SCIENCE, SERENDIPITY AND SOCIETY

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I want to begin by thanking The Science and Technology Foundation of Japan and its Selection Committee for awarding me one of the two Japan Prizes for 1993. I know that this high honor would not have been possible without the support of colleagues in many countries. And I am grateful to all of these friends for their efforts in my behalf. Albert Einstein said "In science...the work of the individual is so bound up with that of his scientific predecessors and contemporaries that it appears almost as an impersonal product of his generation." The Japan Prize is unique in that it honors individuals for the social contributions of their researches. In Einstein's meaning it also calls attention to the efforts of a generation of scientists and engineers who have labored to apply the new knowledge their researches have uncovered to better the human condition. Scientists of my generation in Japan, the United States, and in many other countries have worked to reduce the toll of natural disasters, to create a green revolution that eliminated recurrent famines in many countries, to conquer many of the diseases of humankind, to create jobs and wealth through new technologies and industries, to foster arms control and reduction, and much more.

In this talk, I plan to briefly describe the development of American science over the past 40 years in terms of my own experience. This period has been described as a "Golden Age" of science. I will also characterize the unprecedented use of the new knowledge generated in this period for the betterment of the human condition.

Before the 1940's, America could be characterized as strong in technology and dominance in industrial production and relatively weak in science compared to Western Europe. Most of the basic research was carried out in universities (supported by philanthropy) and a few industrial laboratories. The government's involvement in the support of basic science was secondary to the private sector. Some have said that the United States was the Japan of this period.

The role of American scientists in determining the outcome of World War II had its rewards. They assumed positions of influence to the government. Their vision of science as a force for economic growth and national security was accepted as a rationale for the federal government to assume the primary responsibility for the support of science. With this support, the period between the end of World War II and the present became the Golden Age of science - characterized by explosive growth in numbers of scientists at work and fueled by seemingly unlimited expansion in the level of government financial support. The American research university system flourished, and times ensued of extraordinary creativity and discovery spanning almost every scientific field. The United States rapidly assumed a world leadership position

in science.

My own career reflects this history. My earliest researches were supported by private sources such as the National Geographic Society and the Geological Society of America. With growing government involvement, private sources were replaced by federal agencies such as the Office on Naval Research and the new National Science Foundation. The largesse of the federal government made it possible for me to use advanced equipment. I could secure arrays of detectors to explore the sea floor and the continental crust using elastic waves generated by explosions and earthquakes. In this way, I could obtain geophysical data of a quality and amount that enabled more detailed exploration of the Earth's interior than hitherto possible. This was a period when just about every qualified American scientist with a creative idea could receive a research grant. It enabled a young scientist like me to work as an independent investigator pursuing my own ideas, to design and field new instruments, to acquire the new computers that were just becoming available. I was able to support technicians, graduate students and post-doctoral fellows, all of whom became my partners in research. I was able to engage in joint research with scientists from Japan and Russia. All of this served to increase my own productivity as a scientist. Tens of thousands of American scientists can describe their own careers in these terms. This is the essence of the Golden Age of American Science. But it also was a golden age for the applications of science to human betterment.

A great nation has among its obligations the support of science as a cultural endeavor, as an intellectual quest for new knowledge. However, history shows that the collateral and often serendipitous beneficial fallout from research more than pays for the initial investment in basic science and engineering. This can be measured in economic terms such as improved productivity or the creation of new industries, and in human terms such as improved health, better understanding of the environment and of natural hazards, or developing countries becoming self sufficient in food. Together with many scientists I found that my work in the basic geophysical sciences had important social consequences. The team exploring the seafloor led by Maurice Ewing, in which I participated as a young scientist, pioneered the technology of offshore oil exploration. The arrays of detectors which I and others used to explore the continental crust and mantle became the basic technology for detecting violations of a nuclear test ban treaty. And what I and others learned about earthquakes and volcanoes using the methodologies of our science led to the proposal for the International Decade of Natural Hazard Reduction, perhaps my most important accomplishment. Some examples of the contributions of fundamental science and engineering to

society will now be discussed in greater detail.

Contributions to industrial development. The following are representative examples of new technologies with commercial importance that flowed from fundamental scientific and engineering research. To a large extent this research was carried out in American research universities:

modern agricultural products such as: hybrid crops,
mechanical harvesters, and computerized data bases on crop yields
biotechnology
designer drugs
magnetic resonance imaging systems (MRIs)
penicillin and many other antibiotics
many important industrial catalysts
computer numerically controlled machine tools
digital signal processing (used in communications, exploration for oil, compact discs)
the stored program computer (the basis for all modern computers)
Frequency Modulation (FM)
masers and lasers
ion implantation (in the manufacture of semiconductor devices)
computer work stations
plasma etching
reduced instruction set computing (RISC)
artificial intelligence and neural networks
compilers
word processing
image processing
instrument landing system, loran, inertial guidance
nuclear energy

Other Contributions of Science and Technology. Examples of contributions to the conquest of disease, the understanding of the environment, and the production of food will be given.

Contribution to Natural Hazard Mitigation. The year 1992 was one of the worst years for natural disasters in the United States.

Property damage was large, but very few lives were lost. Our country learned many lessons about improving standards for construction, but did well in minimizing casualties by providing warnings, evacuating populations at risk, and providing post disaster relief.

But it is the poor countries of the world, where two-thirds of the world's population lives, that bear 95 percent of all disaster casualties. Over the past few decades we have witnessed events of devastating proportions in these

countries. Single disasters have set back economic progress by as much as five years. The "Decade" can do much to reduce these losses. For instance, by the year 2000 all countries could have national assessments of disaster risks, plans for prevention and preparedness, and access to global, regional, and local warning systems. Design parameters exist about how much ground motion structures must accommodate. The development of advanced radar technology has greatly advanced our ability to predict tornadoes and other weather-related hazards. Computer modeling of watersheds has led to more accurate flood alerts. Modern fire codes, dam safety standards, seismic codes, and other technologies exist and can help. Training could be provided and these technologies could be transferred to countries that need help.

There is no higher calling than for scientists and engineers to use their talents on behalf of humanity.