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Assessing emergency preparedness in support of hazardous facility risk analyses: Application to siting a US hazardous waste incinerator

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Abstract

Increasing public resistance to hazardous materials transportation and facility operation has elicited a number of suggestions for improved risk communication, early community participation, and provision of incentives. Another potentially useful but hitherto neglected method of addressing local opposition to hazardous facility siting involves community emergency preparedness for a release of hazardous materials. This paper describes a procedure for analyzing local emergency preparedness in accordance with operational guidance from federal agencies in the United States and scientific principles derived from international research on disasters. This procedure identifies vulnerable areas of a community and assesses the capability of the community to take timely and effective protective actions including evacuation and sheltering in-place. Response capability is first assessed by verifying that local emergency response plans address the elements defined in state and federal guidance. Next, implementation analyses are conducted to determine whether the four critical functions of hazard detection and notification, protective action decision making, warning and public information, and protective action implementation can be accomplished with available resources under local conditions. These analyses indicate the degree to which formally designated emergency response activities of community agencies, as outlined by its Emergency Operations Plan (EOP), together with the informal social processes of emergency response known to operate in disasters, provide reasonable assurance of prompt and effective protective action by the public. Results of these analyses can provide administrative and judicial review processes with conclusions on the overall adequacy of local emergency preparedness, local emergency responders with suggestions as to which emergency preparedness improvements should be undertaken, and local residents with a better understanding of risk mitigation measures.

1. Introduction

Despite an increasing need for safe manufacturing and disposal of hazardous materials, the siting and operation of hazardous facilities has met increasing resistance

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in recent years. As a result, the frequency with which facilities such as hazardous waste incinerators have been sited successfully actually appears to be decreasing [1] .

Recent examinations of opposition to hazardous facility siting have yielded suggestions for improved risk communication, early community participation, and provision of incentives. Recent guidance on risk communication advises sources to recognize the differences in the way their audience may conceptualize risk, to treat these differences with respect, and to provide information in a context that enhances the listener's understanding [2–4]. Increased participation by affected communities in the early stages of the siting process has been proposed as a means of establishing a greater sense of trust and control over the siting process [5]. A third suggestion has been to improve the incentives for accepting the facility [6]. Such incentives include mitigation measures, which reduce the risks of the facility and its operations, and compensation, which provides additional benefits intended to offset the risks remaining after all mitigation measures have been implemented.

Another potentially useful but hitherto neglected method of addressing local opposition to hazardous facility siting involves community preparedness for timely and effective emergency response to a release of hazardous materials. Assessing emergency preparedness would be useful because it addresses one of the principal reasons for public opposition identified in a recent EPA report – concern about hazardous material spills in storage, treatment and handling [7]. An emergency preparedness assessment could be an effective framework for risk communication and public involvement because it addresses relatively simple and familiar social systems rather than the unfamiliar engineered systems comprising nuclear power plants, hazardous waste incinerators, and other complex technological facilities. The topics discussed in evaluating local emergency preparedness are ones with which local residents have a significant degree of expertise and can readily understand, thus promoting more effective risk communication. Moreover, if the existing state of emergency preparedness is determined to be inadequate, upgrades can be identified whose increased protection mitigates hazards from the facility. Indeed, because emergency preparedness actions for a hazardous facility are relevant to a variety of other natural and technological hazards, the spillover effects from addressing the risks of the hazardous facility also can be thought of as compensation that mitigates the risks of other hazards to which the community is vulnerable.

Community emergency preparedness for incidents involving hazardous materials can be evaluated with respect to two sets of overlapping standards. The first set of evaluative standards is the guidance contained in the *Hazardous Materials Emergency Planning Guide, NRT-1* [8]. This manual, which describes a planning process and lists a specific set of criteria for emergency plans, has been developed by a committee of 14 US federal agencies having operational responsibility for emergency planning and response to hazardous materials incidents.

The second set of evaluative standards is based upon the principles derived from scientific research on emergency preparedness and response. This second set of standards is derived from decades of research by scientists from a variety of disciplines in the social and behavioral sciences [9–11]. These standards represent an assessment of the current state of scientific knowledge about emergency planning.

The criteria drawn from operational experience and scientific research are overlapping rather than mutually exclusive because operations professionals and researchers have investigated many of the same incidents (albeit with different purposes and methods of investigation), and because there is much interchange between the two groups – with operations professionals describing unresolved problems of planning and implementation, and researchers reporting the conclusions of their work.

As a result of the experience in emergency operations and disaster research, it is possible to identify a number of principles that guide timely and effective response to natural and technological hazards [12]. These principles include preimpact assessment of the hazards to which the community is vulnerable, identification of community resources for emergency response, careful development of emergency plans, and implementation of training and drills. These principles are routinely applied by state and federal officials in evaluating local plans for responding to a variety of emergency situations and, specifically, to hazardous materials emergencies.

Evaluation of community preparedness for an accident involving a release of hazardous materials on-site or in transport to a facility can be conducted in two phases. The first phase involves the identification of community vulnerable zones, which are areas in which protective action would be required by the public in a chemical release. This involves identification of the hazardous facility site, designation of the routes by which hazardous materials will be transported to the site, determination of the identity and quantity of the hazard materials, and estimation of protective action distances.

The second phase involves assessing the adequacy of the community's Emergency Operations Plan (EOP) for responding to these hazards. Specifically, it is necessary to examine the quality of the existing emergency plans and assess the feasibility of its successful implementation during emergencies. This analysis provides a basis for drawing conclusions about the adequacy of the community's overall preparedness. In addition, this analysis can identify needs for further analysis and planning, acquisition of additional resources (e.g., facilities, equipment, materials, and trained personnel) and selection of the most suitable routes for transporting hazardous materials to the facility.

The specific methods by which the emergency preparedness analysis can be conducted will be described in the following sections. In addition, use of these methods will be illustrated by applying them to an emergency preparedness assessment performed in conjunction with risk analyses supporting GAF Chemical's successful application for a permit to build a hazardous waste incinerator in Linden, NJ, USA.

2. Identification of vulnerable zones

Identification of the facility site and designation of the transportation routes over which the hazardous materials will be transported reveals the location of potential release points inside and outside the plant perimeter. Once this information is available, it is necessary to identify the contents and quantities of potential hazardous materials shipments to the facility site. Many manufacturing facilities will have a relatively short list of hazardous materials, while other facilities such as warehouses and hazardous waste incinerators may have a wide variety of hazardous materials being transported to the site. In some cases, there will be standardized quantities such as a known number of rail tank cars per month that are transported to the site, and relatively constant quantities of hazardous materials stored on the site. In other cases, shipment and storage data may be quite variable and may even need to be estimated from records of hazardous wastes generated and shipped within the state in which the facility is located.

