NUREG/CR-6863
SAND2004-5900

Development of Evacuation Time Estimate Studies for Nuclear Power Plants

Sandia National Laboratories

U.S. Nuclear Regulatory Commission
Office of Nuclear Security and Incident Response
Washington, DC 20555-0001

NUREG/CR-6863
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Manuscript Completed: December 2004
Date Published: January 2005

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Prepared for
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U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code J3103

Abstract

Since the publication of NUREG/CR-4831, *State of the Art in Evacuation Time Estimate Studies for Nuclear Power Plants*, technologies supporting the development of Evacuation Time Estimates (ETEs) have substantially changed and additional evacuation considerations have emerged. ETEs are part of the planning basis for each nuclear power plant (NPP), and as such, ETE studies are required to be performed by licensees to estimate the time needed to evacuate the public in the unlikely event of a serious accident. As advancements in new technologies that support evacuations and evacuation planning continue, and as new information on evacuations becomes available, it is important that these technologies and information be considered in development of an ETE.

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Executive Summary

This update to NUREG/CR-4831, *State of the Art in Evacuation Time Estimate Studies for Nuclear Power Plants*, integrates new technologies in traffic management, computer modeling, and communication systems to identify additional tools useful in the development of new, or updates to existing, Evacuation Time Estimates (ETEs). As advancements in technologies that support evacuations and evacuation planning continue, these new technologies should be considered. The *Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants*, NUREG- 0654/FEMA-REP-1, Rev. 1, provided the initial guidance on development of ETEs. NUREG/CR- 4831 provides guidance on the relevant information, assumptions, and methods to be used in performing Evacuation Time Estimate (ETE) studies.

The purpose of the ETE is to provide a tool for preplanning as well as protective action decision making. The ETE identifies potential challenges to efficient evacuation, such as traffic constraints, allowing mitigative measures to be preplanned. The value of the ETE is in the methodology required to perform the analysis rather than in the calculated ETE times (NRC, 1980a, Supplement 2).

Evacuation Time Estimates are part of the planning basis for each site and are required by licensees to estimate the time needed to evacuate the public from the plume exposure pathway Emergency Planning Zone (EPZ) extending about a 16-km (about 10-miles) radius around each nuclear power plant. ETE results provide emergency planners information to support protective action decisions, including whether evacuation or shelter-in-place is the better response to the emergency. In situations where shelter-in-place may be advantageous, the public should be educated and aware of its benefits and appropriateness.

To facilitate data management and calculations of ETEs, computerized analysis tools are readily available to support virtually all aspects of evacuation planning and can be beneficial and cost effective even for small population areas. Computer models and software are available for use in:

- Evacuations - models are available to calculate optimal evacuation routing, evacuation scenarios, and evacuation time estimates;
- Transportation - models are available to assess dynamic characteristics of traffic flow, calculate optimal evacuation routing, and recommend improvements to solve traffic problems; and
- Geographical Information Systems - are available to integrate evacuation and transportation data with the geospatial data and mapping of the area.

Intelligent Transportation Systems (ITS) can provide significant relief in the level of manpower and equipment necessary to manage traffic in an emergency. Common ITS technologies and other communication techniques that should be considered to provide traffic control and potentially reduce the ETE include:

- Dynamic message signs or variable message signs,
- Video surveillance,
- The 511 telephone-based traveler information system (available in many states),
- Highway Advisory Radios,
- Integration with a Geographical Information System (GIS), and
- Use of Internet based traveler information systems.

The complexity of the ETE varies depending on the infrastructure and population density and should be developed following a graded approach. For complex sites, the ETE can become a decision management tool to support preplanned decisions in the movement and routing of traffic out of the EPZ. For less complex sites, a basic transportation management approach may be sufficient. Actions that could be taken to significantly improve evacuation time must be identified (NRC, 1980a).

It is not beneficial to have an overly conservative ETE as this may cause decision makers not to evacuate when evacuation may indeed be the best decision. The uncertainty in parameter values should be identified and the total uncertainty of the ETE should be estimated. This may help the analyst determine if the aggregate effect of conservative parameters realistically reflects the ETE.

This update identifies new technologies and current evacuation planning considerations for use in the development or update of an ETE. Use of computer modeling, integrated with improved traffic management and communications capabilities, provides an opportunity to assess the combination of plausible variables and events that challenge the evacuation capabilities and whether these challenges can be mitigated through the application of these technologies, thus improving the ETE.

Acknowledgments

There were many NRC contributors that helped bring this study to fruition. Kathy Gibson provided the vision and the needed management support to initiate this project. Randy Sullivan provided the technical leadership to ensure this project met the needs of the emergency preparedness community. Debra Schneck was the project manager responsible for contractual matters, Daniel Barss provided technical review, and Joe Anderson assisted with completion and publishing. Joe Jones and Lori Dotson of Sandia National Laboratories preformed the detailed technical investigations. Sandia staff including Joe Schelling, Susan Carson, and Marilyn Gruebel, provided technical support and review for the document.

Acronyms

CFR	Code of Federal Regulations
EPZ	Emergency Planning Zone
ERPA	Emergency Response Planning Area
ESP	Early Site Permit
ETE	Evacuation Time Estimate
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GIS	Geographical Information System
HCM	Highway Capacity Manual
ITS	Intelligent Transportation Systems
LOS	Level of Service
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
TMI	Three Mile Island
USGS	United States Geological Survey

1.0 Introduction

The purpose of the Evacuation Time Estimate (ETE) is to provide a tool for preplanning, as well as protective action decision making. The ETE identifies potential challenges to efficient evacuation, allowing mitigative measures to be preplanned. Decision makers use the ETE when considering protective action decisions regarding whether an evacuation should be implemented. As advancements in technologies that support evacuations and evacuation planning continue, it is important that these technologies be considered during development or update of an ETE.

1.1 Methodology

The purpose of evacuation is to move the affected public out of harms way as quickly and effectively as possible to mitigate the consequences of an impending hazard, thereby protecting public health and safety. Each emergency evacuation is unique and dependent on local and regional characteristics, infrastructure and response activities, as well as the nature of the incident, weather conditions, time of day, day of week, and preparedness of the community to respond. With such a diverse set of parameters to be considered for evacuation scenarios, the methodology for determination of the ETE should be well defined. The methodology should be structured to assure that all components of the ETE are identified, the basis for underlying data is defensible, and the calculations are complete. The value of the ETE is in the methodology required to perform the analysis rather than in the calculated ETE times (NRC, 1980a, Supplement 2).

A simplistic approach to the methodology would be a transportation analysis of the evacuation demand against available roadway capacity. If the roadway capacity were greater than the rate of evacuation demand, no significant traffic-related delays should normally occur. In such a case, evacuation time is simply the time required by evacuees to mobilize plus the time required to drive out of a designated evacuation area. However, where evacuation demand exceeds roadway capacity, additional time is required to account for traffic-related delays. Practical considerations and logistics of actual evacuations are much more complex, and accurate time estimates require assessment of all potential factors affecting the transportation network.

Calculating the ETE for an actual evacuation should include relevant variables determined through a comprehensive assessment of the demographics and characteristics of the emergency planning zone (EPZ). A methodical approach should be followed to ensure that each element of an evacuation is considered in the determination of parameters to produce realistic ETEs. A total systems approach considering each element of an ETE will produce more realistic assessments.

Each element of the ETE is estimated based on data obtained through a comprehensive assessment of many parameters. Some of these parameters, such as trip generation times, may be represented by distributions, which reflect the uncertainty or variability in their values. Other parameters, such as populations, will be fixed values based on the best available information. Selecting the worst-case parameters is not beneficial. It is not beneficial to have an overly conservative ETE as this may cause decision makers to not order an evacuation when that may indeed be the best decision.

1.2 Early Site Permit Regulatory Considerations

The Atomic Energy Act of 1954 (42 U.S.C. 2011 et seq.) as amended, and the Energy Reorganization Act of 1974 places on the Nuclear Regulatory Commission (NRC) the responsibility for the licensing and regulation of private nuclear facilities from the standpoint of public health and safety. Part 100, "Reactor Site Criteria," of Title 10 of the Code of Federal Regulations (CFR) requires that physical characteristics unique to the proposed site that could pose a significant impediment to the development of emergency plans be identified.

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-0654/FEMA-REP-1, Rev. 1 (NRC, 1980a). This document established planning standards and evacuation criteria for emergency response plans, including those related to evacuations. Appendix 4 of NUREG-0654/FEMA-REP-1, Rev. 1, provided guidance on preparing evacuation time estimate studies (NRC, 1992).

