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EARTHQUAKE PREDICTION, UNCERTAINTY, AND POLICIES FOR THE FUTURE

A Technology Assessment of Earthquake Prediction

Prepared for:

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The purpose of this summary report is to present--for the benefit of public policymakers and administrators, scientists, businessmen, special interest groups, private citizens, and the media--the findings of a recent comprehensive technology assessment of earthquake prediction. This assessment focuses on the following: (1) background on earthquakes; (2) outlook for earthquake prediction; (3) responding to earthquake prediction; (4) public policy issues related to earthquake prediction; (5) regional planning for uncertain predictions; and the long-term outlook.

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Final Report *January 1977*

EARTHQUAKE PREDICTION, UNCERTAINTY, AND POLICIES FOR THE FUTURE

A Technology Assessment of Earthquake Prediction

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FOREWORD

This study was supported by the Exploratory Research and Technology Assessment activity of the National Science Foundation's program of Research Applied to National Needs (RANN). An interdisciplinary team from the Stanford Research Institute (SRI) with selected subcontractors initiated the study in June 1974. The cutoff date for substantive input was the Fall of 1975; however, comments were added concerning developments that occurred during the preparation of the final report.

This report reflects a study concept that was developed in concert by the study team. With this shared concept the study team members developed their individual contributions from the perspectives of their disciplines and interests. Accordingly the study report is supported by some 22 working papers that were prepared by the study team. These working papers were prepared for the use of the study team and oversight committee and have not been published. They will be retained for a time in SRI's files for use by others working on related subjects. The selection, presentation, and integration of material in the final report reflect the judgment of the principal author. Nevertheless, the study team had the opportunity to review and comment on it.

Four meetings were held with oversight committee members during the course of the work — two in Menlo Park, California, and two in Washington, D.C. In addition, a panel was formed to assist in defining the appropriate content for an executive digest. Both groups worked diligently and effectively and made valuable contributions. These groups were not expected to generate a consensus on any matter, and the project team was free to accept or reject their comments. Therefore we hesitate to name the individuals since this might imply their full agreement with the study report. Accordingly they have our sincere gratitude but remain anonymous.

The report as it now stands reflects the findings and opinions of the project team and does not reflect the views or conclusions of any federal agency, including the National Science Foundation.

The report itself is preceded by an executive digest. This digest is organized so that ancillary and explanatory material is set off in boxes while the principal findings form the main text.

Except for the executive digest, findings, conclusions, and recommendations are set within the report context. During the course of developing the study concept, it became apparent to the study team that a framework was needed for earthquake prediction as a basis for public action. Given that, both the scientific development and the public assimilation of its products on a region-by-region basis can move forward. We have attempted to provide such a framework. Its use can help the public debate to proceed, and the people of any region can make their choices within being stalled on peripheral issues or without being forced by events themselves.

L.W.W.
Menlo Park, California
December 1976

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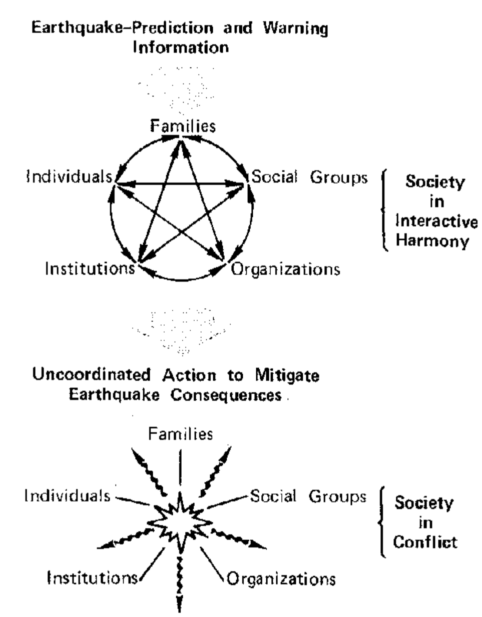
ABOUT THIS REPORT

Encouraging scientific and technological developments during the past few years indicate that earthquake prediction may soon become a reality. The purpose of this summary report is to present — for the benefit of public policymakers and administrators, scientists, businessmen, special interest groups, private citizens, and the media — the findings of a recent comprehensive technology assessment of earthquake prediction undertaken by the Stanford Research Institute.

Although modern society has developed general expectations that science and technology can solve many problems, a realization has also developed that new technologies often have unanticipated impacts. The goal of technology assessment is to identify potential impacts of impending technologies and to raise critical issues so that means to deal with them can be formulated before potential problems develop. This is done within the context of existing public policy so that policy needs can be identified and a range of feasible and acceptable options can be defined for dealing with the issues, either directly or through management of the technology-development process.

Earthquake prediction will be of little value to society unless society is prepared to act in a positive way on the basis of the information produced. Before "earthquake prediction" meets scientific standards of replicability and accuracy there will be numerous "predictions of earthquakes" of varying quality and levels of uncertainty. These early predictions, as well as potentially more reliable future predictions, will give decisionmakers representing multiple and conflicting interests a series of options for action, including the option of doing nothing. The choice of options will be complicated by the fact that some predictions may have very long lead times (more than 10 years). Furthermore, it is doubtful whether any prediction will foretell how an ensemble of earthquakes, including before and after shocks, will take place. Such earthquakes may, however, be predicted on an individual basis with lead times shorter than the intervals between shocks. Finally, the ultimate capabilities of earthquake-prediction technology are unknown. There are questions as to how accurate predictions can be, whether all earthquakes will be predictable, whether long-lead-time predictions will always be followed up by short-lead-time predictions, and whether negative predictions (e.g., "There will be no damaging earthquakes in this region for at least 150 years") will be possible. (see Figure 1.)

The policy issues that result from the scientific and technological development process, as well as those that result from a mature technology of earthquake prediction, are complex and involve many levels of decisionmaking and



A VIEW OF TECHNOLOGY ASSESSMENT

There is no one definition of technology assessment. It addresses the process whereby rational, scientifically based information is translated into public action. Hence the perspectives of the scientist, the analyst, the decisionmaker, and the citizen are all appropriate. At one extreme the scientist expects the logic and self-evident rationality of his perspective to compel public action. At the other extreme the decisionmaker takes the pragmatic view that technology assessment is what the public does with it. Because Congress has addressed the issue, the political viewpoint of technology assessment is institutionalized in Congress' Office of Technology Assessment. The analyst finds himself in the position of a broker trying to bridge the gap between the worlds of science and politics. If he has a commission from a decisionmaking body, he finds his market defined. Otherwise, he experiments with the problem and procedures. He seeks alternatives for the decisionmakers that he defines as appropriate. The outcome is intended to stimulate public discussion, but if it sells, it does so on the customer's terms. The following is one analyst's view of technology assessment.

The concept of technology assessment provides a new mechanism for explaining, in advance, technological choices in the broad context of social policy. In the past, issues have often become politicized as the impacts of a technology have been felt by institutions and individuals and judged to be undesirable. This situation often results in a posture of dealing with adverse impacts by applying after-the-fact "fixes."

Technology assessment, on the other hand, is an exercise in anticipation of the future. By attempting to identify and explore the impacts of a technology before its implementation or application, technology assessment is designed to provide a new basis for informed decisionmaking processes at all levels. This presents an enlarged view of current and emerging choices and issues. With such advance information decisionmakers and citizens can participate in decisionmaking on the choices ahead with better understanding of the more complex interactions that could develop. In the United States the public has standing in court to challenge the planned actions of federal agencies that have a potential significant impact on the environment. In addition, Congress has been charged with the exercise of foresight as well as oversight in legislative matters. Thus, the people and their elected and appointed representatives are charged with the responsibility of basing present decisions on anticipated future events. And technology assessment is one concept to provide analytically derived information into these decision processes.

However, analysis that only develops information about the anticipated impacts of a projected application of technology would meet only part of the information needs of those who would make and influence policy decisions. Therefore, technology assessment also illuminates and explores a range of feasible alternatives for dealing with anticipated impacts.

The issues that are raised by a new technology and its applications are not raised in a vacuum, but are embedded in an environment that is composed of developing trajectories of interacting interests, changing values, and conflicting concerns. Accordingly a technology assessment must also define boundaries for action that are imposed by such constraints. A careful and comprehensive analysis of relevant authorities and powers, the institutional structure of government and the private sector, and the interests and values of the appropriate constituents and stakeholders is therefore an important part of technology assessment. Thus, one of the most important aspects of a technology assessment is the opportunity to examine old questions and issues in new and different contexts.

Uncertainty about the future is the basic problem that challenges our decisionmaking capabilities. We have a limited capability for seeing into the future and we are continually thrown off balance by unanticipated events. This is the problem that technology assessment attacks. Therefore, it does not attempt to settle all issues once and for all; it does try to address issues in the present in a way that helps current decisions to be more flexible to future contingencies. Responsibility is the key to effective decisionmaking and it imposes requirements for analyst and decisionmaker alike. Therefore, one of the most important potential accomplishments of technology assessment is that of facilitating present decisions that responsibly consider the interests and needs of future generations.

nany different time frames. Such policy issues ıdd new dimensions to current policies toward ·arthquake protection. The subsequent sections ıf this report present a framework for under-tanding this situation.

ЗACKGROUND ON EARTHQUAKES

Earthquakes can cause many deaths and in-uries and major property damage in a ;eographical area. Other natural disasters tend o be seasonal and currently have some poten-ial for credible warning, but earthquakes have ıo accepted warning signs and can occur at any ime.

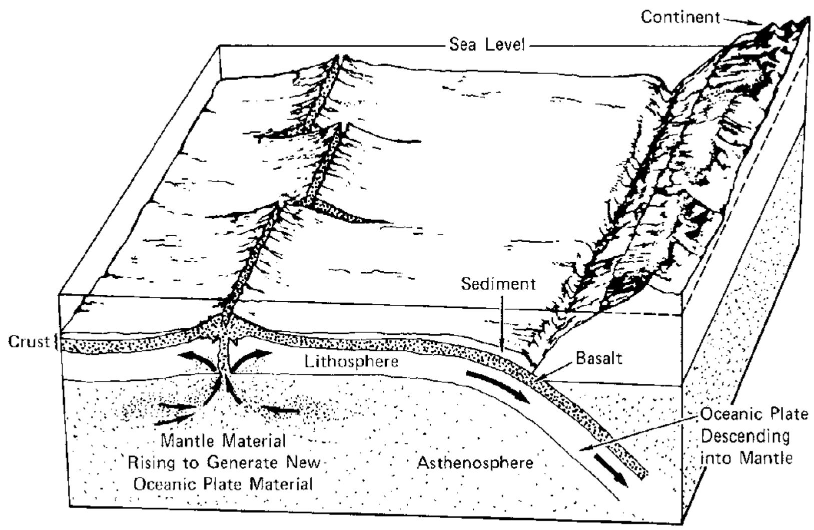
What Earthquakes Are

Earthquakes are explained on the theory of :ontinental drift and plate tectonics, which ıolds that the thin crust of the earth, 10 to 50 niles thick, is not a single rigid shell but con-ˈists of some 10 major plates and several minor ones that float on a sea of hot plastic rock. These great plates are constantly being renewed. In the process of renewal, which by human measures of time is almost impercepti-bly slow, "new" material is formed at one edge of the plate from the underlying plastic rock while "old" material at the other edge is ab-sorbed into the core. These processes cause the crustal plates to collide at their edges. The stress accumulated during these collisions is periodically released as the plates move past one another, and as the released energy is dissi-pated, the crust of the earth moves and shakes (see Figure 2). When this happens, the surface of the earth can rupture and the two sides of the rupture can move relative to each other both vertically and horizontally; landslides can result; sea waves can be generated; and certain types of soil can undergo the process of liquefac-tion in which they act more like quicksands than solids.

Many details of the relationship of plate tec-tonics to earthquake activity are, however, still unclear. The forces that make the plates move

Figure 2

MODEL OF THE PROCESS OF PLATE GENERATION AND SUBDUCTION



THE BOTTOM LINE

A Brief Summary of the Principal Conclusions of the Study

If people had a warning of when an earthquake would strike, they could take action to save lives and reduce damage. Such a warning could come from the developing technology of earthquake prediction. The actions that people might take in response to an earthquake prediction depend on their vulnerability to earthquakes, the length of warning time that they have, and their will and ability to protect themselves from the effects of earthquakes. At the present state of development we do not know how accurate earthquake prediction will ultimately be, but we believe that the warning lead time could vary from tens of years to hours or less.

The maturation of earthquake prediction may take a very long time, perhaps centuries. In the meantime the scientific inquiry will develop hypotheses about earthquakes — hypotheses that people will take as specific predictions. It is important to realize that the scientists will assign to these hypotheses probabilities based on judgment rather than on a track record. Therefore the predictions made during this transition period will probably be very uncertain. This presents difficulties to people as to whether and how to respond to these transition predictions.

An example of the problem that society faces is presented by the "Palmdale bulge" and associated phenomena. In 1976 it was noted that a large area of the earth's surface along the San Andreas Fault near Palmdale, California, had risen significantly. Seismologists and geologists do not know whether these phenomena are precursors to an earthquake in the region. The U.S. Geological Survey (USGS) has allocated funds to study these phenomena. One prediction related to the Palmdale bulge has been rejected by California's earthquake-prediction evaluation panel as not worthy of public action. Although there is concern, no specific predictions worthy of public action have resulted.

To respond effectively people will have to establish strategic and tactical response plans for dealing with the range of predictions that they might face. Although this is a difficult task, it is feasible because, within any region that an earthquake might affect and for which an earthquake-prediction system might be established, the range of predictions and the contingent effects can be bounded. In addition the people in a region will have to establish the political will to follow the appropriate plan when a prediction occurs. This should be accomplished before earthquake-prediction measurements are made in an area.

Earthquake predictions having lead times longer than a few weeks can disrupt both private- and public-sector activities in a community. However, such effects as loss of income and decline in property values may be temporary or made up in other locations, so that there are no net losses to the nation's economy. A severe constraint to responding effectively to an earthquake prediction is the liability that public officials may face as a result of their activities. The response plans can deal with the liability and compensation issues because public agreement can be obtained before the need to take action.

Accurate short-term predictions can save the greatest number of lives with the least disruption. Long-term predictions may result in a response that is very much like the response that people who live in earthquake country should be taking on the basis of existing information about the likelihood of earthquakes. A paradox is that an area that is highly vulnerable to earthquakes (such as China) cannot ignore a prediction and so must respond to long-term predictions however the appropriate response (strengthening structures) is too taxing for its economy. The combination of responding to many short-term false alarms (with an occasional success) together with the frustrations of occasional devastations, which were predicted for the long term, may over time result in serious social stress.

On the basis of the present uncertain promise of earthquake prediction there seems to be neither a reason to stop the scientific inquiry into earthquake prediction nor a reason to deviate from the present U.S. posture of stronger structures as the basic defense against the periodic ravages of large earthquakes. However, the scientific inquiry should be carefully monitored and the utility of earthquake prediction reassessed when better information is available.

re not understood at all, and there are impor-ant regions of earthquake activity, such as 'hina and parts of the United States, that do ot lie along the plate boundaries. Even when he processes that govern the movement of lates are better understood, there is no ssurance that the secondary processes that overn rupture and movement in given areas at iven times will be any better understood.

Where Earthquakes Occur

Most earthquakes occur along the interplate oundaries and in nearby areas where the crust as been fractured. In the United States, four igh-earthquake-risk zones have been defined, n the basis of recorded earthquakes, as shown n Figure 3. It is important to note that the igh-earthquake-risk areas in the United States include many major population centers; n fact, zones 2 and 3 contain about one-third of he nation's population.

What Earthquakes Do

Strong earthquakes close to population cen-ers can have serious consequences. In general erms, earthquakes can cause death and injury y damaging man-made structures. In a nodern urban area the shaking can collapse veak structures and cause parapets, overhang-ng ornaments and signs, windows, and other lebris to fall to the street below, endangering edestrians and people in vehicles. Inside build-ngs, free-standing furniture and appliances an be knocked over, objects can be thrown off helves and tables, and light fixtures and ceil-ngs can fall. Water, gas, and sewer pipes, lectrical and communication cables, and air-onditioning ducts can be cracked or severed. Elevator shafts can be warped enough to put hem out of service, and stairwells can be locked.

Structures on ground that subsides can be orn apart, tilted on their sides, or partially sunk into the ground. A landslide can destroy virtually everything in its path. Earthquake-caused sea waves can inundate coastal communities and cause great damage as they advance and retreat.

Dams can be overtopped by waves or damaged by shaking or ground failure; impounded water can be released and cause flash flooding and inundation of areas below the dams. Fires can be caused by rupture of gas lines, electrical cables or breakage of gas-fired appliances. Fire fighting can be hampered by a loss of water service. Finally, the services crucial to an industrial community — electricity, gas, water, sewage, communication, petroleum, and transportation can be simply choked off.

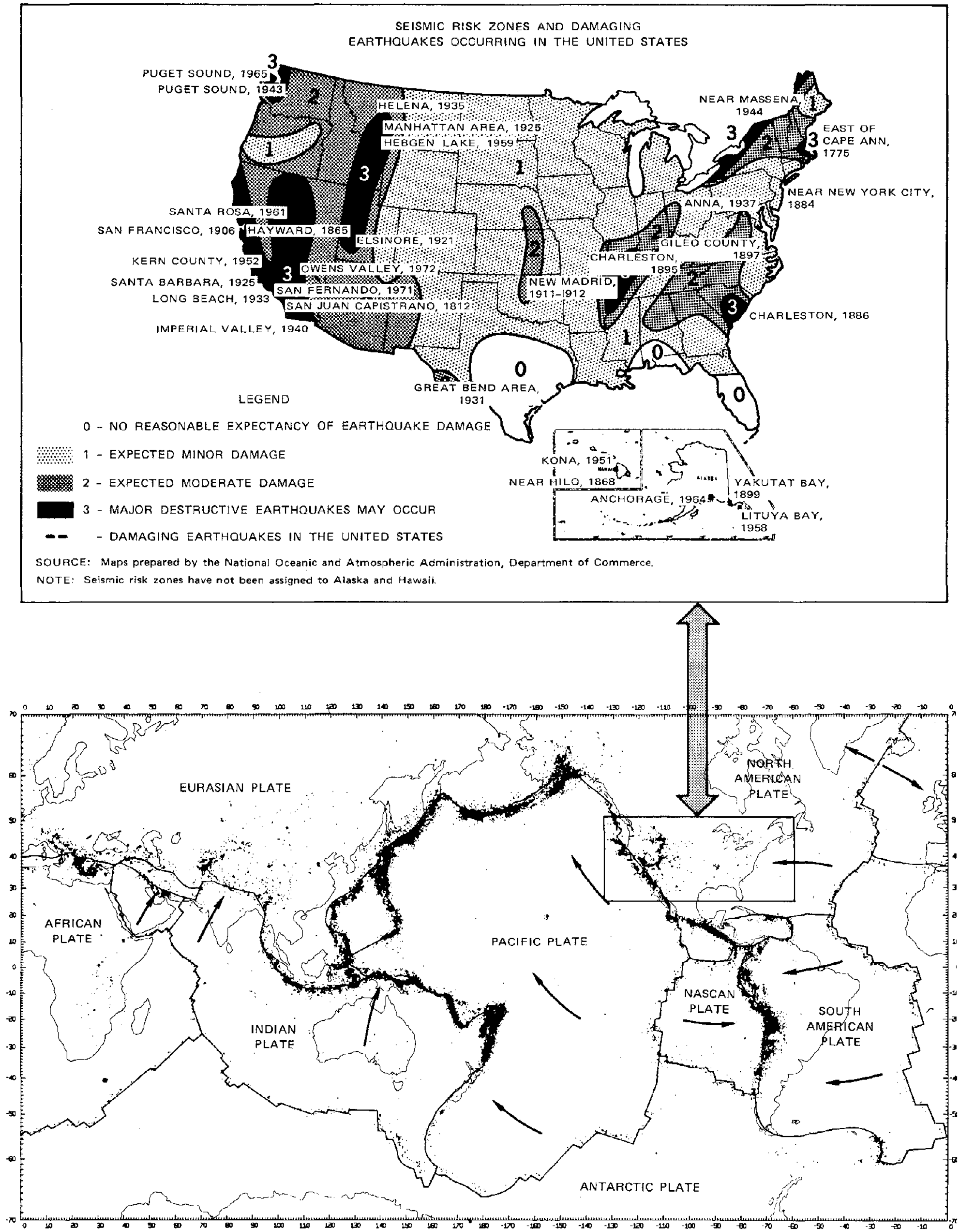
In California, as in much of the United States, the greatest loss of life would occur in an earthquake that occurred as people were beginning to return home from work in the late afternoon. Many people would be in the streets, moving out of high-rise buildings, driving on highways, or riding in buses, trains, or subways. Loss of life would be lowest in an earthquake that occurred at night, when most people were at home, because the typical wood-frame house is one of the least vulnerable structures in an earthquake.

Defense Against Earthquakes

At present, society defends against earthquakes by attempting to prevent damage before an earthquake strikes and by providing emergency care for survivors. Preventive approaches include designing structures to resist earthquake damage or building in areas not subject to strong earthquake effects. Remedial measures include rescue; medical care, food, and shelter; and restoration of essential utilities. In addition, society can and sometimes does compensate survivors for their losses through private or government-backed insurance or governmental disaster relief payments so that they can rebuild.

Figure 3

MAP OF WORLDWIDE SEISMIC ACTIVITY SHOWING LOCATION AND MOVEMENT OF MAJOR PLATES



Opportunities and Problems of Earthquake Prediction

Advance warning of a specific earthquake would provide an opportunity to take action to reduce losses. Much of the loss of life and property damage that occurs in earthquakes might be avoided by clearing dangerous buildings and areas, shutting down hazardous facilities; strengthening weak structures; strengthening essential utilities, increasing staff at hospitals and emergency operating centers; training for emergency operations; and stockpiling structural, medical, and life-support materials.

These benefits cannot be realized without cost. Critics of earthquake prediction point out that if a prediction were made for a region, property values would fall, businesses would move out, jobs would be lost. Tourists would avoid such an area. Customers would switch to suppliers in other areas whose production was less likely to be interrupted. Individuals and institutions would try to minimize potential losses by stopping mortgage and rent payments. Inventories would be allowed to run down. Improvements of real property would be limited to strengthening structures to resist earthquake effects. Purchases of all sorts of durable and soft goods would be held to those deemed absolutely necessary. All of these actions would create secondary effects that would ripple through a region's socioeconomic structure in unpredictable ways. One effect could be that some residents would be in a position and of a mind to grasp opportunities and reap windfalls, while others would lose. Some impacts, both desirable and undesirable, could result from voluntary actions, while others would be imposed by external forces. Critics also claim that the cost of many protective measures generated by an earthquake prediction would increase the cost of doing business in earthquake country. Other critics point to the fact that long-term earthquake predictions (several years), which are potentially possible, might create psychological and social stresses. Still other critics point out that earthquake prediction would convert a natural disaster from an "act of God" into an event at least partially controllable by man. Human institutions would have to assume responsibility for many impacts, not only of the prediction itself but also of the subsequent earthquake, that today are attributed to the "luck of the draw."

OUTLOOK FOR EARTHQUAKE PREDICTION

The success rate of recent earthquake predictions is too limited, and most predicted earthquakes were to small, for present experience and techniques to serve as a basis for the design of an operational earthquake-prediction system. Before such a design can be undertaken, much more prediction experience under a great variety of conditions will be necessary. To improve the accuracy and precision of predictions, particularly with respect to time and magnitude, instrument networks and the associated computational facilities must be expanded, and a sufficient number of moderate to large earthquakes must then occur within instrumented regions. The latter is a step requiring only the passage of time. For proper interpretation of instrumental data, it is likely that some significant theoretical advances will be needed.

Evolution of an Earthquake-Prediction System

The first operational earthquake-prediction system will grow slowly and naturally out of an observational program and related theoretical studies. This system, unlike a space station or a radar system, will not be designed and developed from scratch but will evolve directly out of an ongoing research activity. It is very likely that, as the years go by, larger and larger earthquakes will be predicted successfully with

(Continued on page 12)

MEASURING EARTHQUAKES

The size of an earthquake is measured in terms of magnitude and intensity by two rather complex scales. The most fundamental and scientific unit of measurement is the earthquake's magnitude, a measure proportional to the logarithm of the total energy released by the event. The most common measure is the Richter scale, which is based on measurements of seismograph records scaled to a distance of 100 kilometers (62 miles) from the center of surface energy release (epicenter) by the shock. Since the distance from an earthquake epicenter to any one of many seismic recording stations is never exactly 62 miles, tables are used to convert the seismograph records into a scale from 1 to 9.

The logarithmic feature of the scale means that an increase in magnitude of 1.0 corresponds to a tenfold increase in vibrational amplitude and an increase in energy released of about 31.5 times. Earthquakes whose magnitudes are less than 4.0 are not usually damaging. An earthquake whose magnitude is at least 7.9 is conventionally called a *great* earthquake. The largest magnitude ever recorded was about 8.9 in the case of two earthquakes in the Pacific; the great 1906 San Francisco earthquake had a magnitude of about 8.25.

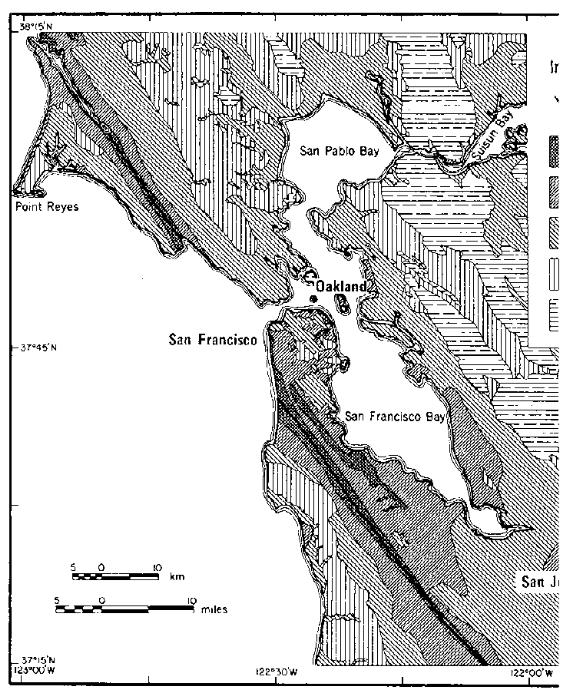
Earthquakes of the same magnitude (energy release) can cause vastly different consequences in different regions. This results partly because of different seismological/geological conditions and partly because of different structural practices. Therefore magnitude has a specific scientific meaning, but unless it is translated into specific effects to structures at given locations it has little sociocultural utility. However the translation requires detailed knowledge of the tectonic/seismological characteristics of the source fault rupture, the transmission path source to site seismology/geology, the engineering geology and soils characteristics of the site of interest, and the foundation and structural design characteristics of the structure itself. This is a complex and expensive undertaking in either a retrospective or predictive mode. There is uncertainty in this process because of the manner in which limited specific measurements of relevant properties are assumed to be representative and because of simplifying assumptions (or limits to our understanding of) important relationships.

Intensity scales have been contrived to measure the effects rather than the energy release of an earthquake. It is through a knowledge of energy release and site specific intensities of past events that reasonable projections of the site specific consequences of similar future events can be made. Through a careful definition of structural characteristics and observable effects, the uncertainty of the subjective interpretation of effects that define intensity is reduced to a minimum. Although there are several scales, the Modified Mercalli (MM) intensity scale is the one most commonly used in th United States. The MM scale employs Romai numerals from I to XII, each number correspondin; to descriptions of earthquake damage and othe effects. Because the damage and ground effects ar influenced by numerous factors — such as distanc from the causative fault, local geology, ground an soil conditions, and accuracy of personal observa tions — reported intensities can vary substantiall from site to site. Thus an earthquake cannot b assigned a single intensity number. Rather, earth quake intensities observed at various locations ar plotted on an intensity or isoseismal map.

Because the MM intensity scale and the Richte magnitude scale measure basically differen parameters, they cannot easily be directly com pared. However, the relationship between the tw measures for ordinary ground conditions i metropolitan centers in California can be gauge from the following intensity map:

THE INTENSITY MAP FOR THE SAN FRANCISCO BAY AREA 1906 EARTHQUAKE
Intensities depend on distance from fault breakage and type of soil.

Magnitude (Richter)	Intensity (MM)	Damage
1	I	Observed only instrumentall
2	I - II	Can be barely felt near epicenter
3	III	Barely felt, no damage repor
4	V	Felt a few miles from epicen
5	VI - VII	Causes damage
6	VII - VIII	Moderately destructive; som severe damage
7	IX - X	Major, destructive earthquak
8	XI	Great earthquake



Source: *A Study of Earthquake Losses in the San Francisco Area*, 1972.

Modified Mercalli Intensity Scale of 1931
(Abridged and rewritten)

To eliminate many verbal repetitions in the original scale, the following convention has been adopted. Each effect is named at that level of intensity at which it first appears frequently and characteristically. Each effect may be found less strongly, or in fewer instances, at the next lower grade of intensity; more strongly or more often at the next higher grade. A few effects are named at two successive levels to indicate a more gradual increase.

Masonry A, B, C, D. To avoid ambiguity of language, the quality of masonry, brick or otherwise, is specified by the following lettering (which has no connection with the conventional Class A, B, C construction).

Masonry A. Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B. Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C. Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D. Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

I. Not felt. Marginal and long-period effects of large earthquakes.

II. Felt by persons at rest, on upper floors, or favorably placed.

III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration may be estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.

V. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle — CFR).

VII. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments — CFR). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations — CFR). Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.

X. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

Source: C. F. Richter, "Elementary Seismology," pp 136-138, W. H. Freeman and Company, San Francisco, 1958.

gradually improving precision and accuracy. It is also likely that predictions of large earthquakes may be made with more precision as the event approaches.

Prediction experience may continue for decades and possibly centuries before replication based on empirical data or theoretical understanding is established. Society must pass through a long uncertain period of successes and failures before earthquake prediction becomes a mature science. During this long development period, society must work out its own ways of dealing with the uncertain and sometimes "incorrect" research products (hypotheses) that will emerge from the scientific community. This will provide the guidance that society will require if earthquake prediction always involves some known degree of inherent uncertainty.

Funding

The U.S. Geological Survey (USGS) is the agency designated by Congress to work on the development of the science and technology of earthquake prediction. In fiscal year 1976 the budget for the USGS prediction program totaled $5.4 million, a sum considered by most specialists to be too low to permit real progress. An increase in funding to a still relatively modest level of some $35 million per year undoubtedly would allow faster progress toward the goal of reliable prediction.* However, an "order of magnitude" increase above that — representing a major national commitment to developing the technology — would not necessarily provide a much more rapid solution,

*An example of a focused and adequately funded seismological research effort was the Vela-Uniform project, which successfully developed a U.S. capability for distinguishing between earthquakes and underground nuclear explosions. The total budget for this project was $250 million, expended between the late 1950s and late 1960s. This program literally brought seismology out of the dark ages and provided the base on which developments such as earthquake prediction could be built.

THE DEVELOPING TECHNOLOGY OF EARTHQUAKE PREDICTION

The factors most crucial to the development of practical earthquake prediction technology are the following:

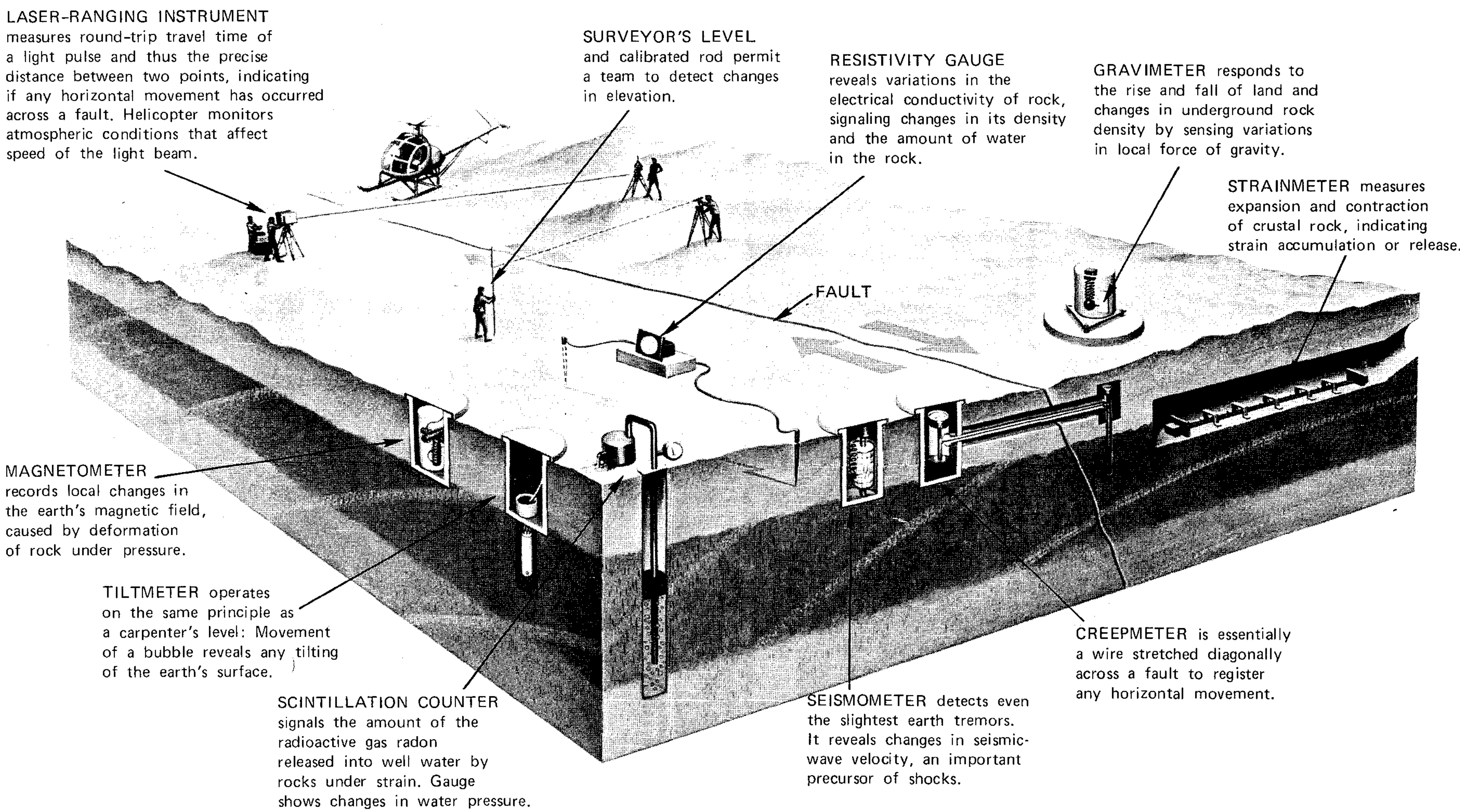
- A well-deployed and varied instrumental network (see drawing).
- An active program of laboratory experimentation and simulation of rock behavior.
- Computation facilities adequate for processing instrumental data and for extensive modeling of crustal rock behavior under stress.
- Theoretical studies for interpretation of analytical results based on field measurements and for integration of these results into existing theories and models.

Features of an Operational Earthquake-Prediction System

The form of an operational earthquake-prediction system is not yet known, but one possible type can be visualized as consisting of arrays of geographically dispersed instruments that are linked to a data-processing system through a telecommunications system. Such a system could even be incorporated into a public utility such as the telephone system. An operational earthquake-prediction system would consist of the following elements:

- Arrays of instrumentation requiring some kind of land acquisition or use rights.
- Field stations to make some periodic measurements and to provide maintenance and calibration of in-place instruments.
- Telecommunications systems to transfer command signals and data.
- Data-processing systems to reduce the field data on a real-time or near-real-time batch basis.
- Central control, probably incorporating not only the data-processing system but also the operational control and evaluation functions.

CONCEPT OF EARTHQUAKE PREDICTION INSTRUMENTATION



because the rate of progress of earthquake prediction as a science is governed by theoretical breakthroughs and by the rate at which earthquakes occurring within the geographical areas covered by instruments provide verification of hypotheses. For large, damaging earthquakes, the rate of occurrence may be on the order of 50 to 100 years in all of California. Thus it could take hundreds of years to prove a hypothesis or even to confirm a theoretical breakthrough concerning the prediction of large earthquakes on one particular type of fault structure.

Successful earthquake prediction in California may not provide a technology that can be directly transferred to all parts of the country and the world. To some degree, a technology of earthquake prediction will be specific to a certain type of fault structure and source-region

EXAMPLE OF PUBLIC-INFORMATION COMPONENT OF EARTHQUAKE PREDICTION

Lead time* (months)	6
Time window† (weeks)	±3
Epicenter or region of fault ruptures	San Juan Bautista to Los Gatos along the San Andreas Fault
Magnitude (Richter)	7.0-7.2
Confidence that event will occur§ (percent)	85
Contingent effects	Possible 8.3 Richter magnitude along entire "locked" San Francisco Bay section of the San Andreas Fault (no confidence judgment possible)

* The *lead time* of an earthquake prediction is the anticipated elapsed time between the prediction and the most likely occurrence of the earthquake.

† The *time window* of the prediction is the time period within which the event is predicted to occur.

§ The *confidence* that the event will occur, or probability, represents a complex problem of interpretation. Any early probability statements are actually an indication of what is not known about the processes that generate earthquakes, rather than what can be expected in a new situation as a result of past experience in similar situations. However, when a track record is accumulated the statements can be based on past experience.

geology. For example, earthquake predictio technology developed in California will provic theoretical knowledge that can be applied t other regions, such as South Carolina, but th South Carolina system will have to be em pirically calibrated and the reliability of th system demonstrated over time. However, ther are sufficient resemblances in geology an seismology between California and some part of China for earthquake-prediction experienc to be readily transferred either way. In this wa the development period could be shortened the political problems could be overcome.

RESPONDING TO EARTHQUAKE PREDICTION

Where measurements are being made (natural changes that may forewarn of earth quakes (premonitors), an anomaly, such as rise in the level of the earth's surface indicatin a possible earthquake, could be observed at an time. On the basis of corroborating premonitor previous observations and correlations, th theoretical understanding of earthquak mechanisms, and seismological and geologica knowledge of what kinds of earthquakes an premonitors can occur at the location in ques tion, a prediction can be produced as a scientifi hypothesis. It would be couched in seismologica parameters with bands of uncertainty, state ments of contingent possibilities, and some ex pression of the probability of the earthquake oc curring at all within the limits establishe(Some statements might contain a combine lead time and window, such as "the earthquak will occur any time within the next 6 months. Some statements might contain a window c high probability, such as "the earthquake wi occur within the 1-month period after months." In the latter statement, 6 months i the lead time.

There will be attempts to structure decisio algorithms for earthquake predictions that wi rovide computer-generated statements of prediction parameters based on the above-mentioned input components. These will prove to be both useful and dangerous. They will be useful to the scientist in that they will provide a consistent means of reducing incompatible, disparate, and and even conflicting data into an operationally meaningful hypothesis. They will be dangerous in that the judgments, assumptions, simplifications, and so on, embedded in the decision model tend to become obscured in the process. In addition, an aura of credibility develops around the product because its generation is complex and is performed by a computer. Because of the "black box mystique" associated with a prediction statement generated in this manner, some or perhaps all of the human responsibility for the uncertainty in the prediction statement may become diffused. Accordingly the validity of the prediction statement as a basis for public response may become distorted.

A Multiplying of Decisions

There are two decision environments relative to earthquakes: before and after the event. As far as the first is concerned, the general response to the possibility of earthquakes in areas with a history of such events is the application in varying degrees of seismic zoning, earthquake engineering, and emergency preparedness. Basic responses during the post-event period center around rescue, medical care of the injured, caring for survivors, rehabilitation, and various approaches to compensation as an incentive to rebuilding.

Now that earthquake prediction has become a serious possibility, there are suddenly three basic decision environments:

(1) The period before an earthquake but with the possibility of a prediction (instruments in place to detect anomalies).

(2) The period after a prediction.

EARTHQUAKE DECISION ENVIRONMENTS

Environment 1

Expectation Earthquake not possible.

Basis: No historical record of occurrences. Extensive geological seismological/tectonic investigations yield no evidence of activity.

Environment 2

Expectation: Slight possibility of earthquake.

Basis: No historical record of occurence. Little or no geological/seismological/tectonic investigations to rule out possibility of activity.

Environment 3

Expectation: Earthquake possible at any time, but not seriously expected until the end of the historical recurrence period.

Basis: Historical record of earthquakes and/or geological/seismological/tectonic evidence of activity.

Environment 4*

Expectation: Earthquake probable within specified parameters.

Basis: Earthquake prediction based on premonitor evidence.

Environment 5

Expectation: Earthquake possible at any time.

Basis: Occurence of earthquake(s) having relatively small energy release.

Environment 6

Expectation: Earthquake not possible for a long time.

Basis: Occurrence of earthquake(s) with a large energy release.

Environment 7*

Expectation: No earthquake within lead-time capabilities demonstrated by premonitor evidence.

Basis: No premonitory evidence of the type for which there exists a demonstrated lead-time relationship.

* Potentially new decision environments created by earthquake predictions.

(3) The postearthquake period after the successfully predicted earthquake, the erroneously predicted earthquake, or the unpredicted earthquake.

New environment 2 presents complex problems of uncertainty and is therefore the basic focus of this report. The critical issue is that society now is obliged to prepare for, and deal with, the event of an earthquake prediction itself. The fact that the post earthquake period now has alternative outcomes relative to periods 1 and 2 illustrates that society has many more choices to make, and many more outcomes are possible. Where society now focuses in a postearthquake period on the traditional tasks of ministering to survivors and deciding where and how to rebuild, it will be obliged to add to these tasks the unfamiliar jobs of deciding whether a prediction warrants action, determining how best to reduce losses, placing blame for faulty prediction or ineffective action, establishing the basis for retribution or compensation, and deciding who is to pay and who is to receive compensation.

Decisions Following an Earthquake Prediction

Issuance of a Warning

A key governmental decision to be made immediately after a prediction of any kind and from any source is whether the information merits an official warning that triggers governmental response, is released "for information only" for discretionary response by private parties and organizations, or is confined to the scientific community to be released in scientific journals and papers. Because of the implications of governmental response it is important that this prediction-validation process and the decision concerning the issuance of a warning be a governmental responsiblity with, of course, assistance from the scientific and technical community. Authorities at the local level mus concur in the decision because many of the sub sequent actions are taken through loca authorities and powers using locally availabl resources. If, however, the decision is made a the state or federal level, some of the burden o political liability is removed from the local leve

Assessment of Risk

If an official warning is issued, there must b an assessment of risk before the decision can b made to adopt a set of risk-mitigating action: In order to conduct this assessment of risk, th geophysical parameters of the prediction mus be translated into expected damage at specifi sites. This must be accomplished for specifi

MAJOR EARTHQUAKE PREDICTION DECISIONS

1. DOES THE PREMONITOR EVIDENCE WARRANT ISSUING AN EARTHQUAKE PREDICTION? That is, does the premonitor evidence provide better information than presently exists about the possible occurrence of an earthquake in a region?

2. DOES THE SCIENTIFICALLY BASED EARTHQUAKE PREDICTION WARRANT ISSUING AN OFFICIAL WARNING? That is, should public and private action be taken to mitigate the anticipated effects of the possible earthquake?

3. WHICH MITIGATION ACTIONS ARE APPROPRIATE TO THE SPECIFIC EARTHQUAKE WARNING? That is, based on an assessment of expected damage, the available warning time, the capabilities, desires, and expectations of the responsible individual and group with respect to reducing risk, and the ordering of public priorities, which alternative mitigating actions are to be taken?

4. ARE LIABILITIES THAT MAY HAVE BEEN INCURRED ACCORDING TO LEGAL THEORIES, LEGISLATION, OR ADMINISTRATIVE GUIDELINES TO BE COMPENSATED? That is, based on the outcome of the expected earthquake and the actions taken, are those who suffered involuntary net losses to be compensated and what or who is to be the source of these transfer payments?

tructures, classes of structures that can be eadily identified, or specific areas containing ertain types of structure or subject to certain :inds of seismic/geological/soils effects or sec- ındary effects like fire or flooding.

Adoption of Mitigating Measures

If a decision is made that the vulnerability to he earthquake effects is unacceptably high, he next decision is choosing mitigating neasures to reduce the risk. Before this can be ιccomplished, alternative tactics must be ιssessed to determine their costs and likely ;ffectiveness. The tactics available are strongly influenced by the prediction lead time. Choice of tactics also depends on the availability of resources: financial, material, managerial, and manpower. The range of tactical options depends on a strategic posture that establishes and maintains the required resource base.

Postevent (or Nonevent) Actions

An earthquake will occur as predicted, outside the prediction parameters, or not at all. As a result, the benefits of mitigation measures will be realized, partially realized, or not realized at all. The costs of mitigation measures completed before the event will occur under any

(Continued on page 20)

EARTHQUAKE-RISK MITIGATION MEASURES

Earthquake-risk mitigation measures are chosen because an individual, an institution, or society wants to reduce losses from an earthquake. Mitigation measures are taken for the overall benefit of the social level (national, state, or regional) adopting them. For example, if the state takes mitigation measures, it will evaluate them in terms of costs and benefits to the entire state. The measures that are available for reducing the risks of earthquakes can generally be classified as follows:

- Earthquake engineering
- Seismic zoning
- Disaster preparedness
- Disaster relief and insurance

Earthquake engineering and seismic zoning reduce the vulnerability of the built environment to the effects of the earthquake. Disaster preparedness prepares individuals or groups to deal with the effects of the earthquake on people. Disaster relief and insurance spread the financial losses incurred as a result of an earthquake to a larger segment of society. Because the first three measures operate before an earthquake, they are directly related to the characteristics of an earthquake prediction. The last two measures interact with earthquake prediction in more indirect ways. All of these measures, however, can be taken in the absence of an earthquake prediction. This raises the question of whether earthquake prediction is a necessary or useful adjunct to the application of these measures.

The selection of the mitigation measure is governed by the lead time provided by a prediction. Consequently, knowledge of the time required for the effective implementation of each mitigation measure is essential.

- *Earthquake Engineering.* As earthquake engineering criteria might be applied to new structures, it will take many decades to significantly affect the earthquake resistance of the structural inventory in a region. However, in terms of strengthening existing structures and otherwise reducing their vulnerability, much less time is required, and the limiting constraint in many cases could become skilled manpower and resources.
- *Seismic Zoning.* As seismic zoning might be applied in a normal environment, it too could take a long time to significantly reduce the seismic vulnerability of a region. In the long term, as higher risk structures in a potentially vulnerable region reached the end of their economic lifetime, only certain uses of the land would be allowed; for

(Continued)

example, warehouses would replace office buildings, parks would replace homes, and in unbuilt areas only certain uses of the land would be allowed as the region expanded. However, in a short-term emergency situation prompted by an earthquake prediction, designated areas or structures could be temporarily abandoned.

- *Disaster Preparedness.* Some disaster preparedness activities (e.g., evacuation) can be carried out with even a minimum warning lead time, but some readiness measures cannot be maintained indefinitely. There is probably an ideal lead time for disaster preparedness that permits the achievement of an optimal posture for a given threat but is not so long that the posture becomes burdensome.
- *Disaster Relief and Insurance.* Private disaster insurance will probably not be available after an earthquake prediction. However, for the relatively long periods between predictions of damaging earthquakes, it could again be made available. The question then becomes whether or not enough persons can be motivated to purchase it. Public disaster relief can become a substitute for private disaster insurance, but public disaster relief is not sensitive to the warning period except to the extent that preparatory actions may be required as a condition of compensation for loss.

Tailoring Mitigation Measures to Earthquake Warnings

A planning and operations guide could be developed to identify measures to be taken for various types of warning (short term versus long term) in places inside and outside the predicted damage area. The guide could be prepared and periodically updated as earthquake prediction is improved and as changes occur in enabling legislation and other factors that influence the preparedness program. If and when a damaging earthquake is predicted, appropriate guidance could be given to the concerned agencies as part of the warning process.

Case 1: Short-Term Warning

The first situation for which guidance could be prepared is that resulting from the prediction that a damaging earthquake will occur within a period of days. During such a period, it would be too late fo preparedness measures that require a long lea time. The recommended actions that might be ir cluded in a warning to communities within the pre dicted damage area are the following:

SHORT-TERM WARNING: DAMAGING EARTHQUAKE HIGHLY PROBABLE

(Risk Areas Specified, Time Insufficient for Extensive Preparedness Measures)

Broadcast public information and advice for th situation.

- Order evacuation of known hazardous structure and restrict access to known hazardous locatior
- Advise public and private organizations to ti down equipment for security against shock or di placement and protect shelf items from falling
- Urge public through all mass media to make fin preparations without delay (e.g., cleaning u trash or filling water containers); advise them t stay out of specified areas and specific types c structures
- Disseminate through mass media information o fire prevention, self-help fire fighting, and med cal self-help
- Order shutdown of hazardous industrial opera tions
- Direct operating departments to suspend all nor emergency functions, alert personnel, chec equipment and supplies, and prepare for deplo ment of forces if ordered
- Mobilize all available organized forces and deplo to preassigned emergency duty stations
- Fully man all control centers and establish 2 hour operations
- Establish and maintain communications wit other jurisdictions and service facilities
- Activate staging areas and make final prepar tions there
- Take actions to ensure the safety of instit tionalized persons
- Discontinue all elective surgery, release a hospital patients except those who are criticall

ill, and take other actions to expand bed capacity and to protect remaining patients

- Deploy assigned personnel, equipment, and supplies to designated staging areas
- Advise utilities and industry to shut down nonessential services throughout the emergency area
- Deploy field units and maintain them on standby so that they can rapidly survey area for damage and other earthquake-induced problems
- Move fire-fighting and other emergency equipment and supplies outside the stations
- Deploy engineering and other equipment

Case 2: Long-Term Warning

The second situation for which guidance could be repared is a longer prediction that provides suffiient time to implement measures to reduce seismic isk and substantially improve capability for disster operations. The general character of the mergency measures that might be recommended in n initial warning to threatened communities is inlicated below. The specific measures would depend n the nature of the prediction (weeks, months, ears) and the characteristics of the threatened ommunity.

LONG-TERM WARNING: DAMAGING EARTHQUAKE HIGHLY LIKELY

(Risk Areas Specified, Time Sufficient for Preparedness Measures)

Establish public policy for long-term situation.

Brief key government and nongovernment officials n situation and basic emergency plan and earthuake response plan.

Review, update, or, if necessary, develop listed tems:

- Legislation and local ordinances dealing with this type of situation
- Organization and assignment of responsibility to emergency service units
- Mutual aid agreements with other local jurisdictions and state agencies
- Plans for informing the public during emergencies
- Preparedness plans for hospitals, other institutions, and organizations that operate essential utilities (power, water, natural gas, sanitation, communications, and transportation, including food and fuel distribution)
- Staffing and operation of emergency operating center and other headquarters; communications with emergency service units and with other localities
- Maps indicating risk areas — fires, potential dam flood areas, landslides, structures that are susceptible to damage, etc.
- Procedures for determining (1) distribution of earthquake damage and ensuing hazards and (2) postearthquake capability of hospitals, water systems, and other vital facilities and services

Conduct planning workshops for each service. Review checklist of postearthquake actions.

- Prepare instructions for service units and personnel, assign responsibility for specified actions, and indicate when, where, how, and with what resources the actions are to be accomplished, and by whom
- Evaluate existing capability for performing the listed actions and where appropriate identify measures and resources that would improve capability
- Identify measures that will reduce earthquake losses
- Determine what normal activities and services could be deferred or curtailed to free funds for emergency preparations
- Develop detailed plans for actions to be taken if a short-term warning is issued
- Determine requirements and prepare standby procurement orders for needed equipment and supplies

Identify and mark hazardous structures and locations in the risk area. Consider actions to reduce risk (e.g., removal, strengthening, prohibition of occupancy)

Expand fire prevention programs and abate fire hazards

- Augment fire-fighting resources; prepare mobilization instructions
- Survey community for current fire risk, modifying or confirming fire contingency plans as appropriate

(Continued)

Earthquake-Risk Mitigation Measures (Cont.)

Begin actions to expand cadre and improve capability of emergency operations

- Recruit, train, and assign personnel as needed to increase service capabilities for rescue, first aid, fire fighting, fire prevention, sanitation, etc.
- Prepare mobilization instruction
- Bring emergency operating center and other headquarters to full readiness; provide for auxiliary power and augment communications
- Arrange for use of facilities selected for staging areas, mass care, and other purposes, and prepare them for use
- Procure previously identified needed equipment and supplies

Improved readiness in potential dam flood areas

- Complete evacuation plans, warning system
- Transfer key facilities
- Develop engineering procedures to determine damage
- Consider lowering water level

Improve readiness and capability of lifeline organizations, resource agencies, essential industries

- Identify measures to reduce earthquake losses and disruption of services
- Activate standby agreements for transportation and other lifeline services
- Activate standby agreements for utilization of commercial and educational facilities
- Consider moving up resources from locations outside risk area

Improve readiness and capability of hospitals, medical and allied professionals, and public health agencies

- Prepare instructions for mobilizing personnel and resources
- Expand stocks of drugs, medicines, and sanitation supplies
- Check readiness of hospitals to discharge or move patients and expand bed capacity, consider deferring elective surgery
- If appropriate, begin moving in resources from locations outside risk area.

circumstances. Some costs, such as disaster relief operations, will only be borne after the event. Depending on the outsome, the perceived costs and distribution of burdens may differ substantially from the realized and expected costs and benefits.

PUBLIC POLICY ISSUES RELATED TO EARTHQUAKE PREDICTION

Once a credible earthquake prediction is made, the general public and each element of society that is potentially affected will make decisions about what can be done to minimize the damage likely to result from the predicted earthquake. The interaction of the tactics adopted will result in various social impacts which in turn will result in much of the local disruption and economic loss often cited as a consequence of earthquake prediction. This raises the questions of whether these local socioeconomic effects should influence the governmental decision to issue a warning and whether these effects should enter the cost/benefit analysis when alternative courses of mitigating measures are evaluated. The policy problem is complicated by the fact that for a long time in the future, the decision to issue a warning will have to be based on scientific hypotheses having varying bases or assigned, rather than historical, probabilities. Nevertheless, these hypotheses will necessarily be interpreted by society as predictions of specific earthquakes that call for decisions as to whether and how to respond. The decision maker will be faced with the problem of plotting a course toward the anchorage of "minimum regrets," having only inaccurate charts and unreliable navigation aids.

The Local Perspective

It is through authorities at the local level that governmental response to earthquake prediction — including many actions initiated at the state and federal level — will be carried out. These authorities will also regulate individual and institutional responses to earthquake prediction. Should the local government fail to respond in a responsible manner, a higher governmental authority may intervene; however, without the cooperation of local government effective action will be difficult. Accordingly officials at the city and county levels are critical elements of the earthquake-prediction response system.

In-depth interviews with 15 representatives of San Francisco Bay area planning and disaster preparedness organizations led to the following conclusions:

- Local officials will respond to the concerns and perspectives of their political jurisdiction. It is irrelevant to them that another area will benefit if they believe that their jurisdiction will be hurt by a warning of an impending earthquake.

PUBLIC KNOWLEDGE ABOUT EARTHQUAKES AND EARTHQUAKE PREDICTION

A recent survey of 1,000 California residents revealed some interesting facts about the general public's knowledge of, and attitudes toward, earthquakes and earthquake prediction. In summary, the findings indicated:

- At least three-fourths of the respondents expressed some concern about the likelihood of a major damaging earthquake in their location. As age increased, expectation of a major damaging earthquake diminished. Los Angeles area residents felt there was a strong likelihood of a major earthquake affecting them.
- Most respondents knew that there is much more to an earthquake than ground shaking. The older, the less educated, and those with lower incomes described fewer things that would happen during and after an earthquake.
- Seventy-two percent of the respondents mentioned having heard or seen earthquake information. Slightly over half named the broadcast media as the source.
- Many respondents (72 percent) felt it was a good idea to give people several months' warning when scientists think a major damaging earthquake is likely to occur.
- Three times as many respondents felt that an earthquake prediction made 18 months in advance would have a negative effect on the economy than believed it would have a positive effect.
- The greatest response ("don't know") resulted from the question of how accurate a prediction would have to be before government agencies were required to act.
- In response to a question on what precautionary measures respondents were likely to take as a result of an earthquake prediction, more than half indicated they would either do nothing or leave, and of these the majority indicated they would leave rather than do nothing.

Thus it appears quite possible to inform almost all the people who would be affected by an earthquake, through prediction and warning. However, although information might be disseminated, not all would act on the information — especially doubters and fatalists.

People in the 30 to 39 age group appear ready to take the actions necessary to avoid secondary effects of earthquakes. People over 60 years old would be hard to inform and would need the most encouragement to take protective action. Other age groups would be relatively responsive to earthquake warning. Analysis by income and education levels shows that earthquake awareness (a combination of concern, understanding of likelihood, and knowledge of secondary effects) and ability or willingness to act cut across all levels.

Although most people would be able to respond to an earthquake warning, information needs and sources would differ from group to group.

- Few local governments have reserves of resources available for earthquake-prediction response activities.
- Acting before the event seems "unnatural" because it is not known what will happen.
- It is unlikely that determining and publicizing specific structures as safe or unsafe in an emergency will ever become a widespread practice of local agencies because it would be extremely unpopular politically.
- Local officials are skeptical about the evacuation of "danger" areas after an earthquake prediction. Evacuation has never been ordered before the fact or without a clear and present danger. It would be expensive, "host" areas would have to be found, and empty

MAJOR [illegible] AND PROBLEMS ASSOCIATED WITH PREDICTION AND WARNINGS

- No characteristics of the initial prediction are known for any given geographical area in the United States.
- Uncertainties permeate the field of earthquake prediction. These uncertainties cannot be avoided in the development of the technology of earthquake prediction.
- The laboratory that earthquake prediction develops in is the world and is occupied by the public.
- To the scientist engaged in earthquake prediction the prediction is only interesting in terms of its scientific validity; however, to the public, such a prediction will be very disturbing regardless of its accuracy.
- Because of the peculiar nature of earthquake prediction, there is little separation of the scientist from the public.
- For a variety of reasons, unless the separation between science and the public is mainteined, both will suffer. In the end, science may lose its authority and credibility, and the public may have its social and political systems severely and unnecessarily disrupted.
- From the public point of view, the main output of the scientific development for the usefully forseeable future will be probabilistic statements.
- The developing technology of earthquake prediction is not alone in its struggle to establish an understanding of probabilistic statements in the public sphere. In fact, this issue has a spreading and pervasive generic form: probabilities in public policy decisionmaking.
- A probabilistic statement issued by a scientist is not in itself a sufficient basis for deciding when to take action. More information must be added, no matter how crudely assembled. The consequences of acting as if the statement were true and as if it were not true must be identified, analyzed, and evaluated.
- Though science can wait for empirical testing of its hypotheses, the public cannot because the event may be one that could kill and injure.
- Earthquake prediction poses a problem for the public in that decisions made now will have consequences in the future.
- On the basis of present technology, the specific kinds or ranges of predictions that could be made are undefined. That is, we do not know how to go about projecting alternative responses to an earthquake prediction because we do not know what that prediction would be like.
- The potential scale of action that may be required is an important dimension of the problem of responding to earthquake predictions. From a public point of view it would be useful to gain experience and confidence by dealing with smaller earthquakes first and then larger ones. However, a scientific statement concerning a great earthquake may come at any point in the development prediction.

property would create law-enforcement problems.

- Certain legal issues would have to be resolved before a jurisdiction could respond to an earthquake prediction. These include consideration of when a jurisdiction is liable and when it is protected from liability, and who should pay the costs resulting from actions taken on a prediction that subsequently proves to be erroneous.*
- Local officials feel that although the public should be informed of developments, no official earthquake warning should be issued until there is an established *track record* for earthquake prediction. Most feel that a record should show at least 90 percent accurate predictions.

It is important to note that the recent emphasis on seismic safety in California is the result of state legislation, not of a "grass roots" movement. Seismic safety is simply not a priority item for local government. Moreover, there is no well-defined local government group that could coordinate an integrated response to an earthquake prediction, and groups with de facto or de jure responsibility are not experienced in the type of response necessary to fully use prediction information. The two local agencies most likely to be involved in responses to earthquake warnings are the planning and building departments, in the case of a long lead time (at least a year), and the disaster preparedness and response agency (if one exists), in the case of a short lead time. However, such agencies will need a considerable amount of help and guidance in responding to an earthquake prediction. For example, the San Francisco city building inspector force would have to be greatly increased to assess within any reasonable time the seismic safety of the city's many thousands of buildings.

*A bill (SB-1950) recently passed by the California legislature is of interest in this regard. Its intent is to grant immunity from liability for actions takèn or not taken as a result of a "scientifically valid" earthquake prediction. This bill was signed into law by Governor Brown on September 29, 1976.

The Role of the State

Traditionally, disasters are declared by the governments of the affected states. Thus an earthquake prediction would logically be evaluated, its validity assessed, and, if appropriate, a warning issued by the state. The state's responsibility would probably not end at this point. A major earthquake is such a large-scale event, involving so many jurisdictions, that the conse-

THE WARNING PROCESS

For earthquake predictions to be taken seriously — that is, believed and used as a basis for action — it is not enough for them to be scientifically valid and made in good faith. They must take full account of the complex social processes by which words are translated into action. The practical benefits of an earthquake prediction cannot be fully realized unless a number of stringent conditions are met:

- The prediction must in fact be a warning: it must convey a sense of danger, not just neutral "scientific" information.
- The warning must be specific as to time, place, and intensity and must accurately identify the areas, people, and structures at risk.
- The warning must contain prescriptions or at least strong suggestions for action.
- The warning must be disseminated through society's existing communication system, using both formal and informal networks of communication.
- The warning system as a whole should adhere to the "principle of redundancy"; that is, it should provide alternative independent sources of communication that are mutually confirming and consistent when cross-checked.

quences of a false warning could be overwhelming to the stability of local governments. The state, as the agency issuing the warning, should probably be at least partially responsible for the results of actions taken in response to the warning. This would diminish some of the constraints that currently inhibit action by local government.