Estimating the size of the downwind protective action distances surrounding the site and transportation routes can be accomplished by means of three methods. First, each of the list of chemicals identified in the previous step can be analyzed using dispersion models to calculate plume isopleths [13]. Such analyses yield relatively precise and scientifically defensible results, but require time, expertise and computer resources not available to most communities.

A second method is to cross-reference the list against the Table of Extremely Hazardous Substances (EHSs) contained in the US Environmental Protection Agency's *Technical Guidance for Hazards Analysis* [14]. Vulnerable zone sizes for EHSs then can be calculated using the screening procedure outlined in Section 3.1 of the *Technical Guidance*. This procedure first requires identification of the EHSs and the maximum quantity of each EHS that could be released in a maximum credible accident. The procedure next requires determination of the EHS's liquid factor ambient (a numerical index of its speed of evaporation), which is listed in one of the tables of the *Technical Guidance*. The release quantity and the liquid factor ambient are used to calculate the release rate (measured in lb/min) for the maximum credible accident involving that EHS. Once the release rate has been computed, it is used together with the level of concern (an index of relative risk, measured in g/m^3, that also is listed in a table of *Technical Guidance*) as entry values to a table of vulnerable zone radii.

Third, the list of chemicals can be screened, using the US Department of Transportation's Emergency Response Guidebook (*DOT-ERG*) [15], to identify those chemicals whose guides advise protective action beyond the immediate release site. Vulnerable zone sizes for chemicals listed in the *DOT-ERG* can be taken directly from the recommendations contained in the emergency response guides or, where applicable, the Table of Protective Action Distances.

Although the first approach provides more accurate results, the latter two approaches also are likely to be useful in identifying the most salient chemical hazards because they are the sources most likely to guide the planning and response of community emergency management agencies. In many cases, the distances provided by the latter two sources are likely to be conservative (i.e., lead to greater protective action distances) because the *Technical Guidance* was deliberately simplified to provide screening analyses for local emergency planners and the *DOT-ERG* was designed to provide emergency guidance for first responders. Systematic differences in the results of these methods should be anticipated because the ones most accessible to community members yield the longest protective action distances. The smaller protective action distances yielded by a plume dispersion model (the method most likely to

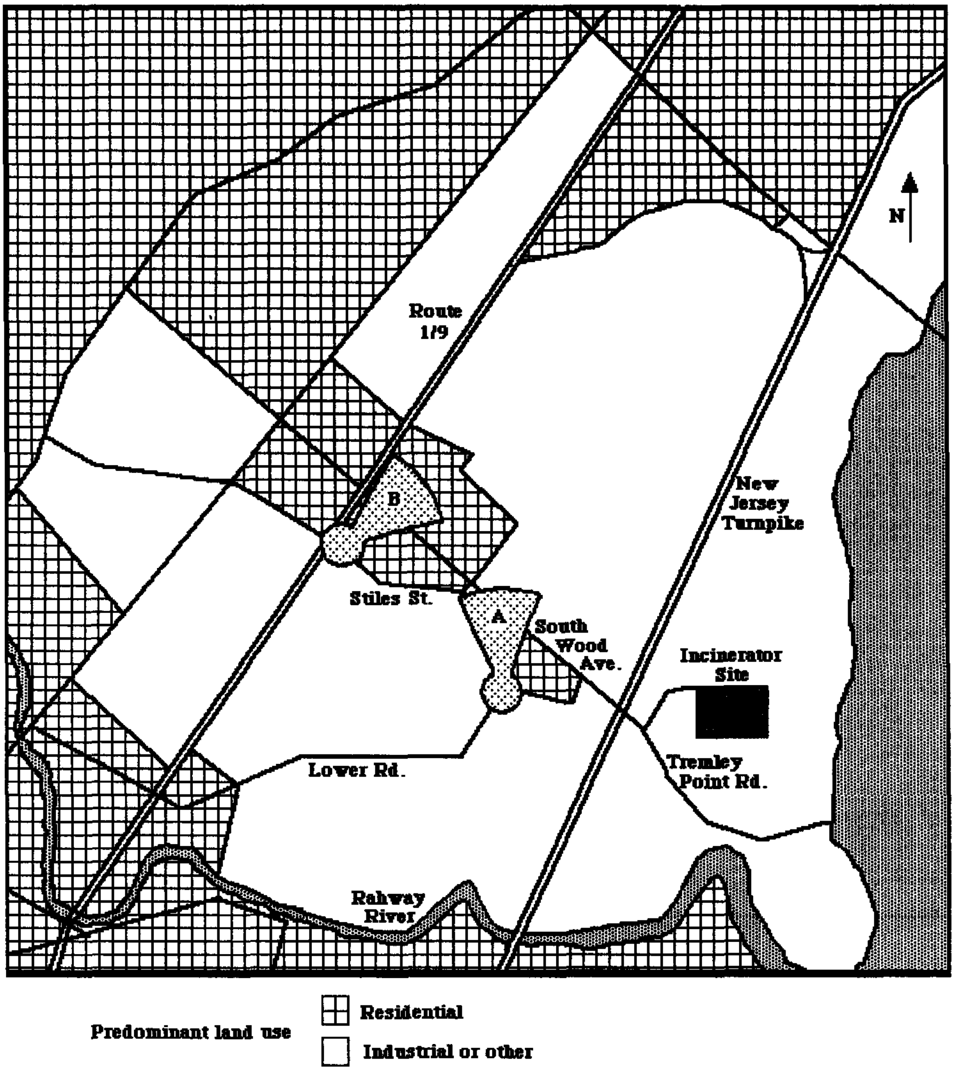

Fig. 1. Schematic map of Linden, NJ, USA.

be used by professional risk analysts) are susceptible to misinterpretation as a deliberate attempt to understate the risks of an emergency release.