In the development of an early site permit (ESP) application, 10 CFR 52.17(b)(1) requires that applicants "identify physical characteristics unique to the proposed site, such as egress limitations from the area surrounding the site, that could pose a significant impediment to the development of emergency plans." The applicant for an ESP is required in 10 CFR 52.17(b)(3) to provide a description of contacts and arrangements made with local, state, and federal agencies with emergency planning responsibilities. NUREG-0654/FEMA-REP-1, Rev. 1, Supplement 2, *Criteria for Emergency Planning in an Early Site Permit Application*, contains additional guidance for ESP applicants for determining significant impediments. The ETE provides a basis for demonstrating whether significant evacuation impediments may exist.

The ETE guidance should support nuclear power reactor operating license applications pursuant to 10 CFR Part 50, Appendix E, Section IV, and the development of protective actions consistent with 10 CFR 50.47(b)(10). In addition, for ESP applications, the ETE guidance may support the identification of physical characteristics unique to the proposed ESP site that could pose a significant impediment to the development of emergency plans, pursuant to 10 CFR 52.17(b)(1).

The ETE is one method for identifying significant impediments to the development of emergency plans, should they exist for the site. Additional guidance concerning an ETE for an ESP site is provided in Supplement 2 to NUREG-0654/FEMA-REP-1, Rev. 1. The methodology for developing the data and calculating the ETE may now be established during the ESP application phase. The data will then be updated, as needed, in order to validate estimates and ensure up-to-date information is used to develop the ETE, when a combined license application, which incorporates an ESP, is submitted.

Sites should consider EPZ boundaries, current and projected demography, topography, land characteristics, access routes, jurisdictional boundaries, scenario development, transportation analysis, demand estimation, and identification of uncertainties in the data during the development of the ETE. This will support identification of potential ETE issues at an early stage in the licensing process for nuclear power reactors, including providing an opportunity to address these issues prior to submission of either an operating license or ESP application.

2.0 Transportation Analysis Considerations

The transportation analysis is a significant component of the ETE methodology. The analysis begins with an assessment of the demographics, infrastructure, and local and regional characteristics of the EPZ. Demand estimations are prepared and evacuation scenarios are developed to calculate ETEs for a range of conditions. The scenarios include fixed elements, such as roadway infrastructure, combined with variable elements, such as traffic loading. In addition, other considerations, such as population groups, including special facilities and their mode of transportation, potential effect of shadow evacuations, and other assumptions affecting transportation should be factored into the analysis and calculation of the ETE.

Roadway characteristics and traffic data are required for proper depiction of the evacuation transportation network. The information should describe the topology of the roadway system, roadway characteristics (including geometry and channelization of traffic), existing traffic volumes, and traffic control devices and their operational characteristics. Much of this information may be obtained from local or state transportation agencies. Traffic surveys should be performed if the data are not available or are not current.

There are a variety of maps available for use in the development of the ETE and each has a specific application. General data can be obtained from the United States Geological Survey (USGS) to support analysis of regional networks. State and local transportation agencies can provide current mapping for the EPZ and surrounding areas. These will generally be more current than the USGS mapping and may provide additional details. Furthermore, many municipalities are using Geographic Information Systems (GIS) and can provide mapping data electronically, which allows greater flexibility in the analysis and presentation of the data.

In all cases, a field survey of the key routes within the EPZ should be performed to check the accuracy of the mapping. Field surveys should validate the mapping and will provide roadway characteristics and information not typically included on maps, such as:

- number of lanes,
- pavement width,
- roadway constraints, such as guardrail locations and physical encroachments,
- shoulder type and width,
- bridge locations and widths,
- intersection lane channelization,
- intersection queuing capacities,
- posted speed limits,
- attainable speed, and
- surrounding land use.

It is important that updates to ETEs clearly identify changes in the transportation network that have occurred since development of the original ETE.

Field surveys are necessary to check on the location and egress of major traffic generators (e.g., population concentrations, special facilities, major employers, schools, and hotels). The roadway network representation for the study area should incorporate appropriately detailed information from mapping and field surveys. To the extent necessary, all major intersections with traffic control, locations of major traffic generators, and locations where the highway geometry changes, should be identified.

A field survey of the major routes in the study area should include verification of data regarding traffic signals at intersections. The operational details, such as signal phasing and automated control capabilities can be obtained from the local or state transportation agency. Signal control can be complex because the signal timing patterns may change by time of day. The signal timing at key intersections should reflect the timing pattern expected during an evacuation. The ETE should also indicate which intersections will be manned by traffic control officers during an evacuation in order that this may be correctly input into the ETE model or calculations.

The speed on a highway segment is taken as the maximum of either the posted speed limit or the attainable speed under normal weather conditions. The capacity of a highway segment is estimated based on procedures described by the Transportation Research Board (Transportation Research Board, 2000 and 2002). The impact of restricted highway geometry should be accounted for in computing the capacity of highway segments and should be clearly delineated in the model input files.

Traffic on highway segments leading into the evacuation area should be evaluated. The frequency of pass-through traffic may be validated through traffic counts in selected areas. Pass-through vehicles will continue through the EPZ until traffic control points have been established, at which time pass-through vehicles would no longer be allowed into the EPZ. Any assumptions should be evaluated against local emergency plans.

2.1 Emergency Planning Zones

The radius of the EPZ for the plume exposure pathway extends about 16 km (about 10 miles) around a nuclear power plant (NPP). It is the area for which planning is needed to ensure prompt and effective actions can be taken to protect the public health and safety in the event of an emergency. It is unlikely that any protective actions for the plume exposure pathway would be required beyond the plume exposure EPZ (NRC, 1980a). The EPZ may be further defined by

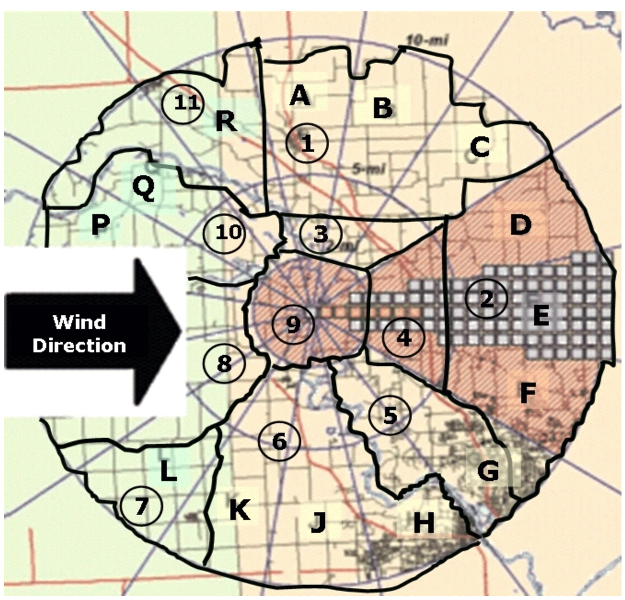

Figure 1. EPZ showing three 22.5 degree sectors for evacuation. Sectors are lettered A-R; ERPAs are numbered 1-11. An evacuation area is likely to include 3 or more sectors.

sectors that encompass the entire area (see Figure 1), and are subdivided at about 3.2 and 8 km (about 2 and 5 miles).

The wind direction at the time of the incident will determine the impacted sectors. An evacuation of the 3.2 km (about 2 mile) radius and the downwind sectors will form a keyhole configuration. Wind direction may vary within the EPZ and local assessment of the wind conditions may support limiting the sectors of the evacuation to the sector containing the plume and a single sector on either side, or may require expanding the area of evacuation to include additional sectors. It is important to understand the meteorological assessment capabilities within the EPZ for potential use in development of scenarios. The plume exposure pathway is the about 16-km (about 10-mile) EPZ, and the area affected is generally the sector or sectors that the plume touches and the adjoining sectors on either side.

2.1.1 Emergency Response Planning Areas

Emergency Response Planning Areas (ERPAs) are defined areas located within the EPZ for which emergency response plans have been developed. These areas are typically defined by geographic or political boundaries to support emergency response planning and may also be referred to as subareas, protective action areas, or other local terminology. There may be several ERPAs depending on the specific characteristics of the EPZ. Figure 1 identifies a conceptual layout of 11 ERPAs within an EPZ. State and local emergency response agencies provide evacuation information to the public through calendars and other means. It is important to engage these agencies early to ensure that data and assumptions used in the ETE calculations are consistent with the response plans.

Protective actions are typically implemented by ERPA. In the event of an evacuation, the sectors to be evacuated will cross ERPA boundaries. Each of the ERPAs that are within the affected sectors would be evacuated. Data obtained at the ERPA level should be used in calculating the ETE for the evacuated area identified in each scenario.

2.2 Demand Estimation

Demand estimation is the systematic approach used to identify the total number of evacuees by assessing population groups and the expected mode of transportation. Demographic data, together with information and assumptions on population groups and vehicle occupancy rates, support determination of the number of vehicles that will be evacuating the area.

