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An overview of protective action decision-making for a nuclear power plant emergency

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Abstract

Protection of the public in a nuclear power plant emergency requires decision-makers to balance the time requirements from two chains of events: the events associated with a radiological release and the events involved with the response to that release. The management of these events is distributed among personnel at the nuclear plant, in the local community, and in state and federal agencies. All of these parties must coordinate their response to the emergency to assure that timely and effective protective response can be made by the risk area population. This article describes the process by which protective action recommendations (PARs) are developed in nuclear power plant emergency exercises and provides recommendations from research on emergency response in other types of natural and technological hazards. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

One of the most important concepts in the selection of protective action recommendations (PARs) for a nuclear power plant emergency is the distinction between two chains of events. The first chain of events is associated with the environmental consequences of the release and the second chain of events involves the social and organizational response to that release [1,2]. It is important to go through each of these two chains of events one step at a time because a systematic examination can explain why certain kinds of problems arise in the selection and implementation of PARs for the population at risk.

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Fig. 1 begins with the reactor coolant system (RCS) in which radiological material is held. As McKenna [3] indicates, some internally or externally initiated events could cause a release of that radioactive material from the RCS into the immediate environment within the containment building. This event could be followed later by dispersion into the extended environment. The nature of this release would be affected by the severity of the accident and also by the ambient geological, meteorological, and hydrological conditions in the environment surrounding the plant. Later, dispersion would take place as airborne radioactive materials are carried downwind and waterborne materials are carried downstream. Ultimately, the dispersion process would result in direct exposures to target populations through direct radiation and inhalation. Moreover, environmental deposition could have indirect effects on human health through ingestion of agricultural products such as milk and vegetables.

The second chain of events, the organizational response to an actual or potential release, begins with activation of the emergency organization. Following classification of the incident, continuing incident assessment actions are taken to obtain information from the RCS and containment building, the extended environment, and the risk area population. Of course, plant personnel also take preventive and corrective actions to avoid core damage, and to delay or avoid a radiological release into the extended environment. However, if the incident assessment indicates that the offsite population is at risk, then protective actions must be taken to limit exposures. Thus, PARs first must be selected and then implemented by means of population warning, preparation, and response.

The fundamental problem in selecting PARs for the risk area population stems from the fact that there is a small, but non-zero probability of a very large release of radioactive material within a short period of time after the onset of a reactor accident.

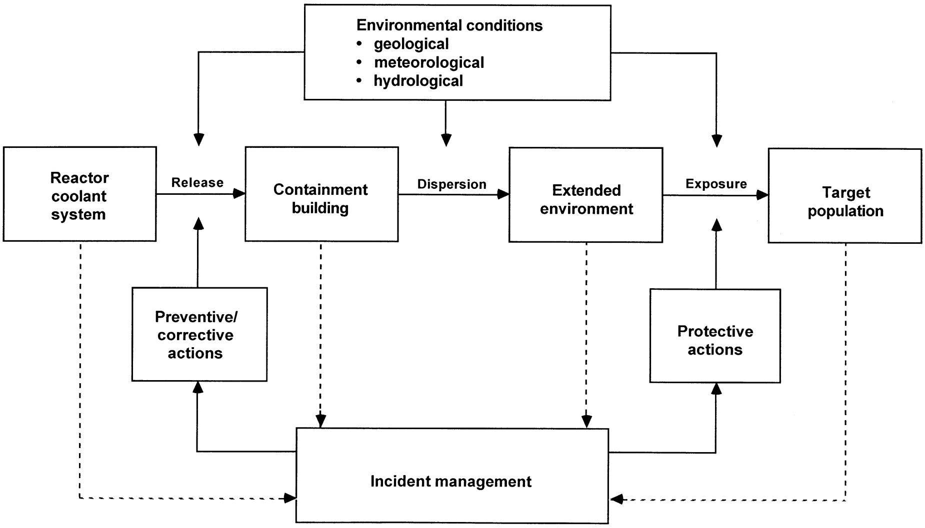

Fig. 1. Chain of events for a radiological release.

The possibility of a very large source term means that unacceptable doses could be received even at great distances from the plant. In turn, this implies that so many people may need to take protective action that their sheer number would delay the successful completion of an evacuation. Consequently, the nuclear industry and federal oversight agencies such as the Nuclear Regulatory Commission, Environmental Protection Agency, and Federal Emergency Management Agency have taken steps to improve radiological emergency preparedness. These steps include conducting reactor accident consequence analyses, performing evacuation time estimate (ETE) studies, developing decision criteria for timely and effective PAR selection, and promoting training, drills and exercises in PAR implementation.

One significant contribution to the PAR selection process has been the Nuclear Regulatory Commission's requirement for all nuclear power plant operators to submit ETEs for the plume inhalation (10-mile) EPZ. These analyses have revealed that evacuation times could range up to 21 h for the general population under normal conditions [4]. Even these estimates are problematic because, as Urbanik [5] indicates, a number of unrealistically low estimates of evacuation time components used in early studies resulted from a paucity of empirical data about the public's timeliness and level of compliance with PARs. Despite the possibility that initial ETE studies underestimated evacuation time components, it has long been recognized that a major release of radioactive material could occur in a fraction of the time required to implement an evacuation. Thus, planning concepts and decision criteria have been developed to increase the accuracy and decrease the time required in PAR selection.

