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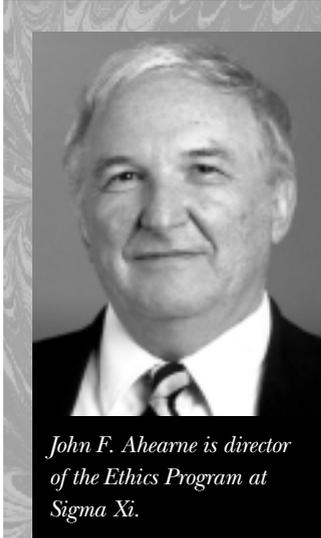
The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

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The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

Editorial



John F. Ahearne is director of the Ethics Program at Sigma Xi.

The Future of Nuclear Energy

In the past few years, there has been a resurgence of interest in nuclear power in the United States. Once advocated by very few, nuclear power is now being endorsed in the political arena, the marketplace, and the public-policy community. In the political arena, Senator Pete Domeni-

ci has long been a supporter of nuclear energy. Beginning with his speech at Harvard in 1997, he has laid out a clear program for research and development that could lead to the development of new and improved reactors and address the nagging problem of radioactive waste. Three clear signals indicate that nuclear power is being seen more favorably in the marketplace. First, not long ago, many were predicting that nuclear power plants would be shut down before their lifetimes had ended. Today, however, so many plants are being proposed for relicensing, which would extend their lifetimes for 20 years, that the Nuclear Regulatory Commission is in danger of accumulating a backlog. Second, whereas several years ago nuclear plants were being sold at fire-sale prices (e.g., for the cost of the fresh nuclear fuel committed to that plant), plants being auctioned now are bringing prices of many hundreds of millions of dollars. And finally, until very recently anyone who proposed that a new nuclear power plant be built in the United States was dismissed as blindly optimistic; today, utilities are discussing joining together to build a nuclear plant. The most aggressive industry advocate for building new nuclear plants, Corbin McNeill of Exelon, advocates a design that has several significant safety features, including fuel resistant to melting, the use of helium as the working fluid, and technologies with passive safety

features. Several designs have features that could have significant advantages, the advanced boiling-water reactor, for example, which has already been built in Japan.

In the past three years, the U.S. Department of Energy, supported by Congress, has developed several programs for research on nuclear technologies. These include: NERI,¹ a broad-based program for research on a wide variety of nuclear-energy-related topics; NEPO,² a program to improve the operation of current plants; and Generation IV, a program to develop new reactor designs for use by 2030. The goal of the latter program, as explained by Gail Marcus, is to develop designs acceptable to the public with improved safety and proliferation resistance and reduced costs.

The focus on 2030 is a sign in and of itself of the resurgence of interest in nuclear power. Another indication is the energy program of the current administration put forth by Vice President Cheney's task force, which is far more supportive of nuclear power than programs by the previous administration. In addition, many pragmatists in the scientific public-policy community, exemplified by John Holdren of Harvard, recognize that the United States will require a balanced portfolio of energy options to meet the challenges posed by greenhouse gas emissions and climate change. He and others now recognize that nuclear power is a necessary element in a balanced energy portfolio. All of the authors in this issue have been involved for many years in making sure that the United States has a balanced energy portfolio and that safe, economical nuclear power is part of that portfolio.

A handwritten signature in black ink, appearing to read 'J. F. Ahearne'. The signature is fluid and cursive, written on a white background.

John F. Ahearne

Notes

1. Nuclear Energy Research Initiative.
2. Nuclear Energy Plant Optimization.

Changing Global and Social Determinants for Nuclear Power

John P. Holdren



John P. Holdren is the Teresa and John Heinz Professor of Environmental Policy and director of the Program on Science, Technology, and Public Policy in the John F. Kennedy School of Government, and professor of environmental science and public policy in the Department of Earth and Planetary Sciences at Harvard University.

Nuclear energy will be an important component in a strategy to address climate change and other challenges.

The choices we make about energy research and development in the years ahead will affect economic well-being, environmental health, and international security everywhere in the world for most of the 21st century. From an economic standpoint, this is well understood: affordable energy is an indispensable ingredient of economic development. Energy costs typically absorb 7 to 10 percent of the cost of living; when they rise above this range, they cause inflation and recession, and they frustrate the economic aspirations of the poor. From an environmental standpoint, energy is a major contributor to dangerous and complex environmental problems at every scale, from local wood smoke in Third World villages to regional scourges of smog to acid precipitation in developed countries to the global challenge of climate change from accumulating greenhouse gases. From the standpoint of international security, energy issues include the potential for conflict over access to remaining supplies of inexpensive oil and gas, which are concentrated in a few regions, some of them politically unstable. Another volatile issue is the link

between nuclear energy technologies and nuclear weapons capabilities.

Another important energy-policy issue is deregulation, which surged dramatically into view earlier this year in California. I would suggest that we cannot have either complete deregulation or complete re-regulation. With complete deregulation, the public good, an essential component of the energy mix, is left entirely to the marketplace, and the market is not capable of controlling, or even wisely considering, externalities such as the security ramifications of over-dependence on imported oil, the macroeconomic benefits of reliable energy supplies, and the environmental costs of different energy choices. At the same time, we must have some deregulation in order to reap the benefits of competition. But deregulation must be done in a symmetrical way. The California system is a good example of the distortions caused by “regulatory asymmetry”; wholesale electricity was deregulated, while retail electricity remained regulated.

If we continue on a “business-as-usual” (BAU) energy trajectory—meaning not that nothing changes but that things continue to change along the lines of recent trends—total world energy use will more than double between now and 2050, and world electricity generation will more than triple. By 2100, energy use will be four times greater than it was in 2000, and electricity generation will be perhaps five times greater or more.

In 2000, more than three-quarters of the world’s energy was produced from fossil fuels. If the disruption of global climate by accumulating greenhouse gases proves to be as serious as now seems likely, the emissions caused by burning fossil fuels will have to be reduced sharply in the 21st century—just when total energy demand is expected to increase rapidly. That will necessitate much greater reliance on a combination of three non-carbon-emitting sources: renewable energy (biomass, hydropower, wind, sunlight); nuclear energy (fission and possibly fusion); and new technologies for capturing and storing carbon dioxide produced by the burning of fossil fuels. Under a BAU scenario, contributions from the non-carbon-emitting sources might have to increase 15-fold in the 21st century. Because the costs and expandability of these options are uncertain, prudence dictates that we make vigorous efforts to develop and improve all of them, as well as to increase the rate of improvement in energy efficiency.¹

In the following sections, I will elaborate on the dimensions of the linked global challenges in energy and climate change and then turn to the role of nuclear energy in meeting those challenges.

Global Perspective

Between 1850 and 1950, the expansion of the world energy system depended mainly on coal, with growing contributions toward the end of this period from oil and gas. The use of oil accelerated rapidly after 1950—and the use of natural gas after 1970. The growth rate of world energy use from 1950 to 2000 was twice the growth rate for the preceding 100 years. World energy use increased about 4.3-fold from 1850 to 1950, and then 4.3-fold again from 1950 to 2000, totaling a 20-fold increase in energy use in the last 150 years. In 2000, fossil fuels were contributing more

Emissions caused by burning fossil fuels will have to be reduced sharply in the 21st century.

than 75 percent of the total. In a BAU energy future, energy use would quadruple again in the 21st century, and the amount of carbon added to the atmosphere by burning fossil fuels would climb from about 6 billion metric tons per year in 1990 to 20 billion metric tons per year by 2100.

The BAU energy future, and potential alternatives, present formidable challenges. Can energy supplies be quadrupled without intolerable increases in monetary and/or environmental costs? If not, can our economic aspirations be met with lower energy growth? Will it be possible to avoid armed conflict over the remaining supplies of cheap, accessible oil and natural gas? The most formidable challenge of all, I believe, will be meeting expanding energy needs without adding intolerable amounts of greenhouse gases to the atmosphere and risking a further destabilization of climate.

The Climate Issue

Climate change is the most dangerous and intractable of all environmental problems. It is the most dangerous because climate profoundly affects all other environmental processes and many aspects of human well-being. It is intractable because our impact on climate is deeply rooted in the world energy supply system, which can only be changed slowly and with great difficulty. Greenhouse gases are not like the fluorocarbons that threatened stratospheric ozone, which had a small economic role and could be easily replaced. The most important source of human-generated greenhouse gas is carbon dioxide from the burning of fossil fuels, the technologies for which supply more than three-fourths of the world's energy and cannot be quickly replaced.

The seriousness of climate change is still widely misunderstood. Many people think warming of only a few degrees would be innocuous, but climate includes both averages and extremes, not only of hot and cold, but also of wet and dry, snow pack and snow melt, winds and storm tracks, and ocean currents and upwellings. Climate influences the productivity of farms, forests, and fisheries, the geography of disease, the livability of cities in summer, damage from storms and floods, property damage from higher sea level, the cost of engineered environments, and even the distribution and abundance of plant and animal species. A change of a few degrees in the average global temperature would entail highly disruptive alterations in climatic patterns.

Based on glacial records, the last 50 years constituted the warmest half-century in 6,000 years.

The evidence that climate is changing is compelling. Based on instrumental records, the average temperature of the Earth has risen about 0.8°C in the last 100 years. Fifteen of the 16 hottest years since 1860 have occurred since 1980; the seven hottest years have occurred since 1990. The hottest year on record, and

likely the hottest in a thousand years, was 1998. Based on glacial records, the last 50 years constituted the warmest half-century in 6,000 years. Observed changes consistent with this warming include an increase in evaporation and rainfall, the melting of permafrost, the bleaching of corals, the retreat of glaciers, the shrinking of sea ice, and a rise in sea level.

The principal contributor to the increased greenhouse “forcing” of climate in the past 250 years has been the increased release of carbon dioxide. Evidence that the observed 90 parts per million volume (ppmv) increase has been caused by human activities follows three main lines:

- The observed increases in atmospheric concentration track almost perfectly with known increases in human additions of CO₂, initially from deforestation and subsequently—and most importantly—from the burning of fossil fuels.
- Ice-core data show that natural fluctuations in atmospheric CO₂ in the past 10,000 years have been only plus or minus 10 ppmv.
- Carbon-14 analysis of tree rings dating back to 1800 confirms the fossil-fuel contribution to the atmospheric CO₂ burden in the last 200 years.

The observed changes in climatic variables so far closely match the predictions of computer models, and no alternative cause with the same “fingerprint” as increasing CO₂ has been identified.

What might be the consequences of allowing CO₂-induced climate change to continue? Some of the predictions based on BAU energy production include the following:

- Global-average surface temperature would increase by 0.2 to 0.4°C every decade in the 21st century, a total of 2°C to 4°C by 2100.
- The Earth would be warmer by 2100 than at any time in the last 160,000 years.
- Sea level would be 20 to 100 centimeters higher than it is today and would continue to rise for centuries thereafter.
- Global average warming would cause changes in climatic patterns, storm tracks, the distribution of precipitation and soil moisture, and extremes of hot and cold.

- The effects of these changes on human well-being would probably be more negative than positive—in part because of their rapid pace.

It is important to understand that changes are not expected to be uniform. Warming in much of the midcontinental area of the northern hemisphere would be much greater than the global average, for example; much less warming would occur in the oceans, which have huge thermal inertia.

In addition, unpleasant surprises, to which no one can yet attach meaningful probabilities, are likely. These could include changes in the virulence and distribution of pathogens; increases in the frequency and intensity of destructive storms; an acceleration in rates of extinction; rapid shifts in ocean currents; a multi-meter sea-level rise from the disintegration of the west Antarctic ice sheet; and a runaway greenhouse effect from the decomposition of methane-bearing compounds.

The options for corrective action are limited to the following four approaches:

- Reduce emissions of greenhouse gases.
- Remove greenhouse gases from the atmosphere (e.g., by planting trees).
- Try to counteract the climatic effects of increased greenhouse-gas concentrations in other ways (e.g., by injecting reflective particles into the atmosphere to reduce solar input).
- Adapt human behavior and living patterns to greenhouse-gas-induced climate changes.

We shall probably attempt all of these things, and we are already attempting some of them. But the problem is so big that no one approach will be enough.

