REAUTHORIZATION OF NATIONAL EARTHQUAKE HAZARDS REDUCTION ACT

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

NINETY-SIXTH CONGRESS

SECOND SESSION

ON

S. 1393

TO AMEND SECTION 7 OF THE EARTHQUAKE HAZARDS REDUCTION ACT OF 1977 (42 U.S.C. 7704) TO EXTEND AUTHORIZATIONS FOR APPROPRIATIONS, AND FOR OTHER PURPOSES

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REAUTHORIZATION OF NATIONAL EARTHQUAKE HAZARDS REDUCTION ACT

WEDNESDAY, APRIL 2, 1980

U.S. Senate,
Committee on Commerce, Science, and Transportation,
Subcommittee on Science, Technology, and Space,
Washington, D.C.

The subcommittee met at 9:35 a.m. in room 6226, Dirksen Senate Office Building, Hon. Adlai E. Stevenson (chairman of the subcommittee) presiding.

OPENING STATEMENT BY SENATOR STEVENSON

Senator Stevenson. The subcommittee will come to order. Today's hearing is on S. 1393, a bill to reauthorize activities pursuant to the National Earthquake Hazards Reduction Act.

When the Congress considered this legislation 3 years ago, major earthquakes had occurred in Guatemala, Italy, the Philippines, Turkey, Indonesia, and China. The Chinese earthquake in July 1976 caused the loss of approximately 650,000 lives.

The United States has been fortunate, but it's only a matter of time before the nation experiences another damaging earthquake. Thirty-nine States are subject to major or moderate seismic risk, which is not a risk for California alone.

The emphasis of this act is on prevention and preparedness, not disaster relief. The act calls for a substantial research effort on earthquake prediction to reduce human losses and injury. We've pointed out, however, that we can predict where floods occur, but people still live in flood plains, and human and economic losses occur yearly.

So the act recognizes that other measures are necessary to minimize losses from earthquakes, even if they do develop a prediction capability. The Congress emphasized the need to use available information to increase earthquake preparedness.

This hearing offers us an opportunity to explore the status of the research effort and also to find out whether the United States is better prepared now than it was when the act was passed, how much better prepared will we be 1, 2, or 5 years from now.

[The bill follows:]

[S. 1393, 96th Cong., 2d sess.]

A BILL To amend section 7 of the Earthquake Hazards Reduction Act of 1977 (42 U.S.C. 7704) to extend authorizations for appropriations, and for other purposes

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That section 7 of the Earthquake Hazards Reduction Act of 1977 (42 U.S.C. 7704), is amended by deleting the periods at the end of subsections 7 (a), (b), and (c) and adding to those subsections the following phrase: "; and, thereafter such sums as may be necessary to carry out the purposes of this Act.".

Senator STEVENSON. Senator Schmitt.

OPENING STATEMENT BY SENATOR SCHMITT

Senator SCHMITT. Thank you, Mr. Chairman. I have no prepared remarks. But as you are aware, and I hope our witnesses are aware, I believe we're sitting on a geological and human and political time bomb. And I don't think the country is putting the resources it has to bear on the problem. I felt that way 2 years ago. I still feel that way.

And I don't mean a massive federal expenditure of dollars; I mean just a prudent common sense approach to being ready not only to predict earthquakes and other geological phenomenon, but to do something about it. All I have to do is look at what's happening in the State of Washington right now to tell you that the Earth is a very active place, even in that area.

Geologists who study those valleys can show you what the effects of massive mudslides are off of those volcanoes. They've occurred in the past. They'll occur in the future.

The question is, when is this country going to wake up to begin to learn how to predict these phenomenon and what to do if you do predict them? I hope that these hearings can contribute to that process, Mr. Chairman.

Senator STEVENSON. Thank you, sir.

I have a statement from Senator Cranston, who was much involved in the enactment of this legislation. That statement will be included in the record.

[The statement follows:]

STATEMENT OF HON. ALAN CRANSTON, U.S. SENATOR FROM CALIFORNIA

Mr. Cranston, Mr. Chairman, I am deeply appreciative of this opportunity to present testimony on extending the authorization for the National Earthquake Hazards Reduction Act. As author of the Earthquake Disaster Mitigation Act, which formed the basis for the legislation you examine today, I want you to know how important the leadership of this Committee has been in bringing Federal earthquake prediction and reduction research to the point where it can do what it is intended to do: To save lives.

Nearly every State in the Nation faces some degree of risk from future earthquakes. Some 70 million people live in the 39 States that are wholly or partly in areas that risk high to moderate earthquake damage. The United States has suffered major earthquakes in South Carolina, Missouri, Massachusetts, Montana, Washington, California, and Alaska. The Pacific Coast States are historically vulnerable, especially Alaska and California, and the threat of major losses of human life has increased as our population becomes concentrated in major cities and along our coastal regions and where major construction has occurred on landfill and other unstable soils.

It was this realization, Mr. Chairman, that we faced a national pattern of earthquake hazards, with concentrated manifestations in the Pacific States, that led us to make earthquake prediction and reduction a national policy priority. Enactment of the National Earthquake Hazards Reduction Act resulted in an early focus upon research activities by the National Science Foundation. In 1979, the President designated the Federal Emergency Management Agency (FEMA) as the lead agency to carry out the program begun under the mandate of the Congress.

Our Federal efforts have brought us to a relatively strong position in the areas of seismological and geological research. Our research in earthquake-related engineering is good. Applied research needs strengthening. The critical question we face, Mr. Chairman, is how can we bridge the gap between what we know and those who need to know it. And this suggests to me, as I believe it will to this Committee, that a major emphasis of the legislation we now draw must be a careful effort in preparedness and public education, while continuing research and related activities.

We must recognize, Mr. Chairman, that the achievement of earthquake protection is not solely technical, but political as well. It calls for a well-planned and soundly carried out program of interaction not only among the various levels of government responsible for reduction of earthquake hazards, but between those agencies and individuals serving the public, both public and private.

The City of Los Angeles, for example, has taken some very responsible steps. A major earthquate (8.3 on the Richter Scale) in Los Angeles-Orange County could result in 10,000 to 20,000 deaths, up to 180,000 persons homeless and property loss up to $20 billion. In response to such a pervasive threat, the City found it could not wait for the fruition of earthquake prediction, but proceeded to build a Task Force on Earthquake Prediction, and on the basis of an Earthquake Prediction Response Plan to direct the comprehensive planning of medical, transportation and communications needs and the creation of one-stop disaster assistance centers. A separate strategy will deal with immediate and long-term shelter needs including zoning waivers and temporary mobile home sites. In this critical process, the City has observed—in the words of Councilman Hal Bernson—that "federally-funded research should result in practical application" with comprehensive planning best undertaken "jointly by the City, the State, and the federal governments."

The kind of action this city and others require has been spelled out in specific terms: Evaluate potential damage to harbor installations, small craft, and breakwaters by tsunamis and seiches; find the effect of a comprehensive seismic safety program of earthquake insurance; formulate procedures for handling earthquake predictions; formulate a plan for post-earthquake reconstruction; create a data system for estimating potential earthquake damages; develop a public education program; evaluate and update hazardous materials codes with respect to earthquake hazards; study the liquefaction potential of the soil; conduct a microzonation study of possible ground motions and soil instability; evaluate residual static strength of various soils, co-relate dynamic soil strength and properties with laboratory parameters; investigate the dynamic strength of gravelly and rockfill materials; study the effects of prior low-level cyclic strength of soils; and study the effects of sample preparation on dynamic soil strength.

Mr. Chairman, I cite this list of specifics because it represents real needs, but even so, it is only partial. These are actions research scientists and responsible officials need to take. It does not begin to cover the needs of industry and private citizens in an acutal quake: Should the gas be turned off or not? Where do I learn what's going on? Do I stay home or leave? Not only are these responsible questions, but they plead a better system for government response: The California Legislature's Subcommittee on Emergency Planning and Disaster Relief has concluded that there is "no significant statewide education program, either in schools or outside, aimed at educating citizens as to how to respond to a disaster which affects them." Such a lack of awareness, says the Subcommittee, "will result in needless casualties and hinder governmental response should a disaster occur."

I recognize the ease of finger-pointing in these kinds of situations, but it misses the mark. Because the fact is that our relatively modest federal effort in earthquake prediction and hazard reduction has come up with some very real answers to earthquake-related responses that are desperately needed by the people who can make use of them. That is why, Mr. Chairman, I feel so strongly that the reauthorization of the earthquake legislation before you is not only critical in terms of continuing our basic and applied research, but is absolutely essential to doing all we can to save lives. Saving lives and mitigating economic disaster is the point of all we do, and we are simply at a critical crossroad in this effort.

Some items I regard as reasonable specifics for support, Mr. Chairman, would include support for technological transfer, funds for local contingency planning including activities between a prediction and its effect, the dissemination of codes and professional standards, and the vital task of public education.

Senator STEVENSON. Our first witness is John W. Macy, Director of the Federal Emergency Management Agency. I'll invite him and all the witnesses to summarize their statements, if possible, in which case the full statements will be entered in the record.

Mr. Macy.

STATEMENT OF JOHN W. MACY, JR., DIRECTOR, FEDERAL EMERGENCY MANAGEMENT AGENCY; ACCOMPANIED BY DR. RICHARD J. GREEN, ASSOCIATE DIRECTOR, MITIGATION AND RESEARCH; AND DR. CHARLES THIEL, DEPUTY ASSOCIATE DIRECTOR

Mr. MACY. Thank you very much, Mr. Chairman, Senator Schmitt. It is a pleasure to have an opportunity to appear before this subcommittee and to discuss the activities of the Federal Emergency Management Agency in the earthquake hazards area.

Before I discuss specific programs in the agency, I would like to briefly recount for you the functions and missions of the Agency, because it is a new institution with assigned responsibilities in the emergency management area. FEMA plays a major role in every aspect of the nation's comprehensive approach to the management of emergencies, be they natural or man-caused, civil or military. We provide the focal point at the federal level for the identification of probable dangers and emergencies, the formulation of plans and programs to manage federal response to disasters, the federal recovery services and assistance, and crisis management.

We are expanding our commitment to incorporate hazard mitigation as an integral part of our programs, going beyond our previous commitment to flood hazard mitigation to include the range of hazards facing our country.

Our earthquake hazards reduction activities are conducted under the leadership of the Office of Mitigation and Research, headed by Richard Green on my right. This Office is the focus for our research and development activities and for the development of innovative programs and approaches in emergency management. Activities in this program are directed at increasing the capabilities of the United States to predict, prevent, and respond to emergencies and disasters, and to recover from their impact.

The objective of this problem-focused program is to improve scientific and engineering knowledge in reducing and mitigating the life loss, injury, danger, and economic and social disruption from such occurrences. Activities are or will be directed at a broad spectrum of disasters, emergencies, and hazards. The earthquake hazards reduction activities of the Agency are intended to be prototypical of the approach to be utilized in moderating the impact of other natural and man-made hazard occurrences.

I'd like to turn now to a detailed discussion of FEMA's presidentially assigned responsibilities under the National Earthquake Hazards Reduction Act. I will first make some observations on the general status of the National Earthquake Hazards Reduction Program from our position as lead agency in this effort. I will then discuss specific activities and planned initiatives within FEMA as they relate to accomplishing the objectives of the Earthquake Hazards Reduction Act.

In accordance with the Earthquake Hazards Reduction Act of 1977, Public Law 95–124, the President has assigned FEMA the following responsibilities, among others:

Overall coordination of federal department and agency programs in research and application;

Leadership and support to the Federal Inter-agency Committee on Seismic Safety in Construction as it develops seismic design and construction standards for federal projects;

Examination of the appropriate role of insurance in mitigating the impact of earthquakes;

And the development of response plans and assistance to state and local governments in the preparation of their plans.

Before discussing our specific assignments under the national program, it is useful to review the purposes, objectives, and implementation of the act. We believe that the act has withstood the test of the past 3 years. The purpose and objectives established within the act are viewed by us to be as complete and appropriate now as when the act was passed.

The act specifically required the President to develop an implementation plan which set forth year by year targets through at least 1980, specifying the role of federal agencies and recommending appropriate roles for state and local units of government, individuals, and private organizations.

The President submitted to the Congress on June 22, 1978, the National Earthquake Hazards Reduction Program, which outlined specific actions and assignments. On June 19, 1978, as part of his Reorganization Plan Number 3 of 1978, the President specified that the then proposed National Emergency Management Agency would exercise responsibility under the act and under the President's program as lead agency.

During the period between this assignment and the executive order establishing this authority in FEMA on June 27, 1979, the Office of Science and Technology Policy discharged the responsibility of interim lead agency.

While progress has not proceeded as well as some of the architects of the program would have liked, substantial results have been achieved, and I hope to show today that we have accomplishments and programs that can advance this effort quickly from here on out. In the past 2½ years substantial progress has been made in a number of areas pertaining to earthquake hazards reduction. I would like now to review the activities undertaken and progress made in each of six objective areas established in section 5(c) of the Earthquake Hazards Reduction Act:

First, earthquake resistant construction. As noted in the report on the National Earthquake Hazards Reduction Program submitted to the Congress in September 1979, the Federal Interagency Committee on Seismic Safety in Construction has been established, and has participation from over 130 individuals from 17 federal agencies and departments.

The Federal Emergency Management Agency chairs this Committee. The Committee has three principal objectives:

Develop seismic design and construction standards for federal projects;

Develop guidelines to ensure serviceability following an earthquake of vital facilities constructed or financed by the Federal Government;

And development of guidelines that provide for independent and state and local review of seismic considerations in the construction of critical facilities constructed and financed by the Federal Government, where appropriate.

The activities of the subcommittee relating to the development of seismic design and construction standards for federal building projects are proceeding well. We currently expect a draft document to be circulated among the Committee members in May.

This is a major assignment to the federal agencies and represents a substantial potential to change building practices of federal agencies once these provisions have been subjected to review and test application. In addition, the Interagency Committee is developing standards and techniques for identifying existing hazardous buildings, the design, construction and retrofit of energy, water, and telecommunication systems, developing standards for design and construction guidelines to ensure survivability of vital community facilities and developing guidelines for the safety evaluation of federally owned critical facilities. These other activities are proceeding slowly.

A key element in the achievement of increased public—that is, non-federal—earthquake safety is the continued development, evaluation and improvement of model seismic design provisions suitable for incorporation into local building codes and practices.

An historically major impediment to achieving this objective has been that the diverse elements of the building community—professional societies, and labor, trade, model code, voluntary standards, public interest and public agency organizations—have not had a forum to develop such standards. This has been remedied through the formation, in September 1979, of the Building Seismic Safety Council, BSSC, as an independent, voluntary body to enhance the public's safety by fostering improved seismic safety provisions.

The Council was formed through the efforts of organizations representing all segments of the building industry, and with the participation of this agency. The Council's objective is to promote the development of seismic safety provisions suitable for use throughout the United States.

The first specific task undertaken by the Council is to review extensively the tentative provisions for the development of seismic regulations for buildings, prepared by the Applied Technology Council under contract to the National Bureau of Standards with the National Science Foundation's support.

After completion of this review, modification of the provisions, and test by trial designs, the member organizations will be encouraged to adopt the resultant provisions. It is important to note that the Council has not been formed to replace the initiatives of its member organizations, but is to provide a national forum where its members can develop seismic design provisions that are responsive to the public's interest.

This is a unique undertaking in the building community. The opportunity for different groups, such as public officials, owners, architects, to consider the merits of proposed provisions before they are incorporated into a code or national standard, without the usual heated, adversary climate, should substantially improve the process of reaching consensus views which provide appropriate and effective public earthquake building regulations.

The Veterans Administration program for assessing the seismic vulnerability of its hospitals, and its major program to rehabilitate hazardous structures, is the notably successful federal construction program actually reducing earthquake risks. They have not only replaced and repaired facilities in the widely recognized hazardous area of the West, but also undertook substantial investments in the East, most notably their Charleston, South Carolina facility.

Second, earthquake prediction. Earthquake prediction is still in the real of a research effort. The basic research of the National Science Foundation and the basic and applied research activity of the Geological Survey are progressing well.

No predictions have yet been made from this scientific effort which have required public action. The USGS has established an Earthquake Prediction Evaluation Council. This Council is charged with evaluating the scientific evidence supporting the prediction presented to it for review. The Committee held its first meeting on February 4 and 5 of this year.

This Committee complements the California Earthquake Prediction Evaluation Council established approximately 5 years ago to advise the Governor of the State of California. There is growing interest particularly in California in the possibility that major earthquakes may be predicted.

This was particularly evident at the recent Earthquake Prediction Information Conference held on January 27–30 in Los Angeles under the joint sponsorship of the USGS, FEMA, the California Seismic Safety Commission, the California Office of Emergency Services, the California Department of Mines and Geology, and the City of Los Angeles.

We in FEMA believe that the near-term prospects for prediction are now sufficient to warrant initiation of planning activities on federal, state and local responses to potential earthquake predictions. We will discuss this later in the testimony.

Number three, model codes. The publication of the Applied Technology Council's "Tentative Provisions for the Development of Seismic Regulations for Buildings," which I referred to earlier, represents a major step toward improving building codes and standards for use throughout the United States.

The provisions represent the result of a concerted effort by a multi-disciplinary team of nationally recognized experts in earthquake engineering. Design professionals, researchers, federal agency representatives, staffs from the model code organizations and representatives from state and local governments throughout the United States were involved.

The provisions are comprehensive in nature and deal with earthquake resistant design of the structural system, architectural and non-structural elements and mechanical-electrical systems in buildings. Both new and existing buildings are included. The provisions embody several new concepts which are significant departures from existing seismic design provisions. An extensive commentary documenting the basis for the provisions is included.

We feel that these provisions for building design and regulation are a major step toward giving the public the array of design aids useful to public and private earthquake safety decisions. After careful review by the BSSC, which I mentioned earlier, we expect these provisions or a derivative thereof to be widely used by the design and regulatory professions.

Fourth, planning and reconstruction. The states of California and Utah and to a lesser extent the state of Nevada have vigorous state seismic safety organizations. In California, the State has developed an earthquake hazards reduction implementation plan which parallels and complements that prepared at the federal level. The western states have formed a western states seismic policy conference as a vehicle to discuss common issues. They will hold their second annual meeting this month.

Earthquake loss estimates studies for San Francisco, Los Angeles, Salt Lake City, and the Puget Sound areas had been completed prior to the passage of the Earthquake Hazards Reduction Act.

Since the passage of the act, such studies have been initiated by FEMA in Alaska and Hawaii and are planned for South Carolina, Massachusetts, the Mississippi Valley, and Upper New York areas.

A comprehensive Federal Response Plan is now complete for the San Francisco Bay Area, although this plan does not include the possibility of earthquake prediction. Such plans will be completed in each of the areas for which loss studies have been completed.

The role of insurance as a means to compensate and encourage earthquake mitigation is potentially great. While residential and commercial earthquake insurance is currently available, it is not widely purchased.

There are serious questions about the capability of the insurance industry alone to absorb the costs of a catastrophic earthquake if such insurance were widely purchased.

FEMA, drawing from its expertise and experience in the administration of national flood insurance programs, is now undertaking a study of the appropriate role of insurance as an earthquake mitigation strategy and an examination of the Federal Government, if any, in this important area.

The Disaster Relief Act of 1974, Public Law 93-288, specified that the President may establish mitigation standards for a community hit by a disaster to follow in its reconstruction efforts, so as to reduce the probability of a repetition of the event.

A FEMA contractor is developing recommendations for guidelines and procedures to implement this section of the act for earthquakes.

Five, Public Education—the National Science Foundation and the Geological Survey have conducted many seminars and training functions directed principally at the design profession community.

Efforts, to date, for general education have been very limited and at the initiative of state and local communities. FEMA is currently investigating the incorporation of earthquake related issues into its public education programs.

Six, Research—a sound basis has now been established in the engineering, geologic, and seismologic sciences on which a more aggressive applied and developmental research program could be based.

Currently basic research programs in each of the physical sciences and engineering are, in our judgment, funded at the proper level. Applied research support tends to be lagging the opportunities presented, and development-related activities are proceeding more slowly.

This latter area represents a substantial opportunity for improvement of the overall National Science and Technological Development Program.

In the areas of social, economic, administrative, and political science research there is a minimal effort currently underway among the federal agencies. The current research program may be inadquate to meet the objectives of the act.

Seventh, and finally, Earthquake Control or Modification—research efforts in this area are limited, appropriately so in our judgment. The extensive efforts on earthquake mechanisms pursued for basic seismic purposes and in support of the earthquake prediction program will provide the necessary basis for future efforts in the areas of modification or control.

We have accomplished much in the past 3 years, but there remains much to be done. The national program has been characterized, to date, by relatively large research expenditures and relatively inexpensive coordination, planning, and staff work for application.

We are now at a point, Mr. Chairman, where the opportunities for application are growing and can be expected to accelerate in the next few years.

Clearly, the principal imperative before federal, state, local, and voluntary and private organizations is to more effectively and efficiently apply that which we know and that which we will learn from research in the next few years.

Responsibilities to lead this overall effort from a federal point of view resides with the Federal Emergency Management Agency. This will not be an easy undertaking.

As noted in the act, portions of 39 states are subject to major or moderate earthquake risks. Yet even California, the widely considered most vulnerable state, is viewed as having shortcomings in its earthquake hazards reduction programs. This is highlighted by the general findings of the California Assembly Subcommittee on Emergency Planning and Disaster Relief, which stated:

> California, as a state, is ill-prepared to respond to a major disaster, such as a major earthquake, striking a metropolitan area; and as a result, could incur unacceptably high levels of casualties and damage should a disaster strike.
>
> The Subcommittee finds that the level of emergency preparedness in California is alarmingly low when considering the probability of such a disaster striking a heavily populated area.

Thus, while California has paid considerable attention to some aspects of building codes and standards, it is not, in the judgment of the legislature, adequately prepared for a major earthquake. This poses a clear challenge to the private sector, local government, state and federal governments to overcome.

During this coming year, FEMA will continue to coordinate Federal Earthquake Hazards Reduction Programs, provide leadership for the Interagency Committee on Seismic Safety in Construction, support federal participation in the Building Seismic Safety Council, accelerate the conduct of earthquake loss studies and preparation of federal response plans, and complete analyses of the role of insurance and financial institutions in mitigation.

Temporary housing in time of disaster is one of the most difficult problems to which the government must respond. I need not remind those of you who have had a major diasaster in your state of the importance to the public of providing timely access to housing.

To date, the largest demand for temporary housing has been approximately 27,000 units. Should a large earthquake strike Southern California, it would not be unreasonable to expect demands for over 50,000 units.

FEMA has undertaken a Southern California Disaster Housing Response Study to examine the needs for strategies to provide adequate lodging to individuals and families, including the congregate or mass accommodations which are usually provided by the American National Red Cross immediately following a disaster.

This housing study is a component of a larger planning effort designed to increase the capability of federal, state, and local officials to provide assistance to victims of large-magnitude earthquakes and other peacetime emergencies.

The study entails:

First, selection of a maximum credible earthquake that could occur on the San Andreas fault, an 8.3 Richter event;

Second, determination of the damage patterns by geographic zones that might result from ground shaking, as well as secondary effects such as liquefaction, landslides, dam failures, utility outages, and fires;

Third, inventory of dwelling units by structural categories, utilizing Census Bureau data and/or tax assessment data for the seven-county planning area and determination of damage functions for each category of buildings;

Fourth, an estimate of the number of housing units made uninhabitable in each category and in each zone;

Fifth, an estimate of the number of families made homeless by the event in each zone; and

Sixth, a preparedness plan for providing rehousing assistance to all families made homeless by the event.

We expect this study to be completed by the end of the summer. Early indications are that perhaps as many as 60,000 families can be expected to be homeless, with 12,000 in San Bernadino County, 2,500 in Ventura County, and 34,000 in Los Angeles County.

This study has been very successful today, due in particular to the way in which city, county, and state officials and the Red Cross staff have willingly made major contributions to the study.

Senator Schmitt mentioned the planning for earthquake prediction response. Let me say a word about that.

The decade ahead promises to be one of significant advances in the science of earthquake prediction. There is a widespread expectation that earthquake predictions will somehow bring about significant reductions in property losses that would otherwise occur during unpredicted earthquakes. The promise is there, but the systems and procedures for meeting that promise are not yet in place.

FEMA is planning a cooperative study with state and local governments and other federal agencies and the private sector to develop an effective program to respond to credible earthquake predictions.

There are several major areas of concern to be addressed in prediction planning. Each of these would contain components of ongoing non-prediction programs, but with special features and adaptations especially suited to the post-prediction interval: Public safety; reduction of property damage; self-sufficiency of families and neighborhoods in the immediate aftermath of the earthquake; emergency response; disaster recovery; and economic impact.

A number of related activities will need to be in place so that prediction response plans can provide timely and effective actions. The related activities include: Coordinated prediction evaluation and dissemination procedures; identification of earthquake hazards; seismic codes and mitigation programs; a consensus among earthquake professionals and public officials regarding productive post-prediction actions; public education resources geared to prediction response needs; viable emergency preparedness plans; and mechanisms for disaster recovery planning.

We look forward to a useful and productive alliance with state and local governments in preparing a prototypical earthquate prediction program. While initially we intend to undertake this using Southern California as a test region, we expect that the procedural tools and techniques developed will be readily available and applicable in other large metropolitan areas in which earthquake predictions are likely.

This is a very exciting program, Mr. Chairman, in which I have taken a great deal of personal interest as director of this new agency.

In conclusion, we believe that much has been accomplished under the Earthquake Hazards Reduction Program. As is true of most substantial undertakings, much remains yet to be accomplished.

We hope that as you view the federal program's accomplishments of the last few years, that you will not only focus on that which has yet to be done, but realize the tremendous distance we have covered during this time.

We are now at a point where public safety can be materially improved with more public education, more effective joint planning, and improved professional practices.

I hope that this assessment of the Federal Earthquake Hazards Reduction activity is useful to the committee in its consideration of reauthorization of the Earthquake Hazards Reduction Act.

We support reauthorization of this act and look forward to working with other federal agencies and with this committee in further development of a sound earthquake hazards reduction program.

Mr. Chairman, I have emphasized the earthquake program in this testimony. However, I want to assure the committee that we have an equally strong commitment to national security research as well as other research efforts directed at the total range of natural and technological hazards facing the country and its citizens.

Dr. Richard Green, Associate Director of the Office of Mitigation and Research, on my right, Dr. Charles Thiel, Deputy Associate Director of Mitigation and Research, and I will now be happy to answer any questions you have on the specific activities in our Earthquake Hazards Reduction Program.

I appreciate your patience and tolerance in permitting me to read this full report. It was my belief that it was important that you have a complete a presentation on the occasion of our first appearance as a new agency with the lead agency responsibility for this program.

Senator STEVENSON. Thank you, Mr. Macy. Your testimony is helpful, and we're grateful for it. It also confirms our fears about not the possibility, but the probability of earthquakes and, at least my own feeling, that we're not doing enough to prepare for such contingencies.

I recognize that your agency has only recently been organized and, since it has been organized, that your efforts and those of your colleagues have been commendable.

But I'm also concerned about the future. Research activities are, on the whole, funded and funded at fairly substantial levels, which contrast markedly with the funding for FEMA's efforts to utilize the products of our research activities.

Expenditures, for example, in fiscal year 1980—estimated expenditures of the total earthquake program effort of $57.3 million, which includes only $1.1 million for FEMA. In 1981, the requests are for a total program effort of $60 million and only $1.5 million for FEMA. And we have estimates, which I believe came from FEMA, which indicate from 1981 to 1985 projections for the total program are going up from $60.1 million to $96.6 million. And of these projected requirements, for program areas' dealing with application activities, which I'm told by staff include the National Bureau of Standards' activities, budget requirements go up from $1.9 million to $10 million.

So, at the far end of the range, the applications activities are about 10 percent. But at the early beginning of that range, they're far less than that.

Now, my question to you is whether you think the projections—maybe we'd better start with 1981—whether the projections for 1981 strike a reasonable balance? After all, it does not seem very prudent to invest heavily in research if you don't take the steps to utilize our knowledge and prepare for the earthquake.

I have to ask also whether that $1.5 million for 1981 still stands. Has that survived the lastest round of budget cuts?

Mr. MACY. Yes, that has survived, Mr. Chairman, and is a part of the budget for FEMA for 1981 under the revised submission this week.

Senator STEVENSON. Well, how about it? Is $1.5 million, out of a total program effort of $60.1 million, a fair balance? You indicated that we're at the point now in which we need to invest in preparedness and utilization. Is that enough? It doesn't sound like very much to me when you consider the magnitude of earthquakes.

Mr. MACY. This is still a modest investment in application. It represents a lead investment by this agency, recognizing that much of the application work is actually going to be performed by other federal agencies or by state and local authorities, and that the efforts made by this agency are of a catalytic nature in attempting to work out an orchestrated pattern at the federal level and to provide assistance to the state and local authorities who have the basic responsibility for a response for emergencies of all kinds.

I also should emphasize that one of the features of this new agency is the drawing together of a number of different programs that have been operating in other parts of the government in order to have comprehensive emergency management so that the work associated with response planning for earthquakes can be closely tied in with the planning to meet needs that may occur if other natural hazards constitute an emergency or disaster.

So that although this is the money that is earmarked for this particular program, we believe that there are supporting funds in other aspects of the FEMA budget which will be contributory to the kind of emphasis which we intend to give to this program.

In our roster of programs, this has high priority. And we will continue that high priority in light of the scientific and technological information that has been provided for us.

Senator STEVENSON. In making your estimates of requirements for applications activities, what kind of assumptions do you make about scientific advances, including possibilities for earthquake predictions? If in the next year or two we did develop such a capability, what would the effect be on the budget projections?