One major contribution to radiological emergency preparedness has been the Environmental Protection Agency's development of protective action guides (PAGs). As Conklin and Edwards [6] indicate, these dose criteria simplify the PAR selection process because they provide emergency managers with quantitative thresholds for initiating protective action to avoid the adverse health effects of radiation exposure. Nonetheless, they provide only a partial solution to the PAR selection process. The problem is that PARs have been determined by comparing PAGs to projected doses, but there is no prescribed basis for making the dose projections. Specifically, local emergency managers can base their dose projections upon releases in progress or upon the source terms they expected to be realized in an imminent release. Even after the accident at Three Mile Island (TMI), many local emergency managers determined PARs from dose projections based upon field measurements of dose rates during releases in progress. They were concerned that making PARs on the basis of projected dose rates for a potential release would result in unnecessary PARs if the anticipated release failed to occur.

The fundamental reason for initiating protective action even when there is substantial uncertainty about whether it is needed is that protective actions take a significant time to implement. Time is required to collate and analyze relevant data about plant status and environmental conditions. Time also is needed to draw the correct conclusions from these data, determine the appropriate PARs, and communicate these to the population at risk. It also is the case that the time needed to evacuate the EPZ increases with the number of people who need to evacuate. In addition, the more people who need to evacuate, the more resources are needed to support them. Finally, resources such as trained personnel and appropriate equipment take time to be activated and dispatched to act in a coordinated manner. Thus, as McKenna [3] indicates, PAR selection based upon releases in progress, or even imminent releases (e.g., challenges to containment building integrity) may provide insufficient lead time. Consequently, local emergency managers must be prepared to make decisions on the basis of information that comes even early in the environmental event chain — critical plant conditions — even if there is only a 10% chance or less of a release occurring.

2. PAR stakeholders and their roles

A fundamental obstacle to protecting the public health and safety in a nuclear power plant emergency is that no single stakeholder has all of the technical expertise and the real-time data about the plant, the surrounding environment, and the population at risk that is needed to make timely and effective PAR decisions. To coordinate the activities of the many technical specialists that will be involved, emergency preparedness specialists must develop plans and procedures, equip and train response personnel, and conduct exercises to test stakeholders' ability to perform their roles. This need is especially great for nuclear power plants, but is not unique to them. Data from the survey of communities near toxic chemical facilities by Sorensen and Rogers [7] can be used to illustrate the types of deficiencies that can be expected in the absence of a strong mandate for emergency preparedness. Specifically, this study found that the link between chemical facilities and their neighboring communities often was unreliable. Over 66% of the community emergency managers cited ordinary phones as their primary means of receiving emergency notification from the plant, and only 30% had backup communications. Moreover, although 90% of the respondents could identify the person who would receive an emergency warning from the facility, 25% could identify neither the position title nor the name of the person at the facility who would transmit this message. Further, many communities do not know what information to request in an emergency. Although most would ask for the type of chemical (79%) and the amount released (57%), only a minority would ask about the human health risk (42%), location of the release (37%), speed of dispersion (24%), potential exposure pathways (24%), or PARs (20%).

This study also found that their respondents expected that an average of only two decision-makers would be required to approve a PAR for a rapid onset release, although five would be involved in a slow onset event [7]. The respondents' average estimate of the time required to make a warning decision was just over 18 min for a rapid onset event and about 30 min for a slow onset event. However, these estimates seem overly optimistic because 67% of the respondents could describe only a vague procedure for making a warning decision. The extent of the optimistic bias in the decision time estimates can be seen in data from 232 emergency decisions in 70 events where the decision to warn the public took an average of 79 min and the selection of a PAR added an average of 105 min [8]. In summary, the data from these studies suggest that appropriate PARs for a large scope, rapid onset chemical emergency are unlikely to be selected and transmitted to the population at risk in a timely manner.

To better understand the selection and implementation of PARs for a nuclear power plant emergency of comparable scope of impact and speed of onset, it is necessary to look more closely at the emergency managers who will be involved in PAR decision-making. Fig. 2 illustrates what has been implemented in response to federal guidance [9]. This figure lists the four principal parties that are involved in PAR selection and implementation: the nuclear utility, local governments, state government, and federal government. Each of those organizations is subdivided, so that within utility, there are the staff of the Control Room, the Technical Support Center (TSC), the Emergency Operations Facility (EOF) and corporate headquarters. The Control Room is always staffed, but the plant operators have only rudimentary training in PAR selection. The TSC, which is activated only at an Alert, provides technical support for reactor operations, guides in-plant assessment, preventive, and corrective actions, and also supplies source term data to the EOF. The EOF, which is activated only at a Site Area Emergency, is responsible for working with offsite agencies to select PARs and coordinate their implementation.