This means that reducing emissions cannot be avoided. Emissions are the product of population times economic activity per person times energy intensity of economic activity times carbon intensity of energy supply. Reducing population growth below the BAU level would be useful but difficult to achieve. Reductions in per-capita economic growth as a way of reining in greenhouse gases is not likely to be popular. Clearly, then, we must take a hard look at the technical possibilities of changing the energy intensity of economic activity and the carbon intensity of energy supply.

The technical possibilities are fairly obvious:

increasing the efficiency of energy end use in buildings, transportation, and industry; transitioning to a less energy-intensive mix of economic activities; increasing the efficiency of converting fossil fuel to end-use energy forms; switching from coal and oil to natural gas;² capturing and sequestering carbon when fossil fuels are transformed or used; and increasing the deployment of renewable and nuclear energy options. A variety of policy measures could increase the incentives and lower the barriers to the selection of low-carbon energy from the menu of options. In addition, research, development, and demonstration of new technologies could improve the characteristics of that menu over time.

Warming in much of the midcontinental area of the northern hemisphere would be much greater than the global average.

Restraining Carbon Emissions

How much will carbon emissions have to be reduced below BAU? Many climate modelers have calculated greenhouse effects on the basis of doubling the pre-industrial CO₂ levels of about 275 parts per million. BAU growth of emissions would triple the pre-industrial level by 2100 and probably quadruple the level or more thereafter. But the effects predicted for even doubling are large enough that society will probably want to avoid exceeding that level if possible. To achieve this goal, carbon emissions would have to peak below 10 gigatons a year between 2035 and 2040, and by 2100 they would have to drop back to about the current level.

A simple thought experiment can illustrate how much the supply of carbon-free energy would have to increase in the 21st century to avoid doubling pre-industrial CO₂. In 2000, the world produced some 450 exajoules of primary energy, 350 of which came from fossil fuels and 100 of which came from non-

carbon-emitting energy sources.³ Under BAU, primary energy would increase to about 1,100 exajoules in 2050 and 1,850 exajoules in 2100. To avoid doubling preindustrial CO₂, however, the conventional fossil primary energy supply could not exceed 500 exajoules in 2050 or 350 exajoules in 2100 (assuming the proportions of oil, gas, and coal in the fossil-fuel mix do not change). It follows that we would need six times as much carbon-free energy in 2050 as we had in 2000 and 15 times as much in 2100.

The BAU scenario assumes that energy efficiency would improve in the economy as a whole at 1 percent per year, which is about the long-term historical average. If we could do half again as well and improve energy efficiency at 1.5 percent per year worldwide, we would need 3.5 times as much carbon-free energy in 2150, and almost eight times as much in 2100. This would cut the necessary increase in carbon-free energy roughly in half but would still present an immense challenge.

It is possible that we could double the rate of improvement of energy efficiency. After the oil price shocks of the 1970s, energy efficiency improved in the United States by 2.7 or 2.8 percent per year for 15 years. But that does not prove that the whole world could achieve a 2 percent increase in efficiency for 100 years. Even if this happened, we would need about 1.5 times as much carbon-free energy in 2050 as in 2000, and three times as much in 2100—still a formidable challenge.

Even with improved energy efficiency, we will need larger carbon-free energy supplies.

As these examples show, improving energy efficiency would have enormous benefits, and everybody agrees that we should do it. But even if we are successful, we will need substantially larger carbon-free energy supplies.

Prospects for Nuclear Power

Nuclear power is already an important source of carbon-free energy. In 2000, it contributed about one-sixth of world electricity supply (amounting to about 6 percent of primary energy supply). For the contribution of nuclear power to increase significantly—say, to one-third of world electricity generation by 2100—it would have to increase about 10-fold beyond its present size. This would mean the equivalent of about 3,300 reactors of 1,000 electrical megawatts each. The feasibility of expanding nuclear energy to this extent depends on five factors: (1) nuclear electricity generating costs that are competitive with alternative non-carbon-emitting options; (2) extremely safe nuclear energy operations—not just in the United States, but around the world; (3) a politically and technically acceptable way of managing radioactive waste; (4) minimal linkages between nuclear energy and nuclear weapons capabilities; and (5) public understanding and acceptance of the need for expanded nuclear energy. In this section, I will describe briefly each of these five factors.

The first issue is cost. The relatively high costs of nuclear power (when plant construction costs as well as operating costs are taken into account) have been a major obstacle to the expansion of nuclear energy in the short term. Cost is somewhat less likely to be a major obstacle in the long run, because on that time scale fossil fuels are likely to become more expensive, and the least costly renewable options—such as wind power—may be limited by the availability of good sites. In my opinion, nuclear energy will meet the competitive-cost criterion in the long run without a great deal of trouble.

The second issue is reactor safety. I would argue that the safety of modern Western reactor types is probably adequate for a world with only a few hundred reactors. In a world with a few thousand reactors, however, safety would have to be improved by 10-fold or more. I believe this can be achieved through greater reliance on passive, as opposed to active, safety systems. Reactor designs based on greater use of passive safety characteristics have already been developed.

Third, radioactive waste disposal must be shown to be manageable in the short term and midterm, without causing significant worker or public exposure to radiation. In the long term, the United States and other countries must find substantially problem-free,

permanent solutions to the waste-disposal problem. These challenges seem manageable technically, but convincing the public that the required level of safety has been attained may be difficult.

Fourth, both technical and institutional means must be used to ensure that nuclear energy systems are adequately proliferation resistant. In the short term, this will require avoiding the use of either highly enriched uranium or separated, reprocessed plutonium; minimizing the plutonium that has already been separated by minimizing reprocessing; and maximizing the conversion of this plutonium into a form that cannot be directly used in weapons. In the long run, this issue could be addressed by postponing the recycling of plutonium indefinitely and using uranium from seawater in once-through fuel cycles or by developing plutonium reprocessing/recycling technologies that do not separate the plutonium completely from fission products or by locating enrichment and reprocessing facilities in internationally operated complexes.

Finally, public acceptance of an increase in nuclear power will require not only that all of the foregoing conditions be met, but also that the public have confidence that they have been met. To achieve this, institutions that operate and regulate nuclear power must insist on a culture of competence, responsibility, honesty, and transparency, and opportunities for public participation in nuclear decision making must be increased.

Recommendations for the Future

To begin with, let me restate the recommendations in the 1997 White House study, *Federal Energy Research and Development Strategy for the Challenges of the 21st Century*, which I chaired.⁴ These recommendations covered the whole panoply of energy options, including fission and fusion, and made the following points about the nuclear options:

- In the context of an R&D portfolio that addresses climate change and energy-related security issues, the federal government should continue its R&D to improve the characteristics of fission energy systems.
- Fission R&D should focus mainly on long-term improvements that emphasize safer and more economical reactors, proliferation-resistant fuel cycles, and radioactive waste management. (The Nuclear Energy Research Initiative recommended by the

study to achieve this was funded at about \$60 million a year in the fiscal year 2001 appropriations, about two-thirds of the recommended level.)

- Another \$10 million a year in government R&D, to be matched by industry, should address issues involved in extending the operating lifetime of existing reactors.
- Federal spending for fusion should be in the range of \$300 million a year, in an overall federal energy R&D budget of about \$2.5 billion per year. (Spending on fusion has not yet reached this level.) Fusion is not likely to provide commercially significant quantities of electricity until some time after 2050, but having this option available then and thereafter could be very valuable.

Commercial-scale reprocessing and deployment of breeder reactors should be deferred.

In closing, let me offer a personal opinion about how we can maximize the chances of expanding the contribution of nuclear energy in the decades immediately ahead:

- Nuclear energy will be expandable to the extent that it is affordable and safe, that radioactive waste management problems have been solved, that emissions are modest, that proliferation linkages are under control, and that the controversies surrounding it have been addressed. Reprocessing and recycling of plutonium will not help us meet any of these goals and in fact will make achieving most, if not all, of them more difficult.
- Commercial-scale reprocessing and deployment of breeder reactors should be deferred. Neither of these technologies will be economical for decades, and avoiding their premature deployment will save money, set a positive example of nonproliferation, reduce the risks of theft of separated plutonium,

avoid increased emissions of radioactivity from the nuclear fuel cycle, and reduce public controversy about expanding nuclear energy.

- We ought to build additional interim storage capacity for spent fuel using the proven, safe, inexpensive cask-storage technology already in hand. This would save money now, avoid the risks attendant upon reprocessing, and buy us time to analyze candidate sites for permanent waste disposal and to consider whether reprocessing and breeding might be attractive in the longer term.
- We should conduct a rigorous program of research on advanced reprocessing technologies, improved reactor design (both breeder and nonbreeder), and the extraction of uranium from seawater. If we learn more about these possibilities, our successors will be in a position a few decades hence to make sensible choices for the longer term.

Notes

1. More extensive summaries of projections of the impacts of climate change under business as usual can

be found in the 1997 and 1999 energy reports of the President's Committee of Advisors on Science and Technology (available online at <http://www.OSTP.gov/Energy/> and <http://www.ostp.gov/html/P2E.pdf>) as well as in the reports and on the website of the Intergovernmental Panel on Climate Change <http://www.ipcc.ch>. See also the draft *National Assessment of Climate-Change Impacts on the United States* at <http://www.gcrio.org/NationalAssessment/>.

2. Natural gas releases less carbon dioxide per gigajoule than coal or oil; on the other hand, the processing and transport of natural gas can release methane, which is a more potent greenhouse gas than carbon dioxide.

3. One exajoule (1,018 joules) equals 0.95 quadrillion Btus or 22 million metric tons of oil equivalent.

4. President's Committee of Advisors on Science and Technology, Panel on Energy Research and Development. 1997. *Federal Energy R&D for the Challenges of the 21st Century*. Washington, D.C.: Executive Office of the President of the United States. Also available online at <http://www.OSTP.gov/Energy/>.

Technology, Safety, and Human Resources

Gail H. Marcus

We may be on the threshold of a “second frontier” in the development of nuclear energy.



Dr. Gail H. Marcus is principal deputy director of the Office of Nuclear Energy, Science and Technology, U.S. Department of Energy, and is currently president of the American Nuclear Society.

After many years of reduced research activity, the status of nuclear energy is changing dramatically. Many of us in the field have envied those who pioneered the development of the industry when nuclear power was a technological frontier. Very recently, however, the situation has changed, and we may be on the threshold of a “second frontier” that promises to be as exciting as the first. The U.S. Department of Energy (DOE) has recently launched plans to strengthen the nation’s nuclear power option through the development of short-term and long-term road maps that address issues related to technology, safety, and human resources.

Generations of Nuclear Power Technologies

These road maps will build on more than 40 years of experience with commercial nuclear power. The earliest plants, which we now call Generation I nuclear power plants, were small prototypes and demonstration plants built during the 1950s and early 1960s at Shippingport, Pennsylvania, Dresden, Germany, and elsewhere. Generation II plants followed. These

are the currently operating commercial power reactors, primarily light-water reactors of both pressurized and boiling-water designs, and some other technologies.

Since the Generation II plants were built, several superior designs (Generation III) have been developed. These include both advanced pressurized-water reactors and an advanced boiling-water reactor. Two advanced boiling-water reactors have already been built in Japan, and one is under construction in Taiwan. Two designs for pressurized-water reactors and one for a boiling-water reactor have been certified in the United States, but none has been ordered. The apparent lack of interest in these designs in the United States is largely because of their high cost. Although recent increases in natural gas prices have made nuclear power economical enough to make these advanced designs more attractive, the cost of construction is still very high.

The objective of NERI is to encourage the development of innovative concepts that might otherwise lack support.

It is clear that the world will require more electrical generating capacity in the future. Because of the significant environmental and other advantages of nuclear power (especially the absence of carbon emissions), it will certainly be an important element in the future global energy mix. We can keep existing plants running longer through license renewals, but in the long run, we will have to build new nuclear power plants. In addition to being more economical to build and operate, new nuclear power plants must address public concerns about safety, proliferation,¹ and waste disposal.

The development and construction of replacement nuclear technologies will take place in two time frames. In the short term (the evolutionary time frame), Generation III technologies will be further developed and implemented. Technologies that could be put into service in the next decade or so—approximately by the year 2010—are called Genera-

tion III+. These new designs, based largely on existing reactor and fuel cycle technologies, will require little new research and development (R&D). Nevertheless, they would be technologically and economically superior to Generation III reactors.