Evacuation trips do not begin instantaneously after a warning to evacuate. There is a delay between the time the public is notified to evacuate and the time at which the actual evacuation begins. This delay varies by population segment, person, household, time of day, and location, and will influence traffic loading rates onto the transportation network. The traffic loading rate represents the number of vehicles that would attempt to enter the roadway network at any given time after the evacuation notification, and it should be treated as a probability distribution in the ETE calculation. Telephone surveys, using a statistically defensible sample size, can provide better data than generalized assumptions. This approach will reduce the uncertainty in the demand estimation.

There are a variety of ways to estimate populations; therefore, it is necessary to document the approach and provide sufficient detail on the basis for the population data used. For the demand estimation, three potential population segments shall be considered: permanent residents, transients, and persons in special facilities (NRC, 1980a). Permanent residents include those people having a residence in the area. The permanent resident population is generally derived from census data. The Census Bureau is currently making a transition to supplement the decennial data on an annual basis for large urban areas and on a five-year basis for rural and small urban areas. This may provide a means to obtain more current population data for developing and updating ETEs. The Census Bureau also maintains data on populations with disabilities which may be helpful in determining special transportation needs. The number of permanent residents shall be estimated using the U.S. Census data or other reliable data, adjusted as necessary, for growth (NRC, 1980a).

The transient population group includes visitors, tourists, shoppers, employees not residing in the area, and other people visiting the area temporarily. The diversity of this group requires a variety of means to estimate the population and may require a different approach for each segment of the transient population. The first task is to identify the potential transient locations, including businesses, shopping centers and malls, parks, recreation facilities, and special events, where applicable. Once the transient locations are identified, a systematic approach to determining the population of the group should be employed. Seasonal characteristics of the transient group should be considered. For instance, some parks or beaches may be closed during the winter months, and thus should not be included in that scenario. Care should be taken not to double count transient populations. For example, motel capacities may be full in the evenings, but empty during the day when tourists are visiting parks or other areas that will be included in the capacity calculations.

To determine the number of employees who work in the EPZ, but do not live in the EPZ, statistically defensible surveys may be necessary, combined with local and state statistical data. Some malls and shopping centers maintain statistics on the number of shoppers. In some cases, it may be necessary to count parking spaces to estimate populations for these facilities. State parks frequently keep data on the number of visitors per year and per season. If this information is not available, counting parking spaces may support the population estimate. Care should be taken to avoid double counting vehicles belonging to permanent residents who use the facilities.

Special facilities include schools, day care centers, hospitals, nursing homes, prisons, and any special events facilities. A detailed list of special facilities should be developed in order to assess each facility on an individual basis. The population estimate for these facilities may be obtained by contacting the facilities and should consider the maximum occupancy rates. A percentage of this population may be expected to be evacuated by family or friends rather than by public transportation; however, care should be taken not to underestimate special transportation needs.

Seasonal changes for schools and day care centers should be considered. Special facilities will have individual transportation requirements for evacuation, which may include buses, vans, ambulances, and automobiles. Furthermore, some special facilities may relocate their residents to other special facilities outside of the EPZ, such as prisons and hospitals, which may be a considerable distance away. This may increase the time to evacuate a facility if return trips are necessary. In some cases, double counting is necessary, such as school children who are counted as permanent residents and as special facility populations, because in some scenarios the school children may evacuate from school and in other scenarios they may evacuate from home (NRC, 1992).

In addition to the three defined population groups, returning commuters and vehicles traveling through the area during the event should also be considered. Returning commuters include permanent residents who work outside the EPZ and return home before evacuating as a family group. Residents of the EPZ who are not at home (i.e., shopping, at parks, etc.) at the time of the evacuation notice may also return home prior to evacuating. Similarly, when special events occur within the EPZ, residents attending these events may return home prior to evacuating.

These commuters will travel in a direction opposite to the general evacuation during the early portion of the evacuation (NRC, 1992). Vehicles traveling through the area during the evacuation should be considered in the capacity assessment. Depending on the potential effect of this group on the roadway capacities, traffic management and control devices may be warranted early in the evacuation process to limit the impact of these vehicles on the ETE. Information on when traffic control is established should be included in the analysis.

Once the data are gathered, GIS software can be used to integrate the data with the mapping of the area, providing a powerful tool to manage the data with respect to facilities and roadway infrastructure. A GIS platform can graphically display the locations of facilities, population centers, and residential demographics, along with the infrastructure, and can be adjusted for the seasonal and site-specific considerations. The GIS can then be integrated with the transportation models to support consistent assessments.

Demand estimations should be considered for different times of day and night. During the night hours (i.e., late evening to early morning), the vast majority of an area's population is likely to be at its place of residence. It is also likely that at the start of any night evacuation the levels of on-the-road traffic are minimal. In contrast, daytime evacuations involve populations in transit, or at work, school, special facilities, home, or other locations (e.g., shopping, restaurants, etc.).

Shadow evacuations, defined as evacuations by persons outside of any officially declared evacuation zone, should be considered in developing the demand estimation. The impact of shadow evacuations occurs when the vehicular traffic of the shadow evacuees converges with the traffic from the population leaving the EPZ. Dotson and Jones (2004) noted that shadow evacuations occurred in approximately one third of the evacuations assessed in that study. Of those, the shadow evacuations only impacted traffic in a small percentage of cases. In the consideration of a shadow evacuation, the estimated population of shadow evacuees can be included in the demand estimation to identify if an issue would exist. Traffic control measures can be planned to alleviate congestion that may occur in the event of a shadow evacuation. Urbanik (2000) noted that voluntary evacuation could be controlled through appropriate traffic management plans that direct traffic away from the evacuation.

Dotson and Jones (2004) and others have identified that a small portion of the public refuses to evacuate during some evacuations. For ETE calculations, it should be assumed that the entire population within the assessed area is evacuated.

2.3 Scenario Development

Scenarios are the planning sequences and events postulated for each assumed emergency condition. The objective of developing various scenarios is to identify the combination of variables and events (e.g., weather, traffic patterns, and special events) for normal and off-normal conditions to provide emergency planners with a realistic estimate of the time to evacuate under these varying conditions. The scenarios are used to generate ETEs, in advance of an emergency, to provide emergency planners the information necessary to determine if evacuation or shelter-in-place is the better response to the emergency.

The data used in the development of scenarios may include fixed-value parameters, such as roadway characteristics, and uncertain parameters, such as formation of family units, which is the gathering together of family members in order to evacuate as a family. For uncertain parameters, best scientific or professional judgment is often used to fit the data to the appropriate type of statistical distribution; however, computer programs also exist that can perform this function. If the calculation outcome is not sensitive to the value of a particular uncertain parameter, a best

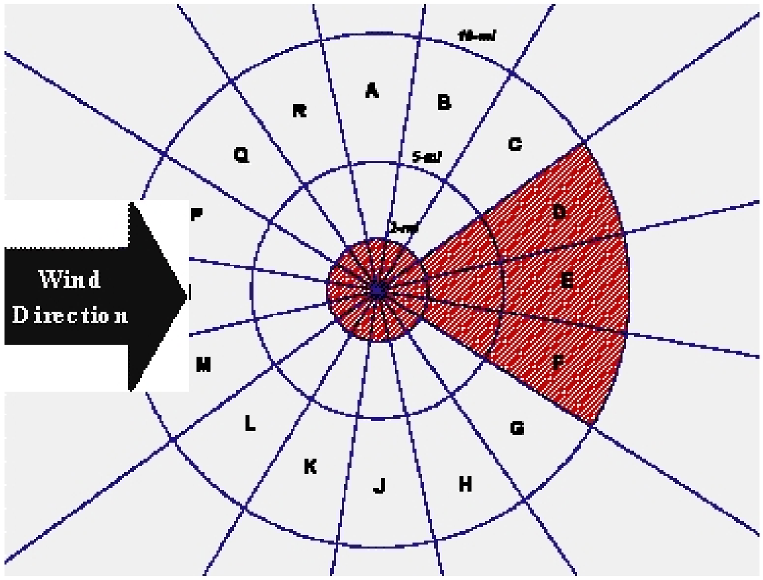

Figure 2. "Keyhole" covering about 3.2-km (about 2-mile) radius and downwind sectors.

estimate value can be assigned to that parameter, thereby avoiding a probabilistic calculation. However, a sensitivity analysis is necessary to determine whether this is the case. Each scenario should quantify the aggregate evacuation time estimated for the impacted population, including all population groups, mobilization time distributions, and combination of conditions.

The scenarios establish the general guidelines of the evacuation, including time of day, day of week, time of year, weather conditions, and if there are special events or circumstances that should be included. Once the set of scenarios is developed, ETE calculations are generated for each sector of the EPZ. A plume is assumed in a sector and the ETE is calculated for all of the ERPAs within that sector and the adjoining impacted sectors. Figure 2 shows the keyhole approach where a plume is assumed in Sector E. The area about 3.2 km (about 2 miles) around the NPP and sectors D, E, and F would be evacuated. Generally, all of the ERPAs touched by the shaded area would be evacuated and the ETE calculated for the about 8 and 16 km (about 5 and 10 mile) keyhole areas. This process is repeated for each scenario rotating around the EPZ until ETEs are calculated for all sectors.