Given a substantial lead time, much could be done locally to increase the safety of older central city areas if state or federal governments would make "predisaster" funding available. States could also provide a pool of building inspectors to assist threatened areas in assessing potentially dangerous buildings. Most important, perhaps, is that for the benefit of local officials states could clarify, by legislation if necessary, such legal and economic questions as the following:

- When is a jurisdiction liable, and when is it protected from liability?
- Who should pay the costs resulting from an erroneous prediction?
- When is the evacuation of dangerous structures or areas worth the social and economic cost?
- What types of seismic effects information should be made available to prospective homeowners, renters, and commercial and industrial establishments?

Federal Disaster Policy for Earthquake Prediction

The complex and unique issues generated by the developing technology of earthquake prediction and responsibility for public actions based on predictions and warnings clearly will require governmental action at the national level. Existing federal disaster legislation is the most logical starting point for the development of national public policy on earthquake prediction.

THE GOVERNOR'S DECISION
(A Scenario)

The U.S. Geological Survey at Menlo Park h
mally notified me, as Governor of this State,
tain scientific facts concerning the potential
earthquake in northern California. The USGS
quarters in Washington has confirmed these
and has told me that it has authorized and di
that this information be withheld from release
public for 24 hours pending my decision on a
of action for the State. This will allow time fo
dination with the White House and key federal
cies.

Several months ago, geologists at the USG
tained some indications of surface-level chan
two stations 20 miles apart along the southe
of the "locked" section of the San Francisco Ba
tion of the San Andreas Fault. Because of th
USGS intensively instrumented that 20-mil
ment with a fairly dense network of tiltmete
has been making regular measuremen
resistivity, telluric currents, and variations
earth's magnetic field. Some deep wells in th
are being monitored for radon emission and
levels. An extensive program — using a netw
seismometers — has been under way for mea
natural microquakes. This program has been
conjunction with periodic surveys employ
Vibraseis (a truck-mounted ground thumpe
called P-wave velocity anomalies are being fo
with this network.

The USGS has isolated changes in earth
premonitors to a 40-mile section of the San A
Fault between San Juan Bautista and Los
which is the southern portion of the so-called
section of the fault. As the result of 3 mon
measurements and studies of changes in thes
monitors, the USGS now estimates that there
85 percent chance that an earthquake of R
magnitude 7 to 7.2 will take place 6 months
now, plus or minus 3 weeks.

The USGS informs me that the fault will
along this 40-mile section, if it breaks a
However, they specifically noted that an earth
of this magnitude may trigger a "great" earth

along the entire locked section of the San Andreas Fault, which would involve a fault breakage about 200 miles long. The USGS also noted that it may be able to pinpoint the time with more precision as the event (±2 to 3 days) approaches but will probably have no better information on the expected magnitude of the predicted event. Also, it will not be able to further resolve the question concerning the probability that the predicted event will set off a great earthquake. All it can tell us now, and all it will be able to tell us, is that the event is "possible." For all intents and purposes, if the predicted earthquake does trigger a great earthquake, the latter would be on the order of an 8.3 magnitude event in the San Francisco Bay area, similar to that of the 1906 earthquake.

If the 7 to 7.2 magnitude event does *not* trigger an 8.3 magnitude earthquake, the stresses that have built up in the locked portion of the fault will have been only partially relieved and the potential for an 8.3 earthquake will have been only slightly diminished. Under the prevailing theory of stress buildup, the northern California section of the San Andreas Fault would remain liable to an 8.3 magnitude earthquake in the future.

My panel of experts has been following this work all along — in fact, some of them are participating in it. They believe that the prediction is valid and the contingent revisions and effects are possible, thereby confirming the USGS work. I have called my panel of policy experts together for advice on what to do. I explained to them that the following alternatives affect the options open to me:

(1) *With respect to the prediction*

- The prediction may stand unaltered.
- The prediction may be modified to represent a different set of facts.
- The prediction may be made more precise with a short-term warning having a reasonable degree of credibility.

(2) *With respect to the earthquake*

- It may not happen at all.
- It may happen as predicted.
- It may happen outside the parameters of the prediction.
- It may trigger a 1906-type earthquake in the San Francisco Bay area.

(3) *With respect to my response to the present prediction*

- I can issue the present prediction for information only for local option action.
- I can issue the present prediction for information only, with the understanding that we have a good chance of getting a short-term warning.
- I can issue a warning that would initiate action based on the present information. Of course, this would be appropriately modified if we received further information.
- I can do any of the above either for a 7 to 7.2 magnitude earthquake that would affect the area in which premonitors are found or for an 8.3 magnitude earthquake that would affect the entire San Francisco Bay area, or I can select a combination of the above for these two situations.

I also told the panel that each of these options involves an element of public risk taking. For each option there will exist a range of response strategies, offering a range of costs and benefits in terms of lives, property, and social disruption. For each option these costs and benefits will fall on different elements or segments of society in a disproportionate manner. This raises an element of political risk taking for me. The optimum public interest may differ from the optimal private interests of my supporters. To make a proper decision I need to know these facts as they relate to or control the decision options available to me.

That's a tall order for any group of people to ponder in 24 hours. If that isn't enough, however, I need to know how I can protect the local official from liability so he will be free to act. I need to determine the extent of liability that I might incur personally and for the state. I need to know how to induce people and organizations to act by implementing effective compensation measures. I need to know what is proper and possible to expect as support from the agencies of the federal government. After all, hasn't this earthquake become their responsibility now that one of their agencies has predicted it?

Congress passed the Disaster Relief Act of 1974 (Public Law 93-288) after more than a year of extensive and detailed legislative inquiry into federal, state, local, and private needs with respect to disaster preparedness, relief, recovery, and reconstruction. The Act was a culminating step in a series of evolutionary policy developments in the field and appears to be a fairly complete policy framework for dealing with natural disasters.

The Disaster Relief Act of 1974 covers some issues related to the actual event of an earthquake, but it does not deal fully and specifically with problems related to earthquake predictions. It appears that the Act might provide an interim framework to define the actions of governments in the event of an earthquake prediction. However, there are several important qualifications regarding the Act's applicability in its present form:

- Under the current provisions of the Act, a governor, after taking certain required state actions, may request that the President declare an emergency on the basis of a *threat* of a natural disaster. This serves as the basis for a request to the President for federal emergency assistance to the state and local governments. In order to make this request the governor need not have received a prior "warning" from the federal government that a disaster threatens. Congress may wish to amend the Act to require the federal government to decide whether to issue a warning to state and local officials in every case in which an earthquake prediction is made. Congress might also want to consider limiting the power of governors to request the President to declare emergencies in those instances where the federal government has warned of the threat. These changes would require the federal government to exercise judgment on the question of whether a specific earthquake threatens. This could lift much of the fiscal and liability burden from the shoulders of state and local officials.
- It is not clear how the Act will be interpreted with regard to the lead time required before a threat of a natural disaster is declared an emergency. The Act is currently being interpreted very narrowly in this regard. In order to clarify this situation and ensure that the question of the appropriate policy framework for dealing with medium- and long-term earthquake predictions is left open for further consideration outside the context of the current concept of disasters, Congress may wish to amend the Act to limit the applicability of declarations of emergencies based on threats of earthquakes, to a given time period prior to the predicted date of occurrence (say, 6 months to a year). A longer time period presents an opportunity to formulate a new policy framework rather than reacting within an existing one.
- A number of potentially important political issues may suddenly emerge in the relationships among governmental levels as the initial prediction is developed and issued. Earthquake prediction has the potential for creating many of the intergovernmental political characteristics of the New York City crisis of the mid-1970s. Congress may wish to consider enacting standby authorities and procedures for dealing with these issues. One approach to this procedure is discussed in the section that follows.

REGIONAL PLANNING FOR UNCERTAIN PREDICTIONS

Earthquake Prediction Impact Statement Process (EPIS)

The present federal disaster policy framework leaves the decisions associated with responding to an earthquake prediction in the hands of state and local officials. There are good reasons for responding at the regional level. Damaging earthquakes affect a region composed of many governmental jurisdictions, and earthquake prediction is a regional practice, inasmuch as prediction increments will be added for areas that for geologic and seismologic reasons form "natural units" for prediction. These units may comprise more than one state and certainly more than one city.

Society has expectations that the perfected technology of earthquake prediction will be accurate and comprehensive in coverage. In other words, it expects that predicted-earthquake parameters will be specified with a high degree of precision, and all earthquakes will be predicted. However, there is no guarantee that the underlying processes will allow such a deterministic approach because the causes of earthquakes may be complex and essentially stochastic.

If earthquake prediction were to develop behind the closed doors of the laboratory, it would probably not emerge into the public realm until and unless it met society's expectations. However, earthquake prediction must be developed in a world laboratory of human affairs. Because of the incremental and iterative way in which science develops, the process of generating political truth on the basis of uncertain scientific knowledge appears chaotic.

Political truth is whatever society accepts as a basis for action. There is a lack of maturity in the technology of earthquake prediction because it is still evolving. Earthquake prediction is not ready for the public realm because it provides no basis for consensus. Implementation of a technology also implies a maturity in the public realm. Science inherently cannot work in the public domain. The pursuit of scientific truth and its application as technology are two different worlds.

The solution to the dilemma of publicly acting on the probabilistic results of a developing science is for society to deliberately choose its relationship to the development of the science. This could require a herculean task of describing all possible but contingent impacts, unless the possible fact situations resulting from a developing science can be placed in a manageable number of categories.

Because earthquakes affect regions having more or less uniform socio/cultural/economic characteristics and because earthquake prediction is a regional practice depending on local geology, seismology, and tectonics, the possible range of prediction fact situations can be bounded on a region-by-region basis. Accordingly the possible consequences can be limited. Describing and assessing them is still a difficult task, but it is feasible.

This study has developed a process of planning for the contingencies that are most likely to result from earthquake predictions in a region. This is called the Earthquake Prediction Impact Statement (EPIS) process; it entails a number of steps leading to the development of a set of response tactics for all possible types of prediction that can be made in a region. The important fact is that what works for one region may not work for another because of differences in seismic characteristics, the man-made environment, and the sociopolitical milieu. Each region must be considered in terms of its unique characteristics.

Levels of Information in Earthquake Prediction

There are several audiences for information in an earthquake prediction. The EPIS process makes use of several levels of information to define the possible damage resulting from the predicted earthquake:

- *Technical Generation Component* — Premonitor indicators, empirical premonitor calibrations and correlations, theoretical understanding of earthquake mechanisms, and the geology and seismology of the source region. The data generated in this component are used as inputs into the public information component.
- *Public Information Component* — Statements

THE EARTHQUAKE PREDICTION IMPACT STATEMENT PROCESS

There are three basic objectives in the EPIS process:

- To develop and promulgate a formal set of earthquake-prediction cases that might emanate from an earthquake-prediction system in a given region.
- To analyze and evaluate the outcome and impacts of responding to this range of earthquake-prediction cases with appropriate tactics for reducing property damage and saving lives.
- To adopt rules for governmental response to the range of possible earthquake-prediction cases based on the analyses and evaluation.

EXAMPLE OF EARTHQUAKE PREDICTION CASE

Lead time (months)	6
Time window (weeks)	±3
Epicenter or region of fault ruptures	San Juan Bautista to Los Gatos along the San Andreas Fault
Magnitude (Richter)	7.0 to 7.2
Confidence that event will occur (percent)	85
Contingent effects	Possible 8.3 Richter magnitude along entire "locked" San Francisco Bay section of the San Andreas Fault (no confidence judgment possible)

When the scientific program in a region generates a hypothesis concerning a future earthquake, the scientific data would first be validated and then translated into a set of prediction facts by an independent committee having technical expertise and public representation. These facts would then be identified with one of the preestablished earthquake-prediction cases. The governmental response would accordingly be governed by the rules that have been adopted for that specific case.

The discussion that follows describes how the process would be applied in a region. The developing technology of earthquake prediction is the background and basis of the entire process on which (1) through consideration of the geology and seismology of the region to be instrumented for earthquake prediction a set of possible prediction cases is developed and (2) a scientific program for developing earthquake-prediction capabilities in the region is initiated.

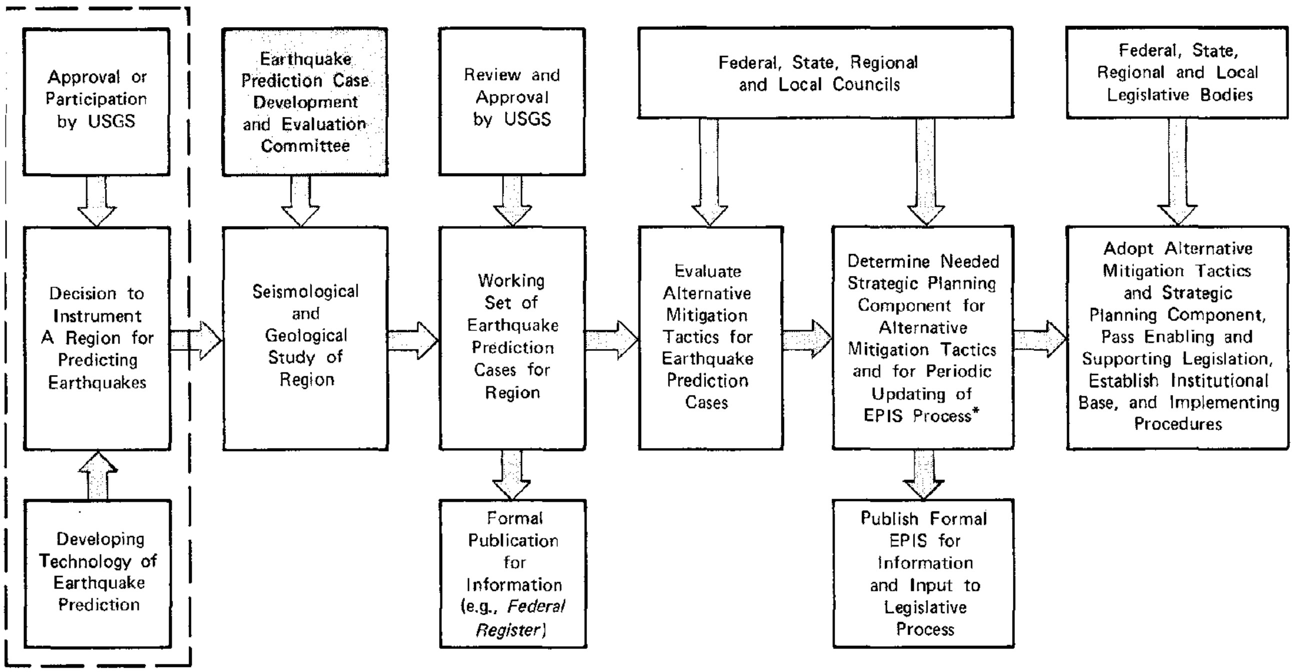
Under the authority of the USGS, an Earthquake Prediction Case Development and Evaluation Committee consisting of representatives of the scientific community and other public interests would develop and adopt a formal set of earthquake prediction cases for the region to be instrumented. This might be the Los Angeles — southern California region, the San Francisco — northern California area, Charleston, South Carolina, or any other area that would be instrumented and considered geologically and seismologically to be a "prediction unit." To enhance the participation and cooperation of the public in this process, the set of possible earthquake-prediction cases should be formally published — perhaps in the *Federal Register*.

All levels of government and private interests will have to participate in the process of evaluating alternative tactics for responding to the promulgated range of possible earthquake-prediction cases for the region. This will require detailed assessments of costs and benefits for reducing deaths, injuries, and property damage. An assessment will have to be made of the number of "false alarms" that can be tolerated for each risk. General criteria will have to be established for responding to residual risk which could change over time. Such studies will require the accumulation of regional data bases that are not presently available, and will in fact prove useful for many kinds of socioeconomic studies.

After the available damage-reduction tactics have been evaluated and ranked according to explicit, but multiple, and not necessarily compatible criteria (e.g., deaths and property damage) the public through its appropriate legislative bodies and through its political process will adopt those alternatives that are deemed most appropriate to the existing goals and objectives of society.

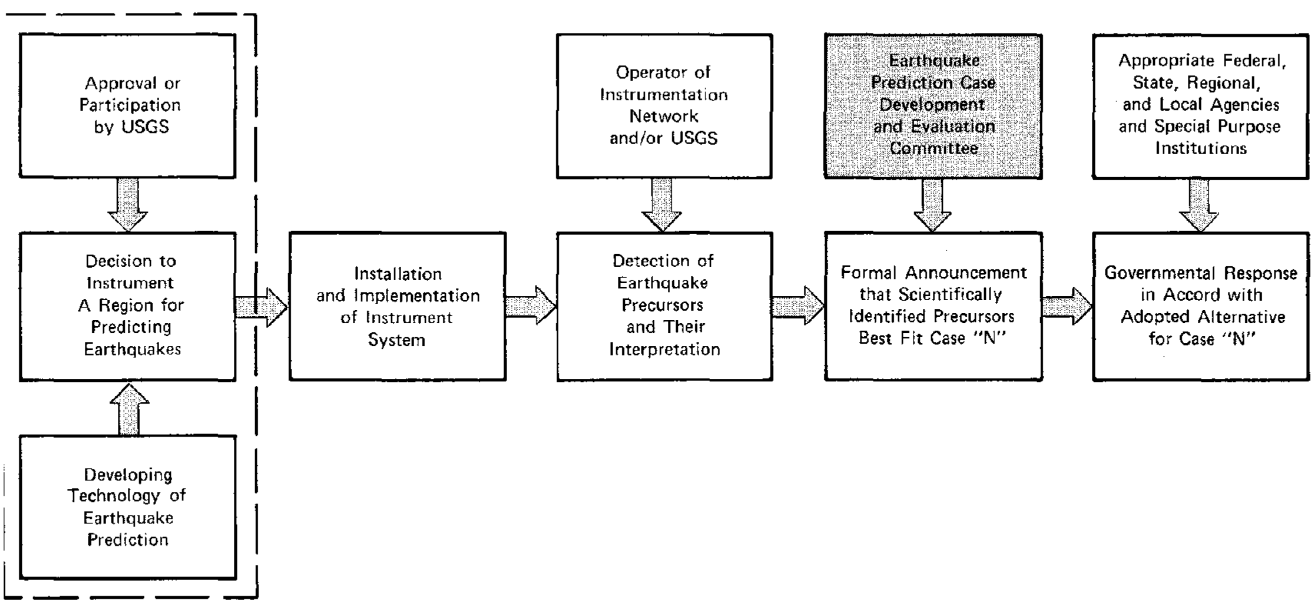
In concert with the process described above a predictive capability will have been established in the area. Accordingly, there is the possibility that earthquake premonitors may be detected. It would then seem logical that the same Earthquake Prediction Case Development and Evaluation Committee that developed the formal set of earthquake-prediction cases should also validate and translate the scientific data into a formal announcement that these scientifically identified precursors best fit one or the other earthquake-prediction cases. The decision-maker is required only to respond with the appropriate, previously adopted alternative. Those alternatives may, of course, provide broad bands of discretion in certain areas, according to the will of the people and the legislature.

THE EARTHQUAKE PREDICTION IMPACT STATEMENT PROCESS



*Can be established generally for several regions within a state, and for the federal component.

APPLICATION OF THE EARTHQUAKE PREDICTION IMPACT STATEMENT PROCESS



of where, when, and what size earthquakes are expected, confidence limits, and possible contingent effects. This information will be presented to the public in terminology most familiar to the seismological profession.

- *Technical User's Component* — The translation of the predicted earthquake characteristics into local seismic effects that can be used to estimate the effects on structures. It requires knowledge of the seismic spectral properties that would be generated in the source region by the predicted earthquake, source-to-site transmission path geology and topography, and local geology and soil structure.
- *Decision Component* — The cumulative uncertainty that is determined for the local seismic effects, resulting from uncertainties in knowledge and translation procedures at each step from the prediction to the local seismic effects.

Purpose of EPIS

The EPIS process is intended to develop a set of strategies whereby political units would agree in advance to respond to the expected range of earthquake-prediction situations in an area, before the capability of making earthquake predictions becomes fully operational. In order to ensure that the EPIS process is an integral part of the overall earthquake-prediction system, it should be linked to a specific decision point in the implementation of the earthquake-prediction system. Earthquakes occur in geologic time; consequently, a few year's delay in implementing the EPIS process in a region will probably not be too significant. However, if the earthquake-prediction investigation is triggered by a suspicious geophysical process, such as the 1970s "Mojave uplift"in southern California, then it is vital that the EPIS process proceed concurrently with further investigation of the phenomenon. The EPIS process should be carried out in an iterative and dynamic fashion with opportunities for updating as the science of earthquake prediction is developed, the methods of risk assessment are perfected, and the goals, objectives, and basic earthquake protection policies of society evolve.

Results of EPIS

The preparation and adoption of an Earthquake Prediction Impact Statement by a region provides the basis for the planning and preparation necessary to carry out certain strategies. Preparations will include educational programs, stockpiling of materials, prepositioning of supplies and equipment, and creation of institutions having the authority to conduct certain essential functions. If the EPIS process is conducted properly, it will also satisfy the requirement of an environmental impact statement under the National Environmental Policy Act (Public Law 91-190).

In addition, the EPIS process tends to accomplish the following:

- Set bounds to the range of possible initial predictions.
- Establish rules for deciding whether and how to act on the basis of probabilistic statements.
- Settle political problems involved in deciding whether and how to act on scientifically derived but probabilistic statements.
- Protect the scientific effort from public demands and so maintain the freedom and independence of a science of inquiry that must be conducted in the world laboratory of human institutions.
- Conversely, reserve for the realm of public action the elements that are the proper subject of politics.
- Allow the public to address the problems and issues of possible future events.

It should be noted that the problem of predictions and warnings becomes manageable under this approach. All the sociological problems of the effectiveness of warning remain, of course, but the EPIS process provides a framework for coupling the decision to act on a prediction with the scientific processes involved in developing the prediction.

Relationship of Governments to Private-Sector Responses

The EPIS process represents the planning of a deliberate, controlled, and participative intervention of government into private-sector activities. Unless it is anticipated and predetermined, an earthquake prediction could cause a largely unmanaged interaction of government and the private sector. Such excursions of government into private-sector activities are mentioned to draw attention to their potential for disrupting normal processes and raising difficult problems for resolution by legal and administrative means.

There are two broad areas in which government and private sectors could be jointly affected. One area relates to the application or extension of ongoing governmental programs to conditions as they would exist under the prediction of an earthquake; the extension of unemployment insurance is an example of an issue in this area. The other area relates to governmental actions to control or subsidize elements of the private sector that could be adversely affected by an earthquake prediction; wage and price controls for the construction and home-improvement sectors are an example of an issue in this area. Extending investment tax credits or other types of subsidy for the cost of strengthening structures is another example. The purpose of such government control or subsidies would be to preserve the stability, balance, and viability of a regional economic unit under the impact of an earthquake prediction. The EPIS process would allow evaluation and analysis of these and other potential situations before they arise so that if a prediction evokes a climate of "emergency economic conditions," the government actions taken to address one element of the overall problem do not cause undesirable "ripple impacts" across other sectors and elements of the problem.

Impacts of Earthquake Prediction on Public Programs

It can be anticipated that all welfare and related programs would be substantially affected by an earthquake prediction, especially where unemployment rises or substantial numbers of persons are relocated. Veterans Administration and Federal Home Administration mortgage programs could be substantially affected. Federal highway and mass-transit programs would be subjected to requirements not now included within their legislative and administrative authorities. The General Services Administration, as the federal property and facilities manager and owner, would be substantially affected, as would the regulatory agencies. It is difficult, in fact, to identify federal agencies, departments, bureaus, or commissions that would *not* be potentially affected in some way by the prediction of an earthquake with a lead time of more than a month or two. An earthquake prediction could be disorganizing to the normal consistency of federal government programs. This situation speaks strongly for the development of a systematically organized, anticipatory effort to assess the effects on the various federal agencies of a prediction of a damaging earthquake, so that the government's responses to a prediction can be carefully thought out, programs coordinated, and, where necessary, enabling or standby legislation enacted.

Strategic Level Planning

Up to the present, the four types of disaster-response tactics — earthquake engineering, seismic zoning, emergency preparedness, and compensation — have been evolving along separate paths rather than in an integrated manner. Integrating the evolving technology of earthquake prediction into society's existing practices and posture with respect to earthquake protection will require the development of a strategic planning function that will provide the additional ability to

- Forecast the course and dynamics of developing earthquake situations as they might be influenced by countermeasures.
- Make "trade-off" choices among technical programs.
- Develop long-lead-time resources and skills.
- Integrate short-term tactical responses with long-term programs.
- Assess major alternative courses of action that require considerable lead time and resources to implement.

Without strategic level planning, society will find it difficult to hold and evolve its present posture toward earthquake-hazard reduction for the considerable period of time — perhaps a century or longer — before the emergence of a prediction capability that would provide a basis for a new posture in some geographic areas.

The EPIS process would be conducted on a regional basis and would be directed at the selection of appropriate mitigating tactics. These mitigating tactics can involve governmental participation at all levels. Without the integrating function of strategic planning at all levels the EPIS process is not a viable concept.

In fact, the EPIS process would encourage the advent of strategic planning. Production of a half dozen or so initial EPISs for the regions of California that might be considered "natural" prediction units will clearly indicate the need for strategic planning at all levels of government as well as the necessary interactions among different levels of government and between government and the private sector.

THE LONG-TERM OUTLOOK — ISSUES AND QUESTIONS

This report has explored the public policy problems likely to arise from the fact that the scientific inquiry into earthquake prediction will be publishing hypotheses that appear to the public as earthquake predictions before prediction becomes a mature technology. A number of additional issues involve policies aimed at altering the anticipated course of development of the technology itself.

Earthquake-Prediction Technology as a Public Investment

In general, the "profitability" of earthquake prediction technology as a public investment will depend on its cost/benefit ratio. This ratio cannot be determined at present, because the end product of the scientific development of earthquake-prediction technology cannot be defined at this time. However, a framework for analysis can be established, and, from this, certain implications can be drawn.

Economic Impacts

The major economic benefits anticipated from the development and use of earthquake prediction technology are the following:

- Reduction in deaths and injuries from an earthquake.
- Reduction in property damage from an earthquake.
- Protection of national security.

The anticipated costs can be categorized as follows:

- Costs of research and development effort.
- Costs of implementing tactics chosen after a prediction (including the costs of making the choice; e.g., the EPIS process):
  - — Direct tactics-related costs (e.g., costs of

personnel and supplies for an evacuation and costs of strengthening buildings).

  - Loss of economic activity and property values.

- Costs of an ongoing strategic planning function.
- Costs of mistaken predictions (repeated tactics implementation costs):
  - Direct tactics-related costs.
  - Loss of economic activity and property values.

Earthquake-prediction technology differs from most other technologies in two ways, which are illustrated by the preceding lists of benefits and costs. First, many of the costs and benefits do not result directly from the prediction; they result from loss-reduction tactics selected after a prediction. Second, for a long time, predictions of earthquakes will not be "certain" predictions; they will be predictions that an earthquake is probable. Thus the major costs of the development and use of earthquake-prediction technology are the costs of implementing the tactics selected after a prediction and the costs of repeated tactics implementation resulting from mistaken predictions. The costs of research and development are relatively small in comparison to these other factors. The same holds for the costs of the ongoing strategic planning function.

The major benefits to be anticipated are reduced deaths and injuries, and reduced property loss from actual earthquakes. These benefits can be realized only if society pursues tactics that remove people and property from the danger zone or increase the likelihood of their survival. However, the potential benefits of earthquake predictions and associated loss-reduction tactics must be measured in relation to the losses that would have been incurred in the absence of prediction. This means that the benefits must be measured in relation to the optimal baseline strategy. A confusing element is that society may not be pursuing the optimal baseline strategy, in which case a major source of benefits can be realized by moving from the existing baseline strategy to the optimal one. These benefits can be related to prediction technology only if the development of such technology causes society to change its baseline strategy.

Effect of Prediction Lead Time

Predictions with Short Lead Times

Various tactics are available to society, depending on how far in advance an earthquake is predicted. It seems likely that the largest source of benefits from the development of earthquake-prediction technology will come from the development of a short-lead-time prediction capability. A short-lead-time (30 days or less) prediction will probably be associated with tactics — such as selective evacuation and emergency preparedness — that have a high potential for saving lives, are very cost effective in reducing property damage, and are not part of society's ongoing baseline strategy. Moreover, it is not likely that substantial net losses of economic activity would occur after a short-lead-time prediction; that is, a loss of output and associated wage and business income that could not be made up elsewhere or at another time. Although a shift of production in time or location might represent no net national or possibly regional economic loss, the local and individual impacts could be substantial.

Predictions with Long Lead Times

The tactics that would be appropriate with a long lead time (50 to 100 years) are the same as those that are being discussed today in the absence of any prediction capability: adoption of strengthened earthquake engineering standards, long-run building-code-enforcement programs, seismic zoning, and the like. A long-lead-time prediction capability should complement and strengthen the use of these tactics in two ways. First, a long-lead-time prediction would provide society with better information than it has today. Actions might be rational on the basis of long-lead-time predictions that are not obviously rational on the basis of earthquake probabilities assigned according to recurrence theory. Second, a long-lead-time prediction capability may hasten actions that would be rational, but more difficult to adopt, in the absence of any prediction capability.

Predictions with Intermediate Lead Times

The implications of a capability of predicting earthquakes with intermediate lead times (6 months to 20 years) are the most complex to evaluate. The complexity has two aspects:

- Tactics for the period following an intermediate-lead-time earthquake prediction are not well developed.
- Concern about potential losses of economic activity and property value is most strongly articulated in the earthquake prediction literature for this lead time.

THE DISTRIBUTION OF BENEFITS AND COSTS OF EARTHQUAKE-PREDICTION TECHNOLOGY

The geographical distribution of the benefits and costs of earthquake prediction raises some critical questions. Examination of these distributional factors results in the following conclusions:

- Specific individuals, businesses, and local economies may suffer losses of income and property value after an earthquake prediction.
- Most of these losses are not net losses to the nation. They represent transfers of income and property value among individuals and businesses in different locations. Therefore the existence of these potential losses is not relevant to national level societal choices about the development and use of earthquake-prediction technology.
- The existence of potential economic losses to specific individuals and businesses raises two important issues:
  - Compensation (see comments below)
  - The possible impact of potential individual economic losses on the postprediction actions of local jurisdictions.
- The concept that individual losers from public policies designed to achieve nationwide net benefits should be compensated is an important idea in the development of public policy in the United States. There are numerous examples of debate over whether individual losers should be compensated and numerous examples of procedures developed to handle the issue of compensation.
- Actual compensation for losses suffered by individuals and businesses from an earthquake prediction would have to be handled after the earthquake. The information necessary to adjudicate claims for compensation would include an assessment of actual losses and an assessment of whether offsetting gains (saving of lives and property) occurred for each individual claimant. These assessments can take place only after the fact.
- Decisionmakers in local jurisdictions may take information about potential economic losses to constituents into account in their decisions on how to act after an earthquake prediction. It is possible that, from the perspective of a local jurisdiction, the potential economic losses to constituents might make the costs of acting on an earthquake prediction appear to outweigh the benefits.
- Thus local jurisdictions, by looking at the local perspective, may act incorrectly in terms of national or even statewide and regionwide costs and benefits. This suggests that a potential problem exists in finding the proper level of government decisionmaking that can take into account all the costs and benefits from acting on earthquake-

It is likely that a greater amount of economic activity would be relocated after a prediction that "an earthquate will occur in 10 years" than after the prediction that "an earthquake will occur in 30 days." There is no evidence on how people would behave after a prediction with a 10-year lead time. However, it is conceivable that the growth rate of cities or even of a region could be changed if people believed and acted on such a prediction.

Yet the net economic costs associated with an intermediate-lead-time prediction could be even lower than those incurred with a 30-day lead-time prediction. If relocations were to occur over a 10-year period, there is no reason to suppose any net loss of production and income. There would be some relocation costs, but they probably would be no higher than in the many other shifts of economic activity among regions that occur constantly in the national economy.

Compound Predictions

For purposes of analysis, lead-time characteristics were considered in isolation from other contingent possibilities; for example, a long-

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prediction information, so that a distributional issue — the existence of economic losses in one jurisdiction that are "made up" in another jurisdiction — will not prevent the capturing of aggregate net benefits (total benefits exceeding total costs) from prediction technology.

- The question of the appropriate level of geopolitical aggregation for decisionmaking of whether and how to respond to an earthquake prediction is a delicate issue. In reality there are decisions that are appropriate to every level. For example, the federal government should consider the national level of aggregation in decisions concerning funding research and development, disaster relief, and disaster insurance. The lowest level of governmental action is the local level supported by institutions and individuals. On the one hand, neither individuals nor local level governments should be prevented from assuming certain very real risks of loss of life, property, and economic activity *as a necessary condition of maintaining a free and open society.* On the other hand, they should not be precluded from freely and temporarily sacrificing such freedoms for the common good of a larger societal aggregation. The issue becomes a matter of the substance and procedure of choice. This is addressed by the EPIS process.
- Economic losses will occur to individuals and groups as a result of voluntary and involuntary responses to earthquake prediction, and it will be difficult to distinguish the losses from voluntary and involuntary responses. People will have different voluntary responses to earthquake-prediction information, depending on their assessment of, and tolerance for, risk. Some people may voluntarily leave the potential earthquake area at the first information of a probable impending earthquake. The economic losses (wages and so forth) occurring for these individuals will be incurred voluntarily. Some people will stay away from the potential earthquake site after the announcement of an official public warning or action — whether they are required to do so or not. Finally, some economic activity may be stopped involuntarily — solely as a result of the official evacuation order.

The same kind of economic losses would be incurred whether they were incurred voluntarily or involuntarily. However, the reason that the issue of potential economic losses is often discussed in the assessment of earthquake-prediction technology is the fear of involuntary losses. The distinction between voluntary and involuntary economic losses may be important for specific policy questions like liability and compensation. It is here that the measurement question must be faced. Unless there is a way of distinguishing between losses resulting from voluntary actions and those resulting from involuntary actions, differential treatment of groups suffering economic losses is impossible on this criterion.

lead-time prediction could be followed by shorter and more precise predictions as the event approaches. In this case the expectations of a short-term prediction could inhibit long-lead-time actions because less costly, more effective measures could be applied.

The ability to predict *all* earthquakes has a different meaning if they are predicted with long lead times than if they are predicted with short lead times. Even the framing of the prediction statement has implications for selecting tactics. A prediction stating that a damaging earthquake will occur within the next 5 years is very different from one stating that an earthquake will occur between 5 years hence and 5 years and 3 months hence. Until a track record demonstrates contingent probabilities, the prudent course is to operate on the information available. It would seem that for a very long time the possibility of an unpredicted earthquake or a predicted earthquake happening at any time should govern the basic earthquake-protection posture of society.

Implications of Other Research on Earthquake-Prediction Technology

The federally supported research on earthquake prediction in the United States is not the only such research in the world. Substantial research is being done in the Soviet Union, China, and Japan. In addition, there are ongoing research efforts in other places in the world and in the United States independent of federally sponsored research programs.

The federally sponsored work in the United States can be viewed as an attempt to reduce the potential for mistakes inherent in any earthquake prediction. It can be argued that additional effort in the United States would shorten the period of high costs from mistaken predictions. A similar argument can be made for cooperation on research programs between the United States and foreign governments.

Precisely because there are ongoing earthquake-prediction efforts in other parts of the world and in the United States independent of federally sponsored research programs, a federal program is a necessity. The federal government should have the capability to verify or deny predictions from nongovernmental domestic and from international sources. It is a legitimate function of the national government to protect public health, safety, and welfare from fraudulent and disruptive forces.

The proper evaluation of the federally supported U.S. effort then would be to compare the cost of the research with the projected reduction in the costs of mistaken or fraudulent predictions over time.

Higher Order Impacts of Earthquake Prediction

A clear distinction must be made between the higher order impacts discussed in this section and those impacts that develop as primary operational impacts propagate through social and economic systems. While the latter have not been traced out in detail (and indeed cannot be in a responsible manner, because of the inability to specify a "representative" set of prediction facts, lack of detailed data in urban locations threatened by earthquakes, inability to generalize from a given geographic area, and limited understanding of the complex interactions of urban social and economic systems), it is clear that they represent value transfers consisting of losses of business income and property values and social disruption. The discussion of "Earthquake-Prediction Technology as a Public Investment" in the preceding section indicates that an attempt to trace these impacts would not be fruitful because the net national economic effect is probably small; they are not relevant to the basic issue of whether earthquake prediction is a good public investment that must be addressed at the aggregate level and there is ample precedent for both the justification of, and procedures for, compensation, which itself represents further value transfers. In some cases, the costs of transfers could be significant because of the immobility of resources or because questions of equity in establishing compensation are complex.

By contrast, in this section the search for higher order impacts addresses such questions as the long-term, social, economic, political, institutional, and individual stress effects of highly uncertain but credible predictions. Such higher order impacts are difficult, if not impossible, to identify and assess by an analysis of the operational context alone. The limitations of our knowledge make it difficult to establish direct, causal linkages between higher order impacts and impacts that can be identified through projected operational situations. However, because there is growing social and political concern about actions in the present that may affect the condition and structure of society in the future, it is important that an attempt be made to infer some possible and contingent types of higher order effects directly from the existing base of knowledge on analogous developments.

Earthquake Prediction and Earthquake Protection

The major alternatives to earthquake prediction as a means of reducing the hazards of earthquakes are earthquake engineering, seismic zoning, disaster preparedness, and disaster relief and insurance. Society's basic protection has been, and still is, earthquake engineering. Earthquake prediction itself does not replace any of these alternatives, but it supplies information that allows society to make a more complete analysis before selection of the alternatives most appropriate to the condition and goals of that society. This raises some critical questions concerning the use of earthquake prediction within the context of improved earthquake protection. These questions, which are presented and discussed below, are interrelated in that they explore different aspects of the fundamental question of whether there is an optimal condition of earthquake protection and, if so, how earthquake prediction affects that condition. The questions include the following:

- What are the goals of society with respect to earthquake protection?
- How does earthquake prediction affect the present earthquake-protection posture?
- Under what conditions is earthquake prediction most useful?
- Are there reasons to stop the development of earthquake-prediction technology or to ignore the prediction of specific earthquakes?

Earthquake Protection and Earthquake Engineering

As mentioned above, society's basic protection against earthquakes in the United States is earthquake engineering; society's position is enunciated in those sections of the Uniform Building Code that are related to seismic resistance. The implications of the Building Code are that state-of-the-art structural engineering should be applied to reduce the risk to lives and that the maximum historical earthquake in a region can occur during the useful lifetime of any structure. Such a posture implies that society is willing to allocate resources to protect itself from the devastation caused by a major earthquake.

Some engineers have voiced the opinion that the attention and resources devoted to earthquake-prediction research detract from the progress that could be made through earthquake engineering. In fact, the two measures are interactive. The capability of making accurate negative predictions with lead times longer than the economic lifetime of structures, of saying "there will be no damaging earthquakes in the next 100 years," would permit structures to be built to standards lower than earthquake-resistant standards. Three-day lead-time predictions of all damaging earthquakes would permit orderly evacuation of substandard structures — but only if the structures had been identified by competent engineering analyses beforehand.

Modest investments in earthquake engineering in the United States — less than 10 percent for most structures and 3 percent for wood-frame dwellings — can greatly increase the resistance of new structures. Furthermore, for a small expenditure the seismic hazards of existing structures can be greatly reduced; removing parapets and overhanging ornaments are examples of low-cost, highly effective measures. The interaction of earthquake prediction and earthquake engineering allows existing assumptions to be questioned against a potentially new and better information base. Both earthquake-engineering and earthquake-prediction technologies have critical uncertainties as to their future characteristics, and both should be pursued diligently.

Freedom To Ignore Predictions

As earthquake prediction develops, the question will arise as to whether or not a governmental entity should be free to ignore an earthquake prediction. For example, if a city should

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AN INTERNATIONAL PERSPECTIVE ON EARTHQUAKE PREDICTION VERSUS EARTHQUAKE ENGINEERING

Earthquake prediction is of more potential benefit to many foreign regions than to the United States, because of high susceptibility to structural damage. It is interesting to compare, for example, the earthquake protection postures of China and the United States with respect to the interplay between earthquake prediction and earthquake engineering.

China's earthquake-prediction program, as it is fashioned within and responded to by the masses, is the outcome of a cultural tradition that identified legitimate political authority with the regulation of nature. This tradition has strongly shaped the meaning and function of earthquake prediction in China, where the benevolence of the central government was more often demonstrated through ritual than pragmatic acts. While the empirical results of these rituals may have been dubious, the psychological and political effectiveness was undeniable. The Chinese Communists have inherited the emperor's responsibility of completing the triad of Heaven, Earth, and Man. Ensuring harmony between man and nature is essential to the credibility of the Chinese Communist Party.

"Science for the people" is a national slogan for the ritual by which the Chinese Communists validate their claims to the Mandate of Heaven. Pragmatic results are sought through the popularization of science, but the psychological satisfactions generated by mass participation in scientific activity are of greater significance with respect to the political goals of the state. China's earthquake-prediction program is inextricably tied to ideology.

Given the American view of science as a professional enterprise, it is highly unlikely that earthquake prediction could be conducted as a mass campaign in the United States. For Americans, science is primarily a pragmatic, instrumental activity. High expectations of certainty and intolerance of false alarms are associated with this view of science. The Chinese, as a result of modest expectations, have been able to implement earthquake prediction at an earlier stage of development than is possible in the United States.

The typical Chinese structure is very susceptible to earthquake damage. The Chinese have not been able to make the investment in structural strengthening required to reduce significantly their earthquake hazard. They are more willing to experiment with the new technology of earthquake prediction, however uncertain it may be. There is clear memory of past earthquake disasters and the sense of imminent catastrophe. Intrinsic motivation to cooperate with warnings and evacuation orders is therefore strong.

For the American situation, earthquake engineering is an economically feasible approach to earthquake protection. It offers an apparently higher degree of certainty than earthquake prediction at its present level of development. Available evidence clearly indicates that well-engineered structures can and do withstand earthquakes and significantly reduce property damage and loss of life.

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decide that its basic earthquake-protection posture is to be earthquake engineering and that earthquake prediction is to be ignored because it is not credible and disruptive, should be it allowed to ignore a prediction of an imminent earthquake? When the vulnerability or residual risk in an earthquake-prone area has been reduced to a low level through effective programs of earthquake engineering and seismic zoning, all but the most reliable predictions are likely to be ignored.

No prediction can be ignored in a region with a high residual risk because a true warning may be hidden among a series of unreliable predictions. Such a situation could clearly lead to chronic social disorders. The obvious prescription in such a case, if it is economically feasible, is to adopt vigorous programs of earthquake engineering to reduce the residual risk. Once this has been reduced to an acceptable level, society can be more discriminating about which predictions to reject or accept and how best to respond to warnings.

Effects on the Science of Earthquake Prediction

The long-run effects on the predictors may be a critical factor in the development of earthquake prediction. Individuals involved in prediction may become impatient with the slow development, and their interest may move to other problems. If predictions turn out to be inaccurate, disruptive, and a cause of contention within society, the scientists engaged in prediction may become discouraged and alienated. Some of this can be avoided by expanding earthquake prediction to other parts of the world, where the results may be more positive and useful.

However, impatience and discouragement may result in a realization that the earth is not a good laboratory and that waiting for naturally occurring opportunities is not an efficient approach to science. With this realization there will be an attempt to gain some control over the experiment. Indeed, such an attempt has already begun. Proposals indicate that, first, deep holes would be drilled to measure fault-stress buildup directly. Next, attempts at earthquake-control experiments would be made. Initially, these would be in sparsely populated regions, but if they show some measure of success, they would move to urban areas.

The implication of this is that earthquake prediction may be bypassed as a technological practice. Reliable earthquake control may become available before prediction matures. This, however, does not imply that work on earthquake prediction should now be redirected into earthquake-control technology. The understanding of earthquake mechanisms that may result from the work on prediction could prove to be the basis of an earthquake-control technology. More importantly, the potential socioeconomic and environmental impacts of earthquake-control technology should be assessed in a detailed and comprehensive manner.

Alternative Futures

It is important to recognize that, in the long term, society can change, as can its man-made environment. Although it is not possible to predict how society will change, it is possible to enumerate alternative directions that society might take and try to determine their implications for the human and social issues affected by earthquake prediction.

Various combinations of social values, relationships, and responsibilities; economic and political conditions, and dependence on technology represent potential alternative futures. These factors operate not independently but in concert to determine society's position on any issue. Earthquake prediction in our judgment is most likely to be accepted by societies that are materialistic, either self-seeking or altruistic, poor, based on an authoritarian structure, and/or technocratic.

Earthquakes were not considered in selecting the location and construction of cities. Now the cities need a technological fix. In the technological web of earthquake-protection measures, earthquake control is the ultimate technological fix. As an alternative, cities might be rebuilt in places of lower risk. Another alternative is to turn man's technological capability on man himself so that he is conditioned through behavior modification to accept with equanimity the risks of natural disasters. What is involved in all three alternatives is the ethical basis of man's use of technology with respect to his limited capability for foresight.

Policies for the Future

One key policy question that must be asked during the development of this new technology is, "Is enough known now to make a responsible decision to stop or alter the technology of earthquake prediction?" The general rule for evaluating future impacts of present decisions is that situations not be created in which unwanted consequences are made certain or future benefits made unattainable. At present, not enough is known about what earthquake prediction will be able to do or what psychological stress and social disruption its development may cause. Consequently, a logical approach is to maintain and develop current earthquake-protection measures while investing enough in earthquake-prediction research to see where it is going and preparing for the contingencies that it may present.

This course of action hedges the bets on each technology. It is a course that the United States can afford. Other countries, notably China, are choosing to rely on earthquake prediction because the cost of building even moderately resistant structures for all would seriously tax their economies or upset other social and political objectives. In the mid-1970s China experienced both spectacular successes and failures with earthquake prediction. Intuitively, one would assume that earthquake engineering could provide any desired degree of protection at a price. However, the incremental cost increases with the degree of protection, so that even the United States could not afford to rely on structural strengthening to achieve a high degree of protection. Furthermore, the 1971 San Fernando earthquake has raised serious questions about uncertainty in the design and building of earthquake-resistant structures.

Technical versus Institutional Reversibility

Earthquake prediction is readily reversible the instrument networks are easy to remove However, if cities and regions have formulated an earthquake-protection strategy around an earthquake-prediction system, it might not be easy to remove the instruments because of institutional pressures.

Monitoring the Technology's Development

In the absence of foreseeability, society needs to develop institutional means of controlling technology. One avenue is to monitor the effects of the technology. Should undesirable consequences begin to show, then the use of the technology can be stopped. Technology assessment is a continuous process. A single action cannot settle all potential issues. At any point in time we can see dimly a little way into the future to determine some of the impacts of a technology The development of the technology and its impacts must be monitored until a "natural" decision point is reached. At that point the question is again asked, "Do we know enough now to decide that we should stop or alter the technology of earthquake prediction?"

The EPIS process is designed to establish decision criteria for the application of the technology in a region. The continuous monitoring and assessment process could be combined with the EPIS process as a way of continuously modifying the decision criteria for responding to earthquake prediction. This would be a component of the strategic planning function that is required to complement the EPIS process.

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I INTRODUCTION

This technology assessment is presented in three interrelated parts, each designed to stand on its own. This allows addressing the problem at three conceptual levels, which relate in various ways to several specialized interests and their needs:

- The nature of the developing technology of earthquake prediction.
- The operational imperatives of dealing with the intermediate products of a scientific inquiry.
- The long-term implications of a mature science and an implemented technology and the potential for dealing with future issues by means of present decisions.

Earthquake prediction provides no material value to society unless society is prepared to act on the information produced. Indeed, the term "earthquake prediction" is, in its present state, misleading to the public. We shall not have "earthquake prediction" until the activity meets standards for replicability and accuracy that are inherent in the science itself. In the meantime we shall have "predictions of earthquakes" of varying quality. To these predictions the different elements of society will react to promote, in their view, their best interests. Thus we shall see a plurality of decisionmakers acting to express multiple and conflicting interests. Accordingly the policy issues resulting from the potential for earthquake prediction are complex, involve many different time frames, are closely interwoven with current policies toward protection against earthquakes and other disasters, are multilevel, and present less than clear-cut alternatives to the many publics involved. In this situation (or, for that matter, in any other) technology assessment cannot, and should not, decide the policy matters; what it can and should do is define the scope and substance of the problem and suggest procedural rules by which society can choose a course of common action through a vigorous and robust debate on the available alternatives.

II EARTHQUAKE PREDICTION IN PERSPECTIVE

This section places earthquake prediction within its historical, philosophical, and practical perspectives; that is, it examines earthquakes in terms of the characteristics relevant to earthquake prediction. It explores the scientific underpinnings and the meaning of earthquake prediction as a scientific inquiry and describes earthquake prediction as a technological practice incorporating hardware systems, resources, manpower, and products. Finally, it assesses earthquake prediction in terms of (1) society's readiness to accept it and (2) the goals of society in achieving earthquake protection as evinced by the adoption of earthquake-engineering and seismic zoning measures.

A. An Introduction to Earthquakes

1. World Review

The theory of plate tectonics holds that the thin crust of the earth, 10 to 50 miles thick, is not a single rigid shell but is fractured into about ten major plates and several minor ones that float on a sea of hot, plastic rock beneath.[1,2*] Moreover, these plates do not remain in one place but are constantly moving (the so-called continental drift) from 1 to 3 inches per year.[3] This is equivalent to 1500 to 5000 miles in 100 million years. Each plate is formed by a process that adds material at one edge to the crust from the hot, plastic rocks beneath. At its opposite edge, it either collides head on with another plate, with much crumpling and folding and the creation of surface features like mountains, or it dives under the opposite plate in a process called subduction and is reabsorbed in the magma underneath (see Figure 1). At other boundaries, plates simply grind horizontally past one another. In this large-scale view, earthquakes

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*References are listed at the end of this report.

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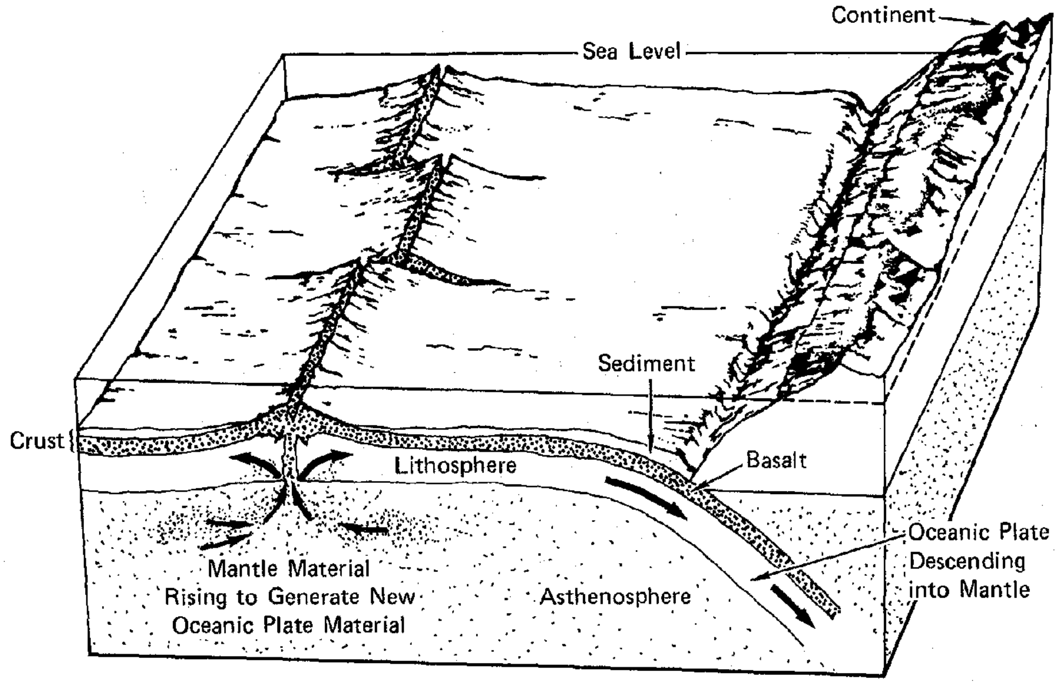


FIGURE 1 MODEL OF THE PROCESS OF PLATE GENERATION AND SUBDUCTION

are "caused" by the jerky release of accumulated stress built up locally in crustal rocks as the plates slowly grind past one another.

The sizes and locations of these plates are readily apparent from a world map that indicates where earthquakes have occurred (Figure 2) since the majority of the world's earthquakes lie along the interplate boundaries and in nearby areas where the earth's crust has been fractured. Since many of the earth's volcanoes and earthquakes lie along the edges of the Pacific Plate, this more or less circular ring of activity is sometimes referred to as the "Ring of Fire."

Many details of the relationship between plate tectonics and earthquake activity are still unclear. The forces that make the plates move are not understood at all, and there are important regions of earthquake activity (e.g., China) that do not lie along the plate boundaries.

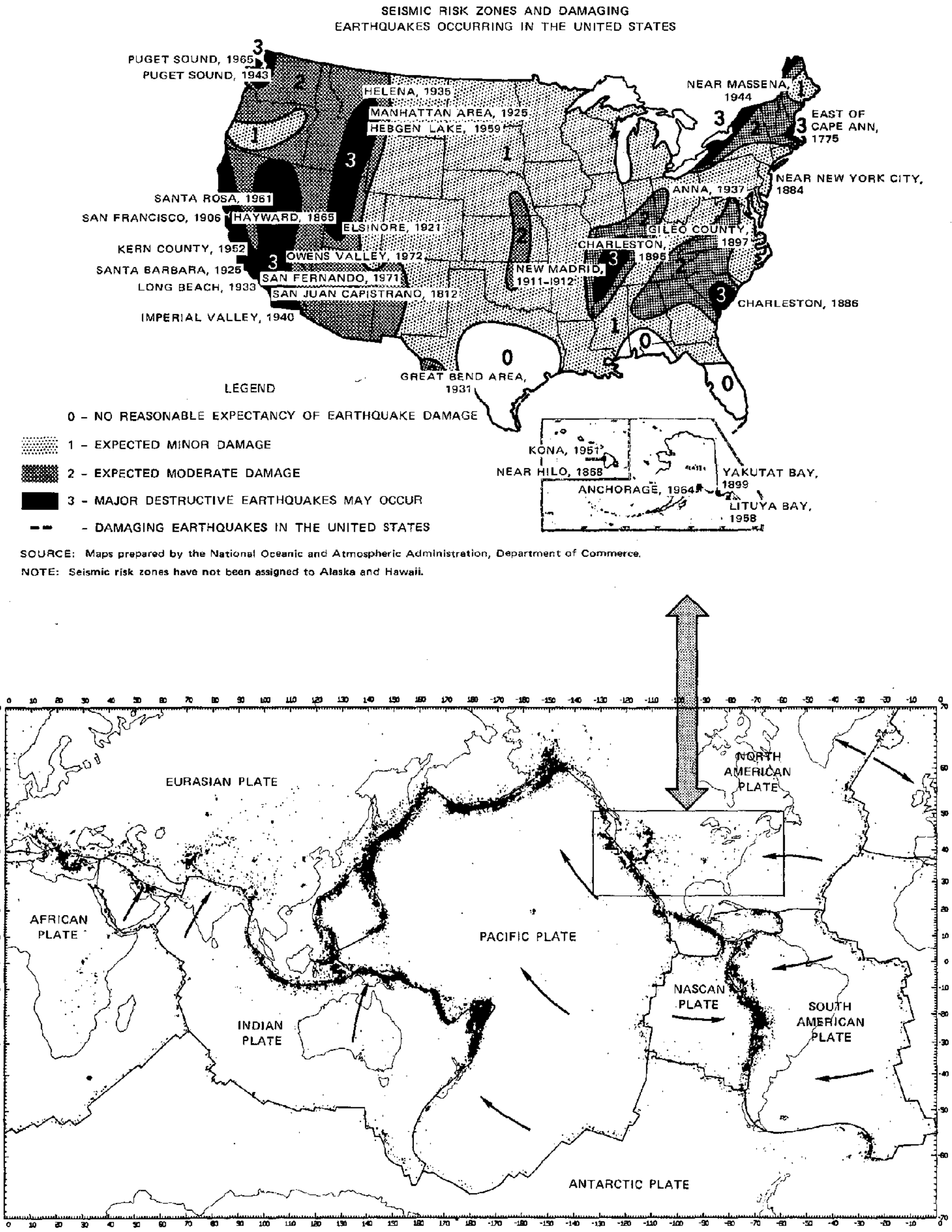


FIGURE 2 MAP OF WORLDWIDE SEISMICITY SHOWING LOCATIONS OF MAJOR PLATES

Man has had to live with the terrifying forces of earthquakes since his beginnings, and history has recorded his speculations about their cause and meaning.[4-6]

Western Europe was rocked by a series of severe shocks between 1750 and 1760. The Great Lisbon Earthquake on All Saints' Day in 1755 killed an estimated 60,000 persons, including those drowned in the subsequent seismic sea wave. Careful studies of these events by several investigators initiated seismology as a serious study of nature. In particular, the studies of John Mitchell,[7] Woodwardian Professor at the University of Cambridge, free from the shackles of ancient views and traditions, did much to convince many who still believed that disasters like earthquakes were retribution for their sins.

2. Impacts on Society

How is it that a damaging earthquake could strike a major U.S. city in the middle of the night and not kill or injure a large proportion of the population, whereas in Turkey an earthquake in the middle of the night can destroy whole villages? One could pose many such questions that would illustrate the apparent capriciousness of earthquakes with respect to different societies. The effect of an earthquake on a society depends on the structures that have been built, how they have been built, and where they have been built. If the structures are built properly and in the right places, they will resist the primary effects of the earthquake. These primary effects are ground shaking and ground failure, such as surface faulting, landslides, and liquefaction. Structures may fail and cause some secondary effects: floods, fires, and the release of toxic materials to the atmosphere. If the earthquake happens to cause earth movement beneath a water body, it can create tsunamis or seiches that can destroy structures and drown inhabitants or observers near the shoreline, often many miles away.

In the United States, most lives would be lost in an earthquake that took place as people were beginning to return home from work in the late afternoon. This would place many people in the streets, moving out of high-rise offices and driving on highways or riding in public transportation vehicles. Morning commuting hours would be almost as hazardous, but the arrival of people in the business district tends to take place over a longer period of time. The safest time is at night, when most people are at home. The typical wood-frame house is one of the safer structures in the United States. However, in parts of the United States--especially California, which receives little summer rain--failure of dams that hold the winter's precipitation for year-round use could cause serious flooding. Many structures in the United States, even high-rise buildings will burn readily if they should be ignited directly or if major fires should occur.

In many parts of the world the most dangerous place to be is in the home. Here more people would be killed by an earthquake at night than during the daytime. In places like Turkey,[8] China, and the rural communities of Central and South America, the typical house is of unreinforced masonry or adobe, which may or may not be structurally braced. People have learned to run out of their houses when they first feel an earthquake, which they cannot do when they are sleeping. The greatest earthquake calamities in Japan are attributable to mass fires that trap great numbers of people. The typical Japanese house of light wood construction does not present much hazard from collapse.

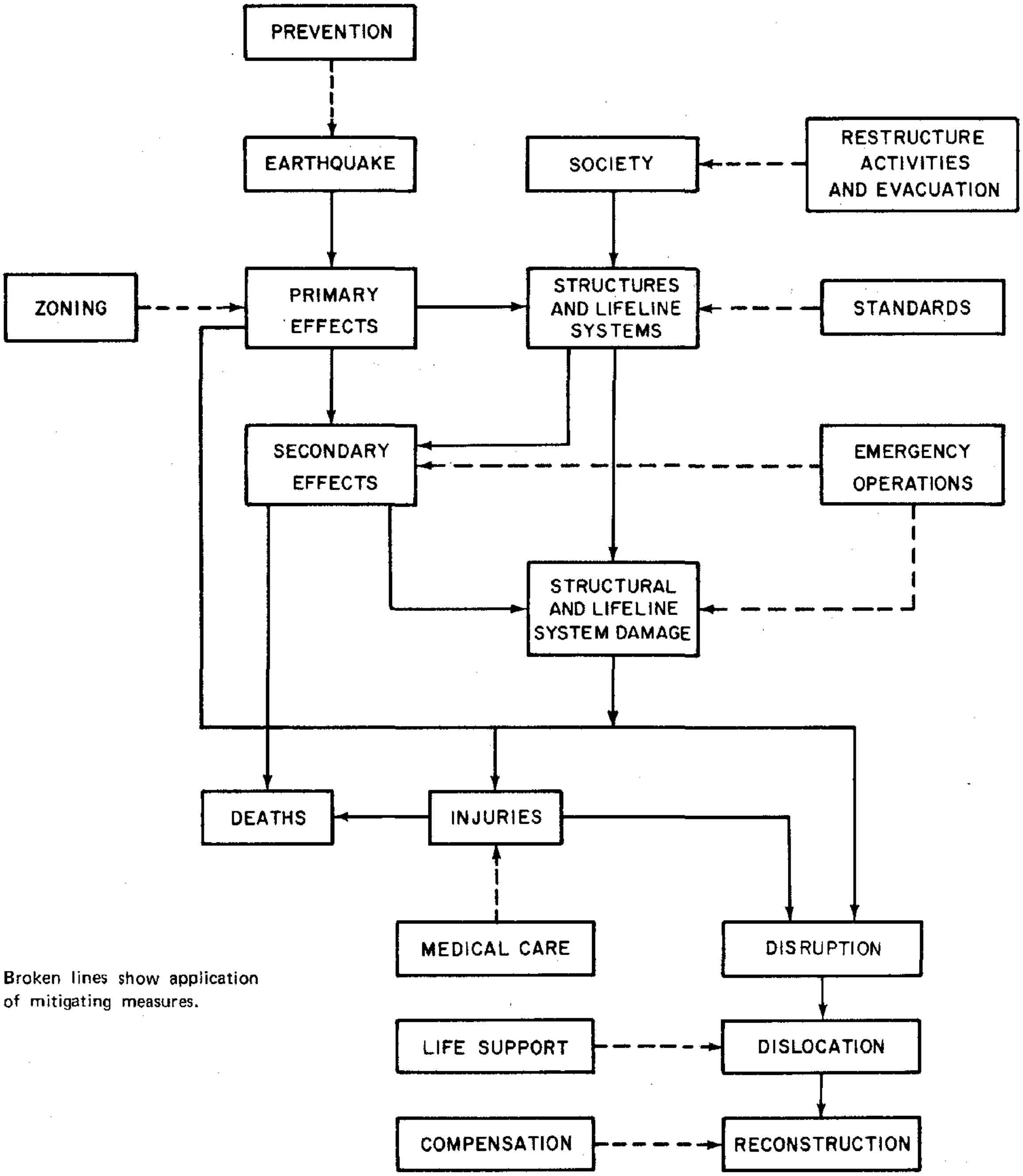
In the United States and other countries, an increasing percentage of the population is residing in apartments, which vary from low-level garden apartments to those contained in high-rise buildings. Modern high-rise earthquake-resistant buildings in two distinct geographic areas were extensively damaged in the Venezuelan earthquake of July 29, 1967.[9] High-rise buildings in Caracas, where some of the damage occurred, are almost always built with reinforced-concrete framing that is resistant to earthquake forces. In the vicinity of two areas in which damage occurred, high-rise construction suffered comparatively little damage. The explanation seems to lie in the unusually severe shaking resulting from the characteristics of the local geology. The moderate magnitude of the earthquake, which had its epicenter near Caracas, would indicate that the design construction of these earthquake-resistant buildings was dificient in dealing with these local geological characteristics.