In the decade or two beyond the implementation of Generation III+, by 2020 or 2030 perhaps, truly revolutionary, next-generation (Generation IV) technologies could be available. These technologies will require substantial R&D and considerably more time to realize than Generation III+ designs. Generation IV technologies are expected to improve economics significantly, produce minimal waste, improve safety, and be proliferation resistant.

Nuclear Energy Research Initiative

DOE has embarked on a multitrack approach to the design and development of both near-term and long-term nuclear reactors. The first track is a research program known as the Nuclear Energy Research Initiative (NERI), which is now in its third year. The purpose of NERI is not to build new reactors but to support small, discrete research projects on innovative technologies that have been selected for their potential to improve safety, be more economical, increase proliferation resistance, or minimize waste.

The NERI approach differs from DOE's past approach to nuclear research. Under NERI, DOE funds investigator-initiated projects that have been selected by peer review, much the way the National Science Foundation and the DOE Office of Science fund their projects. NERI projects are typically funded for three years at \$500,000 to \$1 million a year. The objective is to encourage the development and demonstration of innovative concepts that might otherwise lack support. Among the 50 or so research projects under way are studies of the thorium fuel cycle and metal fuels; light-water, liquid-metal and gas-cooled concepts; large and small designs; and direct energy conversion.²

Road Mapping

The second track of DOE's planning process is an ambitious program to develop a comprehensive plan, or road map, for future nuclear power development. The program is being conducted under the auspices of the Nuclear Energy Research Advisory Committee (NERAC). The Subcommittee for Generation IV Technology Planning (also known as Generation IV

Roadmap NERAC Subcommittee) was established under NERAC in October 2000 to provide guidance for the development of a road map for Generation IV technologies and to oversee Generation III+ activities.³ Subcommittee members include representatives of industry, government laboratories, and universities. The subcommittee's mandate includes these goals:

- Define the requirements for Generation IV nuclear energy plants.
- Review all potential design concepts and select a small number of concepts that would be significantly more economical, safe, and proliferation resistant, that would minimize waste, and that could be developed to be available by 2030.
- Recommend a Generation IV R&D plan that includes sequencing of R&D tasks, initial cost estimates, and the promotion of national and international collaboration to ensure that these technologies would be ready for deployment by 2030.
- Suggest developmental pathways likely to resolve technical and institutional issues for near-term deployment of Generation III+ technologies (by 2010).

Near-Term Road Map

About two-thirds of the members of the NERAC near-term deployment group represent utilities and vendors of nuclear plants, who are well placed to evaluate near-term needs. This group will consider a limited number of technologies that require relatively little R&D and recommend support for those with the following characteristics:

- likelihood of winning regulatory acceptance
- compatibility with existing infrastructure
- credibility of the commercialization plan
- suitability for cost sharing, as appropriate
- demonstrable economic competitiveness
- compatibility with the existing industry fuel cycle

The objective is to select at least one competitive nuclear energy option that has been or could be certified by the Nuclear Regulatory Commission (NRC) in time for construction to begin by 2005 and operation

to begin by about 2010. Technologies that may fit this description include the AP 1000 and the pebble-bed modular reactor.

Although industry will probably not require major government assistance for near-term deployment, cost sharing is included as a criterion because firms or utilities may decide to spread the costs among themselves to reduce their risk and encourage innovation. The committee may also pinpoint areas in which government help will be necessary.

The Generation IV Technology Roadmap Subcommittee has outlined challenging, concept-independent goals

The committee is also working with NRC staff on all aspects of the near-term technologies. DOE is consulting with the NRC and industry to determine the need for staff training and regulatory modifications that would facilitate the licensing review process.

Long-Term Road Map

As a first step in creating a road map for Generation IV technologies, the Generation IV Technology Roadmap Subcommittee recently completed a report outlining challenging goals that are concept independent and have a wide range of applications. These goals address the issues of safety, economics, waste, proliferation, and sustainability. At the same time, an evaluation methodology group has developed some quantitative metrics for formulating first-round criteria for selecting long-term technologies.

The Generation IV subcommittee is attempting to define challenging but attainable goals for advanced technologies, which will be evaluated by several technical working groups with appropriate areas of expertise, such as water-cooled reactors, gas-cooled reactors, liquid-metal-cooled reactors, and "nonclassical" concepts. Another subcommittee of members chosen from the technical working groups will examine crosscutting issues, including fuel, operations,

maintenance, and instrumentation and control, that may involve a number of technologies.

All of these activities are being coordinated by a road map integration team composed of experts from the lead laboratories for reactor technology, Idaho National Engineering and Environmental Laboratory and Argonne National Laboratory.

Future designs must meet the needs of many countries, large and small, developed and developing.

The technical working groups represent a very broad spectrum of expertise drawn from all over the world. Each group has two cochair, one from the United States and one from another country; two representatives each from industry, the national laboratories, and academia; and six international representatives. The first goal of the working groups was to solicit and identify concepts worldwide and screen them. Initial screening was completed during the summer of 2001.

The technical working groups will now gather more detailed information on the most promising concepts for meeting the Generation IV goals and identify the R&D needed to bring them to fruition. Ultimately, they will select a small number of technologies (probably three or four) that DOE, working with other countries, can reasonably expect to support. These might include both small-reactor and large-reactor concepts, as well as quite different technologies to meet varying needs worldwide. A small-reactor concept would be essential to developing countries with small electricity grids. Small reactors may even be useful in a large country like the United States to provide power for “energy parks.” Some countries will wish to focus only on a large-reactor concept, particularly if potential sites are limited.

Finally, a road map for R&D for the selected technologies will be developed. The target date for completion of this road map is September 2002, approximately two years after the initiation of the Generation IV subcommittee.

International Collaboration

R&D for Generation III+ and Generation IV reactors will be more collaborative and international than ever before. The nuclear power community is becoming increasingly global, and the future designs must meet the needs not only of large, developed countries but also of smaller countries and countries in the developing world. Because the market for Generation IV technologies will be international and because research budgets are limited, international research teams are the best way to ensure the effective development of future technologies.

DOE has been involved in bringing together a group called the Generation IV International Forum (GIF) to facilitate international collaboration. Two subgroups, a policy group and a technical group, have been formed. The forum includes representatives of major nuclear power developers and users in the world, as well as smaller countries involved in the development and use of nuclear technologies. The international partners, including Argentina, Brazil, Canada, France, Japan, South Africa, South Korea, and the United Kingdom, are involved in the working groups developing the road map. Other participants include the NRC, the U.S. Department of State, and observers from international agencies, including the European Commission, the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD), and the International Atomic Energy Agency (IAEA). Over time, the IAEA and NEA are expected to participate in various ways, and other countries may be invited to join the GIF. The forum has met four times, twice in Washington, D.C., once in Seoul, and most recently in Paris.

Other Challenges

In order to develop Generation III and Generation IV technologies, the United States and the global community will also have to address the challenges of an aging workforce and aging infrastructure. For a long time, the nuclear power industry has been in a downward spiral; industry has been doing less research, and engineering departments at universities have attracted fewer students to the field. I believe we can reverse this spiral and support a resurgence of expertise and activity. The decline in student enrollments seems to have leveled off, and enrollments are expected to rise again

as the Generation III and Generation IV programs move forward.

In my view, the renewed interest in nuclear power is part of a general change in the energy environment. As recently as two or three years ago, few people were optimistic that nuclear power would be an option for the generation of electricity in the 21st century. Now such optimism is indeed being expressed, and a good deal of planning is being done both by government and industry. As a result of the recent energy disruptions in California and a growing awareness of global warming, public opinion also seems to be more favorable, and an increasing number of members of Congress have voiced their support. In this new environment, many people in the nuclear field believe we are

indeed on the threshold of an exciting period of innovation and discovery in the development of the next generation of nuclear technologies to meet our growing nuclear needs.

Notes

1. Proliferation is the diversion or theft of nuclear fuel, such as plutonium-rich fuel, that can be converted to explosive devices.
2. A list of NERI projects can be found online at <http://www.nuclear.gov>.
3. Other subcommittees of NERAC provide advice on other activities under the Office of Nuclear Energy, such as research on radioisotopes and on space nuclear power.

Economic Determinants and the Role of Industry

Corbin A. McNeill, Jr.

Industry will play a major role in the development and implementation of safe, efficient nuclear technologies.



Corbin A. McNeill, Jr., is chairman and co-chief executive officer of Exelon Corporation. He made these remarks at the NAE National Symposium in Irvine, California, on February 9, 2001.

The future of nuclear energy is one of the most important topics facing our nation today. To see how important, all you have to do is pick up a newspaper. For weeks now we've seen stories almost every day about the energy problems in California. Although some aspects of the current situation are unique to California, daily "Stage Three" alerts have made the entire country aware of what can happen when we run short of electric generating capacity.

The American appetite for electricity is growing every day. Nevertheless, nationally, our installed capacity has remained almost static at about 677,000 gigawatts for the past two years. At the same time, some people in our industry are projecting a nearly 50 percent increase in the demand for electricity in the next 20 years. We want not only abundant supplies of electricity but also cleaner air. To meet these twin demands, the "nuclear option" will certainly have to be an important part of our national energy strategy.

I want to explore with you the benefits of nuclear power and the role of industry in keeping the nuclear option viable. I'll briefly review the

history of nuclear power in the United States and then turn to the current state of affairs, as more states deregulate. Then I will turn to the future and an exciting new technology that has tremendous potential for the next generation of nuclear power plants—the pebble-bed modular reactor (PBMR).

There is general agreement that the person who most influenced the development of civilian nuclear power in the United States was Admiral Hyman G. Rickover. At the end of World War II, America turned its attention to developing nuclear energy to generate electricity. In 1946, work began at Oak Ridge, Tennessee, on the development of a civilian nuclear power plant. The program was abandoned two years later, however, and most of the personnel were transferred to a reactor program being conducted by the Navy, under then Captain Rickover. Known for his tenacity and dedication to hard work, Rickover's crowning accomplishment came in 1953 with the successful launch of the *Nautilus*, a nuclear-powered submarine. The research had involved several types of reactors, but the pressurized-water reactor (PWR) became the standard for the nuclear Navy.

Rickover's work greatly influenced the subsequent design of civilian plants. The first demonstration nuclear power plant, in Shippingport, Pennsylvania, was based on Rickover's submarine reactor, and Rickover was put in charge of its development. Most of the PWRs in the United States today are adaptations of the Shippingport reactor. Rickover also trained many of the Navy and civilian employees in his program, many of whom went on to become officers of the electric utility companies that built America's current nuclear power plants.

During the 1950s and 1960s, nuclear power was a high-technology/high-benefit program that had strong support from the government, as well as regulators, elected officials, and the general public. By the mid-1960s, utilities were considering building larger units in the expectation of an ever-increasing commercial demand for nuclear power. By the early 1970s, orders for nuclear plants were coming in so rapidly that unit size was increased simply to reduce the number of separate projects. Vendors could barely handle the number of orders they had.

But, as inflation began to increase in the 1970s, the cost of plant construction also increased. Then came the accident at Three Mile Island (TMI) in 1979, and

public concerns about safety led to regulatory reviews and re-reviews. As a result, additional, redundant safety systems were required on existing plants, as well as new ones. The antinuclear movement, spurred by the TMI accident, successfully delayed the licensing of many plants, and costs rose astronomically, sometimes at the rate of \$1 million a day. In the end, nuclear plants were high-cost alternative power sources. By 1988, U.S. nuclear production costs were 3.11 cents per kilowatt hour, making nuclear plants uncompetitive with coal-fired and natural gas-fired plants.

By the early 1970s, orders for new nuclear power plants were coming in rapidly.

Another unresolved issue, storage of spent fuel, increased the negative public opinion of nuclear power. Although operators of nuclear plants have an enviable safety record in storing spent fuel, the issue still arouses strong public concerns and will continue to do so until we settle the issue by building a permanent repository.

In the late 1980s, even though nuclear power plants were not competitive with fossil-fuel plants, they were still protected by a regulatory environment that allowed utilities to recover capital costs. That equation began to change six or seven years ago when states began to reexamine the issue of retail electricity competition. In states with nuclear power plants, the most contentious issues in the deregulation debate have come down to how utilities can recover the stranded costs embedded in these plants. Settlements allowing for recovery of stranded costs over a period of years enabled utilities to write down the high capital costs related to the construction of nuclear power plants. Once the plants were written down, nuclear plants could compete strictly on the basis of operating costs, which gave plant operators a very strong incentive to control operating and maintenance costs.