Models may be used to integrate the scenario characteristics with the specific data of the sector, including weather, population, roadway conditions, and other unique attributes of the sector. Overestimation or use of conservative assumptions may produce artificially high ETEs, which could affect the decision to evacuate in the event of an emergency. Care should be taken to document assumptions and identify bounding conditions and uncertainties used to establish these conditions.

Formulating several different scenarios will identify if certain combinations of conditions will cause evacuation demand to exceed roadway capacity and identify the combination of conditions that would generate the highest demand and stress on the transportation system. The ETEs for the scenarios will then be calculated and will provide a range of evacuation times based on a range of conditions. It is this range of conditions that provides the emergency planners the information needed to determine if evacuation is the best alternative.

2.4 Roadway Capacity

The ability of the road network to service vehicle demand is a major factor in determining how rapidly an evacuation can be completed. The capacity of a road is defined as the maximum rate at which vehicles can be expected to traverse a section of a lane of roadway during a given time period under prevailing roadway, traffic, and control conditions. The Level of Service (LOS) is a quality measure describing operational conditions within a traffic stream. For highway operating conditions, the LOS is designated as A through F to represent the range of traffic operational characteristics. LOS A represents free-flow and high-speed operating conditions with optimal roadway design characteristics, whereas LOS F represents a forced flow condition (Transportation Research Board, 2000). The LOS provides a convenient means to display the levels of congestion at select time intervals during an evacuation. The analyst may use the LOS to determine where potential transportation modifications might improve the LOS, and thus, increase traffic flow out of the area.

Capacity can be impacted by obstructions in flow (e.g., accidents or construction), adverse weather conditions, inefficient roadway design (e.g., non-optimal signal phasing, low capacity on-ramps, etc.), and driver behavior. A variety of traffic simulation models and evacuation models have been developed and are used in the design and assessment of transportation networks for evacuation analysis. These models simulate traffic performance under the varying conditions assessed for the ETE and can be used to determine the local roadway capacities for the ETE region. The models incorporate existing roadway features that should be validated through field surveys of traffic performance, including queuing (i.e., the lining of vehicles at intersections and on-ramps), average speed, and signal phasing. Models will allow variations in roadway capacity to simulate weather conditions, accidents, or construction impediments. In addition, the optimum evacuation routes away from the NPP may be identified through the modeling effort.

Use of modeling in the assessment of highway capacities can identify transportation impediments that significantly affect the ETE. Analysis of the results may provide information on the potential implementation of traffic management controls to improve capacity during an event.

2.5 Adverse Weather Conditions

Adverse weather conditions can significantly reduce not only roadway capacity but also operating speed (Transportation Research Board, 2000), resulting in an increased ETE. The adverse weather frequency used in the analysis shall be identified and shall be severe enough to define the sensitivity of the analysis to the selected events (NRC, 1980a).

Improvements in long-term weather forecasts and the real-time availability of this information to transportation management centers and emergency responders, has facilitated the development of programs to reduce the impact of weather-related delays. Better assumptions on adverse weather impacts may be developed for areas where proactive maintenance systems are in place. The Highway Capacity Manual (HCM) provides a means to calculate reduction in capacity for adverse weather using speed flow curves for differing weather conditions.

Development of the ETE should include local or regional data available on traffic congestion during adverse weather (e.g., rain, snow, ice, and fog) and the known or anticipated traffic congestion that occurs during these events. Assessing this information and integrating it with the local traffic management center may identify means to reduce the impact of adverse weather during an evacuation through continuous monitoring of select areas known for congestion, automated remote control of intersections to facilitate improved traffic flow, or staging of roadside service vehicles (e.g., tow trucks) to remove obstructing vehicles.

For scenarios that consider the use of snow removal equipment to clear access roads for the evacuation, discussions with the local roadway maintenance department are necessary to determine the approach. Frequently, snow removal equipment is operating during the snowfall to maintain access. However, time may need to be factored into the ETE to clear driveways and parking lots.

Rain, fog, and ice should also be considered in the ETE, based on the site-specific conditions. Areas of potential flooding should be reviewed during the field assessment activities to determine if flooding would cause an evacuation route to be impassable or reduce the capacity of the route.

2.6 Traffic Accidents

Existing modeling tools provide a relatively simple method for analyzing the impact of accidents on the evacuation time. As part of a fully integrated assessment, an analysis of potential accidents will allow the analyst to determine which roadways are more sensitive to delay from accidents, and then determine whether mitigation of these events should be considered. Although traffic accidents occur infrequently during an evacuation, they can cause delays and should be considered. In a study of large-scale evacuations conducted by Dotson and Jones (2004), traffic accidents occurred in only 8% of the 50 cases studied; however, this impacted the efficiency of the evacuation.

The use of computer models to develop ETEs provides a means to assess the impact of accidents and provide the planners with the information necessary to address the issue. The capacity reduction will depend on the roadway features, including number of lanes impacted, occurrence at an intersection, etc. The HCM provides capacity proportions to support estimation of the capacity reduction value used in the analysis.

Local and regional transportation districts frequently maintain data on traffic accidents, including which intersections are most prone to accidents and the severity and frequency of these accidents. The use of this information may help emergency planners in determining locations to stage additional traffic control or roadside service during an event.

2.7 Traffic Management

The ETE provides a time estimate for the affected population to evacuate the EPZ, and traffic management is a significant factor in this estimate. Detailed traffic management information must be obtained for input into evacuation modeling and must include an assessment of the transportation infrastructure within the EPZ.

With the advent of real-time traffic analysis and improved communication devices, the implementation of interactive traffic management techniques is an excellent way to improve traffic flow by increasing capacity, reducing demand, and reducing the potential for driver error. Any improvements that increase roadway capacities, reduce potential for driver error, or eliminate potential traffic constraints, will improve the ETE. Traffic management is a resource-intensive process and the potential to improve evacuation traffic flow can be limited by the availability of personnel and equipment. The advent of Intelligent Transportation Systems (ITS) may provide significant relief in the level of manpower and equipment necessary to manage traffic in an emergency.

Optimal traffic management requires a balance of traffic control measures, ITS, and the resources available in the emergency response plan. Modeling can be used to identify optimal evacuation routes and alternative routes. This approach considers load balancing of the vehicles to efficiently move traffic out of the EPZ. Reversing lane direction is also an effective method for increasing capacity in the outbound direction. Use of reverse laning should be carefully considered and should address emergency vehicles, public transit vehicles, and returning commuters going against traffic.

ITS are implemented in many communities, including rural areas; however, they are not available everywhere and the complexities of the systems vary. The integration of ITS with standard traffic control practices provides an opportunity to improve traffic flow and should be considered when developing an ETE or updating an existing ETE.

2.7.1 Intelligent Transportation Systems

ITS are the application of computers, communications, and sensor technology to surface transportation (ITS America, 2002b). These systems are advancing and becoming standard operation for all sizes of transportation networks in both rural and urban areas. The extent of ITS within the EPZ should be well understood and integrated into any modeling and ETE calculations. ITS considered in the ETE should be coordinated with transportation and emergency response officials to ensure that the operation of the systems as used in the ETE calculations is consistent with the expected operation during an evacuation. Some agencies may override ITS with manned traffic control, and it is the actual evacuation conditions that must be included in the ETE calculation.

ETE development should consider and utilize the benefits offered through integration of ITS technology in evacuation planning. ITS support advanced transportation management to intelligently and adaptively manage the flow of vehicles through the physical infrastructure, relying on systems that enable traffic surveillance and detection, rapid acquisition of traffic flow data, real-time evaluation of traffic flow, and evaluation of operational responses to traffic flow changes (ITS America, 2002b).

It may be possible to reduce the ETE through implementation of ITS technologies. Depending on the level of ITS within the EPZ, ITS can provide data and tools for analyzing the transportation system, identifying vulnerabilities, and planning in advance for contingencies (ITS America, 2002a). The data from these systems can also provide input for ETE models, providing a potential source for transportation data.

Common ITS technologies and other communication techniques that may be considered to improve traffic control and potentially reduce the ETE include:

- Use of dynamic message signs or variable message signs to provide current traffic information. These signs may be permanent at key transportation points or may be transportable and placed during the event (Tierney, 2001);
- Video surveillance for remote management of intersection signalization;
- Video surveillance at predetermined sites to improve efficiency of detecting, responding, and clearing accidents;
- Use of the 511 telephone-based traveler information system, where available;
- Use of Highway Advisory Radios; and
- Use of Internet based traveler information systems to post evacuation routes, roadway conditions, and other transportation evacuation information.

ITS technologies are evolving rapidly and current technologies should be investigated during the development of the ETE. The local transportation and emergency response officials may provide detail on the current and planned implementation of ITS within the EPZ and the support it may provide during an evacuation. The Federal Highway Administration manages the federal ITS program and maintains current information on technologies (U.S. Department of Transportation FHWA, 2003).