A modern society is tied together by many physical and activity networks. These systems move material, energy, information, and people from one place to another. These networks are typically composed of structures and components that can react to the effects of an earthquake. For example, in the San Fernando earthquake of February 9, 1971, several freeway ramps and overpasses were knocked down. If this should happen to the ramps of the San Francisco Bay Bridge and the Golden Gate Bridge, a serious inconvenience would result. Most of these systems have redundancies and alternatives, but if the damage is sufficiently widespread, large portions can be put out of service. Therefore, an earthquake in San Francisco at night might cause little loss of life but could result in serious shortages of vital services and a virtual shutdown of the region's economy.

Society can try to prevent the damage from an earthquake, and it can try to provide remedies after an earthquake. A preventive approach would be to build in areas not subject to earthquakes. Another approach is to build structures to resist earthquake shaking or to reorder society's activities so that they are not so sensitive to damage to the systems and components that tie society together. The postearthquake remedies are to provide medical care for the injured and food, housing, and other life-support services for the survivors. Lastly, society can compensate the survivors for their losses. In most modern societies a combination of these methods is used as a means of responding to disasters, some receiving more emphasis than others in a given situation.

The Chinese seem to have taken the unusual approach of integrating prediction into their culture. They rely on it primarily for short-term warnings so they can evacuate their structures and save lives. Especially in the villages, the structures are rebuilt, but little is done to make them more resistant to collapse.

Figure 3 is a simplified schematic diagram of the effect of an earthquake on society, the means of mitigating the effects, and the appropriate point of application.



Broken lines show application of mitigating measures.

Source: Stanford Research Institute

FIGURE 3 IMPACT OF EARTHQUAKE ON SOCIETY, SHOWING MITIGATING MEASURES AVAILABLE

3. Earthquakes from the National Perspective

No single earthquake disaster in the United States has had a death toll exceeding 1,000 persons, and only the 1906 San Francisco earthquake and fire even came close to this toll, with 700 to 800 deaths. This is in sharp contrast to the following death tolls in other countries:

820,000 in the Chinese province of Kansu in 1556
60,000 in Lisbon in 1775
99,331 in Tokyo-Yokohama in 1923
12,000 in Khait in Soviet Central Asia in 1949
70,000 in Yungay, Peru, in 1970
20,000 in Guatemala in 1976
655,000 in the Chinese Hopeh Province in 1976

A study published in 1972 prepared for the Office of Emergency Preparedness[10] estimates that a repeat of the 1906 San Francisco earthquake in 1970 would have killed some 10,000 persons had it occurred at 4:30 pm during the evening rush hour. The death toll would be many times greater if any of the dams in the affected area failed before the downstream population was evacuated. For example, the partial failure of the Lower San Fernando Dam in the 1971 San Fernando earthquake required the evacuation of 80,000 downstream inhabitants. The U.S. earthquake-related loss of life has been low for several reasons:

- Many of the serious earthquakes occurred in relatively sparsely populated locations.
- Building construction practices are generally good.
- The earthquakes have occurred at a time of day when the number of persons at risk is small.
- Except for the San Francisco Fire of 1906, there have been no serious secondary effects from earthquakes.

During the 20-year period from January 1, 1949, to January 1, 1969, 160 persons are believed to have been killed by 38 damaging earthquakes in the United States, while 350,000 are believed to have been killed worldwide in 521 damaging earthquakes.[11] Other kinds of national disasters regularly exact a large toll in lives and property damage in the United States.[12]

White and Haas have made a comparative analysis of various natural hazards.[13] This shows the historical earthquake death rate to be approximately an order of magnitude less than the rate from any other natural hazard reported. The analysis also contains a generalized picture of the trends in damages and deaths. In almost all cases reported, the trend in damages is increasing while the trend in loss of life is increasing only for earthquakes, windstorms, and avalanches; it is declining or stable for most other hazards.

Earthquakes, like some other natural hazards, may cause a catastrophic disaster. For example, the nation takes in stride 50,000 deaths from automobile accidents yearly because they are dispersed among the general population; however, 50,000 deaths in a particular geographic region with accompanying property damage of billions of dollars would be viewed in a different light. It is the concentration of deaths, injuries, and property damage that results in a catastrophe.

Other natural hazards have some potential for credible warning. The weather conditions that lead to hurricanes and to tornadoes are evident for hours, if not days, before the event. Some hazards are related to specific seasons of the year. The spring thaw and rains lead to floods. Tornadoes rarely occur in the winter. The hurricane season along the Atlantic and Gulf states is late summer. Earthquakes have no visible warning signs and can occur at any time of year. Most natural hazards are limited to certain regions, and earthquakes are not an exception. However, the detailed mechanisms by which earthquakes occur and their effects are propagated differ among the several earthquake-prone regions. This means that their rate of occurrence and their range of effects will be different for different regions. Accordingly earthquake prediction presents a unique problem as a basis for credible warning.

4. Measuring Earthquakes

Three main parameters are used to characterize an earthquake: time, location, and magnitude. The first two are given with respect to the hypocenter, also called the focus. This is the initial point of origin of the energy release, even though the fault rupture may propagate rapidly into other areas, sometimes with a greater relative release of energy. The instant at which seismic waves begin to emanate from the hypocenter is normally expressed in Greenwich Mean Time (GMT) or Universal Time (UT) to the nearest tenth of a second or better. Location is given by the latitude and longitude of the epicenter, the point on the earth's surface directly above the hypocenter, and by the depth of the hypocenter below the surface.

The "size" of an earthquake is measured in various ways, each important for a different purpose. The most fundamental and scientific unit is magnitude (M), which is a logarithmic measure intended originally to indicate the total amount of energy released by the event. Its value is calculated directly from the amplitude of vibration induced on a monitoring instrument (seismograph) and is calibrated to be independent of the point of measurement.* Consequently, the relation between magnitude and energy is indirect and approximate, and may even turn out to be incorrect. The logarithmic feature of the scale means that an increase in magnitude by 1.0 corresponds to an increase in vibrational amplitude by 10 and an increase in energy released by a factor of about 30. Earthquakes whose magnitudes are less than 4.0 are not usually damaging. An earthquake whose magnitude is at least 7.9 is conventionally called a great earthquake. The two largest great earthquakes on record were of magnitude 8.9.

On the other, hand, intensity (I) is a less precise geological-cultural measure of the severity of shaking experienced at a given site. It can be related to magnitude indirectly, through (1) the distance of the site from the fault (taking into account the extent of fault rupture and depth of the earthquake as well as the geographic distance), (2) seismic wave propagation through the intervening rocks, (3) the duration of the shaking, and (4) the characteristics of the soil at the site.

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*Several different magnitude scales are used, corresponding to the amplitude of different seismic waves emitted from the same shock. Unless otherwise indicated, the magnitude scale referred to here is the the Richter scale, which is the scale that is most commonly used.

The intensity of an earthquake at a given site can sometimes be calculated within one unit if the magnitude and all of these other parameters are known, but for purposes of assessing seismic risk it is usually estimated empirically from the observed intensities of previous earthquakes in the same area, taking into account local geology to the extent it is known. A number of different intensity scales have been proposed in the past, but the one most commonly used in the United States today is the Modified Mercalli (MM) scale, which runs from I (barely felt) to XII (total description), as indicated in Table 1.

Related to intensity, the area (square miles) over which an earthquake is felt is also sometimes used to measure its size.

A third means of expressing the size of an earthquake is by its resultant ground acceleration (A), which is a convenient way of expressing the actual force imposed on objects by vibratory motion.[14] Ground acceleration is usually stated as a fraction of the earth's natural acceleration due to gravity, a unit designated g. Thus an upward acceleration of 1.0 g (a net acceleration of 0 g) would cause an object to levitate--whether that be a boulder, a building, a body of water, or even a part of the earth--regardless of its weight. The main advantage of this particular measure is its direct relevance to earthquake-resistant design since an engineer calculates the strength of a structure in terms of such applied forces.

Ground acceleration can be very roughly related to intensity for design purposes by means of the formula $\log_{10} A \approx (I/3) - 3.5$, but any attempt to make this relationship more precise must introduce other important variables as well--mainly the frequency of the shaking and its duration. In addition, the maximum acceleration experienced in the upper levels of a tall building will often be significantly greater than that at ground level because of the dynamic characteristics of the structure.*

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*A structure may also collapse during an earthquake because its framing or foundation fails.

Table 1

MODIFIED MERCALLI INTENSITY SCALE OF 1931
(Abridged)

I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of a truck. Duration can be estimated.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building; standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects noticed. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars.
IX	Damage considerable even in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Considerable landslides from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
XI	Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Source: Earthquake Information Bulletin, Vol. 6, No. 5, p. 28 (1974).

The engineering importance of acceleration as a measure of earthquake size has led to the installation of more than 1300 strong-motion accelerometers (SMAs) throughout buildings and other structures in the United States since 1963. These large-signal instruments lie dormant until some specified acceleration occurs (usually 0.01 g) in the vertical direction, at which point they begin to record. Typical SMA seismograms for moderate earthquakes rarely indicate more than 0.1 g (instantaneous peaks can be much higher), but a record horizontal acceleration of 1.25 g was measured near San Fernando during the earthquake of February 9, 1971 (magnitude 6.4). Such a high acceleration value for just a moderate-magnitude earthquake has serious implications for earthquake engineering, especially as applied to the design and choice of sites for dams, hospitals, and nuclear reactors.

B. Rise of the Seismic Sciences

Seismology is the science that deals with earth vibrations, natural and man-made, and related phenomena. It is normally regarded as a borderline field that overlaps geology and geophysics.

Seismology arose near the turn of the century with the development of seismographs and other instruments for collecting data on invisible effects. Theoretical physics became important several decades later for the development of models of the earth's crust and interior from seismic data. As a consequence, recent years have seen a strengthening of seismology's ties with the more mathematical side of science and with geophysics in particular.

Geophysics covers the study and application of general physical principles to the earth. In addition to seismology, it includes oceanography, volcanology, meteorology, hydrology, geodesy, tectonophysics, terrestrial magnetism, atmospheric physics, and most recently the physics of the upper atmosphere and near-earth space environment.

The principal goal of seismology as a scientific discipline is to understand the processes that govern earthquakes and their natural physical effects.* An important future application of this understanding might be the ability to predict or control the occurrence of earthquakes to a sufficient degree to reduce their hazard to life and property. Thus earthquake prediction and control constitute potentially significant social applications of seismology.

To date, seismology has been largely an observational science. Theory has been slow to emerge, and though hypotheses abound, they have remained largely unverified because of the difficulties of controlled experimentation. Controlling key physical parameters is very difficult in the natural laboratory of the earth. Seismology will surely remain a predominantly observational science in the foreseeable future. It should be noted that the efforts toward seismic verification of nuclear testing and recently toward earthquake prediction have led to many theoretical advances. Theory will continue to grow, but the growth will be slow because of the sparsity of opportunities for direct, controlled experimentation.

One of the consequences of the observational nature of seismology is that advances are somewhat dependent on how often earthquakes occur. This is true not only scientifically, since more earthquakes mean more and better data, but also politically since funding for instrumentation networks and for research into the causes of earthquakes and their possible prediction tends to increase following the occurrence of damaging earthquakes.

The principal center of research in seismology in the United States is the National Center for Earthquake Research (NCER), part of the U.S. Geological Survey (USGS), with offices in Menlo Park, California. This center ranks high among government laboratories for the quality of its work. Important contributions are also made by several university laboratories and institutes, such as those at the California Institute of Technology, University of California at Berkeley, Columbia University, University of California at Los Angeles, Stanford University,

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*The subject of rock mechanics is not always classified as a part of seismology, but we have done so here as a matter of convenience.

St. Louis University, Massachusetts Institute of Technology, and the University of Colorado. The USGS maintains its headquarters for earthquake studies and its Engineering Seismology Branch in Reston, Virginia. Its Seismicity and Risk Analysis Branch is in Denver.

The total U.S. budget for seismology and all other earthquake-related work rose from $0.5 million in 1958 to nearly $15 million in 1971.[15] It is currently about $13 million. Much of this is appropriated directly to the USGS but about 15 percent of this amount comes through other federal governmental organizations, such as the National Science Foundation (earthquake engineering) and the U.S. Nuclear Regulatory Commission* (siting of nuclear reactors). About 75 percent of the total budget is devoted to USGS's internal program, and about 15 percent goes for programs at universities, under USGS sponsorship. The balance of the budget is from state governments (e.g., the California Division of Mines and Geology) for local studies.

The event of greatest budgetary significance to seismology was the Vela-Uniform project on seismic verification, which was aimed at developing a U.S. capability for distinguishing between earthquakes and underground nuclear explosions.[16] Its budget of more than $250 million in the late 1950s, dwindling in the late 1960s, paid for much research and education is seismology and geophysics generally, including the development of large seismic arrays, modern seismic instruments, and the use of data processing. The termination of this program left a reservoir of talented professionals in seismology, many of whom are not presently working at their potential levels of effectiveness.

The field of seismology has seen relatively little internal controversy, particularly in comparison with some other fields of science. The concept of continental drift[3] proposed by Wegener in 1925 caused some disagreements for many years (particularly between European and U.S. seismologists) before it was vindicated experimentally. It then led directly into the modern theory of plate tectonics. Ten to

*Formerly the U.S. Atomic Energy Commission.

fifteen years ago there was a dispute as to whether seismic waves from nuclear explosions could be distinguished from those due to natural earthquakes. The vela-uniform program in the 1960s ultimately provided a positive answer to this question.

Recently the issue of earthquake prediction has given rise to some internal dissension among seismologists in the United States. The main issue is whether or not large earthquakes can be predicted at all. A secondary issue is less technical: To what extent are the productivity and credibility of a science weakened when some of its ablest contributors choose to work on applications of that science to meet immediate social needs? Such applications may or may not contribute to the solution of important fundamental problems. Society usually welcomes such a change of emphasis, but some critics within science argue that premature applications, not being soundly based, are risky, and even small failures can give the science a bad public image.

C. Why Earthquake Prediction Now?

Scientists use two interacting criteria in selecting the subjects of their research: the kinds of knowledge that appear to be scientifically challenging yet achievable and the prospect of important practical applications. Earthquake prediction appears to be a subject that meets these criteria.

In fiscal year 1976 the budget for the USGS earthquake-prediction program totaled $5.4 million.[17] At this level the program is considered by most knowledgeable observers to be underfunded. Nevertheless, it is feared that, as part of a federal-government-wide economy drive, the program may be reduced by as much as $2 million in fiscal year 1977.[18] However, there are important earthquake-prediction programs being conducted in China, Japan, and the Soviet Union. There appears to be little doubt either nationally or internationally that the sciences are ready and willing to pursue this goal.

Society must concur, however, if the scientific inquiry is to go forward. The type of scientific and technological activities involved require the implicit, if not the explicit, support of society. It is no secret that society's interest in learning how to mitigate the effects of natural disasters is highest just after such a disaster. The last big "shot in the arm" for earthquake-protection studies was the San Fernando earthquake of 1971. At present, there is a growing concern that every day brings us closer to a great earthquake in the Los Angeles or San Francisco Bay regions. Society has seen that prediction of other kinds of natural disasters, such as hurricanes and tornadoes, have saved many lives. Society has the image of a national objective established and solved with the moon exploration phase of the space program. Accordingly society has developed general expectations that science and technology can deal with many of its domestic problems.

A new element has recently been added to society's acceptance of technological fixes for its problems: the need to anticipate the future impacts of a technology. Thus society respects the urge of science to explore new frontiers, but it is asking that the exploration be conducted with an orientation to future consequences. This has come about because society is becoming aware that the solution of some problems has incurred other, unanticipated, problems that ultimately may be worse than the original problem. As a result policymakers call for environmental impact statements and technology assessment as means of trying to anticipate the future effects of present actions.

In this respect, earthquake prediction is in a unique position because it will mature as a scientific activity in geologic time. The rate of advancement of the technology of earthquake prediction will be governed to some extent by the rate at which experiments are conducted. Two factors are involved: the coverage of instruments and the occurence of earthquakes in the area covered. For large damaging earthquakes the rate of occurence may be on the order of once every 50 to 100 years in all of California. This means that it may take hundreds of years to prove a hypothesis or even to confirm a theoretical breakthrough concerning the prediction of large-magnitude earthquakes on one particular type of fault structure.

D. The Science of Earthquake Prediction

1. A Scientific Inquiry

At present earthquake prediction is a scientific inquiry. There is no science of earthquake prediction in the sense that there is a body of replicable knowledge. As a scientific inquiry it is taking several different paths, but there is an implied common goal that binds the working scientists together. This common goal gives individual scientists following different paths a direction to seek; it allows the evolution of scientific knowledge to build on past and related work; and it distinguishes truth seeking as the basic purpose of the scientific inquiry.

At times the development of a science is limited by the supporting technology that is available and progress is stalled until a new technology is developed. The technology that evolves from a developing science may incorporate components of its supporting technology. However, its suitability for employment as a technology must be determined by the standards of science. These require the capability of replication within acceptable limits or an underlying theoretical understanding of the processes that are being measured.

2. The Track Record

By mid-1975 between 15 and 20 earthquake predictions of varying degrees of precision had been made by scientists or scientific organizations throughout the world. A few of these were long-range predictions; for example, the following predictions were made for California:

> A quake of $M \approx 8.4$ around Los Angeles and a quake of $M \approx 8.1$ around San Francisco are more likely to occur in the next 12 years than later. (Hofmann, 1971.[19])
>
> No earthquake of $M \geq 7$ and no earthquake of $M \approx 8$ will occur between San Francisco and Parkfield, California, during the next 7 and 25 years, respectively. (Wyss, 1974.[20])

> The most likely location (and time) for the next earthquake $M \geq 5.0$ within a 350-kilometer segment (between Parkfield and Santa Rosa) of the San Andreas Fault is predicted to occur near latitude 37° before 1978. (Wood and Allen, April 1973.[21])

By August 1975 there had been no events to either verify or refute these long-range predictions.

A less precise but successful long-range prediction was announced by Sykes in 1971, with his designation of three possible sites for the next large earthquake ($M \geqslant 7.0$) in southern Alaska.[22] This prediction was based on the recognition of these sites as seismic gaps.

Probably the most precise successful U.S. prediction was made by Aggarwal et al. in 1973 for a small event in the Blue Mountain Lake region of New York State.[23] It was based on the velocity anomaly.* The shock was predicted to occur within a few days of the announcement and actually took place 2 days later with the expected magnitude.

Two medium- to short-range predictions were made by the USGS for the Hollister area, which is about 90 miles southeast of San Francisco, along the San Andreas Fault. The first was announced publicly and was unsuccessful.[24] The second was kept private and was not specific in time (merely "very soon"), but it came true the following day, when a magnitude 5.2 shock occurred exactly within the small area in question where instrumental anomalies had been observed in tilt and magnetic field.[25] In November 1973 Whitcomb of the California Institute of Technology predicted a magnitude 5.5 event just east of Riverside, California, within 3 months; this event occurred in January 1974, though with a smaller magnitude (4.1).[26]

A number of retrospective earthquake "predictions" have arisen from searches through past seismographic records for indications of a reduction in P-wave velocity through the region in question.[27-30]

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*See Section II-E for a discussion of the various prediction techniques.

However, many earthquakes occurred where this velocity reduction should have been noticeable but was not found.

Predictive work in China has been even more active than in the United States. As noted previously, 10 moderate to large earthquakes have been predicted in China.[31] Half of these predictions were fairly accurate, the accuracy of others being variable. The most recent report claims a sequence of successful predictions of a magnitude 7.4 event in February 1975, a year, a day, and a few hours in advance.[32] Most of the Japanese effort has been directed toward long-range prediction, but a few small events during the famous Matsushiro swarm in 1965-1966 were predicted correctly a few days in advance.[33]

3. Technological Requirements for a Practical Earthquake Prediction System

Although the record of recent earthquake predictions is certainly exciting and impressive in comparison with the state of the art a few years ago, the practical feasibility of earthquake prediction remains questionable. To achieve this feasibility, it will be necessary to develop the ability to predict damaging earthquakes with sufficient precision, accuracy, and credibility to encourage public officials and the public to take effective defensive action before the event. Negative predictions and predictions of nondamaging shocks will also be important. Acceptable standards for precision and accuracy have yet to be worked out in detail. They will vary with the region served, the time frame, and the level of public credibility that prevails at the time of the prediction as a result of previous prediction experience. Nevertheless, the achievement of even minimal standards is well beyond present technological capability.

None of the four scientific approaches to earthquake prediction that are currently being followed by itself meets the requirement for an effective earthquake-prediction system. The <u>theoretical</u> approach is virtually guaranteed of eventual success, to the extent that earthquake prediction is fundamentally possible, but it could be 50 years or more before we would know on this basis alone whether or not earthquake prediction is feasible. The statistical approach has not revealed sufficiently strong regularities in the past occurrences of earthquakes. Future work in this direction will at best uncover long-range or subtle trends to support the developing theory. It might also suggest new directions to pursue or particular variables on which to focus attention. The empirical search for better premonitors has generated many candidates, most of which remain largely unexplored. It may reveal one or more premonitors that are sufficient for reliable and precise earthquake predictions, at least within limited regions. On the other hand, like any empirical approach, this search may turn out to be unsuccessful and therefore is not entirely reliable for developing an earthquake-prediction system. Nonscientific prediction is a complete unknown and an unlikely prospect for the levels of precision and accuracy that are needed.

Consequently, two or more approaches will need to be followed simultaneously if earthquake prediction is to become a reality. In view of their strong interdependence, the theoretical and empirical approaches will most likely form the backbone of future seismological research, at least for the next decade.

The soundest basis for extrapolating the small successes of earthquake prediction to larger events is to be found not so much in the meager results obtained to date with the various premonitors but rather from the support these measurements lend to the evolving models based on theoretical reasoning. The fact that so many of these premonitory variables have exhibited during the preearthquake interval correlated changes that are consistent with physical models constitutes strong evidence that the hypothesized models are indeed valid and that the theory of how earthquakes occur is generally correct as far as it goes. It is mainly for this reason that the dilatancy theory, despite its newness, has been so well accepted. It is certainly incomplete in many ways (e.g., it apparently does not hold everywhere, and scientists are still arguing over the role that water plays in dilatant rock), there is already good evidence that the dilatancy theory holds for certain areas. It may be a real breakthrough in seismological understanding.

On the negative side, the unknowns surrounding earthquake processes are fundamental and theoretical. Many advances and perhaps more breakthroughs will be needed before even a pragmatically complete explanation can be offered of the factors that lead up to and trigger off earthquakes and determine the extent of faulting. Again, complete theoretical understanding may not be needed for prediction by the more empirical approach based on field measurements of premonitors, but the theory will be needed eventually.

The main technical problems faced by seismologists working on earthquake prediction are the following:

- What is the magnitude of typical rock stresses near hypocenters and how does it vary with time to rupture, depth, position along the fault, and from one fault to another?
- What physical process is mainly responsible for actually triggering off an earthquake in the last stages of stress buildup?
- Which premonitory parameters offer the most precise, accurate, and widely applicable indications for medium- and short-range prediction of large earthquakes?
- What physical changes does subsurface rock undergo during the changes in dilatancy as the stress increases toward the breaking point?

In addition, there are many problems in geophysics generally whose solution might be helpful in earthquake prediction. These problems deal with global plate tectonics and certain other crustal and subcrustal processes. For the most part, however, they pertain to long-term trends in regional and local seismicity rather than to the dynamic short-term processes most relevant to earthquake prediction.

The technological factors most crucial to the development of practical earthquake prediction are as follows:

- A well-deployed and varied instrumental network.
- An active program of laboratory experimentation and simulation of rock behavior at typical pressures and temperatures.

- Computation facilities adequate for processing instrumental data and for extensive modeling of crustal rock behavior under stress.
- Theoretical studies.

In the political-economic area, the most critical requirement for an active program is adequate funding. Also important are (1) the maintenance of a program of international cooperation with scientists in the Soviet Union, Japan, and particularly China and (2) continuing public respect for seismology as a science that can contribute to the public welfare.

Finally, to all of these man-controlled factors must be added a natural one: Moderate-sized earthquakes must occur with at least their normal frequency if scientific progress is to continue and public and governmental involvement in earthquake mitigation is to be maintained above threshold levels during the development period.

E. The Technology of Earthquake Prediction

1. Approaches to Earthquake Prediction

In general, there are four approaches that might be taken to earthquake prediction:

- Expansion of the theoretical knowledge of geophysical processes related to earthquakes (e.g., the sources of crustal strain in the earth; rock mechanics; propagation of seismic energy through rocks and soil; causal relations between earthquakes at different times and places; and physical, chemical, and electrical changes that accompany the buildup and release of the elastic strain).
- Searching for instrumentally measurable premonitors, whether or not the reasons for these changes are fully understood in scientific terms.
- Statistical studies of past earthquakes to identify periodicities, trends, and other regularities that might be extrapolated to help predict future events.
- Nonscientific predictions by certain intuitive individuals having a prophetic gift.

The first and second approaches are being pursued most actively at present. The general strategy being followed in the United States is to accumulate data from many sources to build increasingly better geophysical models of one area after another. The discussion that follows emphasizes instrumentally measurable premonitory variables but also touches on statistical studies and nonscientific predictions.

2. The Statistics of Earthquakes

Can anything of possible predictive value be learned by searching for patterns in past earthquakes? That is, do earthquakes occur completely randomly, or is there some regularity to their distribution in space, time, or magnitude that might be helpful in prediction? Statistical analysis of historic earthquake data could reveal such patterns if they exist.

To summarize this work, aside from average frequencies, there are no strong regularities that can be observed in the timing of earthquakes, relative to their locations and magnitudes. The only effects discovered are small, and though important theoretically and possibly for long-term prediction, they are not directly useful for short- and medium-range predictions of large earthquakes. These small regularities do not contradict the broad picture of gradual stress accumulation at interfaces between slowly shifting plates, as indicated by the global tectonic model, but the interfaces appear to be so irregular that the release of stress is largely an erratic, rather than a regular, process. Research in geophyiscs may someday unravel these seemingly random sequences of events or at least indicate how to measure conditions locally to anticipate an earthquake. However, there is little prospect that the statistical approach will yield significant results soon enough to affect earthquake prediction technology materially within the next decade.

3. Premonitors: Experimentation in the Field

Unlike hurricanes, tornadoes, and large sea waves, earthquakes are not preceded by any readily visible premonitors, either at the site of the event or remote from it. Most of the effects of earthquakes occur after, not before, the main shock. Smaller earthquakes that occur ahead of time are called foreshocks, but they can be classified as such only in retrospect and therefore have little predictive value.

Searches for true precursory phenomena that might give short-term warning of an impending earthquake have been carried out unsystematically for almost a century. In recent times the search has been more systematic, leading to the identification of several phenomena of actual or possible value.

In the absence of practical means for monitoring crustal stress directly, a large number of other physical variables that might indicate stress indirectly have been explored. Some of these candidate premonitors have a sound theoretical basis, others have arisen speculatively from theoretical models, and still others have been discovered quite accidentally. They also differ from one another in the amount of experience gained to date in measuring them under varying conditions, in their predictive significance when applied to different fault zones and magnitude ranges, and in their ease of measurement. Some of them have been observed only at a single location in conjunction with a few earthquakes. Few of them are scientifically so well understood that they can be well correlated with one another and their relationship to actual stress established firmly and quantitatively. Many will surely fade into obscurity in future years.

For each of the earthquake premonitors discussed below, answers are provided, as known and relevant, to the following questions:

- What is the significance of the premonitor in physical terms?
- How well does it fit in with current theory?
- Is it potentially useful for long-, medium-, or short-range predictions?
- How well investigated is the premonitor?
- How difficult and expensive are the measurements required?
- How accurately does it specify the location?

- How accurately does it specify magnitude?
- Does it signal all earthquakes or just some? Which ones?
- What are the prospects for widespread deployment of the necessary instruments?
- Do predictive errors arising from this premonitor show up as false alarms or as unpredicted events, or both?

The premonitory variables are discussed below. Those that presently appear most promising are considered first.

a. Seismic Wave Velocity

In the late 1960s the Soviets announced the then contra-theoretical observation that the velocity ratio of P- and S-waves passing through underground rock just prior to fracture changed by 10 to 20 percent.[34-36] These results, now confirmed elsewhere (but not equally well for all earthquake-prone areas), contributed to the development of the dilatancy theory.[37-38] This velocity change, readily observed on seismographs, is best explained as a reduction in the ratio of P-wave velocity to S-wave velocity. It occurs during a premonitory interval whose duration increases with the magnitude of the quake: a few days for a magnitude 3 event to a few months for a magnitude 5 event, as suggested by the graph in Figure 4.*

By extrapolation, this implies a lead time of perhaps 40 years for an earthquake of the size that struck San Francisco in 1906.† Just prior to the earthquake the velocity ratio returns to normal.

This particular premonitor has excited much recent interest, not only because of its theoretical implications but also because its detection requires no novel instrumentation: standard

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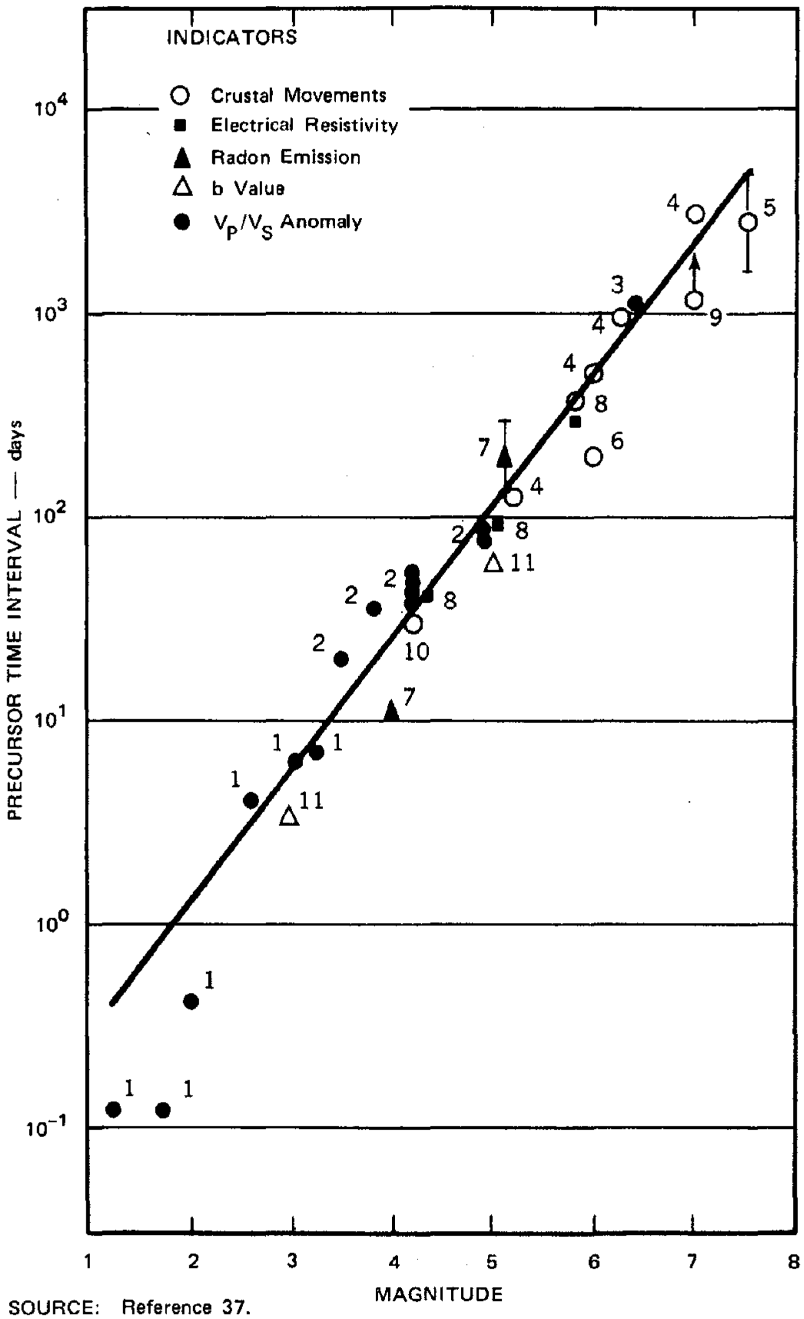
*Lead time in days is approximately related to magnitude by the equation $\log(T) \approx 2(M - 2)/3$.

†The same relation between magnitude and precursory interval appears to hold for some of the other premonitors discussed here.



SOURCE: Reference 37.

FIGURE 4 POSSIBLE INDICATORS AND WARNING TIMES FOR EARTHQUAKES OF VARIOUS MAGNITUDES

Duration time of precursory phenomena as a function of earthquake magnitude. The b value is a parameter that measures the size distribution of earthquakes. Earthquake locations: 1, Blue Mountain Lake, New York; 2, Garm, USSR; 3, San Fernando, California; 4, Kitamino, Kitaizu and Omi, Japan; 5, Niigata, Japan; 6, Odaigahara, Japan; 7, Tashkent, USSR; 8, Garm, USSR; 9, Alma Ata, USSR; 10, Danville, California; 11, Fairbanks, Alaska.

seismographs are quite adequate. In fact, some old seismographic records have been examined and in some cases seem to contain evidence of the velocity change, thereby permitting a few retrospective predictions.[27] To make good velocity measurements there must be a number of small quakes nearby to generate the "test" signals. In some seismically active areas this is not a problem. In others, small detonations of explosives can be set off in quarries or deep wells at a safe distance from the fault, or a Vibraseis unit (a truck-mounted thumper) can be employed to generate the dummy seismic signals. These artificial techniques are expensive but permit more accurate velocity measurements to be made.

b. Microquakes

Very small earthquakes occur continually in seismically active areas, and variations can often be observed in their frequency just before larger events take place. A medium to large earthquake is sometimes preceded by a period of calm followed by a sudden increase in microquake activity immediately before the main event.[23,39,40] This has given rise to the speculation that the long period of quietness (since 1906) along the portion of the San Andreas Fault passing near San Francisco presages a major earthquake there in the near future, and if so, the event would conveniently be immediately preceded by a flurry of microquake activity. However, many large earthquakes in the world have been preceded by a gradual increase, not a decrease, in the number of smaller events in the preceding 2 or 3 years. Consequently, it cannot be claimed categorically that changes in the frequency of microquakes constitute a reliable premonitor. Japanese seismologists have also explored this premonitor with limited success.[33]

c. Tilt

The angle of tilt of the earth's surface is now readily measureable to better than 1/100,000 of a degree. Variations in tilt have been detected near the epicenters* of many earthquakes and have been well correlated with the stress changes that occur during the precursory interval.[41,42] A network of 40 tiltmeters was in operation in California in mid-1975, and additions are planned. The Chinese have more than 250 tiltmeters in the field.[31] Normal changes in tilt due to earth and ocean tides, barometric pressure, and rainfall must sometimes be subtracted from the instrumental records to reveal the residual variations.[41] Tilt changes do not contradict the dilatancy theory, but the directional changes in tilt cannot be interpreted in terms of a simple bulge or swelling in the rock. They probably indicate some more complex volumetric changes in the focal region. Results are encouraging for the use of tilt as one of the main premonitors for prediction.

d. Elevation

Japanese researchers have had some success in correlating earthquake incidence with changes in land elevation near the epicenter.[43] Elevation changes near a fault are detected by monitoring the mean sea level, by measuring the levels of lakes and rivers, or by accurate ground surveying from nearby areas. Laser-interferometry techniques using satellites could be employed in the future. Up to now, however, this particular approach has not been tested or applied widely to detect short-term elevation changes.

e. Surface Strain

Strain is the actual deflection or deformation of rock that occurs under an applied stress. It is typically about 1 part in 10,000 just before fracture. Strain measured at depth would come the closest to direct stress determination, but strain measured at the surface may still be indicative of conditions deeper in the earth.[44]

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*These variations are detectable up to about $M^3/3$ miles from the epicenter for a shallow earthquake of magnitude M.

About 45 stretched-wire creepmeters were in place along the San Andreas Fault in mid-1975. In addition, geodetic measurements between benchmarks implanted on opposite sides of active faults have been made for many years in California and other parts of the world. The latest geodimeter measurements, accurate to almost 1 millimeter, utilize laser techniques between stations 1 to 30 miles apart.[45] Several hundred such measurements are made each year in California. These creep and other readings have been helpful in estimating long-term trends along a fault. However, the jerky movements seen locally have not yet proved to be very significant for short-term prediction. Radiotelescopy, using signals originating from quasars, has also been proposed as a technique for accurate geodetic measurements across faults.[46]

f. Radon Emission

The Soviets and the Chinese have noted changes just before earthquakes in the concentrations of radon, a chemically inert product of radioactive decay, occurring in well water.[47,31] The dilatancy-diffusion theory would suggest that traces of this gas are forced into solution as water penetrates the dilating rock. A variation of this technique is to measure radon emission from soils. An inverted plastic cup containing an alpha-particle-sensitive film in the top is placed over the soil. Since radon produces alpha particles in its radioactive decay, the alpha spot density of the film is a measure of radon emission. Study of this potential premonitor has only just started in the United States.

g. Magnetic Field

The natural magnetic field of the earth to which compass needles respond normally varies slightly from place to place (0.02 percent) because of the variations in the iron content of crustal rocks and from time to time (0.25 percent) because of variations in the extraterrestrial geomagnetic field induced by solar activity. When these time and spatial variations are averaged or subtracted out from readings taken from a network of several magnetometers in an area, a variation in the magnetic field can be observed on instruments closest to the epicenter just before an approaching earthquake.[48,49] The explanation offered for these changes is a process called piezomagnetism--changes in the magnetic properties of rock under stress.[50] The California magnetometer network operated by the USGS contained eight instruments in mid-1975. Seismologists in China have also observed these precursory magnetic field changes.[31]

h. Well-Water Level

Changes in water level in wells near epicentral regions have been monitored by the U.S. Coast and Geodetic Survey for many decades. These changes tend to be strongest after an earthquake rather than before it, but may have some precursory value as well. In particular, two 300-foot wells in central California have shown changes prior to recent earthquakes.[51] Chinese and Soviet seismologists report similar variations.[52,53]

i. Microseisms

Microseisms (as opposed to microquakes) are tiny acoustic-like vibrations occurring in the earth's crust both within and outside faulted areas. Some limited success has been achieved at correlating the level of microseismic activity with impending earthquakes.[54] It has also been suggested that the audiofrequency energy in these microseismic vibrations may be strong enough to be subliminally audible, which may explain the reported sensitivity of animals to forthcoming earthquakes. This premonitor is largely unexplored.

j. Seismic Gaps

When a segment of low activity appears in the middle of a normally active fault, experience has shown that this quiet "seismic gap" is the most likely location of the next moderately large earthquake.[55] A number of retrospective predictions and a few current predictions in the North Pacific have been based on this observed variation in the temporal and spatial distribution of earthquake frequency.[22] It probably has no precursory value for short-range prediction, however.

k. Telluric Currents

Telluric currents are weak electric currents that circulate on the surface of the earth in eight large regions, four each symmetrically located north and south of the equator. They move around the earth as it rotates. Before some earthquakes, daily average current values have been reported by Soviet and Chinese scientists to deviate from long-term average values.[31,56] The source of these variations is not well understood, but it is probably related to dilatancy--the same physical changes that cause the resistivity to vary. Telluric currents are detected by the same sensors that are used for resistivity measurements.

l. Earth Tides

Just like the oceans, the solid earth experiences tides due to the gravitational pull of the sun and the moon. These tides show themselves as a peak of stress and a slight bulge on opposite sides of the earth, passing wavelike around the earth during its daily rotation. Since the solid crust is not fluid like the oceans, the mechanics of earth tides differ from those of ocean tides. Nevertheless, they have the same period as ocean tides (about 12.4 hours between high tides) and combine with ocean tidal loading in coastal areas to produce semidiurnal variations in tiltmeter readings. Although tidal stresses are a small fraction of the rupture stress of rocks, it is conceivable that these changes might be sufficient to trigger off at least some earthquakes, provided they occur in a direction tending to add to the accumulated stress at the fault interface. At least 20 studies have been carried out since the early 1900s to evaluate this earth tidal hypothesis, but the results are inconclusive (see, for example, Refs. 57 through 60). At best it may turn out to be a contributing triggering factor for earthquakes in certain regions.

m. Gravity

Static measurements of the strength of the earth's gravitational field have been used in geophysical prospecting for some time. Very small time-dependent changes in the gravitational field appear to be correlated with earthquake activity, at least after the event and possibly before.[61]

n. Earthquake Lights

The number of well-documented reports of glows in the sky just before or after an earthquake is now too large to be attributed to subjective errors in observation.[56,62] The origin of these "earthquake lights" is unknown. The consensus is that the phenomenon is electrical in nature, but it is not known how electric fields strong enough to ionize air could be occurring in the atmosphere near the epicenter of an earthquake. Some theories have been proposed to explain this, on the assumption that these electrical potentials have their origin inside, and not outside, the earth: piezoelectric effects in quartz-bearing rock,[63] piezomagnetic effects,[50] acoustic modification of the normal atmospheric electrical gradient, and some other possibilities related to earth and ball lightning (see below). These possibilities surely merit more investigation but at present have a low priority among the long list of possible premonitors.

o. Weather

It is common belief and there are a few credible reports that there is a relationship between earthquakes and weather anomalies.[64] There are many popular reports of lightning that has supposedly accompanied earthquakes, and some early data suggest a small but positive correlation of earthquake activity with atmospheric pressure variations.[65] Santos predicted the Managua, Nicaragua, earthquake in 1972 by comparing rainfall records with those for periods preceding past earthquake activity in the Managua area.[66]

p. Rock Temperature

The prospect for this premonitor is based on a single observation: a dramatic anomalous rise (25°F) in the temperature of mineral water from a borehole located at the site of a magnitude 6.5 earthquake in the Soviet Union in 1970.[52] Established theory has no explanation for the source of the heat. Some sort of fluid flow process is surely involved since the thermal conductivity of rock is much too low to serve as a medium for heat transfer to the surface. The hypothesis that there are "hot spots" underneath volcanic belts, and hence under earthquake areas as well, has some theoretical appeal but has never been either proved or disproved.

q. Animal Sensitivity

Erratic behavior by many types of domesticated and wild animals has been reported throughout history and continues in the present. These reports are usually classified with other exaggerated after-the-catastrophe public reports and have been given little credence by science. Recently, however, seismologists in China have revealed the establishment of a widespread network of animal observers, and the use of these observations is an important input in some successful predictions.[31] Even if this animal sensitivity turns out to be valid, however, there is no firm basis for conjecture as to what physical changes the animals might be detecting. Both microseisms and some sort of electrical activity that might precede an earthquake have been suggested as possible explanations since many animals are known to be particularly sensitive to weak sounds or to electric or magnetic fields. Japanese investigators have reported the high sensitivity of catfish to both earthquakes and electrical signals in the water (artificial or natural, presumably telluric currents).[67] Aside from this isolated study, there is no direct experimental evidence to support these conjectures, and there was no investigation of animal sensitivity to earthquakes in progress in the United States as of mid-1975.

r. Earth Wobble

Tiny variations in the axis of rotation of the earth, readily detectable by astronomical observation, have revealed small unexpected deviations at the times of some of the world's great earthquakes.[68]

It is not presently known whether the earthquakes cause the deviations, perhaps through a change in the distribution of the earth's mass, or whether some internal change in the earth is causing both the deviations and the earthquakes.

s. Changes in the b-Value

Changes in the b-value (the constant of proportionality between earthquake frequency and magnitude) have been suggested as a precursor, but this possibility has never been well established.[69] In any case it would probably apply only to long-range prediction.

t. Ionospheric Activity

Anomalous changes in the level of the ionosphere (the radio-reflective layer of ionized gas 50 to 100 miles above the earth's surface) have been reported after three earthquakes in the Pacific in 1968 and 1969, and both before and after two others--the Alaska earthquake in 1964 and a magnitude 6.2 event near Hilo, Hawaii, in 1973.[70,71] Ionospheric changes are readily detected by radiosounding techniques. For the first three earthquakes the level changes were identified through their direct correlation with seismic surface waves (Rayleigh waves), which were apparently transmitted to the ionosphere as pressure waves through the atmosphere. (This phenomenon has been proposed as a basis for an improved tsunami warning system.[72]) Similar ionospheric changes have been observed near large nuclear explosions. No explanation has yet been offered for the observed changes before an earthquake, however, and the phenomenon has not been investigated.

u. Planetary Positions

In 1959, Tomascheck announced his discovery that 15 of the world's 23 great earthquakes occurring during a 3-year period ending in December 1906 happened at times of the day when the planet Uranus was within 15 degrees of its highest or lowest point in the sky.[73] His result is readily confirmed and is statistically significant beyond question. There is no scientific explanation for this remarkable observation. In the absence of any conceivable explanation, it will probably remain unexplored by science for some time. Chinese seismologists have announced that they are employing statistical techniques to search for astronomical correlates of earthquakes, on the grounds that this method was used for prediction in China 2000 years ago.[74]

4. Nonscientific Predictions

There are also numerous reports in the popular press of predictions of earthquakes and other events by prophets, seers, and astrologers. Such predictions are almost always either totally wrong or stated so vaguely that no significance can be attributed to them. Nevertheless, from time to time a few have been shockingly precise and correct--well beyond the chance of a lucky guess. Science offers no explanation of how such predictions are possible.

This strange phenomenon, and the gifted individuals capable of manifesting it, have only recently come under limited scientific scrutiny. Some day, enough experience and understanding may be gained with this little-known faculty of the human mind to permit us to develop it or at least to discriminate accurate predictions of this sort from the others. Even if this approach should never reach the level of accuracy, precision, and credibility needed for public warning, it could be useful in guiding the deployment of instrumentation for the collection of valuable on-the-spot premonitory data.

5. Summary of Features of an Operational Earthquake Prediction System

The main features of earthquake-prediction technology that are relevant to the development of an operational system have been covered in detail in the preceding sections. They can be summarized as follows:

- Earthquake prediction will be approached by a combination of improving theoretical understanding and experimental monitoring of the regions for which predictions are to be made.

- Prediction capability will be developed by moderate to intensive instrumentation of limited areas, one at a time, rather than by distributing the stock of available instruments over the entire portion of the United States that is at risk.

- Issuance of predictions will probably be routine by 1985 and will be accurate for small earthquakes in well-instrumented areas. However, not all earthquakes will necessarily be predicted. Moderate-size earthquakes will be predictable with only fair accuracy in time and magnitude. Initial lead times and time windows will probably be a few months, updated in some cases to shorter times as the earthquake approaches.

- There is considerable uncertainty about how well large earthquakes might be predicted, particularly with regard to time. The most optimistic view of experts is that a large earthquake could not occur in an instrumented area without at least a few clear premonitory indications. The most pessimistic view suggests that large earthquakes will be very difficult to predict with any reasonable accuracy in time and magnitude, and their prediction may even be beyond the state of the art for many decades at least.

- Prediction of a specific earthquake can be expected to be a continuing unfolding picture in which the precision and accuracy improve as the expected time of the event approaches.

- The first effective prediction system will function in northern, central, and southern California.

- Most future predictions will be based on several rather than a single measured premonitor, at least for many years.

- Primary emphasis should and will be focused on improving time and magnitude estimates of predictions.

- Relevant and helpful research results can be expected from China and possibly the Soviet Union during the next decade.

- None of the approaches to earthquake prediction that are currently being considered imply environmental disruption. (This is not necessarily the case for earthquake control.)

- Earthquake prediction technology is not contingent on advances in fields of engineering or science outside geophysics, although breakthroughs in other fields might very well result in unexpected benefits for earthquake prediction.

6. Evolution of the System

The success rate of recent earthquake predictions is too low and too limited, and the predicted earthquakes are too small, for present techniques alone to serve as a basis for the design of an operational earthquake prediction system. Before such a design can be undertaken, much more prediction experience under a greater variety of conditions will be necessary. To improve the accuracy and precision of predictions, particularly with respect to time and magnitude, instrumental networks and the associated computational facilities must be expanded. A sufficient number of moderate to large earthquakes must then occur within instrumented regions, a step requiring only the passage of time. For proper interpretation of instrumental data, it is most likely that some significant theoretical advances will need to accompany this sequence of observations.

The first operational system will grow slowly and naturally out of this observational program and the related theoretical studies. This system, unlike a space station or a radar system, will not be designed and developed from scratch but will evolve directly out of research activity. It is very likely that, as the years go by, larger and larger earthquakes will be predicted successfully, and the precision and accuracy of the predictions will improve gradually. In this respect, earthquake prediction is similar to weather prediction. For the first operational earthquake prediction system, then, there will be no ribbon-cutting ceremony and no public announcement that "earthquake predictions are now possible."

Prediction experience will go on for many years and possibly decades before the system reaches a level of confidence for medium to large earthquakes that is comparable to hurricane warnings and forecasts of high tides. Society must pass through a long period of many successes and a few failures before operational status can be rightfully claimed. During this long development period, society must work out its own ways of dealing with the uncertain and sometimes incorrect transitional research products that will emerge from the scientific community.

For these same reasons, the second and some subsequent operational systems may emerge as geographical extensions of the first and may therefore not be identifiable as distinct "systems." For example, a system for southern California may be gradually enlarged in a northerly direction toward Nevada. Subsequent systems in other high-risk areas will probably begin to be developed before the first systems are operating well. Present evidence indicates that each region has its own unique seismic features and may require a different density of instrumentation, different instruments, or novel ways of interpreting the instrumental data. In any case, at least some, and possibly a great deal of, fault mapping and velocity modeling will very likely be needed for each new region that is to be covered for prediction.

Alternative approaches appear to be possible for the development of an operational earthquake prediction system, as revealed by the differences among the policies adopted in the United States, China, the Soviet Union, and Japan. Even though these foreign programs have a heavy pragmatic emphasis, few if any respected U.S. geophysicists would recommend a reduction in the U.S. theoretical effort to match the foreign programs. Consequently, the choices that are realistically open lie in setting a proper balance between pragmatic and experimental activity on one hand and research for more fundamental understanding on the other. The United States will almost certainly maintain its world leadership in theoretical seismology, even if it undertakes a large-scale program of field experimentation in the near future, at least in the next decade. This leadership will also be maintained even if China, say, is successful in its attempt to build an operational earthquake-prediction system almost entirely on a pragmatic basis.

7. Cost Estimate

Cost estimates for any large 10-year program in the future are always very uncertain, even when the supporting scientific research has been completed and some relevant past experience is available. In the present instance, neither of these conditions is satisified. In addition, there are other complicating factors--such as the unpredictable natural frequency of earthquakes, public credibility, and foreign developments--any one of which could influence the rate of development and the amount of funding that will be necessary to get a functioning earthquake-prediction system in operation, even in a limited geographical area.

The estimates presented here are based almost entirely on the opinions of experts in seismology, with some weighting on the basis of our own assessment of each individual's qualifications for making engineering-economic estimates.

The developmental cost of an operational system for predicting large earthquakes along the most populated portions of the San Andreas fault system, and in the active central California section as well, has been estimated to be between $5 and $100 million. However, most informed seismologists surveyed in the course of this study place the likely cost between $30 and $50 million. The assumed accuracy of predictions obtainable with this expenditure was not given, but it presumably falls in the 75 to 85 percent range.

The major uncertainty in this figure is related to the amount of research that needs to be completed before any activity that might properly be termed "development" can begin. This research has two closely integrated components: a direct experimental approach that may produce dramatic results in the near future and a slower but more certain theoretical approach. The degree to which each of these two parts will contribute to an effective solution is not presently known. Secondary factors in the uncertainty of the cost estimate are (1) the unknown frequency of medium to large earthquakes in the next decade or so, (2) the rate at which public respect for earthquake prediction capability will develop, and (3) technical advances in China, the Soviet Union, and Japan.

The USGS has developed a two-phase plan that could lead to operational prediction systems for Los Angeles and San Francisco.[75] In phase 1, the present small experimental network near Hollister would be upgraded and enlarged and a similar dense network would be established along the San Jacinto Fault in southern California. These experimental systems would "capture" earthquakes in the two areas of greatest seismicity in California and permit development and validation of prediction techniques. Concurrently, less dense arrays would be deployed in the nearby urban areas of San Francisco and Los Angeles. In phase 2, after prediction methods and instruments have been proved, the latter networks would be upgraded to operational systems for the highly populated sectors of California.

The plan would cost about $6 million a year for 5 years. Expenditures for equipment would dominate during the first two years, with funds shifting to operations and analysis in subsequent years. At the end of the fifth year, a decision would be made whether to go ahead with the operational system in other parts of California.

The USGS has also proposed an intensified national program in earthquake prediction research.[76] This program is specified in three options representing increased annual levels of funding over the existing level:

- Option 1 ($15 million per year):
  - Densely instrument a few key areas in California and Nevada.
  - Study six or eight of the most promising types of precursor.
  - Increase the rate of observations of precursors by perhaps a factor of 3.
  - Operate sparse networks of seismic instruments in the central and eastern United States.
- Option 2 ($30 million per year)--All of Option 1 plus the following:
  - Densely instrument six to ten key areas.
  - Study most of the promising types of precursor.
  - Carry out real-time processing of information from large areas.
  - Develop small-scale numerical models of earthquake generation.
  - Drill into the fault zone to determine the properties at depth.

- Increase the observations of precursors by perhaps a factor of 10.
- Work on predicting in detail the effects of earthquakes, especially in California.
- Undertake a moderate effort in Alaska and Hawaii.
- Undertake a minor cooperative effort overseas.

• Option 3 ($50 million per year)--All of Option 2 plus the following:
  - Study all conceivable types of precursor.
  - Undertake a major cooperative effort overseas.
  - Undertake a major effort in Alaska and Hawaii.
  - Develop a three-dimensional numerical model of earthquake systems.
  - Develop techniques for predicting in detail the effects of earthquakes throughout the United States.
  - Produce a controlled earthquake in a remote area.
  - Develop instrumental networks in the central and eastern United States.
  - Study instantaneous plate motion.

The USGS assessment is that Option 2 is perhaps the most reasonable course and that under this option it might be possible to have reliable prediction systems in California within a decade. However, they estimate that under the present funding level and program this goal might take many decades. Option 3 is considered to be a crash program aimed at predicting the next big earthquake in California and at developing a prediction capability at the maximum rate.

An increase in funding of $30 million per year would certainly cause an advance toward the goal of reliable prediction. However, there is a level of funding above which the goal of reliable prediction would not necessarily be achieved much more rapidly. More areas could be covered, and to the extent that results can be transferred between areas, achievement of the goal would be accelerated. Progress is limited by the factors discussed in Section II-D-3. The key uncertainty is whether theoretical progress can be achieved faster than empirical progress and whether theoretical progress will require empirical verification. Even if the latter is not the case scientifically, it will be an element in society's acceptance of the technology.

Some kinds of operational earthquake prediction system can be visualized as consisting of arrays of geographically dispersed instruments that are linked to a data-processing system through a telecommunications system. As such they are similar to a public utility function like the telephone system and could even be incorporated into such a system. The direct sensing of crustal elevation from satellites has been mentioned, but satellites may first provide the telecommunications function by interrogating ground stations and relaying the data to the data-processing system.

As a utility-like function, an operational earthquake prediction system will consist of the following elements:

- Arrays of instrumentation requiring some kind of land acquisition or use rights.
- Field stations to make some periodic measurements and to provide maintenance and calibration of in-place instruments.
- Telecommunications systems to transfer command signals and data.
- Data processing systems to reduce the field data on a realtime or near-real-time batch basis.
- Central control, probably incorporating not only the data processing system but also the operational control and evaluation functions.

F. Decision Trends in Earthquake Engineering

1. What is Earthquake Country?

Section II-C has described how society has come to expect from science and engineering technological fixes for many of its problems. However, society is beginning to demand that science and technology be conducted with concern for the possible future effects of its implementation. Sections II-D and II-E have examined the technology of earthquake prediction. The underlying assumption is that society will be able to employ earthquake prediction as it develops in the future to save lives and possibly to reduce property damage. In other words, earthquake prediction will allow society to take actions that will provide some measure of protection from this dreaded natural disaster.

To obtain a reference point in society's priorities we next want to examine what society is presently doing to protect itself from earthquakes. By doing so we can discover something about society's present assumptions concerning future earthquake occurrences--namely, the hazard that it faces.

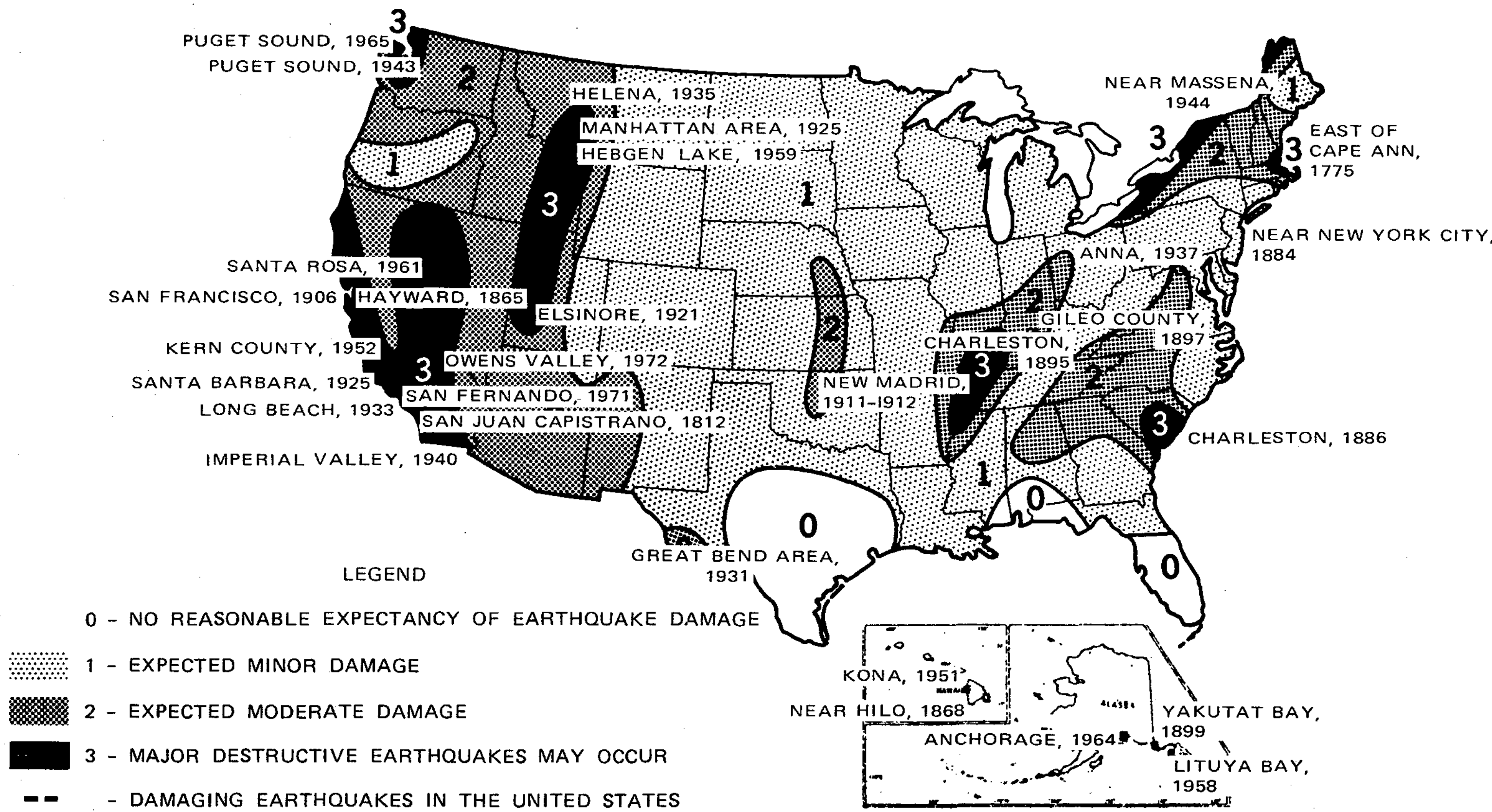
Most of the loss of life and injuries in earthquakes occur when buildings and other structures fail through partial or total collapse. Therefore society has established its primary line of defense against the effects of earthquakes in controlling the type of construction that takes place in earthquake-prone areas. Earthquake country is where earthquakes have been known to take place and their effects felt. The standards of construction are regulated by building codes.

