near, the EPZ who may be responding to an evacuation order directed to people within the EPZ.

Two activities can be planned to account for voluntary evacuation. First, traffic can be controlled to direct voluntary evacuees so they do not interfere with other evacuating traffic. In some cases, traffic control is unnecessary because the path of voluntary evacuees is independent of the designated evacuation routes. Second, the appropriate number of voluntary evacuees can be included in the evacuating traffic demand estimate.

Another possible demand on roadway capacity during an evacuation is "background traffic," which describes vehicles in the EPZ during an evacuation but not associated with permanent residents, transients, or special facility populations. The most common example of background traffic would be through-traffic on major intercity routes such as interstate highways. Access control measures to direct through-traffic onto some alternative route outside the EPZ is the preferred method to handle this sort of background traffic. Through-traffic not rerouted before it enters the EPZ must be considered part of the evacuating traffic for purposes of calculating demand on the available roadway capacity.

Some individuals may choose not to evacuate. Nevertheless, in evacuation time estimate studies, it is normally assumed that all individuals evacuate the EPZ.

Capacity

Transportation analysts classify roadways using the hierarchy of local streets, collectors, arterials, and freeways. Local streets primarily provide access to individual residences. Collectors concentrate local traffic and, ideally, provide access to arterials. Arterials are the roads and streets whose principal function is to move traffic. Freeways are a special type of arterial with controlled access.

The primary evacuation roadway system for analysis purposes generally includes arterials and freeways. Occasionally, collectors or even local streets are used to improve the operation of the evacuation roadway system. Opportunities to improve an evacuation by using any roadway that could reduce evacuation time should not be overlooked; for instance, through traffic management, a minor roadway such as a local street could be used to improve evacuation capacity.

It is unnecessary to analyze all roadways in an EPZ because the critical elements of the evacuation roadway system are those points where large volumes of traffic converge. Delay on the evacuation roadway network (if it exists) generally occurs at the convergence of two arterials or at arterial access to freeways.

To determine roadway capacities, the roadway characteristics (number of lanes, lane widths, shoulder widths, grades, etc.) and traffic control features (traffic signals, stop signs, lane use restrictions, one-way streets, etc.) must be determined through field surveys. Maps and other available databases should not be relied on without field verification.

The quality, or level-of-service, of roadways is quantified using a rating scheme to describe the quality of traffic flow on a scale from A (best) to F (worst). The level-of-service designation is not particularly applicable to evacuations because the issue in evacuation is how long it will take to clear a given area, not the quality of traffic flow. By definition, where demand exceeds capacity, the level-of-service is "F", which is breakdown or forced flow. The existence of level-of-service "F" means that there are bottlenecks due to evacuation demand that exceeds the rate at which a roadway can accommodate traffic without delay. Although level-of-service "F" exists upstream of a bottleneck, the bottleneck itself, in fact, flows at capacity. Vehicles in forced-flow conditions are simply waiting for their opportunity to pass the bottleneck at the capacity flow rate.

The points of a roadway with the least capacity constrain the capacity of the evacuation network. Typical bottlenecks are intersections, especially intersections with traffic signals. Traffic signals assign right of way and determine the capacity of the intersection for movement in a particular direction. The capacity for a given movement is determined by the percentage of time the traffic signal is green. Occasionally, sections of a roadway between intersections may have fewer lanes than other portions of the roadway and thus create bottlenecks at locations other than intersections. Ramps to freeways may also limit the capacity of the freeway to accommodate traffic. A freeway that would have at least two lanes in each direction can never reach capacity with a single one-lane entrance ramp. Of course, if evacuation traffic has more than one access point to a freeway, the freeway itself may reach its capacity.

Adverse Weather

The time required to make a roadway suitable for evacuation must be added to the calculated evacuation time. Adverse weather conditions (rain, snow, ice, and fog) reduce both roadway capacity and the speed of vehicles. Severe snow or ice conditions can make a roadway impassable. Thus, the impact of adverse weather conditions should be assessed at the time a decision to evacuate is being made.

A few studies have addressed roadway capacity under adverse conditions (Jones and Goolsby 1969, Kocmond and Perchonok 1970, Gandhi 1972, Ries 1981, and Hall and Barrow 1988). It has been observed that rain reduces capacity 10 to 20 percent; snow reduces capacity 10 to 30 percent. The effect is determined by the intensity of the rain or snowfall; the larger-capacity reductions have occurred for rates of rain or snowfall that are likely to be of brief duration. Weather-related capacity reductions of 20 to 25 percent are typically used in current evacuation studies.

