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An approach for deriving emergency planning zones for chemical munitions emergencies

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Abstract

The selection of an emergency planning zone (EPZ) for hazardous materials is often a difficult technical as well as a political task. This paper describes a method used in the United States to establish EPZs in the Army's Chemical Stockpile Emergency Preparedness Program. A rationale for a zoned based approach to emergency planning for hazardous materials is developed. The method presented integrates risk analysis data with meteorological, topographical, demographic, and political concerns. The method is then applied at the Tooele Army Depot in Tooele, Utah. Although the analysis concerns chemical weapons, the process is relevant to other hazardous material problems.

Introduction

The United States (U.S.), amongst other countries, is in the process of disposing of its stockpile of chemical weapons. The Chemical Stockpile Disposal Program (CSDP) is mandated by Public Law 99-145. The law requires destruction in a manner that maximizes the health and safety of the public. Chemical agents, however, are among the most toxic hazardous materials in existence and are stored in large quantities. The probabilistic risk analysis for the disposal program identified a number of credible accident scenarios that

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could result in potential fatalities. Emergency planning for an accident was judged to be inadequate in the communities surrounding storage sites. Consequently, enhanced preparedness was recommended in the Final Programmatic Environmental Impact Statement for the CSDP [1] and in the Army's Record of Decision [2]. Currently, such programs are being implemented at the eight sites in the continental United States (CONUS) that store chemical agents and weapons. The Chemical Stockpile Emergency Preparedness Program (CSEPP), jointly managed by the Army and the Federal Emergency Management Agency (FEMA), has the ambitious goal of implementing state-of-the-art plans that achieve maximum public protection [3].

One of the most challenging as well as politically sensitive aspects of developing emergency preparedness plans is to identify the areas around the chemical stockpile facilities that will be identified as being at risk. A useful mechanism for such identification is the delineation of emergency planning zones (EPZs). The objective of this paper is to develop a systematic methodology that can be used to identify emergency planning zones for hazardous chemical facilities and to demonstrate how it has been applied to this particular program. This methodology will incorporate risk and hazard analyses for a facility and link them with site-specific concerns such as population distribution, meteorology, and topography. It will also help insure that there is consistency across facilities. Furthermore, it suggests how other emergency planning elements can be linked to a planning zone concept to achieve a consistent application of the emergency planning effort in areas with diverse facilities. Although this paper is directed towards chemical agents, the methodology presented has significant ramifications for emergency planning for other extremely toxic hazardous materials and the implementation of planning under Title III of the Superfund Amendment and Reauthorization Act (SARA).

The next section of the paper develops an integrated theory of emergency planning zones. This is followed by a discussion of the spatial distribution of risk and hazard. The fourth section outlines how geographical boundaries can be established. Next, criteria are specified to apply the procedure of establishing boundaries. Finally the criteria are implemented for the chemical stockpile storage site at Tooele Army Depot near Tooele, Utah.

Emergency planning zone concepts

A zone-based theory of emergency planning

The use of zones is not a novel approach in emergency planning [4–6]. Floodplains and Floodways are defined in the National Flood Insurance Program and used as the basis for flood-proofing and land use regulation [7]. The same is true for coastal floodplains and tsunami run-up zones. California has special planning zones in areas of high earthquake risk to target hazard information for home buyers [8]. Urban areas are developing micro-zone maps to guide seismic building code requirements. For hurricanes, Maximum Envelopes of Water (MEOWS) determine zones for evacuation planning [9]. Zones of potential ashfall, pyroclastic flow, and mudflow have been established around selected active volcanoes [10]. Plume exposure and ingestion pathway zones have been established for nuclear power plant emergency planning [11].

In this section we present a theory of how to structure planing zone concepts for hazardous materials. A variety of accidents involving chemicals and hazardous materials can occur. Under the authority of Title III of the Superfund Amendment and Reauthorization Act (SARA), the Environmental Protection Agency (EPA) has listed over 350 extremely hazardous chemicals that trigger community notification and emergency planning when they exceed a threshold quantity [12]. Logically, accidents can occur in a storage building/ tank, at a plant site where chemicals are used in an industrial process, or in transit through pipes, vehicles or other means. The distribution of hazard from these accidents is based on a number of factors including how much material is released, how it is released, the duration of the release, the meteorological conditions during the release, the effects of topography on dispersion, the chemical's toxicity, and human health response. Source terms (or the amount of material released) can range from small amounts with little potential for health risks to very large amounts with the potential for catastrophic health effects [13]. The hazard from any single accident scenario (i.e.. holding the source term constant) cannot be easily predicted because of the remaining variables that affect dispersion. On average, the risks from any given accident decrease as the distance from the point of release increases. The potential consequences of exposure also decrease with increasing distance [14]. The risk that an exposure would cause fatalities are greater as one gets closer to the accident site.

Zones and planning effort

As the risk and hazard from an accident decrease and distance from the source term increases, the level and type of planning required also change. Lower risk means that response is less likely to be needed. Lower hazard means that, given a release, exposure is less likely to occur. Greater distance also means that more time is available for response. The major planning and response elements that are affected by distance from the accident site include mobilization of emergency personnel, communication systems, alert and notification systems, protective action options, decontamination and medical resources, public education and information programs, training needs, exercises, and mass care/relocation facilities. For example, for resources near an accident site, a very rapid warning is needed; as the distance from the point of release increases, the amount of available response time increases, thus relaxing the need for rapid warning [15].