It is now clear that nuclear power cannot and should not depend on government subsidies but must stand on its own merits as a competitive source of electricity. That is the challenge facing the operators of all 103

plants in America today. At Exelon, we've met this challenge by vigorously reducing production costs. Most of our plants operate in the top quartile of the industry, making us competitive in all of the regions where we operate.

Nuclear power must stand on its own merits as a competitive source of electricity

The industry as a whole has also taken important steps towards reducing costs. In 1999, for the first time ever, nuclear plant operating costs were below those of fossil-fueled plants. Nuclear plants today generate electricity at about two cents per kilowatt-hour, just slightly below the cost of coal-fired generation. This accomplishment was the result of several factors. For example, we reduced the length of refueling outages. A decade ago, it was fairly typical for an outage to last three months; today, many last only three weeks. The reduction is attributable to employees developing skills in a variety of jobs involved in an outage, the performance of more maintenance while the plant is operating, and the consolidation of plant staffs. Another factor in the decrease in operating costs is the increase of utility mergers in the past few years. For example, the merger last October of PECO Energy and Unicorn, to form Exelon, accompanied by acquisitions made through AmerGen, a joint venture with British Energy, enabled us to assign the administration, maintenance, and outages for several plants to a single staff. So, the debate about whether nuclear plants can compete with coal and natural gas plants is over. The answer is clearly yes.

But simply being competitive today will not meet our needs for tomorrow. The nation's demand for electricity is increasing every day. To meet that demand, new plants must be built. Otherwise, other parts of the country will experience problems similar to the recent problems in California. A great deal of work is being done throughout our industry to

develop advanced thermal reactors, mostly evolutionary design changes on boiling-water reactors or PWRs. Most of these projects are focused on plants in the 1,000- to 1,700-megawatt range, in line with the size of current plants.

However, I think the industry should look in a different direction, namely toward PBMRs. Last year Exelon announced that the company was investing in a research project with ESKOM, the electric utility of South Africa, for the possible development of the PBMR. The study will be completed by the end of this year, and I'm confident that the results will be positive; we can then move forward with the construction of a prototype plant in South Africa. Within a few years, PBMR technology could be exported to Europe and the United States.

PBMR technology is an improvement on the gas-reactor technology used in the first commercial gas reactor, Unit One at Peach Bottom, Pennsylvania, in the early 1960s and similar plants built in Germany in the 1970s and 1980s; the technology is also being tested today in China. PBMR has a simple design basis, with passive safety features that require no human intervention and cannot be bypassed or rendered ineffective. If a fault occurs during reactor operations, the system comes to a standstill and merely dissipates heat on a decreasing curve. There is no possibility of core failure or release of radioactivity to the environment.

The PBMR consists of a vertical steel pressure vessel, 6 meters in diameter and about 20 meters high, lined with graphite bricks 100 centimeters thick. The reactor uses particles of enriched uranium oxide coated by silicon carbide. The particles are embedded in graphite to form fuel spheres, or pebbles, about the size of tennis balls. Helium is used as the coolant and energy-transfer medium to a closed-cycle gas turbine and generator system. During normal operation, the pressure vessel contains about 440,000 balls, 330,000 of which are fuel balls. The rest are pure graphite balls, which serve as an additional nuclear moderator that shifts the power of the reactor away from the control rods and toward the center of the reactor.

To remove the heat generated by the nuclear reaction, helium gas at 540°C enters the pressure vessel at the top, moves down between the hot fuel balls and leaves the bottom of the vessel, having been heated to a temperature of 900°C. The hot gas passes through a closed-cycle gas turbine that drives the electric

generator before being returned to the reactor. The helium, which is chemically and radiologically inert, cannot combine with other chemicals, is noncombustible, and cannot become radioactive when passed through the core.

The inherently safe design of the PBMR would virtually eliminate the need for redundant backup systems and off-site emergency plants, thus greatly reducing the operating costs of the plant. With their modular design, PBMR plants could be built in 110-megawatt units, and new units could be added as demand increases. With standardized designs, the mass production of plants, assembly-line fashion, would become possible, similar to the way commercial aircraft are built today.

All of these factors make the economics of the PBMR very attractive. Just in terms of operating costs, a typical PBMR plant should be able to generate a kilowatt of electricity for less than a penny. The costs for other advanced thermal reactors under development range from 1.16 to 1.50 cents per kilowatt. The comparison is even more favorable when we look at natural gas plants, which have operating costs of 2.35 to 3.05 cents, depending on the market price of natural gas.

The low cost of operation, coupled with relatively low capital costs, make the PBMR an extremely attractive alternative for new plants. Add in the inherent safety of the design, and the benefits of the PBMR are even more striking.

In conclusion, I'm extremely optimistic about the future of nuclear power in the United States. It is the only source of power generation that can meet our growing demand for electricity and also contribute to a cleaner environment. We've come a long way in the past decade. We've demonstrated that we can run our plants more efficiently without compromising safety. We've shown that nuclear power can compete in the marketplace with other sources of power generation. And we're developing exciting new technologies that could mean more efficient plants in the future.

The past 20 years have not been easy for the nuclear power industry, but I think the tide is beginning to turn in our favor. More and more people are learning of the environmental benefits of nuclear power. The industry's focus on safety is restoring public confidence. And the public is beginning to understand that, as a nation, we simply must build more generating plants if we want to continue to enjoy the benefits of a technology-based economy. We now have a unique opportunity. By keeping nuclear power viable, we can meet America's growing demand for electricity and, at the same time, address the concern for cleaner air. And, with new technology, plants can be built at less cost, making nuclear power an attractive economical alternative in competitive markets. In answer to the question posed by this symposium, nuclear power is *the* option for the 21st century.

Nuclear Power for the 21st Century

Pete V. Domenici

Too few Americans understand or appreciate the enormous benefits of nuclear technologies.



Pete V. Domenici is U.S. senator from New Mexico. The following paper was prepared for delivery at the NAE National Symposium held in Irvine, California, on February 9, 2001.

The subject of this symposium, “Nuclear Power: The Option for the 21st Century?” is very much like the subject of the national dialogue I called for in a speech I delivered at Harvard in October 1997. In that talk, I called for a national evaluation of the role of nuclear energy and nuclear technologies. I hoped to stimulate an informed discussion on the vast benefits of nuclear technologies—benefits that too few Americans understand or appreciate. Above all, I stated that the nation must preserve the option of using nuclear energy to meet the energy demands of future generations. Since the Harvard speech, I’ve participated in countless interactions with government, industry, and university groups on these subjects, and a number of successful legislative initiatives have been undertaken that offer real hope for a solid future for nuclear power.

The number of my colleagues in the Senate who appreciate the benefits of nuclear technologies is growing steadily and significantly. Perhaps the best indication of this is the large margin of approval for a bill introduced in 2000 to establish an early receipt facility in Nevada for spent nuclear

fuel. President Clinton vetoed the bill, and the Senate subsequently tried to override the veto but failed by a margin of one vote.

Your selection of California for the site of this meeting is interesting. Californians are often in national headlines, but I'm sure the latest headlines have not been welcome there or anywhere else. The whole nation has watched with fascination and despair as California's splendid economic engine, which represents the sixth largest economy in the world, is sputtering, with no relief in sight. Many experts are now analyzing California's energy woes, and the crisis is already sparking a congressional debate on national energy policy, or our past lack of one. It's become evident that in a number of ways California's so-called "deregulation" was designed to fail spectacularly, which indeed it has done. There are many reasons for this failure, including ultrastrict environmental restrictions that severely undercut California's ability to develop new generating capacity.

Even before President Bush was sworn in, I suggested to him that he create a cabinet-level energy policy board, and I'm very pleased that he quickly announced the creation of this entity. I noted to him that the assumption that the U.S. Department of Energy (DOE) controls energy policy is out of touch with reality. In fact, other agencies play major roles. For example, the Environmental Protection Agency (EPA) is involved in setting standards for everything from emissions of radiation to particulates and can block progress on energy resources regardless of the economic imperatives. The U.S. Department of Interior has demonstrated its ability to block exploration for new fossil fuel resources with policies that have contributed to sky-high and climbing prices for natural gas. I look to the new Energy Policy Development Group, chaired by Vice President Cheney, to evaluate the policies of each agency for their impact on national energy security.

The California energy crisis may encourage Congress to move ahead with improved energy policies, and I'm optimistic that nuclear energy will be one area of emphasis. Senator Murkowski (R., Alaska) is now working on a National Energy Strategy Bill that includes a number of provisions supportive of nuclear energy; I'm working on a major bill focused exclusively on nuclear energy issues. Later in this talk I'll give you a brief overview of my legislation.

But first, I'd like to discuss the progress we've made in the three years since the Harvard speech, which was given around the time of the Kyoto meeting. At that conference, the Clinton administration talked about the risks of global warming but did not note that present nuclear plants do not increase those risks or that increasing the use of nuclear energy could reduce them. I've said many times that we will not be able to meet the Kyoto goals without maintaining nuclear energy as a strong option for meeting our energy needs. Unfortunately, the Clinton administration was determined to undermine support for nuclear technologies. There was no enthusiasm for a rebirth of the nuclear industry, and nuclear engineering programs across the nation were allowed to deteriorate.

California's "deregulation" was designed to fail spectacularly, and it has.

Real progress has been made in these three years, mostly by Congress. The Nuclear Energy Research Initiative was established to encourage serious studies of nuclear topics. Funding for this initiative increased by more than 50 percent this year (2000). A nuclear energy plant optimization program has also been initiated to explore ways to extend the lifetimes of existing plants.

This year also marks the start of the Nuclear Energy Technology Program, a \$7.5 million effort to explore specific areas of technology that can impact the market for new nuclear power plants. Most of the funds are dedicated to studying Generation IV reactors, which would:

- be cost competitive with other energy sources
- have no possibility of core meltdown
- minimize concerns about proliferation
- reduce the production of high-level waste

Building on this Generation IV program, I'm very optimistic that in the next few years we will witness the

construction of a new reactor, perhaps to serve as a demonstration testbed for new technologies. I've been watching with great interest the progress in South Africa on a pebble-bed reactor project. Not too many years ago, the thought of a new reactor in the United States would have been a pipe dream—but today many people believe it isn't impossible.

Our current radiation standards are based on questionable scientific knowledge.

Changes at the Nuclear Regulatory Commission (NRC) have led to renewed interest in nuclear plants, which has dramatically increased optimism about the future of the industry. The NRC has changed from an agency that took forever to study an issue to one that is committed to focused action. The NRC has extended the licenses of five reactors, and done so on tough schedules. Both the NRC and Congress deserve credit for these changes.

In the Harvard speech, I noted the close interplay between civilian and military programs. We simply won't be able to realize the potential of civilian nuclear energy unless the military aspects of nuclear technologies are carefully controlled. Justified public concerns about the military uses of nuclear technologies must be carefully addressed; otherwise, they could completely poison the public perception of the civilian benefits of nuclear energy. Thus, our nonproliferation programs with Russia are critical for the future of nuclear energy, to say nothing of their importance to our national security. These highly challenging cooperative programs with Russia face immense difficulties. Nevertheless, the program for materials protection, control, and accounting, initiatives for the prevention of proliferation, the Highly Enriched Uranium Agreement, and the program to address the disposition of plutonium have all made real progress. Another program, the Nuclear Cities Initiative, received a significant funding boost this year; decisions on future funding will be conditioned on progress against

measurable milestones.

I am a strong champion of these nonproliferation programs, which are a critical investment in our national security. I also asked, without success, the past administration to improve its coordination of these programs by appointing a national coordinator. This idea was included in the Nunn-Lugar-Domenici legislation in 1996 and was emphasized again in the current Defense Authorization legislation. Congress would have more confidence in nonproliferation programs and in their cost efficiency if their coordination were dramatically improved. More importantly, the effectiveness of these programs would be enhanced by careful coordination.

The Bush administration has expressed its strong support for these nonproliferation activities. For example, Condoleezza Rice, the new national security advisor, recently noted that "American security is threatened less by Russia's strength than by its weakness and incoherence. This suggests immediate attention to the safety and security of Moscow's nuclear forces and stockpile" (*Chicago Tribune*, December 29, 2000). The recent Baker-Cutler Report also expressed support. "The most urgent unmet national security threat to the United States today is the danger that weapons of mass destruction or weapons-usable material in Russia could be stolen and sold to terrorists or hostile nation states and used against American troops abroad or citizens at home" (Baker and Cutler, 2000). I look forward to working with the new administration on these critical issues.