2.1. Application to Linden

As Fig. 1 indicates, the proposed site of the incinerator is in an industrial area east of the New Jersey Turnpike. Trucks hauling hazardous waste would access the site by travelling on US Route 1/9 into Linden and, from there, along city streets to the incinerator site. New Jersey siting regulations exempt transportation risk analyses from examining interstate highways and, thus, the analyses focussed upon alternative routes along the city streets connecting US Route 1/9 to the incinerator site. These alternate routes involved taking some combination of (from north to south) South Wood Avenue, Stiles Street, and Lower Road, to Tremley Point Road and then to the site [16]. Two additional alternatives later considered were transportation by truck directly from the New Jersey Turnpike and transportation by rail from a terminal north of the site. The latter two alternatives involved the same types of analyses as those from Route 1/9 to the site and are not discussed further here.

The likely contents of hazardous waste shipments to the incinerator site were determined from an earlier report that inventoried hazardous waste shipments within the state of New Jersey [17]. Seven wastes were identified as salient hazards for shipments to the proposed incinerator because *DOT-ERG* recommended protective action within a 0.5 mile radius if a truck transporting these wastes were involved in a fire. Two other wastes were classified as salient hazards because *DOT-ERG* recommended immediate isolation of 150 ft, followed by further isolation of a 0.5 mile radius if a truck transporting them is involved in fire. Five additional wastes were classified as salient hazards because *DOT-ERG* recommended protective action to a distance listed in the Table of Protective Action Distances. Nine wastes contained constituents that were identified as extremely hazardous substances from Exhibit C-1 in the *Technical Guidance* and calculations of protective action distances were made using the procedure described in that manual.

Table 1 summarizes the data from the analysis of the 23 chemicals identified in the screening analysis for shipments to the proposed incinerator. Column A of the table lists the chemicals identified either through *DOT-ERG* or the *Technical Guidance* list of EHSs, while Column B lists the shipment quantities and Column C lists the assumed release quantities. Further details of the assumptions and intermediate calculations are reported elsewhere [18].

Column D lists the levels of concern (LOC) for each chemical identified in the *Technical Guidance* as an EHS, while Column E lists the chemical's liquid factor ambient. The table is missing entries in column E (liquid factor) if the chemical was not listed as an EHS or was not listed in the *Technical Guidance* in a physical form that would be accepted at the site. Column F contains the release rates calculated from the release quantities and the liquid factors, while Column G contains the vulnerable zone radius resulting from calculations performed for the chemicals identified as EHSs. These vulnerable zone distances are taken from a table in the *Technical Guidance* (Exhibit 3-2) based on urban terrain, with F atmospheric stability class and a wind speed of 3.4 mph. Finally, Column H contains the isolation/evacuation distance listed in the *DOT-ERG* for the chemicals listed there.

Five cells in Column G contain double asterisks, indicating the computed distance was significantly less than 0.1 mile. The *Technical Guidance* cautions the estimation procedure cannot produce valid estimates of distances less than 0.1 mile. Moreover, the table is also missing six entries in column H (DOT protective action distance) for wastes that are not listed in the *DOT-ERG*, or are cross-listed to Response Guides

Table 1

Summary data for chemicals identified in screening analysis

Waste constituent A	Shipment quantity B (drums)	Release quantity C (lb)	Level of concern D (gm/m^3)	Liquid factor E ambient	Release rate F (lb/min)	Vulnerable zone G (mile (ft))	Protective action distance H (mile (ft))
Acetone	(Bulk)	25 000	(Not an EHS)				0.5 (2700)
Acrolein	1	500	0.0011	0.007	4.9	0.7 (3700)	3.0 (16000)
Acrylonitrile	1	500	0.11	0.004	2.8	[a]	0.5 (2700)
Aniline	54	2000	0.02	0.00005	0.14	[a]	[a]
Carbon disulfide	1	500	0.16	0.01	7	0.1 (550)	0.5 (2700)
Chlordane	5	500	0.05	0.000000001	0.0000007	[a]	0.5 (2700)
Chlorobenzene	(Bulk)	25 000	(Not an EHS)				0.5 (2700)
Chloroform	137	2000	0.49	0.009	25.2	0.1 (550)	[a]
Chloromethyl methyl ether	1	500	0.0018	0.009	6.3	0.5 (2700)	(Not listed)
Chlorotoluene	(Bulk)	25 000	(Not an EHS)				0.5 (2700)
Crotonaldehyde	1	500	0.04	0.001	0.7	0.1 (550)	0.2 (1100)
Dichloromethane	(Bulk)	25 000	(Not an EHS)				0.5 (2700)
Ethyl acetate	(Bulk)	25 000	(Not an EHS)				0.5 (2700)
Ethylene oxide	3	500	(EHS only in gaseous state)				[b]
Formaldehyde	(Bulk)	25 000	(EHS only in gaseous state)				0.5 (2700)
Furan	1	500	0.0012	0.03	21.0	1.5 (8000)	0.5 (2700)
Methacrylonitrile	1	500	0.003	0.003	2.1	0.3 (1600)	0.5 (2700)
Methyl hydrazine	1	500	0.00094	0.001	0.7	0.3 (1600)	5.0 (27000)
Nitrobenzene	9	500	0.1	0.0000003	0.00021	[a]	[a]
Phenol	(Bulk)	25 000	(EHS only in powdered, molten or dissolved form)				[a]
Phorate	22	1000	0.0001	0.00000008	0.000112	[a]	(Not listed)
Tetranitromethane	1	500	0.008	0.001	0.7	0.1 (550)	0.4 (2200)
Toluene	(Bulk)	25 000	(Not an EHS)				0.5 (2700)

[a] Wastes with vulnerable zones less than 0.1 mile (Column G) or with no protective action distance listed beyond the immediate spill area (Column H).

[b] Compressed gas; not accepted at the GAF incinerator.

that do not identify protective action distances beyond the immediate hazard area. Protective action distances for these four materials are denoted by double asterisks.

Examination of Table 1 shows the protective action distances in Column H are generally, but not uniformly, larger than the vulnerable zone (VZ) radii in Column G. The reason for the disparity between the two sources of federal guidance is that the VZ radii from the *Technical Guidance* are derived from specific release quantities, while the protective action distances taken from the *DOT-ERG* are based on a crude categorization of releases as 'small spills' or 'large spills'. It is apparent from the table that even the category 'small spills' overestimates the quantity of material released. Moreover, the analysis based on the *Technical Guidance* contains significant conservatism because it assumes pure product rather than waste products. The conservatism arises because hazardous wastes typically are more dilute than the pure materials from which they are derived and, therefore, deliver lower concentrations in the event of an accidental release.

