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RISK OF HAZARDOUS MATERIALS RELEASE FOLLOWING AN EARTHQUAKE

Kathleen J. Tierney
with
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Introduction

It is generally thought that a major earthquake in an industrialized, densely populated area of the U. S. could lead to the release of hazardous chemicals. Since a large post-earthquake release has the potential for posing a life-safety threat to community residents, causing environmental damage and creating other hazards and emergencies, such as fires and explosions, attention to this problem is warranted.

The management of hazardous materials releases has received increasing attention in recent years, particularly in the areas of new legislation and community preparedness efforts. However, while coping with post-earthquake releases is likely to present many challenges and difficulties in addition to those that are present during everyday, nondisaster times, relatively little attention has been paid by policymakers and planners to the special problems associated with these types of accidents.

The volume of hazardous chemicals that are manufactured, stored, and transported in Greater Los Angeles is very high. The Los Angeles Standard Metropolitan Statistical area has the second-highest number and geographic concentration of chemical facilities in the United States, after the Greater New York-New Jersey area (Congressional Research Service, 1985). Los Angeles County is one of only two counties in the U. S. with two hundred or more chemical plants (the other is Cook County, Illinois) (Cheok, Kaiser, and Parry, 1985). Within the Los Angeles area, the Port and its immediate environs have the highest concentration of facilities handling large quantities of hazardous chemicals. Given its close proximity to the Newport-Inglewood Fault and other faults, chemical hazards associated with the Port of Los Angeles deserve close attention.

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This paper contains three general sections. First, based on interviews conducted in the Los Angeles area, the paper discusses how the risk of earthquake-generated hazardous materials releases is perceived by emergency managers in both the public sector and the chemical process industries.

Second, the paper briefly reviews research on failures and spills that have occurred in U. S. and foreign earthquakes in vessels and facilities comparable to those at the Port of Los Angeles. Third, the paper presents an outline of a methodology for assessing, on a regional basis, the risk and effects of earthquake-generated releases and discusses applying this method to the Port of Los Angeles.

Risk Perception

Obviously, studies of perceived risk are no substitute for systematic risk assessment. Perceptions about hazards are frequently based on factors other than objective knowledge and experience. A large body of literature suggests that both the public and experts can hold biased views with respect to the hazards and risks associated with various activities (see, for example, Fischhoff, et al., 1982; Covello, 1983). Nevertheless, gaining information on how knowledgeable persons perceive a hazard can be a useful first-step in problem-formulation. In the summer of 1988, as part of a study entitled "Chemical Hazards, Mitigation, and Preparedness in Areas of High Seismic Risk," funded by the National Science Foundation, in-depth interviews were conducted with twenty-six key individuals responsible for emergency preparedness and response in government agencies and in major chemical manufacturing and processing facilities in Greater Los Angeles. Among the topics covered in the interviews were: perceptions of the probability of major hazardous materials releases, damaging earthquakes, and seismically-caused hazardous materials accidents in the Los Angeles area; assessments of which geographic areas in the region are most vulnerable to releases; judgments about which substances present the greatest hazard to the public; specific hazard mitigation and emergency preparedness activities engaged in by the organizations represented; perceptions about response-related problems that are likely to develop in the event of an earthquake-generated accident; and views on what types of measures for managing post-earthquake hazardous materials emergencies are likely to be effective and politically acceptable. The discussion that follows is based on some of the information obtained in those interviews.

First, while views are not consistent, generally speaking, the interviewees perceive the environment as quite risky. Perceptions about the likelihood of a serious hazardous materials release (i.e., one that would produce multiple fatalities) in Greater Los Angeles by the year 2000 varied considerably among those interviewed, ranging from a probability of 0 to a probability of 100%. However, the average perceived probability was 63%, indicating that most interviewees judge a major release to be a distinct possibility. About the same proportion believe that if a major release were to occur, it would affect not just the facility, but also the surrounding community. Asked about the likelihood of an earthquake of magnitude 6.0 or above by the year 2000 in Greater Los Angeles, the range of estimated probabilities was also wide--from 10% to 100%--but the average estimated probability was 60%, which is moderately high.

Of particular interest to this discussion, the interviewees also see the probability of **earthquake-generated** hazardous materials releases as rather high. While the same wide range in estimates was observed on this item, (5% to 100%), the average probability assessment was about 62%. Two-thirds of the respondents also indicated that if such a release were to occur, it would have an impact on the surrounding community, not just the facility in question. Interviewees considered the highest hazard to exist in facilities that involve the transportation of hazardous materials, as opposed to manufacturing and storage, which is consistent with actual accident patterns. Less than one-fourth of the interviewees thought that the state of preparedness for such events was high; most saw handlers of hazardous materials as placing moderate or low emphasis on the problem.

When asked what magnitude of earthquake would be sufficient to trigger a significant hazardous materials release, no one believed that an event less than M5.0 could cause an accident. About one-half of the individuals questioned thought a release could occur at magnitudes as low as 5.0-6.5; the other half thought a larger event (6.5-8.0) would have to occur to trigger a significant accident.