Mr. MACY. We believe that the capacity to predict is advancing to the point where we need to stimulate more in the way of response planning than has existed previously. We are aware of the hazards that have been identified, particularly in California, and we have stepped up our work with the State of California in order to assist them in advancing their planning to deal with an earthquake that might be predicted on the San Andreas Fault or in other vulnerable areas in the state.

Dr. Thiel, you may want to elaborate a bit on that, based on your closer first-hand association with the prediction picture in California.

Senator STEVENSON. I wish you would.

Maybe he can elaborate on the other 38 states that you mentioned, too. I would assume that the planning would have to be different from state to state, but I may be wrong.

Dr. THIEL. Very much so. Earthquakes that are likely to occur in the central United States or in the eastern United States are substantially different in their character, in the size of the area that may be impacted, from those that could potentially occur along the San Andreas Fault.

You asked what assumptions were made in terms of our budgetary planning, presented I believe, in a copy of a letter which we sent Mr. Brown which you also have. There were a number of assumptions. We assumed there would be no substantial scientific breakthroughs, either in prediction or in economic means to protect structures.

Senator STEVENSON. For this whole 5-year period?

Dr. THIEL. In terms of the budgetary estimates.

Senator STEVENSON. For which year?

Dr. THIEL. For fiscal years 1981 through 1985.

We presumed that there would be no major damaging events either occurring or predicted during these periods. These are hazardous assumptions and they are, I think, at the root of why we need, as specified in the legislation that's before you now to reexamine our priorities from year to year, to adjust them in consonance with the scientific advancements and application advancements that took place during the prior period.

Concerning the seismic risk in the balance of the country, particularly from a planning standpoint, we have a substantially different environment that may be of some interest to you, and would in all likelihood would affect in substantial ways southern Illinois. There might be a reoccurrence of the 1811 and 1812 New Madrid earthquakes. These events, if they should occur—and in all likelihood, historically, it will occur again—would affect seven to nine states with major damage and four federal regions. This poses a political problem of substantially more difficulty than that posed by a California earthquake, affecting only one state and one federal region. So there are interesting problems presented by earthquake occurrences in the Midwest and in the East.

I might say, by way of reference to your own home state, that there is an active group within the state dealing with building codes and standards at a state level. The committee is chaired by William Hall, who is professor of civil engineering at the University of Illinois at Urbana. So there is action also in your state.

Senator STEVENSON. That's very helpful. I accept what you say about the need to assess continually the budget requirements against the scientific and technological developments.

On the other hand, we rarely—I don't think ever in this committee—report out authorizations that are open-ended. We just don't as a matter of practice. I don't think it's a sound practice to give away blank checks. And in this case we were assuming that we ought to go out 3 to 5 years for the sake of some continuity in the authorization.

The bill as introduced includes, "such sums as may be required," I believe. What would you recommend that we put in for authorizations to FEMA and for——

Mr. MACY. I would recommend reauthorization for a period of 5 years. I believe this is a program that should have review with that much periodicity, and that we should recognize the long-term trend to deal with the hazard reduction with respect to this particular threat.

Senator STEVENSON. Well, what does that mean? What kind of figures are we talking about? $1.5 million for 1981?

Mr. MACY. The figures that you cited, which would authorize roughly $78.67 million in 1982, $89.3 million in 1983, $95.2 million in 1984, and $96.6 million in 1985. This includes, of course, the authorization for the research funds that are provided for USGS and for the National Science Foundation.

Senator STEVENSON. And those figures are based on very conservative hazardous assumptions?

Mr. MACY. Very conservative. The assumptions that Dr. Thiel indicated.

Senator STEVENSON. Senator Schmitt.

Senator SCHMITT. Thank you, Mr. Chairman.

How do you respond to the allegation that earthquake contingency planning at the federal and state level is inadequate to respond effectively to a large magnitude earthquake in or near a heavily populated region in the near future?

Mr. MACY. I respond to that statement by indicating that there is an acceleration of effort by the lead agency in the Federal Government to move forward on the various fronts that I described in my statement, but particularly with emphasis on the development of response planning in the areas with highest vulnerability in collaboration with state and local governments.

This is a high priority program within the Federal Emergency Management Agency, and there are ongoing discussions on the specific development of plans, as well as the conduct of studies, such as the housing study that I mentioned, that are aimed directly at dealing with the human problems that would arise in the event of an earthquake emergency.

Senator SCHMITT. Have you performed any simulations using the empirical information that would result, say, from the Good Friday earthquake in Alaska, the San Fernando Valley earthquake?

Mr. MACY. If I may, let me ask Dr. Thiel if he can respond to that.

Dr. THIEL. There have been no state-federal-local tests or simulations performed. There have been individual simulations done by various component parts. On April 22, I believe that the Sixth Army, in conjunction with the Office of Emergency Services and the State of California, is conducting such a test of a limited part of that program. And of course, the State of California runs regular tests in its hazard response programs—I might say, often in deep mud, as in the case of the floods that have occurred this spring in southern California.

Senator SCHMITT. Are there any funds in the budget that would allow you to conduct, say, a simulation based on the extensively studied San Fernando Valley earthquake? You know where the damage occurred, you know where the services were lost. Would that be an exercise worth conducting?

Dr. THIEL. Within the State of California, yes. And indeed, they have gone through exercises that are similar to that.

Senator SCHMITT. But you have not participated? FEMA has not participated?

Dr. THIEL. Our role in those types of disasters is to provide assistance at the request of the state when they don't have the resources or the capabilities to respond.

Senator SCHMITT. Did they request that assistance in the simulations?

Dr. THIEL. In the simulations, I believe so, yes.

Senator SCHMITT. They did? Did you respond?

Mr. MACY. Yes, indeed.

Dr. THIEL. In terms of the planning, yes.

Senator SCHMITT. The plan—I mean, what does that response mean?

Dr. THIEL. We didn't actually put people in the field. It was not that type of response. It's the kind they performed principally—simulations of people in rooms calling to other organizations, units. Our Region IX in San Francisco I'm sure has been contacted in those simulations.

Senator SCHMITT. Has anybody in your office become an expert on the San Fernando Valley earthquake and the kind of damage that occurred and the services that were lost?

Dr. THIEL. Whether you would say that someone has become an expert——

Senator SCHMITT. Well, it's the most recent simulation we have.

Dr. THIEL. It's the most recent occurrence. I am a professional earthquake engineer and since I had led the National Science Foundation's program at the time of the San Fernando earthquake and was the responsible contracting officer for about $5 million of research on that event, I have some familiarity with it. But I wouldn't want to pose myself as an expert on San Fernando.

Senator SCHMITT. There's an awful lot of information. I'm just wondering whether FEMA is systematically integrating that information with respect to the southern California problem into their planning activities.

Dr. THIEL. Yes, sir, we are, and also into our northern California planning. As Mr. Macy has indicated, we have a plan in place for the federal response to a great San Francisco earthquake. This plan is very similar to the kind of management structure that we have placed in southern California for such an event, and it relies very heavily on our learning not only from the San Fernando Valley earthquake, but from other major disasters which have occurred throughout the country.

Senator SCHMITT. But in the case of southern California, you can pretty well predict on the basis of that earthquake, can you not, what services would be lost, to what degree, and what then would have to be provided in terms of communications, hospitals, police protection?

Dr. THIEL. I don't really think so. The San Fernando Valley earthquake was an event that was relatively localized. It did approximately a half a billion dollars worth of property damage.

Senator SCHMITT. I'm getting at totally what structures in that type of an area, in that kind of an earthquake, are going to be lost, and what communications are lost, and what highway systems are lost.

Dr. THIEL. To a certain degree, yes. There have been a number of steps taken within the state to upgrade hospitals, to upgrade communications facilities, emergency facilities.

One of the big disappointments in that earthquake was the degree to which transportation systems, communications systems, electrical power lifelines and the like were very severely damaged. There have been steps taken in the State of California to correct some of those problems.

Senator SCHMITT. Do you think if that earthquake occurred today, that you would not have the same problems in the same area?

Dr. THIEL. I think we'd have many of the same problems in the same areas, as well as a wealth of new problems that did not occur during that event.

Senator SCHMITT. Such as?

Dr. THIEL. There essentially was very little damage to commercial and industrial facilities. Natural gas and petroleum pipelines were basically unaffected in that area, because there were none.

Senator SCHMITT. I thought the gas lines were generally broken.

Dr. THIEL. I'm talking about main lines, as opposed to the distributive tree to residential structures.

Senator STEVENSON. Nuclear reactors?

Dr. THIEL. There are no nuclear power reactors in the southern California area that I think are proximate to major faults. These are facilities which lead the state-of-the-art in earthquake resistant design characteristics. Of all of the facilities in southern California, I would probably put nuclear power plants at the top in terms of the use of the state-of-the-art earthquake resistant design procedures.

Mr. MACY. My reference earlier to the Veterans Administration is another byproduct of the San Fernando Valley experience. Based upon the serious losses that occurred in a VA hospital in that area, the Veterans Administrator moved to have a very thorough survey of all hospitals at earthquake risk across the country, particularly those in areas of high probability.

Senator SCHMITT. Are there any federal guidelines now in effect to establish standards and procedures for the issuance of an earthquake prediction? Have you established any standards that would guide you on how you made that prediction and how you followed up with it, how you handled it if it did occur?

Dr. THIEL. The U.S. Geological Survey is better, I think, equipped to answer at least part of that question, in terms of the evaluation and the issuance of the prediction.

Senator SCHMITT. Is that their responsibility, not yours?

Dr. THIEL. That is correct.

Senator SCHMITT. They can issue a prediction without ever discussing it with you; is that correct?

Dr. THIEL. Yes, sir, that's my understanding.

Now, with respect to the question of providing warning to the population—and I note that there is a substantial difference between issuing a prediction and warning people of actions that they can take to protect themselves—Mr. Macy has indicated in his testimony the initiation of a substantial effort within FEMA with the cooperation of state and local governments, particularly in southern California, to develop the specific plans and programs of action to process such predictions in ways that people can take at their own initiative steps to protect their lives and property.

Senator SCHMITT. Well, let me give you an example. Let's say the Palmdale Bulge began to excite people again, and that not only did it get them excited, some other precursors started to appear—radon releases, the ground squirrels started to leave their holes, and the Geological Survey people on the spot, presumably in cooperation with my dear friends at Cal Tech, decided that they'd better say something publicly.

Would you have any forewarning of the fact that they were going to say something publicly?

Mr. MACY. Yes, we would.

Senator SCHMITT. What if you decided that they shouldn't say anything publicly? Could they go ahead and do that?

Mr. MACY. This would be a matter of combined agency discussion.

Senator SCHMITT. Is it formally a matter of it? Is there a red phone in Bill Menard's office that is connected to your office that has earthquake prediction written on it?

Mr. MACY. No, there is not. There is close and continuing communication, and we are in the process of spelling out in an interagency memorandum of understanding, that hopefully will survive our respective time as an SOP for dealing with that process.

Senator SCHMITT. How do state and local government officials get involved in this process? By the way, if you have a copy of that memorandum of understanding, we would like to have it for our record.[1]

Dr. THIEL. I might say that the working relationships between FEMA and the USGS in earthquake areas probably represent, in my view, anyway, a paragon of virtue among federal agencies. It's very unusual, the close relationship.

In terms of the question of how will state and local government become involved in getting the information of a prediction, there are essentially two or possibly three major communication networks which would be immediately activated.

One is the civil defense warning system, which can get hard copy to 4,000 or 5,000 sites, and which can be activated in a matter of moments.

Second, the NOAA severe weather wire. We've made arrangements to have that system used immediately. Communications under the USGS and under the FEMA programs would go immediately to the governors of the affected states and to the responsible emergency management officials in those states.

In the State of California that would be Alex Cunningham, Director of the Office of Emergency Services. They have a regional structure and a relationship worked out with the local government to assure that that information gets to them in an accurate and useful way, very rapidly. There are still problems with respect to the way in which such warnings can be issued effectively, and those are things that we have a joint commitment with the state to work out and be sure that they are reasonable and responsive to the opportunities to save life and property should a prediction be issued.

Senator SCHMITT. How soon do you think it would be a worthwhile exercise to make a test prediction to see how this system worked, and the USGA through you, the state and local officials, law enforcement, state emergency services, to have monitors in the field to watch it happen?

Do you think that that's a worthwhile system now?

Dr. THIEL. I think that no plan is worthy of consideration unless it has been tested and validated. The programs which we are in discussion with the state and with a number of elements of the government of Southern California suggests that we can have a reasonable plan in place, a program of action within 12 to 14 months of this date. At that time it becomes useful to test the veracity and the efficacy of that plan.

Senator SCHMITT. Have you estimated the cost of such an exercise?

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[1] The Memorandum of Understanding is still in process and will be supplied to the committee as soon as it is finalized.

Dr. THIEL. Of the exercise or of the point to get to such?

Senator SCHMITT. You can answer both questions.

Dr. THIEL. Okay. These are very hazardous estimates because we have not had the opportunity to engage in a full planning exercise with state and local government. The suggestions are around $1.6 million to $2 million to complete the plan and the ancillary support documents and materials.

The exercise of the plan, I suspect the first test would be a relatively procedurally oriented test as opposed to a full field test. And that could probably be conducted for a matter of a few hundred thousand dollars.

Senator SCHMITT. A full field test, you think, with monitors and test conductors, test personnel all over the place?

Dr. THIEL. The controllers and all those other ancillary activities.

Senator SCHMITT. That would cost considerably more than that.

Dr. THIEL. I would suspect that that would cost from a quarter to a half million dollars. However, I do not believe that we should go to a full field test prior to having prepared and debugged a plan by a series of tests that culminate in a full field test.

Senator SCHMITT. But you estimate that you might be ready for a full field test within 18 months?

Dr. THIEL. I think that that could be accomplished.

Senator SCHMITT. Would you keep me informed on that estimate?

Dr. THIEL. Yes, sir.

Senator SCHMITT. Finally, have you begun any thought about how you'd back away from a prediction and leave the public convinced that it was still worth predicting?

Dr. GREEN. That's part of the study, Senator, that we're going to be conducting over the next 18 months.

Dr. THIEL. Both from the standpoint of positive predictions which are made and then retracted and in the condition in which you might issue a negative prediction and then have an event suddenly occur. There are a number of variables of that type which will be studied.

Senator SCHMITT. Doesn't that require just basically a public education program so they understand what you're trying to do and it's in their best interest that you try to do it?

Dr. THIEL. That is certainly a great part of this program, yes.

Senator SCHMITT. There are a number of people who have talked on this subject that are pessimistic about the ability of the public to react intelligently to these kinds of efforts.

I am not a pessimist. I think that all they need to know is what you're trying to do.

Mr. MACY. I'm not, either, Senator. I feel that we have had demonstrations in recent months with other emergencies which indicates that there is a response if there is an awareness on the part of the public as to what is involved.

This is one of the features that we feel must be emphasized in this program.

On your question concerning testing, our general policy position is that paper plans are not enough, that there must be in all hazard areas subsequent testing to make sure that plans that we have are plans that are viable under real life conditions.

We are also emphasizing the critiquing and evaluation of performance of government on the emergencies of disasters that do occur, and to feed back the consequences of that evaluation into planning across the field.

Senator SCHMITT. Mr. Chairman, I note the general absence of media and public interest in this subject.

Senator STEVENSON. Earthquakes are only news when it's too late.

Senator SCHMITT. I'm really surprised that with a beautiful mountain erupting in Washington, people haven't gotten a little more interested in the subject.

Mr. MACY. That is where the media is. They view that as a media event. And the weather has not cooperated to get the kind of pictures they would like.

Senator SCHMITT. Well, I'd suspect if there's a major earthquake, we could fill this room very easily.

Dr. THIEL. There is much interest in Southern California, particularly at this time concerning the possibility of earthquake predictions.

I imagine that there are at least two or three articles per week in the major Southern California press on that subject.

So there is a great deal of interest.

Senator SCHMITT. Thank you, Mr. Chairman. Thank you, gentlemen.

Senator STEVENSON. According to the conventional wisdom, preparedness for cataclysms is inflationary unless they are of Russian origin.

If we were to do something horribly inflationary, like doubling your budget, giving you another million and a half dollars, about as much as one tank costs, what would you, Dr. Thiel, do with it?

Dr. THIEL. First of all, I'd count it.

Mr. MACY. To make sure that the inflation has not made it disappear.

Dr. THIEL. Indeed. The things that I would propose to undertake would have to do with more public education activity, acceleration of both prediction planning and response planning for unpredicted events. I'd undertake an effort to increase the translation of technology, experience, and research results into forms that can be used by architects, engineers, public relatory officials, and make a concerted effort in the technology transfer area.

Senator STEVENSON. Could you use it for those purposes in fiscal year 1981?

Dr. THIEL. Yes, sir.

Senator STEVENSON. Could you use more than a million and a half dollars more? I mean prudently, not wastefully, for those purposes?

Mr. MACY. If I may relieve Dr. Thiel——

Senator STEVENSON. Well, I'd like to hear him first and then you, sir. I directed this question to Dr. Thiel. I want to hear from you, too, but I want to hear from him first.

Dr. THIEL. Speaking now as a technician, a scientist, an engineer in the area, I think that there are more opportunities presented to us for applications improvements than a million and a half dollars could exhaust.

Senator STEVENSON. Even the additional million and a half dollars?

Dr. THIEL. That is correct.

Senator STEVENSON. Thank you.

Dr. THIEL. It becomes a question of priorities.

Senator STEVENSON. That's where Mr. Macy takes over.

Senator SCHMITT. Nature has an interesting way of changing priorities, Mr. Chairman.

Mr. MACY. Mr. Chairman, I responded to a similar question in the House and certainly, I have the same respect for this body that $10 million could be utilized very effectively in this program.

Senator STEVENSON. For fiscal year 1981?

Mr. MACY. Yes.

Senator STEVENSON. Thank you.

Mr. MACY. Thank you.

Senator STEVENSON. Our next witnesses will form a panel. They are Dr. H. William Menard, director of the U.S. Geological Survey; Dr. Anthony Calio, Associate Administrator for Space and Terrestrial Applications of NASA; and Dr. Jack Sanderson, Assistant Director for Engineering and Applied Science of the National Science Foundation.

Gentlemen, again, if your statements can be summarized, your full statements will be entered into the record.

Dr. Menard?

Senator Schmitt. Excuse me, Doctor. Mr. Chairman, at 11:00, I'm going to have to disappear for a few minutes. I will be back. In case I don't get to ask Dr. Menard, would you submit to us for the record some kind of a summary of the knowledge to date of the precursors that may precede different types of earthquakes?

I'm sure that somebody in your group has compiled such a summary. It might be useful for the committee to know the types of precursors and their relative sequence as you now view them, just for our record.

Dr. MENARD. With your additional words, as we now view them, and your quite familiar knowledge that precursors come and go as far as their credibility.

We certainly could supply them.

Senator SCHMITT. I think it would be enlightening for the committee, to see the kinds of things that you're looking at that may in the future represent the system of prediction that we mentioned.

[The following information was subsequently received for the record:]

LIST OF EARTHQUAKE PREDICTION PHENOMENA

Presented below is a list of earthquake prediction phenomena that have been reported or observed in the past. At present we do not have a comprehensive physical model to explain these phenomena nor do we have an extensive enough record to know which are reliable, necessary, or sufficient to use in an earthquake prediction system. The vexing elements are that some of these features are observed without following earthquakes and not all the observation points within an epicentral region will record the precursory phenomena.

Seismic Gap. This is a long-term prediction technique of large earthquakes along the boundaries of the dozen or so tectonic plates that make up the surface of the Earth. The plates are assumed to move at constant velocities and differences in relative motion between plates are accounted for by large earthquakes at the boundaries. A region along a boundary that has not experienced a large earthquake within the last several decades, and where large earthquakes have occurred previously, is called a seismic gap. Seismic gap predictions are usually cast in terms of "high seismic potential" without specific estimates of the time of occurrence or location of the impending earthquake.

Geodetic measurements. Minute changes in the shape of the Earth's surface are the most commonly observed precursory phenomena. Broad areas of uplift have been observed before large earthquakes in China and Japan. This type of change, as is the case of broad horizontal strain variations, take place over hundreds of kilometers a year or more before the following earthquake. Geodetic variations, such as tilt or strain of the Earth's surface, over distances of a few meters have been observed a few weeks or months before some earthquakes.

Seismicity patterns. Changes in the distribution of earthquakes in location, time, and depth and changes in the ratio of large earthquakes to small events have been used as intermediate and short-term predictors.

Seismic velocities. Changes in the velocities or the ratios of velocities of seismic waves have been observed before some large earthquakes.

Water chemistry. Large changes in the trace element concentrations in water, notably of the radioactive gas radon, have been recorded a few days before large earthquakes.

Water level. Precursory water level changes in wells in an epicentral have been observed. It is remarkable that not all wells in the region show water chemistry and level changes.

Magnetic field. Local changes in the magnetic field have been reported before earthquakes in the United States and China.

Electrical field. Dramatic changes in the current between electrodes in the Earth were recorded a few hours before the Haicheng earthquake in 1975.

Animal behavior. Reports of anomalous animal behavior before earthquakes are too numerous to deny. There is, at present, no physical explanation of what causes the animals to behave abnormally.

STATEMENTS OF DR. H. WILLIAM MENARD, DIRECTOR, U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR; DR. ANTHONY J. CALIO, ASSOCIATE DIRECTOR FOR SPACE AND TERRESTRIAL APPLICATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION; AND JACK SANDERSON, ASSISTANT DIRECTOR FOR ENGINEERING AND APPLIED SCIENCE, NATIONAL SCIENCE FOUNDATION; ACCOMPANIED BY DR. ROBERT WESSON

Dr. MENARD. Mr. Chairman, it might be useful for me to make some general statements about the character of the earthquake prediction and hazards assessment program as I've seen them over the past 15 years.

I'll be as brief as you like.

In a general way, I would say 15 years ago there would be very few established scientists in this country who would have accepted the prediction of an earthquake seriously. But in 1966, it was discovered that if you put water down into wells near the Denver arsenal, you could trigger earthquakes.

I was in the Office of Science and Technology when meetings were held to evaluate this. And there was an electrifying reaction in the scientific community.

You certainly could predict those earthquakes. You could run careful experiments. That opened the whole possibility that you could predict earthquakes under controlled conditions and maybe you could figure out what the conditions were that Mother Earth was using to produce earthquakes.

At the same time, the general idea which we now characterize as the theories of plate tectonics developed and we gained a new understanding of geology and geophysics whereby we could link together fragments of information, previously almost unrelatable, and produce a much more coherent picture.

Dr. Sykes here was one of the pioneers in applying seismology to what we call plate tectonics. Once the general idea developed that you could maybe make predictions I think enthusiasm developed in the community. The funding by the Congress largely through ARPA and the NSF and then through the Geological Survey as well, in support of earthquake programs, caused people to feel that as they made more and more observations, that they were getting closer to predictions, getting closer to hazard assessments, and indeed, you could see that hazard assessment is just sort of the long-term equivalent of prediction. They grade into each other.

And fairly soon, precursors of sorts were identified by the seismologists and there was hope that that would relatively rapidly lead to useful predictions.

It was realized almost immediately in OST, as it then was, that most kinds of predictions were going to be of doubtful social value. They had to be precise, and if they were precise, we had to figure out some way to take appropriate measures.

Since so many seismologists come from Southern California, it was appreciated that you cannot reverse the freeways and get everybody out of the city. It just won't work.

So what steps were to be taken?

Well, a whole lot of new investigations were undertaken. Seismologists figured out new ways to measure precursors. The geologists went out and did a lot of new things. And what developed was that there were precursors that appeared useful and were exciting. They were excellent for predicting like stock market predictors, the events of the past, but they weren't very reliable for predicting the future.

And so what has happened is we have put out in the field, under this program, new instruments of unparalleled accuracy. We've made more frequent observations because of this program.

And what we've found is that the Earth is simply a much more dynamic and active place than we ever had any idea. I think you can examine, for example, the Palmdale Bulge. People thought that must be connected with an earthquake that was coming along. It fitted the general theory. It fitted our knowledge of the geology and the geological history and the tectonics of Southern California.

But what has happened, the bulge is now going down. What if we had done it the other way? What if we had picked up not the bulge, but the observations that had been made when the bulge was there?

And what we first picked up was it was going down. We probably would have been just as excited about that because it was a dramatic event, for it was in an area where we had earthquakes. It was correlated in many ways, or could have been correlated, with a prediction for earthquake, but we would have been wrong to predict an earthquake was going to occur near the bulge.

We have no reason to believe it's "righter" to predict an earthquake when the bulge is going down. We're finding that when most of the observations were made, the crest in Southern California was under a north-south compression, which was, of course, consistent with the understanding of how the San Andreas Fault worked.

Now we find there's no longer a north-south compression; there is, instead, an east-west tension pulling it apart, taking away the stresses which caused the San Andreas Fault to stay locked in that area, according to the theories we had at the time.

I think we would have to say that by everything we now understand, it's a great deal more hazardous in Southern California than it has been in the past. But how close we are to an earthquake, we just don't know.

As a result of this program, we know what happens near active faults. A number of things that happen, such as they go up and down and they stretch and they get compressed in ways we can now measure.

We know those things happen in areas where there are earthquakes because we've had sufficient funds to go in and investigate them. And that's a sensible place to go look.

We've investigated the Reelfoot Lake area, and we've investigated Charleston and, of course, we've investigated the Western States and Alaska and particularly California because the earthquakes are focused there. We find that things are happening.

But we don't know that the same things aren't happening everywhere else. We don't have any control. The program has not gone on long enough.

We haven't had the opportunity to find out really how the Earth operates, how it functions on the scale that we're now looking at.

We've had through this growth and support, the resources and the time to build up some of the infrastructure you need to do a scientific program. The research people in the universities and in government have gotten the funds to expand their programs. The professors have taken on new graduate students with Government funding.

They're prepared to, therefore, expand exponentially the research going on. Some of the students have gone into the Government and are now handing out money to their former professors. Some of the people are carrying out research within the Government and so on.

But a lot of the activity has been put into getting tooled up, getting the networks out in the field, getting the people trained, and so on.

One might hope that we would have been lucky and somehow have been able to predict earthquakes by this time. But we haven't. We've learned a great deal about hazard assessment. We have done remarkable things such as determine the average interval between major earthquakes on the San Andreas Fault and on some other faults.

This was truly an extraordinary achievement.

In short, and to summarize, we can predict for some types of natural hazards volcanoes, for example. We understand volcanoes fairly well. We have developed methods with volcanoes for informing people about what we think is going to happen.

The system is highly successful. In Hawaii, where we have frequent eruptions; at Mt. St. Helens, in Washington, we have no experience. But, we at least took the appropriate steps, and we hope we will be able to stay on top of predicting what will happen there.

In earthquakes, we're not so far along. I think in part it's just been developing the system that is needed to ultimately enable us to predict—to do all the things that we're charged to do.

Thank you, Mr. Chairman. I am, of course, prepared to answer any detailed questions. You have my detailed testimony. I'm accompanied by Dr. Robert Wesson here, who is former Chief of the Office of Earthquake Studies in the Geologocial Survey, is now an acting assistant director in the Survey, but has not lost all his knowledge of earthquakes, nor of our program.

[The statement follows:]

Statement of H. W. Menard, Director, U.S. Geological Survey, Department of the Interior

Mr. Chairman, it is a pleasure to appear before the Senate Subcommittee on Science, Technology, and Space to review our progress toward the reduction of earthquake hazards since the passage of the Earthquake Hazards Reduction Act of 1977. The Geological Survey has been at the forefront of this work. We are very proud of the program we have developed in response to this Act and of the results we have achieved to date.

In this morning's testimony, following these introductory comments, I would like to describe briefly the structure and content of our earthquake hazards reduction program. I hope this description will give you a clear picture of how we are implementing the provisions of the Earthquake Hazards Reduction Act and our principal activities under this Act. I shall then indicate the research results we have obtained to date and review our progress in our areas of responsibility as set down in the National Earthquake Hazards Reduction Program. I shall also discuss our views on the implementation and information dissemination issues regarding this program. Finally, I shall describe the Administration's proposal for legislation to continue and to further implement the program established by the Earthquake Hazards Reduction Act.

Briefly stated, I believe we have established a sound and vigorous program of earthquake hazard reduction research. Our program has clear goals and milestones, and we have a cadre of enthusiastic scientists, both Government and non-Government, working toward our objectives. We have made substantial progress in defining the earthquake hazard and risk in certain parts of the United States. Although no foolproof earthquake prediction technique, based on a reasonable physical model, has yet emerged; we are now building instrumentation networks and are obtaining a strong body of data with which to work. From our point of view, the weakest area within the current scope of the national program is in implementation—and preparation for utilization—of research results. Although, as I shall discuss below, we have made substantial efforts in this area, much remains to be done by us and other agencies. Thus, in answer to your question in your kind invitation concerning the preparedness of the Nation to anticipate and respond to a damaging earthquake the answer's yes, we are better prepared. If earthquake precursors occur, we are better prepared to observe them; we are better prepared to evaluate predictions based on this data, and we are better prepared to assess and describe the earthquake hazard and risk in seismically active regions of the United States. However, the preparedness of the public and private and governmental institutions to respond to earthquake warnings and hazards assessments needs to be increased and expanded.

I need not reemphasize the magnitude of the earthquake threat facing us, not only in California and Alaska, but in many regions throughout the country, particularly the intermountain States, the Pacific Northwest, the central Mississippi Valley, the Southeast, the Northeast, and Hawaii. We are currently conducting at least some work in each of these areas. Within the last several months, the potential hazards from earthquakes and the vulnerability of structures to these hazards have been tested by the occurrence of moderate earthquakes in the Imperial Valley and Livermore Valley regions of California. Both these earthquakes occurred in areas of low population density, the Livermore earthquake on the very margin of the suburbs of the San Francisco metropolitan area, and the Imperial Valley earthquake in a largely agricultural area. While the observations from these earthquakes are still being evaluated by scientists and engineers, they already underline the lessons learned from the 1971 San Fernando earthquake. Namely, very large earthquakes, or even moderate earthquakes, located within one of our metropolitan areas, will have very serious impacts.

