GEOLOGICAL SURVEY CIRCULAR 729

Earthquake Prediction— Opportunity to Avert Disaster

A conference on earthquake warning and response held in San Francisco, California, on November 7, 1975

Contributions from:

City of San Francisco, Director of Emergency Services

National Science Foundation, Research Applications Directorate

State of California
Office of Emergency Services
Seismic Safety Commission

U.S. Department of the Interior
Assistant Secretary for Energy and Minerals
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Foreword

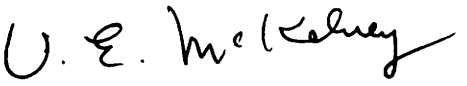
The past several years have witnessed rapid progress toward a capability to forecast the time, place, and size of impending earthquakes. Advances in understanding of earthquake occurrence—together with an ever-growing number of observations of earthquake premonitory signals in the United States, the Soviet Union, the People's Republic of China, Japan, and elsewhere—suggest that the scientific prediction of potentially destructive earthquakes is an attainable goal.

The U.S. Geological Survey has supported a major research effort into earthquake prediction as part of its Earthquake Hazard Reduction Program. Theoretical and experimental studies of earthquake mechanisms and possible geophysical precursors are being carried out, in large measure with the cooperation of university scientists through a grants and contracts program. Seismically active zones in many parts of the United States are being monitored by seismograph networks. Crustal-strain accumulation in the Western United States is being investigated through a variety of geodetic techniques. In central California, the U.S. Geological Survey is conducting an ongoing earthquake-prediction experiment using dense arrays of various geophysical sensors astride a highly seismic part of the San Andreas fault.

Although operational earthquake-prediction systems are not likely to be deployed for a number of years, the prediction capability is achieving significant progress. It must be anticipated that predictions of some potentially damaging earthquakes will be forthcoming during the present research and development stage. Consequently, serious consideration of how predictions will be used by society should accompany the research. Procedures for evaluating the scientific data and issuing predictions must be established, and the responsibilities of Federal, State, and local agencies with respect to disaster warning must be agreed upon. It is important to anticipate public reaction to a prediction and to evaluate the possible responses that can be taken to reduce loss of life, injury, and property damage. Earth and social scientists, engineers, and public officials all have vital roles to play in determining how society will use earthquake predictions.

With these factors in mind, the Assistant Secretary of the Interior for Energy and Minerals convened a conference on earthquake warning and response on November 7, 1975, in San Francisco, California. Federal,

State, and local officials responsible for disaster response were invited, together with representatives from the business and labor communities. The purpose of the meeting was to review the status of and prospects for earthquake prediction in the United States, to present for consideration a proposed Federal plan for issuance of earthquake predictions, and to consider the public policy implications of earthquake forecasts. The ramifications of these issues were explored in a panel discussion that followed the briefing. It is expected that the concepts and viewpoints presented at the conference will help stimulate development of plans and procedures for effectively utilizing earthquake predictions to save lives and reduce property damage.



V. E. McKELVEY
DIRECTOR

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By Edward P. Joyce,

Director of Emergency Services, City of San Francisco

It is a great privilege for me to welcome you to the great city of San Francisco on behalf of Mayor Joseph L. Alioto.

For many years as Director of Emergency Services for San Francisco, my concern has been to develop a viable response to earthquake disaster. Thanks to meaningful assistance from the State Office of Emergency Services, the Federal Defense Civil Preparedness Agency, and the Federal Disaster Assistance Administration, we have an earthquake response plan that has been approved unanimously by our Emergency Planning Committee and our Disaster Council here in San Francisco.

Of course, this plan has been directed to mitigation of the effects that a major earthquake can pose after the fact. I am, therefore, most anxious to hear the status of earthquake prediction in the United States because the reality of earthquake prediction will require a whole new approach to emergency planning. It appears to me that the public policy implications of earthquake predictions are somewhat similar to those for tsunami warnings, although the implications of the latter are of a much lesser degree. At least for tsunamis, we have developed experience with regard to reaction by political jurisdictions that have been in receipt of warnings over many years. I hope that when earthquake predictions are a reality, there will be a shared responsibility by Federal, State, and local officials in prediction announcements and in the actions to be taken.

I am, of course, also interested in hearing about other factors relating to predictions, such as length of advance warning time, reliability of data, ability to predict magnitudes within acceptable limits, likelihood of evacuation and guarantees for property left behind, and other important socio-economic and political implications of earthquake forecasting.

On behalf of Mayor Alioto, I wish you a most enjoyable stay in San Francisco and hope that your participation in this conference is as profitable to you as I know it will be to me.

Earthquake Forecasting: An Opportunity

By Jack W. Carlson,

Assistant Secretary of the Interior for Energy and Minerals

It is appropriate that we meet today in San Francisco. Since 1906, the name San Francisco has been associated, rightly or wrongly, with the terrible destruction that an earthquake can bring upon an urbanized society. Furthermore, our scientists tell us that major damaging earthquakes will continue to strike the San Francisco region in the years ahead.

However, to single out San Francisco as "the city that waits to die" is both unfair and inaccurate. San Francisco is only one of a number of urban areas that face a significant threat from earthquakes. Damaging quakes have hit and will continue to strike the Los Angeles region, California, Seattle, Wash., and Anchorage, Alaska. Salt Lake City, Utah, although it has not yet experienced a major destructive shock, lies astride a large and active fault system that someday will produce a potentially devastating magnitude-6 or -7 quake. Scientists caution us that some important cities in the Eastern United States, including Memphis, Tenn., Charleston, S.C., and Boston, Mass., also are exposed to major damage from future earthquakes. In fact, 15 percent of the U.S. population—more than 31 million Americans—reside in Seismic Risk Zone 3, the zone of greatest earthquake danger. Thus, the earthquake threat is of national concern.

If a 1906-sized event hits any of our major cities, potential losses could be as high as tens of thousands dead, hundreds of thousands seriously injured, and property damage measured in the tens of billions of dollars. A catastrophe of this scale would seriously affect the economy of the whole country, yet it is an event that most earthquake scientists expect to occur sooner or later. Even moderate-sized earthquakes bring death and destruction to urban areas, as we learned at San Fernando, Calif., in 1971. And earthquakes of this size occur relatively frequently, for example, striking California on the average of once every 6 years.

Our earthquake-prone cities do not have to "wait to die." Increasingly, the earthquake threat is being recognized and dealt with at all levels of government. Government and the private sector are following several mutually supportive paths that can reduce the effects of earthquakes: land-use planning, earthquake-resistant engineering, and emergency-preparedness actions. Areas of potential earthquake hazards are being mapped and evaluated so that planners can site future construction away from the most dangerous ground within earthquake-prone regions. The frequency and

level of earthquake shaking are being assessed for areas subject to damaging earthquakes, and the data derived are providing the basis for building codes and for earthquake-resistant design of structures by engineers and architects. Research into the mechanisms of earthquake occurrence and possible premonitory signals of impending quakes is being intensified. Earthquake prediction and its practical application are our subjects today.

Within the past 3 years, seismologists and geophysicists in government laboratories and the universities have made remarkable progress toward an astounding goal: the ability to forecast reliably the place, the time, and the size of future earthquakes. The scientific progress has been truly remarkable because just a decade ago, prediction was considered to be only remotely possible. Today, many scientists are confident that potentially damaging earthquakes can be predicted from precursory changes in the Earth's crust, provided that systems of geophysical instruments are deployed.

Earthquake forecasting will give us an opportunity to help alleviate the ravages of earthquakes by a number of possible actions in anticipation of a destructive event. Emergency service groups can plan and coordinate their responses to the potential disaster. Hazardous structures can be evacuated. The water level behind large dams can be lowered to reduce their susceptibility to earthquake-induced failure. Supplies and materials for postearthquake relief and reconstruction can be stockpiled. Critical facilities such as nuclear reactors and pipelines can be shut down temporarily. The public can be informed of what measures individual households could take to reduce the effects of an earthquake.

Actions such as these, taken in advance of a large earthquake, could substantially reduce the casualties and damage that might otherwise occur.

Society, however, must prepare itself fully to derive the greatest benefit from knowing when and where an earthquake will occur. It is important to evaluate the various possible actions that might follow an earthquake prediction and to assess the impact on all segments of the community. Earth scientists, engineers, sociologists, economists, and public officials all have a role to play in deciding how to best use the capability to forecast earthquakes.

Handled in the proper way, earthquake prediction can be a great blessing to mankind. Our purpose in this conference is to bring you up to date on the prospects for prediction in the United States and the possible implications to society, and to have you consider how earthquake predictions and warnings ought to be disseminated and how an effective public response to prediction should be marshalled.

Role of State Government in Earthquake Warning

By Charles Manfred,

Director, Office of Emergency Services, State of California

State government has a responsibility, which it shares with city and county governments, to be prepared to mitigate the effects of earthquakes that threaten life, property, and the resources of California.

The California Emergency Services Act confers emergency powers on chief executives of the State, including the Governor, chairmen of county boards of supervisors, and city mayors, in order to meet that responsibility. We have an excellent State Emergency Plan, which serves as a basis for the conduct of emergency operations by all jurisdictions throughout the State, and we have established a Seismic Safety Commission which has just begun to initiate programs to reduce earthquake hazards in our State.

Damaging earthquakes have been and will continue to be part of California's natural environment. California's experience with earthquakes has taught us that measures can be taken to preserve life and property during and after an earthquake, that our buildings can be made earthquake resistant, and that appropriate actions by individual citizens can prevent loss of life. Local governments that maintain realistic plans and trained emergency staffs capable of providing the facilities, information, and resources needed by their chief executive for the direction and control of emergency operations do an effective job in the postearthquake environment, caring for distressed people and restoring and maintaining essential services.

The California State government is monitoring the development of earthquake-forecasting techniques and is preparing to modify our emergency-preparedness efforts in the light of new scientific information that might become available.

The Office of Emergency Services has established two advisory committees to deal with problems related to the development of earthquake-prediction technology. One is composed of eminent scientists qualified to evaluate the credibility of earthquake predictions; the other is composed of members representing social, economic, and government disciplines qualified to make recommendations on State government response to earthquake prediction.

In addition, we are cooperating with two research projects being conducted in this area by the University of Colorado and the California Institute of Technology.

The California Emergency Council will consider and discuss the public-policy implications of earthquake prediction at its next meeting on December 10, 1975. The California Legislature Assembly Committee on Finance, Insurance, and Commerce will hold a 1-day hearing on the subject of insurance aspects of earthquake prediction on Wednesday, December 17, 1975.

The technology to predict earthquakes is in the research and development stage—there can be no doubt about that—but questions need to be answered about these research activities and their eventual effects:

- How rapid is the development of earthquake-prediction technology?
- How reliable is the technology?
- Will the Federal Government be able to establish an operational earthquake-prediction system comparable to the Tsunami Warning Service? If so, when?
- How are earthquake predictions to be communicated to the public?
- Will the cost of the social and economic dislocations resulting from the prediction of the time, location, and magnitude be greater than the cost of the physical destruction during and after the earthquake? In this regard, which is the more acceptable risk?
- How will people and their government organizations respond to earthquake predictions? How *should* they respond?

In California, we not only have the problem of what to do once an operational earthquake-prediction system is established, but we have the more immediate problem of dealing with new information about seismic activity in our State—information that has resulted from the various studies and research projects seeking answers to the questions posed above.

These difficult questions demand carefully considered responsible answers from scientists and public officials. Perhaps this conference will provide some of them.

The Status of Earthquake Prediction

By Robert M. Hamilton,

Chief, Office of Earthquake Studies, U.S. Geological Survey

The September 1, 1975, issue of "Time" magazine focused national attention on the rapid progress that has been made in recent years toward earthquake prediction. The "Time" cover story accurately reflects the mood of optimism that currently pervades the scientific community. It also highlights the many scientific problems that remain to be solved before, and the many socioeconomic problems that must be dealt with after, earthquake prediction becomes a reality. The main purpose of this meeting is to call attention to the nature of the problems and to initiate a national dialogue leading to their resolution. My contribution to this conference will be to assess the status of earthquake prediction and to consider the outlook for the future.