In the civilian area, two overarching issues frame the debate on nuclear energy issues: (1) radiation standards and public fears of radiation; and (2) a credible national strategy for disposing of spent nuclear fuel. These two issues are frequently highlighted by anti-nuclear groups. Unfortunately, these groups have not invested much, if any, time in finding credible solutions so the benefits of nuclear technologies can remain available to mankind.

Our current radiation standards are based on questionable scientific knowledge. In June, in response to my request, the General Accounting Office (GAO) issued a study, highlighting the lack of scientific data for the current standards and the immense costs of using highly conservative standards (GAO, 2000). The GAO report also highlighted the serious impact on cost and uncertainty of conflicting guidance for setting

radiation standards from the EPA and the NRC; the conflict has become even more frustrating since the National Academies raised serious questions about the scientific credibility of the EPA draft standards for Yucca Mountain (NRC, 1999). This is precisely the type of conflict between agencies I hope can be addressed by the creation of the cabinet-level energy policy group.

To address the issues raised in the GAO report, Congress created a research program focused on the health effects of low doses of radiation. This DOE program is designed to explore, for the first time, the molecular and cellular bases for radiation standards. The program is now entering its third year, but surprisingly did not receive adequate support from the past administration; in addition, EPA has not shown much interest in its progress. Fortunately, Congress stepped in to provide the resources necessary to keep the program moving forward. This study of the effects of low doses of radiation offers our best hope for improving our scientific understanding as a basis for setting better standards. Just recently I became aware of a parallel, even larger program in France, and I have proposed taking steps to ensure that these two major programs are coordinated at the governmental level. I understand that this coordination is taking shape now.

Perhaps the most frustrating aspect of the future use of nuclear energy is our lack of credible strategies for dealing with spent fuel. I've stated repeatedly that I believe the barriers to progress in this area are entirely political, not technical. I fear we could doom our nation's prospects for the future use of nuclear energy if we don't make progress in this area. We continue to focus on Yucca Mountain as a permanent repository, despite the fact that long-term disposal has not been shown to be in the best interests of all our citizens. Depending on our future demands and options for electricity, we may have to recover the tremendous energy that remains in spent fuel. Furthermore, strong public opposition to the disposal of spent fuel, with its long-term radiotoxicity, may preclude the use of repositories that simply accept and permanently store spent fuel rods.

For these reasons, I've favored centralized storage for a period of time in a carefully monitored, fully retrievable configuration. At a minimum, centralized storage would concentrate the spent fuel from 70 plus locations around the country into one or more

centralized, tightly controlled storage areas. A monitored storage facility could allow future generations to evaluate the need for energy and decide on the appropriate reuse of spent fuel or on its final disposition. In a very real sense, a centralized, monitored, retrievable storage facility for spent nuclear fuel would be a national reserve of nuclear fuel for future generations.

Congress has worked very hard to make progress on the issue of spent fuel. As I mentioned earlier, last year, a bill was passed by large margins in the House and the Senate creating an early-receipt facility in Nevada; the bill would also have created a DOE office to evaluate strategies for spent fuel. The vote was 253–167, a veto-proof majority, in the House and 64–34 in the Senate, both impressive margins. Unfortunately, President Clinton vetoed this bill, and the veto override vote failed in the Senate by a single vote.

Despite the veto, Congress has created other opportunities for making progress on spent fuel strategies by funding research on transmutation. This year, \$34 million has been set aside for an advanced accelerator applications (AAA) program, which includes waste transmutation. As part of an integrated national or international strategy for spent fuel, transmutation could dramatically alter the radiotoxicity of spent fuel

A DOE program is designed to explore the molecular and cellular bases for radiation standards.

and allow much of the residual energy to be recovered. International interest in transmutation is tremendous, and the new AAA program will encourage cooperation. I've been assured that transmutation is technically feasible, but we need solid research and engineering results to provide a basis for assessing the economic, environmental, and proliferation impacts of transmutation. I'm very hopeful that the new administration will encourage serious work on spent fuel strategies, including transmutation. The future of nuclear energy requires that we demonstrate

scientifically sound solutions for spent fuel to the public. We need research today to enable tomorrow's leaders to decide whether some forms of reprocessing and transmutation can reduce the risks and enhance the benefits of nuclear energy.

As I mentioned earlier, several major legislative packages are under development. The National Energy Strategy Bill of Senator Murkowski is a very broad piece of legislation encompassing all forms of energy; his bill will contribute to the development of a coherent national energy policy. In addition, I'm hard at work on a bill focused specifically on nuclear energy. Both bills would establish a DOE office that would develop and coordinate strategies for spent nuclear fuel.

It's too early to discuss the specifics of my bill, but it will address nuclear energy issues in five broad areas:

- ensuring a continued supply of nuclear energy
- encouraging the construction of new nuclear power plants
- treating nuclear energy on a level playing field with other energy sources
- identifying solutions for spent fuel
- further streamlining the NRC

I'd like to mention one additional subject that should be included in discussions about energy policy—the increasing globalization of the world's economies. I don't believe the world can develop in the peace and harmony we all want unless the large differences between the "have" and "have-not" nations are addressed. The standard of living for billions of people lags far behind the standard of living in the Western world. The economies of the developed world rest on reliable sources of electricity, which is a prerequisite for modernization. As you are well aware, there is now a vast gulf in per capita energy use between Western nations, especially the United States, and the nations of the developing world. I firmly believe that globalization offers immense benefits to the American people. We benefit from a network of global trading partners that help create markets for our high technology products. But we can only realize this benefit if the rest of the world increases its standard of living to a level that closely matches our own.

And that won't happen unless they have access to clean, reliable, low-cost electrical power. Nuclear energy, appropriately designed to avoid proliferation and to operate in absolute safety, can play a major role in energizing the rest of the world. It can be one of the solutions to meeting global energy needs and helping to bring many poorer economies into the 21st century.

In closing, let me emphasize that all of us need to remind the public that the standard of living we enjoy today depends on reliable, clean, cost-effective electricity, which enables countless technologies, from the computers to the washing machines we use today. Two words must be part of every discussion on energy alternatives—risks and benefits. Every energy source entails both. Antinuclear groups have focused only on the risks of using nuclear energy. They haven't discussed its benefits or the solid technical solutions for addressing the risks. Therefore, they haven't presented a balanced assessment of this complex issue. The National Academy of Engineering is well positioned to encourage balanced discussions that include both the risks and benefits of nuclear energy.

We need to clarify for the public that energy production, by any technology, represents a trade-off between risks and benefits. The public must have the information to judge fairly both sides of this equation for each type of energy source. Based on that kind of comparison, which you and your colleagues can help to frame, nuclear energy would fare very well. With serious debate and continued progress on many fronts, I believe that nuclear energy will play an increasing role in providing future domestic and global supplies of electricity.

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NAE News and Notes

NAE Newsmakers

Lillian C. Borrone, retired director, Port Commerce Department, Port Authority of New York and New Jersey, and **James M. Coleman**, Boyd Professor, Louisiana State University and Agricultural and Mechanical College, are two of 16 individuals recently appointed by President Bush to the President's Commission on Ocean Policy. Established by the Oceans Act of 2000, the commission will make recommendations to the president and Congress on a coordinated, comprehensive national ocean and coastal policy.

Alan C. Brown, retired director of engineering, Lockheed Corporation, was recently awarded the degree of **Doctor of Science, *honoris causa***, at Cranfield University, England.

P. Ole Fanger, director, International Centre for Indoor Environment and Energy, Technical University of Denmark, received **Denmark's 2001 Civil Engineer of the Year Award**. Professor Fanger was also awarded an **honorary doctorate** from the University of Coimbra in Portugal and was named an **honorary member of the Japanese Engineering Society**.

The **Douglas W. Fuerstenau Professorship in Materials and Metallurgical Engineering** has been established at the South Dakota School of Mines and Technology

through gifts from corporations and friends. **Kenneth N. Han** is the first holder of this professorship.

The American Ceramic Society (ACS) is publishing a series of children's books to teach them about the applications of engineering and technology. **Larry L. Hench**, professor of ceramic materials at Imperial College of Science, Technology, and Medicine, is the author. ACS has just released the second book in the series, *Boing-Boing the Bionic Cat™ and the Jewel Thief*.

Un-Chul Paek, vice president and chairman of the Membership Committee of the Korean Academy of Science and Technology, was recently awarded its second annual **Engineering Prize** for his seminal, sustained contributions to the development of optical-fiber technology. Professor Paek received the prize at the Korean academy's annual meeting in February.

Herman P. Schwan, Alfred Fitler Moore Professor Emeritus, The University of Pennsylvania, was awarded the **D. Phil., *honoris causa***, from the University of Kopio, Finland, on June 22, 2000, and the **D. Techn. Sci., *honoris causa***, from the University of Graz, Austria.

Wm. A. Wulf, NAE president, was elected a **corresponding member** of the Spanish Academy of Engineering on March 9, 2001.

Chang-Lin Tien Receives 2001 Founders Award



Chang-Lin Tien

“For his pioneering contributions in gas thermal radiation, thermal insulation, and microscale heat transfer, as well as his leadership in education for youth around the world,” the NAE has chosen **Chang-Lin Tien**, University Professor and NEC Distinguished Professor of Engineering, University of California, Berkeley, as the recipient of the **2001 Founders Award**.

Dr. Tien joined the mechanical engineering faculty at the University of California, Berkeley, in 1959 and rose through the ranks to become chairman of the department; for two years (1983–1985) Dr. Tien was UC-Berkeley’s vice chancellor-research. In 1988, he left to serve two years as executive vice chancellor and UCI Distinguished Professor at University of California, Irvine; he returned to Berkeley in 1990 as the seventh chancellor of the university—the first Asian-American to head a major research university in the United States. As chancellor, Dr. Tien was widely praised for his visionary leadership in a time of unprecedented budgetary constraints and for his commitment to excellence through diversity.

Early in his career, Dr. Tien developed a physical basis and computational method of quantifying gaseous radiation properties, pioneering work in the field of thermal radiation in gases. His work in the 1960s on thermal radiation transport in microdomains is now considered the basis for the emerging field of microscale heat transfer. He was the first researcher to offer a sound theoretical basis for characterizing dependent scattering, and he provided experimental evidence for delineating the regions of applicability. His basic formulations and analyses initiated the field of thermal insulation. In addition, he addressed all transport modes for multilayer, cryogenic, and microsphere insulation.

Recently, Dr. Tien’s efforts have been focused on microscale heat transfer on the spatial and temporal scales. His work on thermal conduction in thin films,

quantum structures, and fast laser material interaction processes laid the foundation for the field of heat transfer. He has also made contributions to the broad discipline of thermal fluid transport.

Dr. Tien has received many honors, including the Max Jakob Memorial Award in 1981, the highest international honor in his field. In 1962, at the age of 26, Dr. Tien was the youngest professor ever to win UC–Berkeley’s prestigious Distinguished Teaching Award. He was elected to membership in the NAE in 1976 and served as a councillor from 1998 to 2001. An elected member of the American Academy of Arts and Sciences, he is the recipient of 12 honorary degrees from universities in the United States and abroad. In 1999, the International Astronomical Union approved the naming of an asteroid (International Series 3643, a minor planet) as Tien Chang-Lin Star. Recently, he was honored as a foreign member of the Chinese Academy of Engineering and an honorary member of the Japan Society of Mechanical Engineers.

Deeply committed to educational excellence and diversity, especially for underprivileged students, Dr. Tien has been active in community relations and educational reform programs. His leadership in both domestic and international arenas is reflected in his appointments as chairman of the Asia Foundation, chairman of the San Francisco Bay Area Economic Forum, and chairman of the Chief Executive’s Commission on Innovation and Technology in Hong Kong (until July 1999.) In 1999, Dr. Tien was appointed a member of the U.S. National Science Board and the U.S. National Commission on Mathematics and Science Teaching for the 21st Century. He has also served as cochair of the National Commission on Asia in the Schools.

Dr. Tien was born in Wuhan, China, and educated in Shanghai and Taiwan. After completing his undergraduate education at the National Taiwan University, he came to the United States in 1956, earned a master’s degree at the University of Louisville in 1957 and then a master’s degree and a doctorate, both in 1959, from Princeton University. He is the author of one book, the editor of 18 volumes and three international journals. Dr. Tien and Di-Hwa Tien, his wife of 42 years, reside in Berkeley, California.