The Earthquake Hazard Reduction Program within the Geological Survey is cast in five elements or sub-programs. These are: earthquake hazards assessment, earthquake prediction, earthquake data and information, induced seismicity, and earthquake hazards warning. I shall comment briefly on each of these program elements.

1. The earthquake hazards assessment studies form the base of information required to mitigate earthquake losses through understanding of where earthquakes will occur, how often they will occur, and what their effects will be. Assessments of the nature, extent, and severity of earthquake hazards and of the potential resulting losses are needed at various levels of government, by private industry, and by the public for decisions about construction practices, use of land, disaster preparedness, and recovery, and response to earthquake predictions. Earthquake hazards assessments are required at various scales and for various geographical areas to satisfy an array of different needs. Uniform assessments of earthquake hazards for the entire Nation would provide a basis for developing model building codes, for evaluating the earthquake hazard exposure of domestic and industrial facilities, and for incorporating hazard mitigation measures in Federal activities. More detailed assessments at larger map scales, in areas of high-seismic risk would serve to guide Federal, State, and local government policies relating to land use, construction practices, and disaster preparedness and recovery.

Thus far, earthquake hazards studies have made progress in developing methods and techniques for the specification of earthquake risk and in understanding the physical processes and conditions that influence the occurrence and severity of particular earthquake hazards in given regions. This progress supports current efforts to map and evaluate hazards nationwide and in metropolitan regions exposed to damaging earthquakes. However, much work remains to be done to increase our understanding of the geologic sources of seismicity in the eastern United States, our ability to predict the nature of damaging ground shaking, and our knowledge of the conditions and character of earthquake-induced ground failure and landsliding.

2. The goal of the earthquake prediction element of our earthquake program is to predict the time and place of moderate to large earthquakes and to provide estimates of the uncertainties of these predictions. In order to do this, we are seeking to develop an understanding of the physics of the phenomena observed in the predictive process. To reach the goal of reliable earthquake prediction, efforts are being made on a broad scientific front. Given the current level of understanding of the prediction problem, no one discipline or technique can be identified as the most direct path to solution of the problem.

Dense networks of geophysical observations and instruments have been established in California and other seismically active regions of the United States. Data from these networks are scrutinized in intense observational studies that search for and evaluate precursory phenomena. Although interesting and exciting observations have been make by these networks, we have yet to identify a reliable, widely accepted predictive technique.

We are making efforts to share experience and expertise through international cooperation with foreign activities engaged in earthquake prediction research. This pooling of scientific knowledge and field investigations allows us to increase the number of prediction case histories and the number of seismic regions available to us for study. Finally, extensive laboratory studies are being conducted to observe, under controlled conditions, the nature of the deformation and other phenomena in rocks just prior to failure. These experiments have given us significant insight into the processes of geologic faulting and the conditions under which it occurs.

3. The earthquake data and information element of our program includes the support of worldwide networks of seismometers of standard design and the routine analyses of the data from these networks to produce information on earthquake epicenters, magnitudes, and other seismological parameters. The Geological Survey supports the operation of some 120 seismographic stations throughout the world. Data from these stations are transmitted routinely to the United States where they are copied and returned to the cooperating stations. These data are used in basic research on earthquake source mechanisms, earth structure, plate tectonics, and seismic energy propagation. Data from these stations and others are analyzed at the National Earthquake Information Service in Golden, Colorado, from which bulletins and exhaustive lists of worldwide seismic activity are issued. All of these data are forwarded to NOAA's Environmental Data and Information Service for distribution to scientists and the public in general.

4. In addition to earthquakes due to natural causes, we are also studying induced seismicity, that is, seismicity caused by the activities of man. Earthquakes can be triggered by a variety of man's activities including reservoir impoundment, fluid injection, fluid withdrawal, quarrying, and the detonation of large underground

explosions. Our studies have been concerned primarily with reservoir-induced seismicity and the related problem of fluid injection into or withdrawal from geologic formations. We seek to acquire a better understanding of the mechanisms through which earthquakes are induced and to devise techniques for predicting the seismic response of a particular site to reservoir impoundment or fluid injection or withdrawal. Most importantly, we need to determine the conditions under which a damaging earthquake may be induced and the prevalence of these conditions in the Earth's crust.

5. The last, and perhaps the most important, element of our program involves support of activities in the evaluation and dissemination of information on earthquake hazard warnings. This effort supports the National Earthquake Prediction Evaluation Council called for under the provisions of the Earthquake Hazards Reduction Act and the President's Implementation Plan issued in June 1978. This program element will continue to expand to support research on the impact of earthquake hazard warnings on affected communities and the operational aspects of documenting, evaluating, and disseminating earthquake hazard information.

I would now like to take this opportunity to review for you some of the progress we have made in achieving the goals of our program. I will start by outlining our progress in earthquake hazard assessment.

The New Madrid seismic zone, so named for the town of New Madrid, Missouri, contains the epicenters of perhaps the most violent series of earthquakes in United States history. These events, which occurred in 1811 and 1812, caused considerable damage to the few existing structures in the area and caused much deformation of the Earth's crust along the Mississippi River in the States of Arkansas, Missouri, Kentucky, and Tennessee. Seismicity has continued to the present day in this region. Although the potential for damaging earthquakes in the area has long been recognized, until recently it had been difficult to estimate the hazard associated with the seismicity, in part because the source of the seismicity was poorly defined. The great thickness of young sediments covering the zone effectively obscured any major faults. We have recently applied techniques used by the petroleum industry to this problem and have discovered a major fault zone in northeastern Arkansas, across which buried basement rocks may be offset by a thousand feet or more. Improved locations for small earthquakes in the area show they form a linear band coinciding with the newly determined fault zone. Other geophysical studies have shown that the fault zone lies near the center of a much longer rift zone. These observations, and our continuing work, will be of value for estimating hazards in the area.

When an active fault zone is discovered, one question that is obviously important is the length of time between major earthquakes on the fault. Estimates of these return periods can be made by several techniques, including analyses of historical records, examination of disturbed strata in excavations, studies of fault scarps, and theoretical consideration of geologic forces. These techniques have been applied in California, the New Madrid Region, and near Salt Lake City with good results.

In the case of Salt Lake City, the results of this type were used in a study of potential earthquake losses in the Salt Lake City area. The purpose of this study was to provide essential data relating to earthquake effects on local medical resources, estimated casualties and homeless, and immediate and vital public needs under various conditions of earthquake occurrence. The intent was to give administrators of emergency services information needed to plan responses to earthquake disaster.

The determination of recurrence intervals for damaging earthquakes is of considerable value to the Earthquake Hazards Reduction Program because it allows one to quantify the risk associated with a given fault. In the absence of such data, estimates of the interval between large earthquakes are indirect and apt to be uncertain by hundreds of years or more. When reliable data are obtained that establish firmer limits upon return intervals for earthquakes on a given fault, correspondingly more realistic estimates may be made of the hazard presented by the fault to life and property.

A final important result of our earthquake hazard assessment work was achieved this fall when, during the Imperial Valley earthquake, a network of instruments designed to record strong ground motion performed beyond our expectations. Strong ground motion data are used by engineers in the design of earthquake-resistant structures. The strong motion data recorded from the Imperial Valley event form the most complete set of this type of data yet recorded, including the first complete set of known records of shaking in a modern building that suffered structural failure during an earthquake. These data will do much to advance our knowledge of the nature of strong shaking from earthquakes and of how buildings fail in response to that shaking.

Our activities directed toward achieving reliable and accurate earthquake predictions have included intensive geophysical and geodetic measurements along actual faults in California and elsewhere, laboratory studies of rock failure processes, and direct measurements of the state of stress in the Earth's crust. During 1979, two damaging earthquakes occurred in California within dense networks of geophysical instrumentation. Although no obvious short-term precursory phenomena were observed before these events, some possible long-term, regional precursors were identified and the data are still being reduced and analyzed in efforts to substantiate such phenomena.

In addition to recording geophysical data directly relatable to earthquakes, several important observations have been made in southern California during the last few years that are not yet fully understood.

A huge land uplift or "bulge" in southern California, astride a section of the San Andreas fault, has continued to deflate or subside. Geodetic surveys revealed that about 32,000 square miles of southern California was uplifted as much as 18 inches between 1961 and 1974. Since 1974, instead of uplift there has been a rapid decline in elevation with the entire region from Los Angeles to the Mojave tilting to the north. With minor fluctuations, the subsidence of the bulge has continued through the early summer of 1979, with 1978 uplift levels being about one-third of those observed in 1974.

The last year has also seen a dramatic change in the horizontal strain field in southern California. Regularly resurveyed geodetic networks have shown consistently a general north-south compression from 1974 until early in 1978. The most recent surveys indicate that the southern California region is now undergoing an east-west extension with little north-south compression. Observations from radio astronomy have confirmed these surprising geodetic data. The San Andreas fault cuts across this region in a northwest-southeast direction. As long as the north-south compression was observed, our interpretation was that the sides of the fault were being pressed together and perhaps less likely to slip. Now that we are observing east-west extension, the same logic implies that slip on the fault might more easily occur. No physical model has yet been proposed that can account for the subsidence of the southern California uplift and the change in horizontal strain patterns observed in the same region.

Additional measurements in southern California have shown that the minute volume of natural, radioactive gases from certain wells in the Los Angeles region increased far above normal in mid-1979. Similar increases have been observed prior to earthquakes in the USSR, though at considerable distances. Water levels in some wells in southern California have shown changes that are not easily explained on the basis of rainfall or water withdrawal. These hydrological observations may be a consequence of the recently observed patterns in crustal strain.

The use of these observations to predict earthquakes in southern California at this time is not warranted on two accounts. The first is that we do not fully understand the physics of the earthquake process and the changes that take place in rocks prior to fault breakage. Secondly, the length of time over which our observations have been carried out is so short that we cannot tell if observed changes in our geophysical measurements are truly anomalous. It is basically the coincidence in time of observed anomalies in southern California that has caused concern in the scientific community, not their relation to a well founded and well accepted scientific theory of earthquake prediction or a long history of similar anomalies being followed by earthquakes.

As I have indicated earlier, detection and interpretation of short- or intermediate-term precursors remains a challenging task. By contrast, certain long-term predictions seem to be rather successful. The basic premise of the theory is that the margins of tectonic plates move at constant rates when averaged over long periods of time and that most of this movement occurs during discreet events, i.e. earthquakes. Thus, if along a plate boundary, a certain region has not had seismic activity of the size and within the time period of neighboring regions, a seismic gap is said to exist. This gap is said to be the most likely place for the next earthquake along that region of the plate boundary. The seismic gap theory, when applied to the active margins of the Pacific Ocean basin, has predicted the sites of a number of large earthquakes. The method identifies areas where earthquakes have not occurred in some time, and evaluates the potential for occurrence in terms of historic activity and plate tectonic theory. The method has little resolution in predicting the expected time of an earthquake, but serves to focus attention on areas that can then be better and more closely monitored for shorter-term precursors. A case in point is the Yakataga Seismic Gap in Alaska, which was identified as the probable site of an earthquake last year. The response of the Geological Survey to this situation is a subject I will address in a moment.

One final area of significant progress in earthquake prediction has been in the application of techniques to measure directly the state of stress in the Earth's crust. These measurements have been made, among other places, in a profile of drilled bore holes across the San Andreas fault. The results of this work indicate that the crustal stresses decrease near the fault, a finding consistent with estimates made from seismological techniques. This observation gives an indication of the size of stress-related precursory phenomena that might be observed before an earthquake.

Because the prediction program must have data by which to judge theories and prediction methods, cooperative programs have been established with foreign governments. This gives our scientists access to more earthquake data and to more experience observing large earthquakes than would be the case in the United States. The Geological Survey has had cooperative programs with the Soviet Union and Japanese agencies. Last February I traveled to Beijing with the President's Science Advisor, Frank Press, to sign a protocol with representatives of the State Seismological Bureau of the People's Republic of China for cooperative studies in earthquake research. Instrumental observation of earthquakes in foreign countries is carried out by personnel of the Geological Survey and by contract with university scientists. We expect these programs to advance our theoretical and observational base considerably.

The most significant results in our efforts to study induced seismicity have come studies of the Monticello Reservoir in South Carolina. Small earthquakes have been observed in the vicinity of this reservoir since impoundment began in December 1977. By April 1978, over 3,000 small earthquakes had been recorded, most of these occurring during and just after the period when the lake level was rising to a stable level. To test the hypothesis linking the occurrence of these earthquakes to interactions of pre-existing tectonic stress and change in water pressure caused by the impoundment of the reservoir, two wells, each to a depth of about one kilometer, have been drilled near the reservoir and stress measurements have been made in them using techniques employed along the San Andreas. Although the wells were drilled at geologically similar sites, the two are markedly different in the magnitudes of the stresses measured, the distribution and orientation of natural fractures, and sub-surface water pressure. These results demonstrate that distinct earthquake source zones exist beneath the reservoir, as suggested by the geographical seismicity pattern, and that the earthquakes are probably not occurring in response to a high regional stress field. The implication is that the earthquakes are a direct result of the stresses generated by the reservoir loading, and that the potential for triggering a large earthquake due to a broad pattern of large regional stresses is low. If the sizes of potential local earthquake source zones could be found through a detailed measurement program, a more reliable estimate of the maximum potential earthquakes could be made.

The most important recent event in our Earthquake Data and Information program element has been the assumption of the operating responsibility for the Global Digital Seismic Network in FY 1980. This network consists of 16 modern, digitally recording seismographic stations installed at worldwide sites with funding from the Defense Advanced Research Projects Agency. The assumption of the responsibility for this network required some re-programming of funds from earthquake prediction studies.

I have spoken earlier about hazard warnings, and would like to illustrate the process with some examples. I mentioned earlier that a long-term prediction had been issued for an area in Alaska. This area had been identified by a group of university scientists some years ago as one in which a large earthquake could be expected to occur. Early in 1979, a strong earthquake did occur there. This event was too small to be the predicted event, but because of its location and size it focused attention even more upon the region. An analysis of the existing data convinced the scientists at Columbia University and the Geological Survey that the region was indeed the likely site of an impending earthquake, and a scientific paper was prepared to publically state this conclusion. Because of the size of the predicted event and its possible impact on to settled areas in Alaska, an evaluation procedure was initiated to examine the basis for the prediction so that I could take any necessary steps required to inform the appropriate Government officials. A group of university and Survey scientists met and discussed the evidence, and in general the likelihood of an earthquake was found to be high sometime in the next few decades. This information was communicated to officials of the State of Alaska and to the Canadian government.

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I would now like to review our progress toward the specific implementation responsibilities outlined in the President's National Earthquake Hazards Reduction Program. Briefly, we were given five tasks: Conduct research on the nature of earthquakes, earthquake prediction, earthquake hazards evaluation, and induced seismicity; evaluate earthquake predictions with the advice of a National Earthquake Prediction Evaluation Council; prepare national seismic risk maps; evaluate earthquake hazards on a regional basis; and provide data and information on earthquake occurrences and hazards.

Our research programs and accomplishments have been described in detail above and I shall not dwell on them further. The National Earthquake Prediction Evaluation Council has been established and has had its initial meeting. This meeting was used to draft operating procedures for the Council and not to evaluate any specific prediction. The Council is chaired by Dr. Clarence Allen of the California Institute of Technology and is made up of government and non-government scientists. Its purpose is to advise me, or whoever the Director of the Geological Survey happens to be, on the significance and credibility of earthquake predictions, so that I can fulfill my obligations with respect to geologic hazards warnings. The Council will not initiate or make any predictions itself, but restrict its activities to evaluating the predictions of others.

Our efforts to prepare national seismic risk maps are well underway and draft versions of these maps should be completed in late 1980. These maps may be used to estimate the probability of a certain level of ground shaking not being exceeded within a given period of time. The probabilistic method of constructing ground-shaking maps has advantages that deterministic methods do not have, in that the latter cannot reflect the statistical distribution of physical parameters that affect ground motion.

We have made substantial progress in gathering the data necessary to develop a series of maps, on a regional scale (1:250,000), of ground shaking and possibly ground failure. These maps will be useful and more detailed extensions of the national-scale maps. It is anticipated that they will include information such as age dating of faults in California, Utah, and Nevada; results of studies of the causes of earthquakes in the eastern United States; and physical correlation between earthquake occurrence, regional tectonics, and deep geologic features, especially in the eastern United States. These maps will be developed first for those urban areas of the United States where sufficient advances in earthquake source zones have occurred to warrant refining national scale maps. Regions for which maps or reports are being prepared include the San Francisco Bay region, the Wasatch Front area, southern California, the Mississippi Embayment area, and the Charleston, South Carolina, area.

The basic mission of the Geological Survey in the National Earthquake Hazards Reduction Program is to conduct research and to gather basic earth science information, but we recognize that our responsibility does not end with research. This is emphasized in the plan for the National Earthquake Hazards Reduction Program. To contribute to the reduction of earthquake hazards the information developed by the Geological Survey must become an important factor in decisions about building codes, land use, planning for emergency services, and so on. These decisions are made by individuals and institutions in a wide spectrum of private and governmental settings. The reduction of earthquake hazards in the United States cannot be accomplished by mandate. It can only be accomplished through increased awareness and improved provisions in a wide variety of private, local, State, and Federal practices and regulations.

The Geological Survey cannot and should not implement policies to reduce earthquake hazards, but we must provide the best possible scientific information in a manner which is as useful as possible to the decision maker. This is not an easy process and we do not have all the answers, but I would like to tell you what we have done and are doing to develop lines of communication and facilitate public education. We are, of course, proud of the quantity and quality of the scientific publications emanating from this work. These publications must provide the basis for the public information program. But we are working very hard to improve our procedures for transmitting and disseminating information about earthquake hazards to nonspecialists. We are publishing increasing numbers of reports and maps aimed increasing understanding of the earthquake hazard by engineers, land-use planners, and other non-earth scientists. In addition, we have had two workshops involving individuals from widely varying backgrounds and interests on the general topic of earthquake hazard information, one in January of this year focused specifically on the question of earthquake prediction. These conferences have led to a number of recommendations which we are working to implement.

With regard to the reauthorization of the National Earthquake Hazards Reduction Act of 1977, and matters related to our activities under this Act, the Secretary submitted a proposal to Speaker O'Neill and the President of the Senate on May 25, 1979, to extend authorizations for appropriations, due to expire September 30, 1980, for sums that may be necessary beyond that date to carry out the purposes of the original Act. On June 21, 1979, this legislation was introduced in the Senate by Mr. Cannon (by request) as S. 1393. The accomplishments described above represent only a beginning, and authority for extension of authorizations is necessary to allow the continuation of these efforts.

In conclusion, I would like to thank you, Mr. Chairman, for this opportunity to present our program, accomplishments, and plans for reducing earthquake hazards in the United States. We feel we have developed a successful and dynamic program and we look forward to moving ahead vigorously toward our ultimate goal of protecting lives and property from the earthquake threat.

Senator STEVENSON. Thank you, Dr. Menard.

We'll continue with the other statements.

Dr. Calio.

Dr. CALIO. Thank you, Mr. Chairman, for the opportunity to participate in the subcommittee hearings this morning. The topics under discussion today are the Nation's ability to anticipate and respond to a damaging earthquake and provisions undertaken to implement the act, can best be addressed by the Federal Emergency Management Agency and the U.S. Geologic Survey, and the National Science Foundation, which have assigned responsibilities under the act. NASA views itself as supporting the U.S. Geological Survey and the National Science Foundation in providing basic and applied research to aid in the prediction of earthquakes. It is in this area that NASA is best qualified to address the subcommittee's concerns.

The NASA Geodynamics Program supports research in dynamics of the solid Earth, and in particular the major dynamic processes related to earthquakes. The contribution from space technology to earthquake studies is in the area of basic research. We offer no new means to predict earthquakes, and there is no immediate prospect for a sophisticated satellite monitoring system to implement an earthquake prediction program. What space technology can do and is doing is to extend the range of distances over which scientists can measure the deformation of crust, an important type of observation in earthquake research, and to provide a way to do local surveying measurements much more quickly and at less cost than heretofore has been possible.

NASA has been working with other agencies to ensure that the space technology being developed is directed toward appropriate goals and is properly integrated with their efforts and needs. We have established an interagency coordinating group involving NASA, the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, the National Science Foundation, and the Defense Mapping Agency. An interagency agreement is currently being circulated for signature which will formally establish this interagency coordinating committee for the application of space science and technology to crustal dynamics and earthquake research.

There are two areas of application of space technology to solid earth geophysics:

One, the direct measurement of the movement of the tectonic plates that make up the outer solid portion of the earth, as well as the deformation of the plates in earthquake-prone regions;

Two, detailed mapping of the Earth's gravity and magnetic fields.

In this testimony, I will concentrate on the first of these since it is more closely related to earthquake prediction research.

To build a practical earthquake prediction system, it is necessary to understand how and why earthquakes occur. To achieve this understanding, we must investigate the forces that are the ultimate cause of earthquakes, the driving forces that move and deform the tectonic plates.

To understand earthquakes, we not only have to observe carefully what is happening in the vicinity of active faults, but also to study the more general aspects of global geodynamics. Surveying near active faults provides invaluable information for earthquake research, although not all the activity being observed is perfectly understood at present.

The areas of concern for earthquake research cover many tens or hundreds of kilometers on either side of faults, because leveling and trilateralization surveys on the ground must be carried out on a series of line-of-sight steps from one station to the next. Inevitable errors of observation accumulate, to the point that long before the edges of the strained area are reached, cumulative errors mask the small movements that are taking place. By stepping off the Earth and using reference points in space, we are able to measure distances between points that are arbitrarily far apart, the accuracy of measurement does not depend upon the distance.

In the Geodynamics Program, NASA has begun to measure the crustal deformation in California and the Western United States in a network of sites 50 to 500 kilometers apart, depending on the distance from the San Andreas Fault, and to make these measurements several times a year.

A map of strain accumulation and release will be produced from these observations, which will fit into a detailed mapping being carried out by the U.S. Geological Survey in the immediate vicinity of the active faults.

Later in the program, NASA intends to make similar measurements in active fault zones in other parts of the world. This comparison program is necessary in order to understand the behavior of the San Andreas fault, since to comprehend geodynamics in general, we must observe and compare the behavior of different examples and types of seismically active areas. To accomplish this part of the program, NASA scientists are already involved in discussions with their counterparts in Europe, Australia, Japan, New Zealand, South America, the Caribbean, and several other places. I'm pleased to be able to tell you that in all these areas where discussions are taking place, there is great enthusiasm for this kind of program. We believe the prospects are excellent for a truly international study of global geodynamics.

There are two measuring techniques being used to make measurements with the accuracies required to observe plate motion and deformation, laser ranging to the Moon and man-made satellites and very long baseline microwave interferometry. In laser ranging, an extremely short pulse is fired from a laser on the ground, and the time of travel up to a satellite equipped with cube-corner retroreflectors and back down to the laser station is measured. If we know the orbit of the satellites well enough, this establishes the position of the laser station. In practice, the stations work in pairs and measure the distance between the stations.

In very long base line interferometry, the approach is quite different. We record the radio noise from quasars outside our galaxy. By cross-correlating these noise records at two microwave radio antennas, the separation between the stations along the line of sight to the quasars can be established. By measuring these different components of the station separation with about a dozen different quasars, the true distance between the stations can be determined.

The global network of NASA stations is being augmented dramatically by the inauguration of new observatories being built by other countries, such as Japan, France, West Germany, Austria, the Netherlands, soon Italy, and other countries. There are agreements on exchange of informaiton within the framework of the International Astronomical Union and the International Union of Geodosy and Geophysics.

Although NASA lasers have measured the relative movement between the Pacific and North American plates since 1972 as part of the San Andreas Fault experiment, the global network will monitor the actual movement of tectonic plates, something which has never been attempted before on a worldwide scale.

Of most direct interest to the earthquake prediction program, is the operation of small and highly mobile stations, both laser-ranging and very long-based interferometry. NASA now has one highly mobile laser ranging facility, completed this year by the University of Texas, and two mobile, very long base line interferometry stations. The mission of these truck-mounted and self-contained stations is to carry out the deformation measurements near active faults. The stations are already engaged in measurement programs in Southern California, in cooperation with the U.S. Geological Survey. The transportable laser ranging station will move to Southern California this spring when its checkout phase is completed.

Mr. Chairman, that highlights the activity that we have in basic and applied research. In summary, we feel that NASA has a contribution to make and is very pleased with the relationship we have with other agencies in the area of geodynamics.

That concludes my statement, Mr. Chairman. I'm prepared to answer any questions.

[The statement follows.]

STATEMENT OF DR. ANTHONY J. CALIO, ASSOCIATE ADMINISTRATOR FOR SPACE AND TERRESTRIAL APPLICATIONS, NASA

Mr. Chairman and members of the subcommittee, thank you for this opportunity to participate in the Subcommittee's hearing concerning S. 1393, a bill extending authorizations for appropriations for the Earthquake Hazards Reduction Act of 1977.

The topics under discussion today—the Nation's ability to anticipate and respond to a damaging earthquake, and provisions undertaken to implement the Act—can best be addressed by the Federal Emergency Management Agency, the U.S. Geological Survey (USGS), and the National Science Foundation (NSF), which have been assigned specific responsibilities under the Act. NASA has not been assigned a specific role, but rather views itself as supporting the USGS and NSF in providing basic and applied research to aid in the prediction of earthquakes. It is in this area that NASA is qualified to address the Subcommittee's concerns.

The NASA Geodynamics Program supports research in the dynamics of the solid earth and, in particular, the nature of dynamic processes related to earthquakes. The major contribution from space technology to earthquake studies is in the area of basic research: we offer no new ways to predict earthquakes, and there is no immediate prospect for a sophisticated satellite monitoring system to implement an earthquake prediction program. What space technology can do, and is doing, is to extend the range of distances over which scientists can measure the deformation of the crust—an important type of observation in earthquake research—and to provide a way to do local surveying measurements much more quickly and at less cost than has been theretofore possible.

NASA has been working with other agencies to insure that space technology being developed is directed toward appropriate goals and is properly integrated with their efforts and needs. We have established an inter-agency coordinating group involving NASA, USGS, the National Oceanic and Atmospheric Administration (NOAA), NSF, and the Defense Mapping Agency (DMA). An interagency agreement is currently being circulated for signature, which will formally establish an interagency coordinating committee for the application of space science and technology to crustal dynamics and earthquake research.

Informal inter-agency working groups have been at work for almost a year on specific immediate problems such as site selection for mobile stations to measure crustal movements, local supporting surveys, data management, and a contingency plan for immediately sending mobile stations to the area of a large earthquake.

There are two areas of application of space technology to solid-earth geophysics: (1) the direct measurement of the movement of the tectonic plates that make up the outer solid portion of the earth, as well as the deformation of the plates in earthquake-prone regions; and, (2) detailed mapping of the earth's gravity and magnetic fields. In this testimony, I will concentrate on the first of these, since it is more closely related to earthquake prediction research.

To build a practical earthquake prediction system, it is necessary to understand how and why earthquakes occur. To achieve this understanding we must investigate the forces that are the ultimate cause of earthquakes—the driving forces that move and deform the tectonic plates. To us as human beings, earthquakes are awesome natural phenomena that have frequently caused widespread death and destruction, but from a geological point of view, earthquakes are only local phenomena, a means of relieving the strain that is built up in the plates as a result of the driving forces. To understand earthquakes, we not only have to observe carefully what is happening in the vicinity of active faults, but also study the more general aspects of global geodynamics.

Surveying near active faults provides invaluable information for earthquake research, although not all the activity being observed is perfectly understood at present. The problem being addressed by space technology is that the areas of concern for earthquake research cover many tens or hundreds of kilometers on either side of faults. Of course, the faults themselves are long (the San Andreas Fault System extends over 1100 kilometers from Cape Mendocino in Northern California to the Gulf of California between El Centro and Yuma). Because leveling and trilateration surveys on the ground must be carried out in a series of line-of-sight steps from one station to the next, inevitable errors of observation accumulate to the point that long before the edges of the strained area are reached, cumulative errors mask the small movements that are taking place. By stepping off the earth and using reference points in space, we are able to measure distances between points that are arbitrarily far apart, and accuracy of measurement does not depend on the distance.

In the Geodynamics Program, NASA has begun to measure the crustal deformation in California and the Western United States in a network of sites 50 to 500km apart (depending on the distance from the San Andreas Fault), and to make these measurements several times a year. A map of strain accumulation and release will be produced from these observations, which will fit into the detailed mapping being carried out by the USGS in the immediate vicinity of the active faults.

Later in the program, NASA intends to make similar measurements in active fault zones in other parts of the world. This is necessary in order to understand the behavior of the San Andreas Fault. To comprehend geodynamics in general, we must observe and compare the behavior of different examples and types of seismically active areas. To accomplish this part of the program, NASA scientists are already involved in discussions with their counterparts in Europe, Australia, Japan, New Zealand, South America, the Caribbean, and several other places. I am pleased to be able to tell you that in all areas where these discussions are taking place, there is great enthusiasm for this kind of program. We believe the prospects are excellent for a truly international study of global geodynamics.

There are two measuring techniques being used to make measurements with the accuracies required to observe plate motion and deformation: laser ranging to the Moon and to man-made satellites, and very long baseline microwave interferometry (VLBI). In laser ranging, an extremely short pulse is fired from a laser on the ground, and the time of travel up to a satellite equipped with cube corner retroreflectors and back down to the laser station is measured. If we know the orbit of the satellite well enough, this establishes the position of the laser station. In practice, the stations work in pairs, and measure the distance between the stations.