Within the local government, there is a Chief Administrative Officer, who might be either an elected official (e.g., city mayor or chair of the county board of supervisors) or an appointed official (e.g., a city manager or county administrator). In addition, there is a legislative body — a county board of supervisors or city council. Some of these local officials would be located in an Emergency Operations Center (EOC) and from there,

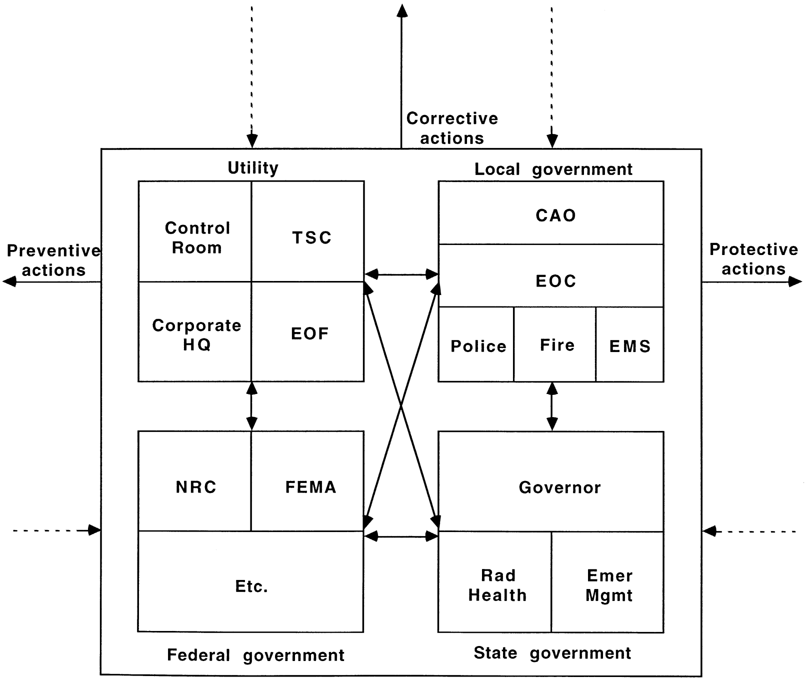

Fig. 2. Block diagram of incident management stakeholders.

they would provide instructions to emergency management, police, fire and emergency medical services who are the primary emergency response agencies.

Within the state government, the governor is the Chief Administrative Officer, while the Department of Public Health and the state emergency management organization are the primary responding agencies. Within the federal government, the Nuclear Regulatory Commission, the Environmental Protection Agency, and the Federal Emergency Management Agency are primary in a very long list of agencies with response roles in a nuclear power plant emergency.

In addition, there are many other organizations and individuals that have relevant expertise, but no official role in a nuclear power plant accident. It is quite possible that some of these will confuse the situation by attempting to involve themselves in the emergency response process without invitation from those that do have statutory authority and responsibility. Accounts of the TMI accident indicate that this was a significant problem during that incident [10]. However, the problem arose at TMI because of the federal, state, local, and utility stakeholders' implicit assumption that radiological emergency response could be improvised. The failure to develop and exercise a plan in advance made it difficult to determine who was a legitimate participant when the incident actually occurred. The development of coordinated emergency response plans and annual full-scale emergency response exercises over the past two decades should make it clear which organizations do have a legitimate role in radiological emergency response and what are their capabilities. In turn, this will make it less likely that intruders will disrupt the PAR process if an incident like TMI occurs again.

It should be obvious from Fig. 2 that there are many stakeholders and, consequently, many interconnections among these stakeholders. Any organization requires — indeed it is the defining characteristic of an organization — that there are restrictions on communication among its members. Consequently, the purpose of emergency planning is to avoid allowing everyone talk to everyone else. There must be discipline regarding who says what to whom, how, when, where and why. Communication discipline is the reason why there is a flow of control onsite as an emergency escalates. The Shift Supervisor is initially responsible for PARs because the Control Room is continuously staffed and can make rapid, approximate assessments. Because Control Room personnel are always available on shift, they are given the basic training for PARs in case there is a very rapidly escalating event that requires an immediate response. Control Room personnel are not given extensive training in protective response issues such as dose projections, offsite response logistics, methods of warning, and timing of protective response. If an immediate protective response is not required, responsibility for PARs is assumed by others who do have more training in this area. As the emergency escalates, there is a shift in responsibility for PARs from the Control Room to the TSC and from there to the EOF so that people who speak for the plant have the specialized training that allows them to communicate effectively with the offsite agencies. The same is true with the agencies in local, state, and federal government. Those who are immediately available usually do not have the greatest expertise, but they do have procedures for immediate action and can activate those who are best qualified to contribute to the PAR process.

Even when all of the relevant agencies have been fully activated, there are significant impediments to the determination of appropriate PARs. Plant operations personnel are knowledgeable about the routine operation of their power plant and industrial radiation protection, but not about accident sequences and radiation protection of offsite populations. State and federal agencies have expertise in the latter issues, but only local agencies are familiar with the size and distribution of the local population; the location of special facilities such as schools, hospitals, nursing homes, and jails; the availability of warning systems; and the quality of local evacuation routes. Consequently, they are the ones called upon to implement any PAR. That is, the local agencies must provide logistical support to households that are sheltering in-place, evacuating, or taking other protective actions that have been recommended by radiation protection experts.