Since it is perhaps impossible, and at least unrealistic, to have plans and response capabilities vary continuously with distance, it is necessary to establish zones to differentiate activities. This may be characterized as a class interval problem. This problem raises a number of thorny issues. How many zones are appropriate? How should the boundaries of the zones be established? At what distances should zones change? How stringently should zones be observed at the actual time of an emergency (e.g., in terms of recommended protective actions)?

The Radiological Emergency Planning (REP) Program for fixed site nuclear power facilities uses a two zone concept [16]. The Plume Exposure Pathway Zone has a radius of about ten miles while the Plume Ingestion Pathway Zone has a 50 mile (80 km) radius. The ten mile criterion for the Plume Exposure Pathway Zone was established based on probabilistic risk assessment of reactor accidents. As a measure of the uncertainty and controversy surrounding answers to the above questions, critics have suggested that such a zone should be changed to anywhere from a one to a 25 mile radius.

In the SARA Title III *Technical Guidance for Hazard Analysis: Emergency Planning for Extremely Hazardous Substances* [17], a single zone concept is recommended for *each* chemical stored at a facility. This zone is based on a vulnerability estimate which is based on estimates of downwind dispersion of the chemicals. The distance is determined by estimating a level of concern, which is defined as a concentration of a chemical in the air above which there may be serious irreversible health effects.

A set of three planning zones (i.e., an innermost immediate response zone or IRZ, a middle-distance protective action zone or PAZ, and an outermost precautionary zone or PZ) was developed for the Chemical Stockpile Disposal Program to provide more flexibility than offered by the REP or the SARA Title III programs. Emergency planning zones (EPZs), developed in consideration of the risk analysis, available response time, distance, and protective action options, establish the areas where the emergency response concepts are applied. This EPZ concept and its three zones reflect the differing emergency response requirements associated with the potential rapid onset of an accidental release of chemical agent and the amount of time that may be available for warning and response. The three sub-zone concept was developed in recognition of the importance of comprehensive emergency response planning and support systems for rapidly occurring events and the critical nature of such programs in areas nearest the release point.

The EPZs were intended to guide the development of emergency response concepts, and were not intended to be applied mechanistically or inflexibly to specific sites or alternatives or to a specific accident scenario. The development of actual EPZs takes into account unique political, social, geographical, and stockpile characteristics of each site (see below for application to one of the eight chemical agent storage/ disposal sites). Conceptually, the criteria for establishing the EPZs are applied consistently across the program; however,

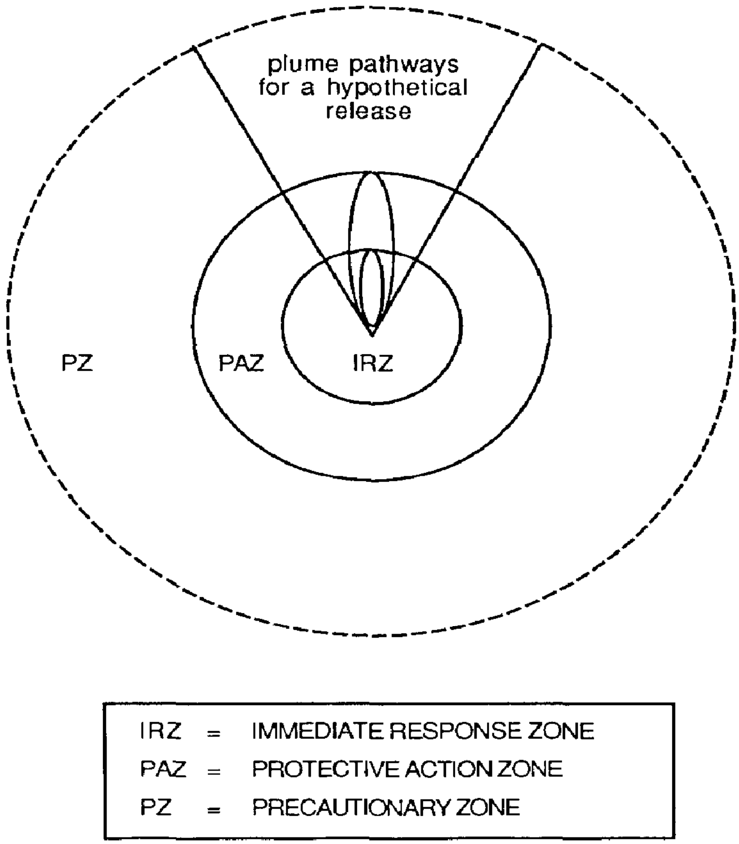

Fig. 1. Schematic of the different emergency planning zones.

due to variance in the above characteristics, specific configurations and associated distances vary from site to site.

As noted above, the EPZs were partitioned into three specific subzones (see Fig. 1). The subzones were based on the types of accidents identified for all of the sites and the amount of time available to pursue appropriate protective actions. The EPZs developed for any given site are based on the hazards posed by specific chemical agents at that site and accident scenarios and associated source terms for those chemical agents, as well as site-specific meteorological, topographical and demographic conditions.

Immediate response zone

Those areas nearest to the facility should be given special consideration because of the potentially very limited warning and response times available within those areas. An IRZ is identified for the development of emergency response concepts that are appropriate for rapid response in areas nearest to the site.