In VLBI, the approach is quite different. We record the radio noise from very distant sources (we use the quasars, which are outside our galaxy) at two microwave radio antennas. By cross-correlating these noise records, the separation between the stations along the line of sight to the quasars can be established, and by measuring these different components of the station separation with about a dozen different quasars, the true distance between the stations can be determined.

Although these concepts are quite simple, the technological complexities involved in implementing them are challenging. This program has most strict requirements: nanosecond-pulse lasers; highly accurate atomic clocks; 120-megabit recording and correlation systems; and correction at the one-centimeter level for atmospheric and ionospheric effects on electromagnetic wave propagation.

With the advent of the DOD's Global Positioning System (GPS) satellites, it is now possible to consider using signals from satellites in the same way that quasars are used in VLBI, in order to make rapid and accurate measurements over distances of 20 to 200km. Since the satellite signals are considerably stronger than quasars, the receiver system can be smaller, more compact, and hence more mobile. NASA is working with NOAA, DOD, and USGS to coordinate the development of receiver systems which use the GPS for geodetic surveying. NASA is developing "SERIES" (Satellite Emission Radio Interferometric Earth Surveying), which uses raw GPS signals and does not require knowledge of the coded transmission. The other three agencies are jointly funding development of a receiver which uses the code to reconstruct the carrier frequency, and measures the phase difference between the signals at two stations. The two approaches will be tested by the inter-agency group, and one system will be selected in 1983 for joint procurements.

Over the past eight years we believe we have solved most of the engineering problems, and we have in operation a number of both laser ranging and VLBI observatories. Through the Smithsonian Astrophysical Observatory (SAO), NASA operates stations in Brazil, Peru, and Australia, and will shortly have an SAO station in India. We have mobile laser stations operating in American Samoa, Australia, Kwajelein Island, and at several sites in the States. VLBI equipment has been operated on an experimental basis at several radio astronomy observatories in the United States and Europe, and NASA is assisting the National Geodetic Survey in establishing a network of three VLNI stations which will be solely dedicated to use for geodesy and geophysics; this network (the acronym is "Polaris") is a necessary part of the space geodynamics program since its primary role is to measure the polar motion of the earth—a quantity which is of scientific importance in itself, but which more practically has to be observed accurately in order to correct the raw position observations of the laser ranging and VLBI stations.

The global network of NASA stations is being augmented dramatically by the inauguration of new observatories being built by other countries: Japan, France, West Germany, Austria, the Netherlands, and soon in Italy and other countries. There are agreements in the framework of the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG). Although NASA lasers have measured the relative movement between the Pacific and North American Plates since 1972 as part of the San Andreas Fault Experiment, the global network will monitor the actual movement of the tectonic plates—something which has never been attempted before on a worldwide scale.

Of most direct interest to the earthquake prediction program is the operation of small and highly mobile stations, both laser ranging and VLBI. NASA now has one highly mobile laser ranging facility, the Transportation Laser Ranging Station (TLRS), completed last year by the University of Texas at Austin; and two highly mobile VLBI stations, called Astronomical radio Interferometric Earth Surveying (ARIES), and built by the Jet Propulsion Laboratory. The mission of these truck-mounted and self-contained stations is to carry out the deformation measurements near active faults discussed earlier in this testimony. The ARIES stations are already engaged in a measurement program in Southern California in cooperation with the USGS, and the TLRS will move to Southern California this spring when its checkout phase is completed.

Last August, ARIES measurements between the Jet Propulsion Laboratory and the Goldstone Deep Space Network station, about 200km to the northeast, indicated that JPL had moved almost twenty centimeters northwest (in the direction of movement on the San Andreas Fault, which runs between Goldstone and JPL) from where it had been in January 1979. Remeasurements in November 1979 showed further movement of JPL back to the southeast, and the most recent measurement, in January 1980, indicated that JPL is back approximately to where it started the previous January. I want to emphasize that these measurements must be regarded as tentative until an intensive review of the hardware performance and software procedures used has been completed, and until ARIES and TLRS are co-located to measure the same line with both laser and VLBI. If the ARIES measurements are valid, they indicate that a broad-scale tectonic phenomenon may have occurred all over Southern California, on a time scale that is unexpectedly short. This view is supported by other geophysical anomalies that were taking place in this area last year: strain measurements made by USGS close to the San Andreas Fault showed a reversal of the previously observed compression; radon content of water wells in the Los Angeles basin fluctuated dramatically; the creep rate on the San Andreas fault observed by the USGS near Parkfield suddenly changed; and there were indications of gravity changes in Southern California.

NASA notified the USGS Office of Earthquake Studies of these ARIES results last fall when the first data analysis was completed, and we have coordinated our further observing schedule in Southern California with the USGS scientists. I believe this is a good example of effective cooperation between Federal agencies.

One implication of the recent Southern California geophysical anomalies is that frequent measurements in a dense network of sites may become increasingly important. It could well be that rapid tectonic movements of the kind indicated by the preliminary ARIES measurements are happening all the time and that we are only now gaining the technological ability to see them.

Before closing, I must add a few words about the relationship between crustal dynamics and NASA's gravity and magnetic field mapping programs. Studies of the solid earth, its interior composition and structure, and the dynamics of its core and mantle, are scientifically important. From space, we have a means of surveying the earth's gravity and magnetic fields on scale which is not otherwise possible. These surveys are directly related to the global earth studies I have just mentioned.

Our knowledge of the gravity field of the Earth improved by orders of magnitude during the National Geodetic Satellite Program, which began in 1964 and lasted for ten years as a cooperative effort between NASA, NOAA, and DOD. The fine details of the gravity field are sensitive to anomalies in the mass distribution within the Earth, and these anomalies are in turn closely related to what is happening in the Earth's mantle to move (or perhaps to hinder the movement of) the tectonic plates. Geophysicists believe that studies of the very short wavelength features of the gravity field will reveal new and important information about the behavior of the crust in the very areas that are of most concern to the earthquake hazards reduction program—the edges of the plates, where they are grinding together, and where most earthquakes occur.

We are not yet at the desired point in mapping the gravity field, however, and our scientists are studying a potential new mission—the Gravity Field Mapping Satellite (Gravsat)—to make the next logical step in refining our knowledge of the Earth's gravity. Gravsat is also a necessary component of a group of missions we are studying to carry out oceanographic objectives—for example, study of nature of the western boundary currents and the mean circulation of the oceans.

Magsat was launched last year to map Earth's magnetic field, and is still in orbit long after its planned lifetime, functioning well and providing unprecedented mapping of the Earth's magnetic field. NASA has a Memorandum of Understanding with the USGS to carry out analysis of the Magsat data. We expect not only to make the first synoptic map of the magnetic field, but to learn a great deal about the mechanism of generation of the field, deep within the Earth, and to derive information on crustal magnetization anomalies which geophysicists believe will be of value in understanding crustal processes and their association with the location of mineral and general resources.

In summary, NASA has a contribution to make, and is very pleased with the relationship we have with other agencies in the area of geodynamics. The interagency program for the application of space technology to crustal dynamics and earthquake research is being focused on the right problems, and the modern technology the space program has made possible is being used in areas specified by the scientists who need the measurements.

Mr. Chairman, that concludes my prepared remarks. I would be pleased to respond to any questions you may have.

Senator STEVENSON. Thank you, Dr. Calio.

Dr. Sanderson.

Dr. SANDERSON. Thank you, Mr. Chairman.

In the interests of time, I would like to put my full statement in the record and make only a few brief remarks.

The National Science Foundation has been assigned responsibility for research in the earthquake hazards area in three primary categories. One category has to do with the understanding of the fundamental natural phenomena occurring in plate tectonics and the understanding of the earthquake process itself. This is an area which is the responsibility of our program in Earth sciences. There are representatives here from that program, Dr. Francis Johnson and Dr. Robin Brett, who can provide you expert information on the details of those activities. There are a number of exciting activities occurring in that part of the program.

You may have recently seen in Science an article on the gap theory of seismic prediction. There are indications that we're beginning to understand the way plate movements are building the forces within the Earth, the way those forces tend to become locked and released so that we can anticipate the prediction, if not in time, at least in fairly specific location, of major earthquakes.

The other fundamental research area has been in looking at the process of the earthquake itself; the way the fault releases energy, the way it locks, slips, and relieves stresses; and the way the energy is generated at the site of the fault.

I would like to briefly discuss the other two program areas, which are under the direct responsibility of Dr. Senich, who is also here, and myself. One of those areas represents the Foundation's major effort in earthquake-related research. That's in the area of earthquake engineering.

This program element divides into two categories. The first category is to develop an understanding of the response of natural and man-made structures to seismic forces. Over the past decade or so, we have made substantial progress in this area and moved from fairly crude models of static forces loading a building or structure, in one or two dimensions to the ability, using modern computer techniques, to understand the dynamic interaction of a manmade structure under real earthquake forces, that has been observed, or may be estimated.

The other part of that program has concentrated on understanding the way strong ground motions, are generated at some point on Earth and propagate through the Earth; the way these forces are reinforced or weakened by the material through which they propagate, and by reflection off geological boundaries within the Earth. Thus, we can begin to predict, using computer models, the precise nature of the forces that a building at a specific site may encounter.

This research also has demonstrated substantial progress over the last few years, and currently we have operating computer models which have successfully duplicated measured ground forces in some of the earlier earthquakes.

Both types of progress—in understanding the true nature of the ground forces that occur at a given site, and in understanding structural response, have been adopted by a variety of agencies, organizations, and members of the engineering profession. They form the basis of the analysis used in examining the seismic risks of nuclear power stations and other major high-potential-risk facilities.

The other area for which we are responsible is societal response, conducting research on the policy, social and legal issues involved, in earthquake prediction, and the responses after an event has occurred.

For a number of years we have maintained a capability, through the National Academy of Sciences and through the Earthquake Engineering Research Institute, to put disaster teams into the field immediately upon the occurrence of an earthquake. This has enabled us to gather substantial amounts of data.

We are currently considering extending that responsibility to include sending teams into the field when predictions are made or when such anomalies as the Palmdale Bulge develop.

We have had research teams conducting field work for over 2 years on the social effects of the Palmdale Bulge and the media response to that event.

We currently have, I understand, a research team from Battelle at Mt. St. Helens interviewing evacuees from the volcano which is occurring there, trying to understand their behavior patterns, the type of response they are making and the way they have responded to prediction.

Of course, all of these activities are at a fairly early stage. We anticipate later a final report on the Palmdale event—hopefully this summer.

With that, I think I will be glad to respond to questions.

[The statement follows:]

Statement of Dr. Jack T. Sanderson, Assistant Director for Engineering and Applied Science, National Science Foundation

Mr. Chairman and members of the subcommittee, it is a pleasure to report to you on the progress and future plans of our Earthquake Hazards Mitigation Program. As you are aware, NSF initiated research on this important national issue in the mid 1960's. That effort began with modest developments to improve seismic resistance in multi-story commercial buildings. Since 1966, we have obligated nearly one hundred million dollars for research in engineering and, to a lesser extent in architecture and the social sciences, to effect changes for the better in those parts of the country that are subject to potential loss of life, personal injury and property damage from earthquakes.

Fifteen years ago, building design procedures were primarily simple extensions of static structural computations—computations which assumed that the building was not in motion as the seismic shock waves, propagating through the ground, displaced the building's foundation. We always knew that this assumption was not true but we had neither the analytical methods nor the computational machinery to make a better approximation. We now are able with dynamic analyses, to predict the elastic response of a given structure to a known ground motion. Admittedly, this does not portray the complete picture and much work remains to be done on time-dependent phenomena, such as the duration of shaking and the material property changes that occur during cyclical loading. We are certain that significant imporvements and completely new developments will continue to be made.

I should like to bring to your attention a few recent samples of how our research is developing an understanding of earthquakes in relation to constructed facilities and enabling us to reduce casualties, damage and societal disruption as a result of earthquakes.

Until recently, the design of buildings to resist earthquake motions was based upon the assumption of equivalent horizontal static forces acting on a single frame system and the elastic behavior of the materials, such as steel, reinforced concrete and masonry. To imporve the behavior of the building to incorporate greater safety and economy, scientists and engineers have developed dynamic techniques that consider the three-dimensional aspects of the building, the inelastic behavior of the construction materials, and the actual ground motions of the earthquake. The new analytical methods have recently become available through the use of electronic computers and the development of new concepts of determining building responses to earthquake motions. These recent developments have led to new design specifications which are being incorporated into local building codes and design procedures.

These new concepts were developed by researchers at Cal Tech, the University of California at Berkeley and the University of Illinois. Various Government agencies, Nuclear Regulatory Commission (NRC), the Water and Power Resources Services and the Corps of Engineers, have also incorporated these latest concepts into their mission activities. The analytical concepts have been verified experimentally for some applications by researchers at UC-Berkeley, and the Universities of Michigan, Texas and Illinois. As a consequence, designers and building officials have been employing these new design tools with greater confidence in the ultimate safety of new and rehabilitated buildings.

Before the seismic response of a structure (i.e., building, dam, bridge, embankment, etc.) can be calculated, it is necessary to determine the dynamic loads that will be applied to the structure as a result of the vibratory ground motions generated by the earthquake.

An essential component of NSF-funded research is the study of earthquake records for the development and verification of ground motion models. NSF has provided support to the Seismic Engineering Branch (SEB) of the USGS to place and maintain ground motion instruments throughout the U.S., as well as in highly seismic areas outside of the U.S. The SEB maintains a library of these records. The U.S. data is used through the world for a seismic design. The usefulness of such data is attested to by the many local, state and Federal agencies, which have recently initiated instrumentation programs.

NSF researchers are now developing procedures for predicting the strong ground motion time-history generated by fault movement, based on known parameters of the fault. For example, K. Aki (MIT) has successfully reproduced the Pacoima Dam record obtained during the 1971 San Fernando Earthquake, which contained the largest peak acceleration recorded up to that time. The soils overlying bedrock can either increase or decrease the amplitudes of the ground motions propagating to the structures. Researchers have developed analytical and numerical techniques to predict such effects, based on the physical and mechanical properties of the soils. These techniques are being utilized by virtually every engineering consulting firm and agencies in the United States engaged in earthquake analysis related to construction. They are used in the seismic risk analysis of every nuclear power plant currently being designed in the United States, and for other critical structures such as dams, hospitals, offshore platforms, and large construction projects of all kinds.

In 1978 NSF provided the Association of Bay Area Governments (ABAG) a grant to organize an interdisciplinary team composed of representatives from the social sciences, law, engineering and the geosciences to study the liability of governments for earthquake hazard. The specific objectives of the study were to: (1) develop knowledge on the nature and extent of local government liability, (2) advise government on how to cope with such liability, and (3) recommend ways the law could be changed to encourage local and state governments to reduce hazards without increasing their liability. Data were collected from several sources, including interviews with officials at sites of recent earthquakes in Alaska, Washington and California, and from a questionnaire survey in 88 jurisdictions in Utah, Alaska, Washington and California. The study has resulted in a significant increase in knowledge on the role of law as an incentive in earthquake hazards reduction.

Through an analysis of the legal aspects of earthquake prediction, the study showed that California law was unclear regarding the liability of government for actions taken in connection with earthquake predictions and that this was a potential disincentive to officials taking appropriate measures, such as issuing public warnings following a scientifically valid prediction. As a result of this finding, the Association of Bay Area Governments staff worked with the California Office of

Emergency Services and the California Seismic Safety Commission in developing new legislation introduced and passed, SB 555, which removes liability from state officials for issuing warnings and taking appropriate emergency actions following a state of emergency declaration.

We are considering options for quick response investigations of community reaction to official earthquake warnings. This activity would be similar to the current project supported by NSF at the Earthquake Engineering Research Institute and the National Academy of Sciences where post-audits of earthquakes have been conducted for several years.

For the Nation, we believe that these and other activities of our program are research investments that will be far overshadowed by savings to be realized from the practical applications of this research.

The program will continue to support the basic and applied research required to reduce the loss of life and property damage due to earthquakes. This necessarily involves a multidisciplinary approach and an emphasis on the transfer of research results and improved engineering techniques to the public and private sectors. Over the next five years, increased effort will be placed on international cooperative activities, such as those planned under the recently-signed agreement with Japan, to provide U.S. research teams with detailed data on large-scale testing of structures and data obtained from instrumented areas subject to frequent seismic risk. In addition to the bilateral agreement with Japan, the Foundation and the U.S. Geological Survey have signed a protocol with the People's Republic of China to puruse cooperation in the fields of earthquake engineering, prediction, hazards evaluation and the basic and applied studies of earthquake phenomena. Also, continued emphasis will be placed on providing detailed analytic and empirical data that provide a technically sound basis for mitigation measures such as the modification of building codes, development of cost-effective land use controls, and improved criteria for strengthening or reconstructing buildings and other structures that are subject to earthquake loadings.

As in all fields of science and technology, there are researchable problems where the likelihood of solutions ranges from high to low. Those areas which the Earthquake Hazards Mitigation program is attacking which we believe have a reasonable chance of generating successful results include:

The three-dimensional constitutive relationships with the dynamics of soils under an earthquake loading;

The analysis of the seismic response of complex structural geometries and large-scale structures involving very large numbers of degrees of freedom;

Quantitative relationships describing structure-soil interactions which amount for the complexities of natural soil media and the incoherence of ground motion in a soil continuum having spatially heterogeneous properties;

The ability to predict the ground motion time-history for a certain magnitude earthquake in a specific area;

Methods of design and construction to achieve optimum economy from all standpoints including materials, energy, and functionality;

The analysis of the benefits and costs of alternative mitigation and preparedness measures; and

The identification of social, economic and legal incentives to ameliorate existing hazardous conditions.

Two other major elements of the Earthquake Prediction and Hazard Mitigation Program of the USGS and NSF described in the Newmark-Stever Report are (1) Earthquake Prediction and Hazard Assessment, and (2) Fundamental Earthquake Studies. The first is primarily under the aegis of the USGS . . . the second under the Geophysics Program of the Earth Sciences Division of the Foundation.

The objective of the Fundamental Earthquake Studies element of NSF is to attain a comprehensive understanding of the natural phenomena involved in the earthquake process. Seismology and other earthquake related areas have been of interest to the Geophysics Program, and have constituted more than half of its program, for the last 20 years. Aspects of this research, related to the NSF–USGS Earthquake Hazards Mitigation Program have been intensified in recent years in accordance with funding Option B of the Newmark-Stever Report.

From fiscal year 1977 through fiscal year 1979 the Program has made 208 grants in the fundamental studies area. They were funded to 51 institutions in 27 states.

The Fundamental Earthquake Studies Program of NSF was, rather arbitrarily, divided into two sub-elements in the Newmark-Stever Report: (1) the Earthquake Process, and (2) the Implications of Plate Tectonics, with considerable overlap between them. Substantial advances have been made in each of these areas in recent years. These accomplishments were made possible by the acquisition of large amounts of very high quality geophysical data, access to good computers, and the availability of a cadre of talented and well trained scientists.

The greatest expansion in theory has probably been in the procedures used to compute synthetic seismograms. This has required a good understanding of seismic sources, earth structure, and the wave transmission properties of the earth. At periods greater than about 20 seconds, there is now, in general terms; a fairly complete understanding of all the details in a seismogram. We have the beginning of an understanding of the dynamic process of faulting—how a fault rupture starts, spreads, and finally stops, and the effects seen on seismograms for each of these three stages in the faulting process.

It has recently been hypothesized that there may be "slow" unfelt earthquakes that precede the more usual ones with which we are familiar. If so, the observation of "slow" earthquakes would provide a predictor. Most seismographs will not respond to such low frequencies. However, the network of 16 worldwide, ultra-long period instruments supported by NSF and operated by scientists at the University of California, San Diego, is ideal for the recording of "slow" earthquakes. A search for their existence is currently being conducted at least three other university research laboratories, using data from this network.

Fundamental studies of earthquakes and the evolving theory of plate tectonics are intimately related. The major earthquake zones of the world mark the plate boundaries. The relative plate motions provide an adequate source for the energy released in plate boundary earthquakes and a basis for estimating how often great earthquakes should occur in these settings. On the other hand, the earthquake source properties provide information concerning the amounts and directions of the relative plate movements and the stress systems involved. Recently there has been convincing evidence that a "seismic gap" concept provides a valid indication of the sites of future large earthquakes on plate boundaries. A gap is a zone along an active fault that has not experienced a large earthquake compared to the frequency of previous large earthquakes along the fault. Several recent large earthquakes have occurred along gaps, for example the 1978 earthquake in Oaxaca, Mexico, partially or completely ruptured that gap.

The COCORP program for seismic reflection profiling of the continental crust relates to the earthquake problem in a variety of ways ranging from the specific geological features that correlate with specific earthquakes to broader kinds of information on the structure of the crust and on crustal processes that must be understood. The ability to detect and trace faults deep in the earth has been amply demonstrated in the southern Appalachians, Wyoming, California, Michigan and New Mexico.

Results from recent work have indicated a number of important directions in which research should currently be directed. It is not possible to predict the content of a program of fundamental research in future years. We can only plan to continue and complete the most interesting and promising work currently in progress, realizing that the actual work over the next few years will be guided by major discoveries that emerge, often unpredictably.

There are many new initiatives that we would like to pursue. From a list of some twenty, I have chosen the following:

(1) Evaluation of the theory of seismic gaps and its seismogenic potential.

(2) Increased seismic reflection profiling of the continental crust in areas of particular earthquake interest.

(3) More laboratory study of rocks with special emphasis on fault gouge and the brittle-ductile transition.

(4) Development of effective techniques to compute synthetic seismograms for 2 and 3 dimensional structures.

(5) Development of ocean bottom seismometers and drill hole seismometers both on the continent and under the oceans for very long-term recording.

We feel that a diligent pursuit of the present program can be expected to result in a more comprehensive understanding of the earthquake process and will help to establish the scientific base of knowledge necessary for the eventual prediction of earthquakes and destructive ground motion.

Our experience has shown that a problem-focused research activity without effective participation by the community which will utilize the results of the research is not likely to have a substantial, positive impact. At all phases of the Earthquake Hazards program, representatives of State and local government, industry and the design professions continue to be involved in planning, review and evaluation of the content and the direction of the program. Without their advice and counsel we can never hope to see the incorporation of our research results in a State and local disaster preparedness system—building codes, zoning restrictions, disaster-response plans—these are the end results for which the program must provide the scientific and technological base. The formal arrangements to ensure participation are developed in two advisory committees: the NSF Advisory Committee to the Earthquake Hazards Mitigation program which is composed of university experts, members of the design professions, representatives of the California Seismic Safety Commission and a staff member from the National Academy of Sciences; and the Interagency Committee on Seismic Safety in Construction composed of representatives of all Federal agencies having significant involvements in construction, the financing of construction or closely related activities.

Two recent developments have significantly influenced the NSF program. The first was the September 1976 report to the President's Science Advisor on Earthquake Prediction and Hazard Mitigation Options for USGS and NSF programs. That report provided the basis for establishing guideline budget levels for Federal research support with an unusually high level of specificity. Detailed budget recommendations were made for our program for the three year period, FY 1978 through FY 1980. The second major event was the passage of P.L. 95–124 on October 7, 1977, which assigned the Foundation a role as an active partner with specific responsibilities within a coordinated, Federal-wide research effort on earthquake hazards reduction.

That law, the Earthquake Hazards Reduction Act of 1977, authorized appropriations not to exceed $102,500,000 for the same three year period covered by the 1976 report, FY 78–80. During this time NSF requested funds for these purposes in the amount of $66,200,000. In response to this request the Congress appropriated approximately $52,500,000 which has been obligated in support of the program. The basis for the NSF request was provided by Option B (i.e., the intermediate option) of the September 1976 report, commonly referred to as the "Newmark Report." Option B was selected by the Executive Office as the budgetary and programmatic guideline which recommended a total $79,200,000 for the program during the three year period. I have prepared an analysis of our program activities which describes the progress made in implementing the Act and describes the accomplishments of our program. I should like to submit this analysis for the record at this time.

In my view, we have made significant progress in research in the social sciences which addresses the crucial problems of understanding how people and communities respond to earthquake disasters and ways in which measures of preparedness can be developed to mitigate these certain but as yet unpredictable disruption. Additional progress is likely as this program develops.

Working in cooperation with the Office of Science and Technology Policy, we have prepared a five year plan which describes the desired position of the program five years hence and how we can achieve it. This document has been reviewed jointly with FEMA, the USGS and several experts from public and private organizations and I believe it represents a consensus of opinion. We will continue to work closely with our partners in the implementation of the Earthquake Hazards Reduction Act.

Thank you Mr. Chairman for the opportunity to share my enthusiasm for this program. We have developed a broad based scientific program and look forward to moving ahead vigorously in meeting the objectives of the Earthquake Hazards Reduction Act.

Senator STEVENSON. Thank you, sir.

Dr. Thiel characterized the budget request for FEMA in fiscal year 1981 and projections for the years through 1985 as hazardously low, I believe. How would you characterize the request for NSF in fiscal year 1981 and projections through 1985? And has the 1981 request survived the current exercise?

Dr. SANDERSON. To answer the second question first, Senator Stevenson, both the fiscal year 1980 plan and the fiscal year 1981 request in the earthquake area have survived the latest round of budget revisions coming to the Congress.

In answering your first question, I find myself philosophically somewhere between the two people at the table earlier who had to answer the same question. Namely, I see very great opportunities for substantial additions to our basic and applied research in these areas and, the same time, I realize some of the pressures involved in making necessary tradeoffs between this research and the other high priority responsibilities which have been assigned to the Foundation.

In responding to your question specifically, we have developed a 5-year plan which has been submitted to the Office of Science and Technology Policy, recommending both a base level program and some high priority add-ons, which we believe are ripe for study and research. That document is available and can be made part of the record.

Senator STEVENSON. Can we have that for the record?[1]

Are those add-ons reflected in these projections which I have and which I believe were supplied by FEMA? They range from $26.6 million for NSF in 1981 to $41.9 million in 1985. Do those reflect the add-ons?

Dr. SANDERSON. I would like to have a chance to compare the numbers more closely with yours.

Senator STEVENSON. Well, if we can get that document.

Dr. SANDERSON. I suspect they reflect primarily the base budget.

Senator STEVENSON. The figures that I just gave you reflect the base budget, not the add-ons.

Well, if we can get that document, we can determine it for ourselves.

Dr. SANDERSON. I was advised by a representative of FEMA that they do reflect the add-ons recommended by the Advisory Committee in part.

Senator STEVENSON. Partly.

Now, Dr. Menard, let me ask you the same question. This chart projects $31.6 million for USGS, up to $41.9 in 1985. Is that adequate? And has USGS survived the current budget cuts?

Dr. MENARD. We have survived, in this program, the current budget cuts. We realize that the funding is not at the level originally recommended by the committee. It's at the minimum level. It started out a little bit above the middle of the recommendation, worked its way to a little bit below the minimum recommendation.

Once again, we are required to balance our needs in this program with our needs in other programs. I guess you could say if we knew there was going to be a major earthquake 3 years from now, we would be putting more of our effort and resources into finding out what was going to happen, because that would be the only responsible thing to do.

Senator STEVENSON. That implies we're better off not finding out.

Dr. MENARD. No. I think if we knew there wasn't going to be a major earthquake for 50 years, then we need not feel this is quite such a high priority program, and we could carry on at a lower level. We are, in short, engaged in a hazardous game of estimating whether or not this program will enable us to make the risk assessments and the predictions by the time there's a need or before there's a major earthquake.

Senator STEVENSON. Now these budget figures which I mentioned, are they at the lowest Newmark-Stevers projection or below the lowest?

Dr. MENARD. I think they're just below it.

Dr. WESSON. Yes, they're below Option A, which was the lowest option in the report for 1980.

[1] The material referred to has been retained in the committee files.

Senator STEVENSON. And for 1980, doesn't it continue throughout? What about 1981?

Dr. WESSON. The original Newmark-Stevers report, Mr. Chairman, contained funding recommendations for 1978, 1979, and 1980. So moving into 1981, we're beyond the end of their projections.

Senator STEVENSON. Dr. Menard, when will the USGS be able to make scientifically credible predictions of earthquakes in this program as presently budgeted?

Dr. MENARD. I can say with some confidence, we don't know. If we knew, we could answer that question directly. I would say that we visualize an orderly process in which we really understand what the conclusion is going to be, and it's a matter of collecting data here and analyzing it there, and it will all come out and in the end we will be able to predict. But it's a complicated Earth out there, and I think we're just going to have to keep doing our best.

I think we've gone through the first step. We actually believe that we can in the long run predict earthquakes. I think that's a widespread belief that didn't exist too long ago. I think I might say that we visualize now a range of useful things we could do beyond the long term prediction. Our aim is to pin down quite reliably, accurately, where the earthquake would be, how large it would be, and when it would occur.

We visualize now that we can render useful services by saying we don't know exactly where it will occur, but more or less, and we don't know exactly when, but more or less; and that appropriate steps could then be taken by FEMA and comparable organizations to prepare the public for this increased risk.

Senator STEVENSON. Is the exchange program with the Chinese producing useful information?

Dr. MENARD. Not very much has gone on in that. But fortunately, Dr. Wesson has been involved in it from the beginning.

One of the problems we've had in the United States is that the Earth has been too benign. When we're all set up to monitor earthquakes, there haven't been many earthquakes, and that's a very good reason for going to China.

Dr. WESSON. Mr. Chairman, with regard to the cooperative program with the Chinese, over the last year the Geological Survey and the National Science Foundation together have negotiated a protocol outlining joint work in the area of earthquake studies. This protocol was signed by the Director, Dr. Menard, in January. We're anticipating that we will actually begin field work under that agreement this summer, and we will have work going on in a number of different areas.

The two principal areas of interest to the Geological Survey's program are, first with regard to earthquake observations for earthquake prediction. We will work with the Chinese jointly to establish instrumentation both in the Beijing-Tianjin-Tangshan region in north China, which has been afflicted by a number of large earthquakes since 1966, notably the Tangshan earthquake of 1976, which you mentioned in your opening statement.