"Seismic risk maps" as currently contained in building codes generally divide the nation into four earthquake zones. These zones are based on (1) the known distribution of damaging earthquakes, (2) the Modified Mercalli (MM) scale of intensities that were associated with these earthquakes, and (3) other strain-release and geologic evidence believed to be related to earthquake activity. The zones are generally described as follows:

Zone 0	No damage
Zone 1	Minor damage, corresponds to MM V and VI
Zone 2	Moderate damage, corresponds to MM VII
Zone 3	Major damage, corresponds to MM VIII or greater

Zone boundaries are broadly based, ranging from a relatively confined and geographically small area such as Boston (zone 3), to an area somewhat grossly defined as central/south/east Texas (zone 0), to almost an entire state such as California (zone 3), to the bulk of the Middle West (zone 1) (see Figure 5). The zone definition presumes that the maximum intensity can occur anywhere within a specified zone. The seismic-risk-mapping process is silent as to frequency of occurrence.

Can and should the seismic risk maps be updated to show more detail in the expected intensities and to consider the frequency of occurrence? We find ourselves in a situation where we have a brief



SOURCE: Maps prepared by the National Oceanic and Atmospheric Administration, Department of Commerce.

NOTE: Seismic risk zones have not been assigned to Alaska and Hawaii.

FIGURE 5 SEISMIC RISK ZONES IN THE UNITED STATES sample of seismic history (200 to 300 years), an incomplete knowledge of all the locations where earthquakes could occur, no indications that earthquakes recur with any regularity either individually or in groups, and very limited data on the earthquake parameters that are of most direct use in designing structures.

In the western United States most of the possible regions of large earthquakes can be determined by geophysical/geological techniques. However, in the eastern United States adequate techniques may or may not be available today. This uncertainty exists because we do not know the mechanisms of the widely felt eastern earthquakes. In the west an earthquake similar to the 1906 San Francisco earthquake would be accompanied by a fault rupture of several hundred kilometers, and its effects would be rapidly attenuated with distance from the fault rupture. The major earthquakes in the east had the same peak intensities as those in the west, but they were felt over much larger areas and had no detectable fault rupture. The area over which an earthquake is felt is very sensitive to the attenuation characteristics of the earth's crust, and this attenuation is much lower in the east than in the west. This leads some seismologists to conclude that the major earthquakes in California, such as San Francisco 1906, released 100 times more energy than did Charleston 1886 and New Madrid 1811/1812.

The Veterans Administration (VA) has made an attempt to put more detail within the broadly defined zone boundaries of the seismic risk map.[77] The peak acceleration to be expected was estimated for 69 VA sites in zones 2 and 3 (see Figure 6) by a number of independent geotechnical consultants. However, the general guidelines were established by the VA, and the determinations were specific to the sites of the VA facilities. Nevertheless, taken along with the factors used in their determination, they can provide additional useful information for structural design. An example of the difficulty in their application is that a structure will experience different ground shaking from a large-magnitude earthquake associated with a major distant fault than from a smaller magnitude shock centered on a closer fault. Therefore an attempt to vary the level of intensity over a particular zone is subject to serious questions about where the earthquakes might occur.

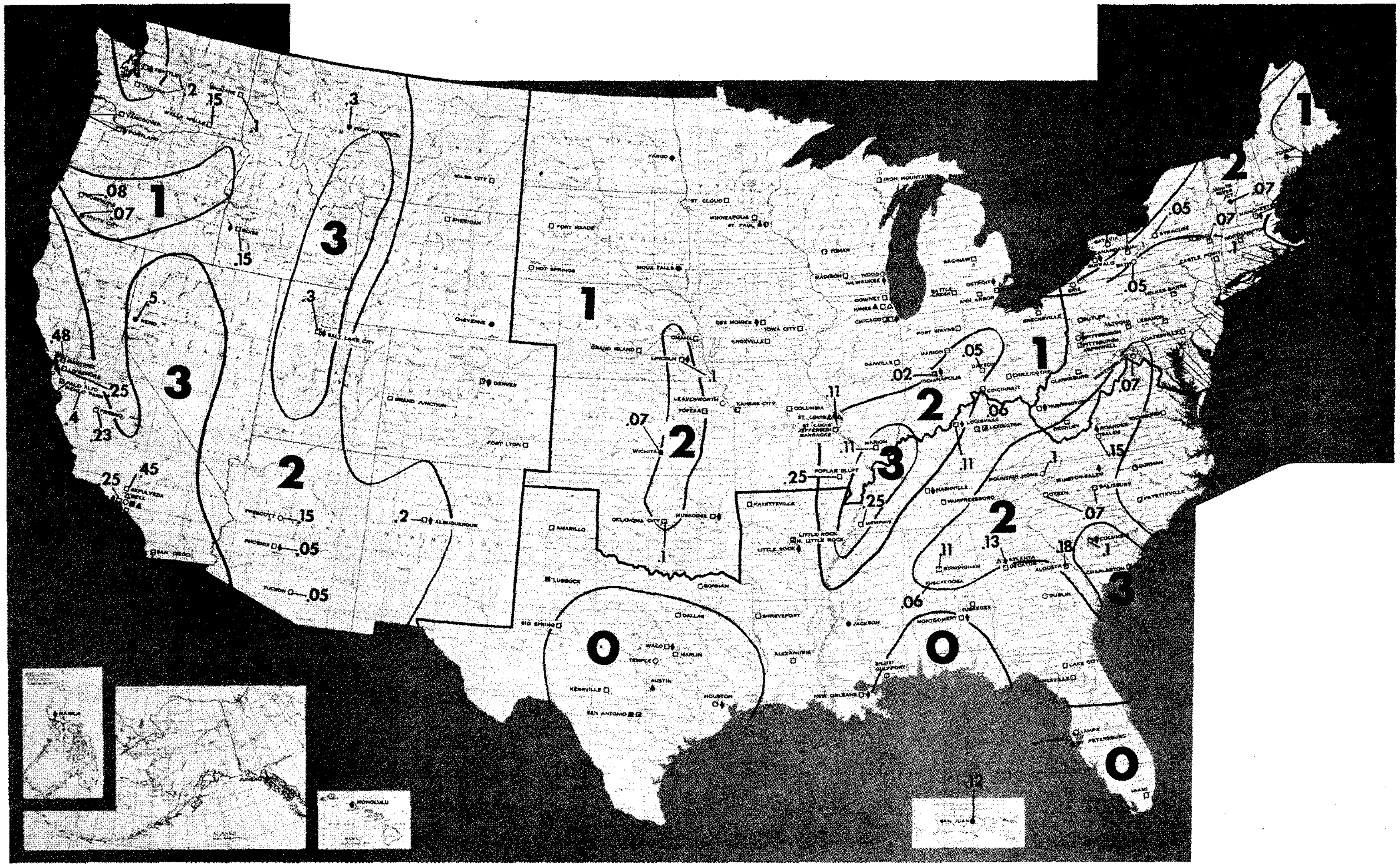


FIGURE 6 VETERANS ADMINISTRATION SEISMIC RISK MAP. CONTOURS ARE FROM THE SEISMIC RISK MAP DEVELOPED IN 1969 BY S. T. ALGERMISSEN; NUMBERS SCALE FROM 0 (NO DAMAGE) TO 3 (MAJOR DAMAGE).

In Section II-E we have seen that statistical examinations of earthquake records (which for China go back some 2,000 years) do not show any regularities in occurrence, and the risk zones in many areas are characterized by one or two isolated events. If return periods of damaging earthquakes were to be assigned to different areas, they would be assigned probabilities on the basis of scant actuarial data. The existing assumption is that the maximum event for any one zone classification can recur during the life of any structure. This is argued as being too conservative in some areas and perhaps not sufficiently conservative in others. Attempts are under way to develop seismic risk maps that incorporate a measure of the recurrence period of damaging earthquakes.

2. Building Codes, Assessment, and Issues

In designing structures for earthquake resistance, the engineer looks to, among others, the Uniform Building Code (UBC), which was first promulgated in 1927 by the International Conference of Building Officials (ICBO). Prior to the 1961 edition of the Uniform Building Code, earthquake provisions were given in an appendix and only suggested for local ordinance adoption. The Uniform Building Code has been revised approximately every 3 years. Lateral force provisions (the primary earthquake-resistance design element) were moved to the main body of the text in 1961 and thereby made mandatory (unless specifically excluded on adoption); they essentially follow the recommendations of the Structural Engineers' Association of California (SEAOC).[78]

Except for a few isolated references to earthquake design requirements in other parts, the major earthquake-related provisions of the Uniform Building Code are contained in Chapter 23, "General Design Requirements," of Part VI, "Engineering Regulations--Quality and Design of the Materials of Construction." The Code's seismic risk map, which was discussed above, enters a factored earthquake zone designation as a coefficient* in the calculation of the total lateral force. This

*Zone 3 = 1.0; zone 2 = 0.5; zone 1 = 0.25; zone 0 = 0.

is assumed to act noncurrently in the direction of each of the main axes of the structure and is distributed over the height of the building.

Although the UBC has wide usage, local code practice may dictate its use in part only or may augment it with supplementary local building ordinances. The following issues and questions relate only to the use of the UBC as written and used without modification:

- There is "an urgent need for a major revision of this document to incorporate all of the latest research findings and practical lessons learned from recent earthquakes."[79] SEAOC's 1973 edition was a partial response. An update in June 1975[80] provides further response. The 1976 Uniform Building Code will contain essentially all of the 1974/1975 SEAOC recommendations.
- It may take several years before there is universal adoption by all cognizant agencies, as well as by ICBO and other code-writing groups.*
- Assuming the new building construction rate to be 1 or even 2 percent per year, it may take decades to realize measurable reductions in potential earthquake hazard.
- Updating lateral force provisions per se is but one form of code change; other forms may be more cost effective in shorter periods of time and over a broader spectrum of occupied buildings.
- The Codes do not relate type, occupancy, and use to the importance of certain types of structures to the general welfare, examples being emergency control facilities and other critical facilities (1973 UBC).
- The Code is silent as to level-of-risk determinations associated with certain types of structures, uses, and occupancies.
- The architectural (nonstructural) and mechanical and electrical portions of a building need code amplification in the context of seismic risk.

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*For example, Building Officials' Conference of America; American Insurance Association; Southern Building Code Congress.

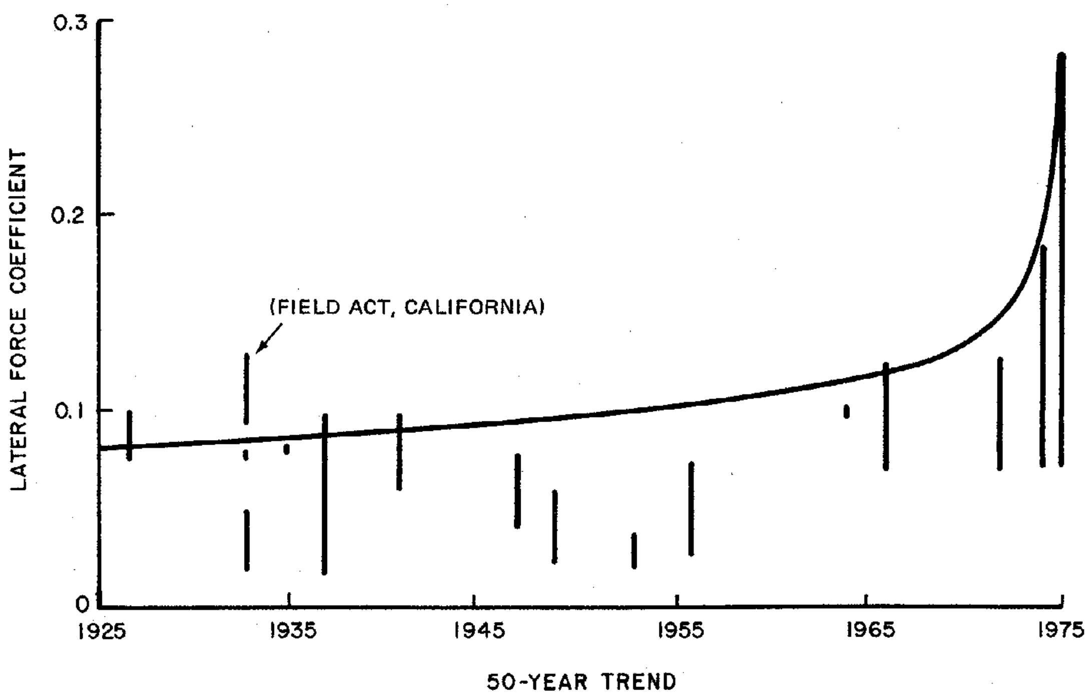
- Considering legislative constraints and the Code's necessary applicability for broad usage, it is probable that little more can be regulated by code language regarding authority, permit requirement, design checking, and construction inspection. The issue here is not one of code improvement per se but rather one of how to, in fact, effect code enforcement.
- The abatement of hazardous structures under the Unsafe Buildings provision of the Uniform Building Code potentially offers possibilities for quicker and broader effectiveness in reducing seismic risk. A systematized and prioritized program of abatement of the worst buildings in the worst locations and with the greatest occupancy is at least an early step to be considered.
- The Code is oriented toward private-sector construction. Generally, state and federal agencies have their own building design standards; for example, the VA undertook an ambitious and costly program of analysis and upgrading of their facilities after the San Fernando earthquake of 1971.[77]
- The Application for Permits provisions of the Code require submission of design data "when required by the building official." Design analysis may simply utilize minimum code requirements and formulas, or it may utilize sophisticated dynamic analysis techniques and be substantially guided by soil and geological conditions as well. The choice depends on such factors as (1) which city, (2) which building official, (3) which design engineer or architect, (4) what checking capability, (5) current feelings about seismic safety, and (6) other variables essentially external and unrelated to the design process itself.
- To date the Code (1973) does not make any direct provision for the soil effects reflected by, say, a ground coefficient similar to that provided for risk zone, type of frame, and natural period of the structure.
- The generalized nature of the seismic risk map seems to at least dilute criticality and increase design and construction costs in certain less-than-critical areas.

The 1974 revised edition of SEAOC's Recommended Lateral Force Requirements was released in June of 1975. This 1975 recommended code expansion reflects (1) the recognition that surface soil layers can significantly modify earthquake effects on structures and (2) the concern over the possibility of substantial damage--both structural and nonstructural--to buildings felt essential to the continued functioning of society after an earthquake. Specific building types are not rated as to criticality in the recommendations since this is considered to be "purely jurisdictional decisions closely related to the concept of acceptable risk and economic reality." The lateral force due to earthquake loading in zone 3 for critical buildings could be approximately twice the previous values.

The curve in Figure 7 shows the upper bound of code-required lateral force coefficients over time. The curve should be considered illustrative only because the vertical bars stem from different codes, different minima and maxima, different definitions of design weight W (to which the coefficient is applied), and the use of different design parameters at different times (e.g., soil pressure, story height, framing type). Nevertheless, the figure illustrates the generally flat trend curve of the past 50 years, with the exception of the dramatic increase in the 1974-75 period. As pointed out above, this climb is essentially the result of adding "importance" and "soil resonance" factors to the lateral force equation.

The trend curve does not of course emphasize the considerable strengthening in earthquake code provisions that has occurred or the definition and precision that have evolved in a broad area of code detail. It does suggest, however, that regardless of periodic refinements, earthquake design lateral loadings as a whole oscillated rather consistently within a fairly narrow range over the past 40 to 50 years.

This of course is not the only criterion for earthquake-resistant design. As pointed out by the SEAOC Seismology Committee, better earthquake resistance cannot simply be equated with increased design lateral force. Among other reasons, ultimate damage may depend more on the building's configuration than on the level of external applied force. Codification of such a possibility is, however, very difficult, considering the wide dissemination and use of universally applied code provisions.



Source: Stanford Research Institute.

FIGURE 7 ILLUSTRATIVE TREND CURVE:
DESIGN LATERAL FORCE REQUIREMENT

Moreover, it does not necessarily follow that increased design lateral loadings will automatically minimize nonstructural damage to, say, building elements, equipment, contents, utilities, and the like. Their seismic performance could well depend much more on careful specification, design detail, and construction inspection than on the applied lateral force.

In the broad perspective, recent history both in the United States and abroad has reflected an increase in public safety in the face of earthquake hazard resulting from building-code modernization. However, improving codes by making them more comprehensive or more stringent is but one small step toward moving technological progress into actual building practice. In this regard, let us consider the number of involvements associated with today's developmental process.

3. What and Who Really Decide a Building's Earthquake Resistance?

After the decision is made to go ahead with a building program, a vast number of public and private roleplayers become involved. Many can have a direct bearing on the building's ultimate earthquake resistance. Others may have only an indirect bearing through social or political influence, or because of a local government's awareness, acuity, or earthquake consciousness.

The following lists these players by major steps in the process:

- Location Selection and Land Use Compliance
  - Owners; developers; governmental owners of public buildings; planning commissions and other lay boards of approval; planning directors and seismic zoners.
- Finance
  - Investors; bond buyers; banking industry; government loan agencies.
- Design Regulation (concurrent continuing activity)
  - Seismologists, geologists, seismic engineer, academicians, code writers, code adopters (governmental officials).

- Design, Specification, and Professional Liability
  - Professional design firms of engineers and architects; public agency designers; soils and other specialized experts; errors and omission insurance companies; bonding companies, legal experts.
- Compliance and Approval
  - Building officials; design checkers
- Build/Install/Erect
  - Contractors, installers, materials suppliers, skilled tradesmen.
- Quality Control and Acceptance
  - Supervisors; inspectors; plant quality controllers; building officials.
- Users and Others
  - Buyers, renters, and third-party public users; neighbors; local government (viz., receivers of tax revenues); fire, accident, and acts-of-God insurers.
- Hazard Assessment and Abatement
  - Hazard assessors: building officials, inspectors, seismic and other experts; attorneys; courts.
- Rebuild/Rehabilitation/Repair or Removal
  - (Can involve many of the above for a second time).

What does this really suggest? Simply, that to ensure earthquake resistance requires the prudent, diligent, and informed response by a multitude of people--by those with special expertise; by business interests; by local, state, and federal government; and by the lay public. Earthquake resistance surely can be affected if unqualified structures are somehow allowed in restricted seismic zones; if legislative requirement is weakened by economic pressure; if earthquake engineering knowledge is not heeded by designers; if good design is vitiated by poor construction supervision and inspection, allowing, say, poor welding, reinforcement-bar placement, or concrete mixing; if the most advanced building codes are not policed or if the public is not willing to pay the small commensurate additional costs; if hazard abatement programs are assessing the wrong or only marginally hazardous buildings; and so on.

4. Need for Broadened Code Provisions

The inclusion of all types of construction, either not presently or only minimally covered to date, is needed to effectively broaden code earthquake-resistance provisions. Codes should be broadened to include the following:

- Architectural and other nonstructural elements.
- Mechanical and electrical components.
- Manufactured buildings.
- Essential-utility structures (transportation, utility, and communications).
- Structural repair or rehabilitation (for hazardous buildings before the event and damaged structures after the event).

Code-recommended criteria, standards, or requirements should provide, among other things, for

- Design lateral loading of structures or portions thereof.
- Load-resistance criteria (e.g., structural, fittings, and connections).
- Design methodology (e.g., where and when dynamic analysis is required).
- Plan approval or certification (should always be required).
- Construction inspection, supervision, and quality control levels.
- Hazard assessment methodology.

Ideally these criteria, standards, or requirements should be consistent with the following:

- Seismicity of region (viz., selected design earthquake; horizontal and vertical acceleration; probability of design earthquake occurring or occurrence frequency).
- Geology of area.
- Soils condition of site (e.g., deep-soil-layer response).
- Soil/structure interaction.
- Type of structure (or lifeline).
- Importance of occupancy (or service).

- Structural system characteristics (i.e., damping, ductility, stability).
- Height; fundamental period.
- Architectural shape.
- Materials or construction (e.g., stress, load, resistance factors).
- Methods of construction.
- Methods of quality control.
- Recognition of acceptable risk levels.

It is in attempting to meet this consistency requirement, though, that the real problem is highlighted--codification in terms of a universally used, nationwide building code. It is one thing to design and construct a specific building for a given time, place, and configuration and another thing to hypothesize wide variances in time, place, and configuration into a coherent set of design prerequisites.

G. Probabilities: A New Decision Basis

In view of the wide historical variation in the frequency of the maximum earthquakes that have occurred in different regions of the country; the wide variations in building use in terms of occupancy, duration of occupancy, and importance to vital social functions; and the impreciseness in the application of existing earthquake-resistance provisions in building codes, concepts for basing seismic design standards on risk have been developed and proposed.[81,82] This section explores the implications of the "risk design concept" in terms of its underlying assumptions, the nature of public decisionmaking, and the relationship to earthquake prediction.

Earthquake prediction provides a new perspective from which to examine the assumptions that society has been using to make decisions about earthquake protection. Because of the potential for earthquake prediction, these assumptions now become express policy issues. The preceding section and this section discuss these emerging policy issues.

1. Seismic Design Decision Analysis

a. The Balanced Risk Concept

The Department of Civil Engineering of the Massachusetts Institute of Technology (MIT) has recently proposed methodology to be used in applying the concept of "balancing of risk"--future loss against initial cost. Although MIT has been working in this area for several years, Report No. 10, Methodology and Pilot Application,[82] summarizes their previous studies and provides an overall explanation of the concept being advanced.

In essence the aim is to achieve "a rational choice of required earthquake design requirements in building codes" by quantifying

(1) The risk of earthquake shaking.
(2) The likelihood of building damage.
(3) The cost of increasing the earthquake resistance of buildings that is required.

The methodology is illustrated with the case of multistory apartment buildings located in the city of Boston.

The authors acknowledge at the outset the general code principles that a building should not collapse during "the largest earthquake that is realistically imaginable" and that other earthquakes which can be expected during the building's life "should not cause economically unacceptable damage to the owner or be socially unacceptable to the community." The authors also point out the difficulty apparent in the uncertainty as to how to actually implement these principles, implicit in which is the "balancing of risk of future loss against the initial cost of providing a stronger building." An explicit statement of this balance is the ultimate goal of this concept.

With a somewhat different view, Muto[83] has summarized the design principles as follows:

> It is a well-recognized fact that to give complete protection against the maximum possible earthquake is not feasible. It is generally accepted that earthquake design force levels should be set large enough

> (1) to prevent structural damage and minimize other damage in moderate earthquakes which occasionally occur, and (2) to avoid collapse or serious damage in severe earthquakes which very seldom occur.

Others will state the principles in still another, yet basically similar, way. Accepting the minor differences in exposition, MIT's point about the imprecision of definition clearly appears to be valid, and the quantification of a risk-balance equation would obviously be ideal--if attainable in a practical, real-world sense.

Fundamentally, the thrust of this risk-balance concept is not to replace static force equivalents or dynamic analysis used in the determination of seismic resistance but rather to provide, through the use of probabilistic models, the means for assessing the costs and benefits of designing for increased seismic resistance. Because of the wide differences of opinion as to seismic design requirements (e.g., varying from: "codes should require greater lateral resistance" to "codes are already too conservative"), the concept attempts to augment the traditionally large role that professional judgment and experience play in the choice of seismic resistance levels by a probabilistic, methodology. The method correctly introduces parameter variations in intensity of shaking, degree of damage, initial and repair costs, and incidental losses, among others. However, a question might be raised as to whether judgment and experience are aided or in fact impeded, especially as to the assignment of probabilities to the various functions of the risk equation. On the other hand, the concept certainly can be credited for its systematic approach in applying these judgments to ultimate decisionmaking.

There are many obstacles to a rational approach to such decisions, including the following:

- The probabilistic nature of the earthquake threat
  - Magnitude of shaking (not of the earthquake itself).
  - Frequency of occurrence.
  - Locational variation (i.e., high- versus low-seismicity areas).

- The uncertainty, if not reluctance, in using "probable threat" parameters.
  - By engineers
  - By building officials
  - By other decisionmakers.
- The almost complete lack of data on tangible costs and benefits.
  - Marginal cost increases of buildings
  - Marginal cost increases of other structures
  - Savings in repair or replacement costs.
- The considerable, if not impossible, task of assigning values to human and social costs and benefits.
  - Death
  - Injury
  - Loss of function or mobility.
- The skepticism as to society's desire for rational decisions regarding risk.
- The effect on the value of even the most rational of balanced-risk determinations by certain external factors.
  - Land-use planning
  - Insurance
  - Disaster relief plans (and funding)
  - More cost-effective uses of capital (i.e., the marginal portion required for the increased resistance).

In the face of such obstacles, concept formulation and validation appear to be a formidable effort. The work is stated to be only the "first step." The pilot test was limited to 5- to 20-story, multifamily type buildings founded on firm ground in Boston. Although the methodology itself may in time prove to be applicable to a broader range of conditions, the pilot testing clearly should be considered as very limited in scope--as MIT states, a first step only. The numerous details that support the seismic, damage, cost, and loss functions should be based on specificity of building (and other structure) types and locations, without undue generalization. Although sensitivity analysis of condition differences may ultimately prove the contrary, detail as to, say, building height, shape, ductility, and construction material; and soil condition would be examples of this specificity.

The suggested evaluative methodology is an iterative one. Damage from a particular earthquake of a particular building system built according to a particular design strategy is weighed against different levels of earthquakes, different building systems, and different design strategies, each set of conditions yielding a different cost base.

b. Factors Considered

1) Seismic Risk

Seismic risk is the probability of ground motion equaling or exceeding a specified intensity. From geologic and geophysical information and the historical record are obtained the recurrence rate and the attenuation of ground movement. As much as it may be desirable to use an objective measure of intensity, such as peak acceleration, the historical data are simply not available. Because of the scarcity of strong-motion records and the fact that the hundred years or more of damage experience that is available has been expressed in terms of Modified Mercalli intensity, the use of the MM measure seems inevitable in spite of its being in subjective measure and a function of the condition of the buildings.

2) Damage Versus Intensity

The concept's damage probability matrix (DPM) aptly aligns various degrees of damage to varying MM intensities. However, the authors point out that

- Even buildings designed to meet the same requirements will have differing resistances, and therefore differing degrees of damage, depending on "the skill and inclination of the individual designer and contractor."
- The dynamic response of identical structures at different locations will differ even though

the intensity of ground motion is generally the same.

- There is little or no data available on buildings that did not exhibit damage; that is, what is the fraction of damaged buildings, by degree of damage, as actually evidenced from real-world earthquakes?

Even if damage could be expressed in probabilistic terms, the above three obstacles seem to raise the question of whether the assignment of values is not somewhat academic.

3) Evaluation

Combining seismic risk with the damage probability matrix yields various levels of damage probability. Future costs and losses are then introduced. Whereas future repair and replacement costs might be rationally determinable, the authors again point out the obstacle of realistically computing the costs of loss of function, service, and life as well as the costs of injury and community impacts.

Again, the relevance of parameter input is clear, but the reliability of evaluation output needs much further testing.

The MIT work has opened the door on balancing the costs and losses associated with earthquake design resistance (possibly for the first time in such depth), but it is only a beginnning. The assignment of probabilities, measurement of socioeconomic consequences, the concept's complexity, codification problems, and real-world use in the political arena are major constraints.

2. Balanced Risk* Design[81]

The City of Long Beach was interested in earthquake-hazard evaluation that included finding "an equitable solution for dealing with old buildings which could be hazardous to the community in the event of a strong earthquake--but at the same time, a solution which would not cause the wholesale demolition of said buildings."

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*Balanced Risk is a registered trademark of J. H. Wiggins, Jr.

Though the study considered the earthquake hazard in a broad framework (earthquake phenomenon, structural performance, code criteria, inspection, standards for repair, post-earthquake operations, and legal ramifications), the following relates essentially to the study's "key" effort--introduction of the concept of Balanced Risk design. The concept stemmed from the development of new code criteria based on equating involuntary (earthquake) risk with voluntary risk situations.

In essence, the concept attempts to establish a basis for legislators to select a "death risk" associated with structural life and importance (use and occupancy); this in turn establishes a basis for (1) the design of new structures and (2) the strengthening of existing ones. The work is based on earthquake conditions in the Long Beach vicinity.

The authors point out at the outset two key constraints:

- Quantifiying "risk" factors are, at best, subject to judgment and compromise (i.e., so many factors are simply unquantifiable).
- The questionable consequences of not considering all social and economic effects beyond just death risk.

In assessing code differences in lateral force provisions, the considerations cited are (1) the difficulty in assessing the seismicity of a region, (2) the heterogeneity of rock formations and soils, (3) the heterogeneity of structural systems, and (4) the lack of a suitable rationale for defining tolerable risks. The first three difficulties are often cited in the literature; the fourth much less so.

The tolerable-risk question is addressed through the concept of Balanced Risk, giving recognition to the life of the structure and its importance. These two factors are equated to a "death risk rate" (e.g., deaths per exposed population per year). The authors indicated a tolerable "death risk" in the report but suggested that ultimate selection is a community decision, pointing out that "selection of a tolerable death risk is totally arbitrary and does not depend on a specific technical expertise." Rates are related, through comparisons, to deaths experienced in past earthquakes and to risks involving motor vehicles, work, the home, and public places.

a. Age Factor

There would be little argument that since buildings last for longer periods of time, the probability of a major damaging earthquake occurring during their life increases with age. The real question, however, seems to be in the realistic setting of a structure's life. There are many buildings, still in use and occupied daily, that have far exceeded their expected design life--whether physical, economic, or operational. In fact, very few buildings are constructed to be "temporary" or to have a short life. The distinction in the Balanced Risk approach between 2, 5, 10, 20, 40, 60, and 80 years appears to be too refined, if not unrealistic in the real world, even though it may be conceptually valid in principle.

b. Importance Factor

As to the "importance" factor, the Balanced Risk concept suggests a possible procedure. Being interwoven with acceleration, probability of occurrence, and death-risk rate, importance-factor determination clearly appears to be a more sophisticated attempt than, say, the 1975 SEAOC introduction of this factor. The need for such a factor in design for earthquake resistance is generally accepted; the degree of complexity in arriving at its value will require testing and validation that this greater complexity is in fact worthwhile.

c. Death Risk

Of the three key factors (importance, design life, and death risk), "implicit to the theory is that the 'death risk' factor is proportioned in some manner to the overall strength of the building." Again, this is sound in principle, but what about the wide variations in the determinants of "strength"? Not only are the theoretical or computational factors that influence strength subject to opinion differences as to, say, ductility, damping, or soil conditions but possibly a more important (death-risk selection) problem relates to the effects on the "strength" resulting from acts of the architect, the engineer, the owner, the contractor, the supplier, the inspector, the building official, or the approving agency during construction. Differences in the structure due to any of these computational or executional variants (or combinations thereof) may affect its ultimate strength to such an extent that it could be irrelevant to say for a given situation which is better--a design death risk of 10^{-5} (one in 100,000 people exposed per year) or of 10^{-6} (one in 1 million). That is to say the uncertainty may be greater than a factor of 10.

There is the question of whether death should be the sole criterion of risk. The authors rightly point out the need for social and economic factors (presumably including injury) in code development but note the difficulty in quantifying these with death risk. Thus death risk alone was used in formulating the recommended code for Long Beach.

Whether the concept's complexity, especially for universally adopted code usage, is warranted may have to await the results of Long Beach's experience in its use (or portions thereof).

3. Problems for the Decisionmaker

The risk design concept raises two problems for the decisionmaker. First, present protection policies are based on the assumption that the maximum historical earthquake can recur at any time and can occur during the lifetime of any structure. An assigned probability based on the calculated rate of historical recurrence begins to say that some buildings will escape the maximum earthquake over their lifetime because the return period of the maximum earthquake in any location is generally greater than the useful life of structures. This places the decisionmaker in the impossible situation of selecting which ones. Second, at present decisionmakers will not deal with explicit levels of risk. Explicit levels of risk as a policy basis raise serious equity questions, real and perceived. These cannot be addressed as a matter of public policy because we cannot compensate, before the fact, for human life.

As an example, take two locations that have historically experienced similar maximum levels of shaking but with different recurrence periods. Ideally, public policy would attempt to balance the risk in these two locations. The decisionmaker in the location with the longer return period has two options to balance the risk with the location with the shorter return period. He can weaken all the buildings a little so that he has larger but not more disasters than before, or he can weaken some of the buildings selectively to have more but less serious disasters than before. Either way he is selecting those on whom the disaster will fall. In addition, he runs the chance that things will not turn out the way they did in the past historical sample. The recurrence period may increase dramatically.

There is another related decisionmaking problem. The use of probabilities in disaster-type situations may distribute the risk mathematically, but not in reality. Those who live near nuclear reactors face higher risks from reactor accidents than those who do not. Those who live in earthquake country face higher risks from earthquakes than those who do not. Those who live in substandard structures in earthquake country face higher risks than those who live in seismically resistant buildings. The public has different views of disaster risks and widely distributed risks. To repeat an example used before, the death of 50,000 persons a year on highways has much less of an impact nationally than would some disaster that killed 50,000 persons in a specific locale.

In view of these decision problems, it seems to be both prudent and necessary that society find and develop the institutional means to deal with probabilistic decisionmaking with as much diligence as appears to be expended on the technical procedures of risk analysis.

4. Interaction with Earthquake Prediction

Earthquake prediction deals with individual earthquakes. The recurrence theory of earthquakes deals with the average period between earthquakes in a region over a long period of time. However, most of society's concerns about earthquakes arise from individual events, and not the long-term average. Therefore earthquake prediction provides a potential new basis for structuring society's basic earthquake-protection posture. Nevertheless, until experience with the emerging technology of earthquake prediction demonstrates the characteristics of individual earthquake predictions, society will have to decide whether the uncertainties of earthquake prediction warrant any modification of the present posture of structural engineering--whether based on a recurrence probability or on the assumption that the maximum historical earthquake can recur at any time. Where it can afford to, society will be forced to maintain its present protection posture with all of its uncertainties but with the opportunity to augment this with other measures as new information is available on individual earthquake events.

An earthquake prediction, therefore, adds a new decision environment that overlays the existing decision environment. At present, society has the preearthquake environment, in which the best information is based on the historical experience with earthquakes in a region, and the postearthquake environment, based on the occurrence of a specific event. An earthquake prediction adds a new decision environment, the period after prediction but before an earthquake--not necessarily the predicted event--within which to act.

III EARTHQUAKE PREDICTION IN SOCIETY

Section II explored the technology of earthquake prediction as it is currently being developed and as it might evolve as a mature science and implemented technology. This section assumes that the scientific inquiry into earthquake prediction will go forward. It then explores how the products of this scientific inquiry would interact with society.

The means for making this exploration emerge out of the science and technology described in Section II. Four sets of earthquake-prediction case "facts" are presented. In the absence of considerable planning and preparation on the part of all elements of society, most public officials and other decisionmakers will have little more to go on than the kind of "facts" presented in these four hypothetical cases.

There is little basis in society's past or present experience for assessing earthquake prediction as a socially useful technology. Society's assumptions concerning earthquakes are based on the fact that they occur, without specific indications that the event is impending. Society accepts inequitable consequences of earthquakes as "the luck of the draw." Earthquake prediction would result in a redistribution of some consequences through acts of human agents. On careful thought, there appears to be considerable wisdom in the observation that through earthquake prediction society would be converting a natural disaster into an act of man. Since we have no guide to the impacts on society of an earthquake-prediction technology, we are forced to create such future conditions without thereby venturing into the irresponsible (from a public policymaking point of view) realm of science and social fiction.

A. Four Cases of Earthquake Prediction

Prediction facts are a translation of scientific information into terms that are intelligible to the public. We are concerned here with the impact of these facts on and within society. In this light a warning to take action is an impact, as is the necessity to translate prediction facts into a warning. The prospective impacts of earthquake prediction are inherently confused and ill-defined. They involve multiple, uncertain, and interlocking actions and reactions, and include differing time horizons for different groups, institutions, organizations, and governments.

The reader is forewarned to take the four earthquake-prediction cases in this chapter seriously. The science and technology were carefully assessed to determine the likely nature of future earthquake predictions. Therefore, the earthquake prediction facts in the cases that follow are entirely possible statements of future events. Although all four cases are possible, only one of them can be true as an initial prediction. An assessment of the impacts on society of the prediction facts in the four cases is the central subject of the subsections that follow, as are the development and assessment of alternative courses of action for addressing them.

All four cases are developed for the San Francisco Bay region in California. Each region of the country has unique seismological features that would control the expected range of prediction facts. Though the impacts of these prediction facts would differ in degree, extent, and distribution for different parts of the country, the range of alternative courses of action for addressing them would be very similar.

All four of the cases depend on a demonstration of the fact that the prediction of earthquakes in northern California is technically feasible. Therefore this provides justification (in a time of general governmental budgetary constraint) to proceed with the installation of a prediction network in the San Francisco Bay Area. Accordingly we have postulated the retrospective prediction of a damaging earthquake in the instrumented region of the San Andreas Fault near Parkfield in central California. This is described in the first case and assumed in the other cases. From this preliminary retrospective "prediction" the four cases develop different but plausible sequences of prediction facts in the San Francisco Bay Area.

Case 1: Long-Term Prediction

The basic prediction facts for this case are as follows:

Date	Event
June 4, 1978	An earthquake of magnitude 7.0 occurs at 5:18 am PDT, with its epicenter on the San Andreas Fault at Parkfield, southeast of King City, in central California.
June 6, 1978	Retrospective 1-day prediction of June 4, 1978, earthquake would be made if the data were being recorded and processed in real time.
June 30, 1979	The northern California earthquake-prediction data network is completed by USGS.
July 1, 1980	A prediction is made that a "great" earthquake affecting the San Francisco Bay Area will occur along the San Andreas Fault within the next 10 years with a probability greater than 50 percent.
January 14, 1982	A prediction is made that there is a 70 percent probability of an earthquake occurring within the next 2 years; the earthquake is predicted to be of magnitude 7.5 to 8.3 and to have its epicenter between Portola Valley and Bodega Bay on the San Andreas Fault.
August 28, 1982	The probability of earthquake occurring is increased to 85 percent.
November 29, 1982	Earthquakes of magnitude 4.0 and 4.5 occur, with their epicenters on the San Andreas Fault near Pacifica.
December 3, 1982	A warning is issued that a "large" earthquake will occur "near San Francisco" within the next several days.
July 8, 1983	Earthquake of magnitude 8.3 occurs at 4:30 pm PDT, with its epicenter just off the Farallon Islands.

A PREDICTION BASIS

There is little seismic activity in the United States to arouse a popular interest in earthquake-protection measures. National economic difficulties continue, with an inflation rate approaching 10 percent per year. The political climate is generally one of belt-tightening at both the federal and state levels. The budget of the USGS for earthquake prediction remains at a fairly constant level, but with inflation, the program is being slowly squeezed. The USGS confines its earthquake-prediction experiments principally to central and southern California. Because there are no large populations at risk in the central California region of the San Andreas Fault and because the region has been seismically active--indicating to some relief of stresses along the fault and to others an imminent large earthquake--it is considered adequate in the interest of economy to analyze the data after the fact. It is also believed, in spite of apparent success in China, that it would be difficult to make a credible prediction of a large earthquake and so after-the-fact empirical correlations of premonitory indicators would be adequate for scientific investigations. The earthquake-hazard-mapping program of the USGS has been cut to the lowest level consistent with a viable program in order to provide some extra support for the lagging predictions program. At the national level, earthquake-engineering research, which is funded primarily by the National Science Foundation, continues to expand, but with inflation, the program remains at an approximately constant level. At the local level in San Francisco, the program of removing parapets and dangerous overhanging objects began quietly in late 1975 and is continuing at a low level; there is little emphasis on increasing the capabilities of the Building Officials' Office, but there are some nominal advances toward certifying more building inspectors. Los Angeles, on the other hand, has been effectively enforcing its parapet-removal ordinance for years, and this hazard has been effectively abolished.

On June 4, 1978, an earthquake of magnitude 7.0 occurs at 5:18 am PDT, with its epicenter on the San Andreas Fault at the town of Parkfield, southeast of King City, in central California. Within one day all of the relevant field data are collected and rushed to NCER at Menlo Park. The data are reduced and compared with the premonitory evidence previously collected. There are fairly complete records of resistivity, crustal tilt, and the velocity of the seismic P- and S-waves that are regularly generated by microquakes in the area. There are also some scattered data from radon measurements in well water in the area, radon emission from the soil, and some nearby measurements of atmospheric electricity.

The program manager, its top geophysicist, an eminent visiting seismologist, and the young investigator responsible for the field program meet to examine the data records.

The young investigator describes the field-measurement and data-acquisition system, primarily for the benefit of the visiting seismologist. He describes quite calmly and in great detail that the operation is experimental, that there are many improvisations and field modifications, that it is run on a very tight budget, and that it is often unreliable. In addition, data are lost because some of the recorders do not recalibrate when driven offscale. Nevertheless, he feels confident that he knows his systems and can generally distinguish good data from poor.

In the long discussion that ensues the program director questions each data point, observation, hypothesis, and conclusion, assuming, much to the dismay of the visiting seismologist, the role of the devil's advocate. Although the system shows more weaknesses than he can explain, the field investigator remains relaxed and develops growing confidence in much of the data. The staff geophysicist takes an almost purely empirical viewpoint and is not too concerned about finding an explanation if he can only show statistically valid correlations or logically consistent measurements. The visiting seismologist continually searches for a unifying theory to explain all observations.

At the end of a hard day, they reach a tentative conclusion that they could have predicted the Parkfield earthquake within one day if they had been making observations and reducing data in real time. However, they would have predicted a magnitude of only 5.2 on the Richter scale. The resistivity and tilt measurements gave good indications, the radon measurements showed an anomaly in the right direction but were not taken frequently enough to pinpoint the time of occurrence, the velocity-ratio anomaly was barely significant by statistical tests. The atmospheric electricity measurements showed peaks just before and during the earthquake. The group decides to write up its findings and send them along with the data to headquarters in Washington for release to the public through normal USGS public information channels. The visiting seismologist feels that they should put in plenty of caveats since their conclusions are based on circumstantial evidence, and the public will tend to run with the conclusions and forget the assumptions and limitations.

A nationally known freelance science writer with excellent credentials and many good connections in the scientific community has been following the development of earthquake prediction for many years. As a writer he is fascinated with the growing interaction of the scientific process with society and the risks that may be unknowingly borne by society. The Parkfield earthquake had been reported shortly after it occurred, and he knew that it was in a region where the USGS had earthquake-prediction instrumentation. When no report had been issued by the Survey in two days, he started investigating and contacted friends and acquaintances within the Survey and outside it. He made a quick trip to the Parkfield site and talked with the local inhabitants and the field technicians. In a couple of days he pieced elements of the story together and learned about some animal responses just before the earthquake that the USGS had not yet tracked down. The story was accepted by the Associated Press and went out to their wire-service subscribers. In essence the story describes enough of the facts of the retrospective prediction to lead the author to conclude that the capability to predict large earthquakes is real. The story is widely used by both the radio-television and print media. In areas subject to earthquakes and especially in California the story is given prominent placement. The USGS headquarters in Reston issues a press release stating that the conclusions reached in the story are premature and that the data and facts quoted were clearly not reviewed by the Survey before publication. The data that they do have are being given close scrutiny by eminent scientists both within the Survey and from leading academic institutions. In addition, they are looking for verifiable instances of animal behavior that might correlate with some limited measurements of atmospheric electricity that were obtained. Finally, they would issue at the earliest possible moment a full technical report for assessment and verification by the scientific community in the usual proved traditions of scientific inquiry. However, because of the unusual public interest in the subject, they would issue interim official press announcements as warranted.

EXPANDING THE NETWORK

The earthquake-prediction story is passed on to the Governor of California as soon as it comes over the wire. The Governor sends a trusted political aide to NCER in Menlo Park to be discreetly briefed on the subject of the retrospective Parkfield earthquake prediction. A hastily assembled group of USGS scientists begins the briefing with a detailed exposition of global tectonics, rock mechanics, earthquake mechanisms, and premonitors and then moves into the existing hypotheses relating to earthquake prediction and how these subjects relate to the Parkfield experience. The Governor's aide politely hears them out and then states that they can qualify, hypothesize, and weasel-word forever, but the AP story has made earthquake prediction a political reality and that is the premise from which the Governor has to operate. What options does he have, what are the opportunities, what are the liabilities? If there is to be public responsibility in the matter, the Governor must initiate it. The aide then asks a series of questions about instrumental coverage, budgets, applicability of the technology to other parts of the state and the nation, uncertainty of prediction as a function of coverage and type of instrument, what could be accomplished with more money, and so on. The Governor's aide also talks to the people in the California Division of Mines and Geology who have been following the development of earthquake predictions to corroborate some aspects of the USGS story. The Earthquake Prediction Council is asked to evaluate, judge, and assess the retrospective Parkfield prediction.

The aide reports back to the Governor that although earthquake prediction is not new, the USGS is onto something real that could be political dynamite for a couple of reasons. First, the AP story has advanced people's expectations beyond what the USGS can now deliver; they may be there in 2 years, and it may take 10 years or longer to resolve the uncertainties in earthquake prediction. They may never know whether an earthquake indicated by a set of premonitors as having magnitude of 6.5 may develop through some triggering mechanism into a greater earthquake. Second, southern California is being covered with an instrumentation network, but the San Francisco Bay Area is not. The issue that the Governor must face is whether to push for expansion of the earthquake-prediction network into the Bay Area or not. His aide advises that if he does so, he should have the blessing of the Seismic Safety Commission. He feels that the Commission will approve but only if the Governor at the same time calls for an active program in earthquake hazard abatement and stronger building codes in some critical areas. The issue cannot be ignored because, with the upcoming local elections in the Bay Area, someone is bound to press the issue. The Governor raises the issue at a special session of the Seismic Safety Commission and with their approval makes an announcement that he is going to push to have the Bay Area instrumented for earthquake prediction. At the first opportunity he and his aide raise the issue with the two California Senators and a representative delegation of California congressmen.

The Mayor of San Francisco responds to the Governor's announcement that on behalf of the City and County of San Francisco he would welcome reliable accurate earthquake predictions, but he wonders if at the present state of the art the Governor might be somewhat irresponsible. He understands that there is a great deal of uncertainty in earthquake prediction and should the city be needlessly and irreparably damaged by false predictions, he would look to the state and federal governments for aid and assistance.

The Mayor of Oakland responds to the Governor's announcement to the effect that he assumed that the Governor intended to push for the entire Bay Area and that it was just as important to install earthquake-prediction instrumentation along the Hayward Fault, not only for Oakland's benefit but also that of San Francisco, as it was to install instrumentation on the San Andreas Fault for the two cities' and indeed the entire area's benefit.

The issue of extending the USGS earthquake prediction instrument network into the San Francisco Bay Area is taken up in an executive session of the House Appropriations Committee. The members agree that if this is done, it should be accomplished by an internal reallocation of funds within the USGS. Because of the relatively large size of the energy-related budget at USGS, it is decided that the reallocation should be from that budget. The discussion centers about the impact on the energy program and the preferential treatment this seems to give a particular geographic location of the country when earthquake hazard is widespread. However, one of the California members from the Bay Area threatens to take the issue to the floor of the House and make a speech precisely addressing the issue of earthquake prediction in places like New Madrid, Missouri, and Charleston, South Carolina. With this there is quickly general agreement by the members not to debate the issues openly because this would raise fears about other parts of the country for which little can be done at present. Accordingly, the Committee agrees to the reallocation of funds within the existing USGS budget. This allows the Senate Appropriations Committee to pressure the USGS to reallocate funds. During the committee meetings there is never any break in the unity of the two California senators on the issue.

The USGS accedes to the Congressional pressure and makes plans to expand its earthquake-prediction instrumentation network to the San Francisco Bay Area on a minimal basis by July 30, 1979. Some groups threaten to challenge this on the basis that the USGS has not filed an environmental impact statement as required by the National Environmental Policy Act, but they back down when they learn that if necessary Congress will exempt the action from NEPA and thereby weaken the NEPA legislation.

The issue now emerges in the local elections in the San Francisco Bay Area. With the exception of one or two candidates who have developed no political record, the candidates initially tend to ignore the issue. However, because there is sufficient concern among the electorate, the candidates one by one come to a realization that they must address the problem of earthquakes in the Bay Area and the moves of the USGS to expand the prediction network into the area. As the campaign progresses and the candidates become aware of the issues, their opinions become sharply divided. Some accuse the USGS of irresponsible speculation and experimentation on the people of the Bay Area, and they accuse the federal government generally of irresponsible meddling in local affairs. They suggest that the Bay Area economy will be permanently ruined and massive unemployment will result because unemployed scientists from the

Vela program want to continue living off the taxpayer. On the basis of articles that have appeared in scientific journals and been reported in the media, they accuse the federal government of adopting Communist Chinese ways of experimenting on the people, asking whether they are expected to sleep in the fields for several months every time some scientist sees his instruments tilt.

Other candidates express deep concern as to whether or not the governments and existing officeholders in the Bay Area are responding to the well-known fact that the Bay Area is long overdue for a major earthquake of the 1906 type. They point to the fact that the building officials of San Francisco have identified, abandoned, demolished, or renovated all unsafe schools and have put pressure on some owners of private buildings to reinforce or in some cases demolish unsafe buildings, but they accuse the existing governments of failure to expressly adopt and enforce safe building codes. These candidates claim that as many as 100,000 lives will be lost because of irresponsible public officials who bend to the will of selfish interests. They point out the need for massive federal and state aid in upgrading existing structures to withstand the earthquake that everyone knows is coming.

THE BEGINNING OF PREDICTION

By the end of 1979 it is apparent that the premonitors are changing in the San Francisco Bay Area. However, the meaning is not clear. The USGS is still under attack for what some consider rash action in reallocating funds from energy research to expand its data network to northern California in 1978-79.

By the end of the 1979 Session, the California legislature amends state law to:

- Make mandatory certain land-use standards based on the seismic safety element of the city general plan, with the threat of the loss of revenue-sharing funds.
- Require cities and counties to survey and condemn unsafe buildings.

- Specify standards for the condemnation of buildings and specify that condemnation examination must be conducted by a qualified engineer.
- Enable and require the State Geologist to determine that a particular geographic region is subject to a specified increased risk from earthquake hazard resulting from geologic factors and/or certainty of event and establishes zone designations to reflect that risk.
- Make mandatory certain training courses and periodic seminars for all building inspectors certified by the State Office of Architecture and Construction.
- Require additional types of buildings and structures (beyond public schools, hospitals, and dams), deemed to be critical because of their permanent or occasional high occupancy or use, to have continuous inspection.
- Provide funds to match federal grant funds in accordance with the above and any applicable federal law.

During the debate on the legislation several issues and questions are discussed:

- Will there be federal enabling legislation to provide financial assistance?
- Will state backing as a practical matter force effective local action in hazard abatement? Local action has been very mixed in this area.
- Should buildings be examined for condemnation by professional engineers or municipal building inspectors?
- Will enough qualified engineers be available to survey all the buildings, even considering only those that exist in the critical zones as revealed by damage assessment mapping?
- Can the engineering community agree on which buildings or parts of buildings are in fact hazardous, and if so, can they be strengthened adequately or should they be torn down?
- Can the state give building inspectors and hired professionals freedom from personal liability in making these decisions, and can the state confirm local agency immunity in implementing these decisions that will not be overturned in the event of litigation?

As a result of the legislation, programs of education are set up by the State, the International Conference of Building Officials, and the state colleges and universities. These courses are well attended by existing and candidate inspectors from the "big" cities, but many smaller cities, even though they are located in known seismically active areas, either cannot afford to send staff or lack sophistication to fully appreciate the need. With this new emphasis on the quality and quantity of building inspectors, local union efforts emerge to "organize" this segment of labor. However, the professional engineering associations become concerned about the potential further inroads of unionism into the province of the protection of public health, safety, and welfare. The professional societies of civil, mechanical, and electrical engineers and architects form joint committees to study the matter. Engineering geologists and seismologists are invited to serve on these committees.

The new mandatory requirements for geologic reports and soils surveys covering a broader spectrum of building types usurp the present "building official option" provisions of the Uniform Building Code and more specifically define the criteria. Private developers, builder associations, real estate interests, and even chambers of commerce show great public concern about the potential higher costs of development. The insurance industry, especially that of professional errors and omissions insurance, is delighted to make "certified inspectors" a requirement of future policies.

After one year of experience with these laws, in 1980 there is serious conflict and great confusion in their application. In 1980 Congress enacts a law amending existing housing law to

- Establish an office of earthquake hazards in HUD.
- Establish funding levels matching state and local grants.
- Amend federal tax legislation to provide relief and incentives for persons conforming to federal requirements.
- Exempt federal officials from liability for decisions made and action taken under this legislation.
- Amend relocation assistance laws to include assistance to individuals and businesses forced to relocate under the earthquake hazards program.
- Establish a postearthquake reconstruction authority.

By 1980, the earthquake premonitors that are being measured in the San Francisco Bay Area are beginning to show definite trends and some correlation. Based on their experience with the Parkfield earthquake of 1978, the USGS feels that some sort of warning is warranted. The carefully worded statement passes through the USGS hierarchy to the Governor of California, who convenes the Earthquake Prediction Council, a panel of experts (including some of the USGS personnel who framed the original statement), to advise him on whether to issue a statement of information or an official warning that would trigger a preplanned response. Ultimately an information statement is issued on July 1, 1980, that predicts a damaging earthquake affecting the San Francisco Bay Area will occur along the San Andreas Fault within the next 10 years with a probability of more than 50 percent.

This prediction does little to affect the tourist trade, but there is some dropoff in conventions, which are booked many years in advance. It does, however, accelerate the earthquake hazards mitigation program that has been established by state and federal law. San Francisco experiences a decreasing tax base as dangerous buildings are demolished. Nevertheless, in spite of New York City's 1976 bankruptcy experience, which depressed the sale of municipal bonds throughout the nation, there is substantial speculation in San Francisco's municipal bonds.

The media sense a great concern and an unfulfilled need. Television is particularly active. There are both sensational and informational shows. The weather reports on the news programs regularly include a seismic report. USGS and academic people often appear as guest experts. There is free and open publication by USGS investigators in the scientific literature. Responsible self-help plans and sensational books appear on the newsstands. The 1975 book on possible small building and housing structural improvements, Peace of Mind in Earthquake Country, becomes a local best seller. The popular 1975 book The Jupiter Effect, which predicted a large earthquake in 1982, passes through five more printings, despite the condemning reviews it received from seismologists when it was first published. Nonscientific predictions from various sources abound and receive their share of publicity. Except for increasing sales of earthquake insurance, the public interest wanes within a year. The state and federal governments find themselves in a confrontation between their responsibilities for health and welfare and a population that does not want to defend itself. However, even when public interest wanes after a time, many hazardous conditions have been in one way or another rectified or improved to some extent.

In August 1980, Earthquake Predictions Risk Analysis Incorporated, a well-financed private consulting group led by a retired former program director at the USGS and with a string of consultants at academic institutions around the country, offers its analysis and forecasting service to insurance companies, financial institutions, and industries. By the end of the year it is flourishing and opens a branch in Long Beach. The USGS is obviously uncomfortable, but supplies EPRAI with instrumental data, which it must do as a public agency. It holds its peace, even as several local governments begin to show interest in hiring EPRAI to make medium-range forecasting studies for their communities.

From 1976 to 1982 several small earthquakes and one medium event of magnitude 5.3 occur in southern California. About half the small ones are predicted quite well in terms of location and magnitude, and time to within 20 to 40 days. (Three earthquakes occur outside instrumented areas.) The 5.3 magnitude earthquake in San Diego on July 17, 1980 was predicted to be larger (~6) and to occur 4 months later than it actually did.

Two large earthquakes occur during March 1981, one in the Soviet Union and a very damaging one in north China. The Soviet event was not predicted, and in fact insufficient data were available for a retrospective prediction. The Chinese claim to have successfully predicted their earthquake and invite a U.S. delegation to examine the data. This is the first time that the Chinese have made prediction data available, and the only explanation seems to be a desire to embarrass the Soviet Union in an area where China has become technologically superior. Based on the information gained in the U.S.-China exchange of earthquake scientists, the USGS is able to resolve its San Francisco Bay Area premonitor readings to give predictions of higher precision. This requires some extrapolation of the Chinese expertise, however. The USGS consults with state and local officials about their plans to release the information.

UPDATING THE PREDICTION

The USGS calls a press conference on January 14, 1982, to update its predictions of an earthquake in the San Francisco Bay Area. It predicts an event within 2 years between Portola Valley and Bodega Bay, to have a magnitude of 7.5 to 8.3, with a 70 percent probability. Although there is some uncertainty in the extension of Chinese data analysis techniques the USGS claims that those uncertainties are included in the probabilities and limits put on the prediction. However, when pinned down, the USGS officials admit that their statement of 70 percent probability is based not so much on calculations from past earthquake activity and from instrumental data as on the lack of a clear understanding of earthquake processes--that is, more on what is not known rather than what is known.

This new prediction receives serious attention in the legislative arena. Congress amends its earlier law establishing an Office of Earthquake Hazards in HUD to

- Give authority to this office to coordinate the civil engineering/public works activities of other federal agencies with respect to permanent hazard mitigation and reconstruction, including planning.
- Confine FDAA's role specifically to disaster planning and operations, including provision of pre- and post-disaster temporary housing.
- Take away the unilateral power of the states to increase the risk designation of geographic areas. It must be concurred in by the federal government.
- Establish procedures whereby state and local governments can adopt plans to respond to earthquake predictions with minimal liabilities. This includes establishing standards for predictors and for scientific review of predictions, and requirements for anticipatory studies that must be completed to determine risks, costs, and benefits of alternative courses of action as a function of prediction characteristics for a geologically defined earthquake area.

In addition, Nevada, Utah, and Alaska enact legislation similar to, but differing in major respects from, that of California's. Congress greatly expands the uses of earthquake-prediction efforts to other seismically active parts of the country. In doing so Congress exempts the USGS from the requirements of the National Environmental Policy Act to prepare environmental impact statements but puts a requirement on the HUD Office of Earthquake Hazards for the above-mentioned anticipatory studies. Congress also amends FDAA's legislation to permit it to purchase and preposition disaster and emergency relief supplies and equipment and increases its funding for planning, training, and exercises related to emergency preparedness and operations.

With heightened legislative emphasis on earthquake preparedness, the American Public Works Association joins with the American Waterworks Association to greatly increase their efforts toward safer and more earthquake-resistant lifeline design and construction. Although research and experimentation have been under way only nominally for the past several years, the APWA does publish its long-awaited guidelines, standards, and other criteria on earthquake engineering related solely to lifelines.

Lending institutions become alarmed as some parties holding mortgages on high-risk structures withhold payment. The financial industry presses for legislative action in the form of specific limits on delinquent payments in order to qualify for any form of real-property-related pre- or post-disaster relief. However, homeowner and neighborhood associations lobby for a mortgage payment "holiday" until after the earthquake. There is debate in the state legislature, but no resolution is made of the problem. As a result, a limited and unpublicized form of "ad hoc" mortgage payment "holiday" occurs throughout the financial industry. Nevertheless, the number of personal bankruptcies and business failures increases.

The Governor of California's board of seismic experts, the Earthquake Prediction Council, suggests that there may be more than one way to interpret the Chinese data, and while they cannot refute the logic of the USGS approach, they can suggest an equally valid alternative. They suggest that a panel be established under the National Academy of Sciences (NAS) to study the implications of the alternative approach. The USGS agrees to this.

After six months, the NAS panel, which includes some of the members of the Governor's board and also USGS staff, reports that the alternative interpretation of the Chinese data results in its not being applicable to the northern California situation. The difference between the interpretations lies in basic assumptions about earthquake mechanisms that cannot be directly resolved. Experiments could be conducted to determine the correct assumption, but they would have to await the occurrences of fairly large earthquakes in a particular region of China and in northern California. In addition to the long time that this might take, there exists a problem that this type of scientific cooperation had not been established in the two countries.

The right-wing press suggests that the Chinese prediction data given to U.S. scientists are contrived to mislead U.S. investigators in order to cause domestic disruption and to turn attention from foreign to domestic issues.

Based on further premonitor changes and using the Chinese data correlation, the USGS is able further to increase the precision of its predictions. Accordingly, after consulting with state and local officials, they issue a new prediction at a press conference on August 28, 1982, stating that the same earthquake predicted in January now has an 85 percent probability of occurring within the next 3 months.

The insurance industry declares a moratorium on writing new earthquake insurance policies, and in late October the industry announces that it will not renew any existing earthquake insurance policies as they come due. This action tends to reinforce the public credibility of the prediction but also raises the question whether the insurance industry knows something that the public is not being told. It is widely reported that the insurance industry has retained EPRAI as consultants.

Experimentation with earthquake control has continued during the period. Tests in oil fields in Colorado continue, and the National Science Foundation funded a 10-year program in Nevada in 1978. Two of the planned six holes have been drilled, and some tests have been conducted. An announcement is made on May 19, 1982, of a breakthrough in understanding how the control process works. This news is given TV and newspaper coverage, and public discussion ensues. After the August 28, 1982 prediction one eminent scientist and several engineers propose seriously that wells be drilled and water pumping started as soon as possible near the expected epicentral region of the predicted earthquake. A majority of scientists are strongly opposed to the idea, however, pointing out that if the breakthrough in knowledge is real, the operation could have a fair chance of success at reducing the magnitude of the predicted event, but it might equally well trigger off an even larger catastrophe. In addition, the earthquake may well occur before enough drill holes could be sunk to be effective. Many eminent scientists consider the proposal to be outright ludicrous. Their weight eventually carries, but not without heightening the sense of uncertainty and confusion among government leaders and the public alike.

Two small earthquakes occur on November 29, 1982, near Pacifica. New data gained from strong-motion instrumentation with these two small earthquakes of magnitude 4.0 and 4.5 are interpreted by some building owners to indicate that the hazard mapping that was begun by the California legislation of 1979 is incorrect in some areas. On this basis lawsuits are filed by several property owners, who allege that their land has been depressed in value as a result of incorrect seismic zoning.

