ANS/ENS INTERNATIONAL MEETING

# The new millennium—A new era for nuclear

AT THE START of the 2000 ANS/ENS International Meeting—held November 12–16, 2000, in Washington, D.C.—ANS President Jim Lake welcomed delegates to the "new ANS, the ANS of the future." This meeting, he said, was different—"more valuable, provocative, and learned"—and marked by a gratifying increase in attendance. Furthermore, he declared, nuclear's excellent safety record and improving economic performance provide a solid foundation for entering the new millennium, which will be a new era for nuclear energy.

The event had high attendance and a well-received program. Some 1451 persons attended the conference, including 328 from 25 foreign countries, with a 26-person delegation from Russia. The event also included three topical meetings and a professional development workshop. The conference used a "track system," grouping sequences of kindred technical sessions to help attendees focus on their areas of interest.

The theme of the meeting was Nuclear Science and Technology: Supporting Sustainable Development Worldwide. In the face of expected growth in energy demand, said Lake, the challenge for nuclear power is to find a new balance of economic competitiveness, environmental stewardship, and social responsibility.

Lake

The theme was timely, as sustainable development is an increasingly important issue for the industry. Opponents of nuclear power, supported by a number of European governments, are pushing to exclude nuclear technologies from the clean development mechanisms provided for under the Kyoto Protocol to reduce greenhouse gas emissions. They claim nuclear is nonsustainable, essentially because the industry does not have an acceptable solution for disposing of its waste.

As a joint ANS/European Nuclear Society international meeting, delegates were also welcomed by Agneta Rising, president of ENS and the Swedish Nuclear Society. Europe, she said, is undecided on the nuclear issue. There have been harsh warning signals: Germany's decision to limit the lifetimes of its reactors to little more than 30 years and Sweden's premature closure of one reactor, Barsebäck-1, with the second unit expected to close in 2003–04. On the other hand, she stressed, there is no public support for closing nuclear plants. Even in Sweden, a majority favors increasing the use of nuclear power to combat global warming. One particular worry for her is that nuclear education and research are receiving reduced resources, leading to a lack of young people who are entering nuclear careers.

Rising

The session's co-chair, Clyde Jupiter, of Jupiter Corp., then handed the meeting over to co-chair Bertrand Barre, of Cogema, and a vice-president of ENS, to introduce the keynote speaker, Donald J. Johnston, secretary general of the Paris-based Organization for Economic Cooperation and Development (OECD). A Canadian, Johnston had previously served as his country's minister for science and technology. On this occasion, Johnston was speaking for himself and not for the OECD, whose membership includes a number of antinuclear governments. He clearly believes that nuclear energy can play an important role in creating a sustainable future.

### *Sustainable development*

Johnston was asked to address the question, "Does the future have a constituency?" His answer, which came from the theme of the meeting, was: "Those who espouse sustainable development, one of the most important issues of our time, are committed to acting for that constituency. That is what sustainable development is about."

While there are different definitions of sustainable development, he opted for: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," which he said is as good as any, combining environmental, social, and economic considerations.

Johnston said that the world is on an unsustainable energy path that has led to a high concentration of greenhouse gases, particularly $CO_2$. The potential effects of radical climate change are frightening, he noted, pointing to the frequent extreme events and unusual weather patterns seen all over the globe in recent years.

"Can we do something to turn the situation around?" he asked. While the industrialized countries are wealthy and smart enough to develop clean sustainable energy technologies, he said, solutions must take account of world poverty and population growth. The United Nations projects a 50 percent increase in global population by the middle of the century. Virtually all of that growth is outside the OECD area.

If the rest of the world is to enjoy the same energy standard as the OECD does today, energy production will have to grow by a factor of 30, said Johnston. While, he added, no one expects such a jump, his examination of the

***Major themes of the plenary:***

- *Nuclear power's challenge: Find a new balance of economic competitiveness, environmental stewardship, and social responsibility.*
- *Europe is undecided on the nuclear issue.*
- *The world is on an unsustainable energy path that has led to a high concentration of greenhouse gases.*
- *Nuclear power is undergoing a quiet renaissance in the United States, and power reactors are competitive with fossil-fired plants.*

different energy sources (including renewables), like that of others before him, led to the conclusion that only nuclear power is able to meet the needs of the future population. "Since 1955, the global population has doubled with most living in poverty. Yet we are denying ourselves the nuclear option," he said.

Johnston has spoken to many distinguished scientists, and, like them, he said he has found the opposition to nuclear power by the green movement bewildering. But, he said, "bewilderment must not suffice. We must ensure that the nuclear option is the subject of informed public debate."

Public perception of many technologies today is negative and fearful, and so he said he does not find it surprising that politicians give way to those fears or simply refuse to deal with an issue. This characterizes the nuclear debate in many countries, he noted. Public education campaigns that lay out facts and dispel fears and myths are needed. Ideally, this should be carried out by political figures who have no vested interests, he noted, and if they abdicate this responsibility, the industry must take it up.

The plenary session then went into a panel discussion, led by the journalist and publisher of *The Energy Daily,* Llewellyn King. We cannot proceed, he said, on the present trajectory of economic development without an enormous non-air-polluting source of energy. This can only be nuclear. King said he found it distressing to see ever new claims of technologies that cannot do the job. He is amazed when he hears talk of "clean coal." Cleaner coal, he said, is not the same thing as clean coal, which, he notes, is nothing but an oxymoron.

King also reminded meeting attendees that beyond energy is electricity. "Nothing does so much to enhance the quality and expectation of lives as electricity. . . . It gives to us exponentially. . . . It is astounding and we do not have enough of it," he stressed.

*Looking to the future*

The next panelist, Nuclear Regulatory Commission Chairman Richard Meserve, fleshed out the future. Population growth is projected to be mostly in regions already stressed by numbers, with 80 percent of the population living in urban areas by 2050, he said. The signs of serious strain are already apparent—deforestation, reduced fish reserves, degradation of fresh water resources, greenhouse gases, loss of species and ecosystems, emergence of infectious diseases, and more. The challenge—the imperative—is to recognize the interdependence of societal demands and environmental limitations and define a path to sustainable development, he declared.

Meserve

Meserve also reminded session attendees that while energy has an adverse effect on the environment, it drives the technologies for improved use of water and land, recycling, and minimization of environmental impacts. The finding of acceptable energy sources is needed to drive the entire process, he added.

Meserve observed that nuclear power is undergoing a quiet renaissance in the United States. Relicensing is one area where the NRC has a particular role. The commission has been formally advised by some 40 percent of U.S. nuclear power plants that they will seek license renewal, with the portion rising to 85 percent if all those planning to apply are included.

While the NRC does not have a promotional role, Meserve said, it nevertheless seeks to ensure that the regulatory system does not stand as an impediment to the role that nuclear energy can play in sustainable development. The commission accepts that needless regulation is a burden to the industry, he acknowledged, and it is engaged in rethinking the regulatory process. For example, one of the most significant programs undertaken is in the use of risk insights in revising regulations and regulatory processes. Meserve said this has permitted the agency to focus attention on those aspects of design and operation that are important to safety, while eliminating regulatory requirements that do not serve to enhance safety.

The NRC must also be and be seen as a rigorous, independent, and capable regulator, he declared. It has identified enhancing public confidence in the commission as one of four major goals in its strategic planning.

Pascal Colombani, head of France's CEA, set out the situation in Europe. While there is considerable opposition to nuclear energy, he noted, he remains confident that when Europe is confronted by social, environmental, and industrial reality, the nuclear issue will eventually have to be revisited. What the U.S. industry is doing today suggests that Germany's recent decision to phase out nuclear may not be in step with the times, he observed. Most people in the European Union (EU) are happy with the 30–35 percent of electricity demand being met by nuclear power, but they are wondering now how to proceed, he added.

The EU, Colombani said, is under considerable pressure. The recent oil crisis shows that it is excessively dependent on oil. Electricity demand is growing rapidly—2 percent within the EU and 3 percent in countries wishing to join—and this trend is expected to continue. Furthermore, deregulated energy markets have a tendency to disregard security of supply and climate change issues. In fact, he said, the European Commission is so concerned about energy security that it will soon release a "green paper" on the issue.

The chances of implementing an appropriate energy policy for sustainable development are not good, said Colombani. The import of energy is expected to grow from 48 percent of the total to 65 percent by 2020; within that, oil imports will grow from 75 percent to 90 percent, and gas, from 40 percent to 70 percent.

Regarding global warming, Europe exhibits a discrepancy between political obligations and market trends, he observed. Under the Kyoto Protocol, Europe is committed to reducing greenhouse gas releases by 8 percent by 2010 in comparison with 1990. Present predictions, however, suggest that it actually will be 7 percent higher. Only France and Sweden are likely to meet their Kyoto commitments, Colombani predicted, because these two produce almost all their electricity from nuclear and hydropower. He further noted that to stay at 1990 levels of emissions, Europe would have to construct about 85 new nuclear units.

Colombani retained some optimism that nuclear power can get back into the game. There is a political need to address the waste issue, which he said is the only one standing in the way of further nuclear development. He supported redirecting R&D efforts to optimize performance, extend plant lifetimes, and prepare for the next generation of reactors as a major component of a sustainable energy policy. Further research, he added, should also be focused on improving the predictability and the control of the impact of nuclear energy on human health and the environment. Also, radiobiological research must be reenforced to assess the effects of low-level activity and to develop scientific bases for more objective regulations in radiation protection.