Second, we will focus joint work in instrumentation in western Yunnan province, which is in southwest China and is a very active area for earthquakes of about magnitude six and a half. Normally one would expect a magnitude of six and a half earthquakes in that region about every 2 years. So, by making observations there we expect to gain information very rapidly.

Lastly, we'll be working with the Chinese in the area of studying the past movements of faults in China and correlating and studying those movements by geologic means and comparing those results with the very long historical record of Chinese earthquakes, going back thousands of years. So we'll be able to make sure that our geologic methods are well calibrated.

We're looking forward to this program and we'll be moving actively into field work over the next several months. In addition, I should say from the Chinese perspective, they're interested in our technology, particularly for computers and so on, and we're interested in data. So we could more or less work out an agreement where we will get new data and observations and we will supply them with some new hardware that they're anxious to receive.

Senator STEVENSON. What about the exchange relationship with the Russians? Has that been embargoed, too?

Dr. WESSON. Not yet, Mr. Chairman. We had a very active and I would say successful program of exchange with the Soviet Union dating back to—the original agreements were signed in 1973, I believe. We've had a great deal of field work going on, particularly in central Asia in the Tadzhik and Kirgiz Republics. We've studied earthquake phenomena, looking for precursors in the Garm region jointly with the Institute of Physics of the Earth of the Soviet Academy of Sciences.

We've studied reservoir-induced seismicity, with that same Institute, near the big reservoir called Toktogul in Kirghizia and also what was then the largest earth-filled dam in the world, the Nurek Dam near Dushanbe in Tadzhikistan.

All of these areas have been very rewarding, and the President's guidance from the National Security Council has been that activities which have to do—I'm sorry, I can't recall the exact words—but have to do basically with the alleviation of human suffering and for national security can continue. Under these guidelines, these programs with the Soviet Union will continue, but I'm afraid their level may be slightly reduced.

But exactly in what way those projects will continue will depend, of course, on future developments with regard to the foreign policy decisions of the United States.

Senator STEVENSON. And the seismic station in Afghanistan, do we still have access to that?

Dr. WESSON. Mr. Chairman, the Geological Survey operates a worldwide network of seismographic stations. Among those stations is one in Kabul, Afghanistan. Despite the rather tortuous political history over the last several years in Afghanistan, we've continued to obtain records sporadically from that station.

It's my understanding that we in fact have received records from the Afghan station since the recent developments there in December.

Senator STEVENSON. Dr. Menard, do you think the law at present establishes clearly enough the responsibility between the state and Federal Government and agencies within the Federal Government, for earthquake warnings?

Dr. MENARD. I believe we're working toward it. The law itself I think would take care of that. Working out the memorandum of understanding and so on, as you heard from Mr. Macy, remains to be done.

When we establish through the procedures that a prediction should be made, indeed, if we're considering it we would inform FEMA, just as we did with the volcano eruption. We informed the State and I presume local representatives, but certainly State representatives and governors are designated to receive this information. So we're not only prepared to issue formal predictions once we believe we have the capacity to do it, but also to keep people informed in an already existing network that we're considering issuing a prediction.

Senator STEVENSON. What about liability for predictions and warnings? Does the law limit such liability?

Dr. MENARD. There matters are a little awkward. Could you spell that out for us?

Dr. WESSON. Mr. Chairman, this is a difficult area and one in which there have been discussions within the administration over the last several months about how this question might be addressed. I'm not an attorney and not an expert, particularly in tort law. But there is a question as to what extent, as I understand it, the Government or individual employees of the Government, or indeed members of the National Earthquake Prediction Evaluation Council who are not, in fact, Government employees but are only advising the Government, might be liable in the event of an earthquake prediction or failure to predict an earthquake.

We in the Geological Survey, of course, as the group which would be responsible for that prediction, feel these pressures somewhat more acutely perhaps than people in other agencies of Government. And we have requested the Solicitor within the Department of the Interior to look into this question and the Office of Legislative Counsel to consider the possibility of proposing legislation which might resolve once and for all these liability questions.

These proposals have not to date been approved by the Office of Management and Budget or, I should say, even by other elements of the administration. One of the principal problems, as I understand it, is that if we were to solve this question directly, it would require an amendment to the Federal Tort Claims Act, which has not been amended for a long time, and would cause the Judiciary Committee and the whole legal establishment within the Department of Justice a great deal of difficulty.

But, Mr. Chairman, you are an attorney. Maybe you can see a different approach to this question. We indeed are quite concerned that somehow this question be fairly clearly addressed, so that when we get into a situation of earthquake prediction or a prediction that turns out not to be right, that we don't find ourselves hopelessly entangled in a morass of legal fighting that would essentially tend to reduce the effectiveness of the program.

Senator STEVENSON. I don't have to be an attorney to know that if you have to wait for Justice and OMB to sign off you're going to have to wait for a long time. But maybe we have a long time. I don't know whether you're going to have that capability for predictions, but I hope you'll keep us informed on that.

I hope we don't have to wait for OMB and Justice if there is a proposal, because those hearings deserve some consideration on the possibility of acting on this question in order to make predictions and warnings more possible.

Dr. WESSON. Mr. Chairman, we feel our responsibility to make predictions quite strongly, and I'm sure we're going to make those predictions no matter what. I shouldn't say no matter what, but based on the proper scientific evaluation of those predictions.

But one could foresee a number of scenarios in which response to those predictions might be—the effectiveness of that response might be reduced if legal questions were raised.

Senator STEVENSON. Dr. Sanderson?

Dr. SANDERSON. Senator Stevenson, I'd like to point out, that in 1978, the National Science Foundation supported a project with the Association of Bay Area Governments in California on the liability issue. They organized a team of lawyers, political scientists, engineers, and seismologists to look specifically at the liability of governments for an earthquake prediction. We supported a number of surveys at recent earthquake sites and a questionnaire survey of some 88 jurisdictions in Utah, Alaska, Washington and California.

As a result of this, I think there has been some significant increase in understanding the way the law would impact on earthquake prediction. Specifically, California law was found to be very unclear in terms of the liability of state and local officials for issuing earthquake predictions and warnings.

And as a result of this study, the Association of Bay Area Governments worked with the California Office of Emergency Services and the California Seismic Safety Commission to develop a piece of legislation, California SB 555 (which I understand has been passed), to clarify liability laws within the State of California and to increase the likelihood that local officials could safely issue a warning if they felt it was in the public interest.

Senator STEVENSON. Could we have what you've got on this, including the study that you mentioned?

Dr. SANDERSON. We'd be happy to provide that to you, sir.[2]

Senator STEVENSON. Thank you.

Dr. Calio, what will the effect of the budget cuts be on NASA's geodynamics program. The latest round is about $224 million, as I recall.

Senator SCHMITT. Abstaining is not an adequate answer.

Dr. CALIO. At present there is no change in the geodynamics program from what was originally proposed. It's still $24.8 million in fiscal year 1981.

Senator STEVENSON. It's not affected by the most recent cut?

Dr. CALIO. That's right.

Senator STEVENSON. What about the cut before? I mean the round before that. Is this an adequate level?

Dr. CALIO. It is, Mr. Chairman. If any additional funds were provided, we would accelerate some elements of the program. But it is an adequate level.

Senator STEVENSON. Senator Schmitt?

Senator SCHMITT. I may be the only scientific optimist in the room. I don't know. I feel a little bit alone in this. But I just feel it

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[2] The material referred to has been retained in the committee files.

in my bones that within the next 3 years—let's say this becomes a 3-year authorization—that you're going to be faced with trying to make a decision on whether you should predict the potential for an earthquake somewhere in this country.

First of all, don't you think that the authorization bill ought to at least take some kind of preliminary stab at the liability issue, given that situation?

Who wants to respond?

Dr. MENARD. Well, as the official who is supposed to issue such a prediction, I certainly would feel much happier to have the issue completely clarified. As Dr. Wesson reported, we get different reports from our counsel on whether there is in fact any liability at all or whether there is or isn't.

But to leave it up in the air would be most unfortunate. I think I can say that no more than any other responsible official, I would issue the warning. If I thought we really knew enough to know whether there was going to be an earthquake, it would be totally irresponsible to not do so.

But to have hanging over me and our advisory council and the other members of the Geological Survey any risk connected with making the prediction would be unfortunate. And moreover, we can't escape the fact that these are going to be judgments as to how certain a prediction is, and that these judgments always face the risk of being clouded by some assessment of personal risk arising from making the prediction.

I feel that would be an extremely low matter, but it cannot be totally disregarded.

Senator SCHMITT. Do you think it's inconceivable that in 3 years, at the present level of effort, we could not in certain specific instances make a reasonable prediction?

Dr. MENARD. Well, I've already said that I was fairly confident that I didn't know when we would be able to make a prediction in the sense that it's now defined as a prediction. When you said you were an optimistic scientist, that the need will arise in 3 years for us to make such a prediction, I would look upon that as relatively pessimistic.

Senator SCHMITT. No, I said optimistic in the sense that we can make it, which believes that science is capable of concentrating its attention and coming up with an application of fundamental science to this kind of a problem.

Dr. MENARD. I would share your confidence on that score, provided we change the definition of prediction. If we want to say at the precise time and the precise place and the precise magnitude, then I do not share that confidence. If it's a question of, can we make a useful prediction that the odds have increased on an earthquake, useful in the sense that one would prudently put bars up in cabinets to prevent things from falling out if there's a small earthquake, or prudent in the sense that you determine that the firemen really ought not to go off on vacations for a certain period, or that sort of thing. I think in the next 3 years we will be able to make such a prediction.

Senator SCHMITT. Well, that's certainly a step in the right direction, to believe that you will be able to do that. Tell me, Bill—I am sure that you and others could imagine if the San Andreas situation strikes a fault near the edge of the continental margin and the kind of precursors that we already know—you can imagine the kind of precursors, where you start getting very, very nervous, right?

You can't say that they're going to occur, but you started to believe that they would occur. Can you imagine that situation, right today?

Dr. MENARD. I certainly can. We voiced that very question to our Earthquake Prediction Evaluation Council, of which Dr. Sykes is a member; Clarence Allen is the Chairman; Kei Aki is on the committee. We're in very good hands. We have a lot of distinguished people from the Survey. I think the country is well served that we can assemble this group. And I asked them that very question: what are the precursors you can imagine that would cause us to make a definite prediction?

And they are very few, indeed, to be able to say that within days, let alone within hours, that something might happen. Certainly the Palmdale Bulge going up and down is not enough to make a prediction.

But what are the exact conditions? A break on the San Andreas fault?

Senator SCHMITT. Let me give you a more specific example. What I am saying is that you set out a series, just get people to stand back and say, "If I saw these kind of things occur, either along that fault in general or in specific parts of it, if I saw these things occur, then I would be willing to make a prediction with these kinds of categories."

Clearly, a number of us might even take a chance at that, of making a list of that kind, where I would be willing to say, "Hey, we ought to be worried." A sequence of events occurring in time—a good example, of course, is the central China case, where there was a fixed set of precursors that they used to predict that event.

If you saw sets like that begin to occur systematically, can't we at least now say that under these conditions, we would make a prediction, even though everything else you've said about the state of the art is true?

Dr. MENARD. If the confounded precursors will only come out in the same sequence, I'd agree with you.

Senator SCHMITT. All I'm saying is let's put together these lists, or consider putting together these lists, and say that if it does, this would be a worthwhile prediction. It may not. One of them may disappear, may not occur, and you'd say, "Well, that list is invalid."

Excuse me for interrupting.

Dr. WESSON. No, Senator, I think that's very close to right. I think it should be said that to some extent we are worried about California right now.

Dr. Menard already alluded to the change in the character of strain accumulation that we saw beginning about one year ago in southern California. This trend seems to have persisted through the year 1979 and into 1980. The year 1979 was a period of fairly increased level of moderate earthquakes.

We had the Imperial Valley earthquake, earthquakes near Livermore, Gilroy, and a number of earthquakes above magnitude five.

A larger number of earthquakes above magnitude five than is typical of a given year.

Many earth scientists working on these questions began to come to the conclusion, or began to speculate, that there was some kind of tectonic episode that was occurring in southern California, something perhaps in a way analogous to the passage of a cold front in the better understood field of meteorology.

Now we see Mt. St. Helens erupting in Washington state. Frankly, this adds to this concern, that we may in some way be seeing a tectonic episode that may be all over the entire West Coast.

Senator SCHMITT. For a minute, I thought you were going to say this gives us a warm feeling.

Dr. WESSON. No, I didn't say that. It's interesting to note—I learned last night that Mt. St. Helens, the last time it erupted in this way, it went on for a number of years, more than a decade, I believe—almost two decades, but terminated in 1857. You may remember that 1857 was the year in which we had the last really great earthquake in the southern part of the San Andreas fault.

So, in a way, over the last 15 years, we've come to these ideas about tectonics and the relationship between spacial phenomena of seismicity, the morphology of the ocean basins, and a number of other kinds of phenomena, but just now we're coming to temporal associations of these kind of phenomena, and it may very well be that over the next 10 to 20 years these will be the important results of the research in earth science.

But to come back more clearly to your question, we are worried about a number of things that have happened over the last year. And if we were to see, for example, a number of swarm earthquakes in the vicinity of Parkfield, California, which is a small town near which we believe the epicenter of the 1857 earthquake occurred, near where we believe now that that earthquake was preceded by a number of foreshocks in that location.

Senator SCHMITT. The name of that earthquake is what?

Dr. WESSON. The Fort Tejon earthquake of 1857. Then we would be very worried, and I think we would certainly consider giving some kind of alarm or prediction.

Senator SCHMITT. This may not be an entirely trivial question with respect to the legal aspects, too, because if we could start to tie down some prediction sequences or precursor sequences, then those could be also the basis for not only dealing with the liability question—both the liability of predicting and not having anything happen, and the liability that may occur for not predicting and having something happen.

Dr. WESSON. Senator, I think that would be a very dangerous thing to try and legislate. Perhaps I am overreacting to what you are saying.

Senator SCHMITT. I'm not saying you legislate a set of precursors, but you give the Government some flexibility in deciding what are they willing to use as a guideline to a prediction. So there's something there, more than somebody just saying, "Well, I think there may be an earthquake."

Dr. WESSON. Well, Senator Schmitt, it certainly seems to me that over the next decade, any earthquake prediction is going to have to be based, certainly, on data, on theoretical models, on an understanding of the Earth, but it's going to have to largely be based on judgment.

And if the officials that we have in the Government aren't giving the people good judgment, then we need new officials.

But I would hate to see the liability or any other kinds of issues put into some kind of form that would give some checklist that an official had to meet, in order to issue a prediction. I think that would be a big mistake.

Senator SCHMITT. Any other comments on this issue?

Dr. MENARD. I'd like to comment on the fact that I have certainly been concerned—and I think there's been a widespread concern—that we might issue predictions and just before we really had the ability—or develop the ability—and meanwhile, we'd lose all credibility in the predictions.

And people would say, "Well, you know, astrologers say something's going to happen, and we don't pay much attention to that, and now the Geological Survey says somethings going to happen, and we won't pay much attention to that, either." And therefore, it might be prudent for us to bend over backwards in not issuing a prediction, even though we're almost certain we should.

Senator SCHMITT. Well, Bill, I would hope that that would not be the case. I think what we have to do is simultaneously begin the process of teaching the public what we're trying to do, as I indicated earlier. I just don't think—my God, that we can sit here and say that we would not issue a prediction if we in our professional judgment felt that the chances were high, and that's what geology's all about. It's professional judgment. It's an art.

Sometimes you hit—when you drill that hole, you hit the ore body, sometimes you don't, but it's a judgment that you're paid to exercise. And we have to exercise that judgment, without qualifying it that we might be wrong.

Dr. MENARD. I wanted to bring the issue up, just to reinforce your statement.

I've come to the feeling that I've been grossly underestimating the ability of people to absorb bad predictions and still be willing to believe good ones when they come along. We have this marvelous relationship on the island of Hawaii, in which the Geological Survey people in the Hawaii Volcanoes National Park monitor the volcano, they understand what's happening, they can watch earthquakes at depth, they can follow the liquid rock coming up, until it's prepared to break the surface.

They watch the volcano swell. They can pretty well predict where the eruptions will occur, when they're going to occur.

Senator SCHMITT. That's no different from monitoring a hurricane, except in the time scale.

Dr. MENARD. But a hurricane you can see on television. You don't need to be convinced.

Senator SCHMITT. Other than a time scale, what's the difference between a hurricane and a fault, or a hurricane and a volcano? It's the time frame in which you view it.

Dr. MENARD. One thing that happens in Hawaii—we've gotten confident enough that we've issued a prediction that some time in the next 2 years there was going to be an eruption. I thought that meant we couldn't pin down exactly what was going to happen. I didn't say it was a useful thing, and I was apprehensive that it would cause a public counter-reaction to the quality of the predictions.

But in fact, after about a year-and-a-half went by, and 2 years approached, the Survey people there merely told the public officials whom they dealt with, almost on a weekly basis that, well, they'd been wrong. It turned out there wasn't going to be an eruption within 2 years, and the newspapers weren't upset; people weren't upset. They were perfectly willing to accept, to believe that the organization was doing the best it could, and that it produced a useful service.

So we'll do the same thing with earthquakes.

Senator SCHMITT. Thank you, Mr. Chairman.

Senator STEVENSON. Dr. Menard, I understand that the Survey has been developing a 5-year program plan. Is the final plan available?

Dr. MENARD. That's this plan, isn't it?

Dr. WESSON. Mr. Chairman, we have developed within the earthquake program a 5-year plan for our own program planning and so on. This is intended to be a constantly evolving document, so it may never, in fact, leave the draft stage. We'd be delighted to provide you with a copy of that document.

Senator STEVENSON. We have a copy of the October 1979 draft. If it has evolved since then, we would be glad to have a copy.

Dr. WESSON. That is the currently operative draft.

Senator STEVENSON. All right. Well, I am told that it's a very competent, professional, good job, and you deserve to be commended for it. If it's reincarnated, we'd be glad to have the reincarnation.

Thank you very much, gentlemen. We may have a few more questions for the record. If so, we'll submit them to you in writing. Thank you.

[The following information was subsequently received for the record:]

QUESTIONS OF SENATOR SCHMITT TO DR. MENARD AND THE ANSWERS THERETO

Question. What kind of relationship exists between FEMA and USGS as participants in the Earthquake Hazards Reduction Program?

Answer. The relationship between FEMA and USGS has been most cordial. FEMA has been supportive of our programs, and cooperation between us is excellent. To institutionalize the relationship, FEMA and the USGS are currently negotiating a Memorandum of Understanding which will define responsibilities and roles of the two agencies within the National Earthquake Hazards Reduction Program. The Earthquake Hazards Reduction Act of 1977 called for a lead agency to "have primary responsibility for the development and implementation of the Earthquake Hazards Reduction Program." The USGS supports the concept of a lead agency to facilitate the coordination of the National Earthquake Hazards Reduction Program. However, the USGS will retain authority and scientific direction over the elements of the program within its jurisdiction area.

Question. Has FEMA been fulfilling its role in this relationship?

Answer. Yes, and we expect that greater attention will be given to this area when staffing and organization development is completed.

Question. Is the present funding of USGS adequate to meet its program responsibilities?

Answer. The current level of funding to the USGS is adequate for us to meet our responsibilities in the National Earthquake Hazards Reduction Program relative to other national issues and budget priorities.

Question. How close are we to predicting earthquakes with a reasonable amount of accuracy?

Answer. The earthquake prediction program is still in the basic research stage. We have extensive geophysical instrumentation networks in place in California and in other seismic regions. From these networks we are gathering a strong body of data to examine for earthquake precursors and to determine the valididty and uniqueness of these phenomena. We hesitate to state that the earthquake prediction problem will be solved on any given date or within any given time frame. We believe that the accuracy of earthquake predictions will increase over time as we gain experience in interpretation of the data and confidence in the theories we use to model the earthquake process. Despite these qualifications, it is conceivable that some accurate earthquake predictions could be made in the next few years should premonitory phenomena be observed in a densely instrumented area.

Question. What is FEMA's role in the earthquake prediction process?

Answer. The respective roles and responsibilities of FEMA and the USGS regarding earthquake hazards reduction are still being discussed. The Director of the USGS has the clear responsibility to evaluate and issue earthquake predictions. We anticipate FEMA's primary role to be in earthquake prediction response planning; i.e., working with Federal, State, and local officials to develop contingency actions to be put into effect once a prediction has been issued.

Question. Are there any major liability problems for USGS in predicting earthquakes?

Answer. As you know, we have established the National Earthquake Prediction Evaluation Council which is composed of Government and non-government members. There is some question about the protection afforded non-government members while serving in an official capacity on this Council. Possible suits against these individuals could discourage highly qualified scientists from serving and could result in the scientist being extremely conservative in evaluating data and advising the Director.

Question. What legislation is necessary to free USGS from such liability?

Answer. We do not believe any legislation is necessary at this time. A Federal interagency group is examining the Federal Government employee tort liability provisions generally to see if there is need for revision of the Federal Tort Claims Act. We plan to present our concerns about liability for prediction of geological hazards, especially earthquakes, for the group's consideration.

Question. On what basis will an earthquake prediction be made?

Answer. As noted in response to an earlier question, we presently do not have any formula or set procedure upon which to base earthquake predictions. We would expect to base our earthquake predictions on physical observation of geological, geophysical, and hydrological phenomena. These phenomena will be evaluated on the basis of physical understanding of the geologic processes involved and on the basis of empirical experience from around the world. Initial predictions undoubtedly will contain a large element of judgment. We would anticipate that initial predictions would be cast in probabilistic terms. That is, we would state that there is a certain chance of an earthquake of a given magnitude occurring in a given region over a given time interval. As we gain experience and confidence, we should be able to narrow the spatial and temporal boundaries of our predictions.

Question. Does the USGS have the necessary authority to predict earthquakes? If not, what steps need to be taken to given the agency such authority?

Answer. We believe we have the authority to issue earthquake predictions based on the Organic Act of the Geological Survey. However, interpretations of the Federal Disaster Relief Act have raised questions about our interpretation. We plan to submit a legislative proposal in the near future to clarify the Director's authority to issue predictions and warnings for all types of geological hazards, including but not limited to earthquakes.

Question. In light of the fact that most earthquakes occur outside of the U.S., does USGS face any international constraints on its research efforts?

Answer. The original Earthquake Hazards Reduction Act of 1977 directed that research elements of the program shall include, among other things, studies of foreign experience with all aspects of earthquakes. We are presently spending approximately $1.5M on studies of foreign earthquakes. Much of our foreign work is accomplished through grants or contracts to universities. This is partly due to Federal restrictions on travel by Government employees.

Question. Is USGS presently cooperating with any foreign governments or agencies in research efforts? What are the goals and what have been the benefits of such cooperation?

Answer. Yes, we are working with a number of countries, including China, Japan, and Russia. We believe much will be gained through this interchange, particularly with China and Japan, in view of China's long recorded history of seismic activity and recent successes in predicting earthquakes and in view of Japan's knowledge in instrumentation. Our work with the Soviet Union has resulted in several published works.

Question. what is the relationship between USGS and NSF regarding the Seismic Engineering Program? What cooperation exists in other areas?

Answer. By Memorandum of Understanding signed in 1973 by the Secretaries of Commerce and the Interior and the Director of the National Science Foundation, the responsibilities for the funding and management of this seismic engineering program were transferred to the NSF from Commerce (NOAA), while the responsibility for operation (and personnel) were transferred to Interior (USGS). This program, now embodied in the Seismic Engineering Branch of the Geological Survey is funded by the NSF. The primary responsibility of this Branch is to record the strong shaking of the ground and structures from nearby earthquakes. This program is the primary source of strong motion data used by engineers in the design of earthquake-resistant facilities. We maintain close, informal contact on programmatic matters and maintain coordination through the joint exchange of liaison representatives to various advisory panels and program review activities, including the review of proposals for grants and contracts to universities.

Question. What responsibilities does FEMA have in the dissemination of information?

Answer. This is still being defined; however, we anticipate that FEMA will play a major role in disseminating earthquake hazards information, warnings, and predictions.

Question. How does USGS disseminate information?

Answer. Our primary means of information dissemination is through publications and reports on results of our research. In addition, we issue press releases when significant new results have been obtained and when damaging or noteworthy earthquakes occur within the United States or elsewhere. We also conduct workshops for the purposes of exchanging information between scientists and for interpreting our research results to non-specialists. Workshops are also conducted to gain advice from non-specialists on what type of information they require in their earthquake hazards mitigation efforts.

Question. Are there funding problems with the Seismic Engineering Program?

Answer. The data gathered by the Seismic Engineering Program is extremely important to designers and engineers and opportunities to obtain such data occur only infrequently at the time of large earthquakes. Discussions are continuing between the USGS and NSF on the level of support and degree of expansion of this program.

Question. How has the underfunding of the policy research element affected the EHR program?

Answer. In the initial development of the program policy research was given a lower priority in relation to other research requirements. As the program matures, we anticipate greater emphasis on policy research to make optimum use of earthquake hazards information and warnings.

Question. What would be your views on having the policy research effort permanently transferred to FEMA to insure a steady source of funding?

Answer. The Geological Survey is principally a scientific organization. We do, however, have the capability to conduct policy research as it applies to earthquake hazard reduction. We have no strong views on that topic.

Question. As of yet, your five-year plan includes no funds for hazards assessment of the Albuquerque area. Why is this?

Answer. In our judgment, the need for accurate seismic hazards information is more acute at this time in other metropolitan regions than in the Albuquerque region. The Albuquerque region will be studied; however, in the interim, the techniques developed and lessons learned by studying the highest priority areas will have spinoff benefits in studying the Albuquerque area. Indeed, the techniques developed and lessons learned in the study of other regions are already applicable to some extent to the Albuquerque area.

Question. In your view, what overlap exists among agencies associated with the EHR program?

Answer. We are unaware of any overlap—the roles and responsibilities of the various agencies involved in the Earthquake Hazards Reduction Program are well defined in the President's Implementation Plan.

Senator STEVENSON. Our next witness is Dr. Lynn Sykes, Higgens Professor of Geology at the Lamont Doherty Geological Observatory in New York. Dr. Sykes.

STATEMENT OF DR. LYNN SYKES, HIGGENS PROFESSOR OF GEOLOGY, LAMONT DOHERTY GEOLOGICAL OBSERVATORY, PALISADES, N.Y.

Dr. SYKES. Mr. Chairman, Senator Schmitt, I thank you for this opportunity to present some of my views about the activities in the United States that are aimed at reducing earthquake hazards and to discuss the extent to which the United States is prepared to anticipate and respond to a damaging earthquake. I will present about half of my written testimony, if that's all right.

Senator STEVENSON. Please do. The full statement will be entered in the record.

Dr. SYKES. I was a member of the Newmark-Stever Committee that recommended in 1976 that the United States make a major effort to mitigate the hazards of earthquakes; I am head of the seismology group at Columbia University, one of the largest university groups in earthquake research.

We operate earthquake monitoring programs in Alaska, Puerto Rico, the Virgin Islands, the states of New York, New Jersey, and Vermont, and three foreign countries.

Today, I would like to review what I consider to be some of the major advances of the last few years in our ability to predict earthquakes, and give you my assessment of future prospects in that area, and to comment about the progress in studying earthquake hazards in the eastern and central part of our country.

Major advances have been made during the last few years in ascertaining where very large earthquakes are most likely to occur during the next 10 to 20 years, and also in estimating their size. The time of occurrence of a few large earthquakes has been predicted successfully in the Soviet Union, China, and Mexico. Japanese scientists appear to have come very close to predicting a large earthquake in one of their test areas in 1978.

Forerunning or precursory effects have been observed before several earthquakes in the United States and in several other countries. As yet, however, no one forerunning effect has been observed with enough regularity, either in our country or elsewhere so that we can feel confident that it can be employed to estimate the time of occurrence of future shocks with a high level of confidence and accuracy.

The subject of prediction should be regarded as being still in its beginning stages. In my estimation, successful prediction will require both fundamental research on the earthquake process and the establishment of the technical means of monitoring forerunning effects.

Clearly, there are several fundamental things we do not understand about the earthquake process. I believe that such knowledge is a prerequisite to successful, reliable, and socially useful prediction.

I think that we have made good progress in the last few years in installing and operating monitoring networks in several parts of our country. Observations and fundamental studies conducted in the United States and in several other countries during the past few years lead me to be optimistic about the chances for prediction of earthquakes within the next 15 years.

Chinese scientists successfully predicted a major earthquake in 1975. Tens of thousands of lives may well have been saved by a warning that they issued, advising people to remain out of doors for a few days. While a few other shocks in China have been predicted successfully, the devastating Tangshan earthquake in 1976 was not.

Several hundred thousand people were killed in that event, probably more than in any other earthquake during the past 500 years.

Soviet scientists have observed several forerunning effects in central Asia that led them to forecast a large shock within 1 or 2 years. They were eventually able to predict correctly in 1978 that a large earthquake would occur within 1 day.

It is clear from these case histories that intensive and repeated monitoring of several quantities must be carried out in any area in which we would hope to predict earthquakes.

Japan, China, and the USSR started major national programs of prediction in the early to mid-1960s. Much of our present program only got underway a few years ago. Those three countries are mounting an effort which I would estimate is about two to five times as large as ours.

For example, Japanese scientists installed what I regard as the world's most sophisticated and comprehensive monitoring network in a region to the southwest of Tokyo that they think is likely to be the site of a great earthquake within the next 10 to 20 years. That area is one of the most industrialized and populated regions of Japan.

Fundamental research in many different areas of the earth sciences in the 1950s and 1960s led to a major breakthrough in understanding the Earth about 1968. That concept is called the plate tectonic model. We now realize that the active earthquake belts of the world occur along zones of contact between several large plates, much like cakes of ice floating on a river that make up the surface of the Earth.