2001 Arthur M. Bueche Award Presented to Ian M. Ross



Ian M. Ross

“For his contributions to semiconductor development, his leadership of engineering for communications networks and the Apollo program, and his role in shaping national policies affecting the semiconductor industry,” the NAE has awarded the 2001 **Arthur M. Bueche Award** to **Ian M. Ross**, president emeritus, Bell Laboratories.

Dr. Ross has had a career of more than 30 years at Bell Laboratories, where he worked in both management and engineering capacities, most recently as president emeritus. He joined Bell Laboratories in 1952, where he became engaged in the development of a wide variety of semiconductor devices. In 1959, he was appointed director of the Semiconductor Laboratory in Murray Hill, New Jersey, and three years later he was named director of the Semiconductor Device and Electron Tube Laboratory in Allentown, Pennsylvania.

In 1964, Dr. Ross was appointed managing director of Bellcomm, Inc., a Bell System subsidiary that provided systems engineering support for the Apollo manned space flight program. Under Dr. Ross’ leadership at Bellcomm, the National Aeronautics and Space Administration (NASA) was able to draw upon the extensive systems engineering experience of AT&T to meet its ambitious timetable for the Apollo program.

Dr. Ross was elected president of Bellcomm in 1968. In 1971, he returned to Bell Laboratories as executive director of the Network Planning Division and was promoted to vice president in 1973, executive vice president in 1976, and president in 1979. He retired in 1992. Dr. Ross led Bell Laboratories through a period of rapid innovations in wired and wireless telephony and systems and devices for data communications over the national communication network.

Dr. Ross was elected to membership in the NAE in 1973. He was elected to the National Academy of Sciences in 1982, to the Engineering Academy of Japan in 1988 as a foreign associate, and to the Royal Academy of Engineering in 1990.

A native of Southport, England, Dr. Ross received his bachelor’s degree in electrical engineering from Cambridge University in 1948. He received his master’s degree and his doctorate in 1952, also from Cambridge University. He currently resides in New Jersey with his wife, Christina.

PREVIOUS RECIPIENTS

Founders Award

1966 Vannevar Bush
 1967 James Smith McDonnell
 1968 Vladimir K. Zworykin
 1969 Harry Nyquist
 1970 Charles S. Draper
 1971 Clarence L. Johnson
 1972 Edwin H. Land
 1973 Warren K. Lewis
 1974 J. Erik Jonsson
 1975 James B. Fisk
 1976 Manson Benedict
 1977 John R. Pierce
 1978 George M. Low
 1979 David Packard
 1980 Hoyt C. Hottel
 1981 Jacob P. Den Hartog
 1982 Kenneth H. Olsen
 1983 Harold E. Edgerton
 1984 John Bardeen
 1985 Willis M. Hawkins
 1986 John R. Whinnery
 1987 Arnold O. Beckman
 1988 Gordon E. Moore
 1989 John S. Foster
 1990 Neal R. Amundson
 1991 George W. Housner
 1992 George H. Heilmeyer
 1993 William R. Hewlett

1994 Ralph Landau
 1995 Ernst R. G. Eckert
 1996 John W. Morris
 1997 Mario Salvadori
 1998 Yuan-Cheng B. Fung
 1999 Stephen D. Bechtel, Jr.
 2000 Charles H. Townes
 2001 Chang-Lin Tien

Bueche Award

1983 Simon Ramo
 1984 Edward E. David, Jr.
 1985 Jerome B. Wiesner
 1986 W. O. Baker
 1987 Lewis M. Branscomb
 1988 Dale R. Corson
 1989 James C. Fletcher
 1990 Solomon J. Buchsbaum
 1991 Norman R. Augustine
 1992 Ruben F. Mettler
 1993 Ralph E. Gomory
 1994 Robert C. Seamans, Jr.
 1995 Roland W. Schmitt
 1996 William J. Perry
 1997 Erich Bloch
 1998 John H. Gibbons
 1999 H. Guyford Stever
 2000 Charles M. Vest
 2001 Ian M. Ross

New Bernard M. Gordon Prize

The NAE received 71 nominations for the first Bernard M. Gordon Prize for Innovation in Engineering and Technology Education. Candidates represent educational institutions across the United States. The prize will be presented at the same time as the Charles Stark Draper Prize during National Engineers Week, February 2002. According to Dr. Mary Good, chair of the selection committee, “the quality of the nominations for the first Gordon Prize will certainly set a high standard for future recipients.”

The \$500,000 biennial prize is made possible by a gift of stock from the Gordon Foundation to the NAE; the stock is valued at approximately \$10 million. The Gordon Foundation was established by NAE member **Bernard Gordon** and his wife, Sophia.

Bernard Gordon, chairman of Analogic Corporation and a recipient of the National Medal of Technology, has a longstanding interest in engineering education, particularly in ensuring that the academic preparation of future engineers keeps pace with the changing needs of the engineering enterprise. Because of NAE’s unique role and its work on engineering education, Gordon decided the NAE was the ideal organization to address these interests and concerns. The Gordon Prize has two purposes: to influence the fundamental

approach to engineering and technology education in the United States; and to reward innovation and novel approaches in the classroom.

“Over a period of time, there has been a growing gap between what was needed in industry and what was being taught in the schools,” Mr. Gordon said. “A number of schools have realized this fact and are trying to do something about it.” Through his gift, Mr. Gordon hopes to reward individuals and programs that prepare students to manage all aspects of an engineering project. Their academic training must include real-world skills, such as the ability to communicate, solve design problems, work collaboratively as part of a team, and develop and adhere to realistic project schedules and budgets.

“For the past decade, the National Academy of Engineering’s Draper and Russ prizes have rewarded engineers who innovate in the laboratory—who design the technologies that propel society forward,” **Wm. A. Wulf**, NAE president, said. “Now, thanks to Bernard Gordon’s generous gift, we are able to reward the equally vital individuals who do their innovating in the classroom—who develop the *talent* instead of the technologies.”

Engineering and Health Care Delivery Systems

On May 21 and 22, 2001, the NAE hosted a workshop in Washington, D.C., to explore the potential of using systems-engineering tools and methods to improve the U.S. health care delivery system (HCDS). The workshop was planned by a steering committee of NAE and Institute of Medicine (IOM) members and was co-chaired by Marshall Fisher (NAE), University of Pennsylvania, and Jerome Grossman (IOM), Harvard University. The workshop brought together 40 leading researchers and practitioners in health care practice, administration, and outcome assessment with leading researchers and practitioners in systems engineering, operations research, and associated fields. The sessions included presentations and panel discussions.

The first goal of the workshop was to cultivate a shared understanding of the changing design parameters of the HCDS created by advances in medical knowledge, new delivery technologies, and the changing structure of health care markets. Keynote speaker Jeff Goldsmith, a health futurist, highlighted three transforming technologies: the genome project, which could enable us to assess and mitigate the risk of disease; stem cell research, which could hold the key to increasing the human life span; and intelligent decision-support systems, which could resolve critical issues of information flow and knowledge management. Study director Janet Corrigan then presented the major findings of a recent IOM report, *Crossing the*

Quality Chasm. The report highlighted the magnitude of the problems facing the U.S. HCDS in the key areas of safety, effectiveness, and responsiveness to patients, timeliness, efficiency, and equity. Corrigan also identified engineering challenges and opportunities associated with each key area. Other speakers addressed broader “environmental” challenges to the effective functioning of health care markets and barriers to innovation, such as the shortage of quality and safety data, inflexible payment/reimbursement policies, burdensome licensing requirements, and other public policies that discourage investment in the very technologies that could improve patient care. Cultural barriers separating the medical community from potential partners in engineering and management science were also identified.

The second goal of the workshop was to assess potential applications of advances in engineering and related fields to the development/transformation of health care delivery at several system levels: the macrodistributed system level (regions, populations, multiple hospitals, and clinics); the mezzosystem level (hospital and clinic); and the microsystem level (patient and family). Four presentations focused on how the widespread application of simulation modeling could improve resource allocation and care outcomes at various levels of the HCDS. Several speakers discussed how the explosion of medical knowledge has created opportunities for practicing evidence-enhanced medicine and acute needs for information management and decision-support technologies to enable physicians and integrated care teams to take advantage of new knowledge. Other speakers highlighted opportunities for applications of human-factors research and risk-management technologies in distributed health care delivery systems. Presentations documented the importance of team-based learning as a basis for adopting new technologies and care delivery processes; reviewed ongoing efforts to measure health care quality at various system levels; and outlined an information-technology/human-factors initiative for tracking and managing the risk trajectories of individual patients and the risk trajectories of particular health care provider groups.

The third goal of the workshop was to develop a preliminary definition of a research agenda/action plan to realize the potential contributions of systems engineering and related fields to the U.S. HCDS. The plan included follow-on activities involving the medical and engineering research communities, the health care industry, federal agencies, the National Academies, and other interested parties. Despite numerous examples of effective applications of technology and engineering methods, there was general agreement that innovations are not widespread. In short, the system is not yet on a track of continuous improvement that could close the vast quality chasm in patient care.

Suggestions for follow-on collaborations between the health care and engineering communities were focused on simulation modeling, clinical information management and decision-support technologies, patient-friendly microtechnologies to facilitate mobile and home-based care, human factors and organizational research, and risk management. The implementation agenda would include initiatives to encourage the widespread adoption of proven engineering and management tools to improve the quality of patient care throughout the HCDS. A complementary research agenda would include collaborative research on the development of new tools, technologies, and delivery models to ensure continued improvements.

Proceedings of the workshop will be published in late 2001. The steering committee is also planning several follow-on activities. These may include: (1) a symposium to provide a comprehensive assessment of current engineering-medical collaborative research, development, and demonstrations and to determine the highest priority challenges/opportunities; (2) a series of workshops to encourage engineering-health care collaborations in high-priority areas; and (3) consensus studies that would provide advice to funding and regulatory agencies, the engineering and medical research communities, and other interested parties. The studies would address research priorities, the structure and funding of collaborative research, overcoming barriers to collaboration, and other issues.

For more information, contact Proctor Reid, by email at preid@nae.edu.

Committee on Engineering Education

The NAE Committee on Engineering Education (CEE) will host an open meeting on the subject of information technology in engineering education on Monday, November 19, 2001. The session will feature a panel of invited speakers who will discuss the need to treat information and communication science as a core subject for all engineering students. The panel will also discuss some of the challenges facing information technology faculty because of the interdisciplinary nature of their research and teaching responsibilities.

The first meeting of the Engineer of 2020 Phase I Steering Committee will be held November 30 and December 1 in Washington, D.C. Recently launched by the CEE, the Engineer of 2020 project is a two-year, vision-casting initiative focused on the future of engi-

neering and the requirements for educating engineers for the future. The first phase of the project will bring together a wide range of stakeholders for a series of activities designed to generate a far-reaching vision of engineering in 2020.

The CEE will host a two-day retreat in December 2001 to generate a framework and plan for an NAE-affiliated research center in engineering education. The retreat will bring engineering administrators and educators, government policy makers, industrial managers, and leading experts in higher education together to discuss the creation of the NAE center and what it might accomplish.

If you would like additional information about CEE activities, contact Patricia Mead by email at pmead@nae.edu.

Diversity in the Engineering Workforce

The NAE Committee on Diversity in the Engineering Workforce is hosting a workshop entitled “Best Practices in Managing Diversity” on October 29 and 30, 2001, in Washington, D.C. The purpose of the workshop is to identify corporate programs that successfully recruit, retain, and advance women and underrepresented minorities in engineering careers and to develop metrics by which to evaluate these kinds of programs. The workshop will focus primarily on personnel policies and programs for engineers employed in industry and consulting services.

The format of the workshop will include plenary presentations followed by small group discussions. An opening panel will present examples of successful diversity programs by manufacturing, design, and professional-services firms. The group will then break up into smaller groups to discuss best practices and metrics for defining success.

There are proportionately fewer women and minorities in the engineering profession than in the U.S. workforce in general and in other scientific and technical fields. The Bureau of Labor Statistics projects a 36 percent growth in engineering jobs between 1998 and 2008. Even as employers scramble to find qualified engineers, the United States has a huge pool of underused talent—women and underrepresented minorities. The goal of the workshop is to describe programs that are working and determine how to measure their impact and make the information widely available to the engineering community. Descriptions of successful programs as well as results of the workshop discussions will be published.