There is little damage from these earthquakes, but they are read by a nervous and expectant public as possible foreshocks of the predicted large earthquake. Statements from scientists are contradictory regarding the significance of these events. After attempting in vain to obtain affirmation of this from the USGS or his panel of seismic experts, the Governor decides on December 3 to issue a warning of an imminent large earthquake near San Francisco within the next several days. Public pressure is high for some action. All of the requirements laid down by Congress for taking action have been met; in fact they were met when the August 28, 1982 prediction was made.

Business and factories are closed, schools are closed, hotel guests are encouraged to leave, tourists are discouraged from coming, conventions and other gatherings of large numbers of persons in structures are canceled or discouraged, people living in dangerous areas of high fire or inundation risk or substandard structures are encouraged to evacuate, forced evacuation is begun in some areas, lowering the level in reservoirs behind substandard dams begins, the utilities instruct people what to do in the event of an earthquake and what not to do before the event, emergency vehicles are parked in the open and positioned in critical areas, hospitals and medical personnel are mobilized as are other emergency personnel.

With this latest warning of an imminent large earthquake, no new building permits are issued and current construction projects are stopped. In areas designated to be of high seismic risk, and to be evacuated, construction sites are abandoned in whatever condition they happen to be. In other areas, however, there have been no specific instructions on how to make partially completed construction safe.

This posture is officially held for 10 days. However, after a few days some kinds of activity spontaneously resume. There is unofficial condoning of these. After 5 days of holding this posture, the business, industrial, and labor leaders of the community approach the mayor, stating that if the emergency is continued much longer, they will be ruined. The mayor in turn calls the Governor. The Governor is not able to obtain any guidance from the technical community. The USGS states that it has seen no short-term changes in the premonitors, but that does not necessarily prove things one way or the other. After 10 days the Governor officially states that the present emergency is over, but in many sectors this only affirms the reality of several days ago.

Community life resumes, but there is no sense of relief that the emergency is over, though most people are satisfied to believe that the inappropriate use of Chinese data by the USGS put them in a frame of mind to overreact to the small earthquakes of November 29. However, they come out of the experience with a heightened sense of the risk that they face and a high state of anxiety and concern. National interest wanes. The price of Bay Area municipal bonds falls dramatically. Some lawsuits are filed for losses suffered as the result of false prediction. Some corporations announce that they are moving out of the area because the cost of going through this once more is greater than the benefits of remaining.

Premonitors continue to change gradually during the next several months, but the analyzed data contain some elements that do not fit the current theoretical hypotheses and are technically confusing. The USGS takes a safe posture, indicating that a large earthquake in the Bay Area is very likely "soon," but they really do not know when it will occur. On May 22, 1983, a few new premonitory changes initiate still another wave of publicity. There is much talk, but the public is becoming apathetic and little action is taken. On July 2, 1983, some dramatic changes in tilt and resistivity are noted, but magnetometer and creep readings remain steady. Many people who would have stayed home leave town for the July 4 holiday, but with the high price of gasoline and travel in general there is no major exodus. Although many scientists at NCER argue for a warning, no governmental action is taken.

On July 8, 1983, an earthquake of magnitude 8.3 occurs at 4:30 pm PDT, with its epicenter just off the Farallon Islands. It is followed by several significant aftershocks, the largest being of magnitude 7.1 at 3:40 am PDT on July 10, 1983. Although it is a serious disaster, the loss of life and property damage was only a fraction of that expected. There were no floods since the reservoir levels had been held low, and there were no mass fires since the public had been well drilled on ignition suppression measures.

On August 1, 1983, the Governor declares, on the basis of information provided by the USGS, that the San Andreas Fault has quieted down and could be considered dormant except for minor aftershocks. He goes on to say that science and technology have learned much from this experience and that the people of the Bay Area need not fear again being caught offguard. He points out that the experience proved the usefulness of earthquake-hazard assessment and abatement, utility lifeline seismic improvements, earthquake provisions in building codes, and emergency preparedness and operations. He calls for long-term land-use planning based on detailed seismic considerations.

On August 13, 1983, representatives of the USGS announce to an assembled group of state and local officials that earthquake premonitors are changing rapidly along a significant section of the Hayward Fault. They cannot make a prediction at this time because the San Francisco earthquake has caused discontinuities and abnormalities in the premonitors being monitored along the Hayward Fault. However, they feel that they could obtain a valid recalibration and make a preliminary prediction in 2 to 3 weeks.

Case 2: Medium-Term Prediction

Date	Event
May 3, 1979	Prediction is made by the partially completed northern California USGS earthquake-prediction data network that a "damaging" earthquake will occur within the next 6 weeks, with its epicenter within 5 miles of Mussel Rock off Daly City along the San Andreas Fault.
June 15 and June 16, 1979	An earthquake of magnitude 6.1 takes place at 12:32 pm PDT, with its epicenter 5 miles south of Mussel Rock, and another with magnitude 7.6 at 6:18 am on the next day with an epicenter 5 miles north of Mussel Rock.
June 21, 1979	An aftershock magnitude 7.1 occurs at 5:10 pm, with its epicenter 14 miles south of Mussel Rock on the San Andreas Fault.

MAKAY'S EARTHQUAKES

PART I

Ted Makay awoke, sweating, and realized it was only another fire engine sounding louder than usual because the bedroom windows were open to the unusually warm May night. He'd dreamed it was the telephone but it wasn't. Sylvia hadn't even turned over. The house was silent at what, one in the morning? The clock was on Sylvia's side; it showed 2:34 and counting. Late. Had he heard the car yet? No. Bob was late. Drinking again? Well, we drank a lot and blamed it on the bomb; I guess having the kids blame it on the coming earthquake isn't so extraordinary. How many days was it since the Governor came on television to pronounce the sentence? He spent half an hour just describing how the USGS scientists in Menlo Park had predicted a damaging earthquake for the Bay Area within the next six weeks. You knew he was serious because he had never taken that long to say anything before. That was thirteen, no fourteen days ago. Twenty-eight days till Earthquake Day. A day at a time. Salami tactics.

Sure, they'd told him his job was secure, but his future was tied to some expensive equipment. If the company brass in Chicago could have hired trucks or even aircraft they would have moved the whole plant lock, stock, and computer that first week. Luckily, Knudsen had figured out a way to protect the equipment and management had bought the idea. It had better work. The workmen who put up the shelter and mothballed the equipment left yesterday. Now only he and Knudsen were left to babysit the plant. The company laid off the others with two weeks pay and whatever vacation and sick time they had coming. Some were leaving town for the high country, others to stay with relatives back east. Only the poor and responsible were hanging around here.

Sylvia's mother couldn't understand why anybody stayed, she thought it was wicked to "risk the children." Lord, how he tried for Sylvia's sake to be nice to that woman, but it was no help. Every damn evening, a minute after the evening rates went on in Kansas City, she called "to see how they are getting along," to suggest again that the children come to Kansas City until "that earthquake thing blows over," to see if Ted still kept that ridiculous plan of camping out in the back yard as E-Day got close. At least she didn't have an answer tonight when he said he wasn't sure he wanted to risk the kids getting caught in a tornado in Kansas City. She'd keep up the pressure until the phone lines went out.

A family ought to stick together at times like this. Not that they would. Bob wanted to go up on Twin Peaks to watch the "biggest show on earth" with some of his friends. It would be poetic justice to send Bob to his grandmother's. A car was pulling up. The clock said 3:14 and 30 seconds, Friday, May 17, 1979. The front door opened and closed. Bob was late coming home from his date. Al Berthoud's daughter. Al was a good guy to know. Al said that NASA was getting information from its satellites that contradicted the USGS data but even Al had salted away enough canned stuff for a month.

Voices down the hall. Bob must have waked up Tom, probably knocked something over. Only nineteen, too--kids were drinking more and drinking younger. Bob liked a new place on El Camino called the Intensity XII, where the specialty of the house was the Big E--three of them cause complete destruction. Sounded like Tom was helping Bob into bed.

Tom was the reliable one. Two years younger and ten years more serious--Tom kept coming up with suggestions for dealing with the earthquake, and some of them were damn good ones.

PART II

The executive committee of the neighborhood swim and tennis club met at 7:30 pm on the last Saturday of the month. The chairman usually tried to get the meeting started before the third round of drinks, but tonight Paul seemed to have difficulty calling the meeting to order. Ted and Sylvia sat down. When things quieted down, he began. "Ladies and gentlemen, please--let's not waste an opportunity to work together as neighbors so that we can come out of this as an intact community."

"Aw, cut the crap, Paul." That was Eddie Foxx, and he always had a bee in his bonnet. "There's only one item on tonight's agenda. Let's close the pool and keep the water clean so we can drink it after the earthquake, or even put out fires. But if my place is burning, forget it--I couldn't get earthquake insurance before the moratorium, but I have plenty of fire insurance."

George Rokazy said "I had my house up for sale, but now I can't give it away. Who do I sue if it doesn't happen as predicted? And what do I do if the quake shakes mine down?"

"Move to your Tahoe place, George," Eddie said.

"He's got it rented for $1,500 a week," Paul broke in. "I wouldn't give up, George--or Eddie either. As I understand it, the shaking isn't going to be too bad up here on the hill--it's down in the flatlands where they'll have to worry. Anyway, our subdivision is built well--the houses are sheathed in plywood, and they have plywood paneling inside. That's called shear wall construction and it's pretty strong. The houses are only one story, and there isn't even a brick chimney to fall. I'd worry if I had one of those old two-story homes on the flatland with the heavy Spanish tile roofs. Just be careful with fire, because these houses burn; strap up your water heaters and shut off your gas and power lines at the first tremor."

"Selling houses isn't the only problem these days. The only new cars I've sold have been four-wheel drives--and for cash. The service department is going great, though. The question is, can you get far enough on one tank of gas?"

"Well, Angelo," replied Paul, "the earthquake warning cut off our highrise construction job in nothing flat. The bank suspended our construction loan even before the building inspector came out to notify us. We had to spend a little time cleaning the job up--nothing loose on the upper floors. We've got plenty of work with the utilities, shoring up towers and pumping stations. I could use more carpenters, but all the carpenters are in the home-strengthening racket. People are fixing up places that don't need it, and paying too much for shoddy work. Now plywood's getting scarce, and what's available isn't going where it's needed. Nobody's spending any real money to strengthen large buildings, though--there isn't time."

"Don't worry, Paul. After the quake there's going to be plenty of construction work for any outfit that can get the people and material in here quick. People aren't giving up on this area."

"Well, I think it's criminal, Paul," George Dawson said hotly. "Every laid-off white-collar worker whose wife gave him a $29.95 circular saw for Christmas is suddenly a home construction expert. And it's tax-free income, too--cash transactions with no records. I should try that racket, myself. After 20 years of wiring homes and apartments, I know where the weaknesses are. What worries me are these three- and four-story wood-frame apartments. Even if they don't collapse, some of the wires are going to be pulled loose and short out. I'm working as a building inspector until the National Guard calls me up. There's a lot the guard could do now, but the only plans are for after the earthquake hits."

"I know one thing the guard could do," said Pete. "In the last three weeks, I've seen all of the safety deposit boxes in my branch bank fill up, and I hear the same thing from other branch bank managers. I'll bet there's a lot of stuff buried in back yards, and once the word gets around, there'll be a crime wave like you've never seen before. I think the guard should start helping the cops now and maybe work gradually into martial law."

Ted wondered if Sylvia's face would give away the fact that their tomato patch contained more than freshly planted hybrid Better Boys.

"The doctor who rented my Tahoe cabin says the place is an armed camp. Everybody who went up there took valuables. Now gangs are breaking into places and terrorizing people. There aren't enough police, so everybody has a gun. Last week some marksman picked off three teenagers who were breaking into a cabin. Nobody knows who did it, and nobody is looking too hard."

"Okay, Mr. Pete Branch Bank Manager, how are we going to conduct our businesses? I got people buying hundreds of dollars' worth of clothes on the tab, or with a check, or with a credit card. I'm getting concerned about collecting. My customers can move away, they can be killed, they can lose everything and go bankrupt, your bank can lose the records. But if I say cash sales only, what do I do with the money, bury it? I know one thing. I'm not spending on inventory until this thing is settled. The Kuppenheimer salesman was in the other day. I told him not to drag his samples out of the car. He says, 'Eddie, if you don't buy now, you won't have any stock for next Christmas.' I said, 'Sam, I don't know if there's going to be a next Christmas.' He says, 'Eddie, why don't you have a Christmas sale now? You know, like they have an early Christmas for the kid with cancer.' Some sense of humor, that Kuppenheimer guy."

Sally Renfrew broke in. "Eddie, what if everybody felt like you? What if everybody tried to work down their inventories and minimize their losses? All kinds of shortages would develop. Pete can put off buying a new suit, but we've got to have groceries."

Pete Renfrew spoke up. "Eddie's right. If businesses are to continue, the credit and banking systems have to support them. If banking breaks down, we'll have to dig up the family jewels and try to barter for what we need. I think my bank has a pretty good plan, and things are under control. We're duplicating everything that's critical in any area expected to suffer damage. We're already doing a lot of our banking by remote control. We've got our records dispersed all over the country. Eddie, when you call my branch to find out if a customer has enough in his account to cover his purchase, you get your answer from St. Louis. The telephone company has equipment in safe staging areas around the region, and they can mobilize an army of workers from all over the country in minutes. We'd be 'off the air' no more than two days. We'll honor checks as long as the account can cover it or until we get a death notice. Credit cards are harder. We can declare a moratorium or run the risk. I think we'll risk it, but if any of you don't pay the first bill after the earthquake, you're going to be cancelled. We may cancel all cards after the earthquake and ask you to apply for a new one. So keep your checking account fat and hold enough cash on hand for maybe a week."

"This is unreal, I mean really," Peggy said. "Here we are discussing a doomsday while we sip drinks and enjoy ourselves. I'm not sure I believe it. Lots of people think the moon landings were staged and fed to the public like so much soap opera. Maybe this is the same thing. Maybe the CIA is behind it, or some nut. Couldn't somebody tie into the telephone lines that feed the data into the computer and screw it up?"

Professor Foster cleared his throat. He wanted the floor and Peggy turned to him eagerly. "Peggy, the human race never has been able to deal with prophets. We used to stone them or burn them or ignore them. Now, even when we can get dependable prophecies from scientific inquiry, some of us still look for the conspiracy and the lie if the prediction is scary enough, and we might even want to kill the predictor.

"Now they've predicted an earthquake. Some people have been able to take advantage of the prediction. Most of us haven't, and some of us have hurt ourselves by our actions. And yet none of us knows the effect of what we may have done on our ultimate well-being. We worry about things and conveniences and comfort when we have been given an extraordinary opportunity to survive and grow, as families and communities as well as individuals. I believe the predictions. I believe that this experience is one that we must pass through, so let's make it into an ennobling one for us all--a real and genuine concern for each other."

Finally Paul took over the meeting again. The simple agenda developed into the beginning of a neighborhood self-help organization.

PART III

The first shock came on June 15. Bob came home that night saying it was kind of disappointing to camp up there on Twin Peaks for a week and not see anything--even with binoculars--but some empty buildings collapsing. The next morning he went into the house--"just for a minute, Dad, I just want to get my guitar." The main shock hit just as he was coming out the patio door, and if he hadn't leaped aside the falling glass door would have killed him.

But that was the worst thing that happened, even during Thursday's aftershock. There was one long narrow crack in the floor slab and the clerestory windows were cracked or broken, but thanks to Tom, little else was broken. He'd spent days figuring out how to secure all the loose objects in the house. But even the refrigerator had moved, and the big couch. The electricity was only off for three days, so Sylvia kept only enough frozen food for ten days and sent the rest to the municipal relief kitchen.

All Sylvia's work in cooking and refreezing all the meat in the freezer--to make it last longer when the power went off--had been successful. The meals weren't at all bad, reheated on the charcoal grill. This morning, the TV newscaster had interviewed the head of the Geological Survey, who showed the instrument readings that the USGS used as the basis of the assurance that only minor aftershocks were to be expected now. So this evening they would celebrate Father's Day by eating indoors.

Between now and then, there was time to bike down to the plant and see how it was coming. On yesterday's trip he had made a list of the damaged parts--almost all of them on the auxiliary units--and sent it by mail (ferry to Oakland and 727 from there to Chicago) along with the report that Knudsen's plan had worked and the big machines along with their computer controllers were almost undamaged.

When he got back to the house, he tried the phone again. This time there was a dial tone, but when he tried the Chicago area code all he got was a busy signal. It was a relief to turn to thinking of work again, instead of nerving up for the next shake and then going out for search and rescue or firefighting.

Bob and Tom had certainly done their share. Bob was the surprise, figuring out which beam to shift to free someone without bringing it all down, giving his old man orders, taking orders. Sylvia hadn't complained, though it really upset her that there was no water closer than the foot of the hill where the tank truck stopped--she said it was worse than not being able to use the indoor toilet and having to make do with a privy.

Case 3: Short-Term Prediction

Date	Event
February 13, 1979	A prediction is made by use of the partially completed northern California USGS earthquake-prediction network that an earthquake with a magnitude of 6.5 to 8.3 will occur, with its epicenter lying between San Juan Bautista and Bodega Bay. The prediction is that the event will occur with an 85 percent probability within the next four days.
February 15, 1979	An earthquake of magnitude 6.5 occurs within its epicenter at San Juan Bautista at 9:05 am PST.

HEARINGS ON SAN FRANCISCO EARTHQUAKE PREDICTION
Good Decision--Bad Outcome?

by

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SAN FRANCISCO--If you place a blackjack bet according to favorable odds but you lose, you made a good decision but experienced a bad outcome. On Tuesday, February 13, 1979, California Governor Williamson warned the San Francisco Bay Area of an imminent earthquake having the destructive force of the great 1906 earthquake. An earthquake did occur on February 15, well within the warning period of four days. The earthquake was felt by San Franciscans as a gently rolling motion that lasted for five seconds, but the damage was centered in the old mission town of San Juan Bautista. The partially restored mission--a favorite tourist attraction--was a total loss, as were several small commercial buildings. Structures were damaged as far north as San Jose and as far south as Salinas. However, an examination into the events of the three days in February disclosed that the official actions and private reactions of individuals put into motion by the warning resulted in more deaths and injuries than the earthquake itself.

Hearings were held in the State Office Building in San Francisco yesterday, April 24, 1979, by the California Legislative Special Joint Committee on Earthquake Prediction. These hearings probed into the events that preceded the warning and followed until well after the earthquake. Was Governor Williamson gambling, and like the card player, did he make a good bet that unfortunately resulted in a bad outcome? If so, did he have any choice in the matter? Governor Williamson did not testify at the hearings. The Special Joint Committee was established by the legislature on March 7. Yesterday's hearings were the first in a series of hearings and special studies to be conducted within the next year on the subject of earthquake prediction and the San Juan Bautista earthquake and warning. The magnitude 6.5 earthquake did very little to relieve the stresses that scientists feel are continually building up on the San Francisco Bay section of the great San Andreas Fault. Similar stresses are building up in the Los Angeles area as well. The reaction to earthquake prediction expressed by many public and private officials at yesterday's hearings cast doubt on the usefulness of earthquake-prediction information for public and private action in future earthquakes until the reliability is greatly improved.

Governor Williamson's 8 pm prime-time appearance on all of the major Bay Area television stations on February 13 warning of a major earthquake in the Bay Area within the next four days set off a chain of events that are by no means to be put to rest by the Joint Committee's hearings. The courts have a heavy backlog of lawsuits to settle, and the issue is sure to be hotly debated in next year's gubernatorial elections.

According to Douglas S. Buchannan, who is Chairman of San Mateo County's Board of Supervisors, Governor Williamson did not issue an official warning in the legal sense that would bind local officials to take action. Supervisor Buchannan testified that "... these facts put the County in the position of having to act on the Governor's announcement, but having no state authority for doing so, and therefore of having to assume the full legal responsibility for the situation."

Mr. Buchannan related how San Mateo County engineers consulted with USGS scientists in Menlo Park and second-guessed the Governor on the probability of a great earthquake occurring. As a result, the County implemented its emergency plans on a selective basis.

Other public officials read the mandate of Governor Williamson's warning differently. Frederick L. Monitor, Chairman of Santa Clara County's Board of Supervisors, said that they "had no choice but to take the Governor's warning at face value. As a result we mobilized our full range of emergency services and implemented an emergency response plan appropriate to the situation, which we considered very serious."

Sara J. Buell, President of the San Francisco Board of Supervisors, agreed. "Because of the City Charter Amendments of 1976, the Mayor could not declare an emergency without approval of the Board of Supervisors. In an emergency session called shortly after the Governor's television appearance, the majority of the Supervisors present agreed the declaration of an emergency was the only course of action, although we had many reservations concerning liability, the availability of state and federal assistance, and so on."

San Francisco Mayor Nicholas Recuperio added that: "The basic emergency action with this type of short-term warning is to keep people out of potentially dangerous buildings. Therefore, except for certain vital functions, we ordered a shutdown of the central business district and evacuation of certain types of structures. In our announcement, which went out on television and radio, we made it clear that the one- and two-story wood-frame dwelling was the safest structure to be in during an earthquake. We also gave instructions about actions to be taken during and after an earthquake, such as finding shelter under a heavy table, or in a doorway, shutting off utilities--especially gas and electricity--and putting out small fires before they could grow. The following morning's newspapers also carried detailed instructions, but that was the last paper issued, because they were shut down for the duration of the emergency."

The USGS, whose earthquake prediction studies are directed from Menlo Park, gave testimony that was intended to emphasize that they presented the scientific facts to Governor Williamson uncolored about whether to issue a warning. Under questioning it did develop that, under the Freedom of Information Act, the USGS could not withhold the information and its policies, in line with executive orders and guidelines, would be to "take positive action to release this information to the public while it still could be acted on" if the Governor did not act. Governor Williamson was made aware of the USGS policies, they testified.

Dr. Robert G. Ainsworth, the Director of Earthquake Studies at USGS Headquarters, Reston, Virginia, responded to sharp questioning from Senator Ernest K. Norris, whose district includes parts of San Mateo County and San Francisco, by stating, "The simple facts are we felt confident enough that we could see the premonitors of an imminent earthquake on the few instruments that we had managed to install along a 10-kilometer section of the San Andreas Fault that included San Juan Bautista. As you know, we have been fighting just to keep this program alive since 1975. The Parkfield earthquake last year did give us a shot in the arm, but not nearly big enough or soon enough. We did feel an obligation to point out to Governor Williamson the implications of what we didn't know; namely, that we didn't know what the rest of the so-called locked northern section of the fault was doing because we didn't have instruments. Even if we did have instruments that showed nothing, some of our people feel strongly that an earthquake of the size indicated anywhere along this part of the fault could trigger the release of accumulated stresses in the entire 'locked' section. In other words, we could put a lower bound on the size of the impending earthquake, but we couldn't specify the upper bound, except that we don't believe that the 1906 earthquake will ever be exceeded in this region."

The Chief of Earthquake Prediction Studies in Menlo Park, Dr. Henry T. Paine, elaborated on this point. "Our basis for predicting large earthquakes in this region is the retrospective prediction of the magnitude 7 Parkfield earthquake of September 4, 1978. This was a classic earthquake from the prediction point of view. We had dense enough instrumentation to see the earthquake premonitors along the entire length of the fault that ultimately broke. Furthermore, we obtained corroborating premonitors from three different kinds of instrumentation. However, that section of the fault has experienced creep and continual small earthquakes so it isn't considered 'locked.'

"Even though a magnitude 7.0 earthquake can be pretty damaging, the corresponding length of fault breakage is from one to two orders of magnitude, or 10 to 100 times, less than a 1906 type magnitude 8.3 earthquake. In other words, if a magnitude 7.0 earthquake represented 40 kilometers of fault breakage in a region, a magnitude 8.3 earthquake could represent as much as 400 kilometers."

Dr. Augustus S. Weiland, the USGS Chief Earthquake Seismologist in Menlo Park, made a telling point for their case: "What is not known in science can be as important as what is known. We knew that the state has an earthquake-prediction evaluation committee, and so we told them what we knew as well as what we didn't know. They certainly have the expertise to sort it out."

Dr. Davis M. Keefer, Chairman of the state's Earthquake Prediction Evaluation Committee and an eminent seismologist from State University, was reticent about discussing the deliberations of the Committee. He appeared under subpoena and made no formal statement. The minutes of the Committee's meeting, which were also subpoenaed, were made part of the record and are more revealing than were Dr. Keefer's tangential answers to direct questioning. The meeting was held with four members present and with five members participating via a telephone conferencing hookup. The Committee agreed seven to two on the minimum prediction, but were unanimously against validating the speculation--as they characterized it--by the USGS about a large magnitude earthquake. Telephone company records showed that the entire conference lasted 17 minutes.

The prediction and its evaluation next went to the Governor's Seismic Advisory Committee at about 4:30 pm. The Chairman of that committee, Mayor Eric T. Fortune of Stockton, defined the function of the Seismic Advisory Committee: "To advise the Governor on the political and public-policy ramifications of a given prediction. As we saw the problem, we had little choice on the minimum earthquake," he added. "The question that we had to wrestle with was the possible maximum earthquake. We knew that the science panel had considered it of little validity as a scientific matter, but as a public matter we weren't too sure. And we were only given two hours to decide. Well, under the press of a 6:00 pm deadline, we reached a compromise position that an 'information only' bulletin be issued on the possible magnitude 8.3 earthquake."

Assemblyman Philander C. Meade, whose district includes Pasadena and Glendale in southern California, commented that "this was like Pilate washing his hands and leaving the decision to the mob." Mayor Fortune replied somewhat testily, "Not at all. We could have advised the Governor to set the scientific committee or the USGS up as the goat if he were wrong. We didn't feel that the information was firm enough to ask the feds for help or to mobilize state forces, but it would have been criminal not to pass on the information, uncertain as it was. Sure, it put the decision to act or not on the locals. Some of them overreacted, some of them played it about right as it happened. Maybe it was luck. Maybe it was a matter of being smart."

Senator Leo Castelli of Santa Clara County, Chairman of the Joint Committee, took the time to sum up for the record his understanding of Governor Williamson's warning statement. "Those areas that could be affected by the magnitude 6.5 earthquake centered in San Juan Bautista in San Benito County were obliged to respond by implementing their emergency plans, while those areas that could be affected by a magnitude 8.3 earthquake, which is the entire Bay Area, could decide to implement emergency plans or parts thereof or not."

Several witnesses testified to the effect that the discretion exercised by local officials had on their individual lives and interests. The executive director of the Greater San Francisco Chamber of Commerce, Abram S. George, testified on the impact of closing down the central business district. "Using hindsight, of course, we can see that this was a big mistake. At the time, Mayor Recuperio painted a pretty dismal picture, and quite frankly, we were taken in. We agreed voluntarily to close down. It was apparent that the mayor had the backing of the Board of Supervisors, and we didn't want people facing the police or National Guard in order to get to work. I don't know what we would do the next time. When the cost of failures in this earthquake-prediction business exceeds the benefits of success, it seems to us that the exercise isn't worth the trouble. I think that we need pretty nearly 100 percent reliability in order to respond responsibly! Who knows how much the city lost during the three days it was shut down? Why, the gross city product is millions of dollars a day. Much of this loss was absorbed by businesses, much of it was passed on to employees in lost wages. Lost wages, by the way, that can't be spent for goods and services. I personally know many businessmen who have or are planning to bring suit for damages."

In his testimony Dr. Allen C. Wheaton, Jr., the noted economist at State University, stated that many of the business losses are merely transfers to other regions or most likely will be made up later by businesses in the Bay Area. He pointed out that many businesses increased as people took actions to mitigate the effects of the anticipated earthquake. "To the extent that these are not permanent improvements in property and so forth, they represent losses to individuals." But Professor Wheaton put this rhetorical question in the record. "How many failures can you afford if one success is instrumental in saving thousands of lives?" He likened the economic impact to an unplanned three-day weekend.

Mrs. Estelle Farrell and two other representatives of the San Francisco Neighborhood Tenants Association described how they and their families were awakened in the middle of the night by policemen and ordered to move to Golden Gate Park. There was no transportation until morning, when Muni buses were pressed into service. When they arrived at Golden Gate Park, there was no shelter, and since it was raining, they refused to get off the buses. They ended up in a school in the Sunset District.

Mrs. Rosa Martinez of the tenant group testified, "My home withstood the 1906 earthquake, so as far as I'm concerned it has passed the test. Where are the poor and minorities expected to live? My home is all I can afford, but it's comfortable and surely looks more solid than those $100,000 cracker boxes that they're building today. They tear down all these fine old homes that we can afford and put up big apartments that we can't afford."

Samuel G. Blaine, President of San Francisco Senior Citizens Association, told of the plight of the elderly who live in old hotels and apartment buildings in or near the central business district. It's the only place they can afford on their income, which is often limited to Social

Security payments. Also, they like to be near the facilities that the central city offers. "These people, who are often physically slow or handicapped and mentally easily confused, were put into a state of shock when they were ordered out of their homes," he said. "I'm not against such evacuation when necessary, but I am against the way it was carried out, and I am fundamentally against the social conditions that put these people in substandard buildings in the first place."

Mr. and Mrs. Robert W. Redman III appeared in sharp contrast to the tenant group and contingent of elderly attending the hearings. They live in the plush Bayview Towers and testified that they had decided to evacuate their quarters when they heard an eminent local structural engineer comment, on an "earthquake special" on television following Governor Williamson's announcement, that as many as twenty of San Francisco's newer high-rise buildings could collapse in a repeat of the 1906 earthquake. They decided to head east toward the safety of their condominium apartment at Lake Tahoe. But they found that they only had a quarter tank of gas. Since there were long lines at all of the stations in their neighborhood, they thought that they would have more luck in Oakland. They got stuck in a traffic jam on the Bay Bridge and ran out of gas in East Oakland. Discouraged because the stations in Oakland were out of gas, they returned to San Francisco on a BART train. Describing their experience, Mr. Redman said, "It was scary as hell sitting on the Bay Bridge knowing that at any time it could start swaying and dump you into the inky black Bay."

Chester L. Joiner, Executive Director of the Bay Bridge Authority, related how, with the help of the Highway Patrol, traffic was redirected on the upper half of the Bay Bridge from incoming to outgoing. This eased the traffic jam for a time until the freeways in Oakland backed up.

Mayor S. David Hall of Oakland, who opted not to warn his community of a possible magnitude 8.3 earthquake, described for the joint committee how his city had become the unintended "host" for thousands of West Bay residents. As a result of accidents, abandoned and stalled vehicles, and exhaustion of gasoline supplies, many would-be evacuees got no farther than Oakland and its suburbs in the East Bay. All public buildings, schools, and churches were opened, and many private citizens offered space in their homes. Mayor Hall admitted that many Oakland residents joined the stream of evacuees as a result of the television broadcasts of the Governor and the Mayor of San Francisco and from seeing the streams of evacuees from the West Bay.

Captain Stanley Hathaway of the California Highway Patrol estimated that 49 deaths could be attributed to the emergency evacuation. Twenty-seven were killed in traffic accidents between vehicles, six pedestrians were run down, seven died from carbon monoxide poisoning; there were also five apparent suicides and four homicides.

Dr. Miles E. Lessenco, the San Francisco Director of Public Health, said that the emergency was too short for a serious public health problem to develop. Because of the inclement weather, seven persons, most of whom were elderly or ill, died of exposure attempting to camp out on the road, in parks, or in their backyards. There were 37 heart attacks during the first 12 hours after the warning. For a time traffic jams were so bad that ambulance service was virtually at a standstill. Many of the persons who were attempting to evacuate went as long as 36 hours without a meal.

San Benito County, where the earthquake occurred, was also plagued with evacuees. The situation got so bad, according to Michael R. Suarez, Chairman of the Board of Supervisors, that they feared that they would not be able to render assistance to victims. Supervisor Suarez testified that, "After consultation with the Board of Supervisors, the Sheriff established checkpoints in the northern and western parts of the county where the heaviest traffic from Route 101 was. The deputies attempted to discourage everyone who was not a resident of the county from entering. The voluntary approach worked very well in reducing the numbers of people entering the County to a trickle during the night of Wednesday, February 14."

Supervisor Suarez further testified that "... the Sheriff estimated that by Friday morning, there were 10,000 additional people in the County. This is half again our total County population, which is just under 20,000."

Suarez estimated that the earthquake damage in the County was $30 million. The majority of this was in the water system and agricultural lands. He put the toll at 21 persons injured, and he guessed that the actions taken as a result of the warning had saved "between ten and twenty lives."

The Superintendent of San Benito County Schools, Harold G. Leslie, testified that the schools, which were being occupied by evacuees from the north at the time, performed very well. All of the county's schools are Field Act schools, which means that they are built to resist earthquake forces.

Although there was confusion over the proper course of action within government circles, this was not the case at the giant Pacific Gas and Electric Company, according to Frederick T. Winslow, Vice President, Gas Operations. "We have been following the science of earthquake prediction for some time," stated Mr. Winslow. "We learned quite a bit at a very high price about geology and seismology during our attempts to site nuclear power plants in California. We and our consultants just didn't put any credibility in the prediction of a 1906-type earthquake. Even if we did, are we to deprive homes, hospitals, and other vital facilities of gas for heat and cooking, especially during winter? Our crews were alerted and standing by, and we could have cut off all primary gas mains within a few minutes after the earthquake. If the homeowners and other gas users would cooperate and close their service valve at the same time, we would have no problems with gas-caused fires. We run a greater risk from unauthorized emergency forces shutting off our high-pressure mains."

Assemblyman Carrasco asked John H. Torkeley, Regional Manager of the Golden State Insurance Company, why a homeowner should be concerned with fire if his home is damaged by an earthquake. "He generally has fire insurance, but not earthquake insurance," stated Carrasco. "Didn't the payment of fire insurance claims after 1906 largely rebuild San Francisco?" Torkeley replied that people have a deep emotional involvement in their homes. "People put a lot of work in their home; their memories are tied up in it; their valuables and treasured possessions are in it; so we don't find people torching their homes even in situations such as you describe," said Torkeley. "Businesses, especially small and marginally profitable ones, are a different story," Torkeley was quick to add.

When asked whether earthquake insurance was still available, Torkeley replied, "Indeed it is. You know the Bay Area still faces a major earthquake; nothing has really changed. but my door isn't being beaten down by potential customers."

On the question of the effect of reliable earthquake prediction on the availability of earthquake insurance, Torkeley stated, "Reliable and accurate long-term predictions would force us out of that business, but we aren't there yet; it's still uncertain and so a risk for the property owner. Insurance is designed to help the individual with the unexpected."

"The warning affected us in two ways," stated Arnhold T. Friendly, Vice President of Banking Service for the Bank of America. "We had a moderate run on our banks for cash on the day after the warning. It's not that people didn't have faith in the banks, but they were concerned that if an earthquake did occur, there would be a strictly cash economy. That brings me to the next point," Friendly added. "Banking today operates on data and the ability to process it. Our data is fairly secure, we believe, but we don't know whether our data processing machines would remain functional after an earthquake; or for that matter whether we would have employees available to operate them. Therefore, we started transferring some of our data to Los Angeles for processing immediately after the warning. Some of it was physically transferred by aircraft. Some was transferred by telephone hookup. We felt we were on top of the situation at all times."

Standard Oil's large refinery at Richmond in the East Bay kept humming all during the situation. Charles J. Veitch, the General Manager of the Richmond Refinery, said, "It takes five days to properly shut down a large refinery complex. We have emergency shutdown procedures that do some damage to some refinery components, but we felt that we could wait until and if the earthquake struck to see what damage would occur. The processing equipment is pretty rugged. We may have problems with large storage tanks, but there wasn't anything we could do about them."

Safeway Stores' Regional Manager Joseph K. Machado told the committee about the difficulty of keeping some foods on the shelves. "People bought especially large amounts of canned goods and packaged dry goods. People normally do their shopping during the latter part of the week, but sales after the earthquake warning were unusually heavy. Many stores were virtually cleaned out of their stocks of these items. However, they were all restocked within a week."

At no time during the emergency was the National Guard called out. Major General Clyde Anderson Stevenson testified: "We were standing by awaiting orders from Governor Williamson, but they never came. It the large earthquake had struck, we would have been needed."

California Office of Emergency Services Director William P. Lampson echoed General Stevenson's remark. "We are set up to coordinate and direct the postdisaster efforts of county and city units of government. We were ready and waiting, but fortunately we weren't needed."

The next hearings of the Joint Committee will be held at 9:00 am on May 8 in the Resources Building Auditorium in Sacramento.

Case 4: Medium-Term Prediction

Date	Event
February 3, 1979	The USGS obtained some indications of surface-level changes at two stations 20 miles apart along the southern end of the locked section of the San Fransisco Bay portion of the San Andreas Fault.
March 15, 1979	The 20-mile segment is instrumented with a fairly dense network of tiltmeters.
June 15, 1979	Using the installed instrumentation as well as regular and systematic measurements of resistivity, telluric currents, magnetic anomalies, radon emission from deep wells, water levels in deep wells, microquake measurements, V_p/V_S anomalies, and Vibraseis surveys, the earthquake premonitors are isolated to a 40-mile section of the San Andreas Fault between San Juan Bautista and Los Gatos. This is translated into a prediction that there is an 85 percent chance that an earthquake of magnitude 7 to 7.2 will take place on December 15, 1979, plus or minus 3 weeks.
June 30, 1979	After receiving confirmation from USGS headquarters in Washington, the USGS formally notifies the Governor of California that it would release this information in 24 hours, which gives him time to make a decision concerning a warning on these facts. They also notify the Governor that there is a real possibility that the predicted earthquake may trigger a great earthquake along the entire locked section of the San Andreas Fault.

This case is intended to suggest several possible outcomes and to illustrate the difficulties faced by a decisionmaker in choosing to translate a set of scientific facts into a warning of a specific event.

THE GOVERNOR'S DECISION

The U.S. Geological Survey at Menlo Park has formally notified me, as Governor of this State, of certain scientific facts concerning the potential for an earthquake in northern California. The USGS headquarters in Washington has confirmed these facts and has told me that it has authorized and directed that this information be withheld from release to the public for 24 hours pending my decision on a course of action for the State.

This will also allow time for coordination with the White House and key federal agencies.

Several months ago the USGS obtained some indications of surface-level changes at two stations 20 miles apart along the southern end of the "locked" section of the San Francisco Bay portion of the San Andreas Fault. Because of this, the USGS intensively instrumented that 20-mile segment with a fairly dense network of tiltmeters and has been making regular measurements of resistivity, telluric currents, and variations in the earth's magnetic field. Some deep wells in the area are being monitored for radon emission and water levels. An extensive program--using a network of seismometers--has been under way for measuring natural microquakes. This program has been run in conjunction with periodic surveys employing a Vibraseis (a truck-mounted ground thumper). So-called P-wave velocity anomalies are being followed with this network.

The USGS has isolated changes in earthquake premonitors to a 40-mile section of the San Andreas Fault between San Juan Bautista and Los Gatos, which is the southern portion of the so-called locked section of the fault. As the result of three months of measurements and studies of changes in these premonitors, the USGS now estimates that there is an 85 percent chance that an earthquake of Richter magnitude 7 to 7.2 will take place six months from now, plus or minus three weeks.

The USGS informs me that the fault will break along this 40-mile section, if it breaks at all. However, the USGS has specifically noted that an earthquake of this magnitude may trigger a great earthquake along the entire locked section of the San Andreas Fault, which would involve a fault breakage about 200 miles long. The USGS has also noted that it may be able to pinpoint the time with more precision as the event (±2 to 3 days) approaches but will probably have no better information on the expected magnitude of the predicted event. Also, it will not be able to further resolve the question concerning the probability that the predicted event will set off a great earthquake. All it can tell us now, and all it will be able to tell us, is that such an event is "possible." For all intents and purposes, if the predicted earthquake does trigger a great earthquake, the effect would be on the order of an 8.3 magnitude event in the San Francisco Bay Area, similar to that of the 1906 earthquake.

Incidentally, if the 7 to 7.2 magnitude event does not trigger an 8.3 magnitude earthquake, the stresses that have built up in the locked portion of the fault will have been only partially relieved and the potential for an 8.3 magnitude earthquake will have been only slightly diminished. Under the prevailing theory of stress buildup, the northern California section of the San Andreas Fault would remain liable to an 8.3 magnitude earthquake in the future.

My panel of experts has been following this work all along--in fact, some of them are participating in it. They believe that the prediction is valid and the contingent revisions and effects are possible, thereby confirming the USGS work. I have called my panel of policy experts together for advice on what to do. I explained to them that I see the following alternatives possibly affecting the options open to me:

(1) With respect to the prediction

- The prediction may stand unaltered.
- The prediction may be modified to represent a different set of facts.
- The prediction may be made more precise with a short-term warning having a reasonable degree of confidence.

(2) With respect to the earthquake

- It may not happen at all.
- It may happen as predicted.
- It may happen outside the parameters of the prediction.
- It may trigger a 1906-type earthquake in the San Francisco Bay Area.

(3) With respect to my response to the present prediction

- I can issue the present prediction for information only for local option action.
- I can issue the present prediction for information only, with the understanding that we have a good chance of getting a short-term warning.
- I can issue a warning that would initiate action based on the present information. Of course, this would be appropriately modified if and when we received further information.

- I can do any of the above either for a 7 to 7.2 magnitude earthquake that would affect the area in which premonitors are found or for an 8.3 magnitude earthquake that would affect the entire San Francisco Bay Area, or I can select a combination of the above for these two situations.

I also told the panel that each of these options involves an element of public risk taking. For each option there will exist a range of response strategies that offer a range of costs and benefits in terms of lives, property, and social disruption. For each option these costs and benefits will fall on different elements or segments of society in a disproportionate manner. This raises an element of political risk taking for me. The optimum public interest may differ from the optimal private interests of my supporters. To make a proper decision I need to know these facts as they relate to or control the decision options available to me.

That's a tall order for any group of people to ponder in 24 hours. If that isn't enough, however, I need to know how I can protect the local official from liability so he will be free to act. I need to determine the extent of liability that I might incur personally and for the state. I need to know how to induce people and organizations to act by implementing effective compensation measures. I need to know what is proper and possible to expect as support from the agencies of the federal government. After all, hasn't this become their earthquake now that one of their agencies has predicted it?

B. What Do We Know About Future Impacts?

1. Introduction

In the course of developing the scenarios in the preceding section, we assessed them for plausibility and found that the events described are possible. However, the scenarios were created on the assumption that society had done little to prepare for the coming fact of earthquake prediction. Since a major purpose of technology assessment is the determination of what actions must, should, or can be taken in the present to influence future events, an assessment faces the policy situation where the future might become a limited basis for present decision-making. This section examines the limits of that basis as derived from the scenarios.

The scenarios suggest that a large number of impacts and issues could result from the anticipation of earthquake prediction, and they are all possible and contingent. This section assesses and organizes general classes of future events and attempts to determine the extent of the uncertainties inherent in them.

2. The Earthquake-Prediction System in Society

Earthquake prediction provides society with information. If it is to benefit from this information, society must learn how to use it. The actions taken by society in the hope of mitigating the effects of a predicted earthquake will affect socioeconomic and environmental systems. Others, individuals and groups, may act on the information for other purposes, creating further impacts. There is a problem therefore of sorting impacts as between (1) those that cause the facts to be questioned in terms of the actions based on them and (2) the actions themselves independent of the facts on which they are based.

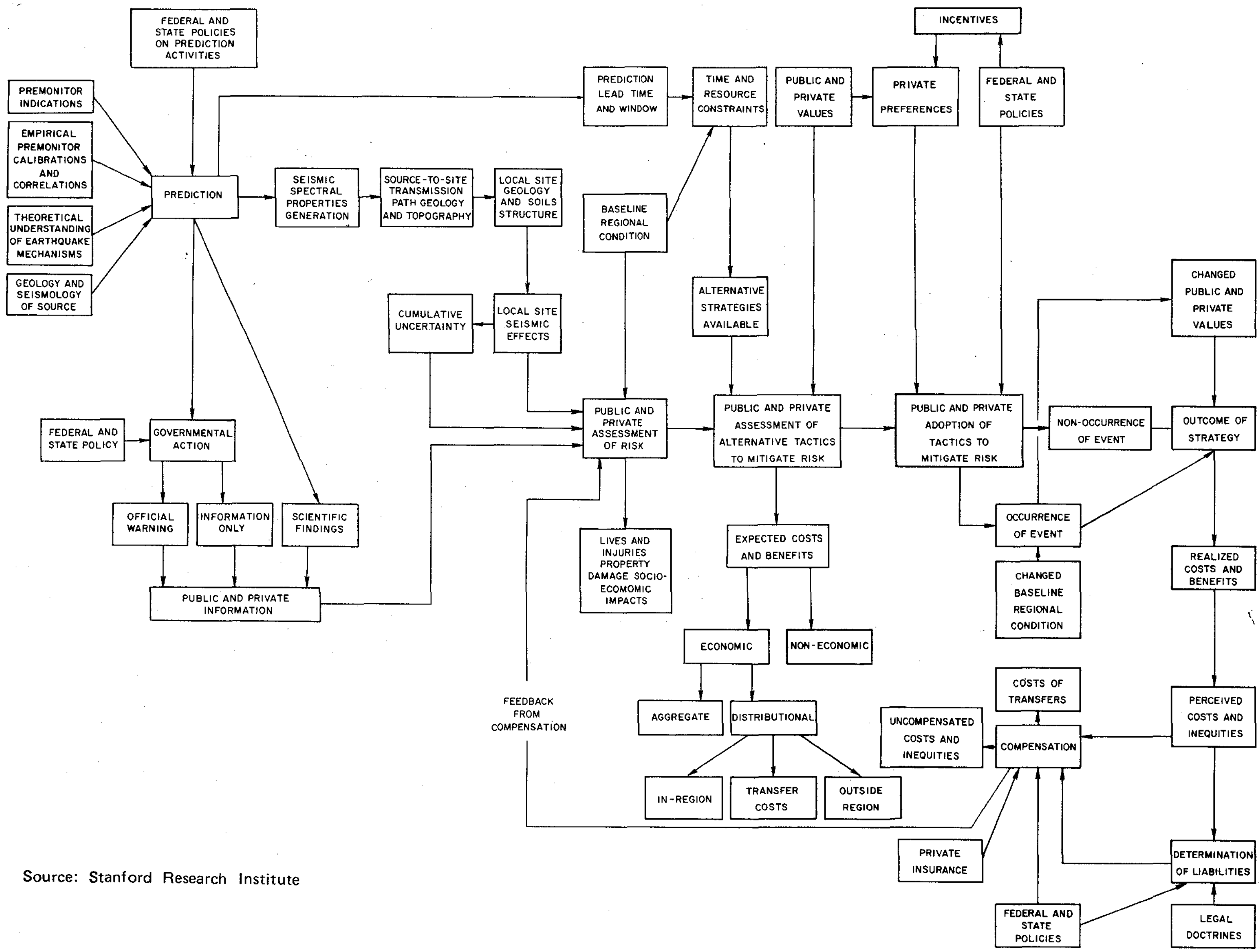
The earthquake-prediction scenarios presented in the preceding section, although taken from different viewpoints and based on different situations, are variations on a general theme. By developing that general theme, we can find appropriate ways of differentiating and categorizing the many impacts and hence the basic issues they raise. We have expressed that generalized theme as a conceptual model of an earthquake-prediction system in society. This is shown in Figure 8. This concept consists of three major parts: prediction information, mitigation tactics, and outcome.

The prediction information part of the concept consists of five components:

- Technical Generation Component--Describes the activities, findings, and knowledge bases that enter into a given prediction.
- Public Information Component--Describes the format of a prediction that will emanate from the technical community. The form and content of a typical prediction are shown in Table 2.
- Warning Component--Describes the process of validating or converting the public information component into information worthy of possible action.
- Technical User's Component--Converts the earthquake prediction into the prediction of effects at a specific location. These are the so-called direct effects of an earthquake, such as ground failure, shaking, and tsunamis and seiches.
- Decision Component--Represents the cumulative uncertainty of the information at each step in its generation and processing, since the uncertainty will increase at each step. The uncertainty should be a factor in any decision based on the prediction information.

The mitigation tactics part of the concept has three components:

- Risk Component--Describes the expected deaths, injuries, property damage, and socioeconomic impacts resulting from the predicted earthquake, taking into account the baseline earthquake-prediction condition at the predicted time of the earthquake.
- Mitigation Assessment Component--Describes the effect of the available mitigation measures in terms of their expected costs and effectiveness in reducing risks.
- Mitigation Adoption Component--Represents the decision process or rules by which a set of mitigation tactics is adopted.



Source: Stanford Research Institute

FIGURE 8 EARTHQUAKE PREDICTION SYSTEM DIAGRAM

Table 2

EXAMPLE OF THE PUBLIC INFORMATION COMPONENT OF EARTHQUAKE PREDICTION

Lead time (months)	6
Window (weeks)	±3
Epicenter or region of fault ruptures	San Juan Bautista to Los Gatos along the San Andreas Fault
Magnitude (Richter)	7.0-7.2
Confidence that event will occur (percent)	85
Contingent effects	Possible 8.3 Richter magnitude along entire "locked" San Francisco Bay section of the San Andreas Fault (no confidence judgment possible)

The outcome part of the concept has two components:

- Outcome Component--Describes the actual outcome of the prediction and the adopted mitigation measures in terms of the costs and benefits realized and their distribution.
- Compensation Component--Describes the extent to which, and the process and rules by which, perceived costs and inequities are to be compensated by whatever policy is in effect.

The earthquake-prediction system shown in Figure 8 is generalized to accommodate all levels of aggregation at which society may respond, from the individual to institutional and governmental levels. In this context, much of the socioeconomic disruption caused by earthquake prediction is the result of interactions between conflicting sets of mitigation tactics adopted by different aggregations of society.

Although not specifically shown, there are also interactions and feedback between the different parts of the earthquake-prediction system. For example, if the baseline regional condition is, by virtue of building and zoning practices, such that there is little residual risk from the predicted earthquake, prediction begins to become marginally useful. Likewise, if there is a liberal federal policy for damage compensation, the assessment of risk will be viewed differently by those potentially affected.

Earthquake prediction is not an activity that can be isolated for one sector of society, viewed in terms of isolated parts of the system, or regarded as an activity isolated from the rest of society. The organization of possible future impacts must reflect these interdependencies.

3. Public Knowledge About Earthquakes and Earthquake Prediction

Eight earthquake-prediction questions were included in the February 1975 quarterly Fieldscope.* Personal in-home interviews were conducted with 1,004 California residents. This section summarizes the results of the survey and describes what the respondents, who were typical members of the general public, knew about earthquakes and felt about earthquake prediction. The survey results allow an assessment of individual potential for action. It reflects the personal information base that people will use in reacting to predicted and unpredicted earthquakes. As such it is important input for specifying the requirements for an earthquake prediction system.

Survey responses have been cross-tabulated as to age, sex, income, education, and area of residence in California. The categories are as follows:

Sex	Male, female
Age	18-29, 30-39, 40-49, 50-59, 60 and over
Income	Under $7,000, $7,000-$9,999, $10,000-$14,999, and $15,000 and over
Area of California	Southern California--Los Angeles and Orange Counties, other southern California
	Northern California--Bay Area, other northern California

*The Fieldscope Report of the Field Research Corporation presents data from a California statewide survey of public opinion.

In some cases, responses by individuals in certain of these categories differed significantly from the typical response. These significant differences serve as the analytical basis for identifying especially strong or weak points to be considered in considering the information flow related to earthquake prediction.

a. Concern About Earthquakes

At least 75 percent of the respondents expressed some concern about a major, damaging earthquake occurring at their location. The group most concerned were those aged 18 to 29, with 31 percent extremely or very worried. Other groups expressing concern were women, persons with incomes under $10,000, persons with 1 to 2 years of college, and those living in the Los Angeles area. Almost 25 percent of individuals in these groups were either extremely or very worried.

With 25 percent of the individuals in some segments of the population worried, it is very interesting to find 25 percent of the individuals in other segments not at all worried. Twenty-five percent of those over age 50, those with incomes in the $7,000 to $9,999 range,* or those living in northern California outside the San Francisco Bay Area were not at all worried. Sixty-three percent of all respondents were somewhat or not too worried about a major, damaging earthquake occurring in their area.

Only 8 percent of all respondents felt that a major, damaging earthquake was not at all likely to affect them in the next 10 years; thus one can safely say that most Californians expect a major earthquake to affect their lives. More than half the younger age group felt it was extremely or very likely that an earthquake would affect them; this is probably the basis for their concern. There were significant differences between age groups: 15 percent of those aged 18 to 29, compared with 32 percent of those 60 years of age and older, felt that a major earthquake

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*Respondents in the $7,000 to $9,999 income group were fairly evenly spread from extremely worried to not at all worried.

was not too likely to affect them. Thus the survey results indicate that the expectation of a major, damaging earthquake diminishes with increasing age. Los Angeles area respondents felt there was a strong likelihood of a major earthquake affecting them.

b. Knowledge of Secondary Earthquake Effects

Most respondents knew that there is more to an earthquake than shaking. The responses to "Please describe what, besides shaking, you think would happen during and after a major, damaging earthquake" fall into such categories as

- Physical loss or damage.
- Interruption of services and shortages.
- Socioeconomic effects.
- Deaths, injuries, and health problems.
- Other results (including response by institutions such as the National Guard or the Red Cross and further seismic activity).

The following list of responses by categories indicates the type of knowledge the general public has about the secondary effects of earthquakes:

Secondary Effect	Percentage of Respondents Mentioning Effect
Physical loss or damage	
Damage and loss of buildings and homes	49
Fire	36
Damaged streets, bridges, and freeways cannot be used	14
Floods, tidal waves, water damage	10
Personal household property damage, broken dishes	8
Explosions	6
Broken windows and damage from flying glass	6
Total	129

Secondary Effect	Percentage of Respondents Mentioning Effect
Shortages and interruption of services	
Water shortage	26
No gas or gas leaks	22
No electricity	18
Utilities out (general)	9
Food shortage	7
Medical facilities overburdened	5
Total	87
Socioeconomic effects	
Panic and chaos	31
Looting, vandalism, violence	13
Homeless, displaced persons	7
Disruption of communications	6
Reconstruction and temporary boom	4
Depression and loss of jobs	3
People will leave state	2
Total	66
Death, injuries, and health problems	
Death	18
Disease, plague, contaminations	15
Injuries	13
Total	46
Other results (including response by institutions and further seismic activity)	
Awful things, topsy turvy	5
Red Cross, Civil Defense, state would help	3
Martial law	1
Earth opens up, things fall in, earth cracks	15
Earth moves, slides, settles, rolls	7
Aftershocks	3
Lots of noise	2
Total	36

Respondents frequently described more than one secondary effect. The groups naming the most secondary effects were those aged 30 to 39, members of households with incomes over $15,000, and those with some college education. The older, the less well educated, and those with lower incomes described fewer things that would happen during and after an earthquake.

c. Public Sources of Information

Respondents were asked, "Have you seen or read any recent information about earthquakes on TV, in the newspaper, or have you seen the recent movie 'Earthquake'?" If the response was yes, the respondent was then asked the source of the information. Seventy-two percent of the sample mentioned having heard or seen earthquake information. More than half (54 percent) named the broadcast media as the source.

The Los Angeles area depends far more heavily on the broadcast media than does the Bay Area. Furthermore, over 10 percent fewer respondents in the Bay Area mentioned any earthquake information from the media when compared with the Los Angeles group, as shown in Table 3.

Table 3

PERCENTAGE OF RESPONDENTS HAVING RECENT EARTHQUAKE INFORMATION

Source	Percentage of Respondents		
	Los Angeles/Orange	Bay Area	Total
TV/radio	60	43	54
Newspaper/magazine	35	32	37
Movie "Earthquake"	11	9	7
Other	2	5	4
Net mentions	76	65	72
None of these	23	33	27
Don't know/no opinion	1	2	1
Total	100	100	100

d. Public Acceptance of Earthquake Information

Most respondents (72 percent) felt it was a good idea to give people several months' advance warning when scientists expect a major, damaging earthquake to occur. Again, the 30 to 39 age group was most inclined to agree; their interest in earthquakes and earthquake protection was consistently higher than that of other groups, from question to question. Younger persons, the college educated, and those with higher incomes were somewhat more favorably inclined toward prediction than other segments. From 10 to 20 percent of the respondents in most groups felt prediction to be a bad idea, with the most negative group being those over 60 years old (31 percent). Some (about 6 percent) qualified their answers about the advisability of prediction. Less than 5 percent of those questioned had no opinion. With over 95 percent expressing an opinion about prediction--80 percent favorably--there is evidence of interest regarding earthquake prediction. This interest indicates that people would be receptive to further information on the subject.

e. Anticipated Effects of Prediction on the Economy

More respondents (three times as many) felt that an earthquake prediction made 18 months in advance would have a negative effect on the economy than a positive effect. About 20 percent felt there would be no effect, and 5 percent did not know. Negative effects were most often named by those aged 40 to 49 and those with higher incomes and education. Respondents aged 18 to 29 and those with the lowest incomes felt that the economic effects of prediction would be positive.

f. The Question of Accuracy

Respondents were asked how accurate a prediction would have to be before government agencies were required to act. Before asking this question, the interviewers explained briefly the nature of prediction and gave an example that included an 80 percent chance of an earthquake occurring in August 1977. The responses suggest that the general public does not understand probability statements or does not know how probability could be used as a public-decisionmaking criterion. This question received the "don't know" response more than did any other question.

The information given may have been confusing in that it did not discriminate between the uncertainty in time and the uncertainty in the earthquake occurring at all. Predictions should show confidence limits or ranges, or probability distributions in the expected earthquake parameters in addition to putting an expression of confidence on its occurrence within the stated parameter limits. If this is not possible, they should differentiate between uncertainty in that time of occurrence and in the event occurring at all. A statement that a damaging earthquake will strike San Francisco in the future is virtually 100 percent certain, but it puts no limits on the time and so has a limited basis for action. A prediction that it will occur in December 1979 has little if any validity and therefore a low probability of occurring and also has a limited basis for action.

Using probabilities or confidence limits in warning statements will require a clear and detailed explanation of their basis and meaning if the public is to understand and respond to them. An alternative is to establish decisionmaking criteria in nonnumerical terms and express warnings in qualitative, rather than numerical, terms. It is expected that early predictions will be highly judgmental and therefore amenable to qualitative expressions. For example a statement that "the odds are better than even" has a strong judgmental connotation, while a statement "that the probability is greater than 50 percent" implies an experiential basis supporting the numerical expression.

g. Precautionary Measures for a Predicted Earthquake

Although most respondents answered the open-ended* question "If you heard that government scientists predicted an earthquake, what precautions, if any, would you take?," nearly 25 percent said there was nothing they could do, as indicated by such comments as "no precautions can be taken," "just wait it out," "nothing you can do." Besides those expressing inability to take precautions or regarding precautions as futile, 2 percent said they would pray. Another 4 percent felt it was not possible to predict earthquakes, and an additional 4 percent said that taking precautions would depend on both the severity and credibility of the prediction. Thus about 33 percent might resist taking specific precautionary measures.

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*An open-ended survey question does not provide categories to the respondent. Respondents are asked the question, and the interviewer records the response. Similar responses are later grouped together and tallied.

The precautions named fall into two general classifications: departure and protective measures. The departure responses can be broken down as follows:

Would leave area temporarily/take vacation	26%
Would move away	12

Five percent said they could not move or leave. More persons indicated they might leave than that nothing could be done. According to this analysis, more than half the population would either do nothing or leave. The remainder, those who would remain and take specific precautionary measures, would act as follows:

Store food, water, other supplies	12%
Secure objects in home/prevent damage	9
Help family and friends/instruct family what to do	8
Find safe place in home (doorway, under table)	6
Safety check of house/reinforce some areas of home	6
Take precautions suggested by government/ follow instructions	6
Turn off gas/electricity/utilities	5
Stay in house/stay where I am	3
Take out earthquake insurance	2

Certain segments of the population were more inclined to leave, while others felt less able to take action. Specifically, younger people would leave, while older persons felt more fatalistic and doubtful.

Income and education appear to be related to mobility. Respondents with higher incomes or very low incomes and those with more education would be most likely to leave the area to avoid the effects of an earthquake. The more permanent moves would be made by those earning less than $7,000 (14 percent) and those with either a high school education or 3 or more years of college (14 percent each). Those in the middle income levels and those with 1 to 2 years of college education would be less likely to move away.

h. Conclusions

Analysis of the Field Research Corporation data indicates that it would be possible to inform almost all people who would be affected by an earthquake through prediction and warning. However, although information might be disseminated, not all would act on the information--especially doubters and fatalists.

People in the 30 to 39 age group appear ready to take the actions necessary to avoid the secondary effects of earthquakes. People over 60 years old would be difficult to inform and would need the most encouragement to take protective action. Other age groups would be relatively responsive to earthquake prediction. When societal segments are analyzed by income and education level, it appears that earthquake awareness (a combination of concern, understanding of likelihood, and knowledge of secondary effects) and ability or willingness to act cut across all levels.

Although most people would be able to respond to earthquake prediction, information needs and sources would differ from group to group.

The 30 to 39 age group named the most precautionary actions. Women indicated more interest in giving and following instructions and finding safe places for the duration of the earthquake than did men. The population segments most likely to take the precautions suggested by government and follow instructions are aged 30 to 39 or over 60, earn less than $7,000, have 1 to 2 years of college, and live in northern California.

4. The View of Local Officials Concerning Earthquake Prediction

Governmental officials at the local level--cities and counties--will be required to implement any state or federal government responses as well as to regulate private individual and institutional responses to earthquake prediction. Accordingly they are critical actors in the earthquake-prediction system. Fifteen representatives of San Francisco Bay Area planning and disaster-preparedness organizations were interviewed in depth to obtain their view of earthquake prediction from the perspective of their authority and responsibility. The interviews were conducted by a member of the project team experienced in the technique and also in local government.

a. The Local Perspective

If it is possible to predict earthquakes, will this allow society to take actions that it cannot take now? Since any action taken is likely to have positive and negative effects, society, or society's agents, must carefully balance perceived harm against perceived benefits in assessing a course of action. This comes very close to a discussion of economic trade-offs that is often developed at the macrolevel.