The IRZ is defined as an area inside the PAZ where prompt and effective response is most critical. This area is obviously the one most likely to be impacted by an accidental release of chemical agent. These impacts would occur within the shortest period of time and are characterized by the heaviest potential concentrations and largest doses. Emergency response concepts in the IRZ should be developed to provide the most appropriate and effective response possible given the constraints of time.

The full range of available protective action options and response mechanisms should be considered for the IRZ. The principal protective actions (sheltering or in-place protection and evacuation) need to be considered carefully, along with supplemental options that can significantly enhance the protection of public health and safety. Sheltering may be the most effective principal protective action for the IRZ because of the potentially short period of time before adverse health effects may result from an exposure to the released agent [18]. In-place protection in the IRZ is particularly important in areas nearest to the release point, since there may be insufficient time for people to complete an evacuation. The suitability of sheltering depends upon a number of other factors, including the type(s) and concentration(s) of agent(s), expedient or pre-emergency measures taken to enhance the various capacities of buildings to inhibit agent infiltration, the availability and feasibility of effective individual protective devices for the general public, the accuracy with which the particular area, time, and duration of impact can be projected, and the ability to alert and communicate instructions to the public in a timely and effective fashion [19,20].

The capability to implement the most appropriate protective action(s) very rapidly is critical within the IRZ. To ensure that a minimum of decision-making is required at the time of an actual release, a thorough analysis of specific locations within the IRZ should be conducted, and a methodology for determining the appropriate protective action(s) under various accident scenarios should be established. This analysis would likely identify certain areas within the IRZ which would implement sheltering under most accident scenarios, with evacuation only available as a precautionary measure if an accidental release is anticipated. Subzones within portions of the IRZ may be defined to accommodate selective implementation of different protective actions. Given a reasonably effective capability to project the area of impact and predict levels of impact at the time of a release, it may be appropriate to implement sheltering in areas close to the release point within the expected plume and evacuation in areas not immediately impacted.

Protective action zone

The PAZ defines an area where emergency response times, and the hazard distances associated with them, are sufficiently large to allow most people to respond to an emergency effectively by evacuating. Although the primary emergency response may be evacuation, other options should be considered.

Evacuation is likely to be the most effective emergency response in the PAZ if time is sufficient to permit orderly egress. However, evacuation, like other protective actions, requires warning. Because time remains limited in the PAZ, effective warning systems are needed both to alert people to the potential for harm and inform them of the most appropriate actions. The time available for protective action varies with agent type, accident, and meteorological conditions at the time. These conditions require careful consideration during site-specific emergency planning.

Precautionary zone

The PZ is the outermost EPZ and extends conceptually to a distance where no adverse impacts to humans would be experienced in the event of a maximum potential release under virtually any meteorological conditions. The actual distance may vary substantially and would be determined on an accident-specific basis. In this area of the EPZ, protective action considerations are limited to precautionary activities to reduce the possibility of human exposure as well as actions to reduce the potential for food-chain contamination.

The time available for response in this zone is sufficient to implement protective actions without prior comprehensive and detailed local planning efforts. Given the likelihood of substantial warning and response times for areas within the PZ, precautionary measures can be planned and implemented at a state or regional level. The development of specific protective actions for the PZ should be based on site-specific needs and analyses. Sheltering in the PZ would largely be a precautionary protective action to reduce the potential for exposure to nonlethal concentrations of chemical agent. Evacuation could also be implemented as a precautionary protective action in this zone. The means for implementing the agricultural protection and other precautionary activities could be based principally on broad-area dissemination of public emergency information at the time of an accidental release. Because of the substantial warning and response time available for implementation of response actions in the PZ, detailed local emergency response planning is not required. Coordination of and consultations among local emergency managers, however, may prove useful.

Participatory planning process for chemical hazards

A community based planning process was proposed in the CSDP's Emergency Response Concept Plan (ERCP) [21]. The structure of the planning process was established so that the Army was responsible for providing funds to local communities through FEMA's Comprehensive Cooperative Agreement (CCA) with states and technical assistance and expertise to assist local planners. The methodology presented in this paper formed part of that technical assistance. An analysis was conducted for each of the eight sites, and a number of alternative planning options were presented to local emergency managers along with the methodology and rationale for the alternatives. Local emergency planners could then replicate the analysis using their own assumptions and data to develop planning zones. This structure partially places the burden of involving the affected publics on the local governments[1].

Despite such involvement of local government, the approach still begs the issue of participation by individual members of the public outside of normal political processes and procedures. The chief involvement has come from a small set of local government officials. To date there is little evidence that the emergency planning community or political leadership has solicited much involvement from those people that will be affected by the designation of planning zones. This lack of early participation by relevant publics may lead to problems in the ultimate acceptance of the planning zones.

Determining the spatial distribution of risks: The derivation of EPZs

Hazard

Probabilistic risk analysis (PRA) for any facility will identify a range of accidents with potential off-site consequences. Usually a PRA does not identify accidents with small consequences (e.g., affecting an area within 0.1 km of the point of release), extremely low probabilities (e.g., a chance of occurring less than 10^{-8} over the life of a project or program), or accidents resulting from deliberate acts of sabotage or terrorism. Given the caveats that risk analyses do not identify all possible accidents, and that historic accidents of significant size (TMI, Chernobyl, Bhopal) have not been predicted by risk analyses, it is important to have a PRA that does a credible job of identifying a range of events that can serve as planning-basis accidents.