The differences among stakeholders in their knowledge and skills means that the development and successful implementation of PARs in a nuclear power plant emergency require a translation from the utility’s language of reactor operations to the community’s language of routine emergencies. Statements about pressurizer water level, steam generator tube failure, loss of feedwater, or even a hydrogen bubble have little meaning for local officials because they are statements about the implications of past plant conditions for the plant itself. Statements about the probability of a release have similarly little meaning because they also are outside the realm of local responders’ professional training and experience. The meaning that must be conveyed to local agencies is ‘‘Are these events likely to produce unacceptable consequences for the community and, if so, what actions need to be taken to prevent them and when do these actions need to be completed?’’ That is, the translation from reactor operations to emergency response is accomplished by linking the environmental release chain of events to the emergency response chain of events. At the heart of that process are the Emergency Action Levels (EALs) that translate plant conditions into one of the four emergency classes (Unusual Event, Alert, Site Area Emergency, and General Emergency).

PARs have meaning because recommendations for continuing normal activities and evacuation are a part of local responders’ training and experience. Sheltering in-place as a protective action is a somewhat different matter because it typically has been discussed only in the context of nuclear power plant accidents. This is unfortunate because it has received increasingly frequent recognition as an effective protective action in other types of hazardous materials accidents as well [2]. Indeed, sheltering in-place occasionally is recommended for some areas in hurricanes [11], frequently is recommended for many areas in high-rise building fires, and is the standard PAR for tornadoes. The problem is that it is not labeled as sheltering in-place in these other contexts. The concept seems unfamiliar largely because the label is unfamiliar.

State and federal agencies have an important role to play in radiological emergency response because it is only at the state and federal levels that the assessment and control of radiological materials arise frequently enough for government to invest in such specialized expertise. Thus, state and federal agencies provide oversight regarding emergency assessment by ensuring that the hazard has been detected, accurately classified, and that the implications of that classification have been translated into language that is meaningful to local government agencies.

3. PAR implementation

As Fig. 3 indicates, there are three PAR implementation steps that must follow emergency assessment and PAR selection before exposure reduction can occur (see also Ref. [5]). First, warnings must be disseminated to the risk area population. Second, as Mileti and Peek [12] indicate, the risk area population must receive the warning, understand it, accept it, and prepare to take protective action. Last, the risk area population must implement the protective action. Only when all three of these steps have been accomplished is exposure reduction or avoidance achieved. Of course, it is important to recognize that warning, preparation, and response are quite complex. First, risk areas are quite heterogeneous, so it is somewhat misleading to refer to the risk area population. In fact, there are many different segments of *the* risk area population. Emergency managers frequently think of the public in terms of an immediate family — mother, father, and children — living in a single family detached structure with a garage containing at least one car. Further, the assumption commonly is made that once a warning is broadcast on television or radio, family members will immediately pack a few items, get into the car, and drive away to safety. Contrary to this oversimplified image, households do not always have ready access to warnings and do not always understand the language in which the warning is transmitted. Moreover, preparation can be impeded if one or more members of the household are at work, school, shopping, or engaged in some other activity outside the home. It is well established that separated households attempt to reunite at home before evacuating together unless members can confirm that they can reunite at a safe location after evacuating separately [13]. Finally, people often spend time attempting to confirm the warning and delay taking action until they are convinced that evacuation is absolutely necessary.

Research conducted over the past 20 years has begun to document the timeliness of risk area populations' warning responses in events as disparate as floods, volcanic eruptions, and hazardous materials spills [2,14] and has shown that warning processes in the general population can be represented mathematically as simple diffusion processes [15]. However, the situation is significantly complicated by the presence of population segments with special needs. For example, there are transients — people who are only temporarily in the area, perhaps for business or vacation. Transients usually do not know local landmarks, do not know where the nuclear power plant is located, and might not even know that there is a nuclear power plant in the community. There also are special facilities, which include health-related facilities such as hospitals and nursing homes;

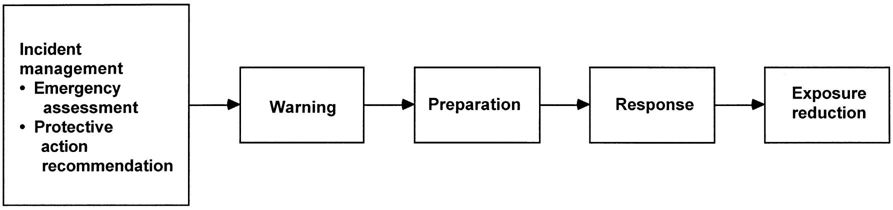

Fig. 3. Chain of events for a radiological response.

penal institutions such as jails and prisons; athletic stadiums, amusement parks and recreational areas, high-density residential, transportation, commercial and educational facilities (see Ref. [2], Table 4.2 for a complete list). Typically, the most significant special facilities in any community are schools, hospitals, nursing homes, and jails. Almost all communities have them and they are the facilities that require immediate attention in connection with PAR selection. The reason for concern about these facilities is the limited mobility of their residents. The general public is ambulatory, but hospital patients, e.g., may require life support. The location of permanent residence is a factor that distinguishes transients from the general population. Periods of use distinguish athletic facilities and amusement parks. User density distinguishes apartments from single-family dwellings.

Another issue is the accessibility of in-place protection. People at athletic fields have no structure in which to shelter, so they must evacuate. At the other extreme, some buildings, e.g., hospitals, are constructed of concrete and are tightly sealed. The air infiltration rates may be well below the average of one air change per hour, and so it may be possible for patients in these facilities to shelter in-place without undue risk. This would be particularly important in surgical or medical intensive care or neonatal units where patients face a very high risk of serious injury or death if they are moved. Finally, another important distinction is between those who are transit-dependent and those who have their own vehicles. Transportation support will be required if people do not have access to their own vehicles.