Second, interviewees have clear views on which areas in the Los Angeles area are most vulnerable and which hazardous substances are most likely to be involved in accidents. Only one of the persons interviewed argued that there are no specific areas in Greater Los Angeles that are highly vulnerable to hazardous materials releases; everyone else saw the hazard as unevenly distributed. Significantly, the South Bay area generally and the Harbor and San Pedro areas in particular were mentioned most frequently by these individuals as likely sites for both releases in general and earthquake-induced accidents. Reasons given by interviewees for designating these areas as hazardous included the large number of facilities located there, the high volume of hazardous materials handled, the fact that Port area is a major transfer point as well as a terminus point for pipelines, and the nearness of the Newport-Inglewood Fault. Chlorine and ammonia were the substances most frequently mentioned as posing potential problems, both during normal times and following an earthquake.

Third, interviewees believe that hazardous materials releases triggered by an earthquake will be much more difficult to manage than releases occurring during non-disaster times. The officials interviewed expressed a variety of concerns with respect to earthquake-generated releases. Among the response-related issues identified (in descending order of frequency) were: difficulties responders would have getting access to the site of a release to provide assistance, because of disrupted transportation routes; the likely loss of important communications media, such as telephones; the probability that resources needed to deal with releases would be in very short supply; the need to establish new priorities because of excessive demands on the emergency response system; disruption of power and water supplies; and difficulties with warning and evacuating the public from hazardous areas. Only three of the individuals interviewed took the position that an earthquake-induced incident would not create response-related problems over and above those present during "normal" hazardous materials emergencies.

Although interviewees' comments about exceptional problems associated with releases following earthquakes were not made specifically with reference to the Port, their applicability to that area is obvious. In fact, for a variety of reasons (the sheer size and complexity of the facility and the wide range of problems that could result following a major earthquake, the vulnerability of much of the soil in the Port, the size of the population in the area) the response-related problems are likely to be even more pronounced than in other parts of the region.

Earthquake Damage and Hazardous Materials Releases Involving Comparable Facilities and Components

The position paper for this workshop notes that the Port can be viewed as a system consisting of various subsystems and components, e.g., cargo handling/container operations, buildings and other structures, and lifelines. Data on how recent earthquakes have affected comparable facilities and components can suggest what might be expected at the Port in a major earthquake, and thus can be a useful starting-point for more systematic risk analyses.

<u>1989 Loma Prieta.</u> There apparently were no significant hazardous materials releases in port facilities following the 1989 Loma Prieta earthquake, and industrial facilities in general were not heavily damaged. However, the Port of Oakland did sustain severe damage as a result of settlement and liquefaction of uncompacted fill (EQE Engineering, 1989; Dames and Moore, 1989).

The earthquake triggered a hazardous material spill at a frozen food cooling plant in the town of Pajaro. Lines carrying ammonia ruptured as a result of earthquake shaking and approximately 1,000 gallons of the substance escaped.

Fifty employees were evacuated from the facility (Association of Bay Area Governments, 1990).

Other Recent California Earthquakes. In the 1987 Whittier Narrows earthquake, a relatively small event, an accident occurred while a cylinder was being filled at a chlorine repackaging facility, resulting in the release of nearly one ton of the gas. A toxic cloud spread to the adjacent area, and problems with telephone and emergency radio communications made it virtually impossible for local officials to exchange information on the event. The M6.7 1983 Coalinga earthquake caused significant damage to equipment and storage tanks in the oil facilities outside Coalinga. Large oil spills occurred, and production at several facilities was interrupted for weeks after the earthquake.

Summary Reports on Worldwide Earthquakes. Kiremidjian, et al. (1983) have reviewed the literature on damage to major industrial facilities in eleven earthquakes in the U. S. and three other countries (Japan, Greece, and Nicaragua) in the past fifty years. They note that in several cases, including the 1979 Imperial County event, earthquake damage to plants resulted in toxic releases that had an impact on the surrounding community.

In other work focusing on components that are comparable to those at the Port, Seligson and Eguchi (1990) recently compiled a report that reviews the seismic performance of liquid fuel pipelines and facilities. The report covers forty earthquakes worldwide, thirty-five of which occurred since 1960. The authors identified five earthquakes that caused significant damage to pipelines, storage tanks, and other system components: 1987 Ecuador (M6.9); 1978 Miyagi-Ken-Oki (M7.4); 1971 San Fernando Valley, CA (M6.6); 1964 Alaska (M8.4); and 1964 Niigata (M7.5). In the Ecuador event, the Trans-Ecuadorian pipeline sustained extensive damage due to slides and slope and bridge damage. In the Miyagi-Ken-Oki event, major oil spills and fires occurred in the Sendai Refinery, and a propane gas holder failed at the Sendai City Gas Bureau. The gas distribution system also experienced heavy damage. In the Alaska event, tank failures at the Union Oil Company facility were followed by fires, and tanks at the U. S. Army Petroleum Distribution Facility were extensively damaged.

CDMG Planning Scenario. The California Division of Mines and Geology's planning scenario for a major (M7.0) Newport-Inglewood event (Toppozada, et al., 1988) observes that earthquake impacts at the Port could include the following: approach failures at the Vincent Thomas and Schuyler Heim bridges; liquefaction affecting rail access and rail-mounted cranes; damage to utility lines, oil pipelines, and waste water lines; ruptured oil storage facilities; and fires. Types of releases other than oil spills are not discussed in the report.