Accidents

Evacuation time estimate studies normally include no special analyses of the effects of traffic accidents because accidents and breakdowns are relatively rare events. During accidents and breakdowns are so few than in normal traffic) th ere is r useful way to account for usually minimize the pote accidents and breakdowns o estimates by providing for t ve disabled vehicles if necessary. clearance of damaged or stalled vehicles will ease any negative effect on roadway capacity.

Traffic Management

The most typical means of reducing evacuation time is traffic management. Traffic management involves traffic control by such means as the directing of traffic by traffic management personnel or discouraging certain traffic movements by use of traffic cones or barricades. Traffic management is undertaken to improve traffic flow on the roadway network.

Traffic management might involve the limited use of capacity enhancement methods, such as the provision of an additional lane at a heavily congested intersection or conversion of a particular road to one-way traffic. Converting all the roads leading out of the EPZ to one-way traffic is not an acceptable alternative because of the need to provide access for emergency workers.

Access control is a type of traffic management. It is necessary to discourage entry into the EPZ by those who do not belong there. Access control measures serve to restrict traffic not associated with an evacuation and keeps it from affecting the flow of evacuation traffic.

Not all nuclear power plants require detailed traffic management strategies because traffic management is implemented only at locations where it is likely to be effective in reducing evacuation time. However, traffic management is a resource-intensive process and its potential to improve evacuation traffic flow is usually limited by the availability of personnel and equipment. Traffic control plans must detail the locations, strategies and resources required to carry out specific traffic management activities so that personnel carrying out those activities understand the goals. A traffic management diagram such as that shown in Figure 1 is an example of how to provide the necessary information to the personnel who will carry out the traffic management plan for a specific intersection.

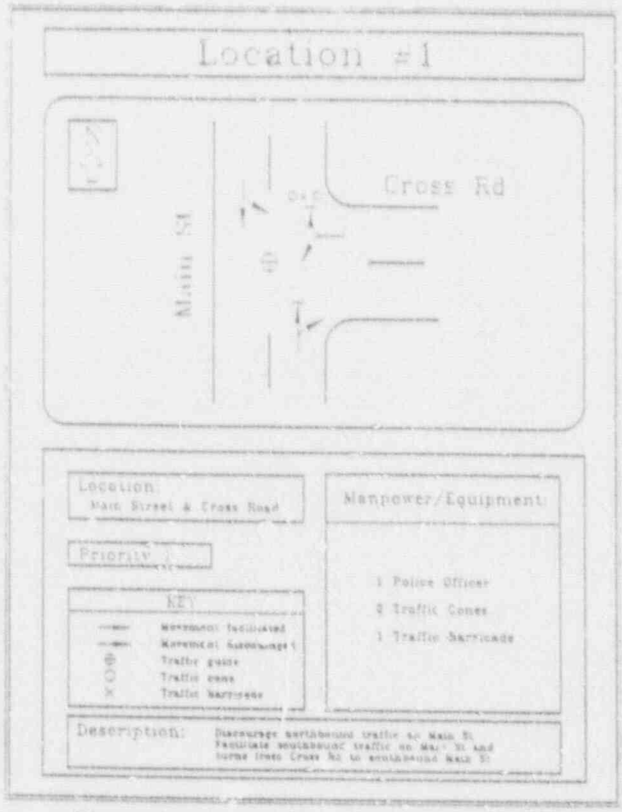

Figure 1. Traffic management diagram.

Roadway Construction

The impact of roadway construction is usually not considered in developing evacuation time estimates because disruption due to construction is usually temporary and dynamic in nature. Although roadway construction can greatly affect capacity of some segments of the roadway network at certain times, decision-makers must deal with these effects on a case-by-case basis. When decision-makers know the sensitivity of the evacuation network to changes in demand or capacity, they can accurately assess the impacts of a variety of conditions, including construction activities.

Driver Behavior

It has been widely observed that during an evacuation, drivers tend not to panic, but act in a manner that promotes good traffic flow (Witzig and Shillenn 1987). They tend to obey the rules of the road and act in an orderly manner during evacuations. Furthermore, it is likely that the best driver in the family will be driving during the evacuation of a family group.