If you would like information about the Diversity in the Engineering Workforce Program, contact Peggy Layne by email at playne@nae.edu.

Mandate for Technological Literacy

The report of the Committee on Technological Literacy, *Mandate for Technological Literacy: Why All Americans Need to Know More About Technology*, is nearing completion. The report is one of several products resulting from a two-year, NAE-led project funded by the National Science Foundation and Battelle Memorial Institute. The Center for Education, part of the National Research Council, collaborated with NAE on the project.

The report will present a detailed explanation of technological literacy, outline the current educational, social, and political environment for technological literacy, suggest a number of benefits of greater techno-

logical literacy, and survey current and past efforts in the formal and informal education sectors that encourage technological literacy. The report will include a number of recommendations for increasing technological literacy among students and the public at large. A project-related website will be launched on or about the same time the report is released publicly.

NAE member **Tom Young**, Lockheed Martin (retired), chairs the 20-person Committee on Technological Literacy. Contact Greg Pearson in the NAE Program Office by email at gpearson@nae.edu for more information about the project and related NAE activities.

Message from the Home Secretary



W. Dale Compton

NAE Project 2003 is proceeding nicely. Members of each section have completed their selections of emerging disciplinary and interdisciplinary areas in engineering, and on August 2, the council reviewed the entire list and identified four focus areas for nominees for the 2003 and 2004 elections:

- bioinformatics, including mathematical/computational biology, functional genomics/proteomics, and the application of engineering to biology
- nanotechnology, including microelectromechanical systems (MEMS), nanoelectromechanical systems (NEMS), nanobiotechnology, nanomaterials, nanomechanics, molecular computing, and molecular self-assembly
- Earth-systems engineering, including energy production, environmental engineering, global change

assessment, and sustainable development

- integration of smart operational systems, including adaptive and autonomous systems and their risks and safety; the human-machine interface; and the integration of information technology in air traffic management, health care delivery, supply chain management, nuclear power systems, robotics, and remote sensing and operations

Five additional at-large allocations will be made available for candidates identified by a special ad hoc peer committee, which will be implemented for the 2003 and 2004 elections. That committee will search for and encourage nominations in the four focus areas and will evaluate all candidates. All 12 section chairs have been asked to suggest members for the committee, which will be formed immediately following the council meeting on October 6. I hope all members will consider nominating candidates.

W. Dale Compton
Home Secretary

Message from the Foreign Secretary



Harold K. Forsen

Items of interest to NAE members in the last quarter include the biennial convocation of the International Council of Academies and Technological Sciences, Inc. (CAETS), activities of the international Frontiers of Engineering program, the election of new foreign associates, and other international activities.

The 2001 CAETS biannual convocation in Espoo, Finland, on June 12–14, was hosted by the Finnish Academies of Technology. The focus of the convocation was “World Forests and Technology.” Speakers addressed many subjects of interest, including engineering education, energy, CO₂ sequestration, and information technology (IT). More than 60 guests and members of the Finnish academies were in attendance, as well as members of more than 20 CAETS academies. The convocation also included two panel discussions, one on the use of high technology in the forest industry and one on the future use of paper in an IT society. Our Finnish hosts provided opportunities for participants to visit local Finnish companies, including Nokia Research Center and a wood products factory. The Finnish academies were gracious hosts; they provided wonderful dinners at very interesting places and delightful entertainment.

Before the convocation, the CAETS Council met with most of the member academies represented and undertook several important actions, including a review of new bylaws and articles of incorporation of CAETS in the United States, which will take effect on January 1, 2002. It will then be possible for CAETS to accept donations and contributions to support its activities. Planners for the proposed study on energy and climate change are proceeding to develop a scope-of-work statement and procedures for carrying out future studies. By year’s end, we hope to begin a search for funding and to select a study committee.

The CAETS Council also approved convocation hosts through 2007: the United States for 2003; Australia for 2005; and Japan for 2007. Off-year council meetings will be held in the Czech Republic in 2002, Norway in 2004, and Belgium in 2004. A process was also approved for selecting member academies. A general discussion was held on programs by various academies to improve the public understanding of engineering, and the sharing of materials among members was encouraged. Under the sponsorship of UNESCO, planning for an international congress on megacities of the future for 2003 or 2004 is under way. The idea for the congress was initiated by the International Council of Engineering and Technology and the World Federation of Engineering Organizations. The International Council of Scientific Unions will be invited to be a partner in the planning. CAETS has agreed to provide two or three members for the steering committee.

Frontiers of Engineering (FOE) with Germany (GAFOE) and Japan (JAFOE) are progressing well, even though funding is always in doubt. Up to now, GAFOE programs in both Germany and the United States were funded by the German-American Academic Council, with funds from the German government. That program has been terminated, however, and GAFOE activities in Germany will now be funded by the Alexander von Humboldt Foundation, again with German government funds. Activities in the United States will be funded with U.S. funds. The next GAFOE meeting will be held in Essen, Germany, on October 11–13, 2001. Once again, a few observers from selected European CAETS academies have been invited to attend to consider whether CAETS would be interested in participating in a regional meeting of this kind.

The second JAFOE meeting will be held in Irvine, California, from November 29 to December 1, 2001. The NAE has invited the Australian, Chinese, Indian, and Korean academies to send observers to this symposium. The Japanese government, through the Science and Technology Agency, funds JAFOE activities held in Japan, but we must raise funds for activities held in the United States, which may be difficult.

Unfortunately, we have not been able to open either the GAFOE or JAFOE symposium to NAE members in general because of limited space and because we want to provide as much interaction and discussion time for young participants as possible.

This year we have elected eight new foreign associates, all from countries that have been previously represented. A large percentage of the nominees were engineers who reside in the United States. To cast a wider net, the NAE might consider a policy adopted by the National Academy of Sciences (NAS), which elects 15 new foreign associates a year. NAS foreign associates are nominated through their sections, but to encourage more nominations from abroad only two foreign associates per year can be residents of the United States. If the Council concurs, I will present this idea to the Membership Policy Committee at its next meeting. I welcome your comments on this subject. You can contact me by email at hforsen@nae.edu.

Although there are more than 80 academies of science, only about 35 have academies of engineering

and only 26 of these are members of CAETS. For these and other reasons, we have been involved with several general science academies to help them develop independent academies of engineering. Whether or not these efforts bear fruit may not be as important as our keeping in touch with them and providing help and cooperation.

In keeping with the Memorandum of Understanding that was signed with the Chinese Academy of Engineering (CAE) last year, we are continuing to work on a joint study on transportation. That study appears to be moving ahead and could be completed soon. The CAE sent a delegation in August to visit the NRC's Water Science and Technology Board and various state and federal programs in the United States. Eventually we may embark on a joint study on water supplies and use.



Harold K. Forsen
Foreign Secretary

Randy Atkins Joins Program Office



Randy Atkins

Thanks to a generous grant from the Elizabeth and Stephen D. Bechtel, Jr., Foundation, NAE has hired its first senior program officer for public relations. Randy Atkins joined NAE's Public Understanding of Engineering Program on August 20. His priorities are to increase press coverage of engineering and the NAE, help develop public relations plans for NAE activities,

and work with Robin Gibbin, director of the Public Understanding of Engineering Program, to improve public understanding of engineering through cooperative projects with professional societies.

Randy comes to the NAE from the American Physical Society (APS), where he was the senior media relations coordinator. At APS, Randy successfully brought physics to public attention through high-profile newspaper articles, television stories, and op-eds. Prior to his work at APS, Randy was the senior science writer for the American Chemical Society.

His experience with the news media includes 11 years as a television reporter and producer for *Inside Science TV News* and the developer of science stories for local newscasts across the country. Randy was also a general assignment television reporter at an NBC affiliate in West Virginia for two years, where he covered everything from science to the state legislature.

Immediately after graduating with a B.S. in microbiology, Randy worked as a microbiologist for the National Institutes of Health and the U.S. Department of Agriculture.

NAE/ASEB Round Table on Aerospace Research and Technology

The NAE and the NRC Aeronautics and Space Engineering Board (ASEB) began a new initiative during the summer of 2000 on current issues in aerospace engineering. The NAE agreed to support a round table on aerospace research and technology to address the issues raised by recent reductions in funding for aeronautics research and the poor health of the aerospace industry. A kick-off dinner was held on February 29, 2001, at the National Academies Building in Washington, D.C. Cochairs for the event were NAE president, **Wm. A. Wulf**; NAE member **Neil Armstrong**, former astronaut and chairman of the board of EDO Corporation; and Robert Crandall, retired chairman and CEO of American Airlines. Other representatives of government, academia, and industry included: NAE member **William F. Ballhaus**, CEO of the Aerospace Corporation; NAE member **Ruth Davis**, president and CEO of Pymatuning Group, Inc.; FAA administrator Jane F. Garvey; NAE member **Daniel S. Goldin**, administrator of NASA; John Hamre, president and CEO of the Center for Strategic and International Studies; Gen. William Hoover, chair of the ASEB; NAE foreign associate **Hans Hornung**, director of graduate aeronautical laboratories at California Institute of Technology; Dr. Martin Jischke, president of Purdue University; NAE member and senior fellow **Hans M. Mark**, former director of Defense Research and Engineering, U.S. Department of Defense; Mal O'Neill, vice president of engineering and technology at Lockheed Martin Corporation; David O. Swain, senior vice president of engineering and technology at

the Boeing Company; NAE member **Peter B. Teets**, retired president and CEO of Lockheed Martin Corporation; and NAE member **Charles M. Vest**, president of Massachusetts Institute of Technology.

A dinner to plan the round table was held on August 29. The group hopes to provide a continuing forum where aerospace leaders can gather periodically to discuss issues of vital importance to the industry. The preliminary discussion focused on five key concerns for the aerospace sector identified by the ASEB: the air transportation system; national defense; the aerospace industrial and defense base; intellectual capital and education; and aerospace research and technology.

The group plans to hold a workshop on issues in aerospace research and technology entitled "Exciting Challenges and Vital Issues" (preliminary title) to bring together leaders in the aerospace sector to identify the top concerns of government, industry, and academia related to aerospace research and technology and to identify future goals and visions in aerospace technology. The group concluded that issues related to education and the engineering workforce could be addressed in conjunction with new NAE initiatives in these areas rather than by the roundtable. The ASEB is also developing a plan for a new study on the air transportation system in conjunction with NASA and the FAA.

For more detailed information on the roundtable, visit their website at <http://www4.nas.edu/cets/asebhome.nsf/web/nae_aseb_roundtable> or call the ASEB at (202) 334-2855.

Protecting Critical Infrastructure

The NAE and the Computer Science and Telecommunications Board (CSTB) launched a workshop-based project called "Critical Infrastructure Protection and the Law" to analyze key issues in protecting critical infrastructures for which the law is an enabler or an inhibitor. The project will also provide a preliminary analysis of information sharing on cybersecurity and critical infrastructure protection between the public and private sectors.

Protecting critical information infrastructures is difficult because of the decentralized ownership and control of infrastructure and increasing infrastructure interdependence. Laws and regulations for protecting conventional telecommunications, for example, provide for priority access to facilities in the event of an emergency, but it is difficult to apply them to protecting the Internet, for which risk management is limited by uncertainties about liability and a lagging market for insurance against information infrastructure failures and associated business interruptions. The expectations for management are changing as demands for greater security for information and systems increase. Additional difficulties are created by decentralized government interests and the organization of government, which often impedes the planning and implementation of programs. Although a

public-private partnership to protect critical infrastructures is being widely discussed, no agreement has been reached on how companies can cooperate with each other and with the federal government. Meanwhile, advocates of privacy and civil liberties have raised concerns about how efforts to protect infrastructure would affect privacy rights.

CSTB has convened a committee of leading technologists and lawyers from academia and industry that includes two NAE members: **Stewart Personick** of Drexel University (chair) and **W. David Sincoskie** of Telcordia Technologies. The committee is organizing a symposium to bring together experts in law, business, technology, and government—including people familiar with critical infrastructure protection and others with insight into the problem. The symposium will be held October 22–23 at the NRC in Washington, D.C. The final report is expected to be released in mid-2002.