Columns G and H of Table 1 show that almost all (19 of 22) of the materials listed have vulnerable zones of 0.5 mile or less, suggesting this is an appropriate choice as a conservative vulnerable zone around the site and transportation routes. This conclusion is further supported by the fact that the shipment volume for each of the remaining three materials was indicated in previous analyses to be only one drum per year. Consequently, such chemicals should be considered separately and given closer scrutiny to determine if the shipment quantity and concentration justifies downward revision of their protective action distances.

3. Emergency Operations Plan (EOP) evaluation

The vulnerable zones should be examined to identify all political jurisdictions that fall within them and which, consequently, would be involved in any emergency response. Some emergency scenarios could involve two or more cities and, thus, the county could become involved to provide coordination between them. Consequently, EOPs for both cities and the county must be examined to assess the capability for timely and effective coordination of their emergency response to an incident.

3.1. Evaluation criteria

NRT-1 identifies eight planning elements: A: Introduction; B: Emergency Assistance Telephone Roster; C: Response Functions; D: Containment and Cleanup; E: Documentation and Investigative Follow-up; F: Procedures for Testing and Updating Plan; G: Hazards Analysis (Summary); H: References. Only a few of these elements are directly relevant to evaluating the ability of the plan to implement prompt and effective protective actions by the public [9]. This can be seen in the lower portion of Fig. 2, which shows that emergency assessment, protective response and emergency management are a critical path for reducing the public's exposure to a hazard. Thus, an emergency preparedness assessment for immediate response to hazardous materials can de-emphasize planning elements D, E, F, and H.

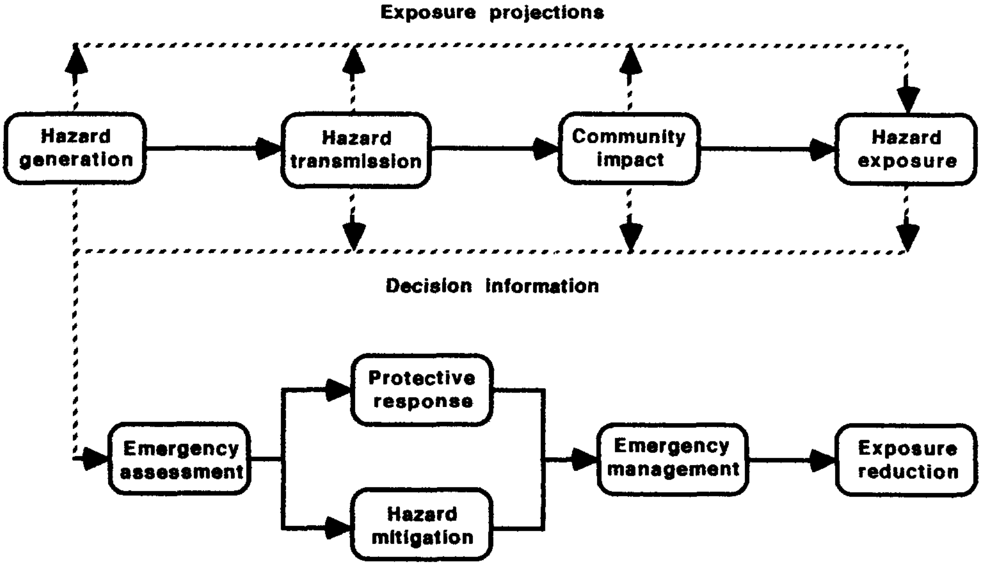

Fig. 2. Chains of events for environmental hazard and community response.

Moreover, only a subset of the specific criteria within the remaining planning elements (A, B, C, and G) are immediately essential to protecting the risk area population from hazard exposure. The specific criteria on the critical path for implementing in-place protection or evacuation include four from Element A, including A.1 (Incident Information Summary), A.3 (Legal Authority and Responsibility), A.6 (Assumptions/Planning Factors), and A.7 (Concept of Operations). Also included is Element B, and eleven specific criteria from Element C. These are C.1 (Initial Notification), C.2 (Direction and Control), C.3 (Communications), C.4 (Warning Systems and Emergency Public Notification), C.5 (Public Information/Community Relations), C.7 (Health and Medical Services), C.9 (Personal Protection of Citizens), C.11 (Law Enforcement), C.12 (Ongoing Incident Assessment), and C.13 (Human Services). The final item is Element G. These specific criteria review the capability of local EOPs to guide prompt and effective protective action by the public. The primary focus is on the degree to which the community emergency plan's Hazardous Materials, Alert and Warning, Emergency Public Information, Evacuation, and Law Enforcement Annexes address each of the specific criteria highlighted in this section.

3.2. EOP evaluation in Linden

Analysis of the Linden EOP revealed all of the relevant criteria had been addressed. Moreover, the plan generally provided clear and consistent guidance to local emergency responders in performing their emergency assessment, protective response and emergency management functions. Further details regarding this evaluation have been reported elsewhere [18].

4. EOP implementation analyses

Evaluation of the extent to which community emergency plans meet established criteria can be thought of as a screening analysis that assesses whether the plan addresses the essential emergency response functions and is internally consistent. However, effective emergency preparedness requires more than just the development of written plans [19–22]. To determine if the EOP can provide a timely and effective response to the specific types of situations likely to arise during an emergency, it is helpful to conduct a more detailed analysis that considers each step of a chain of emergency response actions in light of the specific conditions that exist in the community.

Specifically, the analysis presented below examines detection and notification, protective action decision making, warning and public information, and protective action implementation. Each of these functions must be examined to determine if there is *reasonable assurance that the public health and safety can be protected in an emergency*. This standard of *reasonable assurance*, which is the standard of evaluation used by federal agencies in evaluating radiological emergency response plans [23, 24], recognizes the impossibility of guaranteeing absolute safety. It does, however, recognize the need to assess the capability of emergency response organizations to overcome plausible obstacles in coping with a wide variety of emergency scenarios.