2.8 Roadway Construction

Roadway construction activities slow traffic movement and can affect the ETE. The sensitivity of construction impacts on critical path roadways should be understood. The use of computer models in developing ETEs provides a means to assess the impact of construction, much like traffic accidents, and provides the planners with the information necessary to address the issue. The modeling and assessment of construction activities may be considered as a transportation node, or segment, with a constraint that reduces traffic flow. The reduction in flow will depend on the magnitude of construction (e.g., lane closures, reduced speed, etc.), the type of roadway, and whether it is a critical roadway. The HCM identifies methods to account for capacity reduction during short-term and long-term construction activities.

It may not be necessary to implement advanced planning and contingencies for all construction activities. The analyses may indicate that only long-term construction on select roadways requires consideration in evacuation planning. In a detailed study of evacuations, Dotson and Jones (2004) found that construction activities did not generally impact evacuations, although roadways closed due to the hazard did impact some evacuations.

2.9 Driver/Individual Behavior

Development of the ETE is dependent on the effectiveness of the transportation network along with the ability to anticipate, to an extent, the behavior of drivers operating vehicles under the stress of an emergency evacuation. Once mobilized, the driver should be capable of understanding the directions received for the evacuation, capable of following those directions, and have an ability to respond to change during the evacuation. These changes may be the result of messages on dynamic message signs, traffic accidents, or obstructions in the initial route.

The primary task of the driver is to navigate the vehicle through the evacuation route. A significant percentage of drivers may attempt to communicate with family and friends using cell phones while driving. Cell phones may also be expected to be used for calling the state traveler information systems or other emergency numbers to receive information on the evacuation. The distraction from cell phone use while driving has been studied extensively and continues to be assessed. Studies have shown that the use of a cell phone while driving increases the risk of a collision by up to four times more than a driver not using a cell phone (Redelmeier, 1997). Assumptions regarding driver behavior could be improved, and uncertainty associated with the ETE could be reduced, by collecting information and data on driver behavior. If surveys are conducted to support demand estimates, or to develop information on population groups, it may be beneficial to also gather information on driver behavior.

The manner in which the area population responds to evacuation notices affects the number of vehicles loading the traffic network at any given time. The majority of social science studies of disasters have been conducted only since 1950 (Perry, 1984). Prior to that time, attention was focused on the disaster event itself (i.e., flood or hurricane, volcanic eruption, chemical spill or explosion) and on relating specific consequences of the event. At this level of generality, nearly every disaster is different, and classification would be limited to superficial characteristics. However, more recent research has shown that human response to disasters (e.g., flood warnings) is highly comparable across similar events. This observation has led social science researchers to further examine some generalizations about evacuation behavior based on both natural and man-made disasters. As information on human behavior during evacuations becomes available, it may help in development of more realistic assumptions for the ETE.

2.9.1 General Findings

Dotson and Jones (2004) found that evacuations proceed much more smoothly when the public is familiar with the evacuation procedures, the alerting methods being used, and the hazard that forced the evacuation. In addition, cooperation from evacuees was repeatedly cited as contributing to safe, efficient, and effective evacuations. In approximately half of the evacuations studied, no one refused to evacuate and in the other half, only a very small portion of the population refused to evacuate (Dotson and Jones, 2004).

Zelinsky and Kosinski (1991) analyzed several cases, including Three Mile Island (TMI), and found that:

- The propensity to evacuate varies inversely with actual or perceived distance from the site of a disaster.
- The distance-decay principle generally applies to movements of evacuees, so that the number temporarily residing at a given point will be inversely proportional to the distance from the disaster site or zone of actual or perceived danger.
- Evacuees tend to move in whatever direction(s) are believed to minimize or cancel the effects of the disaster.
- Social relationships and previous travel experience can markedly affect choice of destination by the evacuee.

Evidence from the study strongly confirmed the tendency of evacuees to seek out familiar persons and places for their temporary lodgings. Given a range of options, most evacuees avoided the discomforts and impersonality of official congregate care centers or availed themselves of such facilities for very short periods. During the TMI event, more people evacuated from a much wider zone than emergency response officials deemed necessary. In this instance, concern of the unknown seemed to be a more powerful factor than attachment to familiar surroundings.

2.9.2 Travelers and Transient Populations

Nearly all research on evacuations has focused on the evacuation of households. However, the transient population also requires evacuation and inclusion in the determination of the ETE. Drabek (1996) interviewed tourists, business travelers, migrant workers, and homeless people, as well as lodging industry representatives and local public officials, to determine if a behavior pattern could be detected in response to evacuation warnings. The results showed that evacuation behaviors of the transient population differ in several important ways from people who receive evacuation notices in their home communities. Tourists and transients are more likely to receive evacuation warnings from hotel employees or facility staff. Because this information is secondhand, rather than directly from the mass media, transient groups often have less time to act on warning notices. Transient populations usually have no knowledge of suitable evacuation routes and rely on local staff for recommendations. When evacuating, transients tend to rely more on public congregate care centers for temporary lodging but may also seek hotels away from the hazard or leave the area with no plans to return. These factors all point toward significantly different responses by transient populations than by area households and should be considered in the development of the ETE.

2.10 Radial Dispersion

Evacuation planning should be based on moving the population away from the hazard in the most expedient manner possible. This generally equates to a radial dispersion away from the NPP. The local road network will, to a large extent, dictate the evacuation direction in the immediate vicinity of the NPP. It may be impractical or not possible for all routes to be radially away from the hazard.

As the distance from the NPP increases and additional roadways are available within the EPZ for routing of traffic, calculations may show that balancing the traffic load to optimize the evacuation routing requires travel in the direction of the hazard for a given distance. Justification should be provided for any routing that is not radially away from the hazard.

2.11 Congregate Care Centers

Congregate care centers are established for the evacuated public to provide a place to stay during the emergency. These centers are frequently managed by the American Red Cross and are often schools or large public facilities that are designated as congregate care centers in the event of an emergency. In most cases, it is preferred to locate congregate care centers a minimum of 8 km (5 miles) and preferably 16 km (10 miles), beyond the EPZ evacuation area. However, actual distance will depend on site-specific characteristics.

Dotson and Jones (2004) found that a relatively small percentage of the evacuated public registered at congregate care centers. Frequently, evacuees would go to the residence of relatives or friends outside the evacuation zone. However, with the unique factors of a nuclear power plant evacuation, the awareness level of the residents within the EPZ, and the desire for the evacuating public to be assured they have not been exposed to contamination, a larger percentage of the evacuees could be expected to go to a designated congregate care center when directed to do so. The public should be well informed, typically through public information brochures, on the locations and routing to congregate care centers.

The selection and planning for offsite congregate care centers should include traffic management in the immediate vicinity of the centers to reduce the potential for overloading any portion of the evacuation network.

2.12 Shelter-in-Place

There are situations where shelter-in-place may be advantageous, and the public should be educated and aware of its benefits and appropriateness. The public should be aware of any actions to be addressed at the home or business, such as closing windows and turning off ventilation systems. This information is generally distributed within the EPZ through public information brochures and calendars.

Previous studies have assessed the benefits of shelter-in-place and provided guidance on how to determine the benefits based on type of home construction in the EPZ (Aldrich, 1978). If a shelter-in-place strategy is to be considered, detailed analysis of the local residential and commercial facilities could be performed and an educational program established to clearly convey the benefits of shelter-in-place to the responding public.

2.13 Trip Generation Time

The trip generation time is the total time estimated for an individual or family unit to prepare to leave the EPZ. The trip generation times should be based on site specific information which may be obtained through telephone, Internet, or mail-in surveys. In some instances use of assumptions or generalized data may be sufficient; however, in those instances, the basis for using this data must be provided.

The trip generation time varies depending on the scenario evaluated and the method used in the evaluation. NUREG- 0654/FEMA-REP-1, Rev. 1 provides two approaches for estimating the evacuation time, including a simple approach that considers all events sequentially, and an approach that uses distribution functions for the various evacuation time components. The selected approach should be based on the size and complexity of the EPZ to be evacuated.

Developing the trip generation time requires:

- Identifying the sequence of events,
- Obtaining defensible data for each event,
- Developing statistical distributions for analysis, and
- Calculating trip generation times.

The first step in establishing trip generation times is to identify the different sequences of events for the various population groups. For example, for an event during a normal working day, a trip generation time may include the following elements:

- Notification of the public,
- Preparation to leave work,
- Travel from work to home, and
- Preparation to leave for the evacuation (Urbanik, 2000).

Each element will have a distribution of times for the population. The time distributions vary for numerous reasons. Notification of the public is the length of time between when the evacuation was ordered and when evacuees received this information. Some people will be notified immediately, while others may be at work and notified by coworkers or through announcements. In addition, transient populations may be notified secondhand through park rangers or hotel staff.