Radial Dispersion

In general, evacuees should move in a direction radially away from the power plant. Evacuation routing should not be contrary to the desired radial dispersion solely for the purpose of more effectively using available roadway capacity. However, in some cases it will be necessary, due to the available roads, for evacuees to move *towards* the power plant for some part of their trip out of the area.

Relocation Centers

A portion of the evacuation traffic will go to pre-identified relocation centers. Relocation centers are located at least 5 miles, and preferably 10 miles, beyond the plume exposure EPZ. Facilities that serve as relocation centers should have good traffic circulation in their areas. To the extent practicable, selection of a particular facility to serve as a relocation center should not cause overloading of any portion of the evacuation network.

Trip Generation Time

For estimating purposes, the population within an EPZ is usually divided into segments having similar travel characteristics during an evacuation. Two major groups are 1) those using personal autos to evacuate and 2) those that require special transportation. These groups can be divided further by location and time of day.

"Trip generation time" is the interval between the issuance (notification) of an order to evacuate and the beginning of the response, i.e., travel out of the EPZ. Trip generation time includes the activity of preparation, and will vary depending on the location where notification is received by each evacuee.

Trip generation activities are either independent (can occur in parallel) or dependent (must occur in series). For example, a person cannot prepare to leave home until they arrive home; these are dependent events. However, the spouse can be making preparations to leave while the worker is returning home; these are independent activities.

The preparation time required by an individual varies by activity. The time required for the same activity also varies by individual. It is, therefore, first necessary to identify the various steps in preparation time and their sequence. Then, the distribution of times for the various activities can be determined, as individuals will each have different time requirements.

One example of this process is a person at work who must return home before beginning evacuation. The events associated with trip generation for an individual at work can be summarized as:

1 First notification of public
2 Individual's awareness of accident
3 Leave work
4 Arrive home
5 Leave home.

However, if the individual was at home (weekend or night time), the sequence of events is

1 First notification of public
2 Individual's awareness of accident
5 Leave home.

The trip generation time required for individuals is simply the sum of the times required for each activity associated with the sequence of events. The time required for event sequence 1-2 is the time required for the activity "receive notification." The time required for event sequence 2-3 is the time required for the activity "prepare to leave work." The time required for event sequence 3-4 is the time required for the activity "travel home." Finally, the time required for event sequence 4-5 is the time required for the activity "prepare to leave home."

If everyone had the same time requirements for each activity, the process of estimating trip generation would be straightforward. It would be necessary only to add the times required to complete each activity. If roadway capacity is not a limiting factor, simply adding up the maximum times required for each activity would yield the time required for the last person (the one taking the longest time) to be ready to leave.

Because different individuals have different time requirements, the time required by the person taking the longest time is obviously longer than that required by many individuals. If the capacity of the roadway system is the limiting factor, assuming everyone requires the maximum trip generation time will result in overestimating the evacuation time, because some individuals would have actually left earlier. The use of time distributions is desirable to avoid overestimating evacuation time for EPZs where road capacity affects evacuation time.

To account for the time required by different individuals to perform an activity, a time distribution for the activity must be estimated. The probability distribution for an activity shows what fraction of the population will complete the activity in a given span of time. These probability distributions are constructed in several ways depending on the data available. Estimating the distribution from assumed average and extreme values (minimum and maximum) is a typical approach. Occasionally, surveys of potential evacuees can be used to determine the appropriate distributions.

The various distributions for a given activity must be combined using compound probability. The following example illustrates the process.

The example assumes an evacuation at night from home. The events are: first notification, awareness of accident, and leaving home. Table 1 shows the warning system effectiveness in providing notification (activities 1 and 2). Table 2 shows the assumed time required to prepare (activities 2 to 5). Table 3 is the result of combining the two distributions.

Combining the distributions, as in Table 3, shows that the maximum time required, 45 minutes, is equal to the maximum notification time (15 minutes in Table 1) plus the maximum preparation time (30 minutes in Table 2). The alternative analysis without distributions would ignore the roadway capacity available before 45 minutes. Without distributions, all evacuees are assumed to have left home by 45 minutes after first notification. The use of distributions is desirable in estimating evacuation times for EPZs where roadway capacity causes delays to those evacuating.