Risk Analysis Methodology for Post-Earthquake Hazardous Materials Releases

The data on perceived and objective risk discussed in the forgoing sections suggest that hazardous materials releases are at least a possibility following a significant damaging earthquake in the Greater Los Angeles area. However, the magnitude of the potential problem is not known, because there has been no work undertaken to date to estimate the hazard or pinpoint the types of problems that are most likely to develop. A recent project "Chemical Hazards, Mitigation, and Preparedness in Areas of High Seismic Risk" (see Eguchi, Tierney, and Antonoplis, 1988; Tierney and Eguchi, 1989; Tierney, Seligson, and Eguchi, 1990), which focused on developing a regional vulnerability model for earthquake-generated releases in the Greater Los Angeles area, provides some direction for beginning this kind of effort. Intended as a tool to assist planners, the approach uses available data and a variety of analytic techniques to identify the locations, sizes, and effects of post-earthquake releases.

Undertaking risk assessments for all types of facilities that handle hazardous materials and for all phases of hazardous materials handling (i.e., production, transportation, and storage) would be extremely time-consuming and expensive. For purposes of developing and demonstrating the methodology, the project team focused only on chemical manufacturing and processing plants, and within that category, only on facilities handling large quantities of two very hazardous chemicals, chlorine and anhydrous ammonia. However, the approach can be modified to take into account other types of facilities as well as a range of hazardous materials. Similarly, to keep the analysis relatively simple, we modeled only two outcomes, probability of release and size of the population at risk, but other outcomes such as economic losses and clean-up costs could also be incorporated into the estimation process.

The methodology, which is summarized in Figure 1, contains the following elements:

1. <u>Collection of data from hazardous materials inventories to indicate where the facilities handling large quantities of hazardous chemicals are located.</u> At the time the study was conducted, the information currently mandated by State and Federal laws was not yet available, so data provided in response to a 1985 survey by the South Coast Air Quality Management District were used. Information that is likely to be more complete and accurate is now available and relatively easily accessible.

Twenty-two facilities handling large quantities of chlorine and ammonia were found in the study area. All the chlorine facilities had at least five tons on site; the largest facilities had hundreds of tons of the substance. Ammonia inventories ranged from two to approximately two hundred tons.

2. The use of existing data on the ground shaking intensities associated with probable earthquake. These data, combined with information on where the facilities using hazardous chemicals are located, make it possible to estimate the amount of shaking facilities and components will be subject to in different earthquakes.

Figure 2 shows the types and locations of twenty-one of the twenty-two facilities (the other facility is far to the east and could not be placed on this map), as well as the ground shaking intensities that would be associated with a M7.0 earthquake on the Newport-Inglewood Fault. Five of the facilities are in Intensity Zone IX, and another fifteen are in Intensity Zone VIII.

3. The development of "generic" models of facilities. The most reliable, valid approach to assessing the likelihood of earthquake-generated problems in chemical plants would be to conduct rigorous site-by-site analyses. However, since our interest was in developing a cost-effective method that could be applied to many facilities in a large geographic area, we attempted to streamline the analysis by taking into account what facilities have in common. Because the study dealt only with chemical processing facilities, and because the facilities in Southern California generally follow similar operations (e.g., pressurized storage and transfer, reactions involving toxic gases, and post-reaction separation) and contain the same types of elements, the development of generic facility models was thought to be feasible. A chemical engineer who is very familiar with the design and configuration of local facilities worked with the project members to develop two models: storage and transfer and chemical processing.

4. The assessment of the earthquake vulnerability of the facilities. Likelihood of failure was estimated first for facility components, such as horizontal storage vessels, reactors, and feed controllers. The components selected were those that typically contain large quantities of chemicals and that are especially vulnerable to earthquake motion. Fault tree models were used in order to take into account the interdependency of individual component failures. The critical failure modes--that is, those that could lead to an airborne release of a large quantity of hazardous materials--were identified, and the probabilities of these failure modes actually occurring, given different MMI intensities, were estimated.

Figure 3 shows a fault tree diagram for a release involving a chemical processing facility. As the model indicates, failures can stem from a number of sources, including power loss, damage to the systems that normally keep processes under control, and damage to individual components and connections in the system.

Figure 4 shows generic earthquake damage curves for four types of processing equipment: storage vessels, reactors, temperature control facilities, and feed controllers. (Where empirical data were not sufficient for deriving estimates, expert judgments on the likelihood of damage and failure were elicited.) As the figure indicates, significant levels of damage would be expected for MMIs above IX.

Failure probabilities for each of the components were estimated from the damage curves. The failure modes that could lead to an airborne release of a large quantity of a hazardous chemical were identified, and the probabilities of these modes actually occurring in an earthquake were estimated. As Figure 5 (on the same page with Figure 4) indicates, significant failure probabilities are expected for shaking intensities above MMI IX. As indicated earlier, one-third of the facilities in the study are in the MMI IX Zone.

<u>5. The use of existing models for predicting the behavior of the airborne toxic cloud released from a facility.</u> Failures leading to a toxic release are a function of a facility's vulnerability to earthquake ground motion. However, what happens when a release occurs--that is, how the substance spreads--is a function of other factors, such as the amount of material released and environmental conditions. Based on the types of failures described above, and making additional assumptions about atmospheric conditions and other factors, chemical release footprint models were developed for chlorine and ammonia releases. Different equipment types and capacities (e.g., piping, containers of various sizes) as well as different release rates (continuous leaks versus leaks resulting from catastrophic failures) were taken into account in model development.

The level of chemical concentration modelled in these analyses was ERPG-3 (Emergency Response Planning Guidelines, Level 3), which is a threshold level for significant health effects. (If some other criterion were used, the plume size would differ accordingly.) The concentrations involved were 20 ppm for chlorine and 1000 ppm for ammonia.