Preparation to leave work is the time between receipt of notification to evacuate and when individuals actually leave the workplace. Some individuals can leave immediately while others should shut down operations, feed or shelter farm animals, etc., in preparation for the evacuation.

Travel from work to home is the time it takes to reach home after leaving work. This parameter varies based on the distance from the workplace to the home, direction of travel, and the mode of transportation. Most workers drive to work while some depend on public transit or car pooling for commuting to work. A smaller percentage of commuters that should be included are those that walk, run, or bicycle to work.

Preparation to leave home includes the time to pack and prepare the home for an extended absence prior to leaving. Public information brochures inform people on items to pack, including medicines, pets, personal necessities, and how to secure the home for a prolonged evacuation. The time to prepare varies depending on the size and characteristics of the family. Furthermore, some congregate care centers do not allow pets. Arrangements for pet care may increase the trip generation time and should be considered during development of the ETE.

Because of the diverse characteristics of transient populations and special facility populations, these populations should be evaluated specifically to assess their unique considerations. The transient population is important in the trip generation time because there may be areas where notification of persons is difficult, including campgrounds, hunting or fishing areas, parks, and beaches. These assessments should also consider that some residents will return home to prepare for the evacuation. Discussions with emergency responders, park service, and other agencies to determine the anticipated means of notifying the transient population will help to establish time estimates for this group.

The trip generation time for the special facilities should include the time for mobilization of drivers and vehicles, preparing the evacuees (e.g., patients, prisoners, etc.), loading the vehicles, and traveling out of the EPZ. In some instances, return trips may be required. Surveys of special facilities may provide information to support development of trip generation times.

With the wide range of times for each of the above trip generation time elements, the best approach is to develop probability distributions. The use of distribution functions may result in reduced time estimates due to more realistic assumptions (NRC, 1980a). Furthermore, conservatively assuming that trip generation times are the same can produce extremely inaccurate ETEs (Sorenson, 1987).

Other scenarios to consider include residents that leave directly from home, evenings when persons would generally be at home, car-owning populations, and non-car-owning populations dependent on public transportation. Each scenario has a sequence of dependent and independent temporal events. For dependent events that should occur in series, the times are summed. For independent events, consideration may be given to activities that can occur in parallel, thus reducing the total time required.

Statistically defensible data should be obtained for each element of the sequence for the calculation to provide meaningful results. There are a variety of ways to develop data, including telephone surveys, elicitation from experts, and bounding the maximum and minimum values. The method selected should be documented and performed in a transparent manner to facilitate validation through technical review.

Once the data are compiled, statistical distributions can be constructed either by using commercial software or best scientific judgment. As discussed previously, if the calculation outcome is not sensitive to the value of a particular uncertain parameter, a best estimate value can be assigned to that parameter, thereby avoiding a probabilistic calculation. Commercial codes used for evacuation time estimates allow input of parameters as fixed values or as probability distributions.

The trip generation times are then calculated. It may be beneficial to perform a sensitivity analysis to identify parameters or conditions, such as characteristics of the transportation network, that have a large impact on the trip generation times. Parameters that are particularly sensitive should be evaluated to potentially reduce the uncertainty associated with them.

2.14 Analysis Tools

Commercial computerized analysis tools are readily available to support virtually all aspects of evacuation planning and can be beneficial and cost effective even for small population areas. Use of computer modeling allows for detailed input of evacuation conditions and will provide more realistic results in the calculation of the ETE. It is very important that the analyst understand the analysis tools and the sensitivities of input parameters. Computer models are available for use in:

- Evacuations – models are available to calculate optimal evacuation routing, evacuation scenarios, and ETEs;
- Transportation – models are available to assess dynamic characteristics of traffic flow, calculate optimal evacuation routing, recommend improvements to solve traffic problems, calculate roadway LOS, optimize signal phasing, intersection performance, and freeway on-ramp capacities for urban and rural transportation networks; and
- Geographical Information Systems – systems are available to integrate evacuation and transportation data with the geospatial data and mapping of the area.

Modeling can provide a powerful tool for comprehensive evacuation planning studies, including estimate of evacuation times, development of traffic management and control strategies, identification of evacuation routes, identification of traffic control points and other elements of an evacuation plan (ORNL, 2003). Many of the models can be developed at the macroscopic or microscopic levels, depending on the needs of the assessment, and some models allow interactive use to vary the simulations.

The selection of the model or models used to calculate the ETE depends on the complexity of the EPZ. In using models, the analyst should identify any disparity between data needs and data availability and should document the selection of data for input into the system. All input data should be transparent and available for review, and models used in the analysis should be tested and validated to establish credibility of the simulation and analysis results.

The ETE will be sensitive to changes in input parameters, as well as to the characteristics of the transportation network (NRC, 1988; 1992). For some input parameters, the sensitivity may be extreme. The selection of parameters and their sensitivity should be discussed in the ETE.

Analysis tools that calculate ETEs allow comparison of evacuation plans for varying scenarios. These tools give analysts the means to simulate alternate routes, destinations, weather conditions, traffic control and management strategies, and evacuee response rates. The input may be in the form of probability distributions, such as traffic loading distribution curves or trip generation time distribution curves, which are then statistically sampled in the uncertainty analysis. The iterative capabilities allow the analyst to determine optimum routings and conditions for the ETE.

Transportation analysis tools consist of those used for planning and those that can guide real-time decisions about changes in traffic patterns. Transportation planning tools can be used to predict day-to-day evolutions of travel demand and road network conditions and same-day patterns of traffic flows and travel times, and to compare different alternatives. They also can be used to assist in evaluating proposed changes to local and regional transportation networks. Transportation planning models have some benefit in developing the ETE; however, the analyst should fully understand the algorithms of the model, as some transportation planning models are not necessarily appropriate for evacuation studies.

The analyst should be competent and knowledgeable about the analysis tool, its capabilities and limitations. Furthermore, the analyst should have a thorough understanding of evacuation time estimating and the sensitivity of input parameters. Although these tools can provide direct calculations of the ETE, the results require analysis to ensure that they are accurate and represent the scenarios evaluated.

All models used in the development of the ETE should be qualified and tested for use in evacuation time estimate studies. Documentation of the code, model assumptions, and input parameters should be maintained and available for review.

3.0 Other Considerations in Evacuation Time Estimate Studies

3.1 Assumptions about Evacuation Time

The ETE study can be extensive and have many site-specific assumptions, and all assumptions should be documented (NRC, 1980a). All assumptions should be technically sound, defensible, and when possible, quantified with a level of certainty.

The confidence in the assumptions may increase based on the thoroughness of the public awareness program and surveys of the EPZ population regarding the public's knowledge of actions to be taken in the event of an emergency and expected response. Some high level assumptions may include:

- All persons within the affected area will evacuate;
- Large or small population groups can be evacuated effectively with minimal risk of injury or death (EPA, 1992);
- Evacuees will follow the instructions of the notification to evacuate;
- Evacuees will follow instructions of emergency responders and traffic control barricades and signs (Dotson and Jones, 2004);
- A percentage of the population dependent on public transport will ride share, leaving the area with friends, neighbors, or relatives;
- Panic and hysteria are not observed when evacuation of large areas is managed by public officials (EPA, 1992);
- Emergency responders carry out their required duties in response to hazardous incidents;
- Some double counting of populations will occur with school children who are included in the special facility population and as permanent residents (NRC, 1992);
- Evacuations will be conducted in accordance with the state and local emergency response plans; and
- Existing infrastructure may be supplemented with pre-planned traffic control by law enforcement at key intersections.

It is important to identify the certainty of assumptions through a defensible means. Use of conservative assumptions in all cases may result in unrealistic ETE projections. As a planning tool for protective action decisions, unrealistically high ETEs may result in a decision to shelter-in-place rather than evacuate, when evacuation may be the better option.

3.2 Populations Dependent on Public Transport

Planning for public transportation should be considered for the population that does not have access to a vehicle. This population group may include:

- Households with no vehicles;
- Households with one vehicle that is at work and would not return;
- Households with minor children at home alone;
- Households dependent on public transit or specialized transportation, such as wheelchair vans or ambulances; and
- Business commuters using public transport or those who bike, run, or walk significant distances to work.

The population of this group should be estimated to determine the quantity and types of public transport necessary for evacuation. A consideration in determining the public transport requirements is that a portion of the population may ride share during an evacuation, leaving the area with friends, neighbors, or relatives. Where ride sharing is formalized in local emergency response plans, better data may be available in determining public transportation needs.

This population group needs to be specifically identified to support development of the public transportation plan. Surveys are helpful in identifying the specifics of this population group, including number of individuals, specialized transport needs. The buses, vans, and ambulances required to transport this population and trained drivers should then be identified. Dotson and Jones (2004) identified that there was a lack of trained drivers to support the evacuations in some evacuations studied. Depending upon the specifics of the EPZ, a contingency plan for reserve drivers may be justified. Care should be taken not to double count resources when calculating transportation needs for populations dependent on public transport and the transportation needs for special facilities.