The movement of plates causes pressures and stresses to build up slowly for decades to hundreds of years along the boundaries between the plates.

These stresses are then released suddenly at the time of large earthquakes. We now realize that great shocks do not strike twice at the same place within a time interval shorter than about 30 years. Areas located along the edges of these plates, that have not experienced great shocks for many decades, are now recognized to be the most likely sites of future great earthquakes.

Such places have been given the name seismic gaps. I think we're now examining many of the right places for the great earthquakes of the next one or two decades.

Four of us recently published a map, which is shown in figure 1 of my written testimony, which shows areas that appear to be the most likely sites of future great shocks, for a number of the major earthquake belts of the world. Two areas in southern Alaska which are noted as gaps in the figure 2 appear to have a high potential for being the sites of great earthquakes within the next 15 years.

Alaska is our most seismically active state.

One of the areas of high earthquake potential which is called the Yakataga Gap was recently declared to be an area for intensive study and monitoring by the U.S. Geological Survey. That area is located in the upper right corner of figure 2. Three of us found that the area had ruptured in two great shocks in 1899. What appeared to be a long-term change in the region, possibly a forerunning effect, commenced about 20 years ago.

We submitted our findings to a panel convened by the USGS. A paper outlining our case was prepared for the panel and was published recently in the magazine Science, and it is included as an appendix to my testimony.

Since the time of occurrence of a possible great shock in that area cannot be estimated very precisely, it seemed reasonable to designate the region as one of high earthquake potential and one deserving of intensive study. In this sense, we follow the Japanese program of having several different levels of warning, and we considered this to be the first and lowest level of earthquake warning, or perhaps prediction.

Recent work at my university indicates that great shocks have occurred in the Shumagin seismic gap, which is near the center of figure 2, on the average of every 50 to 75 years. That region has not been the site of a great shock for at least 77 years.

Both of these gaps in Alaska present an opportunity to catch the forerunning signals of a great shock within monitoring networks. Scientists from my university and the USGS are working in these two areas. Nevertheless, the level of work that is now being supported in those two seismic gaps in Alaska is still sparse enough that I believe there is a good chance that we will not be able to detect forerunning effects and then to successfully predict a great event before it happens. On the other hand, we may be lucky enough that, with the equipment and monitoring that we do have, to in fact catch the signals of a large earthquake.

There was a similar case in Mexico of a seismic gap in which subsequently scientists from the University of Texas indicated from some changes in the rate of activity of small earthquakes that there was a good chance of there being a large earthquake there within a few years. And a shock did, in fact, occur in that area and filled in that gap in 1978.

The seismic gap concept does provide a way in which we can estimate the predicted shaking at given points near that gap. Once we have identified gaps, as we have in Alaska, we can, in fact, move on to estimate fairly accurately the level of shaking.

Prior to 1970 very little was known about the earthquake process in areas of our country outside of California. Since then networks have been established in about 20 states, and information is now becoming available on a number of factors, including, for the first time, the relationship of earthquakes to specific faults.

One particular recent finding from trenches that were dug across the Wasatch fault near Salt Lake City, Utah, indicate the previous large shocks have occurred more frequently in that area than most earth scientists had previously suspected. The reason for that is that the historic record in that area is quite short: only about 100 years.

Figure 3 indicates that several damaging historic earthquakes have occurred in many states. Figure 4 shows that for their size, earthquakes in the central and eastern parts of the country are characterized by much larger regions of shaking and damage than shocks in the West. A major effort has been made in the last few years to examine earthquakes on a geologic basis, and faults in the vicinity of the famous Charleston, South Carolina, earthquake of 1886 and the region in the central United States near the famous series of earthquakes in 1811 and 1812. That's in the central Mississippi Valley.

The last figure, figure 5, shows the locations of earthquakes reported during the last 10 years by a new network of stations in New England and some of the mid-Atlantic states. Also in this area for the first time we have been able to identify earthquakes with specific faults.

Since Japan, China, and the USSR started their programs earlier and have had experience in recording larger shocks during the past 10 years than we have, they have obtained more data and more case histories than we on possible forerunning effects to large earthquakes.

I do believe the U.S. program strikes a good balance among the variety of areas that are being monitored, the support of fundamental studies, the mapping of faults, and the estimation of earthquake hazards. The U.S. program is one of the world's leaders in studies of the physics of the earthquake process, laboratory studies, of predictions of the amount of shaking to be expected at given locations in future earthquakes, and the application of space technology to earthquake prediction.

Japan, China, and the USSR each devote a much greater effort to monitoring earth movements, using precise but conventional surveying techniques.

Let me say a word about the funding of the program. Five of the six main program elements of the National Earthquake Hazards Reduction program are being supported well below either of the three funding options recommended in the Newmark-Stever Report of 1976. The lowest level of funding in that report was considered to be barely adequate to accomplish the objectives of the plan. In fiscal year 1980 earthquake prediction received about 77 percent of the funds recommended under the low option, 70 percent of that under the intermediate option, and 55 percent under the high option.

For hazards assessment, the percentages are a little bit lower than that. These various percentages would also be lower if allowance is made for inflation.

Finally, I would like to conclude that I believe that the present program of prediction in our country can be compared with the large effort that was made in seismology 10 to 20 years ago to improve the detection of underground nuclear explosions and to distinguish their signals from those of the many earthquakes that occur each year. That program was successful in that our capabilities were vastly improved through support of basic research in earthquake studies, the development of new instruments, and the development of better data processing techniques, and, of course, the installation of more sensitive monitoring stations.

In the beginning of the nuclear monitoring program, many seismologists believed the prospects for success were good. That judgment, I believe, turned out to be correct. Many of the techniques that initially appeared to be most promising, however, were not very successful. The most powerful methods which were developed through research turned out to be rather different from several of the initial proposals.

Hence, I believe that we've made a good start in our program of earthquake prediction and hazards reduction. But the prospects are good that we do, in fact, have a long way to go, particularly in developing methods for time scales for hours, days, and months.

Senator STEVENSON. Thank you, sir.

The Newmark study projections went through fiscal year 1980, I believe. Do you have an opinion as to what appropriate expenditure levels would be for the agencies participating?

Dr. SYKES. I have not come up with specific monetary amounts, no. But I would still believe that some of the ideas that went into this program are still valid and that the low-level option should be considered one that is barely adequate.

Senator STEVENSON. And we're below the low-level option?

Dr. SYKES. We're below the low level, yes.

Senator STEVENSON. So, presumably, we are accumulating a lot of undone work that might require projections, especially after inflation, at a higher level than those off the chart from the Newmark study?

Dr. SYKES. That's correct. And I have certainly made a list of some of the areas that I think could certainly benefit from increased funding, and ones in which right now we're not able to make a very large dent in them.

Senator STEVENSON. I understand that a research group that you were associated with in New York successfully predicted a minor earthquake in New York several years ago. Is that right?

Dr. SYKES. That's correct.

Senator STEVENSON. How do you feel about the responsibilities of American scientists on their own to make predictions, to offer warnings about the liabilities, if any, associated with such predictions?

Dr. SYKES. We've had some more recent experience, in this case, in Alaska. There was a fairly large earthquake about a year ago in this one seismic gap in Alaska. It only broke a small portion of that region, but it led us to reexamine a lot of the older data, and we saw some changes going on in that region that we believe may be very long-term forerunning effects of that eventual large earthquake.

So, in discussing those findings, we had some meetings with scientists from the Geological Survey to discuss data that they had also collected from that region. And this eventually then led to a formal declaration of that area as the lowest level of warning—in other words, one for intensive study. In some ways that might be called a prediction—but it was not one in which we were able to estimate a precise time of occurrence of a future earthquake.

Senator STEVENSON. Well, I guess what I raised initially is a question of the moral responsibility of scientists. Do you feel it's morally right to wait for the USGS or work something out with the

USGS where you as a scientist have pretty strong feelings that people are in danger in a given area, that you have a duty to issue your own warnings?

Dr. SYKES. Well, I certainly think that we want to make these findings available as quickly as possible. They are not something that can be kept quiet, anyway.

Senator STEVENSON. What if USGS doesn't do anything?

Dr. SYKES. In this case, we felt that we had very good success then in working with them. I think, from some of the press reports in Alaska, some of the newspapers commented that they felt that the level of warning had been a good one and that they were glad that it had been received.

Senator STEVENSON. Are scientists concerned about personal liability for the consequences of warnings?

Dr. SYKES. I think concerned, but I don't think overly concerned.

I know that I was involved in a situation about 7 years ago in the western part of New York State in which some earthquakes, some small earthquakes, were being generated by fluid injection associated with a mining process. And we became involved in that by picking up the earthquakes and notifying the State of New York.

And when I did ask them, the State, for an opinion about our legal obligations that might be involved with that, they did tell me that orally they felt that I or Columbia University could be liable.

Senator STEVENSON. Counsel is telling me that a scientist in southern California, not many years—did make a prediction—he predicted an earthquake in 1 year in a city, and the city threatened to sue him for damaging the economy. This was Los Angeles.

Dr. SYKES. Right.

Senator STEVENSON. That, then, might be a subject for legislation, perhaps, federal legislation, to establish liability or limit it?

Dr. SYKES. I would think so. But it's not something which I have delved into sufficiently.

But, certainly, the case of which you are speaking, with Dr. Whitcomb, certainly brings up what could well become a future problem.

Senator STEVENSON. Am I right: has the government, in its infinite wisdom, located the southern terminus of the trans-Alaska pipeline right in that gap that you referred to?

Dr. SYKES. It's right at the western end of the gap, yes.

Senator STEVENSON. What about Mt. St. Helens, is that volcanic activity caused by earthquake activity, or could it cause earthquakes? Is there a connection?

Dr. SYKES. Very often, in conjunction with the eruption of a volcano or the swelling of a volcano, there are earthquakes, including occasionally some larger shocks. There have been some moderate sized earthquakes in the last few days associated with that process. Whether this, in fact, has anything to do with an earthquake in California, I think, is certainly a debatable prospect.

Senator STEVENSON. I have the feeling that when we last went into this subject, which was about 3 years ago, that scientists were more optimistic then about the ability to predict with a high degree of credibility earthquakes than they are now. Are you optimistic or pessimistic? When do you think we will have this ability, if ever?

Dr. SYKES. Well, I feel quite optimistic.

In my testimony, I mentioned 15 years. I think within that time the chances are good that there will be some fairly good-sized earthquakes so that we will then have the chance to see whether we can pick up forerunning effects. I think that we will probably successfully predict some earthquakes during the next 15 years, but that we may well miss some other earthquakes for some reasons that we don't understand or for lack of monitoring equipment.

Senator STEVENSON. Does the extent or duration of that time frame vary significantly with the level of federal funding for this earthquake program?

Dr. SYKES. It certainly would. In these two areas of Alaska that I have mentioned, I think there is no question that there are three or four critical things that could be done in those areas that would substantially improve our capabilities for predicting. Hopefully, then, too, if we can pick up some signals in places like that, hopefully, that might be useful in, say, southern California or other more populated parts of the United States.

Senator STEVENSON. Things that could be done now with the existing state of knowledge to improve our ability to reliably predict earthquakes in, say, Alaska?

Dr. SYKES. Yes. And, for example, one change that has been seen in a number of areas, that's been the level of water in deep wells where, if we are very close to the coming earthquake, there can be very large changes in the fluid level. That's something that's being monitored to a modest level in southern California. It's not being done at all in either of these places in Alaska.

Senator STEVENSON. Is that a USGS responsibility, or NSF's?

Dr. SYKES. That's a USGS responsibility.

Senator STEVENSON. And it would be in Alaska?

Dr. SYKES. Yes.

Senator STEVENSON. What about animal behavior as a source of useful information on seismic activity, do you have an opinion?

Dr. SYKES. I was part of the U.S. studies delegation of earthquake scientists that visited China about 5 years ago. And I became convinced that there definitely is something to the fact that animals quite certainly are detecting something. We don't understand what that something is. There is a modest level of effort going on in the present program in that field. It's not something that I would recommend a huge effort in that area.

Also, in China, although it's received a lot of publicity in the newspapers here, most of the Chinese program is aimed at monitoring the same forerunning effects we're trying to monitor.

Senator STEVENSON. Thank you very much.

Dr. SYKES. Thank you, sir.

[The statement follows:]

STATEMENT OF LYNN R. SYKES, HIGGINS PROFESSOR OF GEOLOGY AND HEAD OF THE SEISMOLOGY GROUP, LAMONT-DOHERTY GEOLOGICAL OBSERVATORY OF COLUMBIA UNIVERSITY

Mr. Chairman and members of the Subcommittee, I thank you for this opportunity to present some of my views about activities in the United States that are aimed at reducing earthquake hazards and the extent to which the United States is prepared to anticipate and respond to a damaging earthquake. I present these remarks as a person who has been involved in earthquake research for 20 years, and who was a member of the Newmark-Stever committee that recommended in 1976 that the United States make a major effort to mitigate the hazards of earthquakes. I am head of the seismology group at Columbia University, one of the largest university groups in earthquake research in the United States. We operate earthquake monitoring programs in Alaska; Puerto Rico and the Virgin Islands; the States of New York, New Jersey and Vermont; and three foreign countries. I am a member of the Advisory Committee on Earthquake studies to the U.S. Geological Survey and a member of the newly-formed National Earthquake Prediction Evaluation Council.

Today I would like to review what I consider to be some of the major advances of the last few years in our ability to predict earthquakes, to give you my assessment of future prospects in that area, and to comment about progress in studying earthquake hazards in the eastern and central United States.

Prospects for earthquake prediction

Major advances have been made during the last few years in ascertaining where very large earthquakes are most likely to occur during the next 10 to 20 years and in estimating their size. Likewise, we have been able to identify many other regions as not being likely sites of great earthquakes over the next few decades. The time of occurrence of a few large earthquakes has been predicted successfully in the U.S.S.R., China and Mexico. Japanese scientists appear to have come very close to predicting a large earthquake in one of their test areas in 1978. Forerunning or precursory effects have been observed before several earthquake in the United States and in several other countries. As yet, however, no one forerunning effect has been observed with enough regularity either in our country or elsewhere so that we can feel confident that it can be employed to estimate the time of occurrence of future shocks with a high level of confidence and accuracy.

The subject of earthquake prediction should be regarded as being still in its beginning stages. In my estimation, successful prediction will require both fundamental research on the earthquake process and the establishment of the technical means of monitoring forerunning effects. Clearly, there are several fundamental things we do not understand about the earthquake process. I believe that such knowledge is a prerequisite to accurate, reliable and socially-useful prediction. I think that we have made good progress in installing and operating monitoring networks in several parts of the country during the past few years. Observations and fundamental studies conducted in the United States and in several other countries during the past few years lead me to be optimistic about the chances for the prediction of earthquakes within the next 15 years. While I do not foresee a dramatic breakthrough in the next few years that would solve the problem of earthquake prediction once and for all, I do not think solutions are likely to be so far removed in the future that we should not anticipate a much improved capability for prediction over the next 15 years. How fast we move toward prediction depends very strongly upon the level of funding of the program.

Successful predictions in other countries

Chinese scientists successfully predicted a major earthquake that struck northeastern China in 1975. The prediction of the time of that event, which was rich in forerunning effects, was gradully narrowed down from a few years to a few days as the time of the shock approached. Tens of thousands of lives may well have been saved by a warning advising people to remain outdoors for a few days. While a few other shocks in China have been predicted successfully, the devastating Tangshan earthquake of 1976 was not predicted with sufficient accuracy so that a short-term warning could be issued. Several hundred thousand people were killed in that event and the economic consequences were enormous. That event, which probably killed more people than any other earthquake during the past 500 years, brings home the realization that our field of study has the potential of enormous savings of lives and property not only in our country but in many earthquake-prone areas of the world. In retrospect, it appears that some short-term effects were observed a few days prior to the Tangshan earthquake. Officials in one county apparently took actions based on forerunning reports.

Soviet scientists also observed several forerunning effects in Central Asia that led them to forecast a large shock within one or two years. By concentrated and repeated monitoring of the region, they were eventually able to predict correctly on October 31, 1978 that a large earthquake would occur within one day. Japanese scientists also observed anomalous changes in land elevation and in the concentration of the radioactive gas radon in water taken from deep wells before a large shock in 1978. It is clear from these case histories that intensive and repeated monitoring of several quantities must be carried out in any area in which we would hope to predict earthquakes.

Japan, China, and the U.S.S.R. started major national programs of earthquake prediction in the early to mid 1960's. Although a similar U.S. effort was recommended following the great Alaskan earthquake of 1964, much of our present program only got underway a few years ago. After visiting some of the areas that are being extensively monitored in those countries and in following their work in the scientific literature, I conclude that each of them is mounting an effort that is about 2 to 5 times as large as that of the U.S. program. For example, Japanese scientists have installed what I regard as the world's most sophisticated and comprehensive monitoring network in a region they think is likely to be the site of a great earthquake within the next 10 to 20 years. That area is one of the most industrialized and populated regions of Japan.

Sites of future great earthquakes

Fundamental research in many different areas of the earth sciences in the 1950's and 1960's led to a major breakthrough in understanding the earth in the late 1960's. The concept is called the plate tectonic model or the new global tectonics. As a result, we now realize that the active earthquake belts of the world occur along zones of contact between several large plates that make up the surface of the earth. These plates are analogous to large sheets or cakes of ice floating on a river. The movement of the plates causes pressures and stresses to build up slowly for 10's to 100's of years along the boundaries between the plates. These stresses are then released suddenly at the time of large earthquakes.

We now realize that great shocks do not "strike twice" at the same place within a time interval shorter than about 30 years. Areas located along the edges of these plates that have not experienced great shocks for many decades are now recognized to be the most likely sites of future great earthquakes. Such places are called "seismic gaps". Prior to 1968, monitoring nets were often installed in areas after a large shock had occurred. In retrospect we now realize that that is much like closing the barn door after the horses have left. Those specific regions are unlikely to experience another great shock for many decades. I think we are now looking in the right places for the great earthquakes of the next one or two decades.

Four of us at Columbia University recently published a map (Figure 1) showing areas that appear to be the most likely sites for future great shocks or a number of the major earthquake belts of the world. Category 1 indicates regions that have not experienced great shocks for at least 100 years and that are regarded as having the highest potential for being sites of future great shocks. Some areas, such as those near the coasts of Mexico, Central America and southern Alaska are characterized by repeat times of less than 100 years. Hence, some of those areas also have a very high potential for being sites of future great shocks. Category 6 denotes regions, still in earthquake prone areas, considered to be least likely sites over the next few decades.

Two areas in southern Alaska, which are denoted as gaps in Figure 2, appear to have a very high potential for being the sites of great or giant earthquakes within the next 15 years. Alaska is our most seismically active state. Much of the remainder of the boundary between two great plates that extends along the coast of southern Alaska and the Aleutian Islands has ruptured in large shocks within the last 40 years and hence appears less likely to be the sites of future great shocks within the next 10 to 20 years.

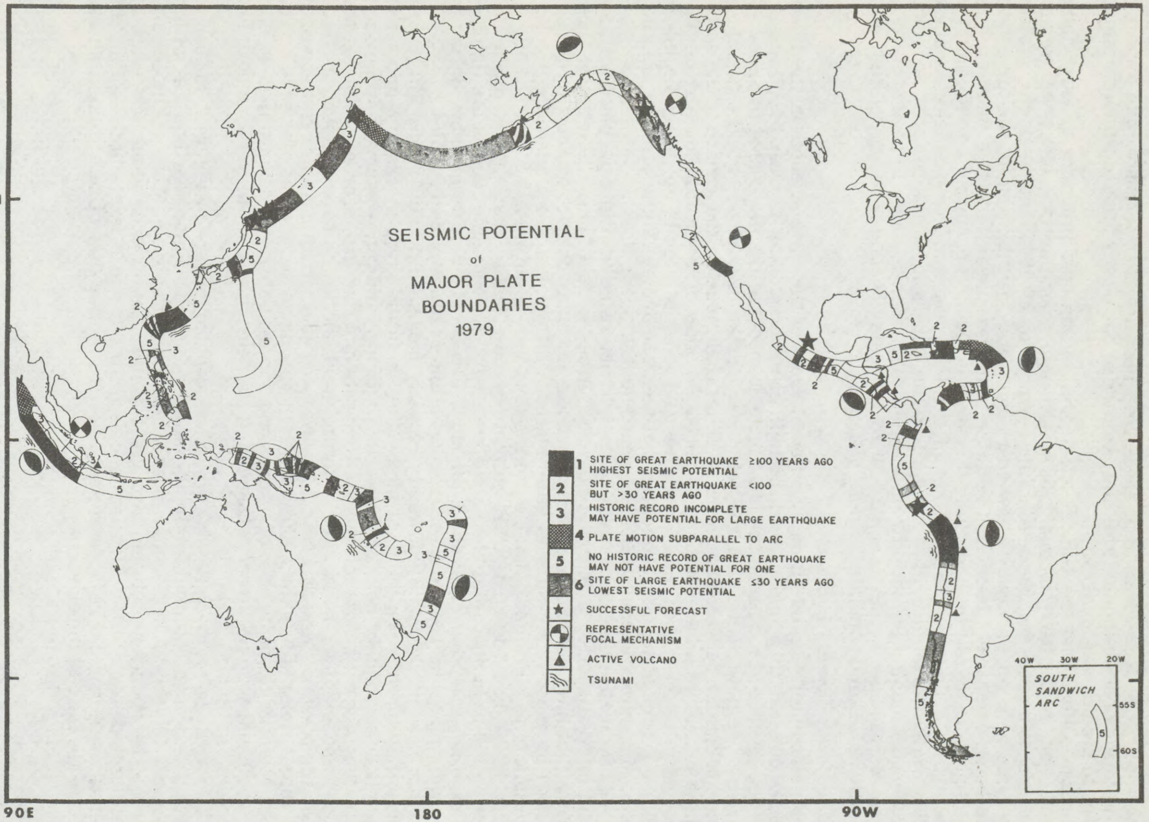

SEISMIC POTENTIAL
of
MAJOR PLATE
BOUNDARIES
1979
1 SITE OF GREAT EARTHQUAKE ≥100 YEARS AGO HIGHEST SEISMIC POTENTIAL
2 SITE OF GREAT EARTHQUAKE <100 BUT >30 YEARS AGO
3 HISTORIC RECORD INCOMPLETE MAY HAVE POTENTIAL FOR LARGE EARTHQUAKE
4 PLATE MOTION SUBPARALLEL TO ARC
5 NO HISTORIC RECORD OF GREAT EARTHQUAKE MAY NOT HAVE POTENTIAL FOR ONE
6 SITE OF LARGE EARTHQUAKE ≤30 YEARS AGO LOWEST SEISMIC POTENTIAL
SUCCESSFUL FORECAST
REPRESENTATIVE FOCAL MECHANISM
ACTIVE VOLCANO
TSUNAMI
SOUTH SANDWICH ARC
40W
30W
20W
55S
60S
45N
0
45S
90E
180
90W

Figure 1

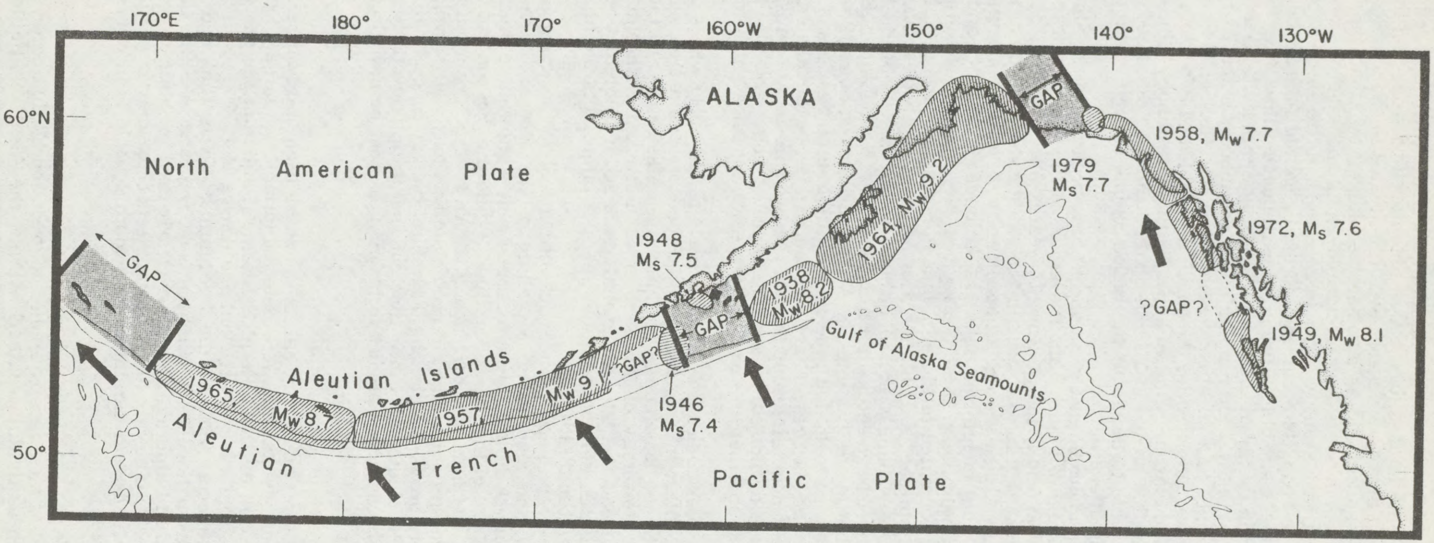


Figure 2. Rupture zones of large earthquakes in southern Alaska and the Aleutians from 1938 to 1980. Gaps, which are places that have not been sites of large earthquakes for many decades, are regarded as likely locations of future great earthquakes. Gap in center of figure is in Shumagin Islands; Yakataga gap is near top right corner.

One of the areas of high earthquake potential in Alaska, which is called the Yakataga gap, was recently declared to be an area for intensified study and monitoring by the U.S. Geological Survey. That area, which is located in the upper right corner of figure 2, was first identified as a major seismic gap by scientists from Columbia University in 1968. A large shock occurred along the edge of the gap about a year ago. Although that event was not large enough to fill in or rupture more than about 20% of the gap, its occurrence focused renewed interest on the potential of the region to be the site of a future great earthquake. Three of us found that the area had ruptured in two great shocks in 1899. What appeared to be a long-term change in the region, possibly a forerunning effect, commenced about 20 years ago. We submitted our findings to a panel convened by the U.S. Geological Survey. A paper outlining our case was prepared for the panel, was published two weeks ago in the magazine Science, and is included as an appendix to my testimony. Since the time of occurrence of a possible great shock in that area cannot be estimated very precisely, it seemed reasonable to designate the region as one of high earthquake potential and one deserving intensive study.

Recent work at Columbia indicates that great shocks have occurred in the Shumagin seismic gap near the center of Figure 2 about every 50 to 75 years. That gap has not been the site of a great shock for at least 77 years. We conclude that the probability is high that great shocks will occur in the two gaps within the next 15 years. Both of these gaps in Alaska present an opportunity to "catch" forerunning signals of a great shock within monitoring networks. Columbia University and the U.S. Geological Survey are working in these two regions. Nevertheless, the present networks are rudimentary compared to those in Japan or in some parts of California. Both areas in Alaska present difficult logistics and are expensive places in which to work. For example, changes in the level of water in deep wells have occurred prior to a number of large shocks in China, the U.S.S.R. and Japan. Since deep wells are not available in the two gaps in Alaska, drilling equipment would have to be brought in if we wish to do that type of monitoring. Investigations of that type appear to be well beyond the present levels of funding for earthquake studies in Alaska. The level of work now being supported in the two gaps in Alaska is still so sparse that I believe we do not stand a good chance of being able to detect possible forerunning effects and then to successfully predict a great event before it happens.

We now know of about 15 examples from various parts of the world where great shocks have ruptured or "filled in" regions that had been recognized as seismic gaps. Our group first identified such a gap along the coast of Mexico near Oaxaca in 1973. Scientists from the University of Texas observed a marked change in the number of smaller earthquakes in that area several years ago and forecast that a large shock was likely to occur there within a few years. A large shock did, in fact, rupture that zone on November 28, 1978.

Hence, the concept of seismic gaps provides us with a tool for selecting a few areas for intensive study and monitoring. Modelling of the seismic source has advanced to the point where shaking at given locations near a gap can be predicted fairly accurately once the size of the gap is identified. While the gap concept itself cannot be used to predict the time of occurrence of future shocks very accurately, detailed monitoring of a variety of possible forerunning effects may well provide the data we need to make more precise predictions. Therefore, the gap concept can only be applied to very large earthquakes. Since that concept is unlikely to be very useful for moderate-size shocks, other predictive techniques must be developed for them.