A typical PRA includes life-cycle events such as storage accidents, transportation accidents, handling accidents, and plant operations accidents. These accidents may result from human errors such as misreading a pressure gauge or puncturing a container with a fork lift, and mechanical problems such as valve failure. A PRA will also cover external events such as earthquakes or plane crashes. Some accidents, such as a fire, or a truck crash, can result from human error, mechanical problems, or external events, or some combination thereof.

Accidental chemical agent releases can occur in several different ways. The type of release determines how much agent is available in forms that can be transported downwind. Modes of release include explosions which cause agent to aerosolize into small particles, fires which vaporize agent, spills which allow agents to evaporate, or some combination of these mechanisms resulting in a

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[1]Planning zones however, are being discussed by some of the local Intergovernmental Consultation and Coordination Boards (ICCBs) [22]. They are also being raised as part of the ongoing site-specific environmental impact assessment process for the CSDP.

"complex" release. Releases can also vary in terms of duration of release, from a short duration, which results in a discrete puff or cloud which moves downwind, or of long (or more continuous) duration, which results in a plume extending downwind over a longer period of time. An event may involve a single known chemical or, at the opposite extreme, multiple chemicals, some or all of which may be unidentified.

The height at which the initial release occurs and whether or not fire is present are also important. A release may be elevated (i.e., not a ground-level release) if it is coming out of a stack or if there is an explosion which propels it into the atmosphere. In addition, fires cause thermal buoyancy which lifts the agent to greater heights. At greater heights the agent is likely to travel downwind more quickly, but lower groundlevel concentrations of agent would occur due to increased mixing.

Meteorology

Meteorological conditions, along with topography and the nature of the release, determine how a release of agent disperses in the atmosphere. Meteorological conditions also determine upwind and downwind directions, of course. The primary meteorological factors which determine plume dispersion are wind speed and atmospheric stability. Secondary meteorological considerations, which influence and are incorporated in atmospheric stability, include heating/cooling and mechanical stirring. Under certain conditions, low-level inversions could trap releases close to the ground.

When a release occurs the wind direction obviously determines the general direction the release will move. Shifts in wind direction will cause the release to meander (or, if viewed from above, to snake back and forth). Releases are more likely to meander under low wind speeds than at high wind speeds.

Mechanical mixing and heating and cooling are the main determinants of stability or the amount of mixing that occurs as a cloud or plume moves downwind. When a high level of mixing occurs the plume travels less distance downwind but covers a wider area When conditions are more stable, little mixing occurs and longer and narrower plumes result. A release that is widely dispersed obviously results in lower concentrations throughout the affected area. while a release that is narrowly dispersed results in higher concentrations.

Topography

Topography affects the dispersion of a hazardous agent in two significant ways. First, the roughness of the terrain helps determine the amount of turbulence. The larger the obstacles that wind flows over the more turbulent the atmosphere. Thus, plumes travel further over smooth terrain than rough terrain. Second, landscape features such as mountains and valleys block or channel the flow of a release. As a plume or a cloud collides with a mountain or a dike, the concentration increases on the windward side of the obstacle as the agent pools and the plume bulges out against the obstacle. Conversely, the concentration on the lee side of the obstacle is reduced. If the landscape feature is high enough, particularly under stable conditions, the release will be trapped. If it is a minor feature, pooling will still occur but the plume will spill over the topographic barrier at a reduced concentration.

Population

A chemical release is of no human health concern unless people are exposed. Exposure can be oral (through ingestion), dermal (through contact with skin), or respiratory (through inhalation). When human health response is dose-driven, the critical parameter is the concentration of the agent integrated over time, or the cumulative amount of material to which one is exposed[2]. When human health response is not dose-driven, the important parameter is peak concentration as well as time exposed to that concentration.

Boundary determining factors

Planning zones can be established as concentric circles with fixed radii, or, alternatively, fixed radii can provide guidance with the boundaries being determined by political, human, and topographical features of the environment. We strongly argue for the latter approach because people can more easily identify features of the local environment than they can a line on a map.

Emergency planning and response capacities are usually organized by political units-counties, parishes, cities, townships, and so forth. Thus it is desirable to have planning zones coincide with political boundaries, particularly when a boundary differentiates responsibilities for emergency planning and response.

The process of human development of an area produces artifacts of a built environment. Some, such as streets, highways, rail lines, canals, and electric transmission lines, provide useful boundaries for planning zones.

Natural features also provide useful boundaries, particularly when they serve as barriers to or moderators of agent dispersion. This category would include mountains, bluffs, canyons, dikes, and large bodies of water. Other natural features, such as rivers, that may not impede dispersion can also be useful boundaries as long as they are not mistakenly identified as barriers to dispersion.

A methodology for delineating zones

Based on the previous discussions, this section specifies a systematic method for establishing emergency planning zones. The method follows a sequence for establishing concentric radii for the generic zones, and then drawing boundaries based on environmental factors.

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[2]It should be noted that lengthy exposures to very low concentrations (e.g., 0.01 mg/m^3) of toxic chemicals may result in over-estimates of adverse health effects.

Hazard-generated concentric boundaries

Two factors concerning hazard are considered in the criteria. The first is the time dimension—how much time is available before a threat occurs. The second concerns the threat *per se*—what is (are) the geographical area(s) at greatest risk. These are used to determine the recommended distances for concentric boundaries for generic IRZ and PAZ planning zones at a site. The boundaries of the PZ are not specified, although local governments may wish to set them based on the potential for catastrophic accidents at a site (see below).