The perspective and concerns of local officials, however, show very different considerations. They are not concerned with the "macro" arguments; they are interested in the effect of such an announcement on their particular jurisdiction. It is irrelevant that another area will benefit if local officials believe that their jurisdiction will be hurt. The natural tendency under these circumstances is to negate the announcement. If they feel that their position could be jeopardized, their negative reaction will be even stronger. Whether such threats are "real" is irrelevant; if they are perceived as real, they will dictate action. This is not a new or startling assertion, but its importance should never be underestimated. People, whether they are acting in a private or a public capacity, tend to protect what they perceive to be their interests. It is important to note that the recent interest in seismic safety in California is the result of state legislation, not a "grass roots" movement. Seismic safety is simply not a priority item to local government.

b. The Actors

Any earthquake prediction would logically be evaluated by the state government. It is the traditional level from which disaster warnings are issued, and local officials feel that this is the appropriate level since the state can more easily assemble the necessary expertise.

Currently, in California there is no single local agency in a position to respond constructively to the governor's warning. The two agencies most likely to be involved in such a response are the planning and disaster-preparedness and response departments. The planning department with the building officials would be most involved in the case of a long lead time, at least a year. This would allow time for implementing programs based on improving the structural characteristics of facilities. However, most local governments would not be able to expend large amounts of resources since they do not have reserves of cash to be funneled into this activity. As one official put it, even with a 10-year lead time, his city could not afford to rebuild its central business district. Moreover, some courses of action would generate extreme resistance in segments of the business community. A shorter lead time would not allow for major involvement by the planning department but would emphasize preparations for responding to the threatened disaster. Even within a given county, each city is responsible for its own disaster plan; the county serves as a coordinator and has disaster-preparedness responsibility for unincorporated areas. The extent of preparedness is likely to vary with the resources of each jurisdiction and the stance of the administrator. Preparedness is further limited by its essential novelty; disaster officials are oriented to action after the disaster occurs. Acting before the event is "unnatural" since they do not yet know what will happen. There is no clear answer to the question of who will act in response to an earthquake warning issued by the state. One can only conclude that there is no well-defined local government group that could fully exploit an earthquake prediction and warning, and the agencies with de facto responsibility are not experienced in the type of response necessary to fully utilize this information.

c. Limitations and Constraints

The agencies with de facto as well as de jure responsibility are constrained by other factors, which may be roughly classed as fiscal and political. California seismic safety legislation mandates an analysis of seismic hazards in each jurisdiction. Although all jurisdictions had performed seismic risk analysis at some level, none of them had concrete estimates of what could occur in the wake of a substantial earthquake. Furthermore, any attempt to develop estimates of property damage is seen as a political "hot potato." It would necessitate a building-by-building analysis of the area, straining local resources and probably generating tremendous resistance from certain segments of the community. Furthermore, once a building is found to be hazardous, the local agency having knowledge of that condition would have to condemn it or force the owner to bring it up to standards. This course of action would be unpopular with real estate and building interests, particularly in those older cities where much of the central city is of doubtful seismic safety. It is unlikely that marking buildings as safe or unsafe in the event of an earthquake will ever become a widespread practice of local agencies. In addition to the reasons cited above, marking buildings raises the question of liability. If a local government knows that a building is hazardous, it is potentially liable for the losses and injuries resulting from that condition.

The types of actions that local officials feel could be carried out in response to an earthquake prediction illustrate their concerns. Reinforcing the worst buildings, alerting local disaster-response officials, collecting supplies, and holding first-aid classes for citizens were all considered feasible. Most important, officials feel strongly that citizens should be informed. Under the existing conditions, it is unlikely that more would be attempted, particularly if additional actions involved added costs.

The use of earthquake prediction to evacuate "danger" areas induces skepticism in most local officials. Evacuation has never been ordered before the fact, without a clear and present danger. An observable breach in a dam would be cause for evacuation. The prediction of an earthquake that might breach the dam is not cause. Evacuation, or indeed any stringent measure, before the fact is a direct departure from the customary response procedure. Any such action would require an entirely new mandate from the state. Moreover, though many people will voluntarily evacuate when advised of a dangerous situation, many others will not, and they cannot be forced to leave against their will.

Large-scale evacuation--for example, clearing major sections in a county--was not considered a viable alternative at all because it presents many fiscal and political problems. First, people would have to be evacuated to somewhere. Other jurisdictions would have to agree to accept the evacuees. Second, the empty property would create major law-enforcement problems. The cost would be tremendous, and local government could not meet it unassisted.

d. The Usefulness of Earthquake Prediction

If earthquake prediction is to become useful, the state will have to assume an active and responsible role. There is strong local sentiment that the state should play a major role in assessing the validity of a prediction. Accordingly, if the state feels that such a course is justified, it should also issue the official warning. Its responsibility should not stop at this point. A major earthquake is such a large-scale event, involving so many jurisdictions, that the consequences of a wrong prediction are overwhelming. As the agency issuing the prediction, the state should be at least partly responsible for the consequences of actions taken in response to its warning. This would diminish some of the constraints that currently inhibit local government. A bill (SB-1950) recently passed by the California legislature is of interest in this regard. Its intent is to grant immunity for actions taken or not taken as a result of a "scientifically valid" earthquake prediction. The bill was pushed through the legislature on an "emergency" basis and was signed into law by Governor Brown on September 29, 1976. This bill raises the questions of what constitutes a "scientifically valid" earthquake prediction and whether the courts would uphold such legislated immunity.

Given a substantial lead time, if the state or federal government were to make "predisaster" funding available, much could be done locally to increase the safety of older central city areas. The state could also develop a pool of building inspectors to assist threatened areas in assessing potentially dangerous buildings. Perhaps most important, the state should clarify the legal issues involved.

When is a jurisdiction liable, and when is it protected from liability? Who should pay the costs resulting from an erroneous prediction? When is evacuation worth the social and economic cost to an area? What types of seismic-effects information should be made available to prospective homeowners? Local officials must be provided with a clear framework of responsibilities and liabilities before they can effectively utilize prediction information.

Any prediction system that is developed should not stop with a description of the event. Rather, some attempt should be made to develop an idea of the potential effect on various areas. Planners do not really care about seismological parameters, but they are concerned with what is going to happen to the buildings in their jurisdiction.

Before earthquake prediction is truly viable in the eyes of local officials, it would have to have an established, very high success rate. Any erroneous predictions, particularly in the early stages, would reduce the credibility of subsequent statements. Although the public should be informed of developments, no official earthquake warning should be issued until there is an established track record to justify such a stance. Most officials feel that a record should contain at least 90 percent accurate predictions!

5. Some Impacts of Earthquake Prediction

Because earthquake prediction is a future possibility, not an accomplished fact, we have no direct experience with the system to check findings. We are not sure what the final product will be, when it will be usable, or where it will actually be used. The judgments expressed in this section are based on comparison with the impacts of prediction and warning in other disaster settings as well as analogies with social programs having similar effects. The limits of the findings are set by the validity of these comparisons and analogies.

a. The Problems of Earthquake Prediction

Current societal response to earthquake hazards is a product of both the level of knowledge about earthquakes and the nature of the event itself. A serious event occurs infrequently. Thus it is unlikely that any one generation will experience more than one such earthquake. Earthquakes occur without forewarning. Warning signs of seismic activity are not visible to untrained observers, who rely on historic evidence to decide whether their area may be subject to earthquakes. Onset of a large or great earthquake is immediate, and the duration of the event is extremely brief (15 seconds to a minute or more); the damage, however, is usually severe, and recovery is a long-term process.

The majority of people at risk have no experience from which to conceptualize the event. This fosters the fatalistic feeling that an individual can do little to change events beyond some vaguely defined and often expensive modifications to the man-made environment.

The ability to predict earthquakes would change one basic element in the disaster scenario: The population would be more immediately aware that an earthquake is imminent. Predictions can vary in accuracy and level of detail. Although prediction may improve the estimate of earthquake probability (within the next few decades), it is not expected to offer certain knowledge of earthquake events.

Arguments against the development of an earthquake-prediction system can be conceived along one or more of three basic lines:

- The prediction of major events would not change the outcome of the event because people would not believe the prediction; even if they did, there is little that anyone can do to escape the consequences of an earthquake.
- Although prediction may appear to benefit society, its overall effects will be harmful. It will induce socially harmful behavior, such as panic, looting, and anxiety. It will increase economic losses by reducing economic activity before the event.
- The costs of protection will fall inequitably on those who can least afford it or who will benefit least from it. This issue has not been brought out specifically in discussions of earthquake prediction, but it plays a role in many public policy decisions.

- The net value of earthquake predictions to society may be positive, but this benefit will be insignificant in comparison to the opportunities foregone for more important research (either in other fields of earthquake protection or on entirely different social problems).

Prediction will affect the entire disaster sequence to the extent that it changes preevent information, behavior, and attitudes. The response may appear in several distinct forms, including psychological adjustments to fear, physical modifications of the natural and man-made environments, and the development of agencies and programs concerned with disaster response.

Individuals and communities can respond to warnings only to the extent that they have resources to do so. For example, an inadequate supply of transportation vehicles or fuel would impede evacuation after a short-term warning. Because resource distribution is unequal, the ability to respond to a warning may vary with communities and individuals.

b. Effect of Policies

Many of the major impacts of a prediction are determined by the public policy that follows the prediction; for example, institutional changes may result from the process of introducing a regionally coordinated emergency response program to respond to a particular disaster threat. Programs of demolition, reconstruction, and renovation have been suggested as a means of responding to a long-term earthquake threat. However, over a longer period the impacts might resemble those of urban renewal programs. Studies of experiences in urban renewal have shown that the process of relocation, even when accompanied by financial compensation, can cause long-term disruption for individuals and social groups. Some groups likely to feel the effects of relocation over the long term are cultural groups whose cohesion relies on elements of the physical setting (e.g., proximity to friends); elderly residents who fail to find housing in a community equally suited to their needs; small business owners who rely on a local clientele established over a long period of time (this group often includes many elderly shop owners who are forced to retire early because they cannot rebuild their business elsewhere); and low-income families who cannot find similar living accommodations for similar rents.

c. Effects of False Predictions

One fear associated with the emerging prediction system is that errors will make the system cost more than it is worth. However, if people are convinced that the warning was given because the disaster was a serious probability, they are not likely to resent the temporary inconvenience. For example, in comparison with the possible devastation that could result from a major earthquake, the inconvenience of an evacuation in response to an earthquake that did not occur may seem insignificant. In cases of long-term prediction, the investments may be greater. The costs may be suffered prematurely but need not be totally wasted. The greatest loss from false alarms may be the loss in prediction-system credibility.

d. Evaluation of the Prediction System

The major problem in managing prediction technology for social good will be in ensuring that it remains useful rather than in preventing potential damage from the system. The greatest variation in earthquake-prediction effects may result from the public policy choices on how to act during the predisaster phase.

A particular earthquake prediction system can be evaluated in detail only when its specific capabilities are known and when the resultant public policies and programs can be anticipated. In many cases the effect of disaster-related policy on the social system may override its immediate effect during the disaster.

6. The Warning Process and Emergencies*

a. Credibility of Warnings

In order for earthquake predictions to be taken seriously--that is, believed, heeded, and used as a basis for action--it is not enough for them to be scientifically true and made in good faith. They must also take full account of the complex social process by which words are translated into knowledge and in turn into action.

The practical benefits of an earthquake prediction--preventing deaths, injuries, and destruction of property--cannot be fully realized unless a number of stringent conditions are met:

- The prediction must in fact be a warning; it must convey a presentiment of actual danger, not just neutral "scientific" information.
- The warning must be specific as to time, place, and intensity and must accurately identify the areas, populations, and structures at risk.
- The warning must contain prescriptions or at least strong suggestions for action.
- The warning must be disseminated through the society's existing communication system, using formal and informal networks of communication.
- The warning system as a whole should adhere to the "principle of redundancy"; that is, it should provide alternative independent pathways of information flow that are mutually confirming and consistent when cross-checked.

b. Content and Specificity of the Warning Message

In all cases word-of-mouth is an essential means of disseminating warnings whether or not they have first been received from the mass media. Those who are not in danger, as well as those who are in danger, must be informed.

In the longer term warning period provided by earthquake prediction, a wider range of communications media could be used. The

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*A selected bibliography on the warning process and emergencies can be found on pages 313 to 315.

longer lead time would also allow greater depth of communication and would create an opportunity to educate the public as to the nature of earthquake risk. As a general rule, providing a higher quality of information enhances its credibility. Warnings that are convincing without causing panic or anxiety are more likely to elicit an effective response.

In the case of earthquakes, many local officials have commented that knowing the Richter magnitude is of little help to them. They need to know what will happen to structures on the surface, not what is going on below the ground.

Some psychological research indicates that ambiguous messages hinder effective response. At least two types of ambiguity are of interest here: conflicting content within the same message and conflict between two different messages. For example, the semantic content of the message may tell the listener one thing, but other signs tell him the opposite. This generally results in disbelief and inaction. Contradictory advice received from two different messages can also lead to undesirable responses. Warning messages formulated on the basis of the current state of earthquake-prediction technology could engender substantial ambiguity and thus hinder effective response.

Predictions of natural disasters usually specify the time, place, and force of the expected event. The details should indicate--with as much precision as the technology allows--<u>who</u> has to prepare for the threat, <u>when</u> they have to start preparing, and relatively <u>what degree</u> of danger to expect.

c. <u>Framework for Action</u>

For earthquake predictions to be effective, they will have to be linked to a relevant framework for action. Communities in disaster-prone areas vary greatly in the extent to which they adhere to a predisaster plan of action. In most disasters, preparedness plans are likely to be upset by events or unpredictable elements. Therefore an appropriate framework for action must take into account not only special-purpose disaster-preparedness organizations but also other community resources that can be mobilized.

The recipient of a warning tries to assess its significance for himself and for others. He seeks information that will guide him in adapting to, and coping with, the new situation. If the warning period is very short, the recipient has relatively few response options. Lengthening of the warning period, as in the case of earthquake prediction, would allow for more thoughtful evaluation. Because long-term earthquake predictions would allow the greatest latitude for action, they would paradoxically be the least effective warnings. The credibility of earthquake predictions would be subject to much closer scrutiny than disaster warnings have been in the past.

d. Communication of Warnings

It has been found that ideas do not flow from broadcast media directly to amorphous masses of people; instead they flow first to someone who is generally accepted as an opinion leader in that area and then to others around that person. Opinion leaders are not always prominent in the community. Furthermore, those who influence opinions regarding the choice of a hairspray may not be influential regarding the purchase of an automobile. Empirical research on communications processes discloses the existence of a greal deal of "horizontal leadership" coexisting with recognized (officially designated) "vertical leadership." Warnings are not exempt from the processes by which other information and ideas are disseminated. To be effective, an earthquake warning process would have to locate opinion leaders in each group or community and persuade them to take disaster preparation action. Such factors as interest, gregariousness, status, and expertise seem to affect a person's ability to influence the opinions of others.

e. Redundancy of Information Sources

Probably the greatest source of uncertainty in emergency warning systems is the failure or inability to confirm information from one source with that emanating from another, independent source. This problem is particularly acute in the case of earthquakes because earthquakes provide no visible or audible clues to anyone except a trained observer of seismological instruments. The recipient of a warning message is often asked, in effect, to make a fateful decision without having the opportunity to verify the message. People seek confirmation from a variety of sources before taking action. They consult with family members, friends, neighbors, and work associates over the interpretation of official warnings. Failure to provide alternative sources of information as part of the disaster warning process results in confusion, inaction, or inappropriate action.

During the period immediately after a warning, warning information is evaluated and evaluations are shared. Evidence from a variety of sources is collated; people compare notes, talk over differences in the information they have received, and decide whether they are significant. If the sources seem consistent, the warning gains in credibility. Longer warning periods, on the other hand, such as would occur with earthquake predictions, would expand the arena of discussion leading to reinforcement or lack of reinforcement. For the earthquake warning process, these findings suggest that different channels and forms of communication be opened up, so that opportunities for confirmation are maximized.

f. Explaining Away Abnormalities

The sociological literature on disasters is replete with examples of people explaining away warning signs and attempting to incorporate them into some normal definition of reality. As long as responsibility can persuasively be attributed to nature, chance, or fate, even man-made disasters can be accepted as normal events.

g. Adapting to Emergencies

Communities with recent disaster experience have consistently been better prepared and organized for disasters than communities without such experience. Since large earthquakes rarely recur in the same locality within a given generation, collective memory cannot be depended on to relate past experience to future planning. Earthquake warnings must substitute to some extent for the disaster experience itself. An earthquake warning requires, in other words, that the affected population adapt to an impending emergency before any physical signs of disaster have appeared. Moreover, it requires that this adaptation be made at the urging of a human agency, rather than as the result of a natural event or the personal experience of those involved.

Would people respond to a warning in the same way that they respond to a real disaster if the warning resulted in some of the disruption caused by a disaster? Presumably the purposes of earthquake warning would be best served if adaptive action on both the individual and organization levels were carried out without disruption. Yet such action would require at least some "controlled disruption" simply in order to recognize and respond effectively to the impending emergency.

h. Uniqueness of Earthquake Prediction and Warnings

Effective earthquake prediction should allow the community at risk to generate adaptive action. People could be confronted then with a long period of emergency preparedness activity while continuing in an apparently normal state of affairs. There is no situation closely resembling this one in the social research on disasters.

i. Human Responsibility for Disasters

No "natural" disaster is completely separate from human responsibility, if only because choices are made as to where to locate human settlements, and these choices pose risks for residents. As we gain more understanding and control over the forces of nature, the scope of human responsibility increases. As a consequence, it becomes more and more difficult to blame a diffuse entity like nature for some misfortune. Blame and responsibility become attributed to people, increasing the possibility of social conflict.

Earthquake prediction would clearly enlarge the scope of human responsibility for earthquake damage. In addition, it could create legal liability for loss of property value. Knowing in advance where a severe earthquake will strike creates a responsibility to take life-saving and property-protecting measures. Earthquake protection is more a private matter than a public one when earthquakes are considered to be absolutely unpredictable. Successfully predicting large earthquakes would tip the balance significantly toward public responsibility. Yet it would not by itself create any new authority. Increased public responsibility would very likely be rejected by local officials until issues related to compensation were clarified and until institutional, fiscal, and political capacity became commensurate with enlarged responsibility (see discussion in Section III-B-4).

j. A Prediction-Induced Emergency?

Some have adopted the point of view that earthquake prediction could be more disastrous than the earthquake itself. They warn of mass psychological distress, abandonment of homes and businesses, and depopulation of whole communities. Earthquake-prone areas, it has been argued, would suffer catastrophic loss of real estate values, decline in tourist and convention business, and reduction in retail sales. Long-term economic decline would occur as the result of businesses relocating to safer areas and buyers seeking a more secure source of supply. Those who have adopted this point of view have, in effect, made an analogy between the social and economic reaction to earthquake prediction and the conventional picture of the disaster itself. There are really two questions here: Would a long-term prediction create such emergency-like conditions when taken seriously, and would it in fact be taken seriously? On-site research has revealed that antisocial behavior during emergencies is negligible and that social systems are often actually strengthened by the demands imposed by emergencies. To the extent that inferences from these data are valid, we can conclude that panic is no more likely after an earthquake prediction than it is after an earthquake.

k. Lead Time and Its Effects

The likelihood of adaptive action would be influenced by the lead time of a prediction. The technology of earthquake prediction is likely to develop the capability of updated predictions that tend to reduce the uncertainty as the event is approached. The implications of this for adaptive action are twofold:

- The original lead time is the maximum available in any case.
- There may be opportunity for long-term as well as short-term responses.

A situation with a few minutes lead time would be virtually indistinguishable from the extremely short term warnings characteristic of past disasters. A few days' warning would resemble also some known past emergencies in that work routines would be disrupted, everyday activity for a large proportion of the community would be redirected to the protection of life and prevention of damage, and personal time perspectives would become drastically shortened. A credible earthquake warning with several months' lead time would alter daily routines less drastically. Efforts directed toward minimizing loss of life and property damage could probably be routinized without disrupting a whole community. Nevertheless they would cause inconvenience. It is doubtful whether a posture of readiness, entailing continuing inconvenience, could be maintained much beyond the several months' lead time specified in the prediction. If the warning specified a time window of high probability, certain protective postures could be restricted to that period. The state of society induced by a credible earthquake warning with several years' lead time would be virtually indistinguishable from its present state. The response to such a warning would become part of the normal environment. This is not to say that earthquake-prone communities are now engaged in such activities to the fullest extent possible, but merely that those communities could engage in such activities without noticeable deviation from the normal state of affairs.

1. Earthquake Prediction and Social Crisis

What are the social conditions that would be associated with an active program of earthquake risk reduction? What role would a credible earthquake prediction play, if any, in generating these social conditions? One plausible scenario capable of yielding these conditions would be the kind of social crisis the American people have experienced in abundance in recent years. A social crisis is to be distinguished from an emergency induced by a natural disaster in that the social crisis is assembled and dismantled in large part by public opinion and those who mold it. A social crisis and the activity it generates do at least four things in addition to the activity's addressing the ostensible problem:

- A crisis enables people to accept sacrifices they would not otherwise endure.
- A crisis justifies large public expenditures that would not be justified under normal circumstances.
- A crisis makes abstract problems real and immediate, providing a forum for popular concern. Issues that are invisible except to specialists are made visible to a wide audience in this way. A crisis demonstrates vividly--in a way no forecast, projection, or prediction can do--the implications of fundamental change.
- A crisis elevates certain skills and kinds of expertise to prominence while reducing the social esteem in which other skills are held.

A crisis with the characteristics outlined above would form one plausible set of social conditions under which expensive earthquake preparation activities might occur. Such conditions would produce a social perception of the earthquake hazard that would differ markedly from the present perception. Priorities for expenditures of public funds would shift toward earthquake-protection activities, and sacrifices would be made in other areas. The problem would appear real and immediate, and experts in various fields associated with earthquake protection would be sought out for advice. To technological and scientific advances would have to be added vigorous lobbying and public relations efforts in order to bring about such a set of social conditions.

Earthquakes do not directly affect the entire nation. Yet it is the nation as a whole that would be called upon to institute a program of earthquake prediction and to pay some of the costs of earthquake protection. Perhaps earthquake prediction would have to demonstrate a significant level of local impacts, either directly or through the adoption of earthquake-protection measures, before federal help would be forthcoming. The question is whether this can be persuasively demonstrated before the fact through appropriate analyses.

A more feasible approach for involving a national constituency would be to adopt a strategy of reducing risks from all natural hazards, through an integrated program of research, insurance, land-use controls, preventive measures, and compensation to those disadvantaged. Earthquake prediction would have to be linked persuasively to a national threat in order to activate a national social crisis. This is essentially a political task rather than a technical or scientific task.

7. Impacts and Issues

The reader will find a rich potpourri in the stories in Section III-A. Although this heuristic approach to impact determination is effective and efficient, it provides no means of knowing whether the impacts so determined are complete and whether they are generally experienced or are specific to the story. Neither does it provide a means of rationally classifying the impacts. Accordingly, in this section we have attempted to derive impacts empirically through surveys and interviews and analytically by defining an earthquake prediction system and using analogies with the findings of social science in other warning and disaster systems and in programs having similar results (e.g., urban renewal).

Social impacts resulting from the development and implementation of technology raise issues of effectiveness, efficiency, and equity.*

*All impacts, even ecological, are ultimately social in nature because they affect the perceived interests of people and institutions.

In other words, does the technology work as intended, is it the appropriate alternative, and does it evenly distribute costs and benefits among different elements of society?

Impacts are often classified as primary and higher order. For earthquake prediction the appropriate distinction is to define the primary impact as the generation of a prediction since that is the basic purpose of the technology. Secondary impacts or higher order impacts in general flow from the activities that are based on the prediction.

In the earthquake prediction system diagram shown in Figure 8, policy components are shown for prediction activities, validation and warning, mitigation tactics, and compensation. This results because there are impacts related to these general issues that raise questions of effectiveness, efficiency, or equity.

The environmental and ecological impacts of earthquake prediction result mainly from mitigation tactics adopted as a response to a prediction and the outcome of these tactics in modifying the effects of the earthquake. The environmental effects of the earthquake prediction system itself--primarily the sensors--will most likely be minimal. However, such tactics as land-use planning incorporating seismic criteria could have significant environmental effects. Lowering levels in reservoirs behind dams and evacuation programs that temporarily locate many persons in a rural environment could have environmental impacts that will most likely be temporary in nature.

C. Earthquake Prediction and Current Protection Measures

1. Introduction

In the preceding section we saw how the impacts of earthquake prediction, which give rise to policy issues, result from the risk-mitigation measures that individuals, institutions, and society at large adopt. In the discussion that follows we consider the various risk-mitigation measures as they relate to earthquake prediction. We also see how they interact with each other through the relationships established in an earthquake-prediction system.

2. Earthquake Risk Mitigation Measures

Earthquake risk mitigation measures are chosen because an individual, institution, or society at large wants to affect the outcome of an earthquake in a way that reduces losses. Obviously it is intended that the outcome be affected at the level of social aggregation at which the measures are adopted. The measures that are available for reducing risks from earthquakes can generally be classified as follows:

- Earthquake engineering
- Seismic zoning
- Disaster preparedness
- Disaster relief and insurance.

The first two operate before the earthquake to reduce the vulnerability of the man-made environment to the effects of the earthquake. The next measure, disaster preparedness, operates before the earthquake to better prepare to deal with the effects of the earthquake as they may affect persons. The last operates to spread the financial losses incurred as a result of the earthquake to a larger segment of society. Because the first three categories of risk-mitigation measures operate <u>before</u> the earthquake, they can be directly related to the characteristics of an earthquake prediction. The last-mentioned measure interacts with earthquake prediction in more indirect ways. On the other hand, all of these measures are available without earthquake prediction. This raises the question whether earthquake prediction is a necessary or useful adjunct to the application of these measures.

The primary characteristic of earthquake prediction that governs the selection of mitigation measures is the lead time provided by a prediction. This raises the complementary question of the time required for each mitigation measure to be effective. By applying earthquake-engineering criteria to new structures, it will take many decades to affect significantly the earthquake resistance of the structural inventory of a region. However, in terms of strengthening existing structures and otherwise reducing their vulnerability, much less time is required, and the limiting constraint could become skilled manpower and resources in many cases.

The application of seismic zoning in a normal environment could also take a long time to reduce significantly the seismic vulnerability of a region. Presumably as certain structures in a potentially vulnerable region reached the end of their economic lifetime, some uses would be banned and only certain uses allowed (e.g., as warehouses instead of as office buildings, as parks instead of homes). Alternatively, in unbuilt areas only certain uses would be allowed as the region expanded. However, in an emergency situation prompted by an earthquake prediction, designated areas or structures could be temporarily abandoned quite rapidly. Earthquake engineering and seismic zoning interact to some extent since some areas could become usable by specifying more resistant structures.

Some disaster-preparedness activities can be carried out with almost any warning lead time. Some cannot be maintained indefinitely. There is probably an ideal lead time for disaster preparedness that allows time to achieve an optimal posture for a given threat but is not long enough to become overly burdensome.

Private disaster insurance will probably not be available after an earthquake prediction. However, for the relatively long periods between predictions of damaging earthquakes, it could again be available. The question is then whether enough persons would be motivated to purchase it. Public disaster relief becomes a substitute for private disaster insurance. Public disaster relief is not sensitive to the warning period except to the extent that preparatory actions may be required as a condition of compensation for loss.

3. <u>Relationships to the Earthquake Prediction System</u>

Earthquake engineering and seismic zoning affect the regional baseline condition. Since these measures have become a part of the normal environment in earthquake-prone regions, they affect the risk assessment on which the mitigation tactics are based. Vigorous programs of earthquake engineering and seismic zoning could, in the period required for earthquake-prediction technology to mature, reduce the residual risk to such an extent that risk-mitigation measures would have little to operate upon. On the other hand, reliable earthquake predictions could allow society to relax its building and zoning requirements because of the opportunity to mitigate the increased risk of death and injury by other measures. To this extent the programs are competitive. However, the argument then becomes based on an economic comparison between the costs of a stringent earthquake-engineering and zoning program on the one hand and structural damage and functional losses and costs of alternative risk-mitigation measures on the other. Involved in this comparison are the useful lifetime of structures and the frequency of damaging earthquakes.

To the extent that prediction allows earthquake-engineering and seismic zoning measures to be taken as risk-mitigation tactics, the programs are complementary. Very long term predictions will tend to merge emergency measures into the normal protection posture. This raises the question of what mitigation measures society would adopt with a 30-year warning that it is not presently doing. Furthermore, is this any different from the information that a region has a return period of damaging earthquakes of 100 years and 70 years have already passed since the last major earthquake? Of course they are not the same when the focus is on the next earthquake. In the prediction case there is no information that an earthquake may take place within a 30-year period or after 30 years, depending on how the warning is framed. In the other case there is only the information that an earthquake has not occurred in 70 years and that the next one becomes more probable with each passing day, but it could take place tomorrow or it could take place 2000 years from now. In any event, these activities that are carried out as a risk-mitigation measure in response to a warning or as a policy of earthquake protection between the warning time and the time the earthquake strikes will reduce the baseline condition of residual risk further.

Widespread compensation for damages, whether it comes from private insurance or public disaster relief, will feed back to the risk assessment. Knowing beforehand that some losses will be compensated will reduce the incentive to adopt loss mitigation tactics. Private insurance companies try to counter this by establishing a 5 percent deductible, which on property valued at $60,000 is $3,000. The deductible is supposedly sufficient motivation for the property owner to take mitigation measures to avoid the loss. Public disaster relief could share costs with the owner or require seismic zoning or the adoption of building codes as a condition of compensation. As described above, this would reduce the regional baseline risk. Either of these strategies is based on the assumption that the cost of the mitigation measure to the owner and thus to society is less than the potential loss.

Disaster-preparedness activities are designed to facilitate emergency operations after the earthquake strikes. Accordingly they directly affect the outcome. Earthquake prediction allows other types of preparedness activities, such as structural strengthening and the evacuation of dangerous structures--items that we have been including under earthquake engineering and seismic zoning. Individuals, institutions, and governments expend resources in these preparedness activities. There are several possible types of outcome:

- The earthquake does not occur as predicted.
- The earthquake occurs, but the realized benefits are not distributed in the same proportion as the expended costs.

Normally the capriciousness of disasters is considered to be a matter of luck or is ascribed to "the will of God." However, as has been discussed previously, by the fact of prediction society and its agents have assumed some degree of responsibility for the earthquake. The responsibilities are the result of both commissions and omissions. Accordingly, when someone is evacuated from a structure that does not subsequently collapse, he has been needlessly put to an inconvenience and cost; if someone is not advised to evacuate a structure that later collapses on him, his heirs may feel that society was negligent in not warning him when it could have done so. Therefore the earthquake-prediction system diagram in Figure 8 shows the outcome of the mitigation tactics leading to inequities, liabilities, and compensation.

4. Disaster-Preparedness Programs

The nature and scope of disaster operations required for various postearthquake situations establish the requirements for a preparedness program. A preparedness program would ideally include both preventive measures to reduce postearthquake problems and readiness measures to improve capability for disaster operations. Readiness activities would include (1) developing emergency operating plans and procedures and (2) providing for emergency operating centers, mutual aid agreements, communications, manpower, and equipment. These ingredients, together with proper training exercises and continual updating, would develop readiness for conducting disaster operations as dictated by the severity of the postearthquake environment.

Except for a few services, such as police and fire departments, the components required for the earthquake response system described above are generally not organized and ready to conduct disaster operations. Effective disaster operations will not be possible until all components are mobilized, organized, and deployed to areas where needed and until the direction and control system for coordinating local, state, and federal emergency operations becomes operational. It is not feasible to maintain readiness for earthquakes or other infrequent disasters because of funding and other constraints imposed by the normal environment.

If earthquake prediction capability is developed, and if a warning is issued, it would become feasible to improve readiness, its degree depending largely on the accuracy of previous warnings. Accordingly, preparedness programs could be accelerated; emergency services could be mobilized and their resources augmented; federal and state agency resources could be mobilized and deployed; emergency operating centers could be fully activated; and other actions could be taken to increase readiness for emergency operations.

An emergency can be defined as a situation in which the normal way of doing things will not work or is not relevant. In this context, issuing an earthquake prediction will result in an emergency situation, and many of the normal ongoing preparedness-program activities may not be sufficient or relevant in view of the predicted earthquake. During such an emergency there would be a reordering of priorities.

Preparedness for disasters is achieved by many interrelated but loosely connected programs. The manner in which these programs are organized and carried out varies considerably from agency to agency and from program to program. However, there is a well-established and accepted system for coordinating the various programs.

At the federal level, the programs of the various federal agencies are coordinated by the Federal Preparedness Agency. In California the State Office of Emergency Services coordinates the emergency preparedness activities of the several state agencies and provides guidance and support to local programs. In like manner, all counties and many cities have an office of emergency services, usually part of the chief executive's staff, which performs similar coordinating functions at the local level. Two federal programs--by the Federal Disaster Assistance Administration and the Defense Civil Preparedness Agency, respectively--are particularly relevant to this discussion. The Federal Disaster Assistance Administration (FDAA) administers the Disaster Relief Act of 1974 (Public Law 93-288). The Defense Civil Preparedness Agency (DCPA) is primarily concerned with civil preparedness for possible future war emergencies. However, many elements of their program are related to and support state and local preparedness for disaster.

To identify emergency measures that might be taken to prepare for a predicted earthquake, it is first necessary to have some understanding of the variety of situations that may result from an earthquake, the character of operations that would be conducted, and the types of emergency action that would be required to cope with earthquake induced problems.

After an earthquake, locations within the damaged area can be grouped into two broad categories:

- Damaged but tenable. This category applies to those locations where damage is substantial, but where the control of ensuing threats by in-place countermeasures is feasible.

- Damaged but untenable. This category applies to those locations where the ensuing hazards cannot be controlled, with the result that threatened areas cannot be protected or occupied and must be evacuated in order to save lives.

Earthquake tremors will be felt for considerable distances beyond the damaged area. Places that are outside the damaged area will be in either one of two categories:

- Close to damaged area. This category applies to places that are close enough to the damaged area to feel the shaking but do not experience significant damage or other earthquake-caused hazards. However, some places that are undamaged may not be entirely unaffected by earthquake effects; for example, utilities serving the community may be disrupted because of damage in other areas, and hospitals and other community services may be nonfunctional for varying periods of time.
- Distant from damaged area. This category should be considered because a major earthquake in an urban area may result in problems that require resources and backup support from federal, state, and local agencies that are distant from the affected area.

The situation after an earthquake emergency will also be a function of the earthquake's effects on water supply and distribution systems, electric power, sanitation, transportation, communications, and other utility systems on which the community normally depends. Generally these interdependent network systems operate on an area-wide or regional basis. Some systems will be disrupted because of damage to their components. Other systems may be undamaged but nevertheless nonfunctional because of external factors; for example, communications may be disrupted because electrical power systems are nonfunctional.

A synopsis of the postearthquake operations that would be appropriate for the first three of the above contingencies is presented in Table 4. The emergency operations are shown as actions taken in response to events that correspond to locally observed conditions.

Even though a capability to predict earthquakes may be developed and may provide a basis for reducing some earthquake-induced losses and ensuing problems, there will be a continuing requirement for earthquake response plans. A systematic approach to planning is required to develop

Table 4

SYNOPSIS OF POSTEARTHQUAKE EMERGENCY OPERATIONS

Event	Response
Earthquake shaking; local effects possible	Find out what happened; poll key facilities and dispatch field units to determine whether earthquake has caused substantial damage or other hazards.
Survey indicates no substantial local damage	Inform the public and advise them to remain ready for possible aftershocks; prepare to support more seriously affected places.
	If other places are reported to be damaged, provide close support to emergency operations. As requested, dispatch units to assist operations in or evacuation from damaged areas; receive and care for injured refugees; establish mass care centers; take action to expand medical care capability.
Survey indicates significant local damage or other effects	Search damaged facilities; rescue and assist survivors to safe locations; protect people and property threatened by fires and flooding; provide first aid and medical care; clear debris from essential transportation routes; provide security and traffic control; continue survey until situation throughout area is determined; provide emergency housing, feeding, medical care, and other services needed to sustain displaced and homeless population. Call for outside support if needed. Restore essential utilities.
	If an uncontrollable fire situation exists or is imminent, evacuate high-fire-risk areas (see event below). If warning is received that the collapse of a dam has occurred or is imminent, evacuate potential inundation areas (see event below).
Decision is made to evacuate untenable areas	Order evacuation of designated areas and direct evacuees to preselected relocation areas; search area as it is evacuated; provide rescue and first aid as needed and assist people to mass care and medical centers in safe areas; control access to evacuated area; provide emergency housing, feeding, medical care, and other services needed to sustain displaced and homeless population.

a comprehensive and coordinated set of plans. A planning process is shown in Figure 9.

The completed plan of a local jurisdiction consists of three parts:

(1) An administrative document that establishes the emergency organization, assigns responsibilities, and covers interjurisdictional agreements such as mutual aid plans.

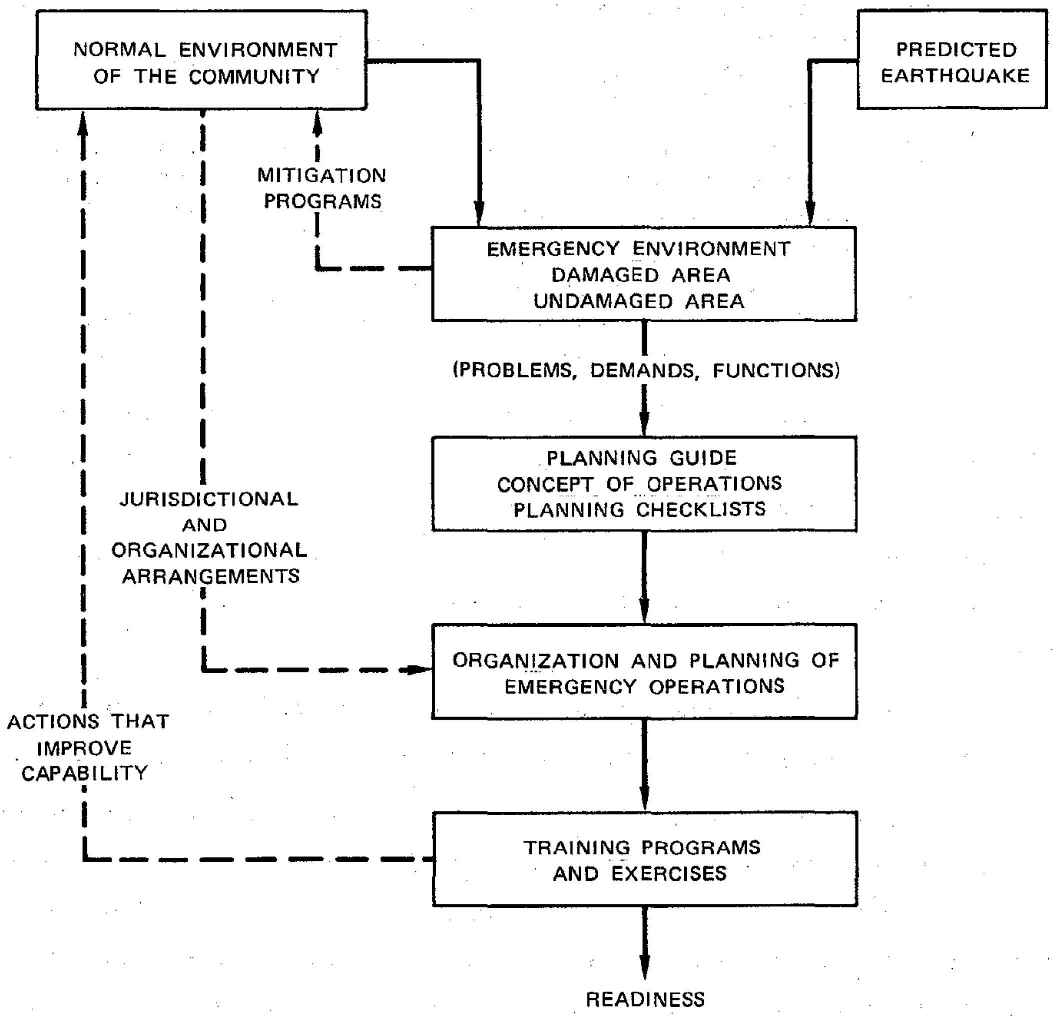
(2) A checklist of actions in which actions are assigned to specific services, operating units, or individuals, Tables 5 through 9 contain excerpts from the checklist of local actions.

(3) Data manual containing resource and other local capability information that would be required to conduct emergency operations.

Many elements of the plans developed for earthquakes are also applicable to other types of major emergencies. The same organizations become involved in disaster operations. Most of the actions and the resources required to respond to earthquakes are the same as those required for other emergencies, though there may be a difference in scale.

Plans for responding to earthquake prediction could be developed by properly adapting the planning process shown in Figure 9.

A planning and operations guide would be developed to identify emergency preparedness measures that could be taken for various types of warning (short term versus long term) in places inside and places outside the predicted damage area. The guide could be prepared and periodically updated as the state of the art of earthquake prediction is improved and periodically revised to account for changes in enabling legislation and other factors that influence the preparedness program. If and when a damaging earthquake is predicted, guidance appropriate for the predicted situation would be selected and disseminated to the concerned agencies as part of the warning process.



Source: Stanford Research Institute.

FIGURE 9 THE EMERGENCY OPERATIONS PLANNING PROCESS

Table 5

POSTEARTHQUAKE ACTIONS TO DETERMINE LOCAL SITUATION

Determine local situation

- Poll subordinate headquarters, hospitals, other key facilities, and emergency service units to determine situation in their vicinity and their ability to function.
- If communications with any of the above are not operational, deploy mobile units to assess situation and to provide alternative communication links
- Deploy teams and units to survey buildings for damage and developing fire
- Dispatch mobile or aerial units to survey predesignated areas for damage, fires, flooding, and other effects
- If zone includes a dam or is in inundation area of a dam, determine whether dam has suffered damage and whether failure of the dam is possible
- Check facilities known to contain hazardous materials
- Monitor communications to determine situation in other zones
- Determine operability of power, water, and other essential utilities serving zone

If not already accomplished

- Activate emergency operating center

If substantial damage is reported

- Report situation to next higher headquarters and begin actions listed in Table 6

If survey indicates negligible local damage

- Report situation to next higher headquarters; request report of situation in other localities
- If other localities are reported to be damaged, begin actions listed in Table 7

Table 6

POSTEARTHQUAKE ACTIONS IN LOCALITIES THAT ARE DAMAGED

Continue damage survey to determine situation throughout locality, including status of dams

Mobilize emergency services; perform search, rescue, and first aid; and protect against developing fire threat and other hazards

- Broadcast emergency advice to public, instructing them to take self-help actions to knock down incipient fires, to assist trapped and injured persons in their vicinity, and to stay out of hazardous localities except as necessary for these actions
- Dispatch fire units to engage fires not controllable by self-help actions
- Determine adequacy of water supply and pressure for fire fighting. Take steps to maintain service or provide emergency supplies
- Coordinate fire fighting and keep all services informed of areas threatened by, or safe from, fire
- Search all occupied facilities that are damaged or are threatened by fire, order evacuation of untenable facilities and areas, and assist survivors to safe locations
- Rescue trapped people, provide first aid, and call for medical support as needed
- Mobilize medical services and activate emergency medical centers as needed to augment hospitals
- Clear debris as needed to support fire and rescue actions, to allow transport of casualties to hospitals and emergency medical centers, and to permit outside assistance
- Activate staging areas as destination point for units coming into area and as base for conducting emergency operations
- Establish access control to damaged areas; assist people to safe areas; control traffic and expedite movement of emergency units
- If hazardous materials or environmental conditions threaten emergency forces, take appropriate precautions while giving priority to life-saving actions

Determine requirements for outside assistance; request help, if necessary, in accordance with mutual aid plans; take control of, and assign missions to, support units sent from other localities

If survey indicates threat of imminent dam failure affecting locality

- Begin evacuation actions indicated in Table 7

When immediate and ensuing hazards are under control

- Begin sustaining and recovery actions indicated in Table 9

Table 7

POSTEARTHQUAKE ACTIONS IN LOCALITIES THAT ARE PARTLY OR TOTALLY UNTENABLE

Advise next higher headquarters of decision to evacuate specified portion of locality

Order evacuation of designated risk areas susceptible to threat; direct evacuees to move to designated relocation sites

- Activate system for warning threatened population and order evacuation of designated evacuation area
- Broadcast instructions and direct evacuees to designated relocation areas, using designated evacuation routes
- Search evacuation area to ensure that people receive warning; assist evacuation and perform rescue and first aid, as necessary
- Provide aid as needed to assist evacuation of injured and others needing assistance
- Consider abandoning fire-control actions in evacuation area
- Continue search and rescue as feasible
- Clear preplanned evacuation routes as needed; if primary routes are not usable, use alternatives
- Expedite evacuation and establish access control to evacuated areas
- Search each facility to ensure that it is evacuated, performing rescue and first aid if possible
- If feasible, move supplies and equipment

Outside evacuation area

- Establish fire lines to prevent fire spread
- Continue search, rescue, and first-aid actions, as needed
- Receive, shelter, and care for evacuees
- Call for needed supplies, equipment, and support services
- Provide first aid and medical care to refugees at relocation sites

When situation is under control

- Report situation to higher headquarters and begin actions indicated in Table 9

Table 8

POSTEARTHQUAKE ACTIONS IN LOCALITIES THAT ARE NOT DAMAGED

Report situation and any essential utility failures to next higher headquarters; request status report for other zones; advise public of situation

If communications with next higher headquarters are broken

- Attempt to establish contact with nearby zones to determine their situation

Assist damaged zones

- Prepare to receive and care for refugees from nearby damaged zones
- Activate mass care facilities
- Restore disrupted lifeline systems if necessary
- Dispatch units to assist operations in, and evacuation from, more seriously affected zones, in accordance with mutual aid plans
- Provide emergency medical care to refugees
- As needed, provide support to sustaining and recovery actions listed in Table 6

If survey indicates that possible or imminent failure of dam will affect zone

- Begin evacuation actions indicated in Table 7

Table 9

POSTEARTHQUAKE ACTIONS WHEN IMMEDIATE THREATS ARE UNDER CONTROL

In consultation with state and federal authorities, develop plans and schedule measures needed to sustain the population

- Resuming operation of essential utilities that serve zone
- Controlling distribution and use of available resources
- Importing resources and services if needed
- Providing support to other localities and receiving and caring for evacuees if there is excess capability to sustain the population of locality

Begin sustaining operations

- As needed, clear debris; open transportation routes; demolish hazardous structures; begin salvage and repair of damaged materials, supplies, and equipment
- Prevent unauthorized movement; provide security for essential supplies; prohibit access to hazardous structures and areas
- Inspect housing and other facilities; rehabilitate if necessary and feasible
- Resume disease-vector control, sewage disposal, food and water inspections, and other essential public health measures
- Take control of emergency service units arriving from support areas and assign them to appropriate local service
- Begin restoration of water distribution, sanitation, power, transportation, communications, and other lifeline systems needed to sustain population and to resume operation of vital facilities; as necessary, use expedient measures or alternate sources to provide needed services
- Transfer casualties to hospitals and other medical facilities and phase out emergency medical centers
- Establish disaster assistance centers to provide for other needs, such as unemployment payments and disaster unemployment assistance; distribution of food stamps; relief related to property losses from earthquake; loans for repair or replacement of damaged or destroyed property; temporary mortgage or rental payments; farm loans; Social Security payments; legal assistance

It would also be necessary to expand the data base that has been developed as part of the ongoing planning program.

The various types of prediction that should be provided for by the guide can be classified according to whether or not sufficient time is available to undertake measures that would materially reduce earthquake risk.

Case 1: Short-Term Warning

The first contingency for which guidance would be prepared is the situation triggered by a prediction that a damaging earthquake will occur sometime within a period of days. During such a period it would be too late for preparedness measures that require a long lead time. The recommended actions that might be included in a warning to communities within the predicted damage area are listed in Table 10. Generally these actions are expedient and temporary measures that could not be sustained for an extended period. Plans for responding to short-term warning could be incorporated into the existing plans for earthquakes without warning.

During a short warning period it would be feasible (1) to mobilize and deploy forces and make final preparations for conducting disaster operations, provided that earthquake-response plans had been prepared; and (2) take expedient measures to prevent or reduce casualties and other easily prevented losses. Most injuries and deaths during an earthquake are caused by the collapse of weak structures that are occupied at the time of impact. The most effective preventive measure for short-term warning would be to evacuate or reduce the occupancy of buildings liable to substantial damage because of their location and construction characteristics. Areas where flash floods might result from the failure of a dam or levee might also be evacuated.* (Large-scale evacuation of

*In California, the Dam Safety Act requires preparation of maps indicating potential inundation areas and emergency plans for evacuating such areas.

Table 10

SHORT-TERM WARNING: DAMAGING EARTHQUAKE HIGHLY PROBABLE
Risk Areas Specified, Time Not Sufficient for Extensive Preparedness Measures

Broadcast public information and advice for this situation

- Order evacuation of known hazardous structures and restrict access to known hazardous locations
- Advise public and private organizations to tie down equipment for security against shock or displacement and protect shelf items from falling
- Urge public through all mass media to make final preparations without delay, such as cleaning up trash, filling water containers, and advise them to stay out of specified areas and specific types of structures
- Disseminate information on fire prevention, self-help fire fighting, and medical self-help through mass media
- Order shutdown of hazardous industrial operations
- Direct operating departments to suspend all nonemergency functions, alert personnel, check equipment and supplies, and prepare for deployment of forces if ordered
- Mobilize all available organized forces and deploy to preassigned emergency duty stations
- Fully man all control centers and establish 24-hour operations
- Establish and maintain communications with other jurisdictions and service facilities
- Activate staging areas and make final preparations there
- Take actions to ensure safety of institutionalized persons
- Discontinue all elective surgery, release all hospital patients except those who are critically ill, and take other actions to expand bed capacity and to protect remaining patients
- Deploy assigned personnel, equipment, and supplies to designated staging areas
- Advise utilities and industry to shut down nonessential services throughout emergency
- Deploy field units and maintain them on standby so that they can rapidly survey area for damage and other problems
- Move fire-fighting and other emergency equipment and supplies outside of stations
- Deploy engineering and other equipment

the threatened area does not appear to be warranted or feasible.) Potentially hazardous buildings and areas would have to be known by responsible authorities before the receipt of a short-term warning.

Case 2: Longer Term Warning

The second contingency for which guidance could be prepared is a longer term prediction that provides sufficient time for measures to reduce seismic risk and substantially improve capability for disaster operations. The general character of the emergency measures that might be recommended in an initial warning to threatened communities is indicated in Table 11. The specific measures would depend on the nature of the prediction (weeks, months, years) and the characteristics of the threatened community.

During the warning period, the initially recommended actions might be modified as a result of changes in enabling legislation, reordering of priorities, completion of programs to upgrade earthquake protection, and revising of the initial prediction.

5. Earthquake Engineering and Earthquake Protection

Earthquake engineering today is society's primary protection against earthquakes. It is therefore relevant to question the extent of earthquake protection in today's man-made environment. What is the residual risk that would provide scope for mitigation measures based on a short-term earthquake prediction?

a. Are We Overprotected?

Even if the state of the art in earthquake engineering could be portrayed in the light of universal agreement among its own participants--not so much as to what earthquake engineering is or is not but more as to what are the real effects of the "art" under the varying conditions of actual earthquakes--an answer to the overprotection (or underprotection) question would still not be obvious.

Table 11

LONG-TERM WARNING: DAMAGING EARTHQUAKE HIGHLY PROBABLE
Risk Areas Specified, Time Sufficient for Preparedness Measures

Establish public policy for long-term situation

Brief key government and nongovernment officials on situation and basic emergency plan and earthquake response plan

Review, update, or if necessary, develop listed items

- Legislation and local ordinances dealing with this type of situation
- Organization and assignment of responsibility to services
- Mutual aid agreements with other local jurisdictions and state agencies
- Plans for informing the public during emergencies
- Preparedness plans for hospitals, other institutions, and organizations that operate lifeline systems on which community depends (power; water; natural gas; sewage disposal and sanitation; communications; and transportation, including food and fuel distribution)
- Staffing and operation of emergency operating center and other headquarters; communications with service units and with other localities
- Maps indicating risk areas--including fire, potential dam flood areas, landslide, structures susceptible to damage
- Procedures for determining (1) distribution of earthquake damage and ensuing hazards and (2) postearthquake capability of hospitals, water systems, and other vital facilities and services

Conduct planning workshops for each service; review checklist of postearthquake actions

- Prepare instructions to service units and personnel, assign responsibility for specified actions, and indicate when, where, how, and with what resources the actions are to be accomplished, and by whom
- Evaluate existing capability for performing the listed actions and, where appropriate, identify measures and resources that would improve capability
- Identify measures that will reduce earthquake losses
- Determine what normal activities and services could be deferred or curtailed to free funds for emergency preparations
- Develop detailed plans for actions to be taken if a short-term warning is issued
- Determine requirements and prepare standby procurement orders for needed equipment and supplies

Table 11 (Concluded)

Identify and mark hazardous structures and locations in the risk area. Consider actions to reduce risk (e.g., removal, strengthening, prohibition of occupancy)
Expand fire-prevention programs and abate fire hazards
• Augment fire-fighting resources; prepare mobilization instructions
• Survey community for current fire risk, modifying or confirming fire contingency plans as appropriate
Begin actions to expand cadre and improve capability for emergency operations
• Recruit, train, and assign personnel as needed to increase service capabilities such as rescue, first aid, fire fighting, fire prevention, sanitation
• Prepare mobilization instruction
• Bring EOC and other headquarters to full readiness; provide for auxiliary power, and augment communications
• Arrange for use of facilities selected for staging areas, mass care, and other purposes, and begin preparing them for use
• Procure previously identified needed equipment and supplies
Improve readiness in potential dam flood areas
• Complete evacuation plans, warning system
• Transfer key facilities such as fire equipment out of area
• Develop engineering procedures to determine damage
• Consider lowering water level
Improve readiness and capability of lifeline organizations, resource agencies, essential industries
• Identify measures to reduce earthquake losses and disruption of services
• Activate standby agreements for transportation and other lifeline services
• Activate standby agreements for utilization of commercial and educational facilities
• Consider moving up resources from locations outside risk area
Improve readiness and capability of hospitals, medical and allied professionals, and public health agencies
• Prepare instructions for mobilizing personnel and resources
• Expand stocks of drugs, medicines, and sanitation supplies
• Check readiness of hospitals to discharge or move patients and expand bed capacity, consider deferring elective surgery
• If appropriate, begin moving up resources from locations outside risk area

Claims of both overprotection and underprotection are made, either in terms of buildings or of economics, politics, and civil protection. The former approach to the protection question is of course the easier one to develop because its "brick-and-mortar" character is more easily perceived. The broader view of the latter, however, is the more relevant one--addressing the issue of protection in a physical, social, economic, and political context. To gain at least some insight into the question, the discussion that follows reviews the area relating to society's physical structures.*

Earthquake-resistant design cannot, in a practical and economic sense, protect against

- Failure of supporting soils by way of faulting, landslide, liquefaction, or major subsidence. (The 1964 Alaska earthquake is the most illustrative U.S. example of such effects.)
- Tsunamis and seiches (e.g., the $7 million tsunami damage at Crescent City, California, resulting from the 1964 Alaska event occurring hundreds of miles distant).
- Erosion and inundation (even though the failure of a distant man-made structure may have been the root cause).
- An earthquake's so-called secondary effects--fire, explosions, and entrance of pollutants into the air and water† (e.g., fire damage estimated[84] at $500 million in the 1906 San Francisco earthquake compared to some $24 million in damage due to earthquake shaking).

For the sake of discussion, let us lay aside the hazards of direct faulting and soils failure, inundation, and secondary effects and pursue the protection question only from the viewpoint of ground

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*The term "structure" is meant to include buildings; bridges; tunnels; dams; embankments; pipelines; cableways; road, rail, and airport runways; and other man-made structures.

†Although other code provisions are directed toward protection from fire and other hazards, they are generally silent as to any association with earthquake phenomena.

shaking due to an earthquake. The question that presents itself is, protection of what?

The obvious response is: people, animals, and structures. A more analytic answer, however, requires a more detailed examination. An assessment of overprotection or underprotection of, say, life and limb will be strongly influenced by varying thoughts about human values, social norms, and arbitrary economic values. The protection of structures through earthquake-resistant design is possibly more manageable in addressing the extent of protection afforded, but even here, life safety (with all its value judgments) is intimately involved. Even the classification "structures" has at least three major components that bear varying degrees of emphasis regarding the protection level.

1) The Structure's Frame

The earthquake provisions in building codes have concentrated on frames. Here is the greatest controversy in regard to the protection question though it is but part of the answer. One view states that the lateral force provisions of present codes are not strict enough (i.e., underprotection), primarily in that actual earthquake peak accelerations are in fact greater than those normally used in design. The opposing view is that the provisions are too conservative (i.e., overprotection) because "code design" does not account for the augmenting strength of nonstructural elements, momentary strengths inherent in the inelastic range of building materials (the stress/strain relationship), or overall ductility in general. Possibly the best conclusion that can be drawn, in the absence of significant data to date, is that both arguments may be valid and that in many real-world instances the effects cancel each other, even though this is admittedly a neutral conclusion as to the protection question.

2) The Nonstructural Elements

Nonstructural elements include the architectural, mechanical, and electrical components as well as all other building elements not considered to be part of the structural system. Even though the structural framing system may well afford the greatest protection to human life (i.e., resistance to building collapse), the extent of nonstructural damage can be more important--mainly in terms of repair or replacement costs and also in terms of personal injury.* To the extent that building codes for the most part have not addressed nonstructural elements from the standpoint of seismic safety, this seems to be an area of underprotection.

3) Lifelines

Utility, transportation, and communication systems constitute lifelines. Structural or system failure of one or more of a city's lifelines can cause not only physical damage and capital loss but also disaster to the city. In physical terms, lifelines constitute approximately 50 percent of the economic value vulnerable to earthquakes.[85] In the broader sense of service loss, social disruption, and the general health and welfare of affected populations, values are essentially incalculable. Considering the only recent acknowledgment of the need for earthquake engineering in lifelines as well as records of actual earthquake damage, underprotection in this area appears to be the case, although its degree is still a moot question. (As with all the other areas discussed here, the reader must be aware that not enough is known in quantitative terms about the nondamaged, the uninjured, and the nonfatalities related to particular earthquakes.)

b. Protection in the Temporal Context

Another factor that must be taken into account is time. For example, consider the following:

- The ever-changing code requirements,† especially the factors used and the methods of determining them in earthquake lateral force provisions.

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*This of course is subject to what value is placed on human injury and the extreme cases of "first aid" or litigated action.

†See the discussion in Section II-F.

- The advancing and (presumably) progressive methodology of dynamic structural analysis as compared with the more traditional equivalent static loading.

- The ever-changing "age" of the structural inventory, characterized by, among others:

  - Type and strength of materials
  - Construction methods
  - Building shapes, heights, and closeness
  - Demolition
  - Building starts
  - States of disrepair
  - Repair and/or rehabilitation.

- The changing attitudes about so-called critical buildings:

  - California schools before and after the Field Act
  - State of compliance with schoolhouse strengthening requirements
  - Dam safety requirements
  - Hospital construction requirements
  - Other emerging requirements relative to the special use buildings considered to be critical in the event of an earthquake emergency.

- The ever-changing densities of populations, and therefore structures, especially where urban growth patterns can change what were relatively safe areas into areas of high risk, or at least higher potential risk.

In brief, then, the changing times in one way or another influence the structural inventory potentially at risk from an earthquake, and in turn effect judgments about whether society is or is not protected from this risk. As to individual structures, it can generally be said that greater earthquake resistance can generally be expected from structures built under later codes, standards, or technologies. Because of the lack of data on the structures at risk, the broader societal question of earthquake protection is but partly answered.

c. Protection in the Geographic Context

Geographic location should be included in consideration of the basic protection question; that is, would the answer be the same for Brownsville, Texas, as for International Falls, Minnesota? or Bangor, Maine, as for Eureka, California? From the historical earthquake record, the answer is "no."

Unfortunately, the answer is not as obvious as it seems. For example, let us consider the Uniform Building Code as being the most generally recognized U.S. code, with its earthquake provisions oriented toward the western states, if not specifically California.* There are those, therefore, that draw the conclusion that the eastern areas of the country are better protected than need be.

This is not necessarily supportable. For example, the attenuation of longer period surface waves from earthquake excitation is less in the eastern United States than in California. This can cause a greater area of destruction for an event with a relatively minor release of energy. On the other hand, at least one western state--Colorado--is said to be inadequately zoned (presently seismic risk zone 1) for its geologic conditions.[86]

Another geographically based issue relates to city-by-city differences in legislated building requirements. In essence, this introduces varying attitudes about seismic protection. In general, city-legislated or state-legislated actions probably have similar origins but the levels of regulation, and therefore protection, can be different.

d. Other Externalities Establishing Protection Level

In the plan/approve, locate/approve, design/approve, construct/inspect, and maintain/operate process, there are literally dozens of both lay and technical people in both the public and private

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*See Section II-F.

sectors who to one degree or another participate in the establishment of earthquake-protection levels (see Figure 10).

Beyond the formal role these many participants may play in the process is the variation in the quality of their actions--from the naively incorrect to the astute. Consider building code use, for example. The code does not guarantee complete seismic safety, sets only minimum standards, is not comprehensive, and explicitly requires enforcement. Clearly, then, its interpretation and care in its use and implementation bear on the resultant levels of seismic resistance.