Considerations in determining the ETE for this population group should include the following:

- Number of persons requiring transportation;
- Special needs of these persons;
- Number and types of vehicles required;
- Number of trained drivers required;
- Time and means to notify, mobilize, and brief the drivers;
- Time to fuel the vehicles;
- Time for vehicles to travel from a transportation depot to the initiation of the route;
- Time for loading individuals;
- Time to drive to the EPZ limit and on to the congregate care center;
- Time to unload at a congregate care center; and
- Return time against outbound traffic for repeat trips, if needed.

The evacuation order will occur prior to the mobilization of public transportation drivers. Information from emergency response plans may be available to support the trip generation times and ETE calculations. It will be necessary to inform the public dependent on this transportation mode of the expected time before the vehicles will arrive at the transportation stops. This may be hours for some routes where the public vehicles must make multiple trips.

Additional considerations for public transport should be assessed. Although the public will be aware of the need to limit personal belongings, it can be assumed that some persons could have substantial carry-on items including household pets, medical supplies, and other accessories. Thus, additional time may be necessary in the calculation of loading and unloading vehicles and the calculation of vehicle capacities should consider this additional load.

Once the input parameters are defined, the sensitivities of vehicle capacity and travel times can be iterated to identify combinations of activities that stress the transportation system. Mitigating measures may then be defined, where appropriate, and modeled to determine the preferred transportation plan.

When there are enough specialized vehicles and drivers to complete the transport in a single trip, the calculations and analysis are simplified. The calculations become much more difficult and require additional information when multiple trips are required. Where multiple trips are required, information from response agencies will be needed to identify which vehicles return to which routes such that accurate modeling may be performed. In the multiple-trip scenario, the travel speeds that are attainable may be limited by evacuation traffic on portions of the route for both outbound and inbound transport vehicles. The travel time estimates for buses, vans, or ambulances should account for delays due to evacuation traffic.

The assessment of the population dependent on public transport depends primarily on the number of persons requiring evacuation, their specialized needs, and the number of vehicles and drivers needed to move this population group out of the EPZ. There are numerous alternatives that should be considered in calculating the ETE for public transport. It is important that this be coordinated with the response agencies to ensure that the data modeled reflects the evacuation planning.

3.2.1 Use of Mass Transit and Alternate Forms of Transport

Many NPPs are located in rural areas and typically are not dependent on mass transit capabilities. When the EPZ does include areas where multiple transportation modes are used to ensure an effective evacuation, each of these modes should be assessed. Mass transit may include bus networks, rail, and other locally available transit. Assumptions on use of mass transit in the ETE should include reference to local emergency response plan agreements that specify response commitments and may identify limitations.

3.3 Special Facility Populations

Special facility populations represent a population group that, by definition, has unique characteristics. A comprehensive assessment and tabulation of special facilities is required to identify the transportation needs for this group and to determine if this group will take longer to evacuate than the general public. Special facilities include, but are not limited to, schools, day care centers, nursing homes, hospitals, correctional facilities, and special events centers. Each of these facilities is unique and should be addressed on a case-by-case basis including consideration of peak population in the facilities. The facilities should have local evacuation plans, which may provide useful information. Evacuation times for large special facilities (e.g., hospitals) may be as long as, or longer than, the evacuation time for the general public (NRC, 1980b).

Contacting the Chamber of Commerce, school boards, and local or regional municipal agencies can help in identifying these facilities. Once the list of facilities is identified, the population of each facility and the characteristics of the population should be assessed. This includes determining the number of patients, bed-ridden individuals, wheelchair individuals, and other characteristics, such as security, that may require additional time to mobilize in an evacuation.

Once the facilities, populations, and special considerations are identified, the number and types of vehicles available to support these facilities should be determined and would likely include buses, ambulances, wheelchair vans, and other special vehicles. The methodology is similar to that used for populations dependent on public transport. The time to mobilize the vehicles should be determined. This includes identifying the method of communication with the drivers, the time needed to contact the drivers, and the expected response time of drivers. Unique considerations include the distance that drivers should travel to obtain the vehicle, factoring in weather conditions and the possibility that a percentage of trained drivers may be unavailable to respond. Dotson and Jones (2004) noted that in some evacuations there was a lack of trained drivers for special needs vehicles.

With the special facility populations, vehicles, and drivers identified, the number and duration of trips may be determined. A trip includes loading the vehicle, traveling out of the EPZ to the drop-off point, unloading passengers, and returning to the facility for a second trip, if necessary. Depending on the location of the facility and projected point in the traffic queue, the second and subsequent trips may not be the same time as the initial. For multiple trips, returning to the facility should also include potential delay caused by moving against the evacuation traffic.

Some special facilities have additional unique requirements and evacuation planning should consider special arrangements that may be necessary, such as security for the movement and subsequent sheltering of prisoners or the transfer of hospital patients to more distant hospital facilities for special care.

Schools, day care centers, and most special facilities, with the exception of correctional facilities, present another unique characteristic with the expectation that a percentage of the residents will be picked up by parents, relatives, or friends. Although this is discouraged in some emergency response plans, the desire to evacuate as a family unit is strong and should not be overlooked. This should be considered and reviewed on a case-by-case basis for each facility. Plans may include establishing offsite pick up areas to reduce traffic congestion of buses and other special vehicles.

Schools and day care centers are typically double-counted (NRC, 1992; Urbanik, 2000) with the students included in the special facility population and in the family unit population. The double counting approach for students remains valid to ensure all students are evacuated. The purpose of assuming a percentage of students will be picked up from special facilities is not to reduce the transport estimates, but to plan for the additional traffic in the event of an evacuation.

3.4 Confirmation Time

Confirmation that the evacuation process is effective is necessary to ensure the public is following the order to evacuate, and to ensure that the entire population has been notified (Urbanik, 2000) and has the opportunity to evacuate. The time required for confirmation of evacuation shall be estimated (NRC, 1980a), and the approach for estimating it should be included in the ETE. For shorter duration ETEs, where mobilization times may be longer than transportation times, special consideration may be necessary to provide timely confirmation of the evacuation.

Dotson and Jones (2004) evaluated large-scale evacuations and found that in over half of the evacuations studied, a portion of the public refused to evacuate. The purpose of the confirmation is to ensure that the public did receive the order to evacuate and to ascertain whether those individuals that remain behind require assistance. Based on the size of the evacuation, it may not be possible to confirm that everyone has evacuated and a statistical sampling method may be applied.

Statistical analysis can be used to determine the appropriate sample size (NRC, 1992), which would vary by sector, depending on the population density within the sector. The statistical analysis is used to determine the sample size to generate the desired confidence that the expected population has evacuated.

The confirmation process requires preplanning and can be a significant effort depending on the size of the evacuation. The timing of the confirmation calls should be staged, based on when the notice to evacuate began and on the ETE. Calling too soon will result in data that does not provide confirmatory results as individuals may still be mobilizing for the evacuation. Callers should have a communication link with emergency responders to report on those individuals who do need additional assistance to evacuate.

The telephone sampling approach may be supplemented by emergency vehicles passing through the EPZ along preplanned routes looking for signs of people that have not evacuated. Depending on the site-specific characteristics, this may be the primary means of confirmation. For remote areas, including campgrounds, fishing and hunting areas, and large parks, it may be necessary to plan for aerial coverage to ensure there are no persons in those areas.

Development of the confirmation time should include a means to communicate the results to emergency responders to facilitate timely evacuation of those persons that require additional assistance. Where Internet sites that compile information from congregate care centers are established, this data may be used to support the confidence that everyone has evacuated.

3.5 Shadow Evacuations

Dotson and Jones (2004) studied shadow evacuations, which are defined as evacuations by persons outside of any officially declared evacuation zone, and identified shadow evacuations in approximately one third of the cases examined. The shadow evacuations impacted traffic movement in only a few of the cases and there was no impact on congregate care center capacity in any event. However, in some large-scale evacuations, the transportation impact from shadow evacuations was significant.

The impact of shadow evacuations occurs when the vehicular traffic of the shadow evacuees converges with the traffic from the population leaving the EPZ and should be considered in developing the demand estimation. The estimated population of shadow evacuees should be included in the demand estimation. Traffic control measures can be preplanned to alleviate congestion that may occur in the event of a shadow evacuation. For example, law enforcement could be stationed at key intersections to help coordinate swift passage of vehicles through these intersections. Shadow evacuation may be controlled through appropriate traffic management plans that direct traffic away from the evacuation (Urbanik, 2000; NRC, 1992).

Sorenson's (1987) model suggested that evacuation response is dictated by awareness of risk, personalization of that risk, and evaluation of alternative actions, followed by a decision on the best course of action. Evacuation behavior would thus be normal and predictable and not based on dread of radiation. Furthermore, Sorenson concluded that the public would not panic during such an event.