One of the reasons for the current optimism about prediction is that some very startling news has been received in recent months from the People's Republic of China. A strong earthquake, measuring about 7.3 on the Richter scale, took place there in February 1975. Apparently the shock was predicted, and actions were taken that saved many lives—perhaps tens of thousands.

The prediction was made by a gradual refining, or homing in, on the place, time, and magnitude of the upcoming shock by using a variety of techniques. As early as 1970, the area of Liaoning Province in northeast China, where the shock took place, was identified as an area of possible risk, apparently on the basis of long-term variations in seismicity. This concern was reaffirmed in June 1974 when the State Seismological Bureau called for increased vigilance in the area. This warning was based on a combination of observations, including migrations of seismic activity, tilting of the ground surface, changes in the water level in wells, changes in electric currents in the ground, and strange animal behavior. These observations prompted the Chinese to move more seismographs and tiltmeters into the area. On December 20, 1974, the local government was warned to expect a large earthquake. Apparently this warning resulted in a false alarm on the part of local officials, and people slept outside in the snow for 2 days. In mid-January 1975, the State Seismological Bureau met again, concluded that an earthquake was imminent, and on January 28, the villages were warned to be prepared. Extra seismographs were set up. On February 1, anomalous earthquake activity began, which was interpreted as foreshocks, and it increased markedly on February 3. At 2 pm on February 4, people were told to expect a major quake within 2 days. Shops were shut in the town of Yingkow, and general evacuation of buildings was ordered in Yingkow and Haicheng Counties. The quake came at 7:36 pm that evening.

This all sounds like the fantasy of a science-fiction writer. If the reports we have received accurately describe the events that transpired, then the Chinese achievement represents a milestone in the quest for earthquake prediction.

Earthquake prediction has long been a lively topic of after-dinner conversation, a proclaimed capability of mystics and soothsayers, and an elusive goal of scientists. The fascination with earthquakes derives mainly from their mysterious nature and their awesome power—the ability to level cities within seconds.

Historical accounts are rich with reports of strange events before earthquakes: dogs howling, strange lights in the night sky, weird sounds, withdrawal of the sea from a harbor, and so on. The significance of these reports has been discounted in many cases, but many of the observations have been sufficiently good to keep alive the hope that earthquakes can be predicted.

Many of the reports of earthquake precursors have come from Japan. A particularly impressive anomaly was observed for the magnitude-7.5 earthquake that caused heavy damage in the city of Niigata in 1964. Level surveys and a tide-gage station revealed anomalous land uplift starting 10 years before the shock. Reports such as this one led Japan in 1965 to establish a formal program to predict earthquakes.

A serious attempt to predict earthquakes is also underway in the Soviet Union. Near the village of Garm, in the seismically active Republic of Tadzhikistan, scientists have been working on prediction for more than 25 years. The fruit of these labors was revealed in the late 1960's; some results were truly electrifying. The Soviet scientists reported that prior to some earthquakes, the speed with which vibrations or waves travel through rocks deep in the Earth showed a distinctive variation. Until then, seismic-wave velocity was thought to be constant. This startling finding opened a new realm of scientific investigation. Incidentally, American scientists are now working at Garm with the Soviet scientists under a long-term program of scientific exchange. The activities of this exchange program were reported to President Ford October 31, 1975, by Russell Train, head of the Environmental Protection Agency, and Academician Israel of the Soviet Union.

Variation in seismic-wave velocity was but one of a variety of phenomena reported from the Soviet Union as earthquake precursors. Radon gas in well water increased anomalously before an earthquake at Tashkent in 1966. Electrical resistivity of the Earth behaved unusually before earthquakes near Garm and in Kamchatka. Migration of centers of seismic activity and reorientation of earthquake-causing rock stress were also observed. Taken together, these findings presented an impressive case that earthquakes indeed have precursors.

These observations have an explanation. It is widely believed that earthquakes are caused by a gradual buildup of stress in rock to the point at which the rock can no longer withstand the forces, and it fails suddenly along a preexisting plane of weakness, or a fault. This, of course, takes place on a large scale in the Earth, the larger earthquakes involving areas of hundreds of square miles. The stresses are created by large plates of the Earth's crust scraping past each other or colliding in a process called by a variety of names: continental drift, sea-floor spreading, or plate tectonics.

The failure process can be simulated in the laboratory by squeezing a rock specimen only inches across. As the stress builds up and the rock nears failure, tiny cracks form that actually cause the rock to expand in volume. Laboratory measurements show variations in seismic-wave velocity, electrical resistivity, and other properties of a rock undergoing such expansion that are similar to the anomalies observed before earthquakes.

American results have by and large confirmed the Soviet findings. In hindsight, it appears that the magnitude-6.5 earthquake near San Fernando, Calif., in 1971 was preceded by a velocity anomaly, as was a smaller shock of magnitude 5.0 in central California in 1972. In the Adirondack Mountains region of New York State, a small earthquake was successfully forecast on this basis in 1973. A resistivity anomaly preceded a magnitude-3.9 earthquake in central California in 1973.

The most encouraging new results in the United States came in November 1974 for a magnitude-5.2 earthquake that struck on Thanksgiving Day near Hollister, Calif. Just south of Hollister, the Geological Survey operates a dense network of instrumentation in an experimental earthquake-prediction system. Strong precursors to the shock were observed in the Earth's magnetic field—the first such anomaly recorded—and in the tilting of the land surface. At a lower level of certainty, anomalies were also observed in the length of survey lines. Such a variety of precursory phenomena had not been previously observed for a single earthquake.

Thus, by 1974, the Soviet Union, Japan, and the United States had taken on earthquake prediction as a national goal and had convincingly established that earthquakes have precursors. At that time, the Chinese effort was virtually unknown to us, but word reached the West that

a major prediction program was underway. The opportunity to find out about it came when former President Nixon's visit there led to an exchange of earthquake specialists. The Chinese came to the United States in spring 1974. They gave little information on their program, saying that they were here to learn of our activities, but they dropped enough hints about their own program to alert American scientists that they had some surprises in store when the U.S. delegation, of which I was a member, visited China in October 1974.

What we found was a well-organized, large-scale effort of research specifically aimed at earthquake prediction. The program began soon after two very destructive earthquakes hit Hopeh Province of China in 1966. China's leaders, including Premier Chou En-lai, visited the stricken area and proclaimed that a serious effort would be undertaken to reduce the dreadful impact that earthquakes have had on the Chinese people. More than 800,000 people were killed in 1556 from a shock near Sian, in central China, and about 180,000 were killed in 1920 near Kansu.

The biggest surprise we found in China was that roughly 10,000 people, including several hundred scientists, were working very hard to predict earthquakes, using a wide variety of instrumentation that includes some of the best in use anywhere in the world today. Virtually every technique that has ever been suggested as a basis for prediction is being studied to some degree. Many precursors have been observed, ranging from reports of unusual animal behavior to well-documented anomalies recorded on the finest instruments. About 10 earthquakes have been successfully predicted, and warnings have been issued, but the Chinese readily acknowledge that many predictions have not been successful.

The Chinese success in predicting the Liaoning earthquake signals that the age of earthquake prediction may be upon us. The laboratory studies show that earthquake precursors should exist, and the many field observations seem to confirm that they are observable. The big questions now are whether all earthquakes have precursors—and whether these precursors are sufficiently regular or uniform in nature to be reliable as predictors. These questions can be answered only through continued studies.

The one area in the United States that has a comprehensive prediction system, mentioned before with regard to the Thanksgiving Day earthquake, is in central California astride the San Andreas fault south of the town of Hollister. This area was chosen for intensive study by the Geological Survey because of its high seismicity. The instrumentation system used there is very much in the experimental phase of development, but at the same time it is a prototype of what could be installed elsewhere in the future.

As is the case with most new technological developments, progress can be a mixed blessing. Earthquake predictions undoubtedly can save lives, as has already been demonstrated in China, but in the finely balanced socioeconomic structure of the United States, a prediction can also cause serious problems; much of our discussion today will focus on these problems. One can imagine, among other things, that prediction of a shock near a major city could lead to a drop in tourism, nonrenewal of earthquake insurance policies, fleeing of the area by the panic stricken, and convergence on the area by the thrill seekers. Failure of the earthquake to occur could result in recriminations, lawsuits, and loss of confidence in the scientists who made the prediction. Unlike a hurricane that veered off course, there would be no way to convince people that they had had a near miss. The fallout of legal, political, social, and economic problems could be serious.

Predictions, however, have the potential to provide enormous benefits. Tens of thousands of lives were saved in 1971 because the lower Van Norman Reservoir was lowered before the earthquake struck at San Fernando, Calif., and caused near-collapse of the dam. Although the action was based on general concern for the dam, rather than on an earthquake prediction, the lesson is clear. Many critical facilities are of necessity sited in regions that will experience strong earthquakes. A warning could avert serious consequences from damage to pipelines, storage tanks, and nuclear reactors.

Much remains to be accomplished before earthquake prediction becomes as useful as weather forecasting. Nevertheless, hopes are high that progress will be rapid. The greatest need is for additional observations of earth-

quake precursors. Observations are needed from a variety of geologic settings to assure that each area will not be a special case. The current level of effort will permit progress toward meeting these needs; however, it does not provide for establishment of any prototype earthquake-prediction system. As a result, the transition to a reliable prediction capability will not be very rapid. Even in the areas that are now under study, the development phase for prediction may stretch over the next decade. In the meantime, we can expect to see many scientific predictions based on only fragmentary data, and we must develop a system for reporting these predictions and for responding to them effectively.

A Federal Plan for the Issuance of Earthquake Predictions and Warnings

By V. E. McKelvey,
Director, U.S. Geological Survey

As Dr. Hamilton showed, we are now entering an age when scientific instruments are detecting signals that can be interpreted to forecast earthquake occurrence. We have not advanced to the stage of full-scale deployment of earthquake-prediction systems. In fact, we now have in operation only an experimental system covering a small area of central California. However, advance indications of a coming earthquake can be detected on fairly inexpensive instruments that would give a scientific basis for making a prediction.

With the increased deployment of geophysical sensors the number of scientifically based predictions is increasing. Scientists recognize that the data are difficult to interpret at this stage, but nevertheless it is clear that the observations must be reported to the public, and the best interpretation possible must be attempted. Developing a plan to issue predictions may appear to be premature when the capability is not really operational, but the impact that a prediction can have requires that even the most fragmentary data be processed in a careful and responsible manner.

The plan we are presenting today is tentative and is intended as a basis for discussion. We expect it to change as a result of this meeting, and we also expect it to evolve as progress is made in prediction research and as experience is gained in issuing predictions.

Before I discuss the plan, I would like to call your attention to a very important point, namely, the difference between a *prediction* and a *warning*. A *prediction*, as we are using the term here, is a forecast that an earthquake will occur at a certain time and place and will have a certain magnitude capable of causing certain kinds of effects. A *warning* is a recommendation or an order to take some defensive action, such as to reduce the water level in a reservoir or to evacuate a building. As you will see in the plan, the U.S. Geological Survey (USGS) has the responsibility for issuing a predicition, but State and local officials have the responsibility for issuing a warning. The plan deals with formulating the prediction and transmitting it to the local officials for issuance of a warning to the public.

The steps in this plan are shown in figure 1. The starting point is with the scientists who are receiving data from field instruments and interpreting them. This is also the starting point of contact with the public, for it is our policy that the raw data be made available to the public. The scientific interpretation of data will be reported through talks at scientific meetings, publications, and information releases. Care will be taken, however, to distinguish between an individual scientist's interpretation of data and the interpretation of his data and other relevant data by his peers that might result in a USGS prediction.