4.1. Analysis of detection and notification

Prompt response to a hazardous materials incident is essential in urban environments because of the large population at risk. The first step in the emergency response is detection of the incident and notification of emergency responders. The local EOP should provide adequate assurance of 24 h availability of a contact point to activate the community emergency response organization. The plan also should make adequate provision for promptly disseminating notification laterally to adjacent jurisdictions and upward to relevant county, state and federal agencies. The greatest uncertainty about this process arises in regard to the initial detection of a transportation incident. Detection is most likely to be achieved by the hazardous materials transport vehicle driver contacting emergency authorities with radio or cellular telephone, or by onlookers telephoning the police or fire dispatcher. Moreover, although onlooker calls often come from people who have observed an accident from their residences or places of business, the increasing availability of cellular telephones in automobiles makes the drivers of other vehicles a likely source of the first contact with the emergency response organization. This not only increases the likelihood of detection at all hours of the day, but also increases the speed of detection, as well. Although limited, the available data on incident reporting indicate that dispatcher notification is more rapid during the day than at night and also is more rapid in urban areas than in rural areas [25]. During daytime and evening hours (7 AM to 11 PM), approximately 95% of all urban accident notifications are received in 10 min or less, while only about 80% of rural notifications are made within this time period. During night hours (11 PM to 7 AM), the percent of urban accident notifications received within 10 min drops to 90%, while the percent of rural notifications made within this time period drops to 65%.

4.2. Analysis of protective action decision making

The two principal protective actions appropriate for a hazardous materials or hazardous waste emergency are in-place protection and evacuation. As Lindell and Perry [9] note, in-place protection is a simple action that can be implemented very quickly. It requires only that those in the risk area enter a structure with adequate protection from air infiltration, close the doors and windows, and shut off any sources of ventilation from the outside. When the plume has passed, occupants of the structures must be given an all-clear signal so they can air out the partially contaminated buildings [26].

Evacuation also can be relatively simple. In some cases, the plume is so small and well defined that it is possible to walk out of the risk area. More often, however, the general public must evacuate in cars. Planners must also be aware that a significant portion of the population has limited mobility because they require close supervision (jail prisoners, young school children, handicapped elderly), are nonambulatory, or even require life support. In addition, there are those who routinely receive transportation support from friends, relatives or neighbors, or use public transit. Most of those who routinely receive transportation support from informal sources will also obtain such assistance during an emergency. Nonetheless, it is important for emergency planners to anticipate the level of need for transportation support and the locations in which it is most likely to be experienced.

The EOPs of most jurisdictions focus on evacuation as a protective response to hazardous materials incidents. Moreover, the *DOT-ERG* is used to guide the selection of protective action distances. The principal advantage of relying on the *DOT-ERG* is that prompt and conservative protective action decisions can be made by an incident commander at the scene. The disadvantage of relying solely on this guide is that the scope of the evacuations can be unnecessarily large for the amount of chemical available for release and that in-place protection often is not considered, even for population segments having limited mobility.

Recent research shows the time required to make a protective action decision has varied substantially from one incident to another [27]. The longest delays are likely to be due in part to inherent ambiguities in assessing the severity of the situation. However, unnecessary delays can be avoided if incident commenders have been trained in the use of the *DOT-ERG*, and if the community's EOP clearly indicates to on-scene personnel when the authority for protective action decision making will be assumed by higher level authorities such as the emergency management coordinator or mayor. Careful coordination of responsibility for protective action decision making would avoid the problem experienced in a number of emergencies in which each responding agency assumed some other agency was taking primary responsibility for protection of the public. The plan also should be clear about the role of any outside hazardous materials response teams in providing advice regarding appropriate protective actions.

4.3. Analysis of warning and public information

Most local emergency plans anticipate warning those in the risk area by means of route alerting with loudspeakers broadcasting warnings from emergency vehicles and by face-to-face contacts with emergency responders going door-to-door. Both of these warning mechanisms would be supplemented by emergency information disseminated through the Emergency Broadcast System (EBS), which is a network of predesignated radio and television stations that have agreed to transmit official emergency messages to the public during disasters [28, 29]. Route alerting, door-to-door, and EBS are the most commonly used methods for disseminating warnings because they require little investment in specialized equipment, provide adequate penetration of normal activities, are not susceptible to significant message distortion, and achieve adequate rates of dissemination over time [9, 30]. However, local EOPs often do not specifically describe the warning procedures for those with hearing difficulties or the non-English speaking. Nor do they set priorities for early dissemination of warnings to special facilities whose residents would take abnormally long times in evacuating, or provide for alternate mechanisms for warning these facilities.

Communities with high hazard vulnerability can establish diverse and redundant mechanisms for rapidly disseminating warnings in an emergency by including other warning mechanisms, such as National Oceanographic and Atmospheric Administration (NOAA) Weather Radio and automated telephone warning systems. NOAA Weather Radio originally was developed to provide prompt warnings of weather emergencies, but arrangements can be made to use it for other types of emergencies, as well. NOAA Weather Radio broadcasts a special tone to activate radios which can then receive a voice message describing the emergency and providing specific instructions for response [31].

Automated telephone systems, which are available from a number of vendors, automatically dial numbers on a list and play a recorded message when the phone is answered. One automated telephone system (ATS), known as the *Prompt Inquiry and Notification System* (PINS), has been operated successfully at a chemical manufacturing facility in southern New Jersey for over three and a half years [32]. This system provides two functions: *inquiry* and *notification.* The inquiry function can be called by residents at any time to obtain prerecorded information about plant status, significant incidents, unusual situations (e.g., odors), and public service announcements. The notification function can be used to identify sectors of the community in the path of a plume and alert affected households to the emergency by playing a recorded warning message each time a telephone is answered.

An ATS could enhance warning dissemination in three ways. First, the rate of dissemination could be enhanced by initiating notification calls on the periphery of the risk area and working inward, while route alerting and face-to-face notification begin in the center of the risk area and work outward. This would allow the ATS to compensate for the relatively slow rate of warning dissemination provided by these other two methods. Second, assurance of warning saturation could be enhanced by continuing ATS notification calls into the center of the risk area (which already would have been traversed by route alerting). By doing this, the ATS could achieve penetration of normal activities (especially noisy indoor activities) that might have drowned out route alert loudspeakers. Last, continuing ATS notification calls into the center of the risk area would yield indirect verification of warning receipt because nonresponse to notification calls is likely to be caused by evacuation.

An ATS also could significantly speed the notification of the non-English speaking and the hearing impaired because specific warnings could be disseminated in the native language of any non-English speakers. Moreover, telephone notification of the hearing impaired could take advantage of light flasher signalling systems already incorporated into existing telephone instruments.

Another recommendation regarding warning and public information involves giving consideration to early dissemination of warnings to special facilities whose residents are likely to take abnormally long times in preparing to evacuate. This can be accomplished by setting priorities for warning these facilities by automated telephone notification or by providing tone alert radios for warning these facilities.