<u>6. Incorporation of census data into a model, to estimate the size of the population that would be affected by releases resulting from different earthquakes.</u> This step in the risk assessment procedure involved the development of a program using a probablistic approach to exposure. Using population data from the 1980 census for enumeration districts in the five-county Los Angeles basin, population exposures were calculated for plumes originating from the facilities in the sample. Failures in different facility components were taken

into account in this model, as were variations in the resultant plume sizes.

Figure 6 illustrates the application of this procedure to the Greater Los Angeles area for a M7.0 Newport-Inglewood event. In this event, the high-risk population centers (that is, those with at least five hundred residents exposed at the ERPG-3 level) are all in the South Bay.

These same types of analyses were performed for 8.3 San Andreas event and 5.9 Whittier Narrows events. For both these earthquakes, the location of the high-risk areas shifted eastward considerably. For the M8.3 event on the San Andreas, only one site in the South Bay was identified as posing a hazard to the population, and for the recurrence of the Whittier Narrows earthquake, none of the population was at risk.

Applicability to the Port of Los Angeles

As applied in the pilot study, the method has a several limitations. First, the analyses focused on a relatively small number of hazardous materials handlers and on only two major types of facilities--chemical processing and storage/transfer facilities. Only stationary sites were included; important hazards associated with transportation elements such as pipelines and rail lines were disregarded.

Second, the project collected inventory information on only two substances. Literally thousands of hazardous substances are present in the Los Angeles Basin, and a thorough analysis would take many more substances into account.

Third, the study focused only on ground shaking hazards. Other hazards, including surface faulting, liquefaction, and fire, might also generate hazardous materials releases.

Fourth, many important distinctions among facilities were deemphasized when the "generic" facility models were developed. Individual facility performance will vary considerably, depending on such factors as facility age, the quality of maintenance efforts, the extent to which facility owners have emphasized earthquake hazard mitigation, and specific site soil characteristics.

Fifth, in the development of plume models, several important factors affecting plume direction and size (e.g., wind direction and velocity, humidity) were not incorporated into the probablistic model. Atmospheric conditions at the time of a release will have a major impact on dispersal patterns and consequently on population exposure. Finally, the method used to calculate the size of the population at risk involved assigning counts of residents to specific geographic points within enumeration districts, resulting in some distortion of the estimates.

These limitations in the analysis as performed were due to constraints on project resources. With more time and effort, the analysis could have been expanded to include other facilities, other hazardous substances, and a broader range of hazards.

With modification, it is possible to apply the method to the Port, The steps involved in the risk assessment would parallel those discussed above and would include:

1) Identification of types and quantities of hazardous materials present at the Port at a given point in time. Since inventories fluctuate, average or maximum quantities could be used. The materials of interest could include both those that produce airborne plumes and those that are likely to create marine spills. This step will obviously involve choices about which substances ought to be given priority--that is, which materials present the greatest potential hazard.

2) Identification of the types of containers and system components that hold or transport the hazardous materials in question, and systematic enumeration of these system elements.

3) Site-specific analyses of soil conditions and the development of severity estimates for various seismic hazards, such as ground-shaking and liquefaction.

4) Analyses of potential failure modes and calculation of failure probabilities for the components in question, under different earthquake scenarios. This stage in the process could involve a number of approaches, including the systematic assessment of data collected in other earthquakes on component performance; experimental or simulation work; and the use of expert panels.

5) Plume and spill modeling to determine the size of the area affected by the release of the hazardous substances, taking into account different types of failures and modes of release.

6) Estimation of the effects of the earthquake-generated release(s). The analyses described above focused on possible health-safety risks to persons in the affected areas. However, other outcomes and costs, such as the costs of repairs and spill clean-ups and the losses associated with disruptions in the supply of the materials in question, could also be taken into account.

As noted above, additional work to refine the risk assessment process would doubtless result in more reliable predictions. For example, the analysis of the Port facilities could include closer attention to specific hazard mitigation practices that might affect the performance of components.

Summary, Conclusions, and Recommendations

Greater Los Angeles is an area in which earthquake hazards and risks associated with hazardous materials are closely intermingled. Research-based projections indicate that the coming decades will be marked by the occurrence of one or more damaging earthquakes. Given the size of the hazardous materials inventory in the Los Angeles Basin, and given the nature of the materials that are routinely handled, we can expect that these future earthquakes will trigger secondary hazardous materials emergencies. Both public officials who work in the area of earthquake preparedness and officials in the chemical industry agree that spills and releases will accompany major earthquakes that occur in the area in the future, and that the Port is a particularly vulnerable facility, especially for a large Newport-Inglewood event.

Major hazardous materials releases are difficult to manage during normal times, but response problems will likely be greatly complicated in the event of an earthquake. In an earthquake situation, it will be more difficult for emergency workers to gain access to affected sites, warn the public, and manage emergency communications. Critical resources will be in short supply, and response agencies will be overburdened.

Hazardous materials management problems are particularly acute for facilities such as the Port, for several reasons. The first complicating factor is the sheer volume and variety the of materials stored and transported in these very large facilities. Second, the hazards change and evolve over time, as the facility grows, tenants come and go, and new materials and combinations of materials are introduced. Third, because such a wide range of agencies, organizations, and individuals are involved--e.g., the City government, small and large individual tenants, long-term leaseholders, emergency response agencies such as the Fire Department and the Coast Guard, as well as regulators and community residents--the interorganizational and jurisdictional arrangements needed for managing the hazardous materials problem are necessarily complex.