Peer review will be provided by the USGS Earthquake Prediction Council composed of 5 to 10 USGS scientists and scientists from outside the USGS whose experience covers all aspects of earthquake-prediction technology. The purpose of this review is to assure the public that, in the judgment of scientific experts, the basis for the prediction is sound. The role of the

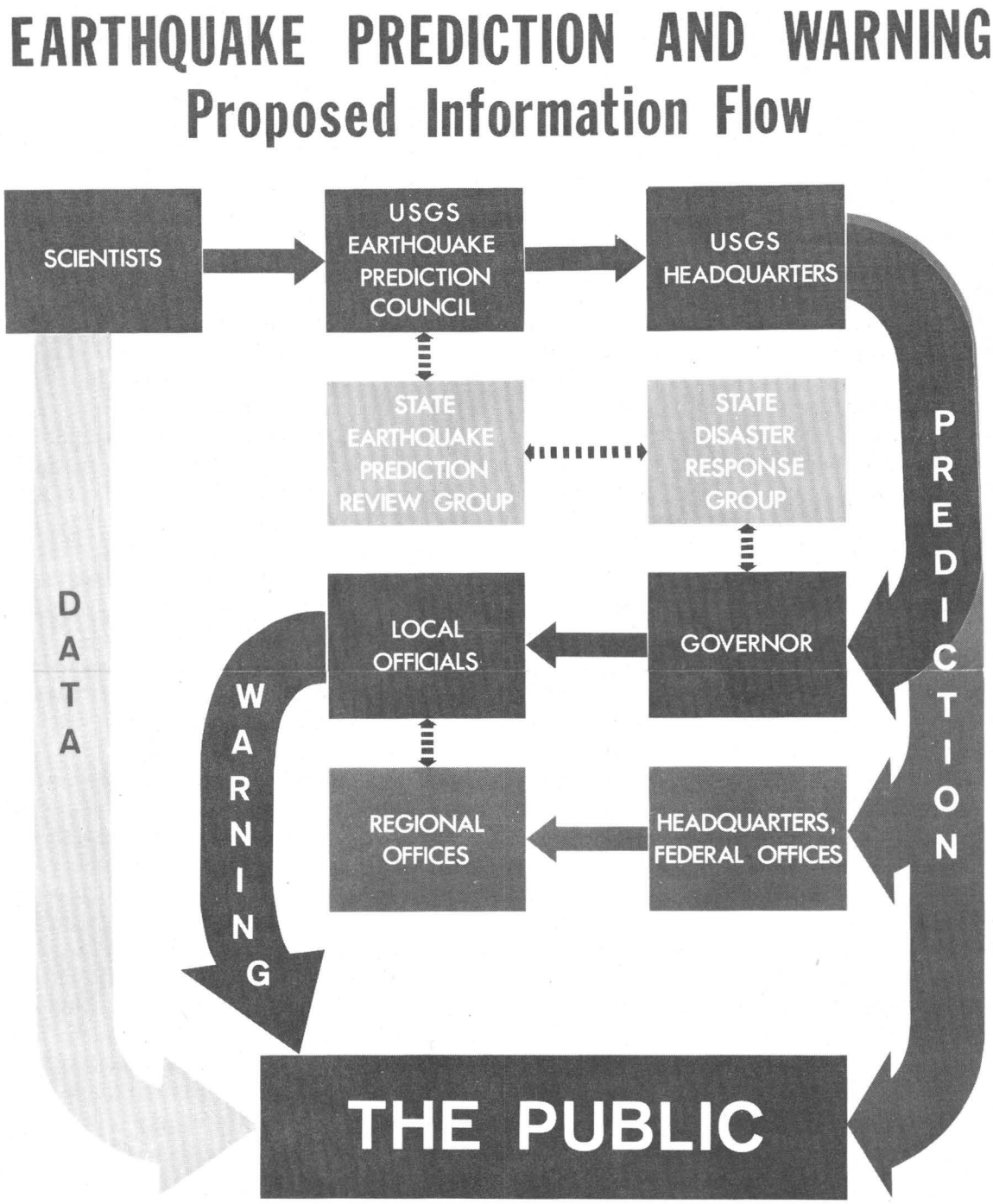

FIGURE 1.—Proposed Federal plan for the issuance of earthquake predictions and warnings. It provides for continual public release of scientific data but ensures that there are firm bases for an official prediction. In the plan, the Geological Survey has the responsibility for issuing a prediction (statement that an earthquake will occur), whereas State and local officials have the responsibility for issuing a warning (recommendation or order to take defensive action).

Council is to review all relevant data and to report its conclusions. The report need not be a consensus report, and it might not agree with the conclusion of the scientist presenting the data. He, of course, could continue to argue his case, but he must make clear that his is not a USGS position.

The report of the Earthquake Prediction Council would go to USGS headquarters, where a decision would be made whether and how to issue a prediction. If the case is not sufficiently strong, a decision could be made to issue an advisory notice, stating, for example, that possible precursors have been detected in a certain area and that that area is under intensive study. The nature of the headquarters action would be tailored to the particular situation.

The statement issued by the USGS headquarters would be communicated to the Governor of the State potentially affected, to Federal agencies with responsibilities for disaster preparedness and response, for example, the Federal Disaster Assistance Administration and the Defense Civil Preparedness Agency, and to the public. This does not necessarily mean that the public would be notified simultaneously with the others, but any delay should be short. It may be judged that the negative impact of a prediction could be lessened if responsibile State and Federal officials received prior notice. A strong case can be made that a warning should be issued with a prediction, so that the public is not left without any recommendation for appropriate action.

Upon receipt of a prediction, we anticipate that the Governor's office would refer the prediction to the State office concerned with disaster response, and the Governor may choose to call together his own group of experts to evaluate the evidence for the prediction. In California, for example, the prediction would probably be referred to the Office of Emergency Services (OES) and then to the Governor's/OES Earthquake Prediction Review Group. USGS scientists would certainly be available for discussion with State personnel, as indicated on the chart by the dashed line.

The Governor's decision about the prediction would be transmitted to local officials and a warning issued. USGS personnel would be available for consultation at every stage of this process. The procedures adopted will surely vary from State to State, so I will let clarification of this part of the chart develop from our discussions today.

The prediction going to the headquarters of other Federal agencies would be transmitted to their regional offices, where coordination would be effected with State personnel.

Scientists not funded by the USGS who find evidence of an earthquake precursor are not specifically considered in this plan. We believe, however, that given the mechanisms I have described, other scientists would be willing to enter the system, by discussing their data with either the USGS Earthquake Prediction Council or the State Earthquake Prediction Review Group. In either way, the findings would be evaluated as a basis for issuing a prediction.

Perhaps this is sufficient discussion of the plan on my part. As I mentioned earlier, this is only a proposal, and we are here to receive your suggestions for improvements. We want a procedure that assures responsible, open, and credible treatment of earthquake-prediction information. We realize that the transition to the age of earthquake prediction will be difficult, but a carefully developed prediction and warning plan can ease the difficulties and yield great savings in both life and property.

Possible Loss-Reduction Actions Following an Earthquake Prediction

By Charles C. Thiel,

Research Applications Directorate, National Science Foundation

Dr. Hamilton has given us a review of the technical aspects of earthquake prediction, and Dr. McKelvey has detailed a proposed plan whereby a prediction will be evaluated and disseminated. I propose to discuss what can be done—what mitigating public and private actions can be taken in anticipation of the event —when a prediction is of such scientific validity that it constitutes an official warning. Whether one agrees with the proposition that earthquake prediction is good (as I do) or not (and there is some dispute) is really a moot point. There are going to be predictions, some scientifically based and others from seers and fortunetellers. It will be the responsibility of the public official, the engineer, the applied scientist, and the entrepreneur to take the information that an earthquake will occur and turn this into public and private policies and actions that allow the individual and the community to reduce the net impact of the earthquake in terms of loss of life, injury, economic cost, and social disruption.

A natural tendency is to think in terms of earthquakes posing a major risk only to the Western States. Without delving into the specifics, 70 million people in 39 States live in regions of major and moderate earthquake risk. This conference is directed at the representatives of the nine Western States at principal risk, each having a major vulnerability to loss of life and property destruction.

I have summarized the extent of the vulnerability of these States in the West by listing in table 1 the population residing in major- and moderate-damage-potential zones and the projected State property values. Although California clearly has the largest number of people at risk, each of the other States have large parts of their population exposed. There is some likelihood that earthquakes will be predicted in the future in each of these States.

It would be nice if, in dealing with earthquake prediction, we could merely decide to leave the area, wait for the earthquake to take place, and

TABLE 1.—*Population and property at high earthquake risk in the Western United States*

State	Population (thousands, 1970)		State's property value (billion dollars, 1980 est.)
	Major risk	Moderate risk	
Alaska	270	25	2.9
California	17,317	2,636	292.1
Hawaii	63	39	19.2
Idaho	200	513	8.1
Montana	142	313	7.0
Nevada	189	300	8.2
Utah	972	48	9.0
Washington	2,169	1,240	46.4
Wyoming	5	19	7.4

then go back and pick up the pieces. Unfortunately, this is impractical. As an example, if the 1906 San Francisco earthquake were to recur in the year 2000, it could cause about $20 billion in damage, 9,000 deaths, and 400,000 injuries. Even so, this does not represent the destruction of the Bay area—it represents the loss of less than 25 percent of the value of structures in the region. The damage would be widely distributed, and those persons in San Jose could not seek refuge in Oakland, San Francisco, or even Marin County. I could just as well show you similar losses for Seattle, Salt Lake City, or Los Angeles. Obviously we cannot count on mass evacuation as a means of protecting the public when the population of the area affected is large; we must seek other means to protect life and property. We cannot run away from the problem.

An earthquake can cause damage in several ways. First, I want you to understand that it is not the fault rupture but the shaking of the ground that causes most of the damage. Extensive ground shaking can cause the disruption of a building's contents and its collapse, the collapse of a dam, the rupture of a pipeline, and many other types of structural damage. Ground shaking can cause soils to lose their capacity to support buildings, causing them to fail. The damage can be from secondary sources—the ruptured dam can cause downstream inundation, toxic chemicals can be released from an industrial facility, or a falling parapet can strike a pedestrian. Old unreinforced buildings are generally the most vulnerable to collapse, and there are lots of them, even in Los Angeles and San Francisco where a long-term attempt has been made to build earthquake-resistant structures. Finally there is fire. Conflagration can be a companion to earthquakes, and the resulting devastation can be nearly total.

Given that an earthquake is going to take place, a variety of actions and procedures can be undertaken to reduce its direct impacts and hasten the restoration of the community.

We can evacuate hazardous buildings or sites. We can reinforce or replace structures that will not perform adequately. Note this last word, "adequately," because we want a hospital to remain operational but may not care if a shed collapses. We can remove the contents of a structure so that they will not be damaged. We can change the pattern of use of a facility or area—for instance, not use a theater, or move a clinic to a "better" building. We can activate emergency-preparedness plans and distribute emergency materials. We can review insurance options. We can adopt tax policies that benefit owners who upgrade their facilities. Finally, we can provide for the relief of the victims and rehabilitation of the community. This list is far from complete. It is meant to show that many methods are available to decrease earthquake impacts.

The actual nature of the specific response to an earthquake prediction will be determined by the size of the predicted earthquake, how long until the event is to take place, the time of year, and whether the earthquake will occur in an urban, suburban, or rural region. It will also depend on the technical and managerial skills of the resident population and its economic and material capabilities. Generally, the longer the period of forewarning, the more the community will be able to do to decrease the impact on the community. As a caution, please remember that, in most cases, it is unrealistic to expend more than can be expected in losses. We must always be careful to balance social and economic costs and resultant benefits in reduced human suffering and property damage.