Fig. 4 shows how warning, the first step in PAR implementation, is affected by a number of different factors. The first of these factors is the warning source, whose influence upon the risk area population is a function of perceived expertise and perceived trustworthiness. The warning channel also is important. The most common method of warning dissemination is face-to-face interaction — especially a uniformed officer going from door to door announcing that there's been an accident, that it is serious, and that people need to evacuate. However, it is most likely that those in the risk area will be warned by sirens alerting people to tune in to radio messages transmitted over the Emergency Alert System. Alternatively, there may be a ring-down system so that people get telephone messages notifying them of an emergency. The success of each type of warning channel depends upon the geographical distribution of the risk area population and the activities in which that population is engaged with [2,15].

Warning content will be effective if it addresses people's concerns and does not conflict with the local population's *pre-existing hazard beliefs*. A warning message will establish a motivation to take protective action if it addresses people's perceptions of the certainty, severity, immediacy, and duration of the threat. People are likely to take the recommended protective action if the message provides specific guidance about what to do (e.g., shelter in-place) and how to do it (stay indoors with the heater or air conditioner off and the doors and windows sealed as tight as possible). One of the critical characteristics of a recommended protective action is the perceived effectiveness of the action in protecting persons. Most people believe that evacuation is effective because they will be safe once they get out of the EPZ. However, there is evidence that people are less sure that sheltering inside an ordinary wood frame structure will protect

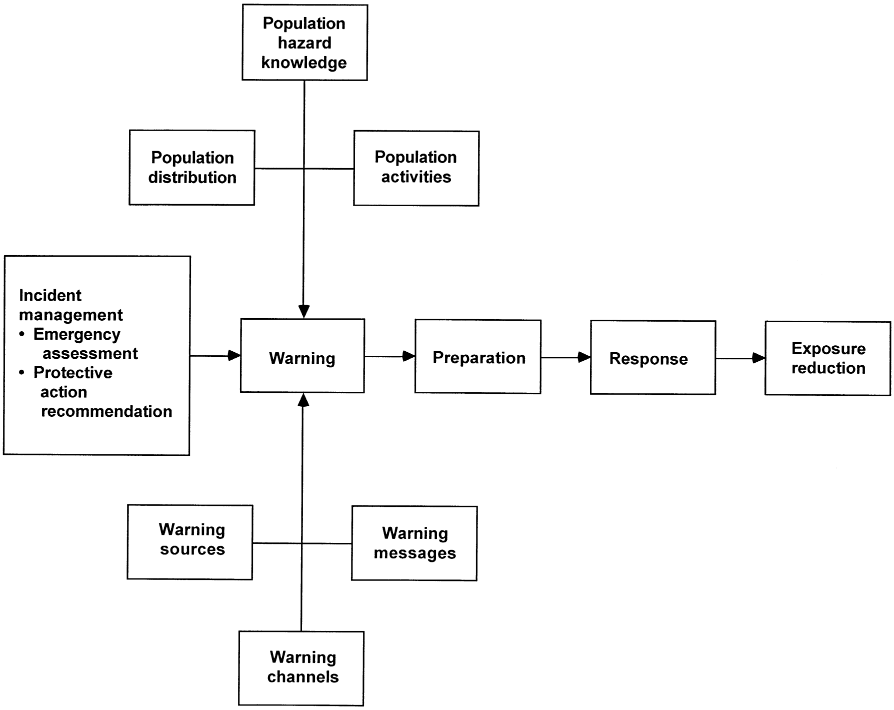

Fig. 4. Factors affecting warning receipt.

them from the hazard [2,16]. Interestingly, the data of McKenna [3] suggest that their intuitions are not greatly mistaken.

Moreover, people have beliefs about the costs of those protective actions in terms of out-of-pocket expenses, and about a protective action's barriers to implementation — e.g., whether it requires specialized knowledge and cooperation from others [2]. They may think that sheltering in-place will be effective only if they follow a complicated set of instructions just exactly correctly. Or, they may think that evacuating at the same time as everyone else will trap them in a traffic jam. In fact, many of those who evacuated during the TMI accident reported that they decided to evacuate early to avoid a later forced evacuation [2]. In summary, emergency managers must understand people's perceptions of the hazard and alternative protective actions if they want people to comply with their PARs. If the public's perceptions are incorrect, the emergency managers must provide information from a credible source that corrects those misconceptions.

All of the factors identified to this point — sources, channels and messages — are at least partially controlled by the utility, and by local, state, and federal government. However, other factors, including such receiver characteristics as the population distribution, are not. For example, if the EPZ is very densely populated, if local structures are poorly suited to sheltering in-place, or if there are few suitable evacuation routes, then problems with PAR implementation are likely to arise. Moreover, the activities in which the risk area population is engaged with at the time of a warning are important determinants of the warning response. Sirens might not be heard if people are sleeping, particularly if windows are shut and air conditioners are loud. Finally, there are population hazard beliefs. As noted earlier, the beliefs people have established about radiation hazard and protective actions before an incident occurs can have a significant effect on their willingness to comply with PARs.