Time–distance relationships are shown in Fig. 2 for three different assumed wind speeds. These are used to help estimate the boundaries of the IRZ and PAZ. For the IRZ, assuming a release of agent with little or no lead time, the leading edge of the agent plume or cloud roughly corresponds to wind speed. With winds at a constant speed of 1 meter per second (mps), it would take about 17 minutes to reach 1 km and 167 minutes to travel 10 km. At 3 mps it would take almost an hour to reach 10 km. Unless a catastrophic accident occurred, it is unlikely that source terms would be large enough. except under stable meteorological conditions, for the plume or cloud to travel a distance of 10 km. If one assumes that preplanned emergency response in the PAZ requires at least 1 hour to mobilize, then at least a 10 km immediate response zone is needed for accidents with no lead time. For accidents which can be anticipated

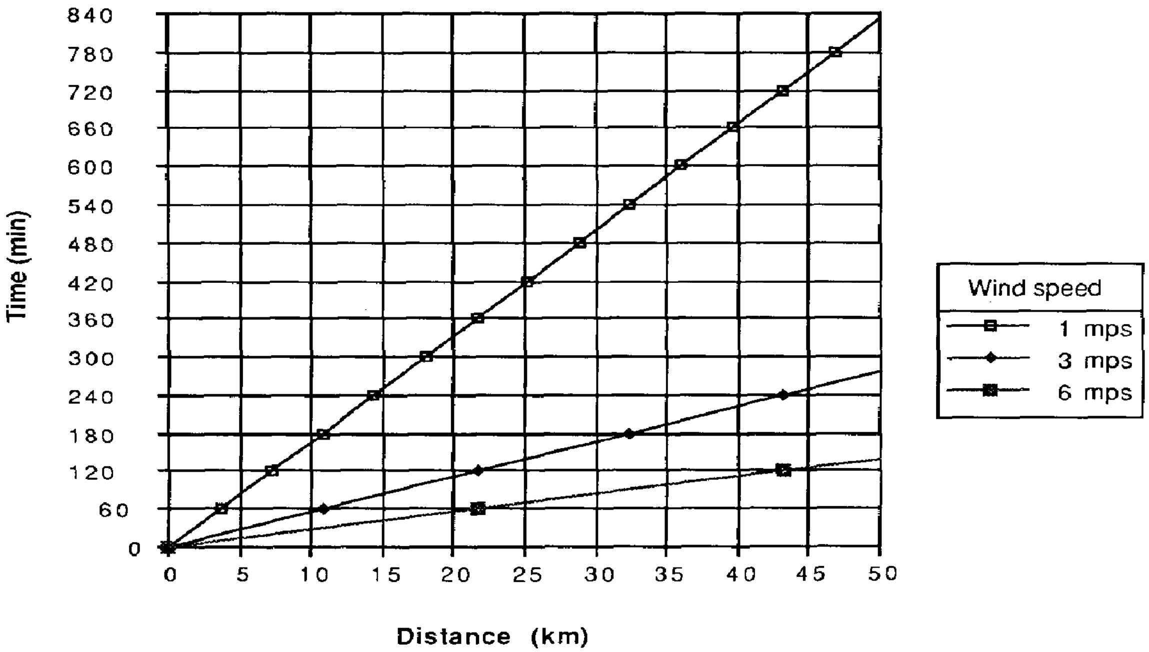

Fig. 2. Time–distance relationships for three different wind speeds.

prior to release the IRZ could be smaller. For example, if all accidents could be anticipated at least 1 hour before release, then an IRZ may not be needed.

Under the concept of no lead time, a PAZ would begin at about 10 km from the accident site. The outer edge of the PAZ boundary is more flexible. If we assume that five hours are needed to mobilize response with no advance preparation, and that the plume travel speed is 1 mps, then about 18 km would be needed for the outermost boundary of a PAZ (5 hours or 18,000 seconds$\times$1 mps). If we are more conservative and assume a 2 mps wind speed, the outermost boundary of a PAZ extends to approximately 35 km. With advanced preparation, less time may be required to mobilize a response within a PAZ, but, alternatively, winds may travel faster (e.g., at 3 mps), thus still requiring a relatively extended PAZ.

Using a suitable atmospheric dispersion code, threat can be represented by the distance materials can travel and potentially cause adverse health effects. A variety of health effects measures are potential candidates for use in establishing zone boundaries. In the CSDP, downwind "no-death" dose distances (i.e., distances beyond which no deaths to healthy adult males should occur) were used. Each dose distance was calculated for each accident scenario under several different meteorological conditions using the D2PC code developed by the Army [23]. Other dispersion codes are available to model downwind hazard distances for other hazardous materials. This article cannot go into detail on all the caveats about dispersion models, but many are succinctly summarized in the documentation of the CAMEO II package, a software system developed by EPA and the National Oceanic and Atmospheric Administration (NOAA) to assist local governments implementing SARA Title III [24-27].

Downwind portions of the IRZ should contain lethal plumes from credible accident scenarios under all but stable meteorological conditions (when sufficient time exists to respond because of the associated low wind speeds). Thus, we propose that the IRZ distance should be expanded from 10 km (based upon time) to contain the downwind "no-deaths" distances of credible (i.e., probabilities of occurrence $>10^{-8}$ for the duration of the program) non-external event accidents occurring with 3 mps wind speeds and neutral atmospheric stability (class D) conditions, plus an uncertainty band of approximately 50 percent.