Shorter-term precursory effects

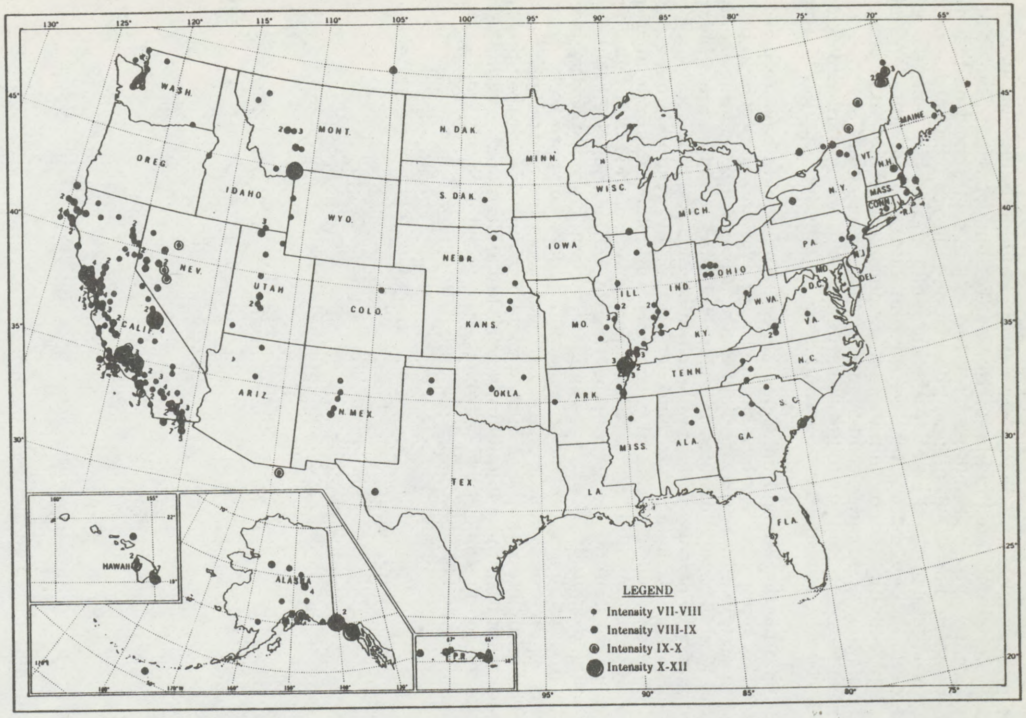
In addition to the short-term precursory effects that have been observed recently in other countries, similar phenomena were detected prior to a large shock in Hawaii and before two recent earthquakes in California. Data from the shocks in California as well as that from a large earthquake in Alaska in 1979 are still being analyzed for precursory effects. Some of the forerunning effects that had been reported for moderate-size earthquakes in northern New York and in South Carolina have not been observed in California. Hence, we clearly need to obtain more case histories before we can decide if certain forerunning effects occur only in particular geologic environments or if certain parameters are more reliable indicators than others of future earthquakes.

Earthquakes in other parts of the United States

The seismic gap concept is most readily applied to great shocks that occur along the very active belts such as those in southern Alaska, the Aleutians, California, Puerto Rico and the Virgin Islands. Prior to 1970 very little was known about the earthquake process in areas of the United States outside of California. Since then networks have been established in Alaska, Nevada, Washington, Utah, South Carolina, Puerto Rico, the Virgin Islands and portions of the central and northeastern parts of the country. For the first time, information is becoming available on the relationship of shocks in those areas to specific faults and on the depths, mechanisms, and stress drops. Trenches that were recent excavated across the Wasatch fault near Salt Lake City, Utah, indicate that previous large shocks have occurred more frequently than most earth scientists had previously suspected.

Since I have been involved in studies of earthquakes in the eastern and central parts of the country, I would like to outline some of the more significant recent results.

Figure 3 indicates that several damaging historic earthquakes have occurred in many States. For their size, earthquakes in the central and the eastern United States are characterized by much larger regions of perceptibility and damage than shocks in the West. This is illustrated in Figure 4 where the dotted areas indicate regions of comparable damage for four well-known earthquakes. The area of a given level of damage and of shaking was much greater for the South Carolina earthquake of 1886 even though its size or magnitude was comparable to that of the California earthquake of 1971. Similarly, the earthquake of 1811 was felt over a greater area of the country than any other known U.S. shock. Nevertheless, in terms of Richter magnitude, it was smaller than the San Francisco earthquake of 1906. Hence, a shock in the central or eastern U.S. does not have to be a great earthquake to cause considerable damage. Earthquakes in the central and eastern U.S. occur within a plate rather than along a plate boundary. Hence, they probably differ in many ways from those in California and Alaska. Earthquakes within plates have been rather poorly studied until very recently.



<u>Figure 3.</u> Damaging earthquakes in the United States through 1969.

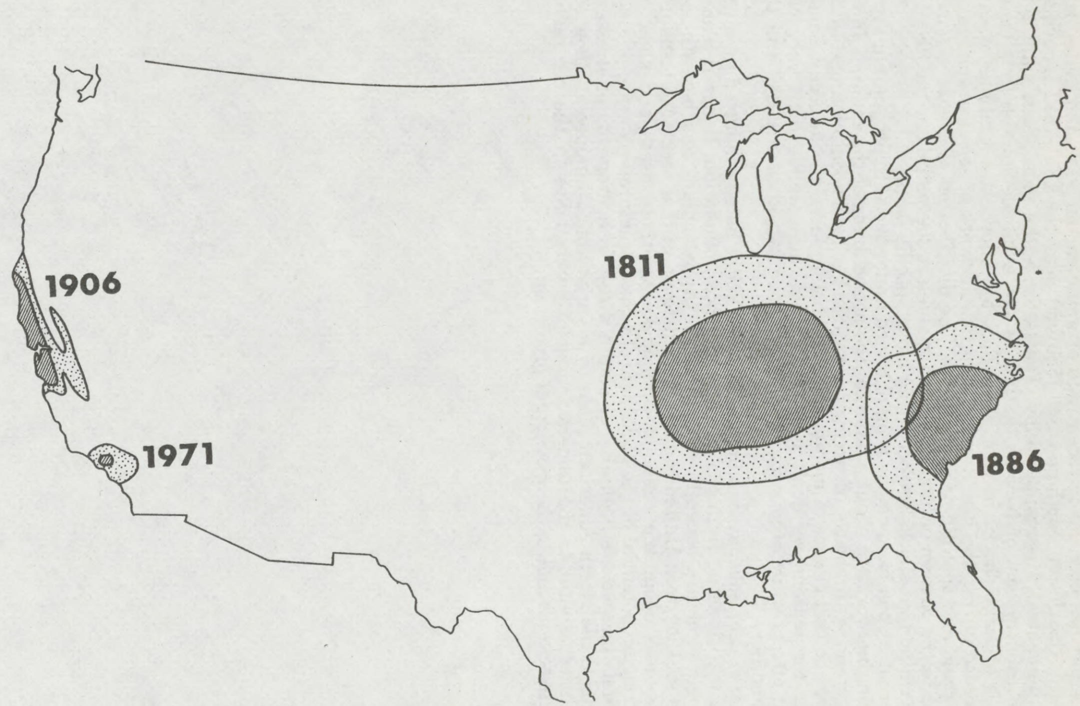


Figure 4. Regions of a given level of shaking and damage for various parts of the United States. Note much larger felt areas for shocks in the eastern and central United States.

A major effort has been made recently to examine earthquakes and faults in the vicinity of the Charleston earthquake of 1886 and near the 1811–1812 sequence of shocks in the central Mississippi valley. The latter is the most seismically active area of the country east of Nevada. Estimates are available for the first time of repeat times of large shocks in that area. Figure 5 shows the locations of earthquakes recorded during the last 10 years by a new network of seismograph stations in New England and the Mid-Atlantic States. The distribution of events is remarkably similar to the pattern of historic shocks of the last 250 years. For the first time we can determine that shocks are occurring along specific faults.

I believe that a good balance has been obtained under the U.S. program in setting up monitoring networks in about a dozen of the active areas of the country. In fact, we must contend with shocks occurring in a variety of geological settings. In that way we have the best chance of monitoring areas before large shocks occur. Some of these areas, for reasons we don't now understand, may well exhibit very clear forerunning effects while others may not. Experience gained in one area can then be used in another.

A program of deep seismic sounding called COCORP is being conducted by several universities with funding from the National Science Foundation. It has revealed a major geologic structure beneath portions of the Appalachians and beneath large parts of the southeastern United States. The existence of that structure leads us to rethink our ideas about the cause of earthquakes in those areas and about the possible petroleum potential of the rocks beneath that structure.

For the first time we are beginning to obtain direct measurements of stresses or pressures inside the North American plate by a variety of techniques. A knowledge of this quantity is vital to the understanding of earthquakes in the central and eastern United States and to their eventual prediction.

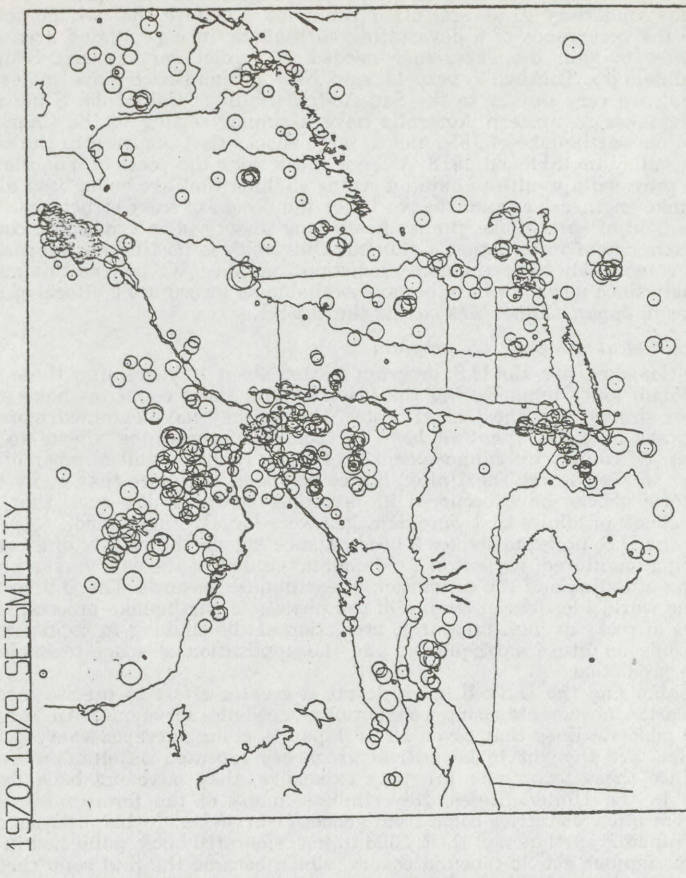


Figure 5. Earthquakes in the Northeast United States and adjacent areas for the period 1970-1979

International cooperation in earthquake studies

We have a great deal to benefit from research programs in earthquake prediction that are now underway in several other countries. I believe that we cannot wait until after the occurrence of a devastating earthquake in a populated area of the United States to gain the experience needed to predict earthquakes. Southeast Alaska, Guatemala, Turkey, Venezuela, and New Zealand each have major fault systems that are very similar to the San Andreas fault of California. Some recent large earthquakes in western Australia have a similar setting to the Charleston, South Carolina earthquake of 1886 and to large shocks that occurred in the central Mississippi valley in 1811 and 1812. A large shock near the coast of Yugoslavia in April 1979 provided a wealth of data on strong shaking that are being used already by earthquake engineers around the world for the design of safer structures. Fortunately, the field of earthquake studies has a long history of international cooperation and exchange of information. Columbia University is hosting an international meeting devoted solely to earthquake prediction this May. We believe this meeting will be timely since new data have become available on forerunning effects of recent earthquakes in Japan, China, Mexico and the U.S.S.R.

Strengths and weaknesses of U.S. program

As I mentioned earlier, the U.S. program started about 10 years after those in the U.S.S.R., Japan and China. During the last 10 years those countries have experienced larger shocks than the United States. Hence, they have obtained more data and more case histories than we have on possible forerunning effects to large earthquakes. Of course, we cannot count on having such a small number of large earthquakes in the future. The United States has been fortunate that many of our larger historic shocks have occurred at favorable times of day such that office buildings, schools or clinics that were damaged were largely unoccupied.

I believe the U.S. program strikes a good balance among the variety of areas that are now being monitored, support of fundamental studies of the earthquake process, the mapping of faults, and the estimation of earthquake hazards. The U.S. program is one of the world's leaders in studies of the physics of earthquake process, laboratory studies of rocks at high pressures, prediction of the shaking to be expected at given locations in future earthquakes, and the application of space technology to earthquake prediction.

Japan, China and the U.S.S.R. each devote a greater effort to precise measurements of earth movements using conventional geodetic surveying. An extensive network of geodetic lines that cover all of Japan is being surveyed every 5 years; lines in what are thought to be critical areas are repeated as often as every 6 months. Since those techniques are very expensive, they have not been used as extensively in the United States. Nevertheless, many of the forerunning effects reported from other countries come from geodetic surveying. In his analysis of the 1906 San Francisco earthquake, H. R. Ried in his celebrated book, published in 1980, described his famous elastic rebound theory, which became the first solid theory of what an earthquake actually is. Ried wrote a chapter of that book on earthquake prediction in which he showed how earthquakes could be forecast by measuring strain buildup by geodetic means. I believe we should be making a much greater effort in that area.

Concluding remarks

I believe the present program of earthquake prediction in the United States can be compared with the large effort that was made in seismology 10 to 20 years ago to improve the detection of underground nuclear explosions and to distinguish their signals from those of the many earthquakes that occur every year. That program was successful in that our capabilities were vastly improved through the support of basic research in earthquake studies, the development of new instruments and data processing techniques, and the installation of monitoring stations. In the beginning of the nuclear monitoring program many seismologist believed the prospects for success were good. That judgment turned out to be correct. Some of the techniques that initially appeared to be the most promising, however, were not very successful. The most powerful methods, which were developed through research, turned out to be rather different from several of the initial proposals.

I believe that we have made a good start in our program of earthquake prediction and hazards reduction, that the prospects are good but that we have a long way to go, particularly in developing predictive techniques for time scales of hours, days and months.

Five of the six main program elements of the National Earthquake Hazards Reduction Program are being supported well below either of the three funding options recommended in the Newmark-Stever report in 1976. The lowest level of funding in that report, Option A, was considered to be barely adequate to accomplish the objectives of the plan. For example, in Fiscal Year 1980, earthquake prediction received 77% of the funds recommended under the low option of the report, 70% of that under the intermediate option and 55% of the high option. For hazards assessment the percentages are 73, 58 and 44, respectively. Also, those percentages are smaller if allowance is made for inflation. A number of measurements that are critical to success in earthquake prediction—such as monitoring of water level in deep wells and the detection of slow deformation of the earth—cannot be done in several key areas unless the level of funding is increased or other important experiments are discontinued.

Appendix

Yakataga Gap, Alaska: Seismic History and Earthquake Potential

William R. McCann, Omar J. Pérez, Lynn R. Sykes

One of the world's major earthquake belts (Fig. 1) follows the boundary between the Pacific and North American plates from offshore British Columbia to southern Alaska and thence to the Aleutian island arc. Most of the movement between the two plates occurs during great earthquakes—events of surface wave magnitude, M_s, greater than 7.8. The repeat time of great shocks along some of the major plate boundaries of the world varies from about 40 to 500 years. Since much of the plate boundary in Fig. 1 ruptured in large shocks during the last 40 years, most of it appears to have a low potential for large shocks during the next few decades.

Nevertheless, Tobin and Sykes (*1*), Kelleher (*2*), and Sykes (*3*) identified four segments of this plate boundary that had not been the locations of large earthquakes for many decades. They concluded that these segments, which they called seismic gaps, were some of the most likely sites of future large shocks. One of the gaps they delimited ruptured in 1972 during the large southeast Alaska earthquake of magnitude 7.6 (Fig. 1).

The locations and magnitudes of at least 12 large earthquakes along some of the simple plate boundaries of the world have been successfully forecast (*4–6*) since Fedotov (*7*) introduced the concept of the seismic gap in 1965. The gap concept by itself, however, does not permit an estimate of the time of occurrence of a future large shock that is precise enough to be called a prediction, which we take to involve precise estimation of time of occurrence, place, and size. Only a small part of the gap in southern Alaska, shown in Fig. 1 near 60°N, 143°W, ruptured during the recent Saint Elias earthquake of M_s 7.7 on 28 February 1979 (*8*). The remaining area, here called the Yakataga seismic gap, its seismic history, and its potential for a future shock are the main focus of this article.

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Repeat Times of Large Earthquakes

In southeast Alaska and along offshore British Columbia, motion between the Pacific and North American plates is accommodated by right-lateral strike-slip motion (*1*) such that the Pacific plate moves in a N15°W direction (heavy arrows in Fig. 1) with respect to North America (*1*, *9*, *10*). Farther west, the Pacific plate is thrust (subducted) beneath the North American plate along the Aleutian trench. The Yakataga gap is located in a transition zone between these two regimes of plate interaction.

In southern Alaska the computed rate of plate movement is about 6 centimeters per year (*9*, *10*). Thus, about 5 meters of

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Summary. A 250-kilometer-long seismic gap in southern Alaska, which is situated along the boundary between the North American and Pacific plates, ruptured in two great earthquakes in 1899. Within the gap, earthquakes of moderate size form a ring of activity around a region of very low seismicity. The number of shocks of magnitude 6 or larger in this ring appears to have increased significantly since the 1958 earthquake, which occurred on the adjacent part of the plate boundary. This space-time pattern is similar to long-term patterns that preceded several large earthquakes in Japan. A shock of magnitude 7.7 on 28 February 1979 ruptured only a small part of the seismic gap. The remaining part, which already may have stored sufficient strain to generate a great shock, warrants intensive study to evaluate its potential for such an event.

potential slip may have accumulated in the gap since the last great earthquake occurred in the area in 1899 if seismic slip is not a significant fraction of the total plate movement and if the main plate boundary, in fact, passes through the gap. As discussed later, we conclude that a zone about 250 kilometers long and extending about 100 kilometers downward and parallel to the dip ruptured during two great earthquakes in 1899. Using an estimated seismic moment of 2×10^{28} dyne-cm (*11*) for each of the two events, we calculate an average slip of about 5 m. Thus, the computed average slip in the events of 1899 is comparable to the potential slip that appears to have been built up during the last 80 years by plate motion. Although only preliminary estimates are available for the seismic moment of the earthquake of 28 February 1979, values of 1×10^{27} to 7×10^{27} dyne-cm, a rupture area of 50 by 60 km (*8*), and a rigidity of 3.4×10^{11} dyne/cm² yield an average slip of about 1 to 7 m. Repeat times calculated from simple plate tectonic considerations should not be taken too literally, since the rate of plate motion is uncertain by at least 10 percent, the seismic moments may be uncertain by a factor of 1.5, and deformation is undoubtedly spatially complex near the junction of the subduction and strike-slip regimes.

The repeat time of great shocks in the Yakataga area may well be much less than that for the areas involved in the great Chilean and Alaskan earthquakes of 1960 and 1964, in which the average slip was much greater—about 20 m (*12*). The 1960 and 1964 earthquakes are also characterized by rupture zones that are very long (700 to 1000 km) and wide (120 to 290 km downdip), by very large seismic moments, and by magnitudes on Kanamori's scale (M_w) of 9.2 to 9.5 (*13*). Very great shocks of this type appear to occur only on long, linear sections of subduction zones. Another requirement appears to be a shallow dip and hence a long zone of plate interaction from the surface to a depth of about 40 km (*14*). Earthquakes located near major changes in the style and geometry of plate movements, as in the Yakataga region, however, appear to be typified by rupture zones that are not more than about 75 to 150 km long, by magnitudes less than 8.1 to 8.5, and by an average slip of a few meters. Since earthquakes like the 1899 sequence are associated with slip of only a few meters, repeat times of 50 to 100 years are calculated from the rate of plate movement. The repeat time for the rupture zone of the 1964 Alaskan earthquake, as calculated from the seismic moment (*13*) and rate of plate movement, is about 220 years. Similarly, earthquakes along the southwest coast of Mexico, where the rate of underthrusting appears to change markedly along the arc, are characterized by magnitudes less than 8.1, lengths less than 100 km, average slip of a few meters, and repeat times of about 30 to 100 years.

Hence, the repeat time of a large shock at a given place along a plate boundary is a function not only of the average rate of plate movement but also of the amount of slip in large earthquakes. The average slip in large shocks and their maximum size appear to be strongly correlated with the downdip length of plate contact and with tectonic heterogeneity on a scale of tens to hundreds of kilometers. The latter does not seem to be unreasonable, since marked changes in the strike, rate, or style of deformation along a plate boundary can lead to stress concentrations that would trigger shocks sooner than on a more linear and homogeneous plate boundary.

Small and moderate-size shocks in southern Alaska from 1964 to 1979 are shown in Fig. 2. The region between 141° and 145°W has been nearly quiescent for small shocks since at least 1964. This doughnut-like distribution of shocks surrounding a region of near quiescence is similar to patterns observed before several large earthquakes (*15, 16*). These facts, as well as the occurrence of the

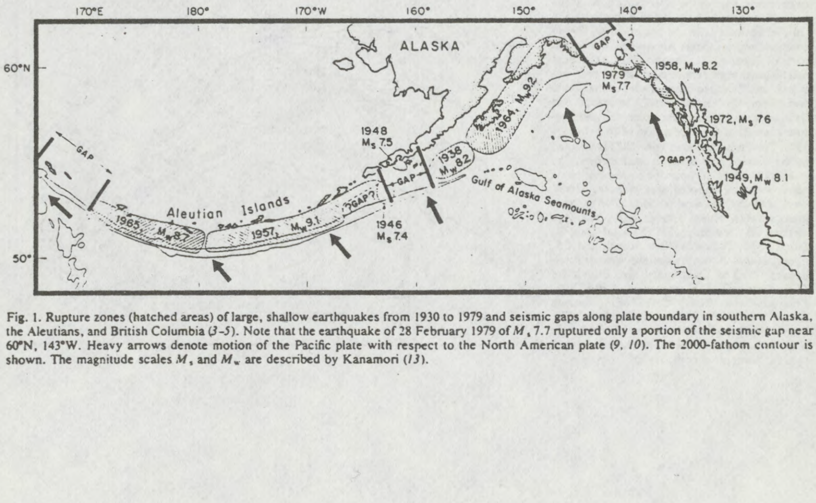


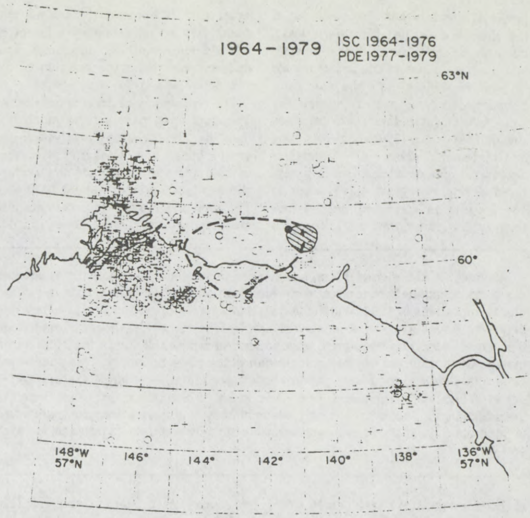
Fig. 1. Rupture zones (hatched areas) of large, shallow earthquakes from 1930 to 1979 and seismic gaps along plate boundary in southern Alaska, the Aleutians, and British Columbia (*3-5*). Note that the earthquake of 28 February 1979 of M_s 7.7 ruptured only a portion of the seismic gap near 60°N, 143°W. Heavy arrows denote motion of the Pacific plate with respect to the North American plate (*9, 10*). The 2000-fathom contour is shown. The magnitude scales M_s and M_w are described by Kanamori (*13*).

large shock on 28 February 1979, led us to make a more detailed investigation of the history of large earthquakes and the seismic potential of this region.

Tectonics of Southeast Alaska

Focal mechanism solutions 1 to 4 in Fig. 3 and the observed surface breakage during the southeast Alaska earthquake of 1958 (*17*) indicate a predominance of right-lateral strike-slip motion along the Queen Charlotte-Fairweather fault system as far north as Yakutat Bay. All of the other mechanism solutions in Fig. 3 indicate a predominance of thrust faulting. The mechanism solutions and the tectonics of this area are described more fully by Perez and Jacob (*18*).

Plafker *et al.* (*17*) indicate that the Fairweather fault has taken up most of the motion between the North American and Pacific plates for at least the last 100,000 years. We take the main plate boundary to follow the Fairweather fault and the rupture zones of the large earthquakes of 1899, 1958, 1964, and 1979 (see Fig. 1). We conclude that the main plate boundary from Yakutat Bay to Prince William Sound is located between 59½° and 61°N. This is based on our interpretation of the rupture zones of great



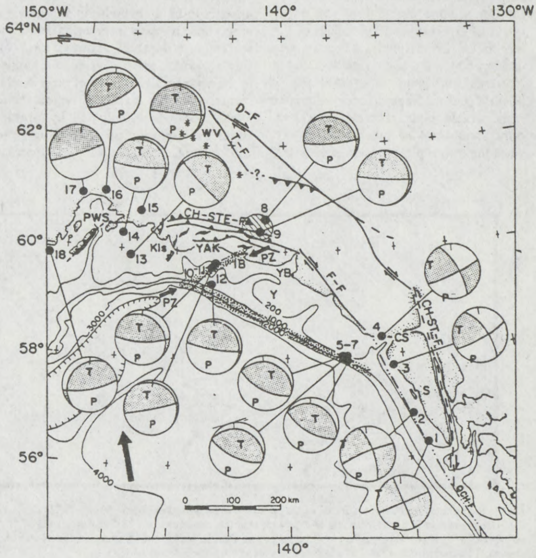


Fig. 2 (top). Earthquakes in southern Alaska (136° to 148°W, 57° to 64°N) from January 1964 to 31 January 1979, reported by various agencies. The dashes surround a region that has been nearly quiescent for events above magnitude 4.0 since 1964. The filled circle and hatched region denote the epicenter and rupture zone of the large shock of 28 February 1979. Symbols denote magnitudes as follows: (+) $m_b < 4.0$, (o) $4 \leq m_b < 5$, (×) $5 \leq m_b < 6$, (*) $m_b \geq 6$, where m_b is the body-wave magnitude. The concentration of activity west of about 145°W represents the easternmost part of the aftershock zone of the great 1964 earthquake. Fig. 3 (bottom). Focal mechanisms (*18*) and major faults (*29*) in southern and southeast Alaska and in adjacent parts of Canada (*18*). Shaded areas in the focal mechanisms represent compressional first motion; *P* and *T* denote inferred axes of maximum and minimum principal stress. The triangle and hatched area indicate the epicenter and rupture zone (*8*) of the earthquake of 28 February 1979. The Pamplona fault zone (*PZ*) is denoted by the stippled area between small arrows. The Yakutat block (*Y*) is bounded by the Pamplona zone, the long stippled area trending northwest, and the Fairweather fault (*F-F*). Other areas are *KIs*, Kayak Island; *YAK*, Yakataga district; *IB*, Icy Bay; *YB*, Yakutat Bay; *S*, Sitka; *PWS*, Prince William Sound; and *CS*, Cross Sound. Asterisks denote Wrangell volcanoes (*WV*) of Quaternary age. Faults are *D-F*, Denali; *T-F*, Totschunda; *CH-STE-F*, Chugach-Saint Elias; *CH-ST-F*, Chatham Strait; and *QCH-F*, Queen Charlotte. The heavy arrow represents motion of the Pacific plate with respect to the North American plate (*9*, *10*). Submarine contours are in meters.

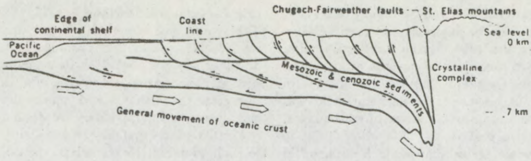


Fig. 4. Schematic structural cross section of plate convergence in the Gulf of Alaska (*21*). The large open arrows indicate the sense of relative motion of the Pacific and North American plates. As the Pacific plate is subducted beneath the North American plate, a series of imbricate reverse faults develop in upper plate in a décollement-style of deformation.

shocks in 1899, as discussed below, and the agreement of the focal mechanism solutions in this region (Fig. 3) with the calculated directions of plate movement (*9, 10*).

The Yakutat block (Fig. 3) is moving at nearly the same relative velocity as the Pacific plate. Nevertheless, marine seismic reflection data (*19*) and earthquakes 5 to 7 in Fig. 3 indicate that some deformation is occurring along the continental margin between events 5 and 12 (*18*). While some deformation may occur along the Totschunda and Denali faults farther north, they have not been the locus of great earthquakes. They do not appear to take up the major plate movement (*18*).

Mechanisms 8 and 9 (Fig. 3) are for two earthquakes of $M_s \sim 5.7$ that occurred in 1965 and 1971 near the edges of the rupture zone of the earthquake of 28 February 1979. These solutions, as well as that for the 1979 event (*8*), indicate either motion along high-angle reverse faults dipping about 80° to the south or northerly oriented thrust motion along shallow dipping faults. The first possibility, however, is not consistent with the sense of vertical motion inferred to have occurred in Yakutat Bay (*20*) during great earthquakes of 1899 or with the sense of vertical motion on the Chugach-Saint Elias and nearby fault systems. In these cases (*20-22*) the northern block is uplifted with respect to the south, whereas the focal mechanisms indicate the opposite sense of vertical motion for the steeply dipping nodal plane. Therefore, we select the shallow dipping nodal plane as the fault plane. This choice of nodal planes is consistent with the Pacific plate being underthrust beneath Alaska in a direction about N15°W, as calculated from global plate motions (*9, 10*).

The focal mechanism solutions, distribution of earthquakes, and geologic data are consistent with the tectonic interpretation of Stoneley (*21*), which is shown in Fig. 4 as a generalized cross section for the Gulf of Alaska. As in Fig. 4, the Pamplona zone, the Chugach-Saint Elias fault, and other major faults may be interpreted as imbricate reverse faults within the upper plate whose dip becomes shallower at great depth. Thus, one or more shallow-dipping thrust faults that constitute the main plate boundary now appear to be nearly quiescent for moderate-size shocks (Fig. 2). We infer that the zone of shallow thrusting moved during the earthquakes of 1899. It is not unreasonable to expect that as stresses build up for another great earthquake, stress concentrations, and hence moderate-size earthquakes, would occur along some imbricate faults, such as the Pamplona zone.