The committee has issued a call for papers, which can be found at www.cstb.org. Papers from business, technical, and legal experts are welcome on how the law could promote or inhibit efforts to protect critical infrastructure. Comments to the committee can be made at any time by contacting the study director, Cynthia Patterson, at cpatters@nas.edu or (202) 334-2605.

In Memoriam

VINCENT S. BOYER, 83, retired energy consultant, died on May 11, 2001. Mr. Boyer was elected to the NAE in 1980 for his pioneering work on the commercial use of nuclear energy and his service to the engineering profession.

MARTIN LANG, 85, consultant, environmental engineering, died on September 4, 2000. Mr. Lang was elected to the NAE in 1980 for his leadership in the development and application of basic technology and research to the environmental problems of New York City.

EGOR P. POPOV, 88, professor of civil engineering, emeritus, and professor in the Department of Civil and Environmental Engineering, University of California, Berkeley, died on April 19, 2001. Dr. Popov was elected to the NAE in 1976 for his contributions in the mechanics of solids and the inelastic cyclic behavior of structural systems.

JOHN F. YARDLEY, 76, retired president, McDonnell Douglas Astronautics Company, died on June 26, 2001. Mr. Yardley was elected to the NAE in 1977 for his contributions to engineering theory and practice and his leadership of organizations that pioneered major space programs.

Calendar of Upcoming Meetings and Events

September 5	NAE/AIChE meeting	October 29–30	Committee on Diversity in the Engineering Workforce Best Practices Workshop
September 6	NRC Governing Board Executive Committee meeting		
September 13–15	7 th Frontiers of Engineering Symposium Irvine, California	November 6	NRC Governing Board Executive Committee meeting
September 21	NAE congressional lunch	November 6–7	NRC Governing Board meeting
September 25	Draper Prize Committee meeting	November 7	Engineering Deans Executive Council meeting
September 27	NAE/AAES IntAC meeting	November 9	NAE Nominating Committee meeting
September 28	NAE/AAES Forum meeting	November 19	Committee on Engineering Education meeting
October 2	Committee on Women in Engineering Website Advisory Committee meeting	November 20	Symposium on Technological Literacy
October 5	NAE Finance and Budget Committee meeting NAE Council meeting	Nov. 29–Dec. 1	Second Japan-America Frontiers of Engineering Symposium Irvine, California
October 6	NAE Council meeting Peer Committee meetings Class of 2001 orientation	Nov. 30–Dec. 1	Engineer of 2020 Phase 1 Steering Committee meeting
October 7–9	NAE Annual Meeting	December 4	Governing Board Executive Committee meeting
October 10–13	2001 German-American Frontiers of Engineering Symposium Essen, Germany	December 8	Committee on Membership meeting Irvine, California
October 15–16	IOM Annual Meeting		
October 18	Gordon Prize Committee meeting NRC Governing Board Executive Committee meeting		

All meetings and events are held in the National Academies Building, Washington, D.C., unless otherwise noted.

National Research Council Update

Effectiveness of the Corporate Average Fuel Economy (CAFE) Standards

Congress asked the National Academies to assess how well the Corporate Average Fuel Economy (CAFE) Program is working and how it could be improved. The committee appointed to assess the program included two NAE members, **Phillip S. Myers**, Professor Emeritus, University of Wisconsin-Madison, and **John J. Wise**, vice president research (retired), Mobil Research and Development Corporation. Although the study had to be completed in less than six months, the report covered a broad range of topics.

Review of the Current Program

The committee concluded that the CAFE program has significantly reduced fuel consumption, although the level could not be quantified. In recent years, CAFE has played an important role in maintaining higher fuel economy even though fuel prices have been relatively low.

The program has also had adverse consequences, especially its effect on safety. The majority of the committee concluded that the downsizing of vehicles and weight reductions in the 1970s and 1980s (partly in response to CAFE requirements) resulted in an additional 1,300 to 2,600 fatalities in 1993. Although fatalities declined overall in this period, most committee members concluded that they would have declined more had the weight reductions and downsizing not occurred. Two dissenting members of the committee did not believe the data supported this conclusion and argued that increases in fuel economy may have had little or no net effect on highway fatalities.

Impact of Raising Standards

The committee did not recommend raising standards, a decision that will involve difficult trade-offs among many factors, such as the costs of transportation, environmental impacts, national security, consumer choice, and safety. The committee attempted to identify these trade-offs but could not complete a full analysis in the short time allotted to this study.

The committee concluded that decision makers will have to clarify the reasons for increasing fuel economy and then ensure that the costs of the increases are consistent with those reasons. Based on an assumed cost of \$.30 per gallon of fuel, the committee concluded that significant improvements in fuel economy could be made at reasonable cost. A variety of technologies to improve fuel economy are already available for cars and light trucks, many of them already on the market in Europe and Japan where fuel prices are much higher. Variable valve lift and timing can reduce fuel consumption by 3 to 8 percent; continuously variable transmissions can achieve another 4 to 8 percent reduction; other technologies under development will be widely available within 15 years. Fuel economy for heavier vehicles can be improved more than for light vehicles, and the resulting fuel savings would also be much greater.

Safety is the most contentious issue to consider. Any increase in fatalities will depend on how manufacturers choose to meet the higher standards. The technologies examined by the committee generally appear to be more cost effective than weight reduction, but CAFE standards as currently structured do not specify methods of compliance. If weight reductions were concentrated in heavier vehicles, weight disparities in the fleet would be reduced. This would have a positive effect on safety because the risks to occupants of downsized vehicles would be more than offset by lower risks to other road users.

Recommendations

The committee recommended that a tradable credit program be part of any regulatory program on fuel economy. Even if the current structure is maintained and the standards are not raised, the program would be more efficient and effective with tradable credits, which would give all manufacturers an incentive to make all of their vehicles more economical. This approach would be less costly than the current approach of treating each manufacturer separately.

An attribute-based system should be considered for the regulatory standard; the partly weight-based system, “Enhanced CAFE,” is a step in that direction. The standard for lighter vehicles (up to 3,500 or 4,000 pounds) would be inversely proportional to their weight. Heavier vehicles would all have the same standard. This system would eliminate any incentive for manufacturers to reduce the weight of light vehicles and would encourage them to reduce the weight of heavier vehicles.

Given the global nature of the auto industry, the distinction between foreign and domestic fleets should be abolished. The committee also recommended that

the credit for dual-fuel vehicles be abolished for several reasons. First, CAFE is not a good way to encourage the use of alcohol fuels. Second, owners of dual-fuel vehicles almost never buy alcohol fuel because it is expensive and difficult to find. And third, the credit lowers the fuel economy of the entire fleet.

The government should continue to participate in cooperative programs with industry to improve fuel economy. The Partnership for a New Generation of Vehicles is the most prominent of these programs. Finally, the National Highway Traffic Safety Administration should update its analysis of the relationship between safety and improvements in fuel economy.

Alternatives for Extending Locks on the Upper Mississippi-Illinois Waterway System

A new NRC report recommends that the U.S. Army Corps of Engineers (USACE) explore all of the options for managing barge traffic before considering lengthening several locks on the upper Mississippi River-Illinois waterway system. Lock extensions could cost up to \$1 billion, would disrupt waterway traffic during years of construction, and could damage the surrounding environment. The report urges that nonstructural alternatives be carefully considered.

More than 120 million tons of cargo destined for international markets—much of it corn and soybeans—are shipped each year along the river through a system of 29 locks and dams spanning hundreds of miles. Many of the locks are at least 60 years old and were originally designed for “tows” of barges up to 600 feet long. As commerce has increased, the length of a typical tow has doubled, and congestion has

increased. If barge traffic could be distributed more evenly, congestion would be decreased and shipping costs would fall.

Nonstructural alternatives include relatively inexpensive options, such as better scheduling of traffic passing through the locks and better equipment for hooking barges together. One way of improving scheduling would be to issue permits for passing through locks at specified times and allowing permits to be traded among towboat captains.

NAE member **Delon Hampton**, president and chief executive officer, Delon Hampton & Associates, Washington, D.C., was a member of the committee that produced the report, *Inland Navigation System Planning: The Upper Mississippi River-Illinois Waterway*. To read the full text of the report, go to <<http://books.nap.edu/catalog/10072.html>>.

R&D Investment for the U.S. Department of Energy

An NRC committee has concluded that R&D programs that advance energy-efficient, fossil fuel technologies have yielded significant economic, environmental, and national security benefits. Looking back as far as 1978, the committee reviewed 17 R&D programs in energy efficiency and 22 programs in fossil energy funded by the U.S. Department of Energy (DOE). These programs have yielded an estimated \$40 billion in benefits from an investment of \$13 billion. Three energy-efficiency programs, costing approximately \$11 million, produced nearly three-quarters of these benefits. The most significant advances were improved compressors for refrigerators and freezers, energy-efficient fluorescent-lighting components (called electronic ballasts), and low-emission (or heat-resistant) window glass. Standards and regulations based on the efficiencies attainable by these new technologies ensured that they would be adopted nationwide, thus dramatically compounding their impact. The study also concluded that DOE research

has produced much larger public benefits that cannot be easily measured in dollars.

The committee also identified program areas that have not lived up to expectations. Among these are programs in which DOE attempted to introduce new technologies that did not have incentives for the private sector to adopt them. The committee recommended steps for improving the management and evaluation of DOE's research program.

Members of the NAE serving on the Committee on Benefits of DOE R&D in Energy Efficiency and Fossil Energy were: **William Agnew**, General Motors Research Laboratories (retired); **Uma Chowdhry**, DuPont Engineering Technology Company; **William L. Fisher**, University of Texas, Austin; **Maxine L. Savitz**, Honeywell; and **John J. Wise**, Mobil Research and Development Corporation (retired).

You can read the full text of the report, *Energy Research at DOE: Was it Worth It?*, at <http://www.nap.edu/books/0309074487/html/>.

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academy Press (NAP), 2101 Constitution Avenue, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP on-line at <http://www.nap.edu> or by phone at (800) 624-6242. (Note: Prices quoted by NAP are subject to change without notice. On-line orders receive a 20 percent discount. Please add \$4.50 for shipping and handling for the first book and \$0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)

Disposition of High-Level Waste and Spent Nuclear Fuel.

Addressing the challenges posed by the disposal of spent nuclear fuel from reactors and high-level radioactive waste from the processing of fuel for military and civilian purposes will require the focused attention of world leaders. The biggest challenges to safe and secure storage and permanent waste disposal are not technical, but societal. \$32.00, paper.

Improving Operations and Long-Term Safety of the Waste Isolation Pilot Plant: Final Report.

This study examines the performance assessment models used to calculate hypothetical long-term releases of radioactivity and suggests ways to reduce the uncertainties. Areas for improvement in the national transuranic (TRU) waste management systems are identified, and current plans for TRU waste handling, characterization, treatment, packaging, and transportation are assessed. \$34.25, paper.

Information Systems and the Environment. This report explores the implications of advances in information technologies (including potential improvements in knowledge management) for setting and meeting environmental objectives for corporations and for sustainable development. The articles are focused on groundbreaking work by individual corporations and

knowledge-sharing tools and techniques under development. Corporate case studies and examples of information and knowledge systems evolving at the interfaces between corporations and society as a whole are featured. The legal context within which these systems are evolving is also discussed. \$42.00, paper.

Opportunities in Biotechnology for Future Army Applications.

This report examines how biotechnology might be used by the Army to improve the survivability and effectiveness of U.S. soldiers in battle. The report reviews current directions in biotech research and applications and identifies the opportunities most relevant to the Army. The major recommendation encourages the Army to develop an in-house cadre of experts knowledgeable in both engineering and biology who can contribute to, interpret, and influence developments. \$27.75, paper.

Research and Development on a Salt Processing Alternative for High-Level Waste at the Savannah River Site.

This report focuses on technical issues related to four candidate processes under development for radionuclide removal from high-level waste salt solutions. The report evaluates the progress and results of R&D being carried out under the sponsorship of the U.S. Department of Energy, assesses the state of technical uncertainties, and recommends improvements. \$18.00, paper.

Under the Weather: Climate, Ecosystems, and Infectious Disease.

This report reviews the current understanding of linkages among climate, ecosystems, and infectious disease and describes research that could improve our understanding of these linkages. The study committee examined the use of climate forecasts and ecological observations to predict outbreaks of infectious disease, identified the components necessary for an early warning system for epidemics, and reviewed lessons learned from the use of climate forecasts for other purposes. \$37.95, hardcover.