Tierney, Lindell, and Perry (2001) summarized the findings from additional studies of the TMI event and of radiation hazards in general (Houts et al., 1984; Lindell and Perry 1983; Lindell and Barnes 1986). These studies concluded that shadow evacuations probably occur because individuals not included in specific evacuation warnings identify themselves as being in danger because of confusing and conflicting information from authorities, geographic proximity to the NPP, and/or similarity to demographic groups targeted in the warning messages.

While Zeigler and Johnson (1984) concluded that shadow evacuations are limited to radiation hazards, other examples of this phenomenon have been documented. Lindell and Perry (1992) attributed shadow evacuations to a chlorine tank car derailment at Mississauga, Ontario, in 1979 and the eruption of the Mount St. Helens volcano in 1980. As an indication that shadow evacuations are not limited to technological hazards, Gladwin and Peacock (1997) also found evidence of a significant shadow effect in their study on Hurricane Andrew where approximately one-fifth of the households in coastal areas that were not under an evacuation warning left anyway.

Shadow evacuations should be considered on a case-by-case basis for each ETE. Plans to address the shadow evacuation population should be developed when calculations indicate that the traffic from the shadow evacuation will constrain the traffic from the EPZ evacuation. This can be mitigated through advanced planning and implementation of traffic control measures.

3.6 State and Local Review

The purpose of the ETE is to provide a tool for preplanning as well as protective action decision making. In the development of the ETE, interaction with state and local agencies should begin early and is necessary to obtain local and regional data, understand the operations of the emergency response capabilities, and understand the traffic management system. For development of realistic time estimates, the calculations must include the planned response conditions.

NUREG-0654/FEMA-REP-1, Rev. 1 (NRC, 1980a) recognizes that the evacuation planning process should be a cooperative effort between federal, state, and local authorities. There is an emphasis on multi-jurisdictional coordination that transcends the needs of development of an ETE. Participation in these reviews should include, but not be limited to, law enforcement, fire protection, emergency response, city engineers and planners, public works departments, and transportation management centers. These agencies understand the resource availability, response plans, local traffic conditions, and site-specific attributes, and can provide valuable input into the development of the ETE.

State and local agencies should review the concepts and decisions of the traffic management plan used in the ETE calculations to ensure consistency with current agency status and vision. These agencies should be able to provide information on growth in the region, long-range master plans that identify infrastructure and development improvements, flood plain maps for consideration in adverse conditions, and details of traffic management center capabilities. Engaging state and local agencies in the development and review of ETEs will provide some assurance that the ETE is consistent with the capabilities of the agencies (e.g., traffic control requirements).

3.7 Reporting

The ETE study presents detailed analyses and calculations of the time to evacuate affected sectors of the EPZ under specified conditions to support preplanning efforts and decision making. The results of the ETE are presented as a suite of ETEs covering all impacted ERPAs for each scenario as discussed in Section 2.3. The quantity and variety of data, calculations, and underlying assumptions can be daunting and should be presented such that emergency responders can understand and use the information as intended in an emergency. To ensure this, the ETE should be developed in a user-friendly format to facilitate response decisions. The ETE will have a number of scenarios and multiple ETEs for each scenario. The protocol for using the ETE study should be presented in a format amenable to all users of the document.

The ETE study is typically incorporated into the emergency plan by direct reference or by citation of select requirements. A summary document may provide an effective means of presenting findings to decision-makers. A summary document might contain only that information likely to be used by a decision-maker, such as:

- Evacuation time estimates for each scenario,
- Guidance on selecting the appropriate ETE,
- Sensitive variables at evacuation time,
- Key assumptions used in estimating evacuation time, and

- Traffic control considerations.

It is important to clearly identify how to select an ETE 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 provide thorough documentation of the study.

Typical reporting formats include population and vehicle data by evacuation area, summarized by sectors and distances of about 3.2, 8, and 16 km (about 2, 5, and 10 miles) from the NPP. Alternatively, data may be provided by geographic areas (i.e., the emergency planning areas defined in the study).

The roadway network used in the analysis should be documented, including a detailed map of the evacuation roadway network. The characteristics of the roadway network, including roadway type, traffic control features, and capacity, should be keyed to the evacuation map. Significant data and information should be provided in tabular form for review, and all sources of data should be documented. Where computer models are used, summary tables should be included in the report with detailed outputs provided in separate appendices. The data input and output results should also be provided in readily usable electronic media for computer models in a format that is transparent to allow validation. It may be beneficial to provide mapping in electronic format as well as in the report. Electronic mapping will allow layers of data to be incorporated to easily identify ETE conditions.

The use of computer models provides the analyst powerful tools to assess scenarios under various conditions. A summary of the model documentation and supporting information, including mathematical basis, assumptions, software quality assurance, and industry acceptance (e.g., peer review) should be provided. Furthermore, a separate section of the report should address sensitive parameters and should include the bases for the values used in the calculations. The detailed documentation for these models should be available for review, including the underlying algorithms and assumptions for all codes. The documentation could be in the form of references to readily available documents or may include detailed documentation in the appendices to the ETE study. Traffic management strategies used to reduce evacuation time should also be documented.

3.7.1 Recommendations to Improve the ETE

Through the assessment of the scenarios and varying conditions for each scenario, the optimum evacuation times will be determined under specified conditions. These evacuation times may be dependent on improvements in the transportation system or response activities that are not currently in place, but if implemented, would reduce the ETE. Specific recommendations for actions that could be taken to significantly improve evacuation time shall be given and where significant costs may be involved, preliminary estimates of these costs shall be provided (NRC, 1980a).

During an evacuation event, there is a small portion of the population that requires a significantly longer time to evacuate. This segment of the population skews the evacuation time estimate to the high side (e.g., 90% of the population may evacuate in 4 hours and the remaining 10% require an additional 2 hours). Therefore, steps should be taken to first identify this population (i.e., who are the last people to leave the evacuated zone); second, identify the reasons for the increased evacuation time; and finally, identify if practical measures can be implemented in the planning stages to reduce the amount of time required for this population to evacuate in order to reduce the overall ETE.

3.8 Updating

Emergency planners depend on the accuracy of the ETE to support evacuation decisions; therefore, whenever the possibility exists that the ETE would change significantly, (increase or decrease) a detailed update should be performed. The ETE is an estimate based upon a snapshot of information assessed at the time of the ETE and should consider the impact and timing of changes that could affect the evacuation time. The primary elements in the ETE, population, and roadway capacity, should be periodically evaluated and updated to determine if there is an impact on the ETE. The population review should not only address increases in population, but also assess the age demographics and special needs population as well. The roadway capacity assessment should include review of transportation improvements, constraints, traffic flow, and changes in transient traffic flow through the EPZ. Additional elements that should be considered are:

- an increase in special facilities or special events;
- implementation of intelligent transportation systems within the EPZ; and
- jurisdictional changes in response authority.

Computer modeling allows most parameters to be assessed for sensitivity to the ETE. Sensitivity analyses allow planners to better determine what parameters are important or worthy of a detailed analysis. Obviously, jurisdictional changes cannot be modeled and should be monitored to ensure that the response agencies have the resources required to support an evacuation under the predetermined scenarios.

The development of the ETE will include working with local and regional planners to understand the long-range master plans for development and transportation. ETE calculations can be performed using higher population scenarios and modified transportation networks to compare the calculated ETE with projected ETEs under various scenarios. As a general rule, a 10 percent increase in population would indicate a need to revisit the ETE (NRC, 1992). Assessing the sensitivity of a 10 percent increase will help determine the key factors that drive the timing of an ETE update and may reduce the frequency of a detailed update or drive the need for more frequent updates.

4.0 Conclusion

The complexity of an ETE varies depending on the infrastructure and population density of the site and should be developed following a graded approach. The ETE provides a tool for preplanning and public action decisions and should include current technologies and understanding of estimating evacuation times. The ETE provides information to emergency planners to support decisions on whether an evacuation should be implemented.

This report updates previous guidance on how to conduct evacuation time estimates provided in NUREG/CR-4831, *State of the Art in Evacuation Time Estimate Studies for Nuclear Power Plants* (NRC, 1992). Advancements in evacuation modeling are identified, along with improved transportation and communications techniques, that may help in the development of an ETE. Furthermore, the development of an early site permit (ESP) application, 10 CFR 52.17(b)(1) requires that applicants "identify physical characteristics unique to the proposed site, such as egress limitations from the area surrounding the site, that could pose a significant impediment to the development of emergency plans." The ETE is one method for identifying significant impediments to the development of emergency plans, should they exist for the site.

Since the publication of NUREG/CR-4831, major advancements have been made in transportation technologies, communication systems, and in modeling of transportation networks, evacuation scenarios, and evacuation time estimates. As advancements in technologies that support evacuations and evacuation planning continue, it is important that these technologies be considered during development of an ETE.

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