If the need for code expansion does in fact suggest a past and present weakness, an argument for underprotection could be made. On the other hand, in view of code modernization over the past decade or so and the increasing requirements for professional qualifications, overprotection (or at least acceptable levels of protection as this is implicitly balanced by society against attendant risk) might be alleged.

Risk balance introduces another externality.* That is, what are, or were, the value perceptions placed on the risk that damage, injury, or even death would occur, given earthquakes of varying magnitude and frequency?

6. Seismic Zoning

a. Seismic Zoning: The Goals

Response through the land-use-management system to earthquake risks now centers around the development of a seismic zoning capability. Seismic zoning would serve two purposes within the broader goal of protection from seismic risks. The first is to provide public agencies with a rational means for considering seismic factors in deciding where to locate different land uses. A second purpose is to provide for the gathering of geologic information to influence construction requirements on a site-specific basis.

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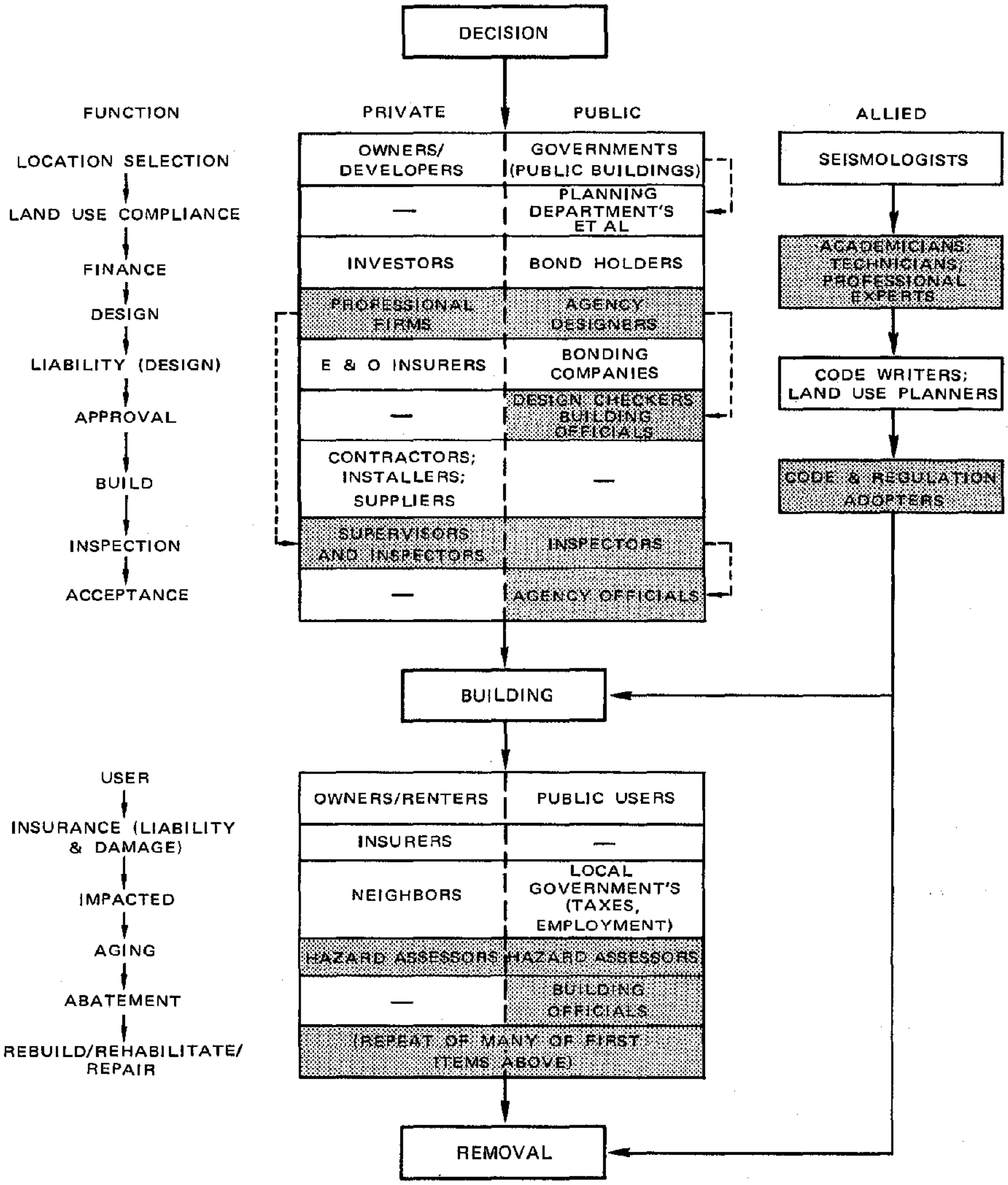
*See Section II-G.



[shaded box] Areas of direct cause for variation in building's earthquake resistance, i.e. Resistance = (f) Lateral force determination and correct usage
Checking expertise
Inspection and quality control
Hazard assessment expertise
Level of governmental awareness and acuity

[open box] Indirect causes

----→ Areas of "self-checking"

Source: Stanford Research Institute

FIGURE 10 "PLAYERS" AND STAKEHOLDERS RELATIVE TO EARTHQUAKE RESISTANCE

For seismic zoning to be a feasible option for earthquake protection, several criteria must be satisfied:

(1) There must be sufficient geologic and soil information available about an area to make clear the variations in risk.

(2) The possibilities and limitations of reducing this risk through engineering practices must be identified.

(3) Variations in risk associated with different land uses must be understood.

(4) Mechanisms for instituting zoning procedures must be available.

(5) Implementation responsibilities must be clearly defined.

To assess the potential impact of seismic zoning, we must look at the extent to which these criteria are now being met and at how much effort would be needed to meet them more completely.

b. Geologic and Soils Data

Sound geologic and soils knowledge of an area is essential as background for seismic zoning. Variations in seismic risk will be associated with proximity to active faults, potential earthquake magnitudes, geologic conditions, landslide potential, liquefaction potential, and ground-motion potential. The ease of identifying these factors varies in and among regions. In all regions, knowledge of geologic factors is incomplete.

The U.S. Geological Survey, in its ongoing microzonation program, has accomplished some research on the availability of such data within a region.[87]

The San Francisco Bay Region seismic zonation study[87] is a useful beginning in improving the information basic to land-use decisions. It is important to recognize both its potentials and its limitations. Although the study provides a general picture of regional variations in seismic risk and describes the different types of risk in some detail, it gives little direction for specific local policies.

c. Land Use and Seismic Risk

With recent concern over seismic risk, some general attitudes toward the location of different land uses with respect to geologic elements are now developing. The basic factors that distinguish between levels of risk seem to be the criticality of the service provided and the occupancy of the structure. Thus hospitals and schools are designated as two uses that should be located away from fault zones and other high-risk areas (where landslides or ground failure might cause structural and functional damage), whereas low-occupancy and private uses--such as single-family homes, warehouses, and outdoor recreation facilities--may be located on more dangerous sites. As with much of the geologic information, these factors are presented on a relative basis, without quantitative standards defining safety limits.

d. Current Implementation Status of Seismic Zoning Programs

Until the mid-1960s, seismic risk was not considered a factor that might influence the distribution of land uses by the zoning process. However, in the following years, planners began further efforts at developing a seismic zoning system, particularly in California. Such efforts have served two purposes so far. They identify seismic activity as a real problem that should concern local agencies, and they begin to distribute responsibilities for coping with these problems.

In California, the state legislature has initiated seismic zoning activity. Through two recent requirements, the state has delineated some basic policies for managing development in areas with recognized seismic hazard. These are the seismic-safety-element requirement in the urban general plan and the fault-zone-management requirements of the Alquist-Priolo Geologic Hazard Zones Act.

The seismic-safety-element portion of the general plan has been required since 1972. Those communities that have completed this element have done so very recently, and there is enormous variation in how the tasks have been approached. The state guidelines for implementing these plans are general and leave the level of detail and direction of emphasis to the discretion of the local government.

The Alquist-Priolo Act (SB-510, 1972) requires that decisions on new development in fault zones take into account the problems that may be associated with proximity to active faults. As with the seismic safety element, directions for implementing the act are minimal. Furthermore, the act addresses only a small part of the state, although many other areas could also be severely affected in an earthquake. For example, the act does not apply to the City of San Francisco, because no active fault traces identified by the State Geologist pass directly through the city.

The present planning legislation, then, provides evidence that at the state level, seismic safety measures are becoming a matter of some concern. However, neither the legislation nor related planning programs are complete enough to provide for a successful seismic-zoning program.

e. Implementation Tools

The fact that seismic zoning programs now stop short of implementation does not preclude their usefulness. However, present implementation tools for land-use plans may be inadequate for implementing effective seismic zoning. Unless communities develop new procedures or are granted new powers, they will basically rely on building-permit procedures and land-use restrictions to control new development. For eliminating the most dangerous existing uses, they may use a combination of code enforcement, urban renewal powers, nonconforming-use amortization procedures (phasing out unsafe structures or land uses), and public purchase of endangered property.

These procedures will be time consuming. Most would require case-by-case consideration, as with special use permits, building and housing code enforcement, and the amortization (or discontinuance) of nonconforming uses. Where broader scale action may be contemplated, as with urban renewal or public purchase of land, the time needed to acquire funds and then take action may be on the order of years. Thus a community may require one or two decades to implement a seismic zoning ordinance, even if the necessary financing and administration are available.

f. Seismic Zoning in the Context of Earthquake Prediction

There is little prospect that seismic zoning will reduce the risk from earthquakes in the United States to the point where other precautionary measures would be superfluous. Seismic zoning may be useful for preventing future development in places with serious earthquake hazards, if local governments can further extend their powers over new development to include consideration of this criterion. However, for the next few decades, there is very little chance that planning agencies will significantly change the present distribution of land uses toward a less hazardous pattern.

Therefore it seems that present trends in seismic zoning will have little effect on the general environment to which earthquake prediction will be introduced. This situation will only change if public concern increases toward both land-use planning and earthquake risks. We can see evidence of a few trends in this direction. Regional planning has expanded recently with concerns for environmental protection and understanding of the interrelations between various man-made and natural elements in the environment. Special purpose districts now have strong regulatory powers over some aspects of the environment, such as air, water, and unique natural sites.

However, the evolution toward increased public intervention in land use is slow, and it is likely to remain slow with respect to earthquake risks as long as the majority of the population continues to discount the seriousness of the risk. An earthquake prediction system, by providing more information on future seismic activity, could affect the climate in which seismic zoning develops. The overall effect could be positive or negative, depending on the credibility of the system in the eyes of the general public, on the actual accuracy of the predictions, and on the lead time of the prediction.

If the system contains uncertainties of the same order of magnitude as those now contained in the geologic information bases available to public agencies, it is likely to have no impact on the development of seismic zoning. If the system is at first credible but inaccurate, it will have sporadic effects. Some communities may make major changes in their development policies and patterns where they are not immediately necessary, whereas others may postpone important measures under the false impression that their area is safe from the risk.

A prediction system that is both credible and accurate over the long term could provide very important input to the development of a seismic zoning program. A community that knows that it will face a major natural disaster in a specific time period will have greater incentive to act, and its officials will probably find much more constituent support for such actions than without that knowledge.

The length of this time period will also be an important factor. Redirecting land-use management would be an inappropriate response to a short-term warning of a few months. Geologic studies, building inspection, demolition, and reconstruction are all time consuming, probably requiring several years of notice.

A prediction of several years could significantly improve the chances for implementing seismic zoning. However, there may be time limits for the usefulness of long-term predictions as well. Thus a prediction of an event within 50 years would probably have no more impact than no prediction at all, because it would offer little change in the sense of urgency that seems to be a necessary element in inducing major action.

D. Public Decisions and the Scientific Inquiry of Earthquake Prediction

As we described in Section II-D, an earthquake-prediction system will produce scientific hypotheses. Those hypotheses will require verification, which means that earthquakes must occur within the general limits of each prediction. When theory and empirical results produce scientific replicability, the technology of earthquake prediction will have matured in its own right.

1. Public Action Based on Uncertainty

As long as predictions remain hypotheses that require verification, we classify them as "transitional products" of the scientific process. Despite their transitional nature in relationship to the development of science, they will nevertheless be available to society as "predictions" of earthquakes. We have explored the nature and range of these types of prediction through the case descriptions in Section III-A, and we saw the extent to which they would be uncertain. This section explores the nature of that uncertainty in terms of the problems posed to society in trying to decide whether or not to act on a specific prediction.

In doing so we examine the nature of scientific hypotheses as probabilistic statements in light of society's traditional decisionmaking processes and institutions and the manner in which opinion is formed as the basis for those decisions. Because the basis for scientific statements differ fundamentally from society's bases for deciding to act, society requires judgmental institutions to "evaluate" the hypotheses or predictions against preestablished standards or rules that assist in determining the question of whether or not to take action. Of course, the judgmental institutions incorporate scientific and technical evaluation capabilities. How these standards and rules could be developed is the subject of the next section.

Assessing the technology of earthquake prediction and the problems related to public warnings of earthquakes, uncovers a number of fundamental issues. If the United States develops earthquake prediction, the problems underlying predictions and warnings of earthquakes must be addressed in the development of any policies and programs related to the earthquake-prediction efforts of the USGS and to the potential for predicting earthquakes by others. The major problems associated with the predictions and warnings of earthquakes are as follows:

- No one knows what the major characteristics of the initial prediction will be for any given geographical area in the United States (e.g., the San Francisco Bay Area or the Los Angeles Basin).
- The question of uncertainties permeates the field of earthquake prediction in all ways and at all levels of consideration and analysis. These uncertainties are a necessary part of the development of the technology of earthquake prediction.
- Science, and its supporting technologies, must proceed by hypothesis and by testing the hypothesis empirically. However, in the development of earthquake prediction, the laboratory in which the effort must be conducted is also occupied by the public.
- What the scientist considers to be his hypothesis--with all its necessary uncertainties--is to the rest of the world a prediction of an earthquake. Although that prediction may have independent meaning for the development of science, which is indifferent to the outcome except as it affects the scientific validity of the hypothesis, to the public--the occupants of that laboratory space--the prediction can be quite disturbing.
- Laboratory walls by custom close out the public. At the same time, however, they provide scientists with the secure and legitimate space in which the development of science can go forward. Those walls do not exist around the scientific inquiries necessary to the development of the technology of earthquake prediction.
- Unless the integrity of the space between these two areas--science and the public--is maintained, both will suffer. In the end, science may lose its authority and credibility, and the public may have its social and political systems severely and unnecessarily disrupted.

- From the public point of view, the main output of of the scientific development for the usefully forseeable future will be statements incorporating probabilities about future seismic events.
- The developing technology of earthquake prediction is not alone in its struggle to establish understanding of probabilistic statements in the public sphere. In fact, this issue has a spreading and pervasive generic form: probabilities in public policy decisionmaking.
- A probabilistic statement issued from the scientific community is not in and of itself a sufficient basis for deciding whether to take action. More information must be added, no matter how crudely assembled. The consequences of acting as though the statement were true and as though it were not true must be identified, analyzed, and evaluated.
- Although science can wait to verify the statement through actual events, the public cannot because the event could possibly kill and injure many persons.
- On the present basis of the technology, the specific kinds or ranges of prediction that could emerge from the scientific effort are undefined; that is, we do not know how to go about projecting alternative responses to an earthquake prediction because we do not know what that prediction would be like.
- The scale of required action, as a factor taken by itself, is a major dimension of the problem. From the point of view of applying the products of science to human action, there is no way that science can promise the public that predictions will deal with increasingly severe events. The truth of the matter is that a scientific statement concerning a great earthquake may come at any point in the development of prediction.
- Earthquakes are where you find them. It is not possible to predict an earthquake until it has been "found." Some have been "found" but by no means all. One can imagine that it may be possible to predict where to find earthquakes, but the lack of knowledge of all possible earthquake locations presently adds another level of uncertainty to the problem.

These facts relating to the technology of earthquake prediction and public action based on them obviously require governmental action. In the discussion that follows we look first to existing federal disaster legislation to determine whether it is a suitable basis for a public policy of earthquake prediction.

2. Potential Application of Federal Disaster Policy to Earthquake Prediction

This discussion focuses on the public policy to issue warnings based on predictions of specific earthquake events. The scope and meaning of the term "warnings" is limited to the policies of governments--to the public policy issues of warnings. For example, questions such as whether or not warnings are effective, should be bilingual, or will reach all persons are ones that relate to the effective implementation of warnings and are therefore excluded. These questions have been discussed in Section III-B-6.

The subject of warnings of natural disasters is crucial to many of the policy issues of earthquake prediction and to the decisional factors on which they are based. This is because many policy issues relate to what is to be done with a prediction of a specific earthquake event. The question of how to decide to act on predictions of earthquakes is intimately involved in the public policy of warnings.

Warnings of other natural disasters occur in exactly the way that we anticipate that predictions of specific occurrences of earthquakes will be developed. The potential social, political, and economic impacts of this set of circumstances appear unusual and unfamiliar. As a result, the inclination is to look for the policy issues and their solutions in the uniqueness of the consequences that predictions might create. This is because situations that are apparently unique and affect the public in a number of ways and at a number of levels of social organization seem as if they are isolated from all past and present experiences and therefore seem to call for unique expressions of policy.

In fact, however, the public seldom finds itself in truly isolated policy circumstances in attempting to deal with a new situation. The problem of apparent isolation due to uniqueness may usually be dealt with by casting about among elements of currently evolved, relevant policies in nearby areas to find a starting point for addressing the issues. In the case of earthquake prediction, this approach leads us rather directly to the field of disaster assistance and relief.

Congress passed the Disaster Relief Act of 1974 after more than a year of extensive and detailed legislative inquiry into the area of federal, state, local, and private needs with respect to disaster preparedness, relief, recovery, and reconstruction. The Act deals with disasters in general, with particular emphasis on natural disasters. This legislative effort included, of course, the subject of earthquakes and their secondary effects: fires, explosions, landslides, and mudslides. The Disaster Relief Act of 1974 was a cumulating step in a series of evolutionary legislative policy developments in the field. It therefore appeared to express a fairly complete policy framework for dealing with the occurrence of natural disasters. Accordingly, it seemed appropriate to inquire whether any portions of that Act might apply to earthquake prediction.

On preliminary examination of the legislative history of the Act the case for adopting its policy framework for natural disasters as the policy framework for earthquake prediction appeared to be extremely strong. Accordingly, it became more useful to approach the Act, on the presumption that its policy framework includes predictions of earthquakes, by asking the question: is earthquake prediction so special an activity that it cannot or should not be addressed within the existing disaster policy framework established by the Congress?

Asking this question appears to beg another: How can governments act on the basis of an earthquake prediction? As discussed elsewhere in this report, this class of policy questions is <u>unanswerable</u> in the absence of an actual prediction of a specific earthquake. But it is also generally <u>irrelevant</u> in light of the current state of development of the technology of earthquake prediction. We do not in fact know what form an initial prediction of an earthquake will take. Thus, based on how <u>little</u> we know from the technology of earthquake prediction about the nature of future predictions--rather than how much we may know about the possible ranges of consequences of predictions--the important policy question at present remains whether there is already in existence a policy framework--that is, a framework for action--that is adequate to define or bound the actions of governments should an earthquake prediction be issued.

On the basis of an examination of the Disaster Relief Act of 1974, an affirmative answer must be qualified in two important respects: first, a number of intergovernmental political issues may emerge as the initial prediction is developed and published. The policy framework is not complete as to all possible issues that might arise from the first prediction. Earthquake prediction has the potential for creating many of the intergovernmental political characteristics of the recently emerged and ongoing "New York City crisis."

Congress may wish to act on the most important of these "open-ended" areas. Under the current provisions of the Disaster Relief Act of 1974, a governor, after taking certain required state actions, may request that the President declare an emergency based on the threat of a natural disaster. The Governor's petition, along with certain other actions, serves as the basis for his request under the Act to the President for federal emergency assistance to the state and local governments. The Governor may make such a request on his own initiative; he need not have received a prior "warning" from the federal government that a disaster threatens.

The federal government has, controls, funds, or is making use of the primary scientific and technological resources in the field of earthquake prediction. Because these resources and capabilities are at the disposal of the federal government, the Congress may wish to ensure, as a matter of policy, that the federal government exercises independent judgment as to the scientific validity of predictions issued by non-governmental sources. To accomplish this, the Congress may wish to amend the Disaster Relief Act of 1974 to require the federal government to expressly decide whether to issue a warning to state and local officials in every case in which an earthquake prediction is made.

If the Congress were to make this change, it might also want to consider limiting the power of a Governor to request that the President declare an emergency based on the threat of an earthquake to those instances in which the federal government has warned the Governor and local officials of the threat. These two changes would have the effect of requiring the federal government to exercise judgment on the question of whether a specific earthquake threatens.

Politically speaking, this is a responsibility that the federal executive agencies do not appear to want, and it is the type of preemption of state and local responsibilities by the federal government that traditionally has been strongly opposed by those levels of government. As the long buildup of the New York City crisis appears to have so clearly demonstrated, the allocation of new types of responsibilities between governments raises political questions that are difficult to resolve unless specific events precipitate issues deserving urgent public policy consideration.

Time is the second qualification that must be placed on the affirmative answer to the question of whether the 1974 Act is an adequate policy expression by which to deal with the potential challenges of earthquake prediction. The Federal Disaster Assistance Administration, as the agency with the responsibility for administering the 1974 Act, has interpreted the Act, as is its prerogative, as applying to disasters that threaten immediately. It has construed those parts of the Act referring to the threat of disasters very narrowly to mean that an emergency may be declared only when a disaster is about to occur. However, an examination of the legislative history indicates that the Act could possibly be interpreted more broadly.

The Act probably would cover predictions of events more remote than 1.5 to 2 years in the future. As a finding derived from the facts underlying the legislation--and therefore one that tends to bound its scope--no other type of disaster event "threatens" longer than about 6 months in advance of its occurrence. By extrapolation from threats resulting from combinations of different types of disasters (e.g., drought and fire), the scope of the Act could be extended to about the 1.5- to 2-year time frame. Beyond that time frame, however, the concept of "disaster" that underlies the Act does not appear either to be useful or to apply. The policy evolution of the current concept of disaster began with emergency relief and assistance rendered after the occurrence of an unwarned disaster event. Only gradually has the concept evolved to its present scope, which includes both threats of disasters and long-term recovery from disasters. The current policy framework is still largely keyed to the occurrence of the event, however.

If an earthquake is known to be threatening for more than a year or two in advance of its occurrence, time begins to play a role in distinguishing between disaster-related actions and other types of actions that can be taken. Longer lead times would allow for the action of planning for--as distinguished from responding to--the threat of the event. A longer lead time than is available for most types of disasters would tend to take the threat of an earthquake out of the category of disaster and therefore out of the framework of the Act.

As implied in the foregoing, the future to which the Act applies is unspecified. For this reason it is conceivable that a Governor might seek to have an emergency declared, and to request federal assistance based on a prediction with, for example, a 10-year lead time. This appears to be legally permissible under the terms of the Act. The President has the discretion to refuse to grant federal assistance. If he were to do so, that action would tend to limit the scope of the Act in that particular case. But in the case of either action--the Governor's or the President's--the conditions created would tend to establish the framework by which the political issues that must be settled in dealing with a long-lead-time prediction would be resolved.

That framework might be fundamentally misleading as to the policy issues that must be debated and resolved. The tendency would be to flaw the debate by molding it in terms of disaster preparedness and response measures rather than disaster-mitigation planning and implementation. The horizon of the former tends to be limited to the occurrence of the event itself, with emphasis on the savings of lives and protection of property during and immediately after the event. Such measures must be taken as the event approaches, and a long lead time would increase the ability to plan for taking them. However, a long lead time would also permit present measures (e.g., reinforcing versus demolition of buildings) to be evaluated on the basis of a decisional framework that relates to the reconstruction and future development of the area that will be damaged as well as to the anticipated damages from, and the consequences of, the disaster itself.

The present policy framework encourages a phased response to disasters. The Act provides

- For developing a general preparedness capability.
- For the declaration of an emergency if a disaster threatens.
- For the declaration of a major disaster* when the event occurs.
- For the creation of institutional and financial means for dealing with the problems of reconstruction after emergency conditions have passed.

Nothing connects these phases together except the passage of time in relationship to the occurrence of the event itself. In other words, pre- and post-disaster actions are decided on under a linear, rather than a comprehensive, policy framework. This is a suitable framework for dealing with the way in which all types of disasters "threaten"--that is, can be predicted--<u>except</u> for medium- and long-term earthquake predictions.

We do not have in the United States an expressly stated, tested, and operable policy framework that is adequate for coupling present actions based on a medium- or long-range earthquake prediction with

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*The Act allows for the declaration that a "minor disaster" has occurred by use of the term "emergency." This is a confusing element in the Act. Essentially, the Congress in drafting the Act employed the term "emergency" for more than one purpose.

considerations based on the kind and nature of physical, social, and economic conditions desired by the public after the event has occurred.* Whether or not such a framework should or could be developed is beside the point, which is that it may be difficult or impossible to establish a comprehensive, evaluative framework if the basic question is perceived as coming within the extended range of our present concept of disaster.

To ensure that the question of the appropriate policy framework for dealing with the characteristics of medium- and long-term earthquake predictions is left open for further consideration outside the context of our current concept of disasters, Congress may wish to amend the Disaster Relief Act of 1974 to limit the applicability of declarations of emergencies based on threats of earthquakes to the period of not more than 1.5 years before the predicted occurrence of the event.

On analysis it appears that the policy framework is in place for making the two changes noted above. In developing the warnings policy contained in the 1974 Act, Congress included two prediction-related aspects in its underlying concept of warnings. First, the legislation speaks only to the issuance of warnings. By the construction and interpretation of the Act, this includes everything necessary to developing information that a specific disaster event threatens. Thus the federal government appears to have no authority to issue a prediction of a disaster independent of the decision to issue a warning that the disaster threatens. The Act does not appear to grant the USGS, for example, the authority to publish a prediction of an earthquake independently of a presidential decision to issue a warning to state and local officials of the threat of an earthquake.

For public policy purposes, this is a consistent point of view. It makes no policy sense for the federal government to issue a

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*The trend toward developing this framework is evident in the Federal Flood Insurance Program and in the congressional debates on "all-risk" catastrophic insurance. This framework will not be addressed to the threat of a specific disaster event, however.

prediction by only issuing a warning to the effect that an earthquake threatens.* This policy also rests on the view that the states, local governments, and "civilian population" are <u>users</u> of the federal predictive expertise and therefore need warnings that include judgments on the validity of predictions--as the basis for taking actions. Once the judgments involved have been rendered and the decision to issue a warning has been made, the Act appears to provide a relatively complete framework for addressing the threat of an earthquake by means of a declaration of "emergency" as the basis for providing federal assistance and relief.

The change to the Act that would require the federal government to decide expressly whether to issue a warning would simply extend present federal responsibilities with respect to federally generated predictions to every instance of prediction from whatever source. Because we can anticipate that predictions will issue from private domestic--especially university--and internationally based sources, this change would primarily be for the purpose of defending the users--state and local governments and the civilian population--from the potentially disruptive effects of predictions whose validity for governmental action purposes would otherwise be in doubt.

By requiring the federal government to issue a warning to state and local officials before a Governor may request that an emergency be declared under the Act for purposes of requesting federal assistance in mitigating the threat of an impending earthquake, Congress would foreclose the potential intergovernmental political issue of who decides the scientific and technological question of whether or not an earthquake in fact threatens while keeping open all other political and policy matters under the Act. This last includes, for example, the question of how much federal assistance is to be rendered to state and local governments in meeting the threat of the disaster and in what forms--directly or indirectly.

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*This condition is limited as to warning time as noted above.

Second, earthquake prediction was not "technologically feasible" at the time Congress was considering the 1974 Act, as was stated to the Committee during its hearings. Because of this, the question arises as to whether Congress intended that earthquake prediction, as a capability acquired after passage of the legislation, be included within the policy framework of the Act.

The federal agencies supporting and conducting research in the area testified that an earthquake-prediction capability would probably be developed in the future. In addition, the lack of a predictive capability for other types of natural disasters was noted, as were the research and development efforts that were under way to improve capabilities in these areas.

Because Congress was aware of these facts at the time it established the policy on warnings contained in the Act, it would appear that its intent was that any prediction capabilities acquired later be included within the terms of reference established by the Act. This is in part supported by the fact that nothing could forseeably be developed as a prediction capability that could not and should not be included within the warnings policy established by the Act.

In fact the one characteristic of earthquake prediction that might take it out of the Act--lead time--was not expressly noted and debated, perhaps because the possibility of long-lead-time earthquake prediction was too remote to be dealt with in the process of formulating the 1974 Act. If, however, we examine the characteristics of short-range predictions in light of congressional warnings policy, it would appear that Congress intended that short-term predictions be included within the terms of the Act. The fact that a medium- or long-term prediction has characteristics that appear to be more appropriately addressed in some other policy framework than that established by the Congress for disasters does not, by itself, appear to be a sufficient cause to find that Congress intended that short-term predictions of earthquakes not be included within the terms of the 1974 Act.

The committees of the two congressional bodies with jurisdiction over disaster relief and assistance represent the _users_ of federal expertise, funding, and other resources. Although some provisions of the Act appear to be directed exclusively toward the responsibilities and obligations of the federal government, the purpose for including such provisions appears directed toward marshaling federal resources in order "to provide an orderly and continuing means of assistance by the federal government to state and local governments in carrying out their responsibilities to alleviate the suffering and damage which result" from disasters. Thus the basic thrust and overall policy framework of the Act, including the policy on warnings, appears to be based on the concept of assistance by the federal government to state and local governments in their attempt to deal with conditions for which they are primarily responsible.

An extension of the present responsibility of the federal government to issue warnings of threats of earthquakes based on predictions developed within the federal government itself to all predictions from whatever sources derived may be viewed in two lights:

(1) The states may consider this a preemption of state responsibility. Our assessment to date indicates that this is unlikely. In representing the states as users of the federal expertise on this matter, the committees of Congress may find that some states may express an interest in sharing this responsibility jointly with the federal government. But it is doubtful that many states, if any, would wish to retain exclusive jurisdiction over the matter.

(2) This change may be viewed as furthering the purposes of the Act in that it would provide the states and local governments with an across-the-board expertise that they do not now have and could develop only at relatively great expense to themselves and over a substantial period of time. By putting an expanded responsibility to exercise the federal expertise within the terms of reference of the 1974 Act, the Congress would be providing the states and local governments as users with additional warning information that could be acted on.

However, the committees of the Congress that represent the users of federal assistance and expertise in the disaster area are not the committees that have jurisdiction over the authorizations and appropriations of the federal agencies providing expertise in earthquake prediction. Under the present policy structure of the Act with respect to warnings, this is generally a matter of indifference because the legislation provides that if the federal government develops a prediction of an earthquake, the President has the duty to decide whether to issue a warning. The Act says nothing about whether the federal government should develop such capabilities. Under these circumstances, those interests in the states, local governments, public, and scientific community that seek to further the federal government's capabilities to predict earthquakes are appropriately directed to the committees that authorize and appropriate the research and development funds to the agencies that would carry out the effort. The Disaster Relief Act of 1974 speaks only to the way that the products of that effort would be used.

If, however, the committees with jurisdiction over the disaster area were to amend the existing Act to require the federal government to decide expressly whether to issue a warning for every prediction that is issued--in essence, to judge the validity of each prediction--then cooperation and coordination between several committees within both congressional bodies would be required in order to ensure that the necessary authorizations and appropriations were made to the agencies that would carry out this requirement. This is a matter of the internal policies of each body, and precedents exist for resolving this type of problem. It is noted here to indicate the fact that by extending the provisions of the Act in the manner indicated Congress would be required to develop cooperative actions between committees with differing subject matter jurisdictions within the same policy framework.

The foregoing may best be illustrated by a hypothetical example: Scientists from a university develop a "prediction" that an earthquake will occur in a particular place in the United States with a certain expected magnitude and time frame. The time frame is very broad.

The USGS "advises" the appropriate federal and state agencies that the prediction has been issued and states that, after reviewing the data and interpretation on which the prediction is based, it does not disagree with the "prediction" as issued by the scientists from the university. The Governor of the state makes informal inquiries of the Office of the President as to whether the USGS or other appropriate federal agencies are prepared to issue a warning to him under Subsection 202(a) of the 1974 Disaster Act based on the prediction. The Governor does not receive a clear answer to his inquiry. Considerable pressure from the state's congressional delegation is placed on the various agencies of the Executive Branch to make and announce a decision. After a time, a federal agency announces that it is reviewing the "prediction" in cooperation with the USGS and the scientific community and is also reviewing federal plans and policies with respect to emergency preparedness and response.

Due to continuing pressures within the state for a clear declaration of the matter, the Governor turns to existing or newly established advisory committees for assistance in evaluating the prediction and alternative responses. These committees include appropriate local and regional officials.

Finally the Governor declares that an emergency exists according to state policy, requests the President to declare an emergency within the meaning of Subsection 301(a), and requests federal assistance "to lessen the threat of a disaster." The Governor's request is primarily for financial assistance, although he also specifies the types of technical assistance he requires from the federal government.

The President at this point "may determine that an emergency exists which warrants Federal assistance" [Section 301(a)]. If he decides to withhold federal assistance--and he may do so on the grounds that a clear need for federal assistance by the state has not yet been demonstrated--he must do so in the face of the fact that a federal agency, the USGS in this case, has "validated" the prediction.

Under these circumstances, it is questionable whether the USGS had the authority to issue an evaluative statement on the prediction independently of the mandated duty in the Office of the President to "insure that all appropriate Federal agencies are prepared to issue warnings of disasters to state and local officials." While Section 202(a) clearly implies that the decision to issue warnings to state and local officials is a discretionary one that rests with the President, it is doubtful whether it authorizes a federal agency to issue a prediction of a disastrous event outside that authority. Under the legislative history of the Act it would appear that the warning includes or subsumes everything necessary to its preparation. Accordingly, an independent confirmation of a prediction outside this chain of authority may be impermissible under the policies laid down in the Act, as an action tantamount to a warning.

One reason that predictions without warning would appear not to be authorized to federal agencies is that, as the example illustrates, the action would undermine the authority of the President to decide to warn state and local officials. Another reason is that, insofar as the official actions of the federal government, including its agencies, are concerned (as distinguished from those of scientists in universities and private employment) there is no difference between a prediction of a disaster and a warning of a disaster. What is at stake in the policies laid down for the federal government is the issue of whether the President shall decide to warn state and local officials, and not the question of whether there is a scientific and technological basis for a prediction. In other words, the issue is action by the government, and not scientific judgment by the government. Scientific judgment may or may not be exercised within the government; but if it is, it would lead only to the decision to act or not to act.

The other significant fact bearing on this subject, one that was included in the legislative history of the Act, is that in many areas it is the federal government, directly and by contract, that has the exclusive expertise to develop the technical information on which a warning could be prepared and issued. Accordingly, as a matter of congressional policy toward state and local officials and toward the "civilian population" in general, it is the federal government that has the expertise to decide whether the technical data are a sufficient basis on which to decide to issue a warning. This interpretation is complemented by those provisions of the Act that leave the decision as to whether to announce that a disaster actually threatens in the hands of state and local officials.

3. Impact of Prediction on Existing Federal Government Programs

While the existing federal disaster legislation could provide an interim public policy basis for earthquake prediction, other existing federal and state level programs would be affected by earthquake prediction.

An effective way to examine the impact of an earthquake prediction on existing governmental programs is to suggest the range and extent of the impacts in this area by citing a few examples. The potential impact on unemployment insurance by an earthquake prediction is discussed in some detail in the next subsection. It can be anticipated that all welfare and related programs, such as food stamps, would be extensively affected by the prediction of an earthquake, especially where the lead time was such that the prediction caused unemployment to rise substantially, where mandatory relocation programs were put into effect, or where conditions encouraged the voluntary relocation of substantial numbers of recipients of social service programs.

Veterans Administration and FHA mortgage programs, which are currently subject to a variety of design and construction standards, could be substantially affected. Federal highway and mass transit programs would be subjected to requirements not now included within the legislative and administrative authorities by which they are operated. The General Services Administration, as the federal property and facilities manager and owner, would be substantially affected. The U.S. Postal Service, though a corporation, would be required to make decisions concerning its facilities, distributional systems, and services. These decisions would have widespread and substantial impacts throughout the areas affected and could substantially impair other public and private programs that depended on the Postal Service.

A rundown of the regulatory agencies indicates that they, too, would be substantially affected by earthquake prediction--even those whose jurisdictions and activities appear remote from responsibilities flowing from the prediction of an earthquake. For example, what will the Securities and Exchange Commission require by way of disclosure in filings made after a prediction has been announced by the President, and how will the Occupational Safety and Health Administration determine that a prediction affects, for example, the working conditions in a chemical processing plant? If the prediction were for Utah, how would the Mine Enforcement and Safety Administration (MESA) determine that the Coal Mine Health and Safety Act applies to underground mining conditions? And how will the Department of Labor and the National Labor Relations Board incorporate the conditions of an earthquake prediction into their programs and rules with respect to workers and organized labor?

It is in fact difficult to identify federal agencies, departments, bureaus, and commissions that would not be potentially affected in one way or another by the prediction of an earthquake whose lead time was longer than a month or two. In fact, as seen exclusively from the point of view of the impact of earthquake predictions on the federal government's programs as currently authorized, organized, and administered, the most desirable and manageable kinds of predictions are those with very short (e.g., 3 days) and very long (e.g., 8 or more years) lead times. The former can be treated within the existing disaster legislative and administrative framework. The latter, if taken seriously, provides sufficient time to develop a systematic assessment of programmatic needs and the development of coordinated responses. A realistic view of the potential earthquake-prediction capability suggests that actual predictions may not be so accommodating to the needs of the federal government.

The potential consequences of a medium-term prediction for government are disquieting. A prediction could have a disorganizing effect that goes beyond the mere public exposure of the occasional apparent inability to respond to disaster situations, as was the case after Hurricane Agnes struck Pennsylvania. An earthquake prediction could be disorganizing to the internal consistency of the federal government and to its ability to conduct programs in difficult areas where its authority is contended.

The potential has been amply illustrated in the recent past as one crisis or another has cut across otherwise orderly governmental programmatic lines in a disruptive manner, causing the very capacity of governance to come into question in certain areas. Earthquake prediction carries this same potential for the federal government. (In different ways, and to lesser degrees, the same conditions apply to state governments.)

This situation speaks strongly for development of a systematically organized, anticipatory effort by which the prospect for prediction of a damaging or great earthquake are assessed across the federal government so that its responses to a prediction can be carefully thought out, programs coordinated and, where necessary, enabling or standby legislation enacted. This is a highly complex undertaking, one that requires the assistance of the technical and administrative knowledge and skills found most commonly in the program areas extended into complex intergovernmental areas involving state, local, and regional governments, all of which would have to be brought into the assessment process.

The undertaking is one that the federal agencies involved are not presently willing to initiate on their own. In part, earthquake prediction, especially in Washington, is simply not credible, especially when measured against the very current realities of earthquake protection and disaster programs. In part, agencies have been given neither the funds nor the authority to begin such work. At this point, even if the above two problems were solved, the agencies do not know what areas the predictions will first apply to nor what characteristics the predictions will have. These problems suggest some of the elements that must go into the development of any federal program for the assessment of earthquake prediction, if one is to be developed at all.

4. <u>Relationship of Governments to Private-Sector Responses</u>

Domestic conditions in wartime offer perhaps the only experience analogous to the way in which relationships between government and private-sector interests may change during the change from "normal" situations to the situation that certain kinds of prediction are possible--a "medium-term," 6 month's prediction, for example. The analogy is at best a rough fit. It does, however, give rise to speculation concerning extensions of governmental control and subsidies into areas that are by political custom, if not by law, reserved exclusively for private concerns. A brief exploration of these possibilities may be useful in establishing whether or not the potential and forseeable problems in this area could usefully be addressed by further study. In doing so we do not seek to determine what the law holds for each of the possible sets of prediction characteristics in this area. Rather we want to explore the range of legal and legislative problems that could arise.

First, it appears useful and necessary to distinguish between two broad classes or areas where governments and the private sector could be jointly affected. One class of problems relates to the application or extension of ongoing governmental programs to conditions as they would exist under the prediction of an earthquake. The extension of unemployment insurance is an example of this class of problem. The other class of problems relates to governmental activities that could be implemented to control or subsidize elements of the private sector. Wage and price controls in certain sectors, such as construction, are an example of this class of problem. The extension of the investment tax credit or some such device to the reinforcing costs of buildings is another.

The first class of problems relating to ongoing governmental programs or the extension of programs tailored specifically to the conditions of an earthquake prediction may come about on the basis of development of new points of common interest between the private sector and governments. Perhaps the easiest way to describe this general area is by extension of the unemployment insurance example mentioned previously to a hypothetical set of prediction facts.

Assume that a prediction has been issued as follows: An earthquake of magnitude 7.2 to 7.5 is predicted on the Hayward Fault with its epicenter in the Oakland area. Scientists have assigned an 80 percent probability to the magnitude. The prediction is that the earthquake will take place 6 months after the prediction is publicly announced. The event could occur any time during the 2 weeks preceding or following the 6-month date; that is, there is a time "window" of 4 weeks. Scientists have assigned a probability of 85 percent to whether the event will occur and a 60 percent probability to whether it will occur within the 4-week time window.

Under these circumstances, firm A, which is engaged in assembly operations using parts supplied from outside the San Francisco Bay area, decides to close its assembly lines during the 4-week period. Allowing 1 week's lead time for the parent firm, which is headquartered in the east, to schedule the transition of production to its other assembly sites, firm A decides to close down operations for 5 weeks. The closedown will affect both salaried and hourly workers.

Firm B, which is engaged in services that are performed in office buildings scattered throughout northern California, decides that only a few of its offices would be at risk should the earthquake strike as predicted. For employees in those offices firm B establishes a policy of covering them all for their annual vacations, whether earned for the year or not, at the time of closedown of the offices. Seventy-five percent of such employees have 2-week vacation benefits, and the remainder have 3 weeks, the maximum offered by the firm. A few employees are offered jobs in the offices of the firm in the Bay Area that it does not plan to close down. Some employees who are offered these alternative-site jobs accept; others decline.

Firm C, which is engaged in the production and delivery of products around the Bay Area, decides that it will attempt a "business as usual" posture throughout the prediction period. It is of the opinion that its production facilities are located in such a way with respect to the predicted event that the effects of the earthquake will not exceed the design of the building and that there is little risk to its delivery trucks, which will be either scattered throughout the Bay Area or parked in the open at the plant yard when the earthquake strikes. The firm has also determined that its plants and vehicles are covered by insurance in the event of losses due to the earthquake. Firm C notifies its employees of its "business as usual" policy. A number of employees quit work in the ensuing 3 months with various stated reservations. The firm hires replacements, who are required to acknowledge in writing the firm's "business as usual" policy as a condition of employment. Several applicants, however, file suit to enjoin this practice. A number of the employees who do accept employment have no intention of working through the prediction period, however. Three months after the initial prediction the state issues a warning to businesses in the area that in effect advises that it may be hazardous for certain types of activities to continue during the prediction period and establishes work and safety guidelines for certain types of business. Firm C loses a number of additional employees during the months following issuance of the warning by the state. Some of the employees are replacements and some are original, pre-prediction employees. Based on the guidelines issued by the state and an assessment of its present and projected employee turnover rate and declining sales trends, firm C decides it is uneconomical to continue operations during the 4-week period for which the earthquake is predicted. It notifies its employees that it is shutting down during this time and will pay vacation time accrued to each employee as of that date. The firm notifies selected key employees who had quit of its new shutdown policy and offers reemployment under prior conditions of seniority, employee benefits, and the like, as part of its postearthquake business preservation policy. Some accept, and the firm fires some replacements to make room for them, plus additional replacement employees who are now unnecessary due to declining sales. Most of the remaining replacements quit firm C 2 weeks before the prediction period on the grounds that the firm broke its "business as usual" obligation, which was a condition of employment.

Without extending this example further it can readily be seen that a number of questions arise from the hypothetical responses of firms A, B, and C.

Which employees are covered by unemployment insurance? Are the employees of firm A entitled to 5 weeks, 4 weeks, or none at all? Are all of the unemployed individuals in firm B entitled to insurance payments or only those who were not offered employment at other locations--or shall only that part of the actual period during which each employee is unemployed and is not covered by vacation payments be covered by unemployment insurance compensation? Does insurance hold for those employees who were offered employment at other locations but declined to accept? For firm C, who gets unemployment insurance? Those who "voluntarily" quit during the first 3-month period after the prediction? Those who were hired to replace them but left when the firm reversed its "business as usual" policy? What about those who had no intention of working through the prediction period? Are the employees who left the firm after the state issued the guideline-warning and before the firm announced that it would close during the prediction period entitled to unemployment insurance?

Both the example and the questions could be extended practically without end. For example, how would labor law be brought into play with respect to seniority and retirement benefits in the case of firm C? The law, in seeking answers to these and other questions of this class in a judicial forum would argue the policies that should be applied to each of the above questions under the existing state of the law and the facts of each situation. For example, should an employer have the right to determine for, and allocate among, its employees the risks of injury and death? Underlying this question is the fact that the particular effects of the predicted event are unpredictable in specific areas and on specific structures. The prediction and subsequent warning by the state are official governmental pronouncements (USGS and the state). Under these circumstances, should employees of private firms be treated as the general public for purposes of the exercise of the governmental powers of health, safety, and welfare--or may their conditions of employment, which are in private hands, determine the risks they shall bear?

The foregoing barely touches on the questions and possibilities for exploring the policies that should be applied in answering those questions as the law might reason on them. Continuation of this line of inquiry would create the danger of losing the central point, however: The potential for earthquake prediction opens whole new legal/legislative policy areas that may be explored in advance of the occurrence of any specific prediction with a view to identifying potential areas where law and policy need to be established against the contingent possibility they may be required to meet foreseeable conditions, and where determination can be made in advance of the conditions establishing the need for principles by which particular problems will be addressed. For most of these problem areas, federal participation will be required. Development of policies also require participation by the private sector.

The second class of governmental activities relates to subsidies or controls aimed at private-sector activities. In general, this class of activities relates to adjustments made to private-sector activities for short-term, emergency-related purposes in order to preserve the stability, balance, and viability of the regional economic unit as it would be affected by the prediction of an earthquake. We have national level examples--albeit highly controversial ones--in the Cost of Living Council and wage and price controls. We have ongoing examples and models of the regional application of governmental controls of certain products in the Federal Energy Administration's activities. New England fuel oil is one example. The actions of the Federal Power Commission and state public utilities commissions with respect to the regional allocation of natural gas and the granting of limited permission to certain utilities located in one region of the country to explore for gas in other regions for their own use are other examples.

On further study of the anticipated, specific impacts of earthquake prediction on identified economic regions of the country--for example, the San Francisco Bay Area, the Los Angeles area, the Alaskan economy, the Greater Charleston, North Carolina area--it may appear desirable to prepare by legislative enactments certain controls and subsidies in order to maintain and adjust regional economies that come under strain due solely to the prediction of an earthquake. The following are limited examples of the kinds of governmental actions that might be taken.

Assume prediction of a damaging earthquake in the San Francisco Bay Area for 3 years from the date of prediction. Assume further that the federal and state governments decide on a policy of encouraging the private sector to reinforce nonresidential buildings and that they do this by enacting a combination of tax credits and low-interest "earthquake loans." It establishes this latter program by enabling the state to establish an "Earthquake Loan Authority," a nonprofit corporation to be chartered by the state. The federal legislation contains a provision whereby the federal government guarantees the loans. It further provides that in the event of substantial damage or total collapse of the structures on which the loans are made, repayment of the loans is forgiven according to formulas specified in the legislation. The legislation also provides criteria, to be administered by the Department of Housing and Urban Development and developed in detail by the National Bureau of Standards, for determining classes of structures that qualify for "earthquake loans." On the basis of the federal legislation, the state enacts legislation establishing the "Earthquake Loan Authority." Establishment of the loan authority and response by the private sector greatly expand the construction-industry sector of the Bay Area's economy. The Bay Area experiences an influx of materials, equipment, and labor much as Alaska has for the pipeline. Temporary housing is in short supply, but sufficient tourist facilities are converted to this use to prevent the housing problem from limiting the influx of workers in construction and related areas. Under these conditions labor rates begin to rise dramatically, as do the costs of materials and equipment, in relationship to preprediction indices for construction and other economic activities. At some point in the rise of wages and prices, the government may be called on to exercise regional controls in order to introduce stability and balance in the local economic picture. The example is extremely limited, of course, because supporting legal and legislative actions would probably be required to enable a dramatic increase in activities related to reinforceing construction where there is a substantial future prospect of a major disaster. For example, new rules adjusting potential liabilities for design, construction, and workmanship may have to be temporarily established in the face of conditions where it may be difficult, if not impossible, to determine causalities between failures of existing designs and workmanship, failures of reinforcing designs and workmanship, and actual earthquake effects that exceed the standards of one or both of these. On the other hand, the conditions under which such construction would be carried out would appear to give ample opportunities to fraudulent and negligent practices by construction contractors, especially in situations where they entered the area on a temporary basis due to the special conditions of employment resulting from the prediction.

Additional legal and legislative impacts could be analyzed by carrying forward the "ripple effects" of the governmental actions described in hypothetical, though not unprecedented, form. The point is that certain kinds of predictions could give rise to governmental actions directed to the economic activities of the region involved that have a heavy impact on the private sector. Evaluation and analysis of such potential situations could be accomplished before they arise, so that should a prediction create a climate of "emergency economic conditions," the actions of the government taken to address one element of the overall problem do not cause undesirable ripple effects across other sectors and elements of the problem. This suggests that considerable preparatory effort will be required by the government and the private sector, jointly, to define the objectives and the role of the government with respect to crises that may develop within the regional economy.

We end this brief analysis of the two classes of problem area where new points of coincidence may emerge between governments and the private sector by noting that legal and legislative matters in such situations depend strongly on the specific prediction and the specific region. One need only change the prediction facts assumed for the examples in this section to 3 days' warning to obviate the need for any preevent consideration of the problems touched on here. This suggests the need to carefully develop and realistically assess, in light of the seismological and geological facts of a given area, the ranges of possible prediction facts that could emerge. The development of anticipatory policies, legislative enactments, and the like could all be rendered essentially useless by the assumption of unreaslitic and impossible prediction facts. Analysis in this area confirms the extent to which the responses to a given prediction are sensitive to the factual assumptions about the prediction itself.

E. Regional Planning for Uncertain Predictions

1. A Policy for a Developing Science

By and large the public believes that science can produce a technology of earthquake prediction that will be accurate and comprehensive in coverage. This attitude is echoed by some in the scientific community in the feeling that there will ultimately be a theoretical breakthrough that will permit a deterministic approach to earthquake prediction. The key to such an understanding of earthquake prediction is knowing what triggers earthquakes. However, there may be more than one contributing factor, they may be inherently stochastic processes, and they may never be directly measurable. The empirical evidence for the theory of continental drift and plate tectonics is impressive if not overwhelming, but the underlying mechanisms are poorly understood. If they were known, the manifestations of the processes--namely, the earthquakes that result when the continental plates adjust--could be better explained. The microprocesses, such as stress buildup and strain relief in crustal rocks, can help explain the macroprocesses, but not the opposite.

If science were to produce a perfected technology of earthquake prediction, the public policy decisions would be relatively easy to implement. The results of the scientific investigation would compare favorably with society's expectations, or they would remain in the laboratory until they did. Scientific truth would correspond with political truth. However, science is forced to develop earthquake-prediction technology not in the isolation of the laboratory but in the world of human affairs. Because of the manner in which science works--from observation to hypothesis to a coalescing of hypotheses to a theory and possibly then through the same cycle that develops a new theory, with the implicit understanding that it may be preempted by still new theories--the process of generating political truth based on the available and uncertain scientific truth at any point in time is chaotic. As a result it is difficult to formulate a public policy on how to respond to the products of a developing science.

The evolving technology of earthquake prediction cannot be ignored by society, nor can it be stopped. Society is forced to address the problem of translating scientific truth into political truth. China has succeeded in implementing earthquake prediction at a very preliminary stage of scientific development, because it is willing to use inchoate scientific information in political decisionmaking. However, China is not an open society, and it has a unique cultural perspective. The United States is an open society, and it has pragmatic expectations of science.

In earthquake prediction we are dealing with a technology that by its very nature demands a unique relationship to society if it is to develop. The developing technology will be producing information. Everyone has his own standard of usefulness for such information. Individuals, families, businesses, governmental entities, and corporations will each optimize their reaction to such information. This inevitably produces conflicts and chaos. A conversion of scientific to political truth means that everyone is walking to the same beat. This can be imposed as in China, or it can be freely accepted. A political settlement by its nature can be acted on as a public matter.

Except as a kind of popular notion based on exaggerated expectations and basic misunderstandings of science, earthquake prediction is unwelcome at this time as a public matter. There is a lack of maturity in the technology because it is still evolving and a lack of maturity in the public realm because there is no basis for consensus. Maturity in the public domain may be the integration of scientifically based knowledge into the actions of society. Maturity in science is inherent in the science itself. It is measured by standards of transferability and replicability based on theoretical knowledge. When a science has matured, it can be applied as a technology. The implementation of a technology implies also a maturity in the public realm. Science inherently cannot work in the public domain. The pursuit of scientific truth and the application of scientific truth as technology are two different worlds.

The solution to the dilemma of acting on the results of a developing science is for society to deliberately choose its relationship to the development of the science. Because a developing technology is inherently uncertain, the impacts are uncertain, and they are experientially bound to an assumption of a set of facts concerning the interaction of the developing technology and society. If one could specify the full range of possible fact situations, the impacts could be bounded, but this could be a herculean task. Earthquakes are a local phenomenon, and the types and kinds of predictions, expected damage, and possible mitigating measures can be greatly limited for a given locality. In other words, the range of fact situations can be bounded, and so the possible impacts can be limited. Accordingly, society can use this knowledge base to choose its relationship to the developing technology of earthquake prediction.

This is still a difficult task and will have to be accomplished by regions that can be as large as the area affected by the maximum expected earthquake or as small as the political jurisdiction that wishes to establish such a relationship. The important fact is that what works for one location or jurisdiction may not work for another because of differences in the seismic characteristics, the man-made environment, and the sociopolitical milieu. Each region then will have a certain degree of internal homogeneity and uniformity if the task is to be successfully completed.

A process for a region to deliberately choose its relationship to the developing technology of earthquake prediction is described in the discussion that follows and is designated the Earthquake Prediction Impact Statement (EPIS) process. There are other approaches, such as "muddling through" on a case-by-case basis and learning from past mistakes or relying on federal-level policy that may or may not apply to the local condition or the specific fact situation, but if chosen, these should be freely chosen after a careful examination of their possibilities, limits, and options.

2. Earthquake Prediction Impact Statement Process

An examination of the earthquake-prediction system diagram shown in Figure 8 and the discussion in Section III-B-2 indicates that there are several kinds of information in an earthquake prediction:

- Technical Generation Component--Premonitor indications, empirical premonitor calibrations and correlations, theoretical understanding of earthquake mechanisms, and the geology and seismology of the source region. The data generated in this component are the inputs into the public information component.
- Public Information Component--Statements about where, when, and what size earthquakes are expected, with statements of uncertainty, confidence that the event will occur within the time period, and possible contingent effects (see Table 2). This information will be presented in terminology most familiar to the seismological profession.
- Technical User's Component--The translation of the predicted earthquake characteristics into local seismic effects that can be used to estimate the effects on structures. It requires knowledge of the seismic spectral properties that would be generated in the source region by the predicted earthquake, source-to-site transmission path geology and topography, and local site geology and soil structure.
- Decision Component--The cumulative uncertainty that is determined for the local seismic effects, resulting from uncertainties in knowledge and translation procedures at each step from the prediction to the local seismic effects.

The EPIS process makes uses of all of these components of an earthquake prediction in a region.

The EPIS process is intended to develop a set of alternative strategies for responding to the expected range of earthquake prediction situations in an area, before the capability to make earthquake predictions is fully operational. Although we describe the process in a static manner, it will actually be carried out in an iterative and dynamic fashion, with opportunity for updating as the technology of earthquake prediction develops, the methods of risk assessment are perfected, and the goals, objectives, and basic earthquake-protection posture of society evolves.

There are three basic steps in the EPIS process:

- To develop and promulgate a formal set of earthquake-prediction cases that represent the known range of possible earthquake-prediction situations, or facts, that might come from an earthquake-prediction system in a given region.
- To analyze and evaluate the impacts of responding to the established range of earthquake prediction facts with alternative tactics for reducing property damage and saving lives.
- To adopt rules for government response to the range of possible earthquake predictions, based on the analyses and evaluation of alternative tactics.

Accordingly, when the scientific program in a region generates a hypothesis concerning a future earthquake, the scientific data are first validated and then translated into a set of prediction facts by an independent committee having technical expertise and public representation. These facts are then identified with one of the preestablished sets of possible conditions. The response is accordingly governed by the rules that have been adopted by the appropriate representational governmental unit for that specific case.

To put the process and the actors together, we will go through the process as it would be applied in a region (see Figure 11). The developing technology of earthquake prediction is the background and basis of the entire process. This is carried on by the USGS and participating scientists in universities and other institutions in the United States and other countries. This program forms the basis on which (1) through consideration of the geology and seismology of the region to be instrumented for earthquake prediction a set of possible prediction cases is developed and (2) a scientific program for developing earthquake-prediction capabilities in the region is initiated.

Under the authority of the USGS, an Earthquake Prediction Case Development and Evaluation Committee consisting of representatives of

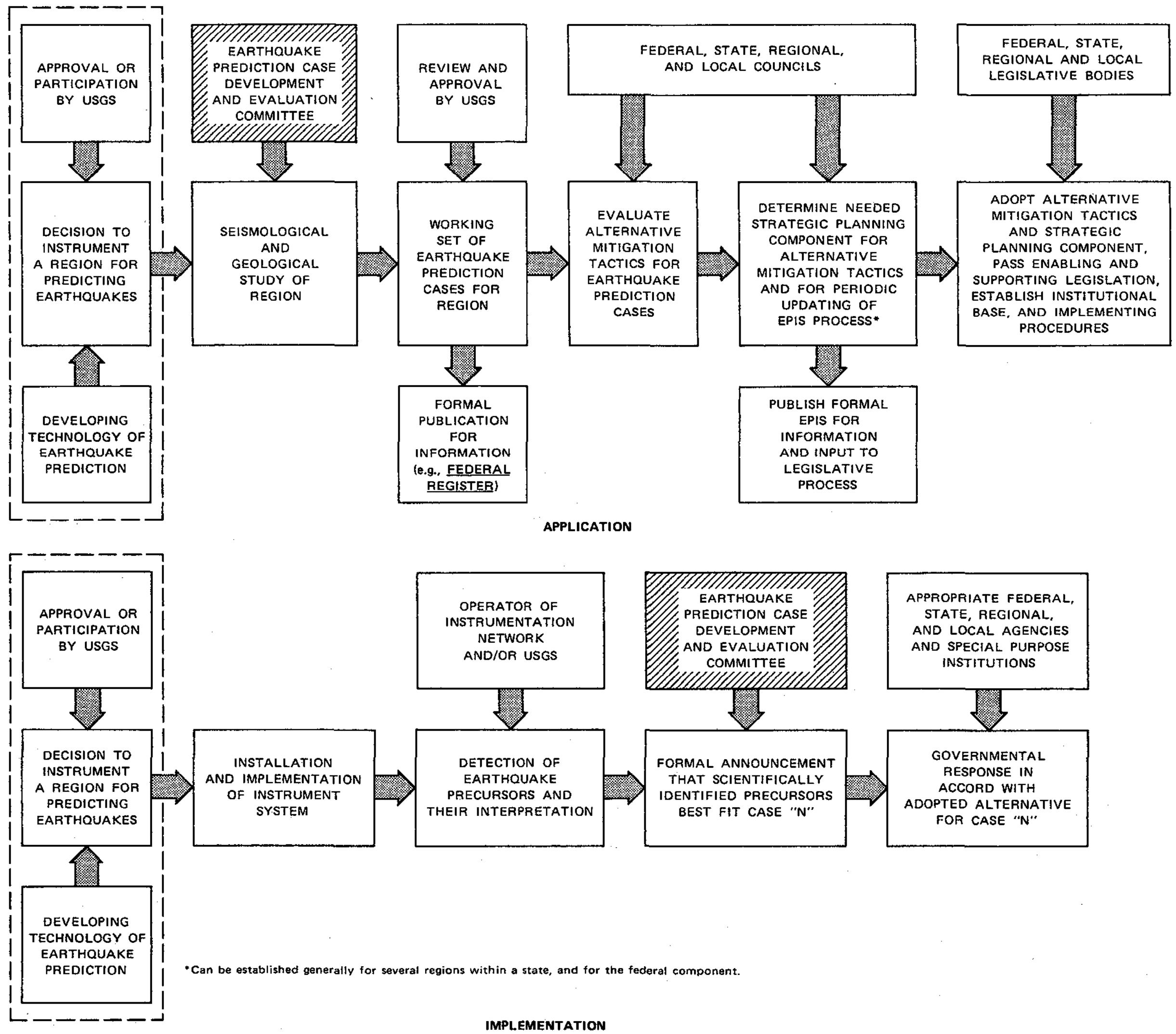

FIGURE 11 GENERALIZED SCHEMATIC OF THE EARTHQUAKE PREDICTION IMPACT STATEMENT PROCESS

the scientific community and other public interests develops and adopts a formal set of earthquake-prediction cases for the region to be instrumented. This might be the Los Angeles--southern California region, the San Francisco--northern California area, Charleston, South Carolina, or any other area that would be instrumented and considered geologically and seismologically as a "prediction unit." To enhance the participation and cooperation of the public in this process, the set of possible earthquake-prediction cases should be formally published--perhaps in the Federal Register.