This same interorganizational and jurisdictional complexity also complicates efforts to develop earthquake hazard mitigation and preparedness strategies for the Port. Co-ordinating the activities of the various stakeholders involved in and affected by the 2020 Project to achieve better earthquake hazard reduction--and resolving the differences in their perspectives--will be a major undertaking. The individuals who are guiding the project are obviously committed to making seismic hazard reduction a key component in their planning. Reducing the likelihood that hazardous materials releases will occur in future earthquakes, as well as determining how such releases will be handled if they do occur, ought to be given a high priority the Port's earthquake hazard reduction program.

In facilities like the Port, major natural disasters, especially earthquakes, will almost invariably be accompanied by secondary technological emergencies such as fires and toxic chemical releases. To contain future losses and facilitate recovery, mitigation strategies and disaster preparedness efforts must address **both** types of hazards. Assessing and reducing potential hazardous materials problems should be an important component in seismic risk analysis and in hazard mitigation. Existing plans for managing both hazardous materials emergencies and earthquakes should be reviewed for compatibility and consistency, updated regularly, and integrated with one another.

Acknowledgments

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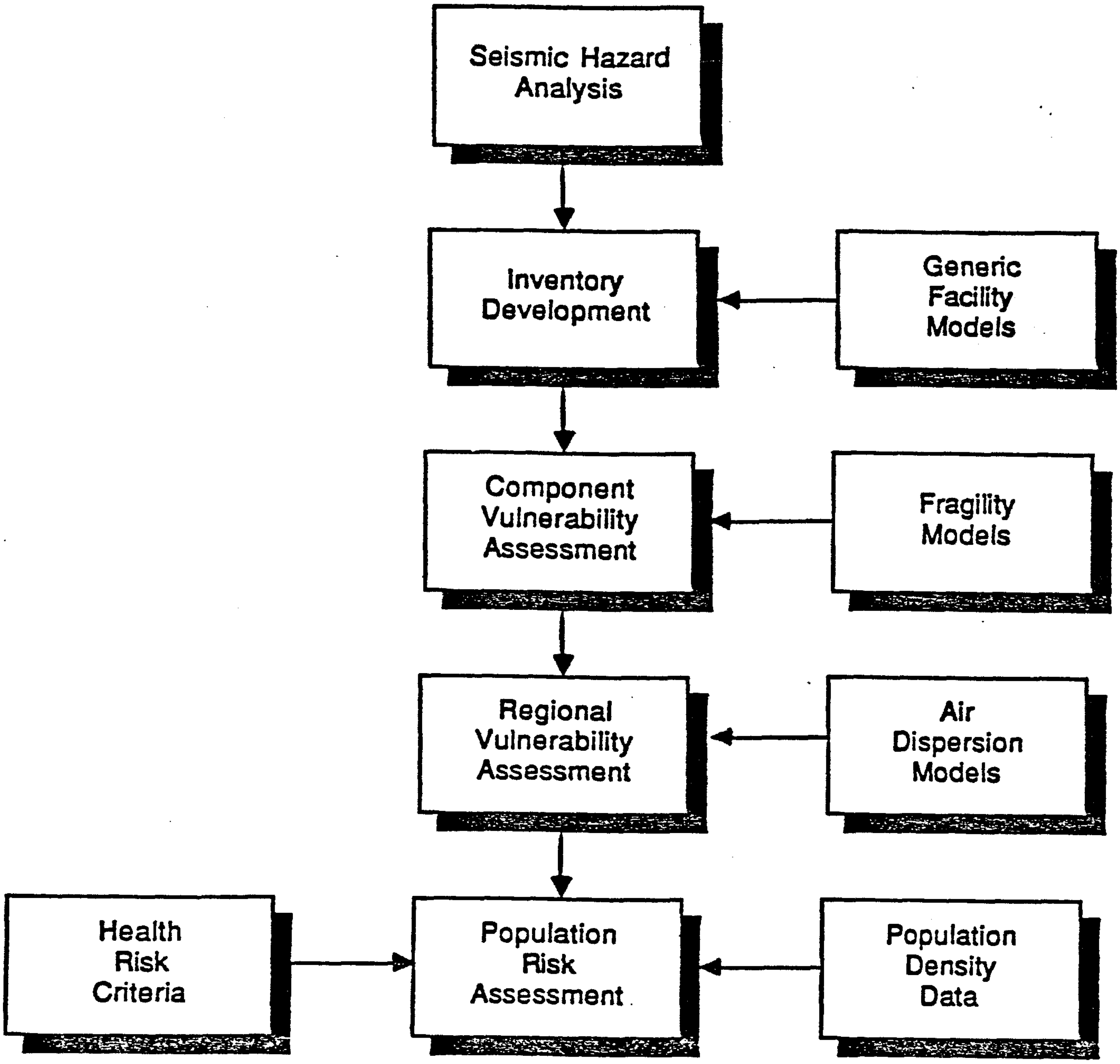

Figure 1 - Methodology for Risk Assessment of Hazardous Materials Release During Earthquake