From an engineering point of view, there seem to be four basic time spans that should be discussed when considering the types of specific actions to be taken. These are 3, 30, 300, and 3,000 days. Table 2 lists a group of actions that could be initiated according to the various stated lead times. I have assumed that we are dealing with an urban event of major magnitude, and have distinguished the actions that could be taken in the time allowed to protect buildings, their contents, lifeline facilities (for example, bridges, communications, water, and hospitals), and special structures (for example, dams, nuclear reactors, and pipelines). If the prediction is a few days in advance, say three, the options are limited to the somewhat obvious. We can evacuate previously identified hazardous buildings and selectively remove contents. Special facilities such as reactors can be closed down. Petroleum pipelines can be emptied and shut down. We can deploy emergency materials and identify staging areas. Use of mass-assembly buildings such as theaters and schools can be restricted.

TABLE 2.—*Engineering responses to an earthquake prediction*

LEAD TIME	BUILDINGS	CONTENTS	LIFELINES	SPECIAL STRUCTURES
3 Days	Evacuate previously identified hazards	Remove selected contents	Deploy emergency materials	Shut down reactors, petroleum products pipelines
30 Days	Inspect and identify potential hazards	Selectively harden (brace and strengthen) contents	Shift hospital patients; alter use of facilities	Draw down reservoirs, remove toxic materials
300 Days	Selectively reinforce		Develop response capability	Replace hazardous storage
3,000 Days	Revise building codes and land-use regulations: enforce condemnation and reinforcement			Remove hazardous dams from service

When there is a 30-day warning period, building inspections can be performed to identify hazardous buildings and conditions. In most cases there will be neither the professional expertise, skilled labor, or materials available to reinforce hazardous buildings in this short time. Reservoirs can be emptied within this time but not much faster. Hospital patients and prisoners can be moved to facilities beyond the area to be affected. Clinics, emergency communications, and emergency response and relief personnel and materials can be moved to less vulnerable sites. Some toxic, incendiary, and explosive materials can be removed from industrial facilities to places where they pose no major hazards.

Only when the period of warning is of the order of 300 days is it realistic to expect that substantial numbers of structures can be upgraded to reduce their vulnerability. During this period an earthquake-prediction response plan can be formulated. Unfortunately it is unlikely that such a plan, which responds to more than obvious opportunities, can be formulated and put into operation in a much shorter time.

Beyond these time periods, in the 3,000-day or about 10-year range, the potential to reduce the vulnerability of the community is great. Building codes can be adopted and enforced that protect the occupants from unacceptable risks of injury. Land-use policies can be adopted that decrease the density of occupations in hazardous landslide areas or filled areas that are likely to be subject to soil failure. These procedures, although useful and obvious, are not the ones that will yield the greatest benefit. *For the next decades the earthquake vulnerability of virtually all this Nation's cities will be dominated by those older structures now standing that cannot be expected to withstand a major shake. The biggest challenge to the public official is to develop economically and politically realistic procedures and policies for the condemnation of substandard structures, and for their reinforcement, replacement, or abandonment.* I wish to call to your attention that these are the same major policies and procedures that we in the engineering profession urge you to take when a specific earthquake has not been predicted but can be expected to occur in the not-too-distant future.

It is logical to ask what the potential impact of all these adjustments during the warning period might be. When the period is but a few days, the major benefit will be in the saving of lives. Property damage will be essentially unchanged. When 30-days warning is available, the damage might be reduced by 20 percent. In 300 days, we might be capable of reducing impacts by 40 percent, and in 10 years, the reduction could be 60 percent or more. These reductions do not consider economic costs incurred in improving physical performance and presume that all available technology is applied.

I would be remiss in my professional responsibilities if I did not point out to all of you that many of the procedures that an engineer or architect might use to design or reinforce a structure economically are yet to be formulated. The same lack of clear-cut procedure is even more true for public-policy matters. Just as a substantial effort must be expended to achieve earthquake prediction, there must be a significant companion research, development, and educational program in the engineering, economic, and social sciences. They must all be pursued together.

In summary, I wish to highlight a few of the public-policy problems, or should I say challenges, that will present themselves:

1. Within the built environment, a particular building or piece of land may be within the jurisdiction of any of a large number of groups, often having overlapping responsibilities. The point is that the control of the physical structures in a community is vested in a vast maze of generally unknown groups.
2. You must start to plan now how you will respond to a prediction, and formulate the basic plans and procedures that you intend to pursue while there is time to rationally contemplate objectives, rather than be forced to respond to the need for immediate action.
3. During the warning period you will have to mobilize trained personnel and materials and protect the public from unscrupulous practitioners pretending to possess capability in the professions dealing with earthquakes.
4. The public will need information on how they can protect themselves and their property. It is logical to assume that they will look to government officials for this information.
5. Finally, there will be the problems of equity. We must formulate and carry out public programs that do not overly benefit some at the expense of others.

Social, Economic, and Political Implications of Earthquake Prediction

By Ralph H. Turner,

Department of Sociology, University of California at Los Angeles

My remarks are based chiefly on a new report, "Earthquake Prediction and Public Policy," prepared by the Panel on the Public Policy Implications of Earthquake Prediction, National Academy of Sciences. This report is available directly from the National Academy of Sciences, Washington, D.C.[1]

In exploring public-policy implications of earthquake prediction, the National Academy of Sciences panel assumed that prediction is inescapably at hand, that it will be fallible throughout the foreseeable future, that we shall have the benefit of warning times ranging from weeks to years, and that we shall be plagued initially with a fairly extended prediction-time window. Lacking experience in the prediction of potentially destructive earthquakes, we must be tentative in everything we say. As far as possible, our analysis and recommendations are based upon research findings from the study of other kinds of public disaster and disaster warning, and upon established principles in the behavioral sciences.

GENERAL CONSIDERATIONS

Earthquake prediction will have its disadvantages as well as its advantages. Under the worst combination of inaccurate prediction and an ill-conceived public response, the prediction and quake might even be more costly than an unpredicted quake would have been. However, it was the considered judgment of our panel that earthquake prediction can be a means for substantially reducing the losses from earthquakes if appropriate social, economic, engineering, and legal actions are taken prior to the quake. Even in case of a false alarm, some of the costs of a well-planned hazard reduction program will contribute to the seismic safety of the community.

There is danger that preoccupation with the costs and difficulties in launching a constructive response may lead public officials to lose sight of the greatest potential benefit from earthquake prediction, which is *the saving of human lives.* Good fortune has kept the loss of life down in recent United States earthquakes, but the toll in case of new earthquakes in San Francisco and Los Angeles could run as high as 8,000 and 20,000 lives, respectively, according to recent estimates. The saving consideration is that earthquakes—unlike hurricanes, tornadoes, and floods—kill few people directly. People die from the collapse of manmade structures, such as buildings, bridges, and dams; from fires ignited when gas and powerlines rupture; and sometimes from tsunamis and landslides. If people are protected from fire and collapsing structures, and evacuated short distances from low-lying coastal areas, very few lives need be lost in even a strong earthquake.

A complete program to save lives and minimize property loss and disruption on the basis of an earthquake prediction will include four kinds of tasks:

1. Authenticating and issuing predictions and warnings;

[1] Copies of the report, "Earthquake Prediction and Public Policy," can be ordered from the National Academy of Sciences, Printing and Publishing Office, 2101 Constitution Avenue, Washington, D.C. 20418, for $6.50 each.

2. Readying emergency services to deal with the situation after the quake has occurred;
3. Implementing a hazard reduction program to minimize loss and disruption when the quake occurs; and
4. Dealing with potentially counterproductive consequences of prediction.

I shall take up these tasks, in turn.

ISSUING PREDICTIONS AND WARNINGS

Many scientists and community leaders are fearful concerning the release of uncertain and imprecise predictions, citing the prospect that a false alarm might diminish response to a later valid prediction, that mass panic might result, and that essential business and political activity might be disrupted. Actually the usual interval of years between serious earthquakes in United States localities is too great to sustain a "crying wolf" effect, and we have abundant evidence from studies of public response to disaster warnings that mass panic is mostly a figment of the imagination. Even a careful reading of reports on the famous 1938 "War of the Worlds" broadcast fails to confirm that any great number of people actually took to the highways or engaged in other extreme actions. Studies repeatedly show that denial of danger and efforts to continue with life as usual, rather than mass panic, are the prevalent responses to warnings of imminent disaster.

The justifiable fear of economic and political turmoil must be balanced by two considerations. If news of a prediction is initially suppressed but property values drop when the prediction is eventually released, persons with inside information stand to gain unfairly at the expense of persons who are not informed. As the recent incident in Kawasaki, Japan, confirms, suppressed information inevitably leaks out, and the ensuing confrontations weaken the credibility of scientists and public officials responsible for withholding information. Only the prompt release of all predictions can forestall these undesirable developments.

Predictions should be prepared, assessed, and issued to the public by scientists, promptly and without respect to policy considerations. Public officials must then exercise their discretion in issuing *warnings* when they judge that the situation warrants action and are prepared to launch an appropriate community response. A panel of scientists should be established on a standby basis to assist public officials in evaluating predictions. The responsibilities of local, State, and Federal officials for issuing warnings should be clarified at once through meetings of concerned parties. Both predictions and warnings must be constantly revised, and public officials must have the benefit of a constant flow of information about the beliefs, attitudes, and actions of the public in response to a warning.

READYING EMERGENCY SERVICES

Earthquake prediction creates new opportunities to place both public and private emergency services in readiness to perform their postdisaster tasks of rescue, relief, and rehabilitation. Emergency plans should now be revised accordingly. Long-term standby civilian organization is not recommended, because activities soon lose their meaning in the absence of imminent threat. Citizen involvement in emergency preparations after a warning has been issued, however, should be a useful way of imparting a realistic understanding of the nature of prediction and the problems of preparing for an earthquake to a wide spectrum of community representatives.

IMPLEMENTING A HAZARD REDUCTION PROGRAM

Because of Mr. Thiel's informative review of hazard reduction measures, our comments here can be limited to a few broad conclusions. First, *large-scale* evacuation will usually be neither practical nor necessary. Second, the prospect of substantially reducing earthquake hazard will be greatest when the prediction response builds on a continuing program of hazard reduction. Where standards for earthquake-resistant construction are already strictly enforced, where some continuing identification of safe and unsafe structures is maintained, and where land-use management has systematically taken seismic risk into account, the response to earthquake prediction will be largely a selective acceleration of existing programs.

Third, long periods of advance warning and the central importance of land-use planning and structural design and maintenance programs require a different allocation of authority than we find in most emergency planning. Departments of planning, building, and safety, engineering and public works, and the like must be given as central a role as police and civil defense agencies in responding to earthquake prediction.

Fourth, depending upon the period of advance warning and other considerations, the ability of the local communities and the region to bear a substantial part of the cost of hazard reduction measures will vary. Careful advance planning and some Federal assistance will be essential.

Finally, because we lack exact precedents and analogies, all phases of earthquake prediction and response will be plagued initially by legal uncertainties. These uncertainties must be clarified and legal obstacles to needed actions must be overcome as quickly as possible, with new legislation when necessary.

DEALING WITH COUNTERPRODUCTIVE CONSEQUENCES

Although most inhabitants of a prediction area will attempt to continue life as usual, regional and national business and financial establishments will likely consider limiting mortgages, insurance, and investment in the threatened area. Combined with a possible net outmigration and reduced tourist trade, these conditions could provoke rising unemployment, falling property values, and reduced tax revenue. The panel recommends that upon issuance of an earthquake warning, a joint governmental and private-sector commission be established to monitor the economy in the threatened area to insure early detection of changes and to make recommendations to government, business, and labor organizations as needed. Representatives of insurance and investment organizations should play an integral part in the commission's work.

Proposals will be made in some quarters to respond to the warning by encouraging an orderly outflow of capital and population, but political realities and the long-term view will favor sustaining the community. Two strategies may be important in pursuing the latter objective. First, many of the short-term costs during the prediction period can be handled as investments in the postquake development of the community, if appropriate planning is undertaken. Second, steps should be taken now to gain acceptance for a policy that much of the outside financial assistance normally available to a community from public and private sources should be made available as needed for hazard reduction measures taken in response to the authenticated prediction of a potentially destructive earthquake. As the fate of the local economy will be largely determined by decisions made outside the local area, it is essential that national support for the threatened community begin when the warning is first issued and not be delayed until the earthquake has struck.