All levels of government and interests will have to participate in the process of evaluating alternative tactics for responding to the promulgated range of possible earthquake-prediction cases for the region. This will require detailed assessments of costs and benefits for reducing property damage and saving lives. An assessment of the number of "false alarms" that can be tolerated for each risk will have to be made. The general criteria for responding against the evolving baseline regional condition will have to be established. These kinds of studies will require the accumulation of regional data bases that are not presently available and will in fact prove useful for many kinds of socioeconomic studies.

After the available damage-reduction tactics have been evaluated and ranked according to explicit, but multiple, and not necessarily compatible criteria, the public will, through the political process and their appropriate legislative bodies, adopt through supporting legislation and ordinances those alternatives that are deemed most appropriate to the existing goals and objectives of society.

In concert with this previously described process a predictive capability will have been established for the area, probably working through an experimental to a monitoring phase and on into an ad hoc operational phase. Accordingly there is the possibility that earthquake premonitors may be detected. It would then seem logical that the same Earthquake Prediction Case Development and Evaluation Committee (or its successor) that developed the formal set of earthquake-prediction cases also validate and translate the scientific data into a formal announcement that these scientifically identified precursors best fit one or the other earthquake-prediction cases. The decisionmaker then has only to respond with the appropriate, previously adopted alternative. Those alternatives may, of course, provide broad bands of discretion in certain areas, according to the will of the people and the legislature.

The preparation and adoption of an earthquake prediction impact statement by a region also provides the basis for the necessary planning and preparation that will have to be accomplished to carry out certain strategies. Educational programs, stockpiling of materials, prepositioning of supplies and equipment, creation of institutions with necessary authorities and powers for conducting important functions, and the like will all be specified and facilitated. Incidentally, if the EPIS process is conducted in the proper manner, it will also satisfy the requirement of an environmental impact statement under the National Environmental Policy Act.

In addition, the EPIS process tends to accomplish the following:

(1) Sets bounds to the range of possible initial predictions.

(2) Establishes rules for deciding whether and how to act on the basis of probabilistic statements.

(3) Settles the political problems involved in deciding whether and how to act on scientifically derived, but probabilistic statements.

(4) Protects the scientific effort from public demands and so maintains the freedom and independence of a science of inquiry that must be conducted in the world laboratory of human institutions.

(5) Reserves to the realm of public action those elements that are the proper subject of politics.

(6) Allows the public to address in the present the problems and issues of possible future events.

Finally, we should note that the issue of converting predictions into warnings seems to disappear under this approach. All of the problems of the effectiveness of a warning, discussed in Section III-B, remain of course. But the EPIS process provides a framework for coupling the decision to act on a prediction with the scientific processes involved with developing the prediction.

F. Lengthening and Broadening the Planning Perspective

1. Introduction

In the preceding section we saw the potential for tactical level planning in relationship to the problems and uncertainties posed by the emergence of an earthquake-prediction technology. This section is addressed to the question of whether such a planning level is sufficient to deal with the full range and scope of the problems introduced into society by a prediction capability.

Examination of the historical development of the four disaster-related programs shows that they are evolving along separate paths rather than in an integrated, interactive manner. This illustrates why society may want to address the problem of integrating the future development of these programs in order that they can be brought to bear on earthquake predictions in a coordinated manner.

The potential for predicting earthquakes will be devoloped in different regions of the United States at different times. Furthermore, developments within those regions will be limited initially to specific localities. For scientific and technological reasons, some localities in the United States will experience prediction before others. In some cases, it will be many years before a prediction capability could be extended to all areas that are exposed to the risk of earthquakes, even in the same state. This suggests that society will be faced with the need to continue to evolve and "hold" its present long-term strategic posture toward earthquake-risk reduction for a considerable length of time--a hundred years or more--in spite of the emergence of a prediction capability that could eventually provide a basis for a new posture in some geographical areas.

2. A Strategic Planning Base

The combinations of the above two factors, plus other complex, long-term elements involved with earthquakes as disasters to society, suggest the need for a planning capability at a level high enough to maintain its protective posture toward earthquake risk. In other words, the integration of the evolving technology of earthquake prediction into society's existing practices and posture with respect to earthquake protection requires the development of a strategic planning function. This would provide the additional ability to

- Forecast the course and dynamics of developing situations as they might be influenced by the application of countermeasures.
- Trade-off choices among technical programs.
- Develop long-lead-time resources and skills.
- Integrate short-term tactical responses with long-term programs.
- Assess major alternative courses of action that require considerable development lead times and resources to implement.

The strategic planning level responds to the prediction that we will have earthquake predictions. The selection of the EPIS as a way of dealing with the problems of responding to earthquake predictions with an appropriate set of tactics is an example of a strategic planning decision. However, this alone would be useless unless society had the resources and trained personnel necessary to implement these tactics. The decisions to stockpile equipment and other resources and to train and drill personnel is a strategic level decision. On an institutional level, as mentioned in Section III-D, there is a need "for devélopment of a systematically organized, anticipatory effort by which the prospects for prediction of a damaging or great earthquake are assessed across the federal government so that its responses to a program can be carefully thought out, programs coordinated and, where necessary, enabling or standby legislation enacted." In addition, many federal programs have long administrative "tails" that extend into complex intergovernmental areas involving state, local, and regional governments, all of which would have to be brought into the assessment process.

In Section III-D we find that considerable preparatory effort will be required by the government and the private sector, jointly, to define the objectives and the role of the government with respect to crises that may develop within the regional economy. The selection of a basic earthquake-prediction posture within the context of possible earthquake predictions, whether it incorporates a specific assignment of risk as a basis or whether it chooses the implied risk in the adopted technical programs, is a strategic level decision. Most if not all of this type of planning would be facilitated by knowing the range of possible earthquake-prediction facts that would be developed as part of EPIS.

Preparation for earthquake prediction within and among governmental and private institutions requires that a strategic planning base be developed. How best to incorporate this type of planning institutionally presents problems. Many governmental agencies at all levels and private institutions have long utilized strategic planning. However, the federal-level view of natural disasters as events that can only be dealt with on an event-by-event basis, and therefore responded to and not planned for, is in a period of transition. This federal view affects the state and local agency view, with which it strongly interacts.

This clash of views is significant for the problems that earthquake prediction will encounter in the federal establishment. Those who hold a basic event-by-event view of natural disaster would preserve a short-term outlook as the basis of public policy decisionmaking and actions. This would establish the past and present as the basis for decisionmaking and respond to events of the future as, and if, they happen. On the other hand, the view that considers recorded past occurrences of floods (correlated with, of course, other technical data not here important for purposes of conceptual analysis) are a basis for projecting flood occurrence into the future holds that anticipation of these future events is both a sufficient and a necessary basis for public policy decisionmaking and action purposes and, therefore, that this class of natural disasters can be planned for. In the case of the Federal Flood Plain Insurance program, the national level view, which tends to correlate more closely with the statistical or future-oriented view, appears to have prevailed in causing the legislation, but more locally oriented views appeared to have assumed that the provisions of the law centered control over application of the program, including the brokering of insurance, at the local level. As has been national legislative experience a number of times in the past 15 years, it appears that past- and present-oriented views, and future-oriented views, can be roughly correlated with jurisdictional territoriality; that is, the views of the constituents are attached to the interests they hold jurisdictionally.

In this context, earthquake prediction poses a direct challenge to the event-by-event view of natural disasters, and the establishment of a new, permanent agency in the federal establishment for an earthquake prediction program would directly undermine the part of its current constituency that supports the federal government's ability to respond directly to citizens' needs for help. The policy context in which earthquake prediction must go forward, if it is to go forward at all, is in transition.

The coordination of the EPIS program through all levels and interests of government and private institutions would provide a focal point for institution building around a strategic planning function. We have presented only the bare framework of such a process. As with an environmental impact statement, EPIS should be required before earthquake prediction can go forward in a region. However, EPIS should only be accepted as a basis for program implementation after it has been demonstrated that the strategic level issues have been resolved. In addition, the capabilities should exist at all levels to update the process periodically.

IV EARTHQUAKE PREDICTION IN THE FUTURE

As we saw in Section III, the intermediate (or "transitional") products of the scientific inquiry into earthquake prediction would be implemented as an operational system before prediction has had the opportunity to become a mature technology. Because it will be necessary to establish the replicability of predictions and because of the infrequent occurrence of major earthquakes (which are required to establish the replicability of predictions) in the United States, the development of a reliable operational system is likely to take a long time. In this section we consider the long-term implications arising from this situation. Our focal point is the final product: a technology based on a mature science.

A number of the issues involved in assessing the impact of earthquake prediction must be dealt with at the level of policies addressed to altering or stopping the anticipated course of development of the technology, if indeed they can be identified and dealt with at all. This section is an inquiry into the questions and issues emerging from this long-term, "macro" level of the assessment.

Included within our exploration of the policy issues in this section is the basic question of whether we could stop the development of the technology even if we foresaw responsible reasons for doing so. We address the related question of whether the anticipated course of the development of the technology could be influenced by policies addressed to modifying or altering that course.

A. Will the Technology "Pay" Society?

1. Will the Development and Use of Earthquake-Prediction Technology Pay Society?--The Nationwide Perspective

A traditional task for economists is to assist decisionmakers in determining whether the total benefits of a public investment will

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outweigh the total costs--that is, whether it will pay society as a whole to proceed with a proposed public investment. Various kinds of national cost-benefit analyses have been conducted for many proposed federal programs ranging from electric power projects to education programs to public transit system investments. An analysis of total costs and benefits has been an important aspect of some technology assessments. The supersonic transport and the liquid-metal fast breeder reactor are two new technologies for which extensive analyses of costs and benefits were conducted.[*] There is extensive literature on the methodology for addressing the question, "Will a public investment pay society?" and on applications of benefit-cost analyses already performed.[†]

For reasons that will be brought out in the following discussions it is not the purpose of this discussion to resolve the question, "Will the development and use of earthquake-prediction technology pay society?" However, a framework for addressing this question can be outlined and some important insights about the economic dimensions of the assessment of earthquake-prediction technology can be derived with only a small amount of information on potential costs and benefits.

The major categories of economic impacts anticipated from the development and use of earthquake prediction technology are listed below.

- Benefits from development and use of earthquake-prediction technology.
  - Reduction in loss of lives from an earthquake
  - Reduction in property damage from an earthquake
- Costs of development and use of earthquake-prediction technology.
  - Costs of the research and development effort.
  - Costs of implementing tactics chosen after a prediction.

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[*] See, for example, Ref. 88.

[†] See, for example, Refs. 89 through 92.

-- Costs of strategic and tactical planning

-- Direct tactics-related costs

-- Loss of economic activity and property values.

- Costs of mistaken and fraudulent predictions (repeated strategy-implementation costs)

-- Direct tactics-related costs

-- Loss of economic activity and property values.

a. Unique Features of Earthquake-Prediction Technology

Two features of earthquake-prediction technology that are different from most other technologies are illustrated by the list of costs and benefits: (1) many of the costs and benefits associated with earthquake-prediction technology result not directly from the prediction but from loss-reduction tactics selected after a prediction; (2) for a long time, predictions of earthquakes will not be "certain predictions; they will be predictions that an earthquake is probable (but uncertain).

An earthquake prediction will open up choices of strategies for society to select from in an attempt to reduce the damage from an earthquake. These strategies, discussed in Section III-C, range from partial evacuation of a city to changes in building codes, seismic zoning, and disaster preparedness. Nearly all of the benefits foreseeable from earthquake-prediction technology will actually come as a result of implementing one or more of these loss-reduction tactics after an earthquake prediction. These tactics will have direct costs--the costs of personnel and supplies for an evacuation, the costs of strengthening buildings, and the like. These costs are included in the list above as "direct tactics-related costs."

The literature on earthquake prediction exhibits great concern with the potential losses of economic activity or property values to individuals and businesses. These potential losses could occur either directly as a result of a prediction or as a result of the implementation of a loss-reduction tactic (e.g., evacuation). These costs are included above as "loss of economic activity and property values." In addressing the question, "Will earthquake-prediction technology pay society?" only net or nationwide losses of economic activity or property values should be counted. Losses to one individual, business, or region that are made up elsewhere in the economy are important distributional (not aggregate) impacts discussed in a subsequent section.*

Earthquake predictions will not be made with certainty for a long time and possibly never will be. The term "earthquake prediction" as used in this study refers to a statement of probability. This means that society must deal with the probabilistic nature of prediction in selecting what action to take after a prediction. The uncertainties associated with earthquake prediction introduce an element of cost into the evaluation of earthquake-prediction technology that is absent from most other technology assessments. The cost of uncertainty is the cost of mistakes. In determining whether or not the development and use of earthquake-prediction technology is worthwhile to society the cost associated with mistakes will be an important part of the evaluation.

The costs of mistaken predictions are shown above as "repeated tactics-implementation costs." If a prediction turns out to be incorrect, society will have incurred (unnecessarily) the costs associated with tactics selected after a prediction. The diagram below illustrates how incorrect predictions and associated costs can be taken into account.

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*On rare occasions, decisionmakers might reject a proposed investment that had positive aggregate impacts because the distribution of those impacts would favor groups with a low social priority (e.g., a project where the beneficiaries were wealthy and those who incurred net costs were poor). Such a situation seems unlikely for the distribution of impacts from earthquake-prediction technology; the balance of aggregate impacts should be a sufficient criterion for determining whether earthquake-prediction technology will pay society.

Time	Alternative 1	Alternative 2
↓	Prediction research	Prediction research
	↓	↓
	Prediction	Prediction
	↓	↓
	Selection of loss-reduction tactics	Selection of loss-reduction tactics
	↓	↓
	Earthquake occurs	No earthquake
		↓
		Prediction
		↓
		Selection of loss-reduction tactics
		↓
		Earthquake occurs

The first alternative illustrates the sequence of events with (1) earthquake-prediction technology developing over time, (2) at some point a prediction is made, (3) society selects one or more tactics to follow for reducing loss, and (4) an earthquake occurs. The second alternative adds the possibility that a prediction might be issued with no earthquake occurring subsequently.

An answer to the question, "Will earthquake-prediction technology pay society?" requires a comparison of benefits and costs. Will the benefits in terms of lives saved and property damage avoided exceed the costs of research and development, implementation of loss-reduction tactics--direct costs and potential losses of economic activity, and uncertainty in terms of mistaken predictions (repeated strategy-implementation costs)? The balancing of benefits and costs can be visualized as shown below. The costs and benefits counted should be aggregate or nationwide costs and benefits since the question asked is from a nationwide perspective.

Benefits and Costs of Earthquake-Prediction Technologies

Benefits	Costs
Lives and property saved	Research costs Tactics-implementation costs Costs of mistaken predictions

b. What Is Known About the Costs and Benefits of Earthquake Prediction Technology?

There is little quantitative data available about the benefits and costs of earthquake prediction and specific loss-reduction tactics. Contemporary studies articulate lists of future research topics. However, some insights can be developed on the basis of the information available. Furthermore, there is considerable confusion about the interpretation of economic dimensions of earthquake-prediction technology--particularly in the distinction between aggregate impacts and the distribution of impacts on particular groups and local jurisdictions. An attempt is made in this and the subsequent sections to make some contribution to the current discussion of the economic dimensions of prediction technology in the acknowledged absence of quantitative estimates of most costs and benefits.

The major benefits anticipated from the development and use of earthquake-prediction technology are reductions in loss of life and property associated with actual earthquakes. These benefits can occur if the prediction allows society to pursue tactics that (1) remove people and property from prospective earthquake areas or (2) increase the ability of people and property to survive during an earthquake. There is no conceptual problem in how these benefits would be expressed. They would be expressed in terms of number of lives saved and value of property saved.*

Conceptual problems are involved in projecting or measuring the potential savings in life and property from earthquake prediction. Savings can be measured only in relation to what might have been lost. Therefore to measure the savings from a given action requires an estimate of what earthquake-related losses would have occurred without that action. The potential savings from prediction

*Work has been done on placing an economic valuation on the loss of life. This work is available for use in the evaluation of earthquake-prediction technology. See, for example, Refs. 93 and 94.

and associated tactics must be measured in relation to the specifics of the projected earthquake and existing conditions.

The National Oceanic and Atmospheric Administration has completed a study of the potential losses from earthquakes in the San Francisco area.[10] The estimate of lives lost exceeds 10,000, with over 40,000 hospitalized cases, for a magnitude 8.3 earthquake on the San Andreas Fault. This is an estimate for just one area in the country. However, it seems reasonable at this point to conclude that the potential losses from earthquakes today could be measured in the billions for property damage and in the thousands for lives lost not to mention the cost of social disruption. Probably not all of the lives and property at risk from a current earthquake could be saved with the use of earthquake predictions. The damage estimates above, however, represent the size of potential savings that prediction technology has to aim at.

Current federal support for earthquake-prediction research is approximately $5.4 million a year.* If the benefits from earthquake-prediction technology had to be measured only against these research costs, the question "Will earthquake-prediction technology pay society?" might easily be answered positively. However, there are three additional factors to be accounted for: (1) the costs of implementing loss-reduction tactics after a prediction, (2) the costs of mistaken predictions, and (3) the possibility that other earthquake-related programs (e.g., earthquake engineering) might so reduce the potential damage from an earthquake that the additional benefits from prediction would be small.

There are two types of costs incurred after an earthquake prediction. One type is the direct costs of implementing a loss-reduction strategy. The other type is potential loss of economic activity and property values. The strategy choices open to society vary depending on the lead time of the prediction. Different strategies

*Proposed research programs could substantially increase the figure.

are available for the case "an earthquake is likely in 10 years" and for the case "an earthquake is likely in 30 days." It may be helpful in pursuing the question, "Will earthquake prediction technology pay society?" to make a distinction between prediction technology oriented to developing predictions with short lead times versus long lead times.

c. Predictions with Short Lead Times

In this discussion, a short lead time means less than 60 days. Evacuation or partial evacuation of an area is a tactic that is usually discussed only for predictions with a short lead time. Other relevant tactics are simple building-protection measures and emergency preparedness.*

One area for future research is in developing sound cost information for implementing loss-reduction strategies (e.g., how much it would cost in terms of personnel and supplies to evacuate and care for the residents from a part of San Francisco for 1 week; how much it would cost to implement an emergency building-protection program for 30 days; how much would other tactics appropriate to short lead times cost). Decisionmakers attempting to choose among tactics will want to know about the relative costs. However, it does not seem likely that direct tactic-implementation costs for evacuation, emergency building protection, or disaster preparedness for a period of less than 60 days could even approach in amount the potential benefits in lives and property from a prediction. The direct tactics-related costs would probably be measured in tens or, at most, hundreds of millions versus the billions of dollars and thousands of lives at risk in a severe earthquake.

Could loss of economic activity and property value be large enough to make the development and use of earthquake-prediction

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*The loss-reduction selected by public and private decisionmakers will be based on their estimates of the costs and benefits associated with each strategy. Some problems arising from this method for selecting loss-reduction strategies are discussed later.

technology uneconomic? Potential losses of economic activity and property values are much discussed in the literature on earthquake prediction. One example that is cited is the loss of retail business if a city is evacuated. Another example is the loss of production and income if a manufacturing plant is closed after an earthquake prediction. A third example is the decrease in the value of property in an area after an earthquake prediction is issued.

It is helpful to distinguish two issues in this discussion. One is, "What will happen? Will businesses close? Will property values drop?" The other issue is, "What would such behavior mean?" How would these losses relate to the question, "Will earthquake-prediction technology pay society?"

As to what will happen, we simultaneously know quite a lot and very little. Property values would drop for property in an area where an earthquake is predicted. It is also likely that some businesses would close either voluntarily or by order of a public jurisdiction after a prediction. In any more detailed sense we know very little. In Section III-B and in other studies are summaries of what is known about human behavior after a natural disaster has been predicted.

However, the answer to the question, "Are potential losses of economic activity a reason (in terms of cost) for not developing earthquake-prediction technology?" is no because it is not likely that any substantial net losses of economic activity could occur after a short-lead-time prediction. The answer would not be changed by any detailed study of human behavior.

It is necessary to distinguish between net economic loss and a redistribution of economic activity with losses for specific firms and groups. A net economic loss would be a loss of output and associated wage and business income where the lost output could not be "made up" elsewhere or at another time. Consider a manufacturing plant closed by an evacuation ordered by a state Governor. The lost output may or may not be a net loss. The output could be "made up" at a later date (a probable occurrence if the plant were not closed for long). The production could also be shifted to a plant at a different location.

With either a shift of production in time or location there would be no net economic loss. There might be substantial distributional impacts, however. If production were shifted to a different plant (conceivably a different corporation), a different group of individuals, firms, and jurisdictions would share the economic activity. Consider a slightly different example. Some retail stores are closed during an evacuation. These losses are almost certainly distributional, and not aggregate, losses. The potential sales will be shifted to another location, to wherever the evacuees go instead.

A last issue in the analysis of the question, "Will earthquake prediction technology pay society?" for short-lead-time predictions is whether alternative protection methods could reduce risk to life and property during an earthquake and make prediction unnecessary. This is the issue of whether society is pursuing an optimal baseline strategy. At present the evidence is that many lives and much property value would be lost in a severe earthquake. It is argued that much more could be done by earthquake engineering and other tactics to reduce the potential damage from an earthquake. These arguments are reviewed in Section IV-C. The question is whether there would ever be a circumstance where society was so protected that the prediction "an earthquake is likely within 60 days" would not lead to a substantial saving of lives or property.

d. Predictions with Long Lead Times

Would a prediction "There will be an earthquake within 50 years" be valuable to society? The tactics that would be appropriate with a long lead time are the same tactics that are being discussed today in the absence of any prediction capability: adoption of strengthened earthquake-engineering standards, long-term code-enforcement programs, seismic zoning, and so forth. A long-lead-time prediction capability should complement and strengthen the use of these tactics in two ways. First, a long-lead-time prediction, even 50 or 100 years' lead time, would be better information than we have today. Actions might be rational on the basis of long-lead-time predictions that are not obviously economic in terms of the current theory of earthquake probabilities, based on recurrence. Second, a long-lead-time prediction capability may hasten actions that would be rational, but more difficult to adopt, in the absence of any prediction capability.

e. Predictions with Intermediate Lead Times

The capability to predict earthquakes with intermediate lead times--for example, from 6 months to 20 years--is the most complex to evaluate. The complexity has two aspects:

- Tactics for the period after an earthquake prediction with 6-month to 20-year lead times are not well developed.
- The concern about potential losses of economic activity and property value is most strongly articulated in discussions of earthquake prediction for this time period.

The tactical choices open to society after an earthquake prediction depend on the lead time offered by the prediction. For a lead time of only 30 to 60 days tactical choices are defined and limited, and for a lead time of 100 years tactical choices are also defined and limited. For the intermediate period choices are less clear. For how long is evacuation a viable choice? How long is needed to thoroughly implement a code enforcement program? How long is needed to make an impact with strengthened engineering standards? When do such tactics as selective demolition and urban renewal become attractive? There is little information on which to evaluate the benefits and costs of tactical choices with an intermediate-lead-time prediction.

It is likely that more economic activity would be relocated after the prediction "an earthquake will occur in 10 years" than after the prediction "an earthquake will occur in 30 days." The ability of individuals to relocate and for production to be moved is greater the longer the time available for adjustment. There is no evidence on how people would behave after a prediction with a 10-year lead time. However, it is conceivable that the growth rate of cities or even of a region could be changed if people believed and acted on such a prediction.

Yet the net economic costs associated with such a prediction could be even lower than those associated with a prediction having a 30-day lead time. If businesses move over a 10-year period, there is no reason that any net loss of production and income should occur. There would be some costs of transition, but these would probably be no higher than in the many other business moves that occur constantly in the national economy.

Suppose that a prediction was issued that an earthquake would occur in the San Francisco Bay area in 10 years. Individuals and businesses might relocate. Prospective immigrants might decide to go elsewhere. Existing businesses might lose sales, and existing property values might decrease. Some redistribution of wealth and economic opportunities could occur among individuals, businesses, and regions. Discussions about whether compensation should be paid to individuals who suffer losses in such a relocation would occur (compensation is discussed below). The net economic losses, however, would be minimal or nonexistent. Therefore, all the potential relocation activity (and the speculation about it) is not relevant to the question, "Will earthquake-prediction technology pay society?"

f. Some Implications of Other Research on Earthquake-Prediction Technology

Federally supported research is not unique. There are many nonfederal programs in the United States, and substantial research is being done in the Soviet Union, China, Japan, and other countries.

This other research affects the assessment of federally sponsored research relevant to the question, "Will earthquake-prediction technology pay society?" Are the benefits of earthquake prediction attributable solely to the federally sponsored research in the United States?

Two significant issues are related to the costs of developing and using earthquake-prediction technology. One issue is whether the cost identified with the development and use of earthquake-prediction technology in the United States is avoidable if the United

States effort is halted. If earthquake predictions will be issued by other countries or by independent research efforts in the United States, then decisionmakers will face many, if not all, of the problems of choice that have been identified relating to the development of earthquake predictions above. If the Chinese government issued a prediction of an impending earthquake in California, decisionmakers in California would have to decide from the same range of loss-reduction strategies that would be open to them if the prediction were issued by the USGS in Menlo Park.

Thus the real evaluation issue may not be simply, "Will the development of earthquake prediction technology pay society?" The question may be, instead, "Will the development of earthquake-prediction technology in the United States pay society, given that some earthquake prediction research will continue in any event?" To the extent that the major cost associated with the development and use of earthquake-prediction technology is the cost associated with the uncertainty of prediction, the fact that other research exists would yield a more positive answer to the question, "Will the development of earthquake prediction technology pay society?"

The federally sponsored U.S. earthquake prediction research effort could then be viewed as an attempt to reduce the potential for mistakes with earthquake predictions that would be issued in any event. The choice is then between having to select tactics on the basis of external research or increasing the total level of research with the U.S. effort. It could well be argued that additional effort in the United States would tend to shorten the period of high costs from mistaken or fraudulent predictions. The proper evaluation of the federally supported U.S. effort would be made by comparing the cost of research with the benefits associated with a projected reduction in the costs of mistaken or fraudulent predictions over time.

The existence of other research means that the choice is not between predictions with uncertainty versus no predictions. The choice is rather between two levels of prediction research with different levels of uncertainty. It is important, therefore, that continuing prediction research in other parts of the world be considered in evaluating the costs and benefits associated with the federally funded U.S. effort toward the resolution of the question, "Will earthquake prediction technology pay society?"

2. Distribution of the Benefits and Costs of Earthquake Prediction Technology

a. The Individual Perspective

The focus in the preceding section was on comparing the total benefits and total costs associated with the development and use of earthquake prediction technology. A nationwide perspective including all individuals, businesses, and local jurisdictions was assumed. In this section the focus is on the distribution of benefits and costs. In particular, the focus is on the question of whether specific individuals, businesses, and nonfederal government jurisdictions could incur net economic costs as a result of the development and use of earthquake prediction technology.

The existence of potential losses for specific individuals, businesses, and jurisdictions is directly related to many policy questions discussed elsewhere in this report and in other discussions of earthquake prediction technology. One set of issues involves whether and in what circumstances individuals or businesses should be compensated for prediction-related losses. Another set of issues involves the relationship between potential "individual" economic losses and the incentive of local decisionmakers to take action after a prediction. Questions of legal liability for actions based in part on a prediction and questions of the appropriate role for earthquake insurance also derive primarily from the possibility of economic losses to specific individuals, businesses, and local jurisdictions from the use of earthquake predictions.

It is important to clarify the relationship between the total benefits and costs from earthquake prediction and the distribution of these benefits and costs. As discussed in the last section, substantial <u>net</u> losses of economic activity or property value on a nationwide basis would not occur after an earthquake prediction. Such individual losses as do occur will be offset by gains either later or elsewhere. Therefore questions about economic losses to individuals, groups, or nonfederal government jurisdictions should not be related back to the question, "Will earthquake prediction technology pay society?"

b. Perspective of Local Jurisdictions

Decisionmakers in local jurisdictions--city, county, region, and state--will make most of the strategy choices after earthquake predictions. Could the balance of costs and benefits look negative to a local government decisionmaker when the nationwide balance was positive? From the local government perspective, after a prediction has been made, the balance sheet looks as follows:

Local Government Perspective
on Benefits and Costs
of Earthquake Prediction

Benefits	Costs
Lives saved	Direct tactics-implementation costs
Property damage avoided	Potential losses of economic activity and property value
	Costs of mistaken predictions

The element of benefits and costs that could be negative from the local government perspective, but not from the national perspective, is "potential losses of economic activity and property value." It is possible that substantial amounts of production, sales, and income could be transferred from one geographic area to another after an earthquake prediction and that property values could fall in one area and rise in another as activities shift locations. Such losses might, if they were substantial enough, make total costs from a prediction look greater, from the perspective of a single local jurisdiction, than the total benefits.

Such a possibility decreases with increasing size of the local jurisdiction. Most of the potential losses will be offset by gains elsewhere within the jurisdiction. As the size of the decision-making jurisdiction grows from a single city to county, region, and state, the possibility of net losses of economic activity and property values within the total jurisdiction decreases. At the state level, for example, it would have to be demonstrated that economic activity would move to another state.

It is not possible at this time to say that no local government decisionmaker would ever face a situation where net economic losses to the residents and business of a local jurisdiction would occur from an earthquake prediction. But what would it mean if such a situation could occur? Would it mean that earthquake prediction technology should not be developed? That a prediction should not be issued? That loss-reduction tactics like evacuation should not be followed?

None of these things should happen. The existence of economic losses in one jurisdiction that are made up in another jurisdiction (a distributional issue) should not prevent the capturing of aggregate net benefits (total benefits exceeding total costs) from earthquake prediction. It is incredible to think of lives being lost or property damaged as a result of inaction simply because some economic activity would shift from one location to another. Yet some of the discussion in the literature on earthquake prediction comes close to endorsing this idea.

The existence of potential economic losses to individuals and businesses in a local jurisdiction does raise important policy questions. Should public jurisdictions be financially liable for losses suffered as a result of prediction-related public policy? Would such liability adversely affect the incentives of local governments to act? What should public policy be regarding losses to individuals and businesses? What is the role of compensation policies? Insurance policies? These questions are discussed in the section that follows.

c. <u>Perspective of Individuals and Businesses</u>

The issues of potential economic losses for individuals and businesses resulting from earthquake predictions can be illustrated with the following example of possible events:

(1) Earthquake prediction research is an ongoing activity.

(2) At some time in the future, seismologists announce that there is a high probability that an earthquake will occur in the San Francisco Bay Area within 60 days.

(3) Some individuals plan extended vacations or temporarily move to other regions. Tourist activity declines.

(4) Two weeks later an evacuation of selected areas is ordered by public officials.

(5) Businesses in the evacuated areas temporarily close. In addition, more individuals make plans to move out of the region temporarily (or postpone visits) as a result of the evacuation order.

Would any economic losses occur to workers or business as a result of the above events? The first condition for establishing that an economic loss could occur is that the economic activity is not postponable. For example, the production of most manufactured goods can be shifted around in time within considerable limits. If the stoppage of production were for a short period, the effect could be like that of a brief labor strike, with most or all of the "lost" output made up when the plants reopened. Similarly, much nonmanufacturing activity, even legal and medical activities, can be postponed within some limits. Therefore research on potential economic losses associated with earthquake prediction should begin with an identification of what kinds of economic activity would simply be postponed and made up at a later date.

It is probable that some economic activity would be lost for specific workers and businesses in the San Francisco Bay Area. Some output it would not be possible to postpone, some retail sales would not be made, some tourist activity would not occur in the region.

The substantial majority of these economic losses would be not net losses to society but rather redistributions. The next alternative to shifting economic activity in time (postponement) is to shift in location. If individuals leave the Bay Area for 60 days (or even move from one part of the region to another part), their purchases will be made elsewhere. If tourists visit another area, their purchases will be made elsewhere. Some orders for manufactured goods will be shifted elsewhere--either to a different plant in the same firm or to a different firm. If economic activity is redistributed geographically, then different workers will receive income, different firms will receive revenue, and different jurisdictions will receive tax revenue (as well as added costs).

In the example above, economic losses will occur to individuals and groups as a result of voluntary and involuntary responses to earthquake prediction. It will be difficult to distinguish the losses due to voluntary from those due to involuntary responses. People will have different voluntary responses to earthquake prediction information, depending on their relative assessment and tolerance of risk. Some people may voluntarily leave the potential earthquake area at the first announcement of a probable impending earthquake. The economic losses (wages and so forth) occurring for these individuals will be incurred voluntarily. Additional people will stay away from the potential earthquake site after the announcement of an official public warning or action whether they are required to do so or not. Finally, some economic activity may be stopped involuntarily--solely as the result of the official evacuation order.

The same kind of economic losses would be incurred whether they were incurred voluntarily or involuntarily. However, the reason the issue of potential economic losses is often discussed in the assessment of earthquake prediction technology is the fear of involuntary losses. The distinction between voluntary and involuntary economic losses may be important for specific policy questions like liability and compensation. It is here that the measurement question must be faced. Unless there is a way of distinguishing losses due to voluntary from those due to involuntary actions, differential treatment of groups suffering economic losses is impossible on this criterion.

The measurement issues seem difficult if not insurmountable. It might be relatively straightforward to get an estimate of how many tourists did not come to San Francisco after an earthquake prediction was released by measuring the difference between normal and actual tourist activity. But how many tourists stayed away because of the first announcement? How many tourists stayed away only because they were forced to? How many restaurants closed voluntarily or because their employees left the area voluntarily? How many restaurants closed only because they were forced to?

d. Economic Implications of Potential Jurisdiction Liability

Public jurisdictions may be exposed to liability resulting from actions taken based on an earthquake prediction. Liability may arise from public action if no subsequent earthquake occurs; for example, businesses might sue a public jurisdiction for alleged losses resulting from involuntary evacuation resulting from an earthquake prediction. Liability might also arise from public jurisdiction inaction; for example, a public jurisdiction might be sued for injuries resulting from an earthquake if no evacuation was ordered even though the public agency was in possession of an earthquake prediction.

There is a critical economic issue related to potential public jurisdiction liability resulting from earthquake predictions. The possibility exists that public jurisdictions would take their potential liability into account when selecting tactics in response to an earthquake prediction. Thus the liability question could feed back and affect society's choice of earthquake loss-reduction tactics and therefore feed back ultimately to the question, "Will the development of earthquake prediction technology pay society?" This result (potential liability affecting the evaluation of the technology) would be wrong in terms of the discussion of net benefits as a criterion for deciding the "worthwhileness" question as set forth in the preceding section.

Potential liability here means potential compensation. Public jurisdictions that incurred liability as a result of earthquake-prediction-related activities would incur a liability to repay individuals or groups for losses suffered as a result of the public jurisdiction's action. Such compensation payments are distributional in nature. They are transfers from one group in society to another. Regardless of whether the compensation payments are desired by society on legal or ethical bases, the fact remains that they are transfers (therefore distributional) and do not affect the net economic impact on society of earthquake-prediction-related activities.

Another way of looking at the issue of potential liability is that it is one way of deciding who should pay for the cost of mistakes based on earthquake prediction. Who should pay for the cost of action when there is no earthquake, and who should pay for the cost of inaction when an earthquake follows? The question of who should pay for losses can be a very important question. However, the manner of compensation for losses does not affect the amount of losses. It is distributional in nature, is after the fact, and is totally separate from the question of what losses occur and what is the best way to minimize net losses from impending earthquakes.

Related research in this study has indicated that the question of potential liability is of high importance to public officials who have potential responsibility for acting on an earthquake prediction. This evidence suggests that if a way were found to relieve these public officials of the problems associated with potential liability, they would be more able to direct their actions to the question of which strategies will profit society in the face of earthquake prediction information.

There may be a number of ways to maintain the idea that people who sustain losses as a result of earthquake-prediction-related public actions have a claim to compensation and at the same time free local and state public officials from having to take their potential liability into account in deciding tactics. One such idea would be to have a federal insurance program that would handle all claims for liability resulting from public action based in part on an earthquake prediction. We could decide as a society that it would be efficient to handle the payment of such compensation as was found appropriate as a total society--that is, at the federal level. There are a number of precedents in disaster relief and related activities for sharing the impacts on a society-wide basis.

B. What Are the Long-Term Effects?

1. Introduction

The earthquake prediction cases developed in Section III-A described possible impacts that relate in an operational sense to relatively near-term predictions for which society was largely unprepared. In this section we develop, speculate on, and assess the implications for society of the higher order aspects of these impacts, plus effects that could not be foreseen from projected relatively short-term earthquake situations.

In Section III-B, we made a distinction between the primary impact, which is the earthquake prediction itself, and the higher order impacts, which result from society's response to the prediction. We made the assumption that the higher order impacts would be relatively near-term. This may not be so, depending on when the next great earthquake strikes a metropolitan area and whether earthquake-prediction instruments are fortuitously emplaced to capture the premonitors. However, they will still be operational impacts, but it is to be hoped that society will be better prepared.

2. Higher Order Impacts

Two questions may serve to illustrate the subject of this section: What are the structural changes in society that result from the potential psychological impacts of overprotection? What would be the long-term social, political, individual, and economic stress effects of a highly uncertain but credible prediction? The relevance of these specific questions aside, these are examples of the higher order impacts that are difficult, if not impossible, to identify and assess through an analysis of the operational context alone. The reason for this situation is that, within the limits of our existing knowledge, it is impossible to establish direct, causal linkages between this type of higher order effect and the primary and higher order impacts that can be identified through projected operational situations. Even if we could use the impacts from the projected operational context as the analytical basis for deriving these kinds of higher order impacts, the operational-level impacts are themselves inherently uncertain and contingent. Accordingly, such an analysis of higher order impact would necessarily contain misleading and irresponsible policy implications.

In fact, however, society does attempt to infer some types of higher order effects directly from our existing base of knowledge of analogous developments. Such inferences raise genuine concern over the possibility that these higher order impacts might come into being because of the future course of development of the technology. Some of these impacts would be "unwanted." Some of them would present opportunities to capture benefits that could escape society's use if not anticipated by establishing policies to bring them under control.

Accordingly in this section we are dealing with an area of the assessment that is clearly difficult to explain and justify through any responsible suggestions as to the policy consequences of the analysis but one that is founded on growing social concerns about our responsibilities for present actions that may affect the future. To address this situation we have classified the higher order types of effects as ones that can be dealt with by policies directed to the level of stopping or altering the development of the technology itself, rather than directed to the impacts of the technology.

Society's basic position toward earthquake protection, enunciated in the evolution of building codes, is that the state-of-the-art knowledge should be applied to protecting lives. There are alternative means of earthquake protection. As discussed in Sections II-F and III-C, and in the section that follows, earthquake engineering complemented by seismic zoning can provide, over a long period of time, the desired level of protection in an area. Earthquake prediction is not likely to demonstrate in the short run that earthquake-engineering measures can or should be reduced. This means that in those areas where an effective program of earthquake engineering is maintained earthquake prediction is likely to be ignored by society, unless in the long run, when the residual risk has been greatly reduced, the technology demonstrates its capability to make reliable short-term predictions.

In any such location reliable short-term predictions of damaging earthquakes are likely to be so infrequent that the experience will not recur more than once in any generation. The conditions of a low residual risk, infrequent but reliable predictions, and feasible and effective short-term actions to mitigate the residual risk are not likely to develop cumulative effects that result in social stresses and social structural change.

However, the combination of high residual risk in a region and frequent but unreliable predictions over an extended period will produce chronic social disorders. The predictions cannot be ignored because some will be correct. The obvious prescription is to adopt vigorous programs of earthquake engineering to reduce the residual risk. Once the residual risk is reduced to an acceptable level, society can be more discriminating in adopting criteria for prediction acceptance and in deciding how best to respond to predictions. However, many societies cannot afford this approach.

Some attention should be given to the long-run effects on the predictors. In any event they will be impatient with the slowness of the development of the technology. Some will devote entire careers to earthquake prediction without experiencing much visible progress. It will be difficult to attract bright candidates to the field. If the predictions turn out to be inaccurate and prove to cause disruption and contention in society, the predictors will feel discouraged and alienated. Some of this impatience and discouragement will be avoided by expanding the earthquake-prediction laboratory to other parts of the country and the world, where the results may be more positive and useful.

However, the impatience and discouragement will be directed toward the realization that the earth is not a good laboratory, and waiting for naturally occurring opportunities is not an efficient approach to science. With this realization there will be an attempt to gain some control over events. Indeed it has already begun. First there will be deep drill holes to measure fault-stress buildup directly. Next there will be attempts at earthquake-control experiments, initially in sparsely populated regions, but if they show some measure of success, then in urban areas. The implication of this is that earthquake control may mature as a science before earthquake prediction.

3. Alternative Futures

We need to recognize the fact that in the long term society can change as well as its man-made environment. We cannot say how society might change, particularly within a given country, but we can attempt to enumerate alternative directions that the various qualities of society can take and try to determine the implications for the human and social issues embedded in earthquake prediction.

Earthquake prediction relates to a survival issue, but it also relates to an issue of using technology to create an artificial environment--conquering the forces of nature. However, the need for this is the result of man's success in creating an artificial environment through the means of technology. Within that environment man finds himself still vulnerable to the occasional manifestations of nature's vast forces. Because man did not exercise foresight in building his cities as to location and construction practices, he needs a technological fix. We have seen that in the sequence of technological development earthquake prediction is an entree to earthquake control. This is ultimate technological fix in this line of development. It will release the stresses that build up in the earth's crust relatively harmlessly or it will allow man to set off damaging earthquakes when he wants to. However, the issue is the same: survival, both individually and collectively. What is changed is the degree of individual and collective hardship that is paid for an increment of survival and perhaps the future technological fixes that will be required to deal with unanticipated and unwanted consequences.

As an alternative, to earthquake prediction and control, man might exercise his options in another way: rebuild his cities in places of lower risk.

Another alternative is to turn man's technological capability on himself, so that he is reconditioned through behavior-modification techniques to accept with resignation the risks of natural disasters. What is involved in these alternatives is the ethical basis of man's use of technology with respect to his limited capability for foresight.

Society's values could change to highly materialistic or highly ascetic; social relationships could become self-seeking or altruistic; economic conditions could become vigorous or stagnant: political conditions could change to totalitarian or to libertarian; social responsibilities could decrease or become directed toward an authoritarian structure; society's relationship to its environment could become technocratic or humanistic.

One might be tempted to group these characteristics in more or less sympathetic a priori categories such as ascetic, altruistic, poor, free, unfettered, and humanistic on the one hand and materialistic, self-seeking, wealthy, totalitarian, authoritarian, and technocratic on the other. However, this is a forced categorization, probably based on biases resulting from the way that the individual observer finds these qualities in individuals. The determinants of a society's economic, social, political, and ethical characteristics are not necessarily related. In reality one could find any combination of these qualities in a society.

These combinations of social values, relationships, and responsibility; economic and political conditions; and relationship to the use of technology represent potential alternative futures. These factors operate not independently but in concert to determine society's position on any issue. Nevertheless, one or the other could be controlling on a given issue. Therefore as a first approximation we can attempt to assess the position of a society on the issue of individual and community protection from earthquakes. This will be done in terms of the extremes of each characteristic attributed to our alternative futures as they might interact with earthquake prediction and its technological progeny, earthquake control.

A materialistic society is more likely to seek protection than an ascetic society. Self-seeking and altruistic societies are both likely to seek protection but for different reasons. A poor society is more likely to accept the uncertainty of earthquake prediction, but a rich society is more likely to accept the certainty of higher cost earthquake engineering and earthquake control. A totalitarian society is more able to deal with the uncertainties, probabilities, risks, and inequities inherent in earthquake prediction. A free society is likely to seek an inherently equitable solution to protection, such as earthquake engineering and earthquake control. A society that is based on an authoritarian structure is more likely to be interested in community protection than a society whose members have little responsibility for each other. A society that is technocratic will be more receptive to technological fixes such as earthquake prediction, but a society that is humanistic will be more concerned about the unpredictible future impacts of novel technological solutions and will seek basic solutions, such as earthquake engineering.

C. National Strategies and Regions

The benefits that can be derived from the prediction of an earthquake depend on the baseline regional condition. This in turn depends on the earthquake protection position that a region has adopted. By examining the baseline regional condition we are raising two fundamental questions:

- Are there alternatives to earthquake prediction?
- Given earthquake prediction, should the baseline regional condition be allowed to change?

There are no alternatives to earthquake prediction in the strict sense, but there are alternatives that can achieve the same result as the combination of earthquake prediction and damage-mitigation tactics. These alternatives, seismic zoning and earthquake engineering, have formed the earthquake-protection posture of society.

1. Is There an Optimal Baseline Condition?

By applying earthquake protection measures, society achieves a certain level of risk and pays a certain cost. We have addressed the question of an acceptable level of risk and overprotection in Section II-G. Here we are concerned with the relationship between risk and cost. In other words, does the lowest unit cost for protection increase or decrease as society buys more protection? At what point, then, should society stop increasing its protection?

At the present level of protection that society is achieving through earthquake engineering, incremental expenditures would buy greater protection. This is especially true for new structures. But there are also many inexpensive steps to reduce hazards in existing structures. However, after a certain point such measures as structural strengthening of existing structures become expensive.

Seismic zoning forbids building on ground that will experience failure in an earthquake. After this there is a trade-off between the cost of earthquake engineering and the cost of seismic zoning. Seismic zoning incurs the cost of determining risk. After this the costs take the nature of compensation to the owners. To the extent that the land contains resources and production is lost, this loss is a net cost to society. To the extent that alternative facilities are available to make up the loss in production, this "loss" becomes a transfer.

The value of anything is determined by its cheapest alternative. It would be of no net cost to society not to develop undeveloped property subject to serious earthquake risks as long as development could take place elsewhere. It is only an added incremental expense, probably less than 10 percent for most structures and 3 percent for wood-frame dwellings, to increase dramatically the seismic resistance of new structures. For a relatively small expenditure the seismic hazards of existing structures can be greatly reduced. This includes such things as removing parapets and cornices, tying up light fixtures, securing water heaters, securing furniture, and putting positive latches on cabinets. As dangerous structures or structures on dangerous ground reach the end of their economic lifetime, they can be cheaply removed from service and demolished. How far the program is carried depends on many factors. But if we were to compare these measures with earthquake prediction, we would have to include for a given earthquake the cost of hazard-reduction tactics based on the prediction and its uncertainties, the number of false alarms, the fact that earthquake prediction may not predict all earthquakes, and so forth. The outcome of either approach could only be based on the actual earthquake experience since the results of an analytical comparison will have large uncertainty factors.

2. Implications for Earthquake Prediction

The implication of a prediction that "there will be no damaging earthquake in this region for 60 years" is substantially changed by adding, "but after that an earthquake could occur at any time without warning." If an earthquake prediction said, "We can have a damaging earthquake at any time, but those that can be detected can be predicted accurately with a 3-day lead time, but only 80 percent can be predicted," this has still further implications. If the regional baseline condition says in effect, "We are confident that all of our structures will withstand the most damaging earthquake that can occur in this region, and furthermore 80 percent will remain completely functional," that has implications for earthquake prediction.

An accurate negative prediction with a lead time longer than the economic lifetime of structures will allow structures to be built to less than earthquake-resistant standards. Predictions of all damaging earthquakes with a 3-day lead time would allow for orderly evacuation of substandard structures and therefore earthquake-generated, rather than man-made, urban renewal. A regional baseline condition of highly earthquake-resistant structures might make earthquake predictions of academic interest only. A regional baseline condition of non-earthquake-resistant structures would make earthquake prediction imperative. However, nowhere in the United States do these conditions exist today. We do not know what earthquake-prediction capabilities will ultimately exist, nor do we have cities consisting entirely of resistant structures or susceptible structures. Therefore, if earthquake protection is a goal of society, we should not at this time, based on what we now know, abandon any approach. For a long time earthquake engineering and earthquake prediction should work in harmony.

To the extent that our present understanding of earthquake recurrence can be expressed by saying, "A damaging earthquake has occurred in this region within the past 300 years of recorded history and therefore one could occur again at any time," the above discussion is as valid for San Francisco, California, as it is for Charleston, South Carolina, or Memphis, Tennessee. What is different about these regions is that the regional baseline conditions are different for historical reasons and the promise of earthquake prediction could be different for technical reasons. Because the attenuation of seismic waves is much greater in the western United States than in the eastern United States, the damage caused by earthquakes in the east results from the release of much less energy. Accordingly, many premonitors of these earthquakes are likely to be much more localized, requiring a dense network of very sensitive instruments.

3. International Considerations

Because of their very poor regional baseline conditions, earthquake prediction is of more potential benefit to many foreign regions than to the United States. It is interesting to compare the earthquake-protection postures of China and the United States with respect to the interplay between earthquake prediction and earthquake engineering.

China's earthquake-prediction program, as it is fashioned within and responded to by the masses, is the outcome of a cultural tradition that identified legitimate political authority with regulation of nature. This tradition has strongly shaped the meaning and function of earthquake prediction in China. The emphasis on the expressive function of earthquake prediction as a satisfying end in itself is considerably removed from the more pragmatic concerns of Americans. In China the benevolence of the central government was more often demonstrated through ritual rather than pragmatic acts. Though the empirical results of these rituals may have been dubious, the psychological and political effectiveness was undeniable. The Chinese Communists have inherited the emperor's responsibility of completing the triad of Heaven, Earth, and Man. Ensuring harmony between man and nature is as essential to the credibility of the Chinese Communist Party as it was to the imperial court.

"Science for the people" is the national slogan by means of which the Chinese Communists validate their claims to the Mandate of Heaven. Pragmatic results are sought through the popularization of science, but the psychological satisfactions generated by mass participation in scientific activity are of greater significance with respect to the political goals of the state. China's earthquake-prediction program is inextricably tied to ideology.

Given the American view of science as a professional enterprise, it is highly unlikely that earthquake prediction could be conducted as a mass campaign in the United States. For Americans, science is primarily a pragmatic, instrumental activity. High expectations of certainty and intolerance for false alarms are associated with this view of science. The Chinese, as a result of modest expectations, have been able to implement earthquake prediction at an earlier stage of development than is possible in the United States.

The typical Chinese structure is very susceptible to earthquake damage. The Chinese have not been able to make the investment in structural strengthening through earthquake engineering required to reduce significantly their earthquake hazard. They are more willing to experiment with the new technology of earthquake prediction, however uncertain it may be. There is clear memory of past earthquake disasters and the sense of imminent catastrophe. Intrinsic motivation to cooperate with warnings and evacuation orders is therefore strong.

For the American situation, earthquake engineering is an economically feasible approach to earthquake protection. It offers an apparently higher degree of certainty than does earthquake prediction at its present level of development. Available evidence clearly indicates that well-engineered structures can and do withstand earthquakes and thus significantly reduce property damage and loss of life. Evidence also clearly indicates that supposedly well-engineered structures that meet applicable codes can fail in earthquakes. Earthquake engineering is also plagued with uncertainty.

D. Policies for the Future

1. Introduction

This section raises and assesses certain issues relating to the question of adopting present policies designed to influence the future of the technology. Exploration of the contrast between institutional and technological reversibility is one such issue.

We explore that question in this section and assess its policy nature and implications in the context of those issues that relate to the future course of the development of the technology. In doing so, we examine the means that exist for stopping or altering the technology under our existing policy structure by asking whether the technology could be stopped or altered even if we had policy reasons for doing so. In the course of this we reach issues relating to the freedom of scientific inquiry and the close interdependence of science and technology under modern conditions. In the context of the question, "Do we know enough now to decide responsibly to stop or alter the technology of earthquake prediction?," we also explore the conflicts among vested interests over the adoption of policies designed to influence contingent future events.

In the absence of a clear-cut policy need to stop development of the technology, we explore the potential for establishing a policy framework designed to continuously monitor the emerging technology for strategic decision points where influence could be exercised to alter its further development or where the public necessity to stop it altogether becomes clearly visible. Basically, exploration of this strategic policy framework is examination of a "compromise" alternative between the complete abandonment of any expressly adopted policy attempt to deal with the emerging technology and the adoption of policies related to strict measures of control. The purpose of exploring this "compromise" alternative is an attempt to define a present, workable policy model that might be applied in limited situations where there is a perceived need to establish policies for the future.

2. Strategies for Capturing Economic Benefits and Alleviating Costs and Damages

The rule with respect to future impacts of present decisions is that we should not lock ourselves into situations where we are assured of unwanted consequences nor should we foreclose the opportunity for future benefits. This says that with limited foreseeability of future impacts we do not foreclose options and we make decisions with good prospects for favorable outcomes. With the prospect of earthquake prediction, we want to make decisions concerning that technology that will result in a low level of risk from earthquakes at the lowest cost. If we could be sure of reliable short-term predictions, then we might take some action with respect to earthquake-engineering measures. If earthquake prediction is to be unreliable both with respect to false alarms and missed events, then we should hedge our bets. At this point we do not know what earthquake prediction will be able to do, so we sit tight, maintain our existing earthquake protection posture, and put enough money into earthquake prediction to see where it is going.

This question also involves the incidence of costs and benefits--that is, who is to pay and who to benefit? This question cannot be explored outside the current and developing disaster and risk policies. Essentially they are as follows:

- Make insurance available for disasters where it is not now available.
- Control the development of future land uses in known areas of risk.
- Reduce, where possible, existing risks.
- Give assistance and relief to those whose interests are affected by a disaster, but only on the basis of "need." This solution tends to help only "low-income" population.

With respect to the incidence of payment of costs:

- On a national basis, spread the costs as an insurance matter.
  - Either everyone pays the same, with the federal government as "reserve" or
  - Everyone pays in rough proportion to the risk he is exposed to, with variations, and the federal government is the "reinsurer."
- On a regional basis, the cost distribution is obliterated or absorbed under one of the above as a matter of insurance. As a matter of disaster relief and assistance, there are no regional differences. It comes out of the federal treasury, with state cost sharing, but the trend is to regionalize as the logical policy manifestation of the aggregate, national-level view.
- On a regional basis, with respect to <u>preparedness</u>, there is no distinction. The nation pays for all research and development, measurement and monitoring, and communications systems. The trend here is probably <u>not</u> to allocate costs in accord with presumed benefits.
- On a regional basis, with respect to the costs of federal emergency operations, there is some cost sharing with the states.
- On a regional basis, with respect to economic recovery, the federal government assists with loans and expertise. To the extent that there is a cost to the federal government, everyone pays.
- On a regional basis, with respect to the costs of responding to a prediction:

- As an emergency, the federal government pays some at the discretion of the President; there could also be a supplemental appropriation by Congress.
- As a matter of regional economic support, the federal government may pay directly through the Economic Development Agency. But the federal government can and does exert influence heavily through, for example, defense contracting, availability of mortgage money, and federal construction contracts.

The reader should be alerted to the fact that the national-level view of disasters and the imposition of the ramifications of its policy on the existing facilities and structures of the nation are sources of the current non-sense doctrine that high risks, now newly defined by a new view of the occurrence of natural disasters, have been "voluntarily incurred" by all of the people exposed to them. It is the apparent circularity of the policy problems involved that gives some plausibility to this argument. It can be maintained, however, only if there is no reference to the underlying facts of the matter--that is, so long as it can be assumed that the national-level view of natural disasters has existed throughout the period during which all of the facilities and structures were under development and that all of the people who now have an interest in them obtained that interest knowing of, and "rationally" evaluating, the risks involved.

It should be noted also that one way this circularity of policy formation is sometimes broken is simply to impose the incidence of loss on the current interest holders. This solution tends to be infrequent, however, and is most often resorted to when the numbers and classes of individuals who will suffer are small in comparison with the rest of the population and/or the loss is really a temporary dip in property values. There is great reluctance to simply impose the will of the majority on the minority. One of the purposes of government under the Constitution is to ensure that justice is done in situations requiring tough policy decisions, and this is not accomplished by mere counting of noses and allocation of costs.

3. Contrasts Between Technical and Institutional Reversibility

The technology of earthquake prediction is easily reversible. The instrumental system is easily removable and would leave few if any irreversible environmental effects. However, if cities and regions have formulated an earthquake-protection strategy, that is a social institution, around the earthquake-prediction system, it is not so easy to remove the instrumental system because of institutional pressures. Earthquake prediction is based on scientific inquiry, and the scientists involved could, for one reason or another, abandon the field at any time. However, if it becomes a social institution, they have a responsibility to keep it operating.

The resolution of any conflicts arising out of the dual nature of the enterprise comes about when the science has "matured." When the science is reliable and replicable, it takes on the nature of a technology that can be used for different purposes. In this case there would be no conflicts with its social use because it could be dedicated to that alone. The problem with earthquake prediction is that its development will take a very long time, and there will be a very long time, therefore, when it must maintain this duality of a scientific inquiry and a social institution.

The question now becomes, "If some region so chooses, can it ignore the results of the scientific inquiry"? If a city should decide, for instance, that its basic earthquake protection posture is to be earthquake engineering and that earthquake prediction is to be ignored because it is unreliable and disruptive, can it in fact ignore a prediction of an imminent earthquake? If it cannot ignore the warning, can the city have this scientific activity stopped because it is disruptive?

Do scientists have the right to conduct experiments even though they are disruptive to nearby regions? The answer is obviously no in case of physical disruption that threatens life and injury, but earthquake prediction is not that kind of activity. It is potentially disrupting to the extent that one believes it sufficiently to act on it.

We are now back to the question, "How free is one to ignore an earthquake-prediction system that has not demonstrated its reliability"? Is a madman responsible for deaths resulting from panic when he shoults "fire" in a crowded theater even when everyone knows him to be a madman? But even a madman might recognize a fire.

4. Do We Know Enough Now To Decide Responsibly To Stop or Alter the Technology?

If we were certain that earthquake prediction was to be the cause of great psychological stress and social disruption, we could give a positive answer. The fact is we do not know and we cannot know. After some experience we may be better able to foresee but less able to act because of the growing institutional momentum behind the generation and use of earthquake prediction. The question is not unique to earthquake prediction but is common to many technologies with possible future (and therefore unforeseeable) impacts. The following quotation from Hans Jonas[95] spells out the issue clearly:

> One other aspect of the required new ethics of responsibility for and to a distant future is worth mentioning: the insufficiency of representative government to meet the new demands on its normal principles and by its normal mechanics. For according to these, only present interests make themselves heard and felt and enforce their consideration. It is to them that public agencies are accountable, and this is the way in which concretely the respecting of rights comes about (as distinct from their abstract acknowledgement). But the future is not represented, it is not a force that can throw its weight into the scales. The nonexistent has no lobby, and the unborn are powerless. Thus accountability to them has no political reality behind it yet in present decision-making, and when they can make their complaint, then we, the culprits, will no longer be there.

The issue requires, at least, a robust public debate.

5. Could the Technology Be Stopped?

It is argued that if we in the United States were to stop the technology, it would still be developed in China, the Soviet Union, and Japan. Therefore it will ultimately be available anyway. That is true to the extent that instruments and procedures will be available. It is even possible that long-distance predictions will be a reality; for example, China might predict an earthquake in California.

However, on the other side, earthquake prediction is, at this time, specific to given regions. It will take an unusual amount of individual and institutional perseverance and good luck to bring it to the stage of a mature technology. It is vulnerable to lack of interest (little seismic activity nationally) and early unreliability.

The development of the technology is vulnerable to budget allocations within the USGS as it might respond to some agency budget cut imposed by the President and Congress. It would seem that below some threshold amount, little experimental work would be accomplished. The technology would also be vulnerable to some other "glamorous" or high-priority program that would require similar skills and experience.

6. Can the Technology Be Altered?

It has been mentioned that reliable short-term predictions of damaging earthquakes would fit most easily into the United States earthquake protection posture as it is evidenced in California. These would be least disruptive (if prepared for) and most effective in reducing deaths and injuries. It is possible that this capability will develop either directly or as updated information from long-range predictions.

The science is highly empirical and is taking many paths. Other paths may be found and may provide different capabilities.

A purposeful attempt to guide the direction of a scientific inquiry of this nature would be folly. There is much trial and error and a large element of chance in its outcome.

Institutionally, funding allocations would be one way to shape the development or emphasize certain aspects of the science. This takes place naturally since scientific fads develop based on success by an investigator and potential promise in his discovery. Because of the variety of approaches and of institutional participation, it would take a grand conspiracy of a great many interests to force the activity in one direction or another.

7. <u>Decision Strategy Based on Monitoring--Strategic Decision Points</u>

In the absence of foreseeability, society needs to develop institutional means of controlling technology. One such means is based on monitoring the effects of the technology. Should undesirable consequences begin to show, then the use of the technology is stopped. There are many difficulties with this approach:

- Finding indicators related unequivocally and specifically to the technology and its application.
- Finding indicators that are measurable over the background noise.
- Finding indicators that show no threshold, time lag, or discontinuity in their relationship to the technology and its application.
- Exercising authority to stop a technology over the objections of the interests that have become vested.
- Achieving agreement on what is undesirable.
- Knowing the points in a technology's development and implementation process at which it is susceptible to action.

In effect we are saying that technology assessment is a continuous process. It cannot be accomplished once and all potential issues settled. At any given time, one might be able to determine the actual impacts of a technology and see dimly a little way into the future. The question then becomes, "What policy can we implement now that would be responsibly based on what we know now and can see, albeit dimly, in the future?" We monitor the technology and its impacts until the technology reaches a decision point, perhaps to go from an experimental program to a pilot-scale operation. The assessment process is iterated at that time, based on the new knowledge from monitoring, the foreseeability of a future that is closer, with eyes that are sharper from peering in the dark, and the same question is asked. Perhaps at that time the answer is negative--the technology is too risky. More special studies are needed. Better and more effective alternatives are available, and so forth.

Perhaps the answer is positive; we can see no reason to stop the technology. Again the pilot program would be monitored, and on its completion, the technology is again assessed against its new knowledge base and the prospect of its implementation in a region. Perhaps this time the answer is definitely "No, do not proceed." But the forces on the other side are stronger. They argue that because of the pilot program the undesired impacts are already with society and they are not really that bad. In this situation the argument becomes political and the only responsible solution is an extensive public airing of the issue.

The EPIS process is designed to set decision criteria for the application of the technology. The decision strategy based on the monitoring process could be folded into the EPIS process as a way to modify the decision criteria for responding to earthquake prediction in a region as the technology is developed.

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