Table 1. Notification Distribution (Activities 1 and 2)

Elapsed Time (Minutes)	Cumulative Percent Notified
5	20
10	60
15	100

Table 2. Preparation Distribution (Activities 2 to 5)

Elapsed Time (Minutes)	Cumulative Percent Prepared
5	15
10	30
15	60
20	75
25	90
30	100

Table 3. Trip Generation Time

Elapsed Time (Minutes)	Cumulative Percent Ready
5	0
10	3
15	12
20	30
25	51
30	72
35	86
40	96
45	100

Analysis Tools

The analysis simply involves estimating the number of vehicles that will evacuate during each of several time periods and comparing those numbers (the demand) with the roadway capacity. The analysis can be done manually when populations are small and roadway systems are not complex. As evacuation demand exceeds the capacity of the roadway network, the analysis becomes more tedious. The use of computer models can reduce the computational effort and allows for the consideration and refinement of more alternatives. However, the use of computer models requires a competent transportation analyst. The computer model does not totally represent reality, and the process of simplifying a real roadway system into a computer representation can be poorly done. The use of computers can also give a false sense of accuracy.

The IDYNEV computer model is a public domain program that is available through the Federal Emergency Management Agency (Urbanik et al. 1988a and 1988b). The IDYNEV model has been successfully used at nuclear power plants around the United States.

OTHER CONSIDERATIONS IN EVACUATION TIME ESTIMATE STUDIES

Besides those issues covered in a transportation analysis, evacuation time estimate studies often involve such issues as examining assumptions about evacuation time, populations dependent on public transport, special facilities, confirmation of evacuation, state and local review, reporting of evacuation results, and updating of evacuation planning.

Assumptions About Evacuation Time

A number of significant assumptions must be made in order to estimate an evacuation time for a particular situation. It may be appropriate to conduct surveys or collect site-specific data upon which to base significant assumptions. However, regardless of the basis, any assumptions used should be documented. Documenting the assumptions that went into a particular evacuation time estimate allows the decision-maker to better compensate for different conditions that may exist during an actual emergency.

Populations Dependent on Public Transport

Some portion of any population does not own or have access to an automobile in which to evacuate. In addition, some members of the general population have special transportation needs. Those with special needs must be provided transportation using buses, vans, or ambulances. Surveys must be conducted in the EPZ to identify those requiring special transportation and determine their needs. The buses, vans, and ambulances required to transport these people must then be identified.

If enough vehicles exist to transport all those requiring special transportation in a single trip, the analysis is relatively straightforward. The only questions to be answered are 1) the time required to mobilize the vehicles, 2) the time required for the vehicles to travel to their respective assignments, and 3) the time required to load the vehicles. If the time for these special evacuation vehicles to be mobilized, driven to the loading site(s), and loaded is greater than the evacuation time for the general population, the evacuation time estimate for this group will be different from that determined for the general population.

The analysis is more complicated when multiple trips are required because of the difficulty in estimating the outbound speed of special population evacuation vehicles in evacuation traffic conditions. In the one-trip scenario, the special population vehicles cannot be delayed beyond the time required for the last vehicle to evacuate the EPZ. In the multiple trip scenario, the travel speed that is attainable may be limited by evacuation traffic on portions of the route. The outbound travel times for buses, vans, or ambulances must account for delays due to evacuation traffic.

There are many alternatives in evacuating the population dependent on public transport. The final choice will depend on local circumstances and the preferences of those providing the service. The critical issues are identifying

- the number of persons requiring transportation,
- the available vehicles,
- the number of trips required,
- the mobilization time,
- the inbound travel time,
- the route time, and
- the outbound travel time (taking proper account of traffic conditions).

Special Facility Populations

Special facility populations are similar to the transport-dependent. The first step is to identify the location and number of persons at special facilities. The next step is to determine the number of vehicles available, the number of trips required, the mobilization time, the inbound travel time, the loading time, and the outbound travel time. If multiple trips or trips to multiple facilities are required, delays due to evacuation traffic must be considered. In some cases, certain special facilities (for example, prisons) have unique requirements and evacuation planning has to take into consideration special arrangements that may be necessary, such as security for the movement of prisoners.

By definition, special facilities are unique and addressed on a case-by-case basis in evacuation planning. The issue is not the identification of individual evacuation time estimates for these facilities, but the determination of transportation needs, the unique requirements at each facility, and whether special facilities, as a group, will take longer to evacuate than the general population.