4.4. Analysis of protective action implementation

The success of protective action implementation depends substantially upon the number of persons in the vulnerable zone, together with their ability and willingness to implement the recommended protective actions. The number of persons can vary significantly over time, with diurnal, weekly and seasonal variations being common.

Implementation of in-place protection is relatively similar for all members of the affected population. At least one person in each occupied structure must receive a warning and respond by shutting off all means of ventilation. Evacuation response, however, differs significantly from one segment of the public to another, and it is important to examine the distinctive evacuation requirements of private vehicle users, mass transit users, school children, special facilities residents, transients, and dispersed groups such as handicappers living throughout the community. Each of these three implementation issues, in-place protection, evacuation of the general public, and evacuation of special facilities, is examined in the following sections.

4.4.1. Implementing in-place protection

As noted earlier, most local emergency plans do not explicitly address sheltering in-place as an emergency response alternative, let alone indicate analyses have been conducted to examine the feasibility of this protective action for the public or for special populations in the vulnerable zone. Linden's EOP was no exception to this rule; no mention of sheltering in-place could be found. Communities should consider conducting surveys of special facilities and representative residences in the vulnerable zone to assess their air infiltration rates. Such surveys would provide the basic information permitting emergency managers to determine if in-place protection is a feasible protective action for the types and quantities of materials involved in an incident.

At minimum, a curbside survey of the vulnerable zones for the transportation routes should be conducted to determine the extent to which residential structures in the area have storm windows and doors. If storm windows and doors are present, it is likely that lower cost measures such as weather stripping also have been adopted. Thus, all other things being equal, the presence of storm windows and doors suggests residences have significant levels of resistance to air infiltration. However, if many of the structures are old, there is likely to be leakage elsewhere in the structure. Consequently, further analyses should be conducted to determine typical levels of air changes per hour for residential structures in the vulnerable zones. Such analyses are especially important for special facilities housing relatively immobile populations (e.g., hospitals, nursing homes, schools, and jails). Once data on air infiltration rates have been obtained, it is possible to examine alternate hazardous materials release scenarios to identify the types of situations in which sheltering in-place provides adequate protection.

In the event that local structures are insufficiently airtight, consideration should be given to promoting a cooperative program with the local power utility to upgrade the weather sealing of these structures. The vulnerable population would benefit from such a program in two ways. First, decreasing air infiltration rates would provide increased protection in a hazardous materials release. Second, decreasing air infiltration rates would also decrease monthly energy consumption, thus providing a direct economic return to local residents.

4.4.2. Implementing evacuation of the general public

Timely and effective evacuation of private vehicle users in the risk area can be achieved if two conditions are met. First, everyone in the vulnerable zones always must have at least one evacuation route that is safe, regardless of the hazardous materials release location and the wind direction. Second, the evacuation road network must have the capacity to handle the load of evacuating vehicles so that the last vehicles in line are not overtaken by the plume.

With regard to the first condition, examination of Fig. 1 shows all the hazardous waste transportation routes in Linden provide at least one evacuation route under all conditions for the population affected by a release. The greatest threat to these routes would involve a release of waste containing a chemical that, in its pure form, would have a protective action distance greater than 0.5 mile when the wind was blowing directly north. Such a plume (Plume A on the map) would prevent residents of the neighborhood immediately to its east from using either of the normal routes out of the area, Lower Road and South Wood Avenue. Even so, this neighborhood could be evacuated successfully using a controlled access gate onto the New Jersey Turnpike.

With regard to the second condition, it is important to note the flow of evacuation traffic is governed by the "number and distribution of evacuating vehicles; rate at which these vehicles enter the roadnet (the loading function), which is influenced by the distribution of warning and preparations times; normal capacities of the individual links, and the overall geometry of the roadnet; uncontrollable external events that affect roadway traffic capacities; and transportation support and traffic management actions performed by emergency response personnel" [9, p. 230]. Accordingly, it appears the most congested evacuation would occur if waste containing a chemical with a protective action distance greater than 0.5 mile were released on Stiles Street immediately adjacent to its intersection with Route 1/9 when the wind was blowing northeast (Plume B on the map). In this situation, the plume would prevent any evacuation to the northwest and force evacuation of the surrounding neighborhood toward the southeast onto a single route, Lower Road. The total number of evacuating vehicles can be estimated from the number of dwelling units in the evacuation area and the number of evacuating vehicles per household. The number of dwelling units in the evacuation area can be estimated from the total number of dwelling units in this neighborhood (this procedure is conservative because one would expect households west of the plume centerline to be evacuated directly onto Route 1/9). A previous analysis [16] estimated the number of dwelling units in this neighborhood at approximately 1200, while evacuation data [9, Table 8.5] indicate 67% of households in one study evacuated in one vehicle and most of the remainder evacuated in two vehicles). Thus, the total number of evacuating vehicles would be 1600.

The loading of the evacuation route can be estimated by assuming [9, Fig. 8.8] that 30% of the evacuees depart in the first 15 min after warning receipt, 50% of the evacuees depart in the second 15 min, and the last 20% of the evacuees depart in the third 15 min. This *assumed* loading function is more rapid than any *actually* reported in the evacuation literature and, thus, is conservative because the assumed loading would be more likely than any actual loadings to produce congestion. According to the assumed loading function, there will be 480 vehicles on the road in the first 15 minutes, 800 vehicles in the second 15 min, and 320 vehicles in the third 15 min. Under these conditions, some congestion could result if all of the evacuees are routed onto Lower Road and traffic capacities were as low as the 1200 vehicles per hour per lane expected for forced flow on a two-lane undivided rural road with one lane in each direction [[33], pp. 2–22]. This congestion could be avoided in an actual evacuation by routing some of the traffic down South Wood Avenue onto the New Jersey Turnpike. The Turnpike would certainly have sufficient capacity for this traffic if Turnpike authorities are notified to control upstream traffic. Congestion could also be avoided through increasing the capacity of Lower Road by directing both lanes one-way southbound. Moreover, even if the traffic were congested, *the tail of the traffic queue would develop in an area that is at a right angle to, not under, the plume.* Thus, even if a traffic queue did develop, no exposure to the plume would be expected to result.