We further propose that the PAZ should contain plumes from credible accident scenarios under more stable weather conditions. Thus, we propose that the PAZ distances should be adjusted from 35 km (based upon time) to contain the downwind "no-deaths" distances of credible non-external event accidents occurring with 1 mps wind speeds and class E stability conditions, plus an uncertainty band of approximately 50 percent.

Setting the actual boundaries

Concentric circles are useful guides but are not very helpful during an actual emergency. People do not necessarily have an extant understanding of a dis-

tance in the context of their image of the environment. Furthermore, there may be sound technical reasons to have an irregularly shaped EPZ. To reflect this, the generic concentric-radii boundaries derived from the method discussed above are adjusted based on a number of criteria:
(1) The concentric boundaries of the generic IRZ and PAZ should be adjusted to account for local topographical features which may interact with meteorology to affect dispersion. For example, at one of the western chemical agent storage/disposal sites (the Tooele Army Depot in Utah) a mountain range and a natural dike were used as the boundaries because they would tend to prevent or impede dispersion. At another site (the Lexington-Blue Grass Army Depot in Kentucky) a river canyon was suggested as a boundary of the PAZ because agent would tend to sink into the canyon and be inhibited from reaching beyond the canyon. At yet another (the Umatilla Depot Activity in Oregon), the IRZ was extended along a river valley which would likely channel dispersion.
(2) The boundaries of the IRZ and PAZ should not bisect a populated urban area but should be adjusted to include or exclude those areas. This was consistently applied in developing the recommended zones around the eight chemical agent storage/disposal facilities.
(3) Where boundaries of the generic zones coincide approximately with political boundaries. the political boundary should be used as the boundary of the zone. For example at one site (the Newport Army Ammunition Plant in Indiana), a state boundary was used for portions of the IRZ boundary even though it was 9 km from the facility. For emergency plans developed under SARA Title III, the jurisdiction encompassed by the Local Emergency Planning Committee may be considered a useful political boundary.
(4) Where no political boundaries coincide, it is desirable to use a feature of the built environment such as a road, highway, or rail line as the boundary of an IRZ or PAZ. In the CSEPP roads and highways were frequently chosen as recommended boundaries.
(5) When no natural or political boundary or feature of the built environment exists, a concentric circle with the appropriate radius may be used as a boundary.

Dealing with catastrophic events

In recommending generic distances based on hazard and accident distributions, we excluded external event accidents. This was done for three reasons. First, such events often have a low probability of occurring and contradict a common-sense approach to planning. Thus, one does not plan for meteorites falling from the sky or planes falling out of the air as initiating events. Second, the event that causes the accident may also reduce or eliminate response capabilities, as in the cases of an earthquake or a tornado. Third, such events include large-consequence events that stretch atmospheric dispersion modeling capabilities beyond their limits, resulting in downwind hazard estimates that are fairly unreliable; for example, a release predicted to travel 70 km at 1 mps under E stability would require more than 19 hours of such constant meteorological conditions, even though such conditions are unlikely to persist for such an extended period of time. In any case, we believe that detailed planning is not needed when time allows a response to be implemented as an expansion of activities beyond the PAZ.

If emergency planners dealing with chemicals are concerned with large catastrophic events, a formal designation of the precautionary zone can be made. In the CSDP we cannot envision it extending more than 100 km. It is extremely difficult to develop an accident scenario with source terms large enough and atmospheric transport conditions such that a lethal dose of agent would exceed that distance.

Application of zone-based emergency planning at Tooele, Utah

Tooele Army Depot (TEAD) stores 42% of the nation's continental stockpile of chemical agent (additional agent and weapons are stored at Johnston Island in the Pacific Ocean). The depot is located southwest of Salt Lake City, Utah; chemical munitions are stored in the South Area of the Depot (TEAD-S) in the Rush Valley of Tooele County. This is the only place in the U.S. in which an accidental release of chemical agent from nearby Dugway Proving Grounds had serious offsite consequences when, in 1968, a number of sheep died from an airborn release of nerve agent.

The risk analysis identifies over 100 credible accidents for the Tooele site [28]. Screening indicates that the largest (in terms of source term) of these is from a vehicle accident while transporting land mines containing the nerve agent VX from the storage igloos to the disposal facility. In this case, a resulting fire causes the landmines to explode. About 830 pounds of agent are released, mainly by detonation and vaporization (as opposed to evaporation). Using the D2PC dispersion code the lethal downwind distance, for 3 mps wind speeds and class D (neutral) stability, is calculated to be 7.5 km. For 1 mps wind speeds and class E (stable) conditions, the lethal downwind distance is calculated as approximately 33 km. If these distances are adjusted byadding 50% to account for the uncertainties in the code, the estimated distances are 11 km and 50 km, respectively. These distances are greater than the time-generated boundaries of 10 and 18 km for the IRZ and PAZ (see above). Therefore and IRZ boundary of 15 km and PAZ boundary of 50 km are the recommended hazard concentric boundaries.