In these brief remarks I could only touch on a few of the problems explored and recommendations offered in the panel's report. I believe the full report merits your careful attention, not for any final answers, but as a starting point in meeting the challenge of earthquake prediction. The new-found opportunity to save thousands of human lives is the reward for dealing effectively with this challenge.

Earthquake Prediction is the Beginning of Problems—Not the Answer

By Karl V. Steinbrugge,

Chairman, Seismic Safety Commission, State of California

San Francisco's Chinatown area typifies the problems associated with the prediction of damaging earthquakes in California, and no realistic answers yet exist to help us deal with such problems.

A great many of the older unreinforced brick and similar buildings in Chinatown are potential collapse hazards in the event of a major earthquake. From such collapses, we can expect large life losses. The narrow congested streets and resulting debris and fires will make evacuation, search and rescue, and fire suppression difficult.

When a disastrous earthquake is predicted, critical public-policy questions will demand answers. Should the seriously deficient buildings be immediately strengthened? If so, who pays if the owner cannot? If buildings are closed, where do the residents go and who supports them? Unemployment? Taxes? Rents? Loss of business? Real estate values? Realistic answers to the foregoing must include historic, cultural, and economic considerations in addition to the obvious life-safety problems. Clearly, an earthquake prediction is the *beginning* of many real problems and not the answer for many public and private organizations and citizens. The policy questions involved in such negative consequences of earthquake prediction are of vital concern to California's newly created Seismic Safety Commission.

Concern for these problems is not new. In 1968, a Commissioner wrote:

"Suppose, for example, that the public were told that there was a 50–50 chance of a destructive earthquake occurring within three years of the announcement. What might be the response? In many cases, major industrial and commercial construction would probably be postponed until after the anticipated event, or relocated elsewhere, thus resulting in a major dislocation for large segments of the local economy. Painting and other maintenance work on dwellings, as well as other buildings, would probably be postponed until after the predicted earthquake, if possible. In many instances, inventories subject to damage would be reduced or relocated elsewhere, in anticipation of the earthquake."

The State Office of Emergency Services (OES) already has taken steps to deal with problems posed by earthquake prediction in its areas of responsibility. OES has established a scientific advisory panel to advise

it on the credibility of earthquake predictions and a committee on State government preparedness to strengthen the response posture of several State agencies.

Now that prediction is seemingly imminent, solutions to these problems are mandatory. Practically speaking, what then can the commission do?

Its first role is to examine in detail the problems to be faced by the public, including the human aspects (such as safety, evacuation, temporary housing) and the financial aspects (such as unemployment, insurance, mortgage loans, property damage, and taxes) to see where adequate assistance may not be available. On the basis of its findings, the commission's actions *may* be:

1. To see that local, State, and Federal agencies are not letting the problems go by default by ensuring that the problems are addressed by the responsible agencies, recommending executive actions to the Governor, advocating necessary changes in Federal laws and programs, and other measures.
2. To recommend needed legislation to inaugurate new and expand existing programs to minimize the negative effects of prediction.

The Seismic Safety Commission is headquartered in Sacramento. It is directly responsible to the Legislature and to the Governor for seismic safety policy in California. The commission includes in its membership scientists and engineers, planners, and local governmental policymakers. The members were appointed in June 1975 as a result of recommendations by the Legislature's Joint Committee on Seismic Safety and the Governor's Earthquake Council. It has replaced both bodies. The Seismic Safety Commission is now beginning to take decisive actions to continue the work of minimizing earthquake hazards in the State.

Earthquake Warning and Response—A Panel Discussion

Moderator:

Jack W. Carlson, Assistant Secretary for Energy and Minerals, United States Department of the Interior

Panelists:

Richard Courter, Department of Emergency Services, State of Washington
Charles R. Ford, Assistant Vice President, Home Office Research Department, Fireman's Fund American Insurance Companies
Robert J. Gregory, Director, Civil Defense and Disaster Agency, State of Nevada
Robert M. Hamilton, Chief, Office of Earthquake Studies, U.S. Geological Survey
Edward P. Joyce, Director of Emergency Services, City of San Francisco, California
James S. Lee, President, State Building and Construction Trades Council of California
Charles Manfred, Director, Office of Emergency Services, State of California
Dale Marr, Business Manager, International Union of Operating Engineers —Local No. 3
V. E. McKelvey, Director, U.S. Geological Survey
Donald T. McMillan, Director, Utah Geological and Mineralogical Survey, State of Utah
Terry Nidiffer, Alaska Disaster Office, State of Alaska
Honorable John H. Reading, Mayor of Oakland, California
Major General Valentine A. Siefermann, The Adjutant General and Director of Civil Defense, State of Hawaii
Karl V. Steinbrugge, Chairman, Seismic Safety Commission, State of California
Robert Stevens, Federal Disaster Assistance Administration
Honorable George Sullivan, Mayor of Anchorage, Alaska
Charles C. Thiel, Research Applications Directorate, National Science Foundation
Professor Ralph H. Turner, Department of Sociology, University of California at Los Angeles
Darrell Waller, Staff of Adjutant General of Idaho
Seymour Wengrovitz, Defense Civil Preparedness Agency

MR. CARLSON: I propose to go back to our keynote speaker, Charles Manfred, and refer to the questions that he raised, because these seem to encapsulate the main problems. So let me start off with those questions and see if we tend to agree with the person who presented the paper as to the dimensions of the problem in each area.

First, how rapid is the development of earthquake prediction technology? I gather from the comments presented by Mr. Hamilton that the full development will take a long period of time. However, there has been rather rapid advance during just the last 2 or 3 years. Also, that it is clearly worth trying to predict, and clearly worth passing on predictions to the public and private sector.

Are there any members of the panel who feel they would like to discuss this aspect?

MAYOR SULLIVAN: Do I understand from your comments that the Chinese are much, much further ahead than we are in predicting? And if so, when do we catch up, if possible?

MR. HAMILTON: The Chinese are ahead in the sense that they have already issued earthquake predictions and have taken action that has saved lives.

They readily concede that they have made many mistakes in their predictions. They have issued warnings for earthquakes that did not come. It seems that the Chinese are not as concerned about this as I think we would be in the United States.

MR. CARLSON: Were the benefits commensurate with the fact that they had at least one false alarm?

MR. HAMILTON: The benefits appear to outweigh the adverse effects because tens of thousands of lives were saved. That is just my opinion. We don't have any details from China.

MR. CARLSON: Mayor Sullivan?

MAYOR SULLIVAN: I just have one follow-up question. About 2 weeks ago, on the car radio, driving to work, I heard a statement, from either A.P. or U.P.I., that I think could have come from your office, about a prediction for an earthquake in the Cordova area of Alaska.

I searched very carefully in the newspapers the next 2 or 3 days, and there was nothing in the papers about this. Are you familiar with this?

MR. HAMILTON: No, I am not. As far as I know, we have no predictions that are pending.

MR. CARLSON: Mayor Reading of Oakland?

MAYOR READING: Yes. Maybe I can pose the question in a little different way. What is the state of the art in terms of your ability to predict? How long will it be before you estimate you will be able to predict?

Putting it another way, how long will it be before I can expect to get a call from the Governor saying "there is going to be a major earthquake in Oakland in 3 days?"

MR. CARLSON: That goes to the second question brought up by our keynote speaker—how accurate is the technology?

MR. HAMILTON: We are in a very difficult situation. We have instrumentation deployed in the San Francisco Bay region that could provide a basis for predictions. So, it would be conceivable that within the next year we could acquire some data that might lead us to believe that there would be an earthquake in this area.

Now, the big problem is that we do not have any experience with having made predictions in the area. We mainly have seismographs in this area. We don't have many of the other types of instrumentation that would support seismic evidence.

So, in answer to your question, it would be conceivable that within the next year we might have evidence that we feel we should pass along. We would have to admit that that evidence was fragmentary.

MAYOR READING: So, it's a question of the degree of accuracy. Are you talking about a 10 percent degree of accuracy, or a 50 percent degree of accuracy? Can you predict in that way?

MR. CARLSON: There are two questions in that. One is you may not have the best equipment existing in the Oakland area, and that is the first problem. You may just be dealing with half of the necessary equipment. And if you have all of the equipment, your predictive efficiency may be higher.

The second is: If you have optimal equipment available, what is the probability of a prediction? Maybe you can respond to the latter question instead of the former one?

MR. HAMILTON: I think the ability to assign a percentage, or a judgment of reliability to a prediction, will have to come from experience.

The Earth is a very complicated system. If we move into a new area with new instrumentation, we cannot be sure, until we have observed at least one or two earthquakes, that we really know that the same prediction techniques are going to work there that work elsewhere.

I should point out that even in the central California area, south of Hollister, we have only observed several earthquakes of magnitude 5, and so far no magnitude 6's. So, we really haven't been able to test fully our ideas in that area.

Reliability, at the outset, will be very difficult to assess. As an example, before the Thanksgiving Day earthquake, we saw a magnetic anomaly, the first observed so far in central California. Now, the next time we see a large magnetic anomaly in central California, we will be inclined to think there is another earthquake coming. If it occurs, the reliability of magnetic anomalies for prediction will go up. This is very much an empirical approach.

MAYOR READING: What was the lead time on that magnetic anomaly in central California?

MR. HAMILTON: It was a matter of weeks.

MAYOR READING: So, it would be in the 30-day category?

MR. HAMILTON: That's right.

MR. CARLSON: I think to summarize, we're not anywhere near the reliability of weather forecasting, and we all know the reliability there.

But, the key thing is that it is better than a table of random numbers. And the fact that you can start identifying earthquakes with some probability of success, even though it tends to be low until we develop the confidence, makes it worthwhile doing.

MAYOR READING: Well, you know, I think there is a responsibility, as pointed out here, for the public officials to pass on this information if they get it. It would seem to me necessary to do this in order to maintain the credibility of not only the people who are making the forecasting, but also the officials, and also to inform the people themselves so we can determine what they're going to do, based on that information. It would be helpful if a public official could say: "There is a 10 percent chance that there may be an earthquake in the next 30 days." It would be better if you could give an idea of the reliability of the prediction.

MR. CARLSON: Yes. I think that you should do that like weather forecasting, giving the probability as opposed to whether it's going to happen or not happen. And I agree with you regarding the information.

Mr. Thiel?

MR. THIEL: There is an assumption in your question that the predictions are going to be issued to you through the Governor's office, or through some political process. I think that is an assumption that is not warranted.

MAYOR READING: That is what the information flow chart shows.

MR. MCKELVEY: It is a proposal.

MR. THIEL: That is only for predictions coming out of the USGS system.

A number of the predictions that were referred to by Mr. Hamilton were not made by USGS scientists. One was made in the State of New York by scientists at Columbia University. The post-prediction of the San Fernando earthquake was made by Caltech scientists. And right at your own doorstep, there is a large university, operated by non-USGS funds, engaged in earthquake prediction activity.

So, it is likely that predictions would be issued from non-USGS sources that are not subject to the Federal Government's program for evaluating and disseminating predictions arising from its own staff.

MAYOR READING: Well, what are your lines of communication and coordination with these other facilities?

MR. CARLSON: Before we get to that, may we just make sure we have completely explored the reliability aspect and the state of the art?

MR. COURTER: Yes. Let me clarify the question. Are we talking about an earthquake prediction reliability for only those kinds of earthquakes that have some kind of surface breakage or visibility?

In the Puget Sound area, through a study of the USGS, we found that most of the earthquake activity is deeply seated and results chiefly in ground shaking. And because of the large amount of water in our area, there are many areas of weak soil. We would, therefore, be vulnerable to ground shaking. Now, are you also including this kind of earthquake in your predictions, and how reliable are they? It is hard to build up an awareness by public officials if they can't see any visible cracks in the surface of the Earth.