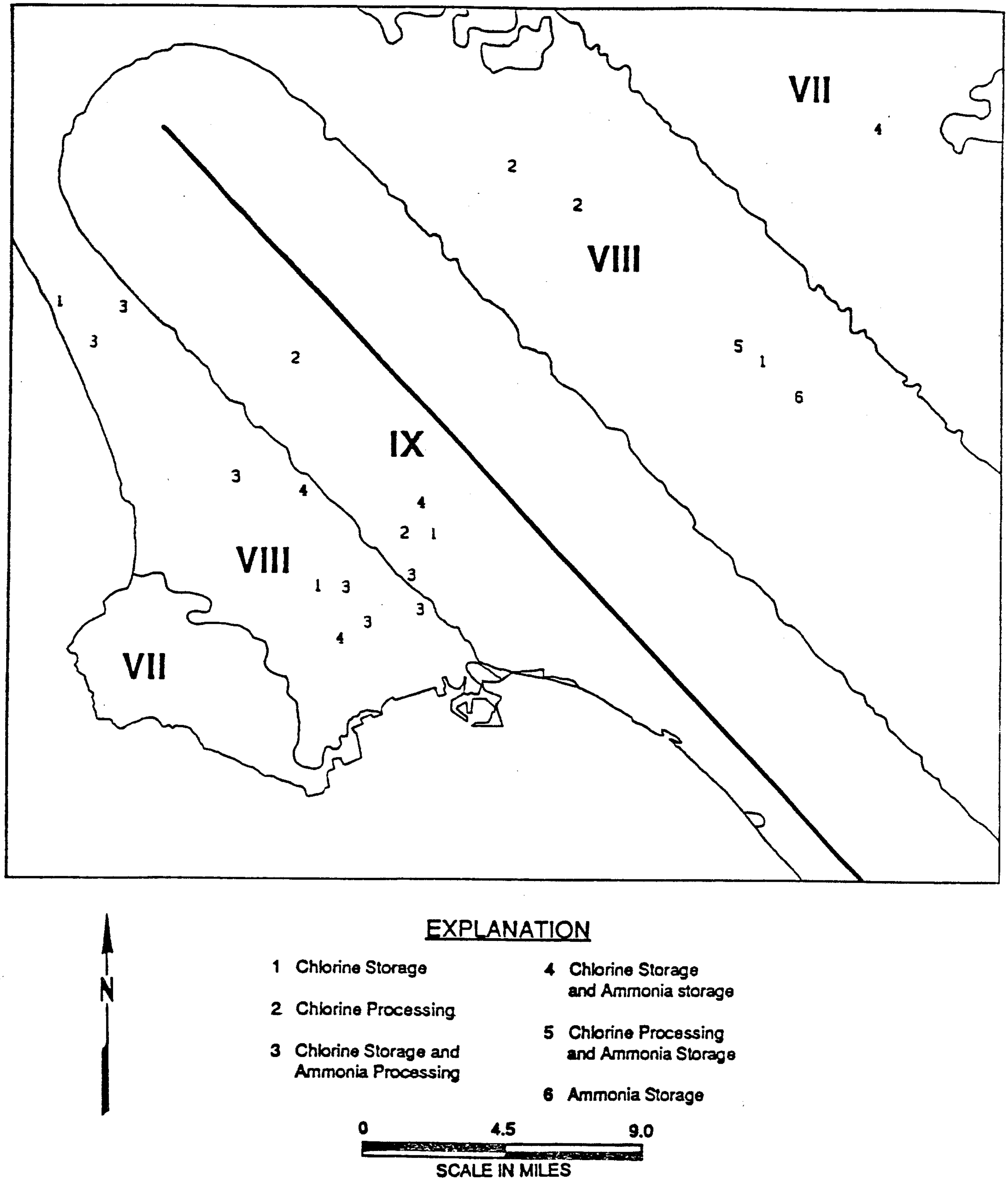

Figure 2 - Seismic Hazard Map (Modified Mercalli Intensity) for a Magnitude 7.0 Earthquake on the Newport-Inglewood Fault with Site Locations