The terrain near TEAD-S would significantly affect agent dispersion in the event of a release (see Fig. 3). The storage area and proposed disposal facility are located in the center of Rush Valley and are surrounded by mountain ranges to the west (Onaqui and Stansbury), east (Oquirrh), south (Tintic), and southeast (Thorpe Hills) and by a natural dike to the north (the lower South Mountain). These mountain ranges separate Tooele Valley from Rush Valley

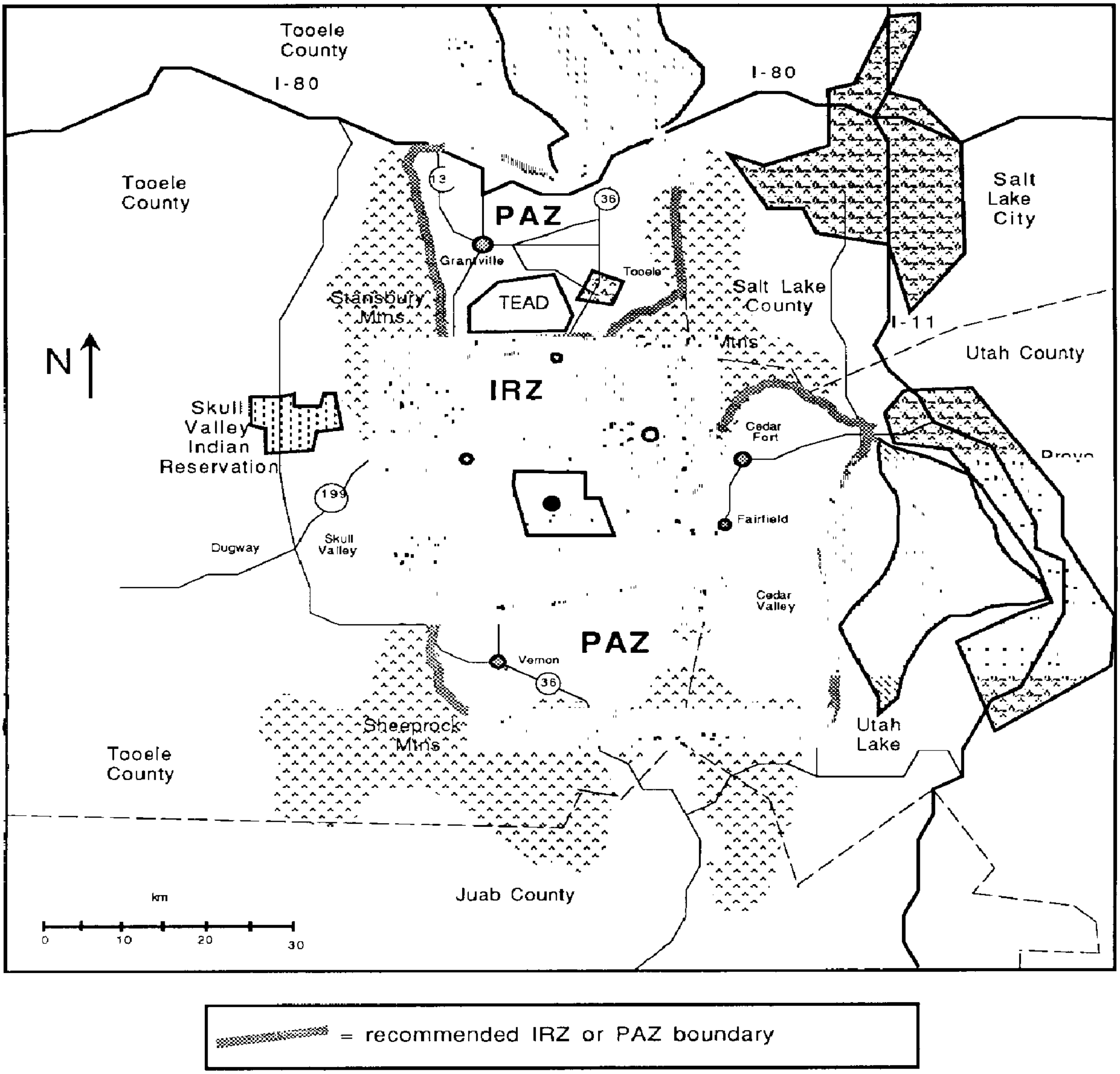

Fig. 3. Practical application of zoning to the Tooele Army Depot.

and provide partial physical barriers to agent dispersion. The South Mountains are particularly important as a partial barrier for diurnal shifts in wind direction; for a moderate to large nighttime accident occurring when slow stable winds are from the south, the agent would tend to move up the Rush Valley until it reached Stockton, where it would concentrate due to the obstruction of the natural dike caused by the South Mountain, with some agent spilling over into Tooele Valley at lower concentrations. As weather conditions change during daylight, the concentrated agent near Stockton would either move back down the Rush Valley in a wider and more dispersed plume or continue to move into Tooele Valley where it would be further dispersed and diluted by winds. If the release were large enough to result in concentrations as far north as the Great Salt Lake, the agent would likely curve around to the east due to wind effects from lake; it is unlikely, however, that a release could reach Salt Lake City.

Just as a large enough release could result in agent going over and around the South Mountain to the north of TEAD-S, with winds from the north or west it could also leave the Rush Valley to the east-southeast of the installation through Fivemile Pass; in this event, the agent could move into Cedar Valley. In the more unlikely event of winds coming from the east to TEAD-S, agent could move to the west through Johnson Pass or Lookout Pass. It is extremely improbable that agent would move over the Oquirrh Mountains to the east or the Onaqui/Stansbury to the west, which are both approximately 1,500–5,000 ft (450–1500 m) higher in elevation than the storage/disposal area.