MR. HAMILTON: The idea is to include all earthquakes that could cause damage, and not limit it to those that could cause surface faulting. Incidentally, the study in the Puget Sound area is funded by the USGS, although it is done by University of Washington scientists.

GENERAL SIEFERMANN: Speaking of predictions of volcanic eruptions rather than earthquakes, I think that Drs. Tilling and Lockwood of the Geological Survey's Hawaiian Volcano Observatory have done a remarkable job predicting the last one almost to a T. Their forecasting is such that we pretty much believe them. There was an earthquake associated with that eruption, but it was localized. And there was one just a few days ago at Mauna Loa. So, we are expecting an earthquake and eruption within 2 weeks to 2 years.

We think we can pretty well determine where the eruptions would occur, that there would be minor damage, and what control we would have. We are even making studies to determine what action we would take to divert a lava flow.

Predictions, I feel, in the case of Hawaii, as far as eruptions are concerned, have come a long way.

MAYOR SULLIVAN: Do I get the understanding that some universities are predicting earthquakes?

MR. HAMILTON: The science writer for the Los Angeles Times pointed out recently that there have been 2½ successful earthquake predictions in the United States, and one failure. The two successes belong to the universities; a half success belongs to the Geological Survey, mainly because its prediction was made informally; and the failure belongs to the Geological Survey.

MR. CARLSON: As Mr. Thiel brought out, there is no attempt at fragmentation in the scientific community. If the community remains together, we can make sure we have no pluralism of predictions.

MR. THIEL: There also are private individuals who are issuing predictions.

MAYOR SULLIVAN: Mr. Hamilton and Mr. McKelvey were speaking of deployment of instrumentation in California. Are the systems going to be nationwide, or is it just going to protect California?

MR. CARLSON: Can you give us an idea, so everybody will know, what kind of initial costs and operating costs would be required for a city like Anchorage, or a city like San Francisco, so people will have an idea of the range?

MR. HAMILTON: Well, we prepared a proposal for developing what we could call a prototype earthquake-prediction system in the two most active seismic areas of California, that is, the central California area and the San Jacinto fault area. The purpose of the two prototype systems would be to confirm our present findings with respect to earthquake precursors and try to show whether it is justified to expand that system further, and then, if things work out, also to expand that system into the two major urban areas of Los Angeles and San Francisco. We estimate we can do that on a budget of about $5 million a year.

In Alaska there are more difficult operational problems, so the costs would be higher. But I think that gives us a feeling for the kind of money that is involved.

Now I would like to say again, at this point we are still in the experimental phase, and I don't think we know just exactly what we would recommend for large-scale deployment. We still have to do quite a lot of research before we would recommend that instrumentation be deployed on a really large scale.

MR. CARLSON: You're talking about a pinpointed area like Anchorage, or Reno, or Salt Lake City. You may be talking about $2 million for the capital investment and about $1 million for operating. Then, for larger areas such as Los Angeles and San Francisco, would you go up to a higher figure?

MR. HAMILTON: You have to approach prediction on a regional basis. You can't approach it on a pinpointed basis, because the volume of rock that is involved in storing the stresses of the earthquake extends over hundreds of miles, and you have to cover that whole area in order to recognize the precursor signals.

Part of the evidence as to the size of earthquakes, we think, will be the size of the area involved in the premonitory signals. So, a prediction system must be established on a regional basis.

I think for southern Alaska, we are talking about something like $10 million.

MR. CARLSON: For the whole region?

MR. HAMILTON: Yes, including Anchorage.

MR. CARLSON: But, it's not entirely a lump sum. You can talk about a closer net, or more instrumentation and less instrumentation. So it is not an all-or-nothing type of investment, is it?

MR. HAMILTON: That's right.

MR. CARLSON: Does that answer your question, Mayor Reading?

MAYOR READING: Can you tell us what is the status of instrumentation in San Francisco, Oakland, and along the San Andreas fault?

MR. HAMILTON: The main instrumentation that now exists in the San Francisco Bay area is a network of seismograph stations. The additional instrumentation that could be installed would be tiltmeters, magnetometers, and sensors for monitoring the electrical resistivity of the ground.

At the present time, such a blend of instrumentation exists only in the region south of Hollister, in what we call the experimental system. In addition, in the Bay region we carry on what are called trilateration surveys, which are surveys to detect changes in the length of lines to look for horizontal deformations in the Earth. But the main type of instrumentation in the Bay region is the seismograph network.

MR. CARLSON: We do not have funds in our budget to go ahead and instrument San Francisco, Los Angeles, Anchorage, or other communities at this time. In fact, I was hopeful that this conference would help us to see if we should move in that direction.

MR. GREGORY: Mr. Secretary, I have a question of Mr. Hamilton.

This instrumentation that is in the Hayward and San Andreas fault area, would Reno be in a region that such instrumentation covers?

MR. HAMILTON: No, although the University of Nevada operates some instruments in the Reno area. We are operating networks of seismographs in a number of areas in the United States. If I may briefly list those regions, we are operating a network of seismograph stations in the Puget Sound region through the University of Washington; there is a network in southern Alaska (partially concerned with environmental monitoring for the Trans-Alaska pipeline); in western Nevada through the University of Nevada at Reno; in Salt Lake City through the University of Utah; in southern Missouri through the University of St. Louis; and we are beginning to fund some work in the Northeastern United States.

MR. WENGROVITZ: Mr. Hamilton, you have stated that your instrumentation was placed in a somewhat large geographic area. What I am wondering about is the ability to be able to predict exactly where an earthquake is liable to occur with respect to a smaller sized area.

For example, if you're talking about an area that extended from Los Angeles to San Francisco, would you be able to say that both areas are likely to be subjected to an earthquake, or can you be more precise than that and say the Oakland area would be subject to it, but not the Los Angeles area, and perhaps not San Francisco?

MR. HAMILTON: We anticipate that the predictions would be specific as to the area involved. So, it would not be a general prediction for the whole State of California. However, a magnitude-8 earthquake could have precursory signals that extend over a fairly large area.

MR. MANFRED: I just have one more point. What are the prospects of increasing, in money and time, these research activities in the next couple of years to change the rate of progress? Would the prediction capability develop faster? What are the prospects?

MR. CARLSON: Obviously, there are several options as to how fast we can proceed. It will be important to us, from the Federal viewpoint, to gain some insight from you as to what would be appropriate. It also requires an assessment of the benefits we can expect from this new technology.

Let me see if I can summarize. Although we have seen fairly rapid advances in recent years, we believe that the development of a prediction technology will continue for many more years—that it isn't going to be attained overnight. However, I judge from the suggestions in the presentations we've heard at this conference that it is worthwhile pursuing. And, if we do pursue prediction, we must consider its utilization aspects, which I would like to talk about now. That is, how does a State government, a local government, or the private sector use this information when it is available? I would like to consider the outline that Mr. McKelvey proposed for the flow of predictions from the scientific community to the public. It is obvious that some sort of process for handling predictions would have to be established.

Let me turn this topic over to Mr. McKelvey.

MR. MCKELVEY: Could I just say something with respect to Mr. Thiel's point regarding the earthquake-prediction flow chart?

We talked about the Geological Survey predictions and the way in which they would be handled. But as I mentioned during my talk, I think it's likely—if we are successful in setting up the system I've described with the Earthquake Prediction Council as the review mechanism, and if the States are successful in setting up a similar kind of mechanism, such as California has already done—that the responsible scientists in the academic community will want to enter that system. They will want to have their predictions understood and reviewed.

So, I think that would follow if we set up the kind of system that we're talking about.

MAYOR READING: I would like to comment on that. I think it's imperative that you get cooperation and coordination. We know about other reporting agencies and what has been brought out here very emphatically today is that there is a multitude of problems attached to any announcements of this sort, and that there ought to be an orderly plan for the distribution of that information. If you have someone who holds a press conference and all of a

sudden announces publicly that next week he thinks there is going to be an earthquake, then it completely disrupts the orderly government process.

MR. CARLSON: I think the essence of your statement, Mayor Reading, is that first, we have freedom of speech. Obviously, anybody can speak on any topic they wish. However, it may be useful to identify an agency, so that if somebody does have information, they know where they can take it. And that agency would put the data into a system of screening and verification so the people may judge how reliable that prediction may be.

MAYOR READING: Well, it seems to me that the responsibility is one that belongs in the Federal Government, for example, in the Geological Survey, or with someone who can go to these various agencies and say, "Look, are you willing to cooperate with us and to run through the normal screening processes if you have such a prediction?"

MR. CARLSON: In terms of the Federal family, the Geological Survey would be the appropriate place. But you're talking also about academic communities that are not under the jurisdiction of the Federal Government. You would want to have some sort of comprehensive policy that would enable the Federal Government to process information from other sources.

I do think it is important to be careful how this information flows, and to have responsible people who provide moderation to statements that might come out of the blue.

MAYOR READING: That is the point I am trying to make, it should go through an appropriate channel.

MR. MCKELVEY: At the present time we don't have the authority to require one. We don't have the system established fully, either. But I would think that if we do have the Earthquake Prediction Council that I've described set up and operating, it would be entirely within its purview, if it learns of a prediction that is being developed, to invite the person to submit his data. And the State Council could act similarly.

MAYOR READING: I fully understand that you don't have the authority to direct a person to do that. But I think that you could develop a plan—which you've done—and then persuade the scientific community that it's to their best interest as well as everyone else's that they go through approved channels.

MR. MCKELVEY: Scientists are going to feel that responsibility.

PROFESSOR TURNER: I think we have come to this crucial problem: We are tempted to solve our problems by restricting the flow of information. The moment we start doing that, we create all sorts of complications which tend to make a bad situation worse. And I think we must distinguish between the matters of releasing predictions, authenticating predictions, and issuing warnings. These are three different things.

Now, I understand that the proposal presented by Mr. McKelvey has to do very largely with the authentication of predictions and with steps toward issuing warnings.

But just think what is involved in trying to prevent people who think they have evidence that there is going to be an earthquake from making a public statement. Is that going to include astrologers, or are you only going to restrict legitimate scientists?

You simply have an absolutely unmanageable and uncontrollable situation if you start trying to prevent people who, for whatever reason, honestly believe that they have evidence, from releasing that information.

And, in any case, I would like to remind you again that information leaks out. The longer we hold it back, the longer we try to deliberate over whether to release it or not, the greater the certainty that the press will get it and it will come out. Then the people who are trying to be responsible about it will be embarrassed.

It is a much better alternative to have the information come out independently and then simply say: Well, we don't know whether this information is valid yet. But we are giving it serious consideration.

Everything we know about public reaction indicates that when people have confidence that the scientists and the officials are seriously considering a question, they don't force precipitate action; it's when they think that something is hidden that then they start to force precipitate action.

MR. CARLSON: I think you can see that the precursors don't start the night before an earthquake. There is a buildup of suggestive data that permits people to say, "Can we interpret it this way or not?"

It's not like something that develops overnight and is hidden from view—indications tend to build up over time. So, we do have time to formulate plans.

An earthquake-prediction review system *can* be built around what Mr. McKelvey has said. Perhaps the geophysical information will flow through those channels for weeks or months while people develop an actual prediction, and have some confidence to give a warning, together with the costs and benefits associated with it.

MR. MARR: This is related to a situation we had recently at Oroville, California. I happened to be in Utah for a meeting the night of the earthquake, and you wouldn't believe the number of phone calls I received. People were just staggered with the idea of an earthquake, because there was a likelihood that the Oroville dam would be affected. And knowing the volume of water behind that dam, if someone had said that the dam might fail, there could have been a real panic of people trying to get out of the way.

It amazed me how many of our members who work near Oroville traced me down and asked what to do. There could have been a really chaotic situation.

So, when officials are handling predictions, there has got to be careful analysis of who is going to be issuing statements.