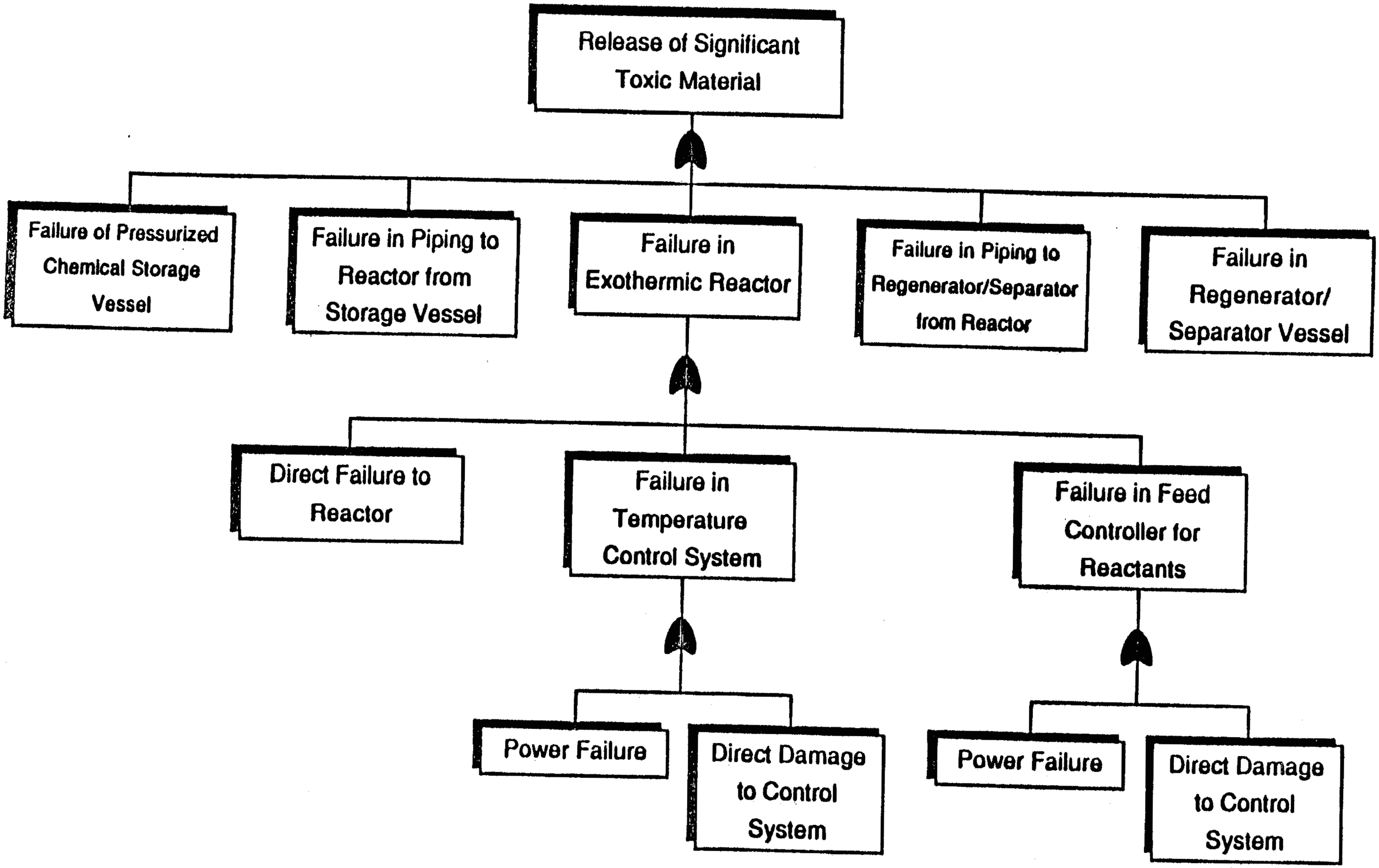

Figure 3 - Fault Tree Model for Toxic Chemical Release for Chemical Processing Facilities