The next step in the protective action implementation process, *preparation*, refers to the period between receipt of a warning and actually initiation of a protective response action. At minimum, preparation requires assembling the household members who will be responding, reaching consensus within the household regarding which action will be taken, and collecting whatever materials and supplies members need to support their response. However, there is more to preparation for protective response than just *logistical preparation*. Immediately after receiving a warning, there is a period of *cognitive preparation* during which people typically think about the warning information, discuss it with other members of their family, and seek additional information from other sources. If some members of the household are not present, time is spent trying to contact those who are absent. Often, time is needed to plan a safe route of travel and an acceptable destination.

Moreover, research has shown that people are not inclined to leave their homes unless they have a specific evacuation plan [13,17,18]. Thus, as Fig. 5 indicates, one of the factors that impact preparation times is formulation of a household adaptive plan. If a household plan exists prior to an emergency, preparation time is decreased. Preparation time also depends upon what people are doing at the time of warning dissemination. It may be that they are involved in activities that make it difficult for them to begin immediate evacuation preparations, e.g., working some distance away from home. Personal role obligations also affect preparation times because they cause strong ties to

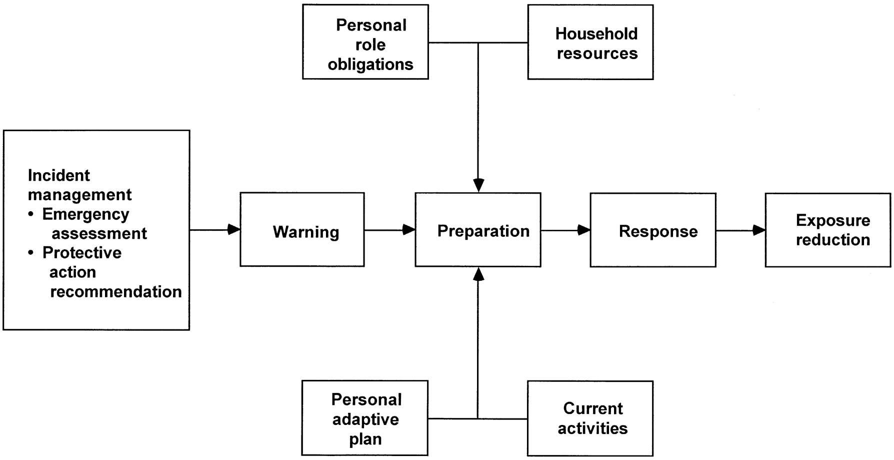

Fig. 5. Factors affecting response preparation.

friends, relatives, neighbors and co-workers, and a desire to ensure that these people also will be safe. These ties gives rise to informal warning networks in which people call to ensure that others have heard the warning, see how they have interpreted the message, determine whether others have additional information, and inquire how they are planning to respond [2,15].

Problems also arise in connection with people's ties to their jobs. If information about the threat is ambiguous, people who are paid hourly may be concerned about the situation, but still go to work. On the other hand, salaried personnel in the same situation may be more likely to take the afternoon off and call it vacation time. Indeed, there is reason to believe that this phenomenon contributed to the response at TMI [19]. The governor's limited evacuation advisory occurred on the first sunny Friday afternoon of the spring. Apparently, some people decided to visit relatives out of the area and call it a long weekend. People who were paid hourly were less inclined to leave because they had a conflict between a sure loss of income vs. an uncertain increase in safety. The single group least likely to leave were people with livestock (especially dairy farmers, who also were the group most reluctant to evacuate during the eruption of Mt. St. Helens), because they stood to lose substantial amounts of money if they abandoned their cattle for an extended period of time. People who work at industrial facilities where a plant must be shut down very slowly also will have greater preparation times.

Household resources — such as the availability of a credit card or ready cash and access to transportation — also are important in compliance with PARs. Those who can evacuate to the home of a friend or relative will experience relatively little cost to an evacuation and might find the experience to be relatively pleasant. A family that evacuates to a hotel, but has a credit card, may find that evacuating is expensive but not unpleasant. For those who must evacuate to a Red Cross shelter, the decision to leave may be more difficult. Of course Red Cross shelters are excellent facilities given their resource constraints, but mass care facilities are locations that most people would prefer to avoid. Consequently, the inconvenience of evacuating is something that people tend to balance against the perceived risk.

Finally, there are factors that directly affect response. Of course, these factors principally affect evacuation because sheltering in-place involves minimal logistical arrangements and usually can be completed more quickly than evacuating. As Fig. 6 indicates, two important factors affecting evacuation are the distribution of evacuating vehicles and the roadnet design capacity. Both of these are factors over which emergency managers have little control at the time of an emergency. They can be changed before an emergency if the population density (and thus the number of evacuating vehicles) is restricted in the vicinity of the power plant, if existing roads are widened, or if new roads are built to improve the roadnet.