The style of deformation in Fig. 4 appears to be similar to that which occurred during the 1964 earthquake farther west. Motion during that event involved shallow thrusting accompanied by high-angle reverse faulting along the Patton Bay fault on Montague Island (*12, 23*). Similarly, the reverse faulting that was inferred to have occurred in Yakutat Bay during the great shock of 10 September 1899 (*20*) can be interpreted as motion along one or more high-angle reverse faults that accompanied shallow-angle thrust faulting at depth. The observed surface displacements in Yakutat Bay in 1899 (*20*), even if they extended to a depth of 30 km, contribute only a small fraction to the seismic moment (*11*) for that shock. Thus, slippage during that event must have been much more extensive areally than reported by Tarr and Martin (*20*). The maximum deformation of 14 m observed in Yakutat Bay (*20*) is highly localized and may represent a stress concentration, which may have been stored over several seismic cycles. It is unlikely that each imbricate fault in Fig. 4 moves during each great earthquake that affects the main zone of shallow thrusting at depth.

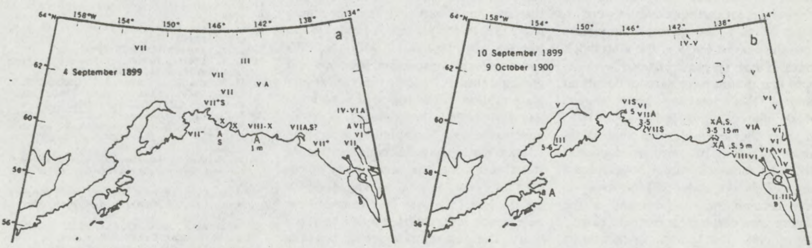


Fig. 5. Macroseismic effects inferred from the report of Tarr and Martin (*20*) for three great earthquakes in 1899 and 1900. Roman numerals indicate intensities on the modified Mercalli scale for shocks on (a) 4 September and (b) 10 September 1899. Arabic numerals in (b) denote intensities for the shock in 1900. Also indicated are observed uplift in meters, local sea waves (*S*), and aftershock (*A*): the size of the symbol qualitatively indicates numbers and strengths of aftershocks reported. Note the extensive region along the coast affected by the earthquake of 4 September 1899. Stippling denotes the region of strongest observed shaking, which is taken to approximate the rupture zone of the shock. The earthquake on 10 September 1899 appears to have ruptured an area to the east of that broken on 4 September. Events of 4 and 10 September appear to have ruptured most or all of seismic gap between the rupture zones of the 1958 and 1964 earthquakes. The shock of 9 October 1900 (b) appears to have occurred near Kodiak Island.

1946. Thus, a marked increase in the number of shocks of magnitude 6 or larger appears to have occurred about 1958 within the ring of higher activity that surrounds the zone of near quiescence in Fig. 2. It should be noted, however, that no events of that size are reported in standard catalogs within the zone of quiescence itself from 1908 through 1978. We find no evidence of a change in activity with time for events larger than magnitude 5 in the quiescent zone.

It is difficult to ascertain whether a change in activity for events smaller than magnitude 5 occurred in the Yakataga gap around 1958, since detection may not have been complete for events of that size before 1964. A surge of seismic activity occurred both on the periphery and within the zone of quiescence (Fig. 2) in the Yakataga gap following the great earthquake on the adjacent part of the plate boundary in 1964 (Fig. 1). These shocks appear to lie outside the aftershock zone of the 1964 event. Uplift associated with that earthquake (*23*) diminishes rapidly along the coast to the east of Prince William Sound (Fig. 3) and is less than 1 m to the east of Kayak Island. Hence, the Yakataga gap does not appear to have ruptured significantly during the 1964 earthquake; the surge in seismic activity in the gap in 1964 appears to have been triggered by the nearby great earthquake. A shock of magnitude 6.2 occurred in the Pamplona zone 3 months after the large 1958 earthquake. These surges in activity following the 1958 and 1964 shocks may be indicative of high stress concentrations on the periphery of and perhaps within the zone of near quiescence.

We found several other surges of seismic activity that occurred within 1 year of several great earthquakes and were located 100 to a few hundred kilometers from the nearest parts of the aftershock zones. These surges coincided with regions that in turn were parts of doughnut patterns that preceded great shocks which followed the surges by about 10 to 20 years. For example, the great earthquake (M_w 8.1) off northern Japan in 1952 was followed within 1 year by a surge of shocks about 200 km away in what became the southern end of the rupture zone of the great earthquake (M_w 8.2) of 1968. The location of this surge was also the site of a large (M_s 7.5) earthquake in 1960.

Seismic activity in the Yakataga gap was not distributed evenly in time during the last 15 years. The period 1964 to 1968 was characterized by rapidly decreasing activity for moderate-size events following the 1964 Alaska earthquake: after 1966 much of the gap was nearly quiescent for events above magnitude 4.0. In 1970, however, the Pamplona zone was the source of a swarm of earthquakes, the largest of M_s 7.0. After 1971 no events above magnitude 5 occurred in the Yakataga gap prior to the large (M_s 7.7) earthquake on 28 February 1979. In 1976 a few events with magnitudes near 4.5 occurred near the rupture zone of the 1979 event. Since 1958 the observed temporal pattern of seismicity in the Yakataga gap has consisted of bursts or swarms of activity with intervening periods of lower activity around the perimeter of the zone of near quiescence in Fig. 2. Wyss *et al.* (*27*) show several examples of surges in seismic activity, both preceded and followed by periods of quiescence, that they interpret as forerunning large shocks. In the Yakataga area we observed at least four surges of activity (1958, 1964, 1970, and 1979), any of which could have been interpreted as precursory effects. Also, we have not observed a sudden decrease in the number of small shocks within the zone of quiescence that resembles the changes reported by Ohtake *et al.* (*28*) prior to several earthquakes. Thus, we do not find any clear evidence in the Yakataga area for temporal changes on a time scale shorter than about 20 years.

Conclusion

Macroseismic data for the great earthquakes of 4 and 10 September 1899 indicate that much of the plate boundary between the 1958 and 1964 earthquakes ruptured at that time. The potential slip that may have been built up in the region from 1899 to the present is similar to the average slip associated with the 1899 events. Focal mechanism solutions and geologic studies indicate that convergent plate motion in the region is accommodated in shallow thrust planes, as in the zone to the west that ruptured in the 1964 Alaska earthquake. A large portion of this thrust zone has been nearly quiescent for events as small as magnitude 4.0 for the last 15 years. This zone of near quiescence is surrounded by a ring of activity. The number of larger earthquakes in the ring appears to have increased significantly since the 1958 earthquake on the adjacent plate boundary. This doughnut-like pattern resembles in many ways the spatial-temporal patterns that preceded several great earthquakes (*15, 16*). The spatial and temporal changes that we observe within the Yakataga gap, however, do not permit us to estimate precisely the time of occurrence of a future great shock that would rupture the gap. Intensified field studies are needed to identify effects that may be precursory to such an event. Nevertheless, the observation that this region ruptured in a series of large shocks in 1899, the calculation of a repeat time of about 80 years, and the occurrence of a large earthquake in the area in 1979 suggest that the Yakataga gap is likely to be the site of a great earthquake within the next 10 to 20 years.

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Seismic History of Southeast Alaska

Richter (*24*) locates three great earthquakes in 1899 and 1900 in the region near Yakataga and Yakutat Bay (Fig. 3). Figure 5 shows our interpretation of the modified Mercalli intensity inferred from reports in Tarr and Martin (*20*) for various positions throughout southern Alaska. It should be remembered that this region was very sparsely populated in 1899, and inferences about rupture zones may well be biased by this as well as by site conditions. Our results are in general agreement with the intensities inferred by Meyers *et al.* (*25*) with some significant exceptions. The highest intensities, which are found along the coast, appear to us to be lower than those inferred by them. These differences, however, do not change our interpretation of the regions that were most strongly affected by those great earthquakes.

The first shock (M_s 8.5) occurred on 4 September 1899 (3 September, local time) and was felt most strongly from localities west of Kayak Island to Yakataga, a distance of about 180 km. From a ship offshore (*20*) large avalanches were observed in the mountains between Icy Bay and Kayak Island (Fig. 3). This region and the zone of highest observed intensities are shaded in Fig. 5a. Many aftershocks were reported from the western end of the shaded area; few were reported from Yakutat Bay (*20*). One meter of uplift was reported at Yakataga (*20*). Since coseismic uplifts are generally smaller than horizontal motions during great earthquakes along subduction zones (*12*), the average slip on the plate boundary during this event was probably several meters, which agrees with that inferred earlier from the seismic moment. In previous studies, intensities near VIII have been successfully used as a guide to delimit the approximate zone of rupture (*4, 26*). The higher intensities, uplift, and distribution of aftershocks clearly associated with the 4 September event indicate that rupture probably extended along much of what is now the Yakataga seismic gap.

Another great (M_s 8.4) earthquake occurred in southern Alaska on 10 September 1899. It was preceded by a large (M_s 7.8) foreshock (*24*) and was followed by aftershocks that were strongly felt near Yakutat Bay (Fig. 5b). Coseismic uplift, which locally measured as much as 15 m, was observed (*20*) near Yakutat Bay. Significant deformation may have extended to the west of Yakutat Bay into an area of large glaciers that was not studied by Tarr and Martin (*20*). Since the intensities in Fig. 5b drop off rapidly to the southeast of Yakutat Bay, the rupture zone of the earthquake of 10 September may have extended more to the west of Yakutat Bay than to the southeast.

The rupture zone of the large shock of 10 July 1958 may have extended as far west as 140.3°W (Fig. 6). Hence, the 1958 shock may have reruptured a portion of the zone that broke in 1899. Although most of the rupture zone of the 1958 earthquake involved strike-slip motion, several aftershocks at its northern end (*3*) delineate an east-west trend from 139.5° to 140.3°W along 60.3°N. The aftershock zone of the 1979 earthquake abuts the western end of this zone.

Richter (*24*) locates a great earthquake on 9 October 1900 near Yakataga. Thatcher and Plafker (*11*) assign it a magnitude of 8.1. The strongest intensities and the only reports of aftershocks, however, are from the vicinity of Kodiak Island (Fig. 5b) (*20*). Hence, this event appears to be located several hundred kilometers to the southwest of the Yakataga gap and appears to have no direct connection with the shocks of 1899. The historical record does indicate that the two great earthquakes of 1899 probably ruptured much or all of the plate boundary between the rupture zones of the 1964 and 1958 earthquakes. Thatcher and Plafker (*11*) reach a similar conclusion from a study of the seismic moments of the shocks of 1899.

Seismic Potential of the Yakataga Seismic Gap

In a study of several great earthquakes near Japan, Mogi (*15*) finds that large ($M_s \geq 6$) shocks tend to cluster in a ring surrounding the rupture zone of the coming great shock for 10 to 20 years prior to its occurrence. The rupture zone itself tends to become quiescent for large shocks (but not necessarily for smaller shocks) during the same period. Kelleher and Savino (*16*) report a similar doughnut pattern but find that the region interior to the ring of higher activity tends to be quiescent for several decades before great earthquakes. They find that activity is also concentrated near the epicenter of the coming earthquake.

The patterns of activity in southern Alaska resemble in many ways those described above. During the past 21 years, six shocks of magnitude 5.9 or greater have occurred (Fig. 6) around the periphery of the zone of near quiescence shown in Fig. 2. One of these (1970) was of magnitude 7.0. The 1958 and 1964 earthquakes bound the eastern and western sides of the gap (Figs. 1 and 6). Also, the event of 28 February 1979 is located along the eastern side of the doughnut pattern. No shocks of magnitude 6 or larger, however, are reported in standard catalogs in the gap between the 1958 and 1964 earthquakes for the 25-year period from 1933 through 1957. These catalogs are probably complete for $M_s \geq 7$ for that period and for $M_s \geq 6$ since about

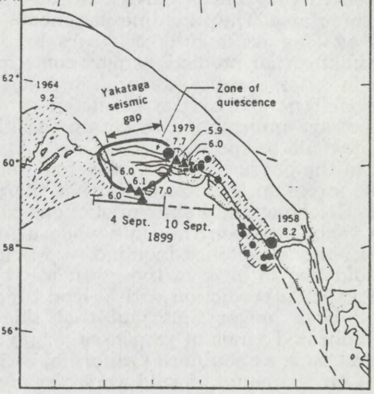

Fig. 6. Earthquakes of magnitude 5.9 or larger near the Yakataga seismic gap from January 1958 to February 1979. Note that seven of these events are situated at the edges of the zone of near quiescence for small shocks (heavy solid line) shown in Fig. 2. Large circles denote the epicenters of main shocks of large events in 1958 and 1979; small circles, aftershocks of the 1958 earthquake; triangles, shocks of magnitude 5.9 to 7.0. Faults are from (*29*). Inferred lengths of the rupture zones of two great earthquakes in 1899 are indicated. Hatching indicates the rupture zones of the 1958 and 1964 earthquakes. Numbers below dates are magnitudes.

Senator STEVENSON. The subcommittee is adjourned.

[Whereupon, at 12:20 p.m., the hearing was adjourned.]

[The following information was subsequently received for the record:]

STATEMENT OF GILBERT F. WHITE, NATURAL HAZARDS RESEARCH AND APPLICATIONS INFORMATION CENTER, INSTITUTE OF BEHAVIORAL SCIENCE, UNIVERSITY OF COLORADO, BOULDER, COLO.

WHAT IS ENOUGH INFORMATION ABOUT EARTHQUAKE PREDICTION?

The discussion launched this morning comes at the right time for several reasons and would have been impossible and inappropriate as recently as six years ago. The immediate threat and accompanying public speculation about the great southern California bulge has sensitized people in some measure to the possibility of a serious scientific prediction, but they are not facing a specific warning. It is encouraging that the principal government agency involved in this area—the Los Angeles City Council—already has suggested administrative plans for action in the event of a prediction and that these have been the subject of extensive and incisive public criticism. From the federal standpoint, we now have for the first time in FEMA an organization which can play a coordinating role and which has a strong sense of the importance of emphasizing mitigation of losses as well as emergency response to a disaster. The results of half a dozen years of research on aspects of social response to earthquake prediction can be put alongside those from a much longer period of physical research on recognizing precursors and generating predictions. We are in quite a different position than we were six years ago when there had not been the experience with the bulge, when local agencies had not attempted to come to grips with predictions in an integrated fashion, when the federal establishment in the emergency management field was in disarray, and when research on earthquake predictions and response to them was just getting underway.

It is impossible to tell how far we are from generating a prediction with a narrow confidence limit for an earthquake of significant magnitude in terms of human loss. Perhaps it will come next week, perhaps not for some years. The joint USGS-NSF research program is moving ahead and is subject to reappraisal as new evidence accumulates. The sanguine judgments of 1974 that a great quake might be predicted as long as months or years in advance have been replaced by more sober estimates that predictions may come in less than six hours before the event or may be in a less precise, general format that does not specify time horizon or zones. Beyond the geophysical prediction we should ask how close we are to having the necessary information to obtain socially optimal results for the various conditions that would be specified.

On the physical science basis for prediction, although earlier studies laid considerable stress on the possibility that there might be a long lead time, experience with the Heicheng and Pamir predictions suggests that it may be only a matter of two to six hours between the time when a prediction is warranted and the actual event. With this possibility in mind, it would seem wise to think of the information we would like to have in the event of (1) a prediction with a lead time of only a few hours, (2) a prediction with a lead time of a few weeks, recognizing that there may well be a longer time, but that this will permit more leisurely and also more complicated kinds of responses, or (3) a warning of likely movement in designated areas, such as Southern California, without a precise time horizon.

A large amount of solid work already has been done in drawing analogies between earthquake prediction and warning systems for other kinds of natural hazards, such as hurricane evacuation, and in digging deeper into the peculiar circumstances attaching to the issuance of earthquake predictions. Let me note only seven major reports which are literally in our hands and which, supplemented by others not mentioned, collectively constitute a broad outline of productive lines of action: (1) The Stanford Research Institute technology assessment of earthquake prediction; (2) The National Research Council report on earthquake prediction and public policy; (3) The National Research Council program of studies on the socioeconomic effects of earthquake prediction; (4) The Office of Science and Technology Policy review of issues for an implementation plan on earthquake hazards reduction; (5) The Council of State Governments review of earthquake prediction, and reaction and response to prediction; (6) the Haas, Mileti, Hutton and Sorensen studies of policy issues related to earthquake prediction; (7) The Consensus Report on the Task Force on Earthquake Prediction in the City of Los Angeles. These are abstracted in an accompanying document.

In addition, there is important work that is nearing completion and from which there already are tentative results: (1) The work by Turner, Nigg and others on awareness of earthquake treats; (2) Studies by John Wiggins and Associates on responses of local governments; (3) The examination of political aspects of earthquake prediction by Wyner and Mann; (4) Studies at the Midwest Research Institute on modes of estimating earthquake damage from a predicted quake, as at New Madrid.

The physical science approach to earthquake prediction begins with the event and seeks to understand the processes generating the event sufficiently to be able to forecast it. The social science approach begins with the postulation of a prediction and tries to understand how people will respond in what circumstances. The administrative and preparedness planner uses the findings of both to design and carry out a plan to enable individuals, corporations, and public groups to cope effectively with the circumstances. Some of the action cannot be taken until a prediction is made. Much of it can be taken without awaiting a prediction and would be desirable if there were never to be a prediction.

Reviewing the present state of research findings in terms of the firmness of their capacity to accurately predict the consequences of a given action, the physical scientists are the soft scientists and the social scientists are the hard scientists. We are less precise about dilatancy than about confirmatory behavior, less confident about radon's relation to crustal movement than about the effects of using various communication channels on hazard awareness.

One way of stating the purpose of this conference is to ask "What is enough information about earthquake prediction?" to sharpen your thinking about the suitable answer, I suggest a tentative response: we need a great deal more information about the geophysical grounds for making an earthquake prediction, but we probably have close to eough information at present to judge what to do whenever a relatively confident geophysical prediction is formulated. Because we do not know how soon that may be, it follows that the most urgent task is to get on with the application of knowledge that already is in hand or that is likely to become available soon.

Think of a time when a sober prediction of a large movement is warranted on scientific grounds. At that point we would like to know exactly what to do that would benefit society most during the hours, weeks, months or years that may separate the first prediction and the actual event. We now recognize that a prediction is only the first link in a long chain of action. Principal links include the format and content of the warning message, the channels of communication, the credibility of information sources, the capability of recipients to take action, their knowledge of possible efficacious measures, and the like.

To take those steps wisely requires specification of the type of prediction, the sectors of society to be affected, the response that would be desirable for each sector, and factors that would enter into the scientific judgment in generating the prediction.

We begin with the aim of trying to reach all sectors of society with a prediction, but with the knowledge that various income groups, age groups, and geographical areas will be affected differently and will require different flows of information and action. We possess considerable findings about what kinds of social responses would be economically and politically desirable, including estimates of some of the negative consequences of predictions for specified lead times. Most of the economically warranted measures are ones that should be taken in the long run, as with lifeline design, or with the strengthening of weak structures where practicable, even though there were never an accurate prediction. Others are clearly oriented to the prediction period.

It is apparent that the physical scientists who will make a judgment about the next prediction inevitably will bring to bear some of their own valuation of the social consequences, and that this will influence their decision as to when to publish a prediction of the expected event and how to couch its estimates of magnitude and probability.

Returning to the opening question, I'm sure that all of those here who are involved in administration and public action will expect the conventional and logically irrefutable answer: we need more research. We all know that every proper research report ends with an appeal for further investigation and that there will never be enough information to satisfy those who look for precise understandings of the workings of tectonic plates and of human individuals and groups. The basic scientific inquiry will continue. But we can't be satisfied with the traditional in this instance. We recognize that there is some limit to the expenses that can be justified for carrying out additional research. We also confront the likelihood that the longer research proceeds on questions of response to earthquake prediction, the longer responsible people are encouraged to procrastinate in taking action which may be warranted now or in the near future in the absence of valid predictions.

A healthy posture for each of us now to take is that of a devilish advocate who argues that no more research is needed unless it can be shown that it will be applied by a responsible person to public action. We know from experience with other hazards that unless the administrator thinks it feasible to use the research findings, they will have no significant effect upon society. In many instances it is argued that potential users are unaware of the research or of its potential significance. Such an argument would have been appropriate and largely correct if made six or even two years ago. It is not so today. As a result of the bulge, of the Chinese experience, and of the extensive activities generated by the earthquake loss reduction program of OSTP, a large number of potential users have become aware of the problem, and an imposing array of specific courses of action believed to be efficacious has been drawn up.

Today we should recognize that only a small proportion of the research findings on earthquake prediction has been put into practicable action. For example, suggested coordinating measures by FEMA have not yet been taken. Specific risk assessments and maps or procedures for making them for homeowners, corporations and government agencies in areas affected by earthquake prediction have not been drawn up. One can enumerate other promising measures not taken. This failure becomes apparent as one looks at the presentations in this conference. Few, if any, communities have advanced as far as Los Angeles, and it is still six to twelve months from having a preparedness plan to use when predictions are made.

Why is this so? In a few instances people are not informed. In many instances they are not convinced of the desirability of taking such action. Each measure needs to be evaluated in terms of its prospective costs and benefits to the individuals or groups affected. For some measures, the net gains may be large, while for others the net losses may make them undesirable. Perhaps in an even larger number of instances it takes time to generate practicable action: this takes money and changes in institutional procedures and authorities, particularly in relation to local-state-federal relations. These come slowly during times when there is neither an anticipated crisis nor a post-disaster atmosphere.

In these circumstances, this whole conference may be regarded as an exercise in asking wherein, if at all, lack of information now prevents us from achieving adequate prediction and response. Let us take what the statistical analyst likes to call the null hypothesis. Let us argue that enough is already known to work out practicable programs of response to a prediction. Let us require of any who disagree a specific showing of where information is needed that is not now available in some place. In going through this exercise we may show remaining gaps with respect to: 1) prediction format, 2) means of disseminating warnings, and 3) means of helping individuals and organizations to respond effectively to warnings. We may also conclude that, taking steps already warranted by the information at hand, the major position should be to ready society for responding to the next prediction.

Inevitably, there will be some gaps that remain, and we already know that certain information of necessity cannot be obtained until a major prediction is issued. The latter was pointed out in the Turner report, among others, as being information which could only be gotten at the time of a major prediction in order to observe specific responses and to follow through day-by-day action in comparison with the postulated action. In that sense, we already have a research program to be undertaken when the prediction is made. We should be certain that we know precisely what that is and how it will be carried out. I doubt that the funds and procedures are in prospect to get such work promptly underway. Beyond that, the conference should be as concrete as time will permit as to what additional work now needs to be undertaken, and where and how.

Let me return to, and expand a bit, the tentative conclusion with which I began. Our greatest need at present is for improved information about how to generate an earthquake prediction; this is a matter of further research and skillful application in physical science. Social science has already gone a long distance towards specifying the effects of alternative types of policies and concrete measures which could be undertaken at the individual, local, state and federal levels whenever a prediction is generated and a warning issued.

At the same time, probably the largest need is for the application by public and citizen groups of the information already in hand. A substantial body of scientific judgment has accumulated about appropriate measures. At this point, many administrators may feel like Mark Twain who said he did not mind people expressing their judgment to him—he did object to its being sent by bulk freight. We have a bulk of research findings—the significant ideas and recommendations must and can be readily winnowed from that bulk. The more difficult task is to expressly translate these into practical action at the political and operational level within the limits of funds and political collaboration.

Some cynics would suggest that this will not happen until, and unless, there is a real-life prediction of a major tremor. If they are completely correct, the worst that this conference can do is to outline what will need to be done frenetically, hurriedly, and inefficiently whenever the crisis situation arises. The best it can do is to agree on steps to take without awaiting a crisis and without awaiting further research.

Statement of Dennis S. Mileti, Department of Sociology, Colorado State University, Fort Collins, Colo.

Earthquake prediction technology, if soundly developed, could be useful if put into practice in such a way that it helps increase earthquake emergency preparedness and decrease earthquake vulnerability to damage. The usefulness of the technology can only be practicably measured in terms of how it can help achieve these two goals. These goals exist independent of earthquake prediction capabilities, and are pursued by other technologies, policies and adjustments to the earthquake hazard in the United States.

Earthquake prediction technology holds promise to help achieve preparedness and vulnerability goals because predictions could provide much more specific information about earthquake risk than exists in the absence of a prediction. This information, if used in light of knowledge about how people and groups will respond to such information, could allow many decisions and activities to be made in a population that would end in decreased earthquake loss because of increased preparedness and decreased vulnerability. These potential gains from predicting earthquakes do not exist independent of possible costs. Earthquakes predictions could alter some aspects of local social and economic life in ways which many could perceive as negative impacts. Long-term predictions hold the most promise, however, for providing the time necessary to accomplish actions to significantly achieve prediction preparedness and vulnerability goals. Short-term predictions hold the least potential for negative secondary impacts, but also provide less time in which to accomplish the goals of decreased vulnerability and increased preparedness. Although the theoretically possible costs (negative impacts) of the use of prediction technology will not likely be high, there is also no reason to expect that the possible gains of prediction technology (decreased vulnerability and increased preparedness) will automatically fall into place when predictions are issued. Three important questions must be answered and those answers converted into practical action and policy before we can be sure that the funds spent to develop prediction technology will have been worth the expenditures. These questions are: (1) how can the information contained in a prediction be used to increase preparedness? (2) how can the information contained in a prediction be used to decrease vulnerability? and (3) how can we reduce the potential for negative socioeconomic impacts associated with the information contained in a prediction to acceptable levels? Sound answers to these questions require knowledge about how people and human groups respond to risk and to the kind of information likely contained in an earthquake prediction. Fortunately, the past few recent years have produced great advances in knowledge compiled by social scientists investigating behavior in response to risk, hazards and earthquake prediction. A good level of confidence exists in some of the conclusions which can now be made about this kind of behavior. More than enough evidence exists on which to begin policy-tied actions to guarantee practicable answers and solutions to the three questions stated previously.

Two Appendices have been attached to this statement. Appendix A,[1] entitled "Human Adjustment to the Risk of Environmental Extremes," is an attempt to synthesize knowledge in the social sciences about how and why people and groups adjust to the risk of a future possible disaster. This synthesis summarizes the kinds of behavior, and the reasons or causes of it, associated with the risk of disaster in everyday life not characterized by a prediction or warning. Appendix B,[1] entitled "Human Response to Earthquake Prediction," is an attempt to present what I and some others feel about how and why people and groups will respond to the information contained in an earthquake prediction. Taken together, these two Appendices suggest that there is a range of alternative strategies that are in use or could be in use to reduce vulnerability and increase preparedness to natural disasters. Earthquake predictions could escalate activities along many of these fronts, although many activities are already ongoing.

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[1] The appendices are in the committee files.

Appendix A suggests that people and groups do things to decrease vulnerability and increase preparedness for future disaster: (1) if they think there is reason to adjust, (2) the costs and bother to adjust are seen as worth the benefits that could be gained, (3) on the basis of available information which is often biased and incomplete, (4) on the basis of risk perceptions which are typically inaccurate, (5) if the work required to maintain and adjustment does not require much change from the pre-adjustment status quo of life, (6) if opposition to adjustment which typically arises on the basis of alternative goals is not great, and (7) if large level units of human aggregation impose policy to command or provide incentives or information relevant to policy adoption and implementation by a social unit at a lower level of aggregation.

Appendix B suggests that people and groups will likely do things to decrease vulnerability and increase preparedness in response to an earthquake prediction on the basis of: (1) perceptions about risk and likely damage, (2) their exposure to risk, (3) access to information, (4) socioeconomic ties to the local area, and (5) amount of resources available to them.

At the most basic level, both Appendices can be summarized as follows. Information about risk (access to it, consistency in it, reputability of it, and so on) causes people to form alternative risk perceptions (can a disaster occur, when will it occur, what will happen to me, my family and possessions). Perceptions of risk (which are often quite inaccurate, overestimated, underestimated) coupled with the resources to act and other social-structural characteristics of the ability to act, define what people and groups do or not do in response to risk of disaster in everyday life and in an earthquake prediction. Current evidence suggests (see Appendix B) that largely because of a great lack of policy on correcting for flaws in the flow of information in an earthquake prediction, that many will over-react to a prediction thereby increasing unduely the potential for negative secondary impacts. More importantly, many more will under-react to a prediction thereby constraining behavior that would lead to achieving earthquake prediction goals. These problems can be addressed, along with other problems pointed to in Appendix B, were assembled evidence in the social sciences considered in policies at all levels of government to install prediction technology into American society. That this transfer of relevant knowledge has been slow is hardly the fault of the drafters of policy; blame lies with we social scientists.

Of paramount importance in understanding hazard risk mitigation and preparedness, however, is the well-established notion that activities are related to one another. This is particularly true in reference to earthquake prediction. Earthquake predictions are no more than specific information about disaster risk. As such, predictions can be fruitful only to the extent that they spark productive behavior (see Table 1, Appendix A) that can reap rewards. These rewards or adjustments exist independent of prediction and are also enhanced by other technologies and policies. For example, earthquake hazard microzonation is information that could increase preparedness and decrease vulnerability. Earthquake insurance can decrease what an individual has at risk. There are other examples. Evidence is also strong that when the nation has placed great reliance on one solution to disaster risk-mitigation, for example, flood protection works, that risk and loss has actually increased. Effective hazard mitigation demands a multi-pronged approach. Future national policy for hazard mitigation of any sort must take past national lessons into account and seek balanced programs of multiple adjustment to disaster risk. Reliance on a sole solution to mutigate disaster risk could be counterproductive if not accompanied by efforts to enhance risk-mitigation through all available adjustments.

In addition, it is fool-hearty for the nation to mount an effort to increase preparedness and decrease vulnerability to one hazard as if risk mitigation for earthquakes were something different than for floods, landslides, tornadoes, hurricanes and other sources of natural disaster and calamity. In the long run, national resources would perhaps accomplish the most were they expended in ways to escalate a balanced set of adjustments to the risk under which we live of a range of the causes of natural disaster.

O