MR. CARLSON: I'm wondering if Mr. McMillan would like to add to that, because of your familiarity with your part of the country?

MR. MCMILLAN: We, of course, are also on the watch. Salt Lake City lies astride the Wasatch fault and is in a potentially active earthquake zone. But you can't ignore the fact that in 150 years of settlement in the Salt Lake Valley, there has not been a destructive earthquake.

What I would like to ask Mr. Hamilton is: Whether or not there are long-range predictors—or if he thinks there will be long-range predictors—that might give a lead time of 1 or 2 or 3 years, during which time instrumentation can be increased so that the imminence of a potential shock can then be predicted in time intervals of 30 days and on down to a 10-day or 48-hour prediction?

MR. HAMILTON: There is evidence that the bigger the earthquake the longer the lead time in terms of when the signals first begin.

In Japan, before the earthquake in 1964, the first changes in sea level occurred about 10 years before the earthquake. Similarly, for the earthquake that occurred in Tashkent in the Soviet Union about 10 years ago, changes in radon gas had increased in well water about 10 years ahead.

So, for the big earthquakes, there is evidence to indicate that there may be very long lead time—on the order of perhaps as much as 10 years.

We would expect that, as you pick up signals that indicate that something may be developing, you would move additional instrumentation into the area to confirm the early results and to sharpen the prediction.

There have been several occasions in the last few years where we, in our studies, have picked up something that looked suggestive of an anomaly. We followed up with additional instrumentation. But in all cases, the anomaly was not confirmed.

MR. MCMILLAN: And wouldn't this be an avenue worth pursuing in order to bring the art of earthquake prediction into a widespread area, and yet control the rather high cost of closely spaced instrumentation?

MR. HAMILTON: Yes. That would be the approach. But, I should point out that you have to have at least a partial network of instrumentation.

In the Salt Lake City area, we have a rather sparse network of seismograph stations, but no other type of instrumentation. The University of Utah has some instrumentation, but it's not adequate to constitute a prediction system, even of a sparse nature. But you're right. Probably the best approach is to gradually upgrade the instrumentation, and then when you identify a problem, to intensify the efforts.

MR. THIEL: Mr. McMillan, you made a statement that I can't agree with. There have been a number of damaging earthquakes in the Salt Lake City area since the time it has been occupied by European man. There have been no great earthquakes, but please note that a great earthquake, in terms of damage and intensity, in the Salt Lake area, does not have to be the giant titanic process that takes place on the West Coast. The seismic resistance of the structures in the Salt Lake area does not match that of the principal West Coast areas. Therefore, a

smaller shake can cause the same intensity of damage.

MR. MCMILLAN: You're right. I had no intention of downgrading the potential dangers. For instance, the Pocatello Valley earthquake of last March 29th [1975], had it occurred in Salt Lake City, would have caused major destruction. It was a stronger shock than that which destroyed the City of Managua, Nicaragua, a few years ago. We are well aware of that.

And, you're right. There have been shocks which did cause damage in Salt Lake City. I didn't mean to say that there haven't been. But what I did mean is that there has not been, during that period of time, a major destructive earthquake in the immediate Salt Lake City area.

MR. CARLSON: I gather from our discussion, we are agreeing with the general approach to earthquake warning that has been outlined in Mr. McKelvey's proposal. Even though it is rather general, the process provides for verification and for identifying who is the responsible person. That is something we all support. We would frown on trying to hide the information from the news media. There would have to be a responsible release of information as that information is gathered over a period of time.

That moves us to Mr. Manfred's comments on how our earthquake predictions could be communicated to the public. The question we have yet to talk about is: How do we release this to the public?

Now, we have made some mention of the extent that this might be on a probabilistic basis: "We expect an earthquake of magnitude three to five on the Richter scale in the next 90 days in such and such an area. The probability of this occurring is 10–20 percent, or 40–50 percent, or some range of probability."

Are there comments on how we would release information to the public, no matter who is doing it, whether it's the scientific community or a public body.

And of course, the release has to be tied to what you are going to do about the problem. What is the government to do, and the people who provide the goods and the services? So, you would have to accompany a warning with what steps are expected to be taken. May we talk about that for a minute?

GENERAL SIEFERMANN: With regard to prediction of volcanic eruptions in Hawaii, the scientific community contacts the Governor, and the Governor makes the determination to release the information. It then falls on my office, which handles the emergency and civil defense, to disseminate the information to the public and to direct the action they would take and to coordinate the action we would take. This seems to work really well.

MR MCKELVEY: I wonder if I could ask for a reaction to the idea that an authenticated prediction—and with reference to the system that we've proposed, predictions having been authenticated and released by the Geological Survey—ought to go to the State Governor before it goes to the general public, so that a warning and prediction reaches the public at the same time? So that the public is not given a prediction without also being given something from the State and local authorities as to the defensive reactions that they can take?

GENERAL SIEFERMANN: I think it should go to the Governor so the flow of information can be controlled. You get more factual information disseminated to the public.

MAYOR READING: In view of what you have told us here, I think it is important that there *is* a body that authenticates a prediction. I also think it important that the prediction go through the Governor and the local officials so that when it is announced you also can relate the precautionary measures the public can take.

MR. CARLSON: Then, you will need to have the interpretation following rather quickly, if not simultaneously, the announcement of what could happen. And, the elected officials of the State and Federal Governments are the ones whom we normally trust in our society to carry out that function. So I think you're generally saying that you favor this approach.

MAYOR READING: Absolutely.

MR. COURTER: Not only that, but I think it's also very important that the prediction be presented in language that can be easily understood, not only by the public officials at the State and local level of government, but also by the citizenry who is going to receive this kind of information.

Often times, we get information that can be misinterpreted. If we are going to receive a prediction, it should be stated in understandable terms, and it should be given with a suggested action or alternatives so that we really have

something to evaluate at the State and local government levels.

MR. CARLSON: Possible responses were outlined in the paper presented by Mr. Thiel: If you have 3 days, there are some things you do; with 30 days, you do other things; and with 3,000 days, you can respond in other ways.

MR. MANFRED: I think we have to be very realistic about it. There are no secrets; we have a free and open society.

I do think that the Survey should establish a council to authenticate predictions. You should make a special effort to see that responsible officials in the area of concern are notified. But, chances are that the responsible officials and the public are going to be notified at just about the same time. Emergency service organizations have to begin to give this some thought and come up with plans and procedures early in the prediction stage: What are we going to do if the Survey tells us an earthquake is imminent?

MR. CARLSON: It is going to be important for society to know that there is a responsible group that can provide an authoritative appraisal of what is being talked about.

MR. STEINBRUGGE: I certainly agree with the ideas expressed in the proposed plan. I would like, however, to ask a question.

Is there mechanism so we don't have two groups developing diverse answers? Let us say that university seismologists make a prediction and it's in the gray zone, which we all feel may well be the case. Would this prediction be reviewed by the USGS?

I am concerned that there may be substantial differences in the interpretation of the scientific data. We must be sure that we aren't faced with the USGS stating that a prediction is probably true, while some other credible institution states that it is probably not true, or vice versa. I think this can be a disaster in itself.

MR. CARLSON: Well, I think the key thing is: We want to make sure there is a responsible body somewhere to verify a prediction.

MR. STEINBRUGGE: I am not critical of the proposed plan. I only see a problem which might arise. I find no fault with what has been proposed. But I would like to see the plan structured in such a way that a scientific consensus might develop with regard to a prediction.

MR. CARLSON: Mr. McKelvey?

MR. MCKELVEY: The situation that Mr. Steinbrugge is anticipating is one we can expect from time to time. The situation in which the significance of evidence is not agreed to by all specialists in the area is not an unusual one in scientific matters at all. And indeed, it does pose an additional complexity in the problem.

But, as I indicated, we would expect that an Earthquake Prediction Council in the Survey—and I think this would be probably the case in State organizations also—would from time to time issue conclusions that are not agreed to by all members. This may be such that we would evaluate the situation as one of greater uncertainty. Those facts would have to be presented to the State and to the general public, and additional emphasis would have to be placed on the investigative process to try to narrow the range of uncertainty.

We are not facing a problem with easy solutions here. And we can expect to have to cope with difficulties of many kinds. This is only one of them.

MR. CARLSON: Let me throw into our deliberations some of the final points that Mr. Manfred gave us earlier. Will the social and economic costs resulting from prediction exceed the cost of the earthquake destruction? In this regard, which is the more acceptable risk? And how will the people and their government organizations respond to earthquake predictions? Let's consider these points in our discussion.

MR. THIEL: I've a two-part question. There are going to be a number of panel meetings by committees on procedures. How would procedures apply to the Federal level; and are these prediction meetings going to be open to the public and will they include a participation phase?

First, I would like to ask Dr. Turner whether the prediction review meetings *should* be open to the public. And secondly, I would like to ask Mr. Carlson whether they *will* be open to the public.

MR. CARLSON: Professor Turner?

PROFESSOR TURNER: Well, that is a loaded question. I have to answer it as from a personal viewpoint, as this is not something that was discussed in the National Academy of Sciences panel, and therefore I can't shift the responsibility to anybody else for the answer.

I think technical questions and policy discussions are two different things.

Technical questions have to be answered on technical grounds. Any time political considerations and policy considerations enter into the determination of a technical matter, we're in trouble.

Now, I think the point is that when you open up a technical discussion to the public, you invite the intrusion of political policy considerations. So, I would say that insofar as a panel or group is involved in the technical evaluation of evidence to determine whether there is going to be an earthquake or not, it should be a closed meeting of technical people.

The question of policy is another type of question. But I would make that distinction.

MR. CARLSON: Within the Federal Government there is a Freedom of Information Act, and anybody can demand access to that kind of information, and we would be obligated to provide it. In fact, frankly speaking, I see no reason to withhold the technical information, for it is going to be building up over a time. It is going to be available. The interpretations will come more slowly.

On the policy side, I'm sure that the important policy is set prior to the occurrence of the event. What we will do depends on given circumstances. If you have a 3,000-day lead time, then obviously, policy decisions will develop over a long period of time. There may be some brainstorming going on that wouldn't necessarily be public. But, I certainly think that the technical data would be generally available to the public. And we have made a point of making sure that the scientific findings of the Federal Government are separate, as much as possible, from the policy side.

PROFESSOR TURNER: Let me just make sure my answer is clear. It is the *deliberations* of the technical body which should be private. But once the technical body reaches some sort of conclusion, then all that information should be public and none of it should be withheld. There should be no censoring or withholding of the technical information, because the scientist must not decide what is good for the public to know and what is not good for them to know.

MR. CARLSON: Science is too important to society to be left to scientists; is that what you are saying?

GENERAL SIEFERMANN: During the last event that we had in Hawaii, we responded on a local government level just about as you stated. We had a consultation with the scientific community. Then, it was the local government that issued the information.

We are now working with the scientific community and the Geological Survey to set up the basic procedures whereby we can get together and almost immediately develop the information necessary so that it can be disseminated to the public.

Being an optimist, I think that more information is always more useful than less information. There may be occasions when that isn't true, but I would hypothesize that most of us feel it is worthwhile taking action as opposed to not doing so. We would have to look at it on a case-by-case basis to see.

MAYOR READING: Mr. Chairman, I have a question of Mr. Manfred. It's pointed out here that when the dissemination of the prediction is made—and as far as I'm concerned that would only come from my office after it has gone through the review board—we should have a response plan that we would start to implement. And that plan would be announced to the public.

Now, it seems to me that it's rather impractical, and a duplication of effort, if every local municipality developed their own plan. It seems the more realistic approach to this would be for the [California] Office of Emergency Services to develop model emergency plans for the use of the counties and cities in the area of a prediction.

MR. MANFRED: Yes. You can be sure that our Governmental Response Committee, meeting in Oakland, is identifying the problems, and we will be developing a plan in California.