Confirmation Time

Confirmation that the evacuation process is effective and the public is following the order to evacuate is to assure that all the population has been notified. Additional reasons to confirm public evacuations are to provide assistance to those having difficulties and to maintain security. In plume exposure EPZs with a large population it is not possible to confirm that everyone is in compliance in a timely manner. A sampling approach may be used to determine the effectiveness of notification systems, or patrols may be established to pass through the entire EPZ.

The sampling approach is to determine the sample size to generate the desired confidence that the expected percentage of the population has evacuated. Statistical analysis can determine the appropriate sample size to use. A possible sampling approach is to begin calling randomly selected households 1 hour before the expected completion of evacuation. If no one is home at the expected number of households, notification is determined to be effective. Otherwise, the process is repeated after the expected time of completion of evacuation. Those at home during the telephone survey can tell the caller if any problems exist with notification or if there are unanticipated problems with transportation. This sampling approach could be supplemented by vehicles passing through the EPZ along planned routes. The use of vehicles could also be the primary means of confirmation.

State and Local Review

The evacuation planning process is a cooperative effort of state and local authorities. It is appropriate that those involved in developing an evacuation time estimate should obtain input to and review of the evacuation time estimate study by state and local officials, including those who will be involved in implementing traffic management plans.

Reporting

The evacuation time estimate study documents the results of a technical analysis of a specific site. It is important that the results be presented in a format that makes the emergency response decision-maker aware of the significance of the estimates and the underlying assumptions.

The evacuation time estimate study is typically incorporated into the emergency plan by direct reference or by citation of key findings. A summary document may be the most effective means of presenting study findings to decision-makers. A summary document could contain only that information likely to be used by a decision-maker, such as time estimates, guidance on selecting the appropriate evacuation time estimate, critical variables at evacuation time, and key assumptions used in estimating evacuation time. Key issues are how to select an evacuation time estimate and carry out the proper actions necessary to achieve the predicted time estimate. If a summary document is used, a separate technical report should be prepared to thoroughly document the study.

The level of documentation provided in the evacuation time estimate study itself should allow a competent transportation professional to replicate the results of the study, albeit at great effort. Typical reporting formats include population and vehicle data by evacuation area, summarized by sectors and distance (2, 5, and 10 miles) from the plant. Alternatively, data may be provided by geographic areas (i.e., those emergency planning areas defined in the study).

The roadway network used in the analysis must be documented, including a map of the evacuation roadway network. The characteristics of the roadway network, including road type (freeway or other type of highway), traffic control features (traffic signals including type and signal timing, stop, or yield), and capacity, should be keyed to the evacuation network map. The data should be provided in tabular form for manual analysis or in the form of a computer listing for computer models.

The features and capabilities of computer models not in the public domain should also be documented. The documentation could be in the form of references to readily available documents or by providing detailed documentation in appendices to the evacuation time estimate study. Traffic management strategies used to reduce evacuation time should be documented.

Updating

The evacuation time estimate is only as good as the input data used in the analysis. Changes in the two key determinants of evacuation time, population and roadway capacity, must be regularly monitored and updated. Monitoring of population growth over time is critical. As a general rule, a 10 percent increase in population indicates a need to check evacuation times. An initial assessment would involve determining whether growth had taken place in areas constrained by roadway capacity. If the possibility exists for increased evacuation times, a detailed analysis is necessary. A reevaluation should typically be done every 3 to 5 years. In areas of little growth, the evaluation would typically involve verification of the accuracy of the underlying data and assumptions used in the analysis.

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11. ABSTRACT (200 words or less)

In the event of a major accident at a commercial nuclear power station, exposure of the public to airborne radioactive materials can be prevented or greatly reduced by evacuating the area immediately surrounding the reactor site. Reactor licensees are required to conduct studies to estimate the time needed to evacuate the public from the area surrounding each nuclear power station. The results of such studies are used by regulatory personnel and emergency planners to assess the potential effectiveness of protective responses for the public. The time required to evacuate the public from a 10-mile emergency planning radius is estimated by analyzing the available transportation facilities and other relevant conditions within this radius. To support the analysis, data must be collected and assumptions must be made regarding the transportation facilities, the size and characteristics of the population and other conditions in the planning zone. This report describes standard approaches and provides recommendations regarding the relevant information, assumptions and methods to be used in performing evacuation time estimate studies.

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