4.4.3. Implementing evacuation of special facilities

As Planning Element A.6 indicates, emergency planners should examine vulnerable zones for the presence of facilities requiring special consideration. Table 2 (derived from Lindell and Perry's Table 4.2) provides a reference list of such special facilities. The eight types of facilities on this list (nursing homes, athletic fields, community recreation centers, churches, apartment complexes, commercial/industrial parks, business districts, and elementary schools) found within 0.5 mile of the alternate transportation routes to the incinerator site illustrate the importance of examining such facilities.

Moreover, Table 3 (derived from Lindell and Perry's Table 4.3) indicates these facilities are of special concern because the facility users' personal mobility, density, access to effective in-place protection, or need for transportation support might be an

Table 2
Reference list of special facilities

Health related
Hospitals
Nursing homes
Halfway houses (drug, alcohol, mental retardation)
Mental institutions

Penal
Jails
Prisons
Detention camps
Reformatories

Assembly and athletic
Auditoriums
Theaters
Exhibition halls
Gymnasiums
Athletic stadiums or fields

Amusement and recreation
Beaches
Camp/conference centers
Amusement parks/fairgrounds/race courses
Campgrounds/RV parks
Parks/lakes/rivers
Golf courses
Ski resorts
Community recreation centers

Religious
Churches/synagogues/temples
Evangelical group centers

High density residential
Hotels/motels
Apartment/condominium complexes
Mobile home parks
Dormitories (college, military)
Convents/monasteries

Transportation
Rivers/lakes
Dam locks/toll booths
Ferry/railroad/bus terminals

Commercial
Shopping centers
Central business districts
Commercial/industrial parks

Educational
Day-care centers
Preschools/kindergartens
Elementary/secondary schools
Vocational/business/specialty schools
Colleges/universities

impediment to the timely implementation of protective actions. Concerns about each of these types of facilities are discussed in more detail below.

Nursing homes and hospitals: These facilities pose significant evacuation problems with respect to the timeliness of evacuation because their residents have reduced mobility and require transportation support [34]. Indeed, safety may be a concern for any evacuating residents on life-support systems. However, evacuation would not be required if the structure provides adequate protection against air infiltration and ventilation systems can be shut down promptly in response to notification from emergency management authorities.

Athletic fields and parks: Athletic fields are of concern because they provide no opportunity for in-place protection from inhalation of hazardous materials. Moreover, to the degree that they concentrate significant numbers of people from outside the area in a small area, athletic fields can add to the size of the evacuating population. However, the facility users are typically ambulatory and have their own transportation. It should be recognized that athletic fields are likely to be in use primarily during evenings and weekends, which are times when local commercial or industrial facilities are likely to be operating at reduced levels. Thus, the use of athletic fields and parks

Table 3
Characteristics of special facilities

Characteristics	Categories
Mobility of users	Ambulatory Require close supervision Nonambulatory Require life support
Permanent residence of users	Facility residents Residents of hazard impact area, but not of the facility (e.g., prison guards) Transients
Periods of use	Days of week/hours of day Special events
User density	Concentrated Dispersed
In-place protection	Highly effective Moderately effective Minimally or not effective
Transportation support	Would use own vehicles Require buses or other high occupancy vehicles Require ambulances

would coincide with a reduction in the overall loading of evacuation routes from commercial and industrial sources.

Parks that include swimming pools are likely to be in use all day long during the summer season, but its users are also likely to be ambulatory and have their own transportation, while capacity often is not large enough to materially affect the loading of evacuation routes. However, users who arrived on public transportation might need assistance in leaving the area. This is unlikely to be a problem because the well-documented prevalence of socially integrative responses in emergencies [10] suggests those without personal vehicles are very likely to be offered rides by others in the area. Specific estimates of the number of users requiring assistance can be obtained by conducting facility user surveys.

Community recreation centers: A community recreation center also is likely to attract significant numbers of people from outside the area, adding to the size of the evacuating population. Like users of the athletic fields and parks, community recreation center users are typically ambulatory, have their own transportation, and are likely to be using the facility only during evenings and weekends. Thus, community recreation centers also are likely to be in use at a time when the overall loading of evacuation routes from the area would be reduced. Unlike athletic fields, community recreation centers might provide an opportunity for in-place protection from hazardous materials inhalation.

Churches: Like other facilities, churches must be examined to determine their size and, thus, the degree to which they might add significantly to the loading of evacuation routes in an emergency. Like athletic field and recreation center users, church goers would be mobile, have their own transportation, and be using the facility during off-peak hours of commercial and industrial activity. Finally, the structures might serve as effective in-place protection.

Hotels and motels: These facilities have a relatively high population density, but the occupants of these facilities are ambulatory, have their own transportation and are most likely to be in the vulnerable zone during periods of reduced industrial activity. Because they are occupied by transients, motels are likely to be evacuated promptly when a warning is received, but occupants may require very specific directions when evacuating because they are likely to be unfamiliar with the area. Motels might provide adequate in-place protection from inhalation of hazardous materials.

Apartment complexes: Apartment complexes are of concern principally when high population density could add significantly to the loading of limited evacuation routes. In the event that protective actions were required in the area of these apartment complexes, the structures would probably serve as effective in-place protection.

Commercial/industrial parks: These facilities have a high population density that could clog evacuation routes, especially during shift changes. Evacuation of such facilities often can be initiated promptly because the entire population of each facility can be notified by a public address system following receipt of a telephone call from emergency management officials. Moreover, the occupants of these facilities are ambulatory and have their own transportation. Occupants of these facilities are likely to evacuate promptly when warned and do not require specific directions because they are familiar with the area. Many commercial and industrial facilities are likely to provide adequate in-place protection from inhalation of hazardous materials.

Local business districts: Local business districts might have a significant proportion of their customers arriving by means of public transportation and, thus, needing transportation support in the event of an evacuation. For those arriving by car, the extent of on-street parking will provide an indication of the extent to which this source of vehicles will contribute significantly to evacuation route congestion.

Schools and day-care facilities: Schools are of concern for emergency planning because elementary school students require close supervision and transportation support during an evacuation. The latter problem is compounded by the number of students, coupled with the period of school occupancy. Specific procedures for the evacuation of schools should be developed and appended to the Emergency Plan's Evacuation Annex. Specifically, this procedure should provide for immediate notification of schools in the event of a hazardous materials incident. The procedure should direct teachers and students to take immediate protection by sheltering in-place pending a decision by the authorities about whether evacuation of the school is advisable. Next, bus companies should receive immediate notification to stand by (or activate if necessary). The procedure should provide for the dispatch of as many buses as are required to evacuate all students in one wave.