Another factor affecting response is the *loading function* — the rate at which vehicles enter the road network. Emergency managers can alter the loading function by the dissemination of emergency information and by the selective issuance of evacuation recommendations to residents of different areas of the EPZ. Evacuation also is affected by *traffic management actions* that maintain or even temporarily increase the capacity of evacuation routes. Traffic management actions can expedite traffic flow by, e.g., setting stoplights to a constant green or instructing police officers to wave traffic

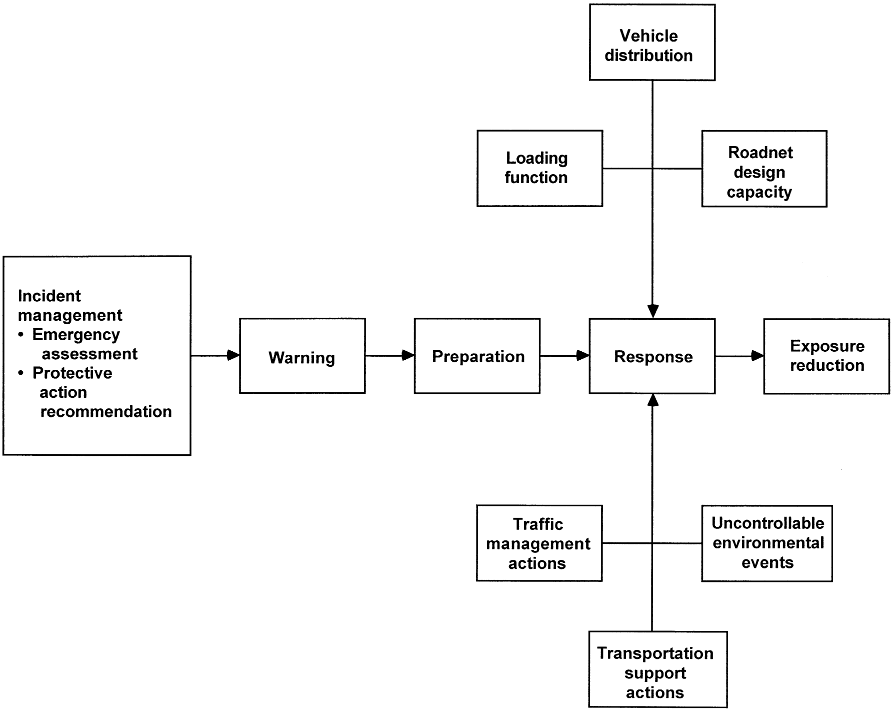

Fig. 6. Factors affecting evacuation response.

through stop signs on routes out of the EPZ. By contrast, *transportation support actions* enhance evacuation by providing rides to segments of the population that lack their own vehicles. This includes buses for school children and transit-dependent adults, or ambulances for those in hospitals and nursing homes. Of course, *uncontrollable environmental* events can impede the response. This can happen, e.g., if there is snow or rain or if there are traffic impediments such as automobile accidents.

4. Conclusions

The chains of events model integrates a number of useful ideas about protective action decision making. First, the chain of events associated with the release is long and there are many uncertainties at each step. In addition to the inherent uncertainties about what is happening to the plant — uncertainties that arise from imperfect assessment actions — there will be uncertainties about the success of corrective actions. That is, a given diagnosis about what is wrong with the plant may or may not be correct, and the corrective actions intended to restore the plant to a safe shutdown may or may not be successful. Minimizing the chance of unnecessary protective action — i.e., unnecessarily evacuating or sheltering in-place — requires initiating such action as late as possible so that plant conditions can be diagnosed as accurately as possible. The disadvantage of waiting is that the chain of events associated with population response often is quite lengthy and there are many uncertainties at every step in that chain as well. Waiting for more information to confirm that a release definitely will occur inevitably increases the risk that radiation exposures will occur in the event of a release.

Conversely, minimizing the chance of unnecessary exposures requires taking action as early as possible, but this increases the likelihood of unnecessary protective action. This is an essential dilemma that arises in any hazard having a large scope of impact (i.e., it affects a large geographical area) and has an imperfectly predictable developmental sequence. This dilemma, which also affects emergency managers for hurricanes, volcanic eruptions, and toxic chemical releases, entails a number of specific consequences. First, the irreducible uncertainties in the chains of events for the release and the population response create the potential for two types of decision errors. One error is a false-positive response, i.e., recommending protective action when it is not needed, and the false-negative response, i.e., failing to recommend action when it should be taken. As a general rule, people from the utility tend to express just as much concern about a false-positive response as about a false-negative response. By contrast, the government agencies tend to have substantially less concern about a false-positive response than about a false-negative response.

Second, as Ford and Schmidt [20] indicate, the stakeholders in the incident management system must develop a shared schema, or common set of beliefs and expectations (see also Ref. [21]). Personnel from the nuclear utilities must understand the problems faced by personnel from local government agencies and vice versa. All stakeholders have to understand the whole problem, not just their own small part. They need to strike a balance between these two types of errors through comprehensive protective action planning and training in advance of an emergency.

Protective action planning is needed to ensure that each stakeholder understands the capabilities and limitations of others and to allow the parties to resolve the conflicts before the public health and safety is at stake. All parties should recognize that either a false-positive or a false-negative error could have significant consequences for the affected population, but it is important to recognize that the two types of errors have different kinds of consequences. The consequences of a false-positive response are economic. By contrast, the consequences of a false-negative response affect the public health and safety. This requires a trade-off between these two consequences. It would be unnecessarily cautious to evacuate everybody in the EPZ every time there is an Alert at a nuclear power plant. On the other hand, a Site Area Emergency — which is probably the minimal condition for initiating offsite protective action — is expected to be a very rare event. When plant conditions reach that level, there is a very high risk of some part of the local population receiving a radiation exposure before protective action can be completed. Emergency managers can reduce the potential consequences of a decision error by dividing the responding population into segments such as the general public, transit-dependent, special-facilities residents, and transients. Once this has been done, they can establish different PARs for each population segment and escalate population protective action over time as conditions warrant [1,2].