Finally, although not everyone believes this, Colombani said, the idea that nuclear must be part of the energy mix is making progress in Europe, particularly at the commission level.

*Making nuclear competitive*

In introducing Corbin McNeill, chairman and co-chief executive officer of Exelon, King said no one is more deserving to be called a hero by the industry for keeping the nuclear option alive and even expanding it. "While many were fleeing the field, he refused to run away from nuclear power," declared King.

McNeill

McNeill began by thanking all those young people who are hogging the Internet and driving electricity growth to 3–4 percent, as opposed to the 1–2 percent of the previous decade. He also identified a number of other drivers of the market, notably deregulation, for which nuclear power has played a particularly central role. The first regions to deregulate, he noted, were those that had high tariffs caused by large nuclear plants coming on to the rate base in the 1970s and 1980s, when construction costs and interest rates were very high. What has driven deregulation, in his opinion, is the variation in prices. Those states with high prices realized they were at a competitive disadvantage, and deregulated to reduce prices.

The key problem, explained McNeill, was how to make these plants competitive in this environment. Operators achieved this by many means, including reducing outage times, developing leaner staffs with increased

skills, streamlining administration, etc. The result, he said, was capacity factors that rose from 66 percent in 1990 to about 90 percent last year—"and [nuclear plants] became safer–dramatically so."

The final critical factor was getting stranded costs included as an element in deregulation, McNeill observed.

Today, nuclear plants are competitive with fossil-fired plants, he declared. And now that natural gas prices have risen, he added, it is better than that. Furthermore, most states would not be able to meet the requirements of the Clean Air Act without nuclear power. "It is my belief," said McNeill, "that we can get nuclear power certified as environmentally preferable under the guidelines of the EPA. We are working to do that. It will take some work, but I believe it can be done. Many of our customers are asking us to do that."

Furthermore, he said, "Our record for handling waste is better than any other industry. We must speak up for our industry, of the enviable record we have in managing spent fuel and protecting the environment, avoiding the emissions that would be choking our cities, and that it is economically competitive. Nobody else will."

Showing no lack of confidence, McNeill also referred to the 85 percent of nuclear plants seeking relicensing, declaring, "I have told the other 15 percent to come see me and I will cut a deal with them."

During the discussion period, Bertram Wolfe (retired vice president and head of General Electric's nuclear energy organization) questioned Exelon's decision to invest in the Pebble Bed Modular Reactor being developed by South Africa's Eskom utility. Experience shows, he noted, that establishing new plant designs takes many years. Furthermore, Wolfe maintained, with the price of natural gas rising so much, if a current design were built now, it would be competitive.

Wolfe

McNeill explained that under the present competitive economy, the investment risks of a four-plus-year construction time and the market disruption that will occur when a large 1400-MWe plant goes into service—driving prices down to marginal cost pricing—will mean that the plant will not get an acceptable return on investment. He admitted that if there were average cost pricing throughout the life of the plant, the project could succeed. But that would not be the case, he noted: The generator would see marginal cost pricing during the period of oversupply.

McNeill went even further. Speaking candidly, he said, "I do not think we will see another LWR [light-water reactor] built in the U.S."

"I tend to disagree with you about this," said Wolfe.

"That's fine," said McNeill, "but I've got the money."

# Sen. Domenici honored with Smyth Award

Sen. Pete V. Domenici (R., N.M.) was honored on November 15 with the Henry DeWolf Smyth Nuclear Statesman Award, presented at the banquet of the ANS/ENS International Meeting. He was recognized for his longstanding contributions to many aspects of nuclear energy and technologies. Domenici is a ranking member of the Senate Energy and Natural Resources Committee, and chairman of the Senate Appropriations Subcommittee on Energy and Water Development.

He has been a leading proponent of providing adequate funding for new nuclear R&D initiatives. Under his leadership, Congress has increased funding for advanced nuclear technology R&D by about $50 million during the past three years.

Domenici

"Sen. Domenici has been a tireless advocate for all the many components that must come together for nuclear energy to succeed in this country," declared Joe Colvin, Nuclear Energy Institute president and CEO, who presented the award. "He has advocated the use of nuclear technologies as a major contributor to global peace and an improved quality of life by pointing out the clean air benefits of nuclear energy."

In his acceptance speech, Domenici pointed to America's future in the world economy and the importance of nuclear technology. He declared that globalization has a real chance of dramatically affecting the "deplorable standards of living" that affect two-thirds of the world's peoples. It can lift the standard of living for hundreds of millions of people, he noted, and America can be in the forefront of involvement with "its businesses, its technology, and its workers" providing the necessary supplies and services.

Domenici also spoke with optimism about the future of the nuclear industry. "Nuclear is coming back because we are moving ahead in the science, technology, and practicality of nuclear energy in this very difficult economic world," he said. "For a change, in America, there are business people talking about making an economic 'go' of nuclear power, and they might be seriously interested in the next generation of nuclear power plants." He observed that in contrast, "three or four years ago . . . everyone in this business was under the table, frightened to death—at least in America," though not in France, Japan, or other nations. Domenici called for action by the industry: "Let's move ahead and let's be bold about it."

He called for progress regarding some specific issues. "What we need now is an advocate or a number of national advocates to lead America out of the inherent fear of . . . anything that comes from nuclear and that yields low-level radiation or radiation." Domenici said that if in the next 24 months, the two issues of a new standard for low-level radiation and temporary storage of nuclear waste "were to come out our way . . . we would make a huge, huge stride in the direction of common sense."

ANS and the Atomic Industrial Forum, a predecessor organization to the Nuclear Energy Institute, established the Henry DeWolf Smyth Award in 1972. The award recognizes individuals who have made outstanding contributions to the peaceful use of nuclear energy.

The award commemorates the life's work of Dr. Henry DeWolf Smyth, a physicist who played an important role in the development of atomic energy before his death in 1986 at 88. Smyth chaired Princeton University's physics department and authored the federal government's official report on the development of the atomic bomb, "Atomic Energy for Military Purposes," made public shortly after the atomic bombings of Hiroshima and Nagasaki in 1945.

He served on the Atomic Energy Commission from 1949 to 1954 and, in 1961, was appointed by President John F. Kennedy as the U.S. representative to the International Atomic Energy Agency with the rank of ambassador, a post he held until 1970. Smyth advocated the establishment of an international partnership to develop peacetime uses of atomic energy.

## President's Session

Jim Lake's President's Session continued the theme of long-term globally sustainable energy options. Nuclear power is looking at a much brighter future, he said, than it has in many years past. There is even hope of an announcement of a decision to construct a nuclear plant in the United States in the near term.

Nuclear power is very healthy, demonstrating excellent economic performance and receiving relatively good public support, Lake added. If global projections of the growth in population and energy needs are near to being true, there is every reason to believe that around the world, many nuclear power plants will be built. The challenge now, he said, is to think in terms of sustainable development.

Lake pointed to three main imperatives: economic competitiveness, environmental stewardship, and social responsibility.

The industry needs to develop a nuclear power technology that is more economic, safer, and proliferation-resistant, and that deals with the waste and the fuel cycle in a better way than it has in the past, he declared.

There are a couple of major international programs starting to develop the needed solutions—the Generation IV initiative and the IAEA's advanced reactor and fuel cycle program—in which a lot of countries are involved, Lake explained.

He noted, however, that from a socially responsible point of view, things will have to be done differently from the way they've been done in the past. The industry must confront the public with possible solutions and options at an early stage and get their feedback. "We may then end up with decisions that are a little different than we would have come up with before," Lake observed. "But if we do this correctly, the technologies we come up with will fit socially much better than the technologies of the past."

A large part of future energy consumption and global pollution will come from China. "By 2020, China will exceed the U.S. to become the world's number-one $CO_2$ producer," said Li Jun Feng, vice president of the Energy Research Institute, in China.

According to Li's paper, annual economic growth was about 9 percent in the 1980s and 8.2 percent during the 1990s. To drive growth, the energy policy was simple: Increase supply as much as possible. Electricity capacity increased from 65 GW in the 1980s to 360 GW in 2000. The country already consumes 27 percent of coal produced in the world. It is therefore no wonder that 40 percent of China is suffering from acid rain and 62 percent cannot satisfy air quality standards.

The policy now is to develop renewables, including hydropower and wind power, as much as possible. Nuclear energy, however, is the natural choice to satisfy future needs.

Over the next 20 years, the Chinese economy is expected to grow by 6 percent annually, and in the following 30 years, 3.5–4 percent. Energy demand will double and triple over those periods. "This will be very bad for the environment," Li declared.

By 2050, coal production will reach its limit, because of transportation constraints, of 2.4–3.6 billion metric tons (t) of coal each year. Transporting coal now takes 23 percent of railway capacity, 25 percent of highway capacity, and 20 percent of waterway capacity. To achieve the 2050 target, China will have to build eight or nine more railways in the same mountainous areas and in the same directions as now.

China has been a net importer of oil since 1993, Li said. In 1999, total net oil imports were 50 million t, far beyond projections. The country has limited reserves of natural gas of suitable quality, and most of it is located far away from population centers.