Traffic management procedures (including evacuation routing and access control) should be designed to assure the buses are given the highest priority for entry into the risk area, while bus drivers should be directed to transport the students and staff of the school to a predetermined Reception Center where the students can be reunited with their families. Because the operating hours of schools largely coincide with the hours of operation of industrial facilities, careful planning is required to ensure that arriving buses are not impeded by departing automobiles. Finally, parents should be notified at the beginning of the school year what is the procedure for reunification with evacuated school children. This procedure should specifically identify the Reception Center location and the need for parental cooperation with the EOP in order to ensure a timely and effective evacuation of schools. These arrangements must be made to ensure parents do not impede a school evacuation by attempting to enter the evacuation zone to pick up their children.

As was the case for nursing homes, evacuation of schools would not be required if the structure provides adequate protection against air infiltration and ventilation systems can be shut down promptly in response to notification from emergency management authorities. A school is likely to provide such protection from inhalation of hazardous materials, but this can be confirmed by air infiltration analyses.

5. Conclusions

Assessing community emergency preparedness has the potential for making a number of positive contributions to the siting of hazardous facilities. Assessment of emergency preparedness in Linden provided judicial and administrative review processes with conclusions about the overall adequacy of local emergency preparedness for transportation of hazardous wastes to the proposed GAF incinerator. Indeed, the company's permit application ultimately was approved by the state siting commission. In addition, the assessment provided local emergency responders with suggestions regarding emergency preparedness improvements that should be undertaken in anticipation of plant operation. Most of the recommended improvements would be just as effective in enhancing emergency preparedness for Linden's other hazardous facilities and transportation routes as they would be for the GAF incinerator and its transportation routes.

Of course, emergency preparedness assessment cannot eliminate all opposition. Cross-examination of the author's testimony on the Linden assessment described here raised five significant issues that were typical of intervenor contentions in hearings on other hazardous industrial facilities. These issues are the size of the risk area, cost of evacuation, secondary risks of protective response, timeliness of response, and the criterion of acceptability.

The size of the risk area, or vulnerable zone, can be a contentious issue because, as noted earlier, different methods of analysis lead to different estimates. Analysts estimating the size of a vulnerable zone should be aware of the different methods for conducting the analysis and be prepared to explain the differences among them. Local emergency responders are almost certain to use the *Technical Guidance for Hazards Analysis* or *DOT-ERG* as the basis for protective action decision making in an emergency. Thus, these distances should serve as the default basis for emergency preparedness assessments unless the hazardous materials facility operator, shipper, or carrier has established an explicit written agreement with local authorities for use of another value.

The cost of an evacuation is a concern sometimes raised by facility opponents but is, arguably, irrelevant to an assessment of emergency preparedness. Even if it were to be considered as an impact of facility siting, the cost of an evacuation is most likely to be negligible because of the limited geographical scope and temporal duration of a hazardous materials evacuation. A major snowstorm would be likely to have a much greater economic impact on the community.

Secondary risks of protective response are also raised as an objection but the principal sources of risk to evacuees caused by the evacuation itself are traffic accident risks and risks of aggravating pre-existing health conditions. Available evacuation data indicate "the accident rate for private vehicles is almost certain to be no higher and quite likely to be lower than during normal driving periods" [9, p. 100]. The possible exception to this conclusion would be for an incident occurring during severe weather condition [9, Appendix A, Section II.A.1].

Analyses of protective response are likely to elicit two types of concerns. One of these is that local residents will receive fatal exposures while trapped on evacuation routes overloaded by evacuees all departing at the same time. Analyses of the evacuation of the general public, as presented in Section 4.4.2, should resolve this concern.

The second concern is that plume onset will be so rapid local residents will receive fatal exposures before they can evacuate. In response, one should note first that it is not a foregone conclusion that an accident will necessarily produce an immediate catastrophic release. Many hazardous materials incidents minor or no releases at the outset. Second, even if an immediate release were to take place, the duration of exposure could be quite limited. A car travelling at normal speed for residential streets 25 mph, will be out of the most vulnerable zones (0.5 mile radius) in about 1 min.

Ultimately, however, the concerns about timeliness lead to the issue of acceptable risk. Specifically, it is *possible* that a rapid onset release could produce immediate fatalities. However, emergency preparedness can no more provide *absolute assurance* of complete safety than can any other mitigation measure. However, emergency preparedness can provide *reasonable assurance* that emergency response organizations can overcome plausible obstacles in coping with a wide variety of situations to protect the public health and safety. This standard of reasonable assurance is derived from the US Nuclear Regulatory Commission's safety requirements for the siting and operation of nuclear power plants [23, 24], but is equally applicable to the siting of other hazardous facilities as well. Linking local emergency preparedness with the NRC's standard of 'reasonable assurance' provides a basis for drawing conclusions about safety that can be presented in administrative proceedings about incinerator siting and operation.

At present, the margin of safety can only be described in qualitative, not quantitative, terms. That is, emergency preparedness analysts can make a global judgment about whether local emergency preparedness provides adequate assurance and describe the strengths and weaknesses of local emergency response resources that support their conclusion. However, methods yielding quantitative estimates of the timeliness and effectiveness of protective action decision making [27], sheltering in-place [26, 35] and evacuation [36, 37] are only in their early stages of development.

Moreover, emergency planning analyses can serve a risk communication function by providing a basis for describing potential accidents in terms of actual event sequences, and the actions local emergency response organizations would take to mitigate the risks of a release. This is especially likely to be important in presenting the results of probabilistic risk assessments because many such analyses assume no protective action is taken by the public in response to an accident. Risk analysts may believe that taking no credit for effective emergency response provides a desirable degree of conservatism in the analysis, but the atmosphere of suspicion and mistrust pervading most siting decisions may lead critics to believe emergency response has been omitted deliberately because it is completely ineffective and the analyst is attempting to conceal this from the public.

In summary, emergency planning analyses could provide a valuable supplement to other forms of risk communication based on psychometric and participation paradigms [38] . A combination of these methods could prove to be effective in obtaining greater public support for facility siting. Moreover, given society's increasing vulnerability to toxic chemical hazards – Cutter [39] recently noted the occurrence of 25 technological disasters in the past 15 years requiring the evacuation of 5000 or more persons – emergency preparedness assessment appears to provide an increasingly important method of assuring the public it will be protected after the facility has been constructed.

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