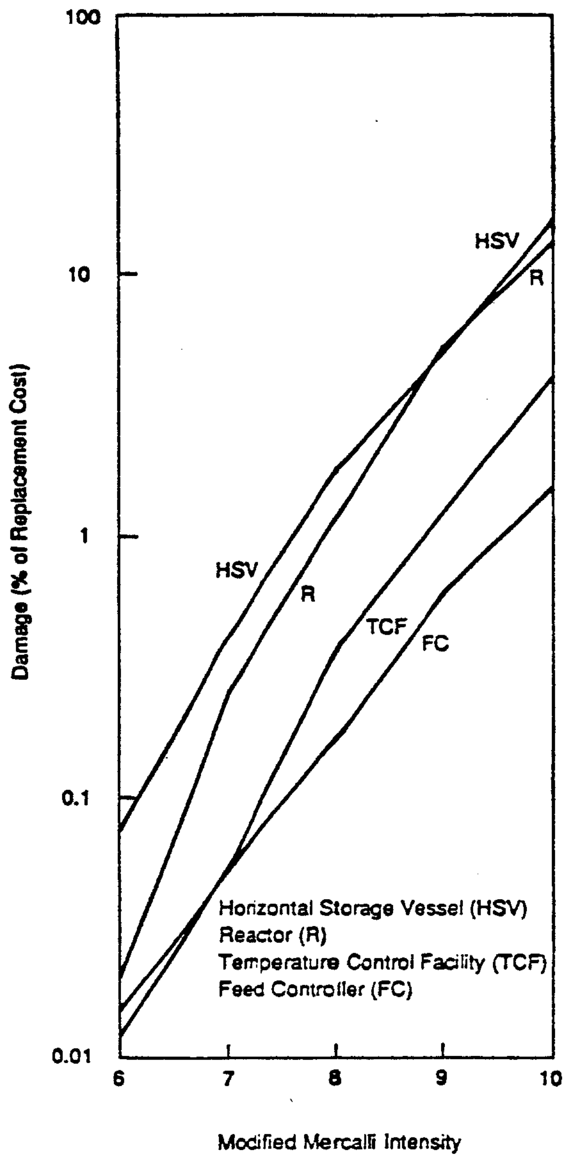

Figure 4 - Earthquake Damage Curves for Chemical Processing Equipment

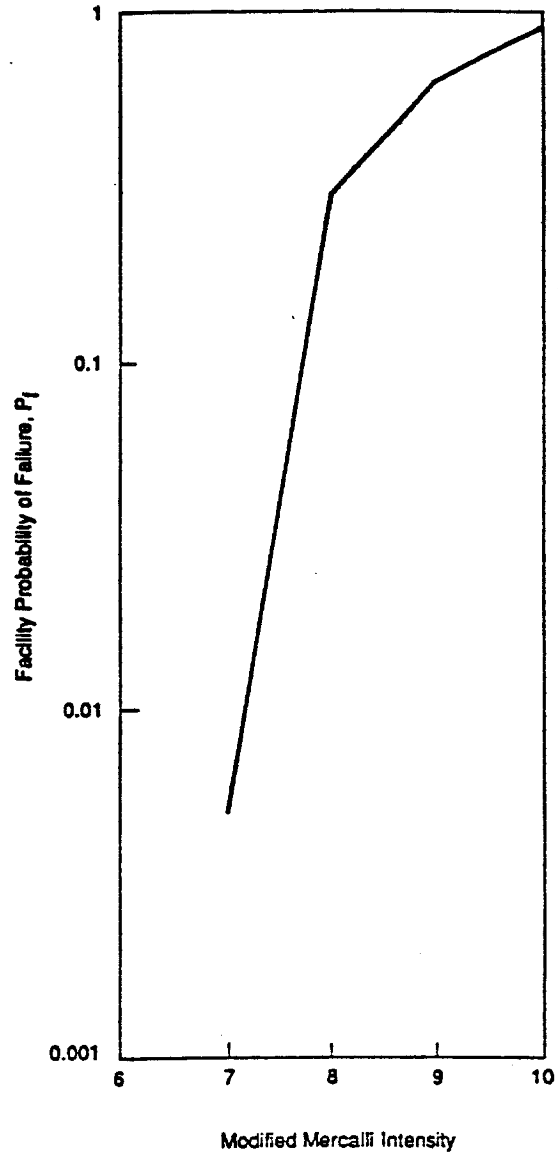

Figure 5 - Earthquake Probability of Failure Curve for Chemical Processing Facilities

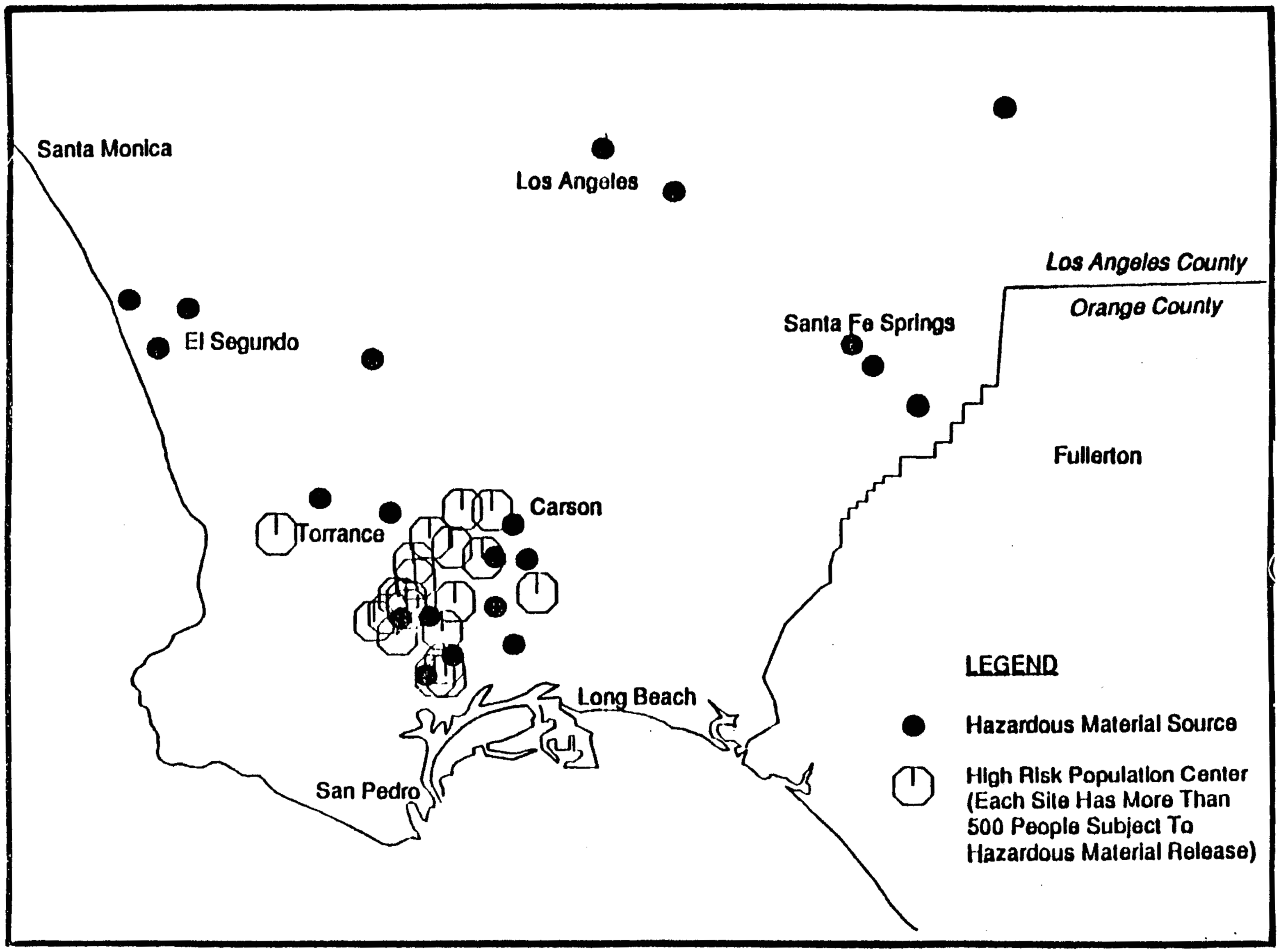

Figure 6 - Population Centers with High Risk Potential from Hazardous Materials Release During a Magnitude 7.0 Earthquake on the Newport-Inglewood Fault