Some argue that nuclear power is not economically competitive in China, noted Li. The capital costs of building nuclear plants are much higher than those of coal or gas plants, as are fuel and O&M costs.

Although the state development planning commission and the Nuclear Power Corporation announced a temporary halt in nuclear ordering, security of supply and sustainability demands still makes nuclear power very attractive in the long term, Li explained. The energy ministry forecasts that in 2010, the nuclear capacity will be 20 GW, 3.8 percent of total capacity; in 2020, nuclear capacity will be in the range of 30–50 GW, 6 percent of total capacity; and in 2050, nuclear may reach 200 GW, about 12.5 percent of total capacity. Seven provinces are doing feasibility studies for nuclear plants, raising finances, and looking for sites.

U.S. Rep. Joe Knollenberg (R., Mich.), a fierce supporter of nuclear technology, went straight to the essentials.

He noted that in 1999, nuclear power supplied approximately 20 percent of electricity in the United States, about the same as its worldwide contribution. By 2020, the current list of developing nations will consume more energy than the current list of industrial countries do. Looking at global demand in 2020, just to maintain nuclear's 20 percent market share would require 240 additional 1000-MWe plants.

His view of the alternatives is the following:

■ Fossil fuel supplies and reserves are sound. This year has seen a large increase in prices, a situation that will hold for at least the short term.

■ Hydropower is limited by geography and by the political pressure of the "extreme greens," who are against the development of large hydro projects.

*Continued*

Other renewables are not practicable on a large scale, but, Knollenberg said, they should be part of our energy mix. In some cases, they can make good financial sense, but generally they have not yet proven competitive and are not able to meet the needs of reliable baseload. The government has been making considerable investments in these, with little to show for it. And these technologies have been around for a long time.

The Congressman said that in his opinion, nuclear power is experiencing a real renaissance and that it has a long-term and sustainable future. He is hopeful for the Generation IV system, particularly noting the features of "walkaway safety" and reduced time of construction.

One of the less visible problems faced by the industry is the setting of unreasonable radiation standards, which leads to large additional costs. He noted that this issue must be reexamined—outside politics.

On climate change, Knollenberg is one of a number of Americans who oppose the Kyoto Protocol as risking unnecessary loss of jobs and economic hardships on Americans, while leaving developing countries free to continue to release greenhouse gases (GHGs). There is deep concern about the climate and its impact on our way of life. Measures, however, have to be based on sound science. He warned: "Let us not subsidize failure, let us subsidize things that work. That's the direction I think we should go."

In any case, Knollenberg does not believe that nuclear power's future needs be tied to reductions in GHG emissions. "Nuclear power does not need the schemes and treaties," he said. "It is good for the environment."

He also pointed to a shift in attitudes in Congress. There is now a bipartisan Nuclear Issues Group in the House of Representatives with about 80 members. Although it is still difficult to get anyone in the administration to say the "n" word, he observed, he said that he expected that there will be a move in that direction. "People are going to see," he said, "that the extreme greens really stand for nothing."

Angie Howard, executive vice president of the Nuclear Energy Institute, took this message further. Since 1990, she said, the industry has brought on line a virtual nineteen 1000-MWe plants because the average capacity factors have improved from 58 to 88 percent. That is also why they continue to supply 20 percent of electricity.

Howard

Perhaps the most important global issue of this century is how to meet humankind's growing energy needs without compromising the ability of future generations to meet their own, Howard reflected. The nuclear industry also has a responsibility to play its part in this challenge, she added. In 1993, the electricity industry joined the program in partnership with the DOE to voluntarily reduce GHG emissions. According to Howard, nuclear power accounted for almost half of the reductions achieved under the Carbon Challenge Program—this is the new capacity, not the existing capacity already in place.

Developed nations also have a moral obligation both to develop technologies and, as suitable, to transfer them to developing countries, she said. They must be given the options to progress, but we cannot dictate to them by, for example, giving them a limited set of options. Sovereignty is an integral part of the principles that came out of the Rio conference in 1992.

In the subsequent discussion, Wolf Häfele pointed out that if nuclear is to make a meaningful contribution as a long-term, sustainable energy source, several thousand nuclear plants will have to be built. This means society will have to handle large amounts of plutonium. The complications recently experienced in arranging the disposition of just 68 t from the U.S. and Russian weapons programs indicated how sensitive and difficult this issue could be, he noted.

Häfele

A large global nuclear program, Häfele says, will require operating a large-scale reprocessing regime. This task will require further development of the technology and require other issues to be resolved, including the proliferation problem and various institutional needs. The solutions cannot be of the same nature as today, he observed.

## Global climate change

The sessions on the Impacts of Global Climate Change, cosponsored by the American Meteorological Society, were an opportunity to hear from the authors of the main reports produced by the U.S. climate change assessment program. At last year's ANS Winter Meeting in Long Beach, Calif., the climate sessions focused on the processes involved in climate change. This meeting was concerned with the impacts of climate change on the environment and society.

The U.S. Global Change Research Program was set up under a 1990 law that called for periodic national assessments of the potential impact and consequences of climate change. The assessments, which include topical reports, are coming out now.

The first speaker, Anthony C. Janetos, gave an overview of potential impacts in the United States and discussed how these were determined. Janetos, head of the World Resource Institute, co-chairs the National Assessment Synthesis Team. He was followed by Martin Parry, of the United Kingdom, who described the European climate change assessment project. After Parry, the authors of the topical reports presented their findings.

The U.S. effort began with a series of workshops held across the country to listen to the views and concerns of all interested parties. The results of these were fed into the various assessment projects to ensure that the concerns would be dealt with. At the same time, a national synthesis team was set up to oversee the process. There are more than 20 regional and topical studies covering specific issues, such as forestry, health, water, and agriculture. The reports were subject to peer reviews, federal agency reviews, and a 60-day public comment period.

The assessments make use of climate scenarios to determine the consequences of possible futures—"they are not predictions of the future," stressed Janetos. The base climate scenario is the Intergovernmental Panel on Climate Change's "A" scenario, which makes no assumption of any national policies on climate change being implemented—the "business-as-usual" scenario. Janetos also mentioned two particular models that all the speakers referred to: the United Kingdom's Hadley Centre model (the "warm and wet" model) and the Canada model (the "hot and dry" model). These two provide a useful range of possible global changes.

*Possible effects*

One challenge for the team was to convert their results into meaningful terms, such as the effects on quality of life or on ecological systems. For example, the report presents an index of average July heat that tells us something about how "comfortable" future summers will be.

Using models of different ecosystems, the teams can determine what would happen to a system if a particular climate model were to occur—for example, how the distribution of trees and plant communities changes across the country over time as a result of a particular change to the climate. Each climate scenario will provide different results and each can be mapped and compared. The ecosystems of particular interest include forests, grasslands, alpine meadows, fresh water, and coastal marine systems.

Key findings include the following:

■ *Global warming:* There is widespread consensus that the rise in temperature is real and that evidence that people have altered the composition of the atmosphere outside the range of any natural variability, particularly for $CO_2$, is growing. The increase in $CO_2$ levels is due to changes in land use and fossil fuel burning; over the last 50 years, fossil fuel combustion has swamped the effects from land use change.

■ *Climate variations:* Changes in climate and their impacts will be different from region to region.

■ *Ecosystems:* Natural ecosystems (those not managed) are the most vulnerable; some, such as alpine meadows and coastal marsh lands, will be pushed out of zones where they can maintain themselves. They have few ways of adapting.

■ *Water resources:* The supply and availability of water varies from region to region, and depends on factors that may be influenced by climate—snow pack is critical in the north, while the east of the country is dependent on

rain every two weeks.

■ *Food supply:* On a national basis, food supplies will not be affected overall, but farmers will be.

■ *Forests:* The additional $CO_2$ will increase growth of forests, but increasing weather disturbances will affect regeneration and growth.

■ *Permafrost:* Permafrost regions are already seeing significant impacts. Alaska and central Siberia have seen the largest regional warming of any regions of the globe in the last 30 or 40 years. Permafrost melting and retracting is taking place where it existed for thousand of years.

■ *Coastal regions:* Sea levels will rise with global warming and there will be an increase in storm surge.

■ *Health:* There are many unknowns and questions. Will malaria and other tropical diseases come to the United States? Will respiratory problems increase? While health risks will certainly increase, the actual impact will depend on the adaptations made and investment in public health infrastructure.

Janetos also noted that the impact on the United States will probably be much less than on most of the developing world, notably in agriculture. "This is not to underestimate the fact that we are sure to be surprised," he predicted. In the future, he said, we need to understand how the environment responds to multiple stresses, and not just climate and $CO_2$ stresses, and to adaptations strategies.

*Possible futures for Europe*

To put this work in an international context, Prof. Martin L. Parry described the approach taken in Europe. Parry is director of Jackson Environmental Institute, in the United Kingdom, and editor of Europe's climate impact assessment project, called ACACIA (A concerted action towards a comprehensive climate impacts and adaptations assessment for the European Union), which has just been published. A summary of the report can be downloaded from <http://www.jei.uea.ac.uk>.