Meteorological conditions would play a vital role in determining the degree of impediment or containment that surrounding topography would cause in the event of an accidental agent release. During stable atmospheric conditions (e.g., a temperature inversion) with light winds, the mountains would cause a "damming" effect in which most of the agent would be diverted at the mountains' base to flow parallel to the base of the mountains rather than being lifted.

During unstable conditions, however, the agent would mix more easily in the atmosphere and cross the mountains with less difficulty. Also, during high-wind conditions, the plume could be lifted over the mountains more readily. It should be noted that during unstable or high-wind conditions, the atmosphere would also dilute the agent much more readily, resulting in much lower concentrations of agent reaching the same downwind distance. In such situations a health risk would be extremely unlikely in the PAZ. although protective actions might be taken for infants, small children, the elderly, and others with pre-existing physical problems.

Thus, because of terrain and meteorological conditions, the three valleys at risk from the largest credible nonexternal event accident under stable meteorological conditions-Rush, Tooele and Cedar-form the geographical basis for establishing planning zones. Figure 3 depicts the Tooele area along with the 15 and 50 km radii, the suggested boundaries of the IRZ and PAZ, and major features of the landscape. The boundaries of the IRZ follow the contours of the Rush Valley on the east and west. To the north, South Mountain and the natural dike north of Stockton form the boundary. This extension was justified due to the pattern of winds that blow from south to north that could pool agent at Stockton [28]. The southern boundary is along a road that runs from Five Mile Pass to Faust, Utah.

The PAZ includes Tooele Valley to the north, the remainder of Rush Valley to the south and Cedar Valley to the east. It would be extremely unlikely that agent could disperse to the Skull Valley to the west or affect southeast Salt

Lake City to the northeast. The extreme northern boundary is drawn to include Interstate 80 at the 50 km radius and follow the edge of the Great Salt Lake. To the south, the Sheeprock and Tintic Mountains provide a natural boundary. To the east, Utah Lake and the mountains provide a useful natural boundary.

The IRZ is wholly contained in Tooele County, which reduces the problem of coordination among multiple local jurisdictions. The PAZ includes other portions of Tooele County and a western portion of Utah County, and thus requires a greater level of inter-jurisdictional planning. Salt Lake County is not included in the risk area zones but can be called upon to support other aspects of planning. Should an evacuation occur, Salt Lake City could provide shelter for the evacuees. Additionally, many resources to support an emergency response would come from the Salt Lake area.

Conclusions

The methodology and analysis presented here provide a starting point, a concept, for the establishment of planning zones. The ultimate objectives, *officially* establishing such zones and implementing associated emergency response capabilities, are largely subject to local political processes and must be accomplished with the concurrence of the local population. The process of establishing EPZs is finished when lines are drawn on a map with a greater level of detail, and those lines meet the needs of the population living in the area.

It will doubtless be difficult to gain the concurrence of all involved because the implications of imperfectly derived zones, and the subsequent emergency response enhancements associated with them, are fundamentally important in the unlikely event of an off-site release. The process of deriving and establishing such zones should be simplified. However. if a common approach and base of information are accessible to all involved. Thus, the analysis and resulting zones can then be modified or used, driven perhaps by making different assumptions, to yield more suitable results. In short, we caution that this conceptual approach should be implemented by persons having greater familiarity with site-specific information than we or any other distant professionals might have.

In the Tooele case discussed above, the recommended boundaries of the IRZ and PAZ were endorsed by the state and adopted by the local jurisdiction involved. This will not be the case at all CSDP sites. At Aberdeen Proving Ground in Maryland, the state is opting for a 20 km time-generated radial distance for the PAZ instead of the 25 km that was recommended [29]. At Pine Bluff, Arkansas, the state accepts the recommendation of a 50 km PAZ [30], but prefers a radial circle instead of natural and other features as the boundaries.

This paper presents a rationale and a systematic methodology for establishing emergency planning zones surrounding facilities that handle or store extremely hazardous substances. They derive from work done at the eight facilities scheduled to dispose of chemical munitions in the continental United States. The approach combines procedures that are the result of empirically based calculations (but still subject to large uncertainties) along with ones that hold practical appeal in an attempt to develop zones which encompass both scientific and political reality. The chief advantage of this approach is that it provides more flexibility to planners in developing emergency response capabilities for a hazardous facility site. The lack of flexibility is a major constraint to effective emergency response [31]. This approach also gears resources to meet planning needs, an important condition for effective emergency planning [32]. History abounds with cases where emergency resources are not deployed commensurate with their needs in a disaster [33]. A typical example of this is the warning to the public that either fails to include or excludes the affected population [34]. A failure to adopt the types of principles embodied in this approach can lead to a mis-allocation of resources thus increasing the vulnerability of certain members of the community. In addition, it is hoped that the approach makes common sense; if it belabors the obvious, then we have succeeded more than we had expected.

The approach is not flawless. We cannot be certain that the risk analysis covers all events. Atmospheric dispersion models can only roughly predict downwind dispersion. Information about the distribution of people, resources, and topographic features, and knowledge of relevant meteorology at the time of a release are all limited and. in some cases, changing. Lines on a map do not adequately differentiate levels of risk.

Despite such caveats, the purpose of establishing zones is not one of precisely predicting the impacts of an accident, but rather to allocate resources and to plan the proper responses to a large range of accidents. It attempts to take a complex problem with many relevant variables and reduce the problem to one that can be more effectively managed than an unknown or poorly understood one.

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