I mentioned in my talk that California is fortunate in terms of our emergency organizations, and particularly our planning. Our plan is based on the consignment of shared responsibilities in a mutual manner. We work closely with the cities and counties in the State, and will continue to do so to meet this problem.

MR. CARLSON: Let me pose two additional questions. And I'm wondering if I could call upon Charles Ford, of the insurance industry, and also Mr. Dale Marr, to suggest: (1) how the public at large, as opposed to the governmental sector, would tend to react towards

earthquake predictions; and (2) the benefits that may be associated with prediction from the perspective of the insurance industry.

And after we hear from these two gentlemen, I would like the rest of us to be thinking of the important next steps that we should consider after this meeting is over. Do you feel that we should move in the direction of improving the prediction capability, of authenticating the predictions, of having a warning system tied to it?

MR. FORD: Let me say first that these are personal observations not related to any organization.

I think we must look at insurance response in two parts. The insurance mechanism deals with fortuitous events. In our private organizations, we have earthquake insurance available at reasonable cost. This has been substantiated by Mr. George Bernstein, then Federal Insurance Administrator, before the Congress, and by Mr. Lawrence Baker, then California Chief Deputy Insurance Commissioner, who addressed the same subject before the Senate Investigating Committee on the San Fernando earthquake. There is earthquake insurance and it is available. The problem is that it is not generally purchased. We would like to see earthquake insurance more broadly purchased, but this can't be done without a willing buyer.

Insurance is something that is bought for a price—the premium—for a contractual expenditure under circumstances of fortuitous loss for a specified amount of indemnity. Does prediction based on precursors remove the earthquake event from the fortuitous and does the event become an actuality at that time? If it does, then the purchase of insurance *after* a prediction, as when any loss is imminent, is not a proper involvement for the insurance mechanism.

No one would expect to place insurance on a burning building nor would they expect a life insurance company to insure the man in a hospital bed who has been advised by his doctor that he is terminal. To require the certain loss rather than the fortuitous unexpected loss would put a cost burden on the insurance-buying public which would be unthinkable and an economic disaster.

The problem then is to get people to buy earthquake insurance on a long-range basis. If a person has purchased and holds a policy, the company will stay with it and respond. Witness these circumstances drawn from our experience when Hurricane Betsy lay off the coast of Louisiana. It sat for 3 days and then directed itself at the coast at New Orleans. The insurance industry did a lot of fingernail biting and waited for the roof to fall in.

MR. CARLSON: Did you sell a lot of insurance the day before?

MR. FORD: No. We stayed with the contractual obligations that we had and those prudent people who had insurance.

I think we have a necessity of getting broad acceptance of earthquake insurance coverages. What means this may take—in what way it can be done—I don't know.

After the San Fernando earthquake, a number of companies ran full-page ads in the "Los Angeles Times" advertising earthquake insurance, and cutting the price. They didn't get their bait back. The new premium didn't offset the cost of the advertisements.

We have a lot of thinking to do with regard to capacity should insurance become required or generally accepted. Then you are talking about loss potential in the Los Angeles area on dwelling property alone which could amount to $3 billion dollars. Plus another $5 billion for nondwelling property. Certainly there is no insurance mechanism in the world that could take care of this magnitude of loss.

At the present moment, earthquake insurance is available. We must find some way of getting more people to buy it, whether it be mandated or whatever means. At some point, more capital will be required than is presently available.

At the present moment, we are insuring earthquake loss, we are anxious to provide it, but people won't buy it.

MR. SULLIVAN: Let me respond to the issue of rates. Are you speaking only for the State of California, or are you speaking about the 50 States?

MR. FORD: I'm speaking generally.

MR. SULLIVAN: In Anchorage, we operate our own port. The question is, we have a tremendously hard time trying to get earthquake coverage on the port facility, even partial coverage. The rates on it are another question. They are extremely high rates.

MR. FORD: What is reasonable in the Port of Alaska [Anchorage], I don't know.

I know that the Golden Gate Bridge Authority had trouble filling their insurance require-

ments a few years ago. There was not capacity in the world market to give them enough policy limit to cover the appreciated value of that bridge. There was no problem when it was built, at the level of costs at that time. But with the escalation of inflation and everything else, they ran out of market.

MR. CARLSON: Mr. Dale Marr?

MR. MARR: Well, Mr. Chairman, the people I represent are pretty practical people.

The question that Dr. Turner raises is the one that I think is the key as to how the general public, at least the public that we represent (some 37,000 members), will react. The problem is: who do you believe and how do you keep the issue out of politics?

We have a prime example of that right here in California today in the nuclear-energy hearings that are going on in Sacramento. If we have the same thing for earthquake prediction, the public is going to take a very jaundiced look at it, I'm afraid.

We are seeing some world-renowned scientists say that nuclear energy is the only way to go, but we also have other equally well-known scientists disputing that.

And so, the public is saying, "Who's paying who to say what."

It is not fair to the scientists, but unfortunately this is what I'm hearing out in the field. I just don't know how you can prevent this, because scientists have to discuss things. How do you get the public to understand that the experts are going to disagree on many subjects for a long time to come?

Now, look at Crescent City. When the people there were told to evacuate because a tidal wave was coming, they didn't get out. And the wave was something that could be tracked and was estimated to be only a few hours away. People just didn't believe it was going to happen. Look at Hilo—it has been wiped out several times in the last century or two by tidal waves, and people move right back in again, and they say, "It isn't going to happen again."

How do you get the general public to really believe the scientists? And when the scientists get into arguments in the press among themselves, I think it further confuses the general public, which doesn't have a scientific background.

MR. LEE: Mr. Secretary, I want to ask one question.

I am the president of the State Building and Construction Trades Council of California, representing 350,000 members.

Now, when you take into consideration the members, plus their families, we are talking about a line of communication that we possess in this State with a million people. My question is: How can organized labor and, in particular the building trades, help? What part can we play in participating fully in an earthquake warning program, particularly as far as disseminating information to the membership is concerned?

MR. CARLSON: That's a good question. And in fact, that could be an item we can consider in terms of follow-up from these deliberations today.

Let me go around the table for any recommendations you'd like to make on the question I posed earlier. And if you don't have any particular recommendations at this time, and you would like to share some with us later, we would appreciate a note.

I will start with Bob Stevens:

MR. STEVENS: I don't think I have any recommendations that haven't already been made, except to say that we certainly endorse all speed in the direction we seem to be headed. And I think it's critical that we have this as fast as reasonably prudent in order to accomplish our goals.

MR. CARLSON: Mr. McMillan?

MR. MCMILLAN: We find, in the Salt Lake region, there is very little interest in earthquake insurance as demonstrated by the fact that the people simply don't buy it. I would be interested in pursuing the insurance angle.

MR. CARLSON: Mayor Reading?

MAYOR READING: We are in the stage of developing some hazard analysis of our own, and we are also interested in the insurance phase.

MR. CARLSON: Mr. Wengrovitz?

MR. WENGROVITZ: Yes. I have two points. The first is reemphasizing the statements made by Mr. Manfred and Mayor Reading, pertaining to the development of emergency operation plans, not only at the State level, but also at the local level for those communities that are involved.

And secondly, you have got a promotional job to do. You've got a selling job to do in the sense of convincing the community that earthquake prediction and warning is valid, is accep-

table, and is accurate. That message has to be conveyed to the public. Until then, until you get the message across, you will not get any follow-up action.

MR. CARLSON: Thank you.

Mr. Nidiffer?

MR. NIDIFFER: Well, it seems apparent the funding in this direction will be limited for the next few years.

It seems to be appropriate that the dollars available should be put into the first predictable event and that a pilot program be developed that could be transferred to another locality. That would be my recommendation, rather than each community or each State spending a tremendous amount of time and effort without the benefit of the sensors and the prediction ability.

MR. CARLSON: Mr. Courter?

MR. COURTER: Agreeing with that, I would also emphasize that urban planning or land-use planning efforts be included in our endeavor.

In addition to that, I think we should address the code enforcement and building construction standards aspects.

MR. CARLSON: General Siefermann?

GENERAL SIEFERMANN: I don't have anything further to say, except I would like to make a statement with regard to the ones that have been made—about people moving back into Hilo. There was a land-use program for redevelopment of the city of Hilo that resulted in siting an entirely different government and commercial complex away from the area affected by the last tsunami. So actually, we did have proper land-use development there.

MAYOR SULLIVAN: Following the 1964 earthquake in Alaska, we did upgrade substantially our building codes by working with the architects and engineers in Alaska and from out of State, too.

And secondly, we are working very closely with the Governor's Office of Preparedness and have a very active program of our own in the community.

MR. GREGORY: I would urge the Federal Government to establish a line of communication and coordination with all academic and private agencies that are involved with earthquake prediction systems to try to eliminate predictions going out inadvertently and sporadically and instead to have them all come through one central office, the Governor's office of the State involved.

Also, I would encourage the Federal Government to provide the responsible agency within the community information which the agency could use to educate the public as to the validity and feasibility of earthquake predictions.

For I think once the public is educated, you'll get a better response from them.

MR.CARLSON: Is there anything additional that you would like to add? Mr. McKelvey?

MR. MCKELVEY: I would only add this: An invitation to all of you, including the audience, to send us additional thoughts that you may have. We would welcome them.

PROFESSOR TURNER: Two quick points.

I think we must very quickly establish a policy of treating the issuance of earthquake warnings as emergencies for legislative purposes, and that we should examine current legislation from this point of view.

We will certainly have to make some additions to the Relief Act of 1974, and/or other legislation, to make available in the community as soon as there is a warning, some of the types of assistance that would become available to them after the earthquake is over.

And the other point is to emphasize that most disaster emergency plans focus on the police and other emergency agencies. This is quite appropriate when you're speaking of, say, a warning of a few days. But if it is a relatively longer period of warning that is involved, the major activity will have to do with land-use planning, building improvements, and so on. So most emergency plans need to be modified to put the planning departments, building construction departments, and so on, centrally into the plans.

MR. CARLSON: Thank you, Professor. Mr. Joyce?

MR. JOYCE: I would like to second the statement of Professor Turner. The physical crisis in the cities and the counties, to my mind, requires a great deal more funding to be coming forth from both the Federal and State Governments for emergency preparedness. We should not wait until such time that predictions are available. Because it's too late then. This funding must be looked at, the plans must be prepared, and it must come together before, and not something that comes after, the prediction.

MR. CARLSON: Last but not least, Mr. Manfred?

MR. MANFRED: Well, as I indicated in my opening remarks, I think we can judge the policy in California by our actions.

We will continue to monitor the development of the technology. We are in the process of modifying our emergency-preparedness plan and programs, and we are going to keep the lines of communication open with the Federal Government and will pass on any information we get to the cities and counties.

We'll work together, Mayor Reading, on that model plan.

MR. CARLSON: Well, ladies and gentlemen, I think we've had a full morning. I learned a lot from the formal reports and from our discussions.

Obviously, we will not solve all of our problems today. This conference is just one of many steps in the direction of utilizing a new technology that will permit the forecasting of destructive earthquakes.

We have considered the questions Mr. Manfred raised:

How rapid is the development of earthquake predictions and how reliable are they? They apparently will be of sufficient value to justify continued research.

Will the Federal Government be able to establish an earthquake-prediction system? This will depend on further research progress and additional funding.

And how are earthquake predictions to be communicated to the public? I think we can move in the direction proposed, including an authentication system for the prediction of earthquakes.

How will the people in the Government organizations respond to earthquake predictions? That is reflected, in part, in what we have discussed today.

Judging from your comments here, I think that it is incumbent, on each of us, from various levels of government and the private sector, to give additional consideration to these questions.

The bottom line is: Are the benefits of prediction worth the cost of additional steps in the public policy area? I think most of us here are saying, "Yes!" We will have to proceed with these additional steps, and we would appreciate your help in defining what they should be.

We have greatly appreciated your participation in this conference. I certainly felt it was worthwhile and I look forward to the next occasion to meet with you.