Parry noted that the U.S. assessment is much more research-based. The European report is a synthesis with gaps filled by expert knowledge. Unlike the U.S. approach, there is a good deal about policy. This is possible, he says, as the European effort was not under the control of government, although the project was funded by the EU. The report was reviewed by government, but not approved. As an example, the potential impact climate change will have on immigration, which is a major political issue in southern Europe and North Africa, was considered.

The purpose of the report is to answer questions such as: What are the most likely climate change futures? What would be the impact on biosystems, economies, and society? What can be done about it in terms of adaptations? It considered the impact on many different sectors, including transport, energy, industry, tourism, finance, etc.

Parry gave a number of examples of how climate change may affect Europe.

■ Winters currently classified as cold (occurring 1 year in 10) become much rarer by 2020 and disappear almost entirely by 2080. In contrast, hot summers become much more frequent—by 2080, nearly every summer is hotter than the present 1-in-10 hot summer.

■ Climate change will be more negative in the south than in the north, aggravating most current environmental problems, such as desertification, a degradation of natural habitats, and water quality issues. It will likely exacerbate existing political tensions between north and south.

■ The secondary and tertiary sectors, such as insurance, transport, energy, construction, and tourism, will be challenged by changes in demand. For example, there will be reduced demand for energy in central heating systems in northern regions, increased demand for air conditioning in the south. The increased incidence of extreme weather episodes will affect most sectors, particularly insurance and tourism.

■ Climate change will exacerbate the European agricultural imbalance, which already accounts for well over half of the EU's budget.

*Water resources and agriculture*

Climate change effects on water resources was described by Peter H. Gleick, president of the Pacific Institute for Studies in Development, Environment, and Security, who was co-chair and lead author of the water sector team.

He noted that there is now compelling evidence of changes occurring to water resources. These include changes in precipitation and temperature patterns, in snowfall and snow melt patterns and timing, and in migration patterns of birds and butterflies. It is also seen in glaciers receding and permafrost melting in Alaska.

Gleick mentioned the runoff of the Sacramento basin, which supplies most of California's water. The spring snow melt from the Sierra Nevada mountains has been decreasing, although the total has not. This means runoff in winter is increasing, which is the opposite of what is wanted, he explained. California needs the water in the summer, when there is little rainfall, for agriculture and other uses. This is precisely the sort of impact expected from climate change.

Generally, climate change could pose serious challenges to water systems, said Gleick, who expressed concern about how they will be managed. Water planners and managers have traditionally assumed that the future will look like the past, he noted, and reservoir designs are based on historical records. In the future, this approach could lead to wrongly designed systems, which could result in flooding, and, at the same time, unfilled reservoirs. In the future, water management must take account of climate change, he declared.

Gleick admitted that water resources would be more affected by demand than climate change. He showed a graph of water demand that the nuclear business would find familiar. In the 1960s and '70s, he noted, forecasts of how many man-made reservoirs would be needed by 2000 were about as accurate as forecasts of how many nuclear power stations would be built by then. In fact, he said, consumers actually withdraw less water today than they did in 1980, for a variety of reasons. "We have broken the hard link between economic development and water demand, as with energy demand," he observed.

The potential impact of climate change on agriculture was described by John Reilly, of the Massachusetts Institute of Technology. Agriculture, being a managed resource, is influenced by many factors besides temperature and precipitation. He noted recent examples where the location of corn and soy beans had moved northward, which would be an expected result of global warming. In this case, though, this movement was not due to climate change. Global warming, however, is expected to shift the economics toward dry land farming from irrigated farming. The net effect in the United States, he concluded, is generally positive, although better for consumers than producers.

Steven McNulty, of the U.S. Department of Agriculture, described the forest sector assessment, which considered several aspects of forestry, including forest processes (e.g., productivity, carbon storage, and water use), biodiversity (change in distribution of plants and animals), and economics of forest resources (timber and lumber supply).

The range of climate factors used in the assessment included ozone concentrations, acid rain and nitrogen disposition, temperature, and precipitation. Some of conclusions were:

■ Average forest areas are expected to decrease by 11 percent.

■ Pine forests will move north, leaving more grasslands in the south.

■ High alpine forests will move up the mountain and will then disappear.

■ Bird species will move northward.

■ Colder adapted species will decrease.

■ Pests and diseases may move into the north.

Because productivity is going to go up, however, there will be a greater supply of timber, with consumers being better off than producers.

*Coastal areas and marine resources*

Donald Boesch, of the University of Maryland, described the impact of climate change on coastal areas and marine resources, which are quite vulnerable to changes in water temperature, in the ingress of saltwater into freshwater around coasts, in the number and severity of storms, and others. Coastal land, he explains, is not static, but continually rising and falling. Coastal wetlands are particularly threatened, but are difficult to predict since they are so dynamic.

Temperature changes will affect ocean oscillations, like El Niño, the Gulf Stream, and ocean "conveyor belt" currents. There is even a mechanism that could stop the Gulf Stream, which would have large effects on western European weather. The impact on coral reefs, whose organisms are killed off by heat stress, was of particular concern to Boesch. There has likely been a considerable loss recently following the rise in temperature due to El Niño. The level of $CO_2$ concentrations in tropical waters is another critical factor.

*Continued*

The effects of climate change on health were discussed by Michael A. McGeehin, of the National Center for Environmental Health. His team looked at areas where weather might affect health and then examined the possible effects of climate change on these. The main areas identified were waterborne disease, vector-borne disease (usually involving an insect, such as a mosquito), heat effects on morbidity and mortality, respiratory effects of pollution, and injuries from extreme weather events.

McGeehin said the point is that there are already problems in these areas, and global warming will exacerbate them. Waterborne disease, whose symptoms typically include diarrhea, is not heard much about, but there are now billions of such cases each year in the United States. About 200 people die from heat stress each year, and in a bad year this can rise to hundreds. "We know how to prevent and mitigate these problems," he argued, "but we haven't done very well at it. We need to prepare now to save lives and lessen the costs."

At the start of the discussion, a questioner asked McGeehin why he had not spoken about cancer caused by the burning of fossil fuels. McGeehin explained that this was not relevant to the climate change effects he was studying.

The ANS audience apparently wanted to know why the climate scientists were not making recommendations on energy sources. The speakers were clear that their task was to look at the impact only if no action were taken to reduce greenhouse gases. As one person stated, the question "Is nuclear better or worse from a public health point of view than the alternatives?" is outside the scope of this national assessment. The team was not asked to make policy recommendations on which adaptation measures to introduce, or to assess the effects of different strategies to reduce GHGs. There is an enormous machinery in government, it was said, that considers what can be done to mitigate the effects. Congress separated the two sides of the question. Decision-making on what to do was to be hammered out in policy circles. The assessments, on the other hand, are to inform that debate.

## New construction

Recent developments in the nuclear power industry indicate a possibility of seeing third- or fourth-generation plants operating in the United States by 2020. A special session chaired by Carolyn Heising was organized to discuss the likelihood of new construction.

ANS President Jim Lake opened the session by saying that the U.S. nuclear power program is still seen around the world as a trailblazing industry. During his travels, he noted, even in countries with healthy construction programs such as China, Korea, and Japan, there is great interest in the U.S. program, both in the operating side and the new construction side. "I think it is viewed as an important signal around the world that one of the most powerful nations—and one of the earliest countries involved in nuclear power, and with the most nuclear power plants operating—has enough faith in nuclear technology that we're willing to move forward," he said.

Victor Reis, director of the Center for Nuclear Strategies, an organization of Science Applications International Corporation (SAIC), followed Lake with a talk on the Nuclear Strategies Project. Developed in the past year, the project develops relatively simple and focused models for various nuclear-related issues, including new construction. The project is sponsored by SAIC, along with the Sandia, Los Alamos, and Lawrence Livermore national laboratories and the Defense Threat Reduction Agency. Representatives from those organizations work on the project.

The project built a model that emulates the decision-making process of an independent power generator faced with the choice of building a nuclear or natural gas plant to satisfy shortfall in baseload electricity demand. "We assume all power generators go through the same process, have the same criteria (discounted profit), and we aggregate the results for a set of power generators and watch what happens to market share and other relevant parameters over time, typically 50 years," Reis said.

Inputs to the model are chosen in real time and consist not only of physical and cost parameters of the plants, but also of economic and policy parameters that will affect estimated discounted profit—for example, imposition of a carbon tax on fossil, or streamlined licensing for nuclear.

Because the model is relatively simple, much discussion by project participants revolves around how it can be improved, which is, "of course, part of the learning process," Reis explained.

But the most important output of the project, according to Reis, is not a specific strategy or model, but the development of a language that connects policymakers with industry leaders. "The development of such a language will permit a deeper and richer understanding of nuclear issues and opportunities," he said.

Reis concluded by offering his personal view of nuclear development, separate from the official stance of the project. "There are few programs as critical for global economic, environmental, and, yes, national security well-being as the fourth generation reactor program," he declared.

George Davis, director of governmental affairs for Westinghouse Electric Company, commented that there is "a lot of comfort in the industry by what is occurring." What is occurring, according to Davis, are conditions that are paving the way for expansion of nuclear energy. These include:

- The deregulation of the power industry, which is driving many changes.
- Nuclear plant sales, coupled with consolidation of plant owners and suppliers, which are creating a "healthy, viable industry," according to Davis.
- Continued reductions in operating costs and improvements in performance, which are making nuclear a low-cost option.
- An improved regulatory environment, along with license extension, which is creating optimism about nuclear's future.
- Nuclear's environmental contribution to clean air.
- Nuclear's exemplary safety record.
- The shrinking of electricity reserve margins while demand growth increases.
- The availability of space on existing nuclear plant sites to build new units.