Of course, as Ford and Schmidt [20] indicate, extensive training is needed in order to achieve reliable implementation of complex procedures such as this. Moreover, because actual emergencies rarely turn out exactly like training scenarios, the entire response chain from assessment actions through PAR selection to protective action implementation, will undoubtedly require improvisation [22]. Improvised plans need to be coordinated among the relevant parties, but the processes of communication and review that are essential to this coordination process also take time. To ensure that PARs can be implemented before radiation exposures occur, local emergency managers need to identify all of the tasks that must be performed in order to successfully execute the population response.

The last few points to be addressed here are that a strategy of escalating action over time for different population segments must come, first of all, from sources perceived to be expert and trustworthy by the affected population. Inconsistency among the utility, local government, state government, and federal government in their assessment of the situation will adversely affect the credibility of all of them. Constant communication between the utility's near-site EOF and EOCs at the local, state, and federal levels is needed to facilitate collaboration on PARs rather than have one stakeholder make PARs that other parties cannot support or, worse yet, cannot implement. If all of the stakeholders agree — utility, local government, state government, and federal government — they are will have greater credibility and, thus, better timeliness and compliance with PARs by the risk area population.

Second, PARs must be perceived to be commensurate with the threat. Once again, it is the public's perception that is crucially important here. It is not just what the experts think is the certainty, severity, immediacy, and duration of the threat but what are the perceptions of the risk area population. The news media are likely to seek out other sources to publicize ''the other side of the story from the official line''. These other opinions may well be different from official recommendations, but they will not carry much weight with the risk area population if there has been an adequate public information program conducted in advance. An adequate public information program will help people to understand the hazard and alternative protective actions. It also will instill confidence in the incident management system so that when the risk area population does receive a PAR from official sources, they will accept the recommendation even if they cannot independently verify its validity.

Third, it is important to recognize the limits of the incident management system's control over response timeliness and compliance levels. People will not necessarily wait for a PAR that is specifically directed at them. If decision-makers evacuate nonessential personnel from the plant or recommend that a local hospital discharge its ambulatory patients because of the severity of the incident, then the local population will take that as a cue to the incident's severity. One anecdote illustrating this principle occurred during the TMI accident. One of the members of the Nuclear Regulatory Commission staff, who lived in a Maryland suburb of Washington, DC, later recounted that his neighbors — who knew he worked for the NRC — admitted after the incident was over that they had been watching to see if his family evacuated. That neighborhood is more than 100 miles from TMI, but people had such misconceptions about radiation hazard that this seemed to them to be a reasonable idea. Had his wife, by chance, decided to visit relatives for the weekend, the entire neighborhood would have evacuated. The fundamental point, of course, is that people follow the example of others if they do not have any information about the situation or if they do not trust the information provided by official sources.

In summary, it is impossible to establish complete control over the response of the risk area population. If a PAR is made for one group, there may also be a response from other groups as well. The extent of the response will depend, in part, upon people's perception of their similarity to those who are listed in the PAR. For example, if the PAR calls for evacuating everyone within 5 miles of the plant, some of the people who are 6 miles from the plant will assume that they are at almost the same level of risk and are likely to also evacuate. Moreover, people will judge their similarity to those listed in the PAR in other ways as well. The Governor's limited evacuation advisory at TMI mentioned pregnant women and preschool children within 5 miles of the plant. Later research showed that the people who evacuated but were not in the group identified in the advisory tended to be similar to the designated group [19]. Specifically, households that did not have pregnant women and preschool children, but were within 5 miles, were more likely to evacuate than comparable households that were farther away. In addition, households with pregnant women and preschool children beyond 5 miles also tended to evacuate. Moreover, there was not a sharp dividing line with regard to children's age; the likelihood of household evacuation increased as the ages of the children got closer to preschool age. People did not recognize (mostly because there is no evidence that they were told) that the PAR was directed toward the fetus at risk. Consequently, it was women of childbearing age, or women in general, who were perceived to be at risk.

The effect of perceived similarity to those that are in the target group is that the public response is more likely to be a shallow gradient rather than a sharp defining line. That clearly that will be a problem if there is, as has been observed in many emergency exercises, creeping conservatism in the PARs. Creeping conservatism occurs when the TSC suggests a modest PAR, but increases its scope ''just to be safe''. The PAR is transmitted to the EOF, which also increases its scope ''just to be safe''. From there, the PAR goes to the state EOC, where it is once again increased in scope ''just to be safe''. When there are two states involved, neither wants to be perceived as incautious, so the scope may be increased again ''just to be safe''. The problem of creeping conservatism can be avoided if emergency planners address this issue ahead of time. At each level, analysts and decision-makers must be aware of the assumptions and the degree of conservatism adopted at each of the previous levels in the PAR formulation process. Moreover, the public health and safety will be protected better in an emergency if the decision-makers understand how people will interpret the emergency information they disseminate and the risk area residents receive advance training so they understand how the PARs are made and what they mean.

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