In order to construct a new plant, vital steps must be taken, Davis continued. These include reducing "overnight" capital costs to $900–$1000/kWe, with construction schedules of three years or less; establishing business models "for allocating risks and responsibilities"; demonstrating a regulatory process that works for new plants (e.g., construction and operating license); and establishing government support where appropriate.

Davis then reviewed the Westinghouse next-generation designs: the AP-1000 (*NN,* Sept. 2000, p. 39), which is a 1000-plus–MWe reactor that is expected to reduce overnight capital costs to the $900–$1000/kWe target and is expected to receive design certification from the Nuclear Regulatory Commission by 2005; the Pebble Bed Modular Reactor, which will have overnight capital costs of $1000/kWe for a 110-MWe module and is the subject of a South African demonstration project (including the participation of BNFL and PECO) that could provide Generation IV technology by 2005; and the IRIS (International Reactor Innovative & Secure), which has an eight-year straight burn core and could be deployed by 2010.

Ward Sproat, director of strategic programs for Exelon Generation, explained that commercial reality for nuclear power means it must be safer, faster, and cheaper in the future or face extinction. "The nuclear option is still viable, but not with its current offering," he said. "It will only survive if it can provide a competitive return in the marketplace."

Sproat warned that time for resurgence of the industry is small and continuing to decrease, with perhaps a 10-year window for new nuclear plants to kick-start the industry. "The nuclear infrastructure is shrinking," he said. "All you have to do is take a look at how many people are [in the industry] today and compare it with how many there were in the late '70s and early '80s. Also, the intellectual interest in the technology is waning. The average age [of nuclear plant workers] is probably in the mid-40s. Quite frankly, this is not a happening industry. People are not coming out of college saying 'I've got to go into the nuclear business!'"

The reason it is difficult to attract new people, according to Sproat, is that "engineers like to build things, we don't like to go into an industry just to maintain existing plants and make them run."

And as the industry shrinks, Sproat continued, competing technologies are developing, such as fuel cells and microturbines. "We only have a limited amount of time before these technologies are not only technically viable but economically viable, and the infrastructure to put them in on a widely distributed basis is there," he said.

Frank Lopez, manager of new generation for Bechtel Corp., questioned whether the United States is ready for standardized (mod-

ular) plants, which is how the fourth-generation units would be constructed. He answered with the affirmative. "I believe the opportunity—if we're ready to accept the challenge to build a standardized plant—is there," he said. "Certainly, we have limited U.S. experience in nuclear standardization, but growing international experience has shown that it can happen."

Lopez added that significant fossil developments have shown how standardized power plants can be taken to the marketplace.

Ron Simard, senior director of the Nuclear Energy Institute, talked about a program being quarterbacked by NEI to assist in making plant-building decisions. "Don't think of it as a plan, rather more of a framework for identifying what we need to do to help us move forward," he said.


Simard

Goals of the program include reducing cost and schedule uncertainties for new plants, achieving the necessary changes to regulations and legislation, and integrating and coordinating industry efforts to support new construction and continued operation of existing plants.

Ongoing activities of the program, Simard added, include assessing financing approaches to similar capital-intensive, long-lead projects in other industries, and identifying and achieving necessary changes to NRC regulations, such as treatment of financial qualifications and decommissioning funding assurance.

To reduce time to market, the program is working on developing rulemaking to improve the design certification process, while evaluating an early site permit process; developing a proposal for combined operating and construction license conditions; and meshing NRC inspections with the license construction schedule.

Looking ahead, Simard continued, the program seeks to define a role for the Department of Energy in removing barriers to commercial deployment of advanced designs, to continue to broaden the base of support for new plants within the Congress and administration, and to continue to broaden the base of support with private sector policy groups and the financial community.

To ensure "a robust infrastructure" that will lead to new construction, Simard said, the industry must have enough qualified people to work in design, construction, operation, and regulatory oversight. It must have necessary manufacturing capabilities and equipment suppliers. And there must be reliable and economic sources of fuel fabrication, conversion, and enrichment services. To that end, NEI is forming a task force to investigate and work toward solutions to these issues.

"I am going to leave here today remembering a couple of points that were made," Simard concluded. "First of all, extinction is a possibility, but second, there really is a window of resurgence. It's real and we have an opportunity to take advantage of it."

## Hot topics

Decommissioning and spent fuel management were certainly appropriate subjects for the "Hot Topics and Emerging Issues" session, chaired by Tom LaGuardia, of TLG Services, Inc. A lot of money is tied up in nuclear plants, and the many elements of decommissioning, including funding, waste storage and disposal, decontamination and dismantling, and regulations, need to be right. And it was obvious from the discussion that there is a long way to go.

First, Tom Tuschen, whose company—Grantham, Mayo, Van Otterloo & Co. LLC—sets up decommissioning trust funds, described the effects of deregulation and industry changes on funding. Tuschen explained what a fund is and how it is set up and operated. The idea is simple: While the plant is earning money, the utility puts some of it into a decommissioning fund, which is invested to generate more income. Once operation ceases, money is used to finance all the activities leading to the plant's being fully delicensed.

There are many variables and uncertainties to funding. Tuschen's list included:

- Income (from customers and the state).
- Core inflation.

*Continued*

■ Tax rates.
■ Decommissioning costs.
■ Liability streams (e.g., decommissioning and storage of spent fuel).
■ Changing regulatory involvement of regulators (Tuschen listed the state, the Federal Energy Regulatory Commission, the Nuclear Regulatory Commission, and the Internal Revenue Service).
■ Funding shortfalls.
■ Funding surpluses (many would want their share, including ratepayers, owners, regulators, state and federal governments, and other "stakeholders").

Plant owners will want to control these as much as possible to limit exposure, reduce costs, and increase income.

When Congress passed legislation establishing waste compacts, it expected that this would foster the creation of several regional repositories. Since then, no new repositories have been set up. And now, virtually the only disposal site available to the whole country, Chem-Nuclear's Barnwell repository, is to stop receiving waste from all but three states in 2008.

James Latham, of Chem-Nuclear, described how the governor of South Carolina charted a path to end the state's role as a waste site for numerous states. This year, South Carolina, and with it Barnwell, joined the compact already in existence with Connecticut and New Jersey, renamed the Atlantic Compact. This means that South Carolina is now allowed to limit, and ultimately exclude, other states from disposing waste at Barnwell. Latham described what this would mean for its present customers.

*Decommissioning methods*

The traditional idea of decommissioning a nuclear plant is to decontaminate any material that can be released and ship the rest for disposal. One variation of this is "Safe-store," where the facility is left untouched for a time while contaminated material decays.

The NRC's Stephanie Bush-Goddard discussed another option that had not been given much consideration until recently: entombment. Entombment involves leaving the material on site encased in a structure of long-lived material, such as concrete, and leaving it, maintained and under surveillance and institutional controls, until the waste decays to an acceptable level for unrestricted release (greenfield status) of the site, which is 25 mrems per year.

While this solves some of the problem of finding adequate disposal capacity, Bush-Goddard explained, it does mean that the site will have to remain under control for a very long time.

Small-scale entombment has been done at Department of Energy facilities—for example the Hallam, Piqua, and Bonus reactors—and at some plutonium production facilities at Hanford. She noted that as there is no experience entombing power reactors, the Pacific Northwest National Laboratory (PNNL) did an assessment using a reference pressurized water reactor, looking particularly at how effective the isolation would be. Previous work on low-level waste sites was seen as relevant, but the source term and site characteristics would be different. Entombment would have less waste generated and lower doses. PNNL concluded that it would be a viable option.

After PNNL completed its report, a workshop was held with licensees, industry, and some states' officials. The participants agreed that something structurally sound could be built. The states are particularly interested, as they see this as reducing decommissioning funding requirements. The workshop participants preferred to exclude the greater- than-Class-C waste, although Bush-Goddard said that the NRC is considering allowing this waste to be included by "concentrate averaging." They concluded that a site-specific study was needed.

NRC is putting out an advanced notice for the industry and other stakeholders to comment on how to proceed, looking particularly at licensing issues, the extent and timing of surveillance, dose levels, and release criteria. Other issues concern intrusion, long-term control, and ownership responsibility.

Ed Davis, of NAC International, explained his concerns about the licensing of dry storage casks. He said it is generally agreed, both inside and outside the NRC, that rulemaking reform is needed. He expressed concern that there are not enough resources at the NRC's spent fuel management project office to review all the applications and other work to be done.

He expressed particular concern about the length of time involved for rulemaking on applications for storage canisters, which requires a review of 12–14 months. Any changes to a Certificate of Compliance, no matter how small, require the same. That process has to be streamlined, Davis said. He said the office is under-resourced, adding that the needs of decommissioning have turned out to be much greater than expected and that the resources are not there. He said that he fully supports the work done by the staff. The NRC wants to change it, but that will also take resources that are not there.

*Spent-fuel policy*

Another hot issue is what the United States' spent fuel management policy is going to be over the next four years. There is now a de facto policy—to leave spent fuel in place—as a result of the default of the DOE on contracts to take spent fuel.

A future issue is high-burnup fuel (over 50 000 MWd/t), which is now coming out of reactors. The present canisters are not licensed for these levels of burnup. In fact, it is not possible to license any, because there are no technical standards.

Two prematurely shut down reactors, Maine Yankee and Connecticut Yankee, chose to contract out the bulk of their decommissioning activities to general contractors. Although the idea seems simple, there are potentially large commercial risks for a contractor. Of course, the extent of the risks may not have been appreciated when these contracts were agreed upon.

Session attendees heard the presidents of both plants, Michael J. Meisner (Maine Yankee) and Russell A. Mellor (Connecticut Yankee), describe their experience of transferring risk to decommissioning operations contractors (DOCs). Maine Yankee first placed a general contract with Stone & Webster. Connecticut Yankee followed, choosing Bechtel as its DOC. The experience at both plants with the DOCs has been relatively good—but Maine Yankee's contract with Stone & Webster was terminated in May 2000 because S&W was going into bankruptcy (*NN,* June 2000, p. 17). Meisner said that Maine Yankee has accepted bids for another potential DOC and is evaluating them now.


Mellor

Meisner described the risks carried by different activities, pointing out some surprising items. While decontamination and dismantlement activities are being straightforwardly dealt with, the plant was found to contain a considerable amount of material covered in paint contaminated with low levels of PCBs and lead, as well as a lot of radiologically contaminated soil that will have to be dealt with at considerable cost. Maine Yankee is also concerned about sub-slab contamination (below the foundations), a potentially expensive unknown.

On the regulatory side, an operator must develop a license termination plan. As no plant has yet completed one, this task is considered a medium risk. There is also concern that after the NRC terminates the license, the Environmental Protection Agency could step in, label it a Superfund site, and require additional cleanup beyond the NRC's 25-mrem standard. It is generally believed that EPA wants primacy over all radiological issues.

Maine Yankee had planned to use rubble from demolished concrete structures for filling the foundations of new buildings being constructed on site. Being slightly contaminated, the rubble was to be decontaminated to NRC 25-mrem standards. This was initially considered a low-level risk activity. The groundswell of opposition from local and state people to leaving on site any contaminated material that could be removed, however, was unexpected. Meisner admitted that Maine Yankee went into the area of state licensing very naively.

Finally, having described the downside of being a DOC, Mellor (who is also CEO of Connecticut Yankee) listed reasons a contractor would be interested in this business:
■ Marketplace advantage.
■ Acceptable level of risk.
■ Business profile fit.
■ Capability of the organization.

It is unlikely, however, that a DOC would take on all risks, even if the plant owner were paying, Mellor explained. Besides those licensed responsibilities that cannot be transferred, the contractor would likely not be the appropriate party to deal with challenges

brought by regulators or intervenors, nor be responsible for long-term spent fuel storage.

## Tokaimura: Lessons learned

One surprising aspect of the accident at a uranium conversion facility at Tokaimura, Japan, on September 30, 1999 (*NN,* Nov. 1999, p. 42), was that there was no real public panic in the vicinity. Of course, explained Kenji Sumita, chairman of the Japan Atomic Energy Society, Tokaimura is a special case as local people were fairly knowledgeable. Furthermore, he found that the media handled the accident very well.

Tom McLaughlin, cochair of the session on "Lessons Learned from the Tokaimura Nuclear Criticality Accident," noted how different this was from the response of the public and media in the United States during the Three Mile Island-2 (TMI) accident. And, as at TMI, the industry responded immediately to the Tokaimura event, reviewing policies and practices, and putting measures in place to improve criticality safety and emergency response.

In November 1999, the U.S. Department of Energy began a criticality safety improvement initiative. One task, a review of five key sites whose work included solution processing, was led by the DOE's Jerry N. McKamy, who described the effort. Over 120 days, his team assessed the sites, focusing on four major areas: criticality safety controls and limits, work control, configuration control, and line management oversight. They found no imminent criticality accident risks. The sites had implemented criticality standards very well.

For the review, the team toured the facilities, giving pop quizzes to staff, asking them, for example, to describe the contingencies relied on and barriers to criticality. They found strengths and weaknesses across the sites, said McKamy. At Los Alamos, the team found the interaction between criticality safety staff and operations staff exemplary. Operations staff knew the criticality scenarios and their controls; criticality safety staff were seen and welcomed in the operations area.

Some common weaknesses were identified, McKamy noted. Most sites did not have a formalized process to ensure that criticality safety engineers understood the operations and the processes they analyzed. There was a tendency to assess the processes remotely, rather than walking the facility to understand and identify risks. This also meant that they were not available to teach operators about criticality safety controls.

*The team's recommendations*

The review team made several recommendations, including:

- Ensure that criticality controls and their technical bases are understood. Criticality safety engineers must be made familiar with operations and interact with the operators so they understand what can go wrong and why the controls are in place and get their participation in developing the controls.
- Ensure rigorous adherence to procedures and controls. It is particularly important that operators understand they have "stop-work" authority when something is out of bounds.
- Improve feedback to senior managers. Managers need to know the overall condition of the criticality safety programs to improve oversight.

The team also recommended that the DOE strengthen its programs, attract more experienced professionals, and train those in place.

Following the incident, the Nuclear Regulatory Commission asked licensees to review their operation, focusing on processes involving comingling of high- and low-enriched uranium, training procedures, startup authorizations, accident recovery operations, and management oversight.

The NRC's investigations of the gaseous diffusion plants and high-enriched uranium (HEU) facilities identified no significant criticality safety issues. According to Dennis C. Morey, of the NRC, the commission concluded that the existing regulatory program makes it unlikely that an accident could occur. Licensees review criticality potential in the licensing process, using a defense-in-depth approach that considers prevention, mitigation, and emergency preparedness. Licensee requirements for criticality safety also include administrative controls, internal auditing, operator training, independent plant safety groups, and event reporting. The NRC also found that its current oversight program makes an event unlikely, and concluded that no revisions to the program were required.

Chris Robinson, of the Y-12 facility at Oak Ridge, explained that soon after the Tokaimura accident, the plant stood down for a few days to discuss the situation with staff, to look at the plant's vulnerability to a similar incident, and to undertake plant-wide training in criticality safety. A rather rigorous formal assessment of the more vulnerable facilities and processes was undertaken. One particular concern was the effectiveness of the large-geometry exclusion program to avoid the introduction of containers with large geometries into the HEU solution areas.

Operators at the plant reasonably asked if they had been working unsafely before. The answer, Robinson said, is no. It is the level of documentation and information that are needed today that has changed. In addition, efforts are being made to explain why the rules are in place. This is very different, notes Robinson, from earlier times when information such as what the real limits were was held back in case it could be used for causing industrial problems. Workers were expected to follow procedures blindly.

Another example of how industry reacted was given by Christa Reed, manager of nuclear criticality safety (NCS) at the Navy Nuclear Fuel Division (NNFD) of BWX Technologies. The Lynchburg, Va., plant has operated for 45 years and can handle uranium of all enrichments. Her group of 11 engineers has considerable experience with plant operations.

Reed

Right after the Tokaimura accident, daily briefings were set up with operations in case something needed to be done immediately, said Reed. Fortunately, this did not happen. The general manager also posted information for the whole plant. Chemical process operators were particularly interested, so one-on-one talks and training were arranged for them.

*Areas examined*

Two weeks after the Tokaimura accident, the plant manager chartered a group to see if the facility was susceptible to a similar event. It particularly looked at:

- Operator training.
- Geometry of solution transfers (at Tokaimura, the workers did not appreciate the importance to criticality of the geometry of the containers).
- Availability of containers of nonfavorable geometry in solution process areas.
- Enrichment controls.
- Emergency response capabilities.

The group did not find any unsafe conditions, but suggested upgrading training in some areas and improving material transfers, Reed noted. They found that the chemical processing area has expanded so it was right next to the shipping and receiving area, where different types of containers may be located. Solid walls were built to prevent problems.

It also found that a good emergency response plan was in place that included quarterly drills for practicing criticality incident scenarios all the way to the hospital. It found, however, that the plant was not prepared to communicate with press, local agencies, or company headquarters. Since then, a script describing what a criticality accident is and what it means for the surrounding community was prepared. The response team has now coordinated with state and local emergency agencies to discuss what the plant would expect from them and what they could expect from the plant if an incident occurred. Although arrangements with local hospitals were already in place, they were contacted to make sure they could handle highly irradiated people.

The plant was also visited by an assessment team from the Nuclear Energy Institute (NEI), which found a good culture at the plant, noting the presence of NCS officers on the floor. The NEI team interviewed the operators and found that they knew the procedures, understood that they could not deviate from them, and could stop operations they felt were unsafe or they did not understand.They also understood that a criticality accident is a bad thing and could kill them.

The NEI discovered, however, that operators could not explain what criticality is, in the sense of a self-sustained nuclear chain reaction, some suggesting it means an explosion or metal ingesting. They could not explain the fundamentals of mass, moderators, and controls. The NCS unit is working to improve this and is finding it quite a challenge.

Reed noted a lot of willingness at the plant to change things after the accident, as did the next speaker, Kathleen E. Bhanot, of British

Nuclear Fuels plc (BNFL), in the United Kingdom. She said that once the management and commercial people in her organization discovered that the incident would affect their business, they became very supportive of her group's work.

Although most of the material processed at BNFL's Springfields fuel fabrication facility is low-enriched uranium, the plant does handle small quantities of HEU recovered during the decommissioning of BNFL's old HEU facilities. The residues are dissolved and downblended before being put back into the plant process.

The accident had a direct impact on BNFL's business. The company was in the middle of selling its integrated dry-route process, which converts $UF_6$ to $UO_2$ powder, to JCO Company, Ltd. Contracts had been placed and equipment was being manufactured. The sale ceased. "The commercial people now realized what criticality safety was about," she said.

This led the director to ask her to look at the findings of the reports on the Tokaimura accident from the Japanese government, the International Atomic Energy Agency, and the NEI to determine possible implications for operations at Springfields. All observations and recommendations made in the reports were checked against the situation at Springfields to see if any action was needed. The review found no showstoppers or any reason to make changes to procedures, said Bhanot.

The review did find, however, a lack of awareness and training of personnel, as well as some complacency among the staff. Improvements in accountancy procedures in all mass control areas were also needed. Measures are under way to deal with these deficiencies.

While no fundamental problems were identified at Springfields, the Tokaimura accident provided an opportunity to review all procedures and policies. Such an opportunity does not arise very often, and the criticality group has taken full advantage with support from management to improve procedures and practices.

Under normal conditions there is a good notification system in place to involve the criticality officers whenever there are modifications to plant, said Bhanot. But it is not always early enough. Problems can also occur when something unusual happens, for example when operations are changed or the plant is down for any reason, like an audit or a VIP visit. The staff now know to call in the criticality officers if there is any change in operation or a production difficulty. This is now working well.

Finally, although the media attention brought some rewards, Bhanot noted, in covering the JCO accident, the BBC used archive footage of a hole in a roof of a facility caused by a fire some three years ago. Until then, she had found the BBC a credible news source. She said that she no longer does.

*The NEI team*

John C. Brons, a special assistant to Joe Colvin at NEI, described the findings of the NEI team that visited the country's 10 commercial facilities that process uranium solutions. "We were looking at how safety procedures were applied and the attitudes of staff applying them. Are they used consistently and wholesomely?" The report, *Assessment of Nuclear Criticality Safety and Emergency Preparedness at U.S. Nuclear Fuel Plants,* was praised by many at the meeting.

Brons

At the beginning of a plant visit, the NEI team asked plant managers to explain how they achieved their safety goals, and what they expected the team to find. The team then went into the plant to see if they could find it. Despite the business and other commercial pressures, the team found uniformly good linkage between operations staff and management regarding what was expected. Safety was considered crucial, and the operators had a clear sense of their authority to stop the process for any reason. The NEI team found procedures in use flowed well from the license conditions of the facility.

At all facilities, operators said that they expected procedures to be followed. Brons said, however, "When you get down to the shop floor, there is a wide range of interpretation of what that means." They found that operators always believed they were carrying out the intent of the managers. The interpretation of intent concerned the team. As Brons said, "I could argue that at Tokaimura, the intent of the procedure was followed, at a very broad level. But lots of important details were overlooked." Basically, the understanding of management and operators regarding what the procedures mean and how they are applied must be the same, Brons emphasized.

The NEI team identified many good practices actually being implemented that are included in their report. They found only one good example, however, where operators had a good understanding of criticality and criticality controls. Many plants considered this too difficult to teach, as if, said Brons, it meant making nuclear physicists out of the people. Brons says this must change. If operators know the reasons for restrictions, they are much more likely to adhere to them when the crunch comes. If not, it is easy to bypass them.

Another concern was that some audit and surveillance programs were unduly responsive to the NRC. At the best run facilities, the staff knew who was running the show.

Finally, the team was reassured, said Brons, because it found no one who believed that criticality could not occur.

## Neutron applications

Innovative uses of neutron-related technologies were reported on in the session, "Neutron Detection, Spectrometry, and Dosimetry–II."

Paul Goldhagen, a physicist at the Department of Energy's Environmental Measurements Laboratory, presented a paper on measuring cosmic ray–induced neutrons aboard an aircraft, as well as on the ground. Goldhagen and his group undertook these measurements primarily to study radiation protection for aircrews. They determined cosmic ray neutron spectra over the full energy range at various altitudes and latitudes.

In 1997, there were more than 167 000 aircrew members working for airlines in the United States. The hours aloft are typically 500 to 1000 hours for each aircrew member every year. "As a whole, they are one of the most exposed groups of radiation workers, which we completely ignore here in the United States," Goldhagen said. "But, in the European community, aircrew are true radiation workers, and starting this year, efforts will be made to determine their yearly dose rates and keep records of it."

Goldhagen explained that cosmic rays are energetic atomic nuclei coming from space—primarily protons, as well as some helium ions and heavier ions. When they collide with the atmosphere, they produce neutrons, amid other kinds of radiation. There are two basic kinds of cosmic rays: galactic and solar. The galactic rays are continual and ever-present, and can have very high energies. They dominate the dose to aircrews. Solar rays are sporadic, occurring only during solar particle events, of which there are only a few for each 11-year solar cycle. They produce high dose rates for a few hours to a day or so. They are typically lower energy, producing significant doses only at higher altitudes.

*Three variables*

Dose rates from galactic cosmic rays in the atmosphere depend on three primary variables, Goldhagen explained. The first is altitude, because of the amount of shielding provided by air.

The dose rates also depend on magnetic latitude. Because of the earth's magnetic shield, the horizontal component of the magnetic field bends the primary charged cosmic rays back into space (if they're sufficiently low in momentum). Subsequently there is a higher flux of these particles near the magnetic poles than at the equator. As a result, at an equal altitude, the dose equivalent rate at the poles is roughly six times greater than at the equator.

There is also the variable of the solar cycle, owing to variances in the magnetic field carried out by the solar wind. "The important thing to remember here is you get a maximum of galactic cosmic radiation at the earth when the sun spots are at a minimum. So, solar minimum is radiation maximum," Goldhagen said.

Until the last five years or so, uncertainties in measuring the neutron spectrum were the main cause in not knowing the effective dose at high altitudes, Goldhagen said. The ionization chamber measurements from 20 and 30 years ago had measured the directly ionizing component fairly well, he said, but there were relevant uncertainties in what the neutrons were doing.

The experiments Goldhagen reported on, called the Atmospheric Ionizing Radiation

Measurements project—or AIR Measurements—were started by the NASA Langley Research Center and grew into a collaboration of more than a dozen laboratories.

The researchers obtained a NASA aircraft and loaded on to it a suite of more than a dozen radiation measuring instruments. The instruments were placed in the nose of the aircraft, in wing pods, and in a section of the fuselage. They then flew at a range of altitudes, from 52 000 to 70 000 ft, and latitudes, from 18° to 60° north.

The effects of latitude affected the neutron fluence, but had little effect on the spectrum. At the southernmost measurement location, the total neutron fluence was one-eighth of what it was at the northernmost location. The spectrum, however, hardly changed. "This is very good news because it means that this variable does not affect the shape of the neutron spectrum and therefore won't affect the calibration factors of simpler [radiation] monitors that you might fly on airplanes," Goldhagen said.

The effects of altitude were greater. When they dipped in altitude, the fluence hardly changed—only a 3 percent decrease. But, there was a slight change in the spectrum, which resulted in the dose equivalent changing by 9 percent, and the effective dose by 11 percent. "So, that's big change," he noted.

The data they collected have other applications besides radiation protection, Goldhagen said. "Also important . . . are the so-called single-event effects, when neutrons strike the very small electronic components in chips and upset them. They can cause bit flips. And if you change a bit in a program that's helping you fly your airplane, you could be in trouble.

"So, it's nice to know what the spectrum of neutrons is, because it's an energy-dependent effect. And neutrons are causing most of the bit flips, even here on the ground. This effect has become important as computers have more and more memory and smaller and smaller sizes. These results could also be used to validate the radiation transport codes that are used to determine the doses to the astronauts traveling through the much smaller layers of shielding."

In addition, the surface of Mars is equivalent to flying at 80 000 ft above the earth, Goldhagen said, so these measurements have possible implications for travel beyond Earth.

Brent Lewis, a professor of nuclear engineering at the Royal Military College of Canada, while reporting on a model of prediction for cosmic radiation exposure of commercial aircrew, said his crew of researchers developed an extensive data base of doses. Over the course of taking radiation measurements aboard dozens of flights, they collected over 20 000 ambient dose equivalent measurements, which he believes comprises the largest such data base in the world. From those measurements they developed a code to predict air crew exposure.

Lewis

*Radiation search tool*

Rick Seymour, president and founder of Nuclear Safeguards and Energy Systems, provided a progress report on the ongoing development of a briefcase-sized portable radiation search tool for the International Atomic Energy Agency (IAEA) Safeguards Group.

The device, as designed, uses neutron-sensitive scintillating glass-fiber sensors, which represent a new approach to conventional neutron detection. They provide several advantages over neutron-sensitive gas tubes for plutonium detection in portable applications. "The fibers are much less sensitive to microphonics, to vibration, so they're quite robust. They're very good in harsh environments and ideally suited for portable applications," Seymour said.

The requirements from the IAEA were very specific, he explained. The inspectors travel from country to country, and have to be able to carry the equipment in and out of the country. The device had to be robust and reliable. They wanted it to be modular so they could make changes in the field if something happened to go wrong. They wanted to have both neutron and gamma-ray detecting capabilities, but they did not want a spectroscopy-based system. "They simply wanted a gross counting system that had maximum sensitivity," he said.

*Continued*

The neutron-sensitive glass fiber that helped fulfill the IAEA requirements "is a real alternative for thermal neutron detection," Seymour said. "It is a solid-state detector for neutron detection. It allows you to do very large areas. It allows you to use very robust detectors in harsh environments. It is very well-suited for a portable radiation search tool."

NucSafe is scheduled to deliver the first units to the IAEA next month.

*Land mine detection*

Richard Craig, who specializes in detector physics at Pacific Northwest National Laboratory, gave a presentation on land mine detection using timed neutron methods.

There are thought to be 110 million mines in place around the world, Craig said. These are being removed at one-twentieth the rate the mines are being placed. Mine detection has been made more difficult in the last decade because fewer mines have metal in them anymore, foiling conventional methods of finding them.

Many recently made land mines are fabricated using organic material, which contain large amounts of hydrogen, Craig explained. The moderating property of hydrogen, greater than that of other nuclei, provides a mechanism for finding these otherwise difficult-to-detect mines.

"Commercial methods do not detect hydrogen. They'll detect metal," Craig said. "If you have a mine that has absolutely no metal . . . the detection rate is zero. You need some metal. Even the mines that contain some metal contain about the amount of a half of a pin. Take a pin, cut it in half: That's the amount of metal it has. . . . The theoretical results are that we would be much better than the commercial [detectors], even for metal mines."

The method that Craig described is based on timing the reflection of neutrons. On average, a neutron reflecting off of hydrogenous material deposits half its energy. When reflecting off other material, such as the soil, it loses much less energy.

In that method, if a neutron is emitted from the source and goes into the soil, it is reflected back quickly because it loses very little energy when hitting the soil. This principle forms the basis of how to detect nonmetal mines. "We only want to see the slow neutrons, the ones that have interacted with hydrogen. So, we don't count the ones that come back very quickly," Craig said. Only moderated neutrons that return to the detector after an appropriate time delay are counted. Neutrons returning too quickly are rejected.

The method by which the detector signals a positive indication of land mine is important, Craig said. "Typical metal detector devices or metal detector–based mine detectors use an audible signal. One of the things the Army has discovered is that the people who are doing this have heard a lot of explosions in their day, and they can't hear worth a darn. . . . So, we want to do something that's a little more simple to use."

Craig's prototype mine detector, whose structure was once a hardware store weed-whacker, detected mine simulants in the desert, he said. "We have an entirely new approach. We've demonstrated the physics of the approach. . . . Right now we're working on getting access to DOD minefields, where they've planted deactivated, but not inert, mines. So, we can demonstrate with the mines that have TNT and RDX [explosives] in them but no detonators. . . .

"We know that our results aren't as sensitive when the ground is saturated. We're not going to find mines in a swamp. At least not yet. But we will find them in dry sand. We will find them in slightly wet sand."

## Applications of Cf-252

The intense neutron-emitting and potential cancer-killing properties of californium-252 have been known and studied for decades. The radioisotope's promise as a cancer therapy was recognized by the Atomic Energy Commission in the 1960s, said Rodger Martin, of Oak Ridge National Laboratory, who, during the session "Medical and Industrial Applications of Cf-252–I," gave a presentation on Cf-252 brachytherapy.

The radiobiological advantages of neutrons for tumor cell killing, when compared to the conventional photon therapy sources such as iridium-192 and iodine-125 sources, are numerous. Neutrons have high relative biological effectiveness (RBE) values, Martin explained, which means that for the same dose rate, neutrons will kill significantly more cells. Also, the effectiveness of photon therapies is limited to oxygenated cells. Neutrons are effective on either oxygenated or oxygen-deficient, hypoxic, cells. In addition, neutrons are not as cell-cycle dependent as photons: A cell will die if hit with a neutron, regardless of the moment in the cell's life cycle.

*Several advantages*

There are several other practical advantages to using Cf-252 brachytherapy, in which synthetic radioactive seeds are deposited near or in the tumor, Martin explained. Treatment with neutrons shrinks bulky tumors much more quickly than does photon therapy. The dose is localized around the source, in order to spare the healthy tissue farther away. Conformal therapy with multiple sources, which shapes the dose field around the tumor region, can be performed. There is also the promise of combined neutron-photon therapy: Attacking a tumor first with the neutrons tends to break it up and reoxygenate it—which allows the following photon therapy to be more effective.

One interesting new possibility for cancer therapy is boron-enhanced Cf-252 brachytherapy. Martin said that some studies have indicated the potential usefulness of using the same boron pharmaceuticals developed for boron neutron capture therapy in combination with fast neutron therapy. "After these fast neutrons have thermalized and been made available for capture by boron, you can start getting some significant enhancement of boron, of total dose, at several centimeters from the californium source. . . . The advantage with this boron coupling is that you can use another variable to tailor the dose distribution around the tumor to reduce necrosis of the healthy tissue. But also, an additional capability [is] increasing the dose to neighboring metastases, which [present] a problem in long-term tumor control."

Martin concluded by saying that extension of Cf-252 brachytherapy to radioresistant tumors, such as brain cancer, will require both smaller sources and higher doses.

"Our existing source is the wire. . . . For the high-dose rate, we're trying to put more and more californium oxide into a metallic matrix. . . . Ultimately you run into material stability problems when you're trying to work with this material. It hardens. So, you're going to run into a tradeoff between how much material can you get in and how small can you make the wire."

*Developments in China*

China has made significant progress in conventional radiation therapy—including Cf-252 neutron therapy-—in the last two decades, said Sharwin Zeng, M.D., of Cafmed-China, who provided a background on Cf-252 neutron therapy in China.

Chinese radiation oncologists were interested in californium neutron therapy in the early 1980s, but Cf-252 sources for medical use were not available in China until 1992, when a joint venture was established between the China Institute of Atomic Energy and Russia's Institute for Nuclear Reactors. In 1995, 25 Cf-252 seeds were sent to China for preclinical investigation. Since then, Cf-252 neutron therapy in China has developed rapidly. It is estimated that within five years, one out of 10 radiation oncology centers with brachytherapy practices there will be equipped with Cf-252 units for intracavitary treatment. Nonetheless, that is, on average, only one unit for every 40 million people in China, Zeng said.

To address the problems of demand for californium neutron therapy in China, Zeng said, attention should be focused on doing basic work in radiophysics and radiobiology, including source calibration, clinical dosimetry, and quality control, and establishing training courses for radiation oncologists and physicists involved in californium neutron therapies.

*Cervical cancer treatment*

Anita Mahajan, M.D., a radiation oncologist at the New England Medical Center, in Boston, Mass., has been working with gynecologic cancers for the past several years. She described the potential for Cf-252 brachytherapy to treat cervical cancer and plans for a new clinical study of the procedure.

Approximately 12 800 cases of cervical cancer will be diagnosed in the U.S. this year (2000), and there will be 5000 deaths due to the disease, Mahajan said. When first diagnosed, 55 percent of the patients have localized disease, 31 percent have regional spread, and about 10 percent have distant disease spread.

"The local control of the bulky tumors is a major problem," Mahajan noted. Local con-

trol is obtained in 50 to 60 percent of the patients. About 70 percent of the patients who have local disease, however, relapse.

With conventional radiation treatment of the disease, a dose of 45 to 50 gray has generally been delivered to the large pelvic area, incorporating the primary site, as well as the lymph node drainage, Mahajan said. The treatment is typically given over five-week period.

In traditional brachytherapy techniques, low-dose rates have been delivered using cesium sources. "It's effective," Mahajan noted, "but it is somewhat cumbersome for the patient. They have to be admitted into the hospital. They're immobilized for 48 to 72 hours." The benefit is, though, because of the brachytherapy dosimetry, the surrounding tissues receive less dose. The low-dose rate brachytherapy doses are generally 20 to 40 Gy per application, given in combination with the external beam dose, for a total dose of about 80 to 90 Gy.

Over the last two decades, high-dose rate (HDR) therapy, using cobalt-60 and iridium-192, has been explored because of physical as well as practical issues, Mahajan explained. The advantages are that patients can be treated on an outpatient basis. Treatment is delivered usually in a half hour or less. There is rigid immobilization during the delivery of the radiation, which is not the case during low-dose rate brachytherapy. Subsequently the instruments are generally smaller and less cervical dilation is required, so it becomes a less invasive procedure.

The promise of HDR Cf-252 neutron brachytherapy for treating cervical cancer is based on several factors. For one, the higher RBE of neutrons is considered to be beneficial in treating slow-growing tumors.

Also, neutrons are not as dependent on oxygen as photons are to be effective. Oxygen is not diffused very far from capillaries, and so, in bulky tumors there is going to be a significant hypoxic area.

In addition, neutrons have a higher linear energy transfer. At the amount of damage deposited, neutrons would potentially cause a double-stranded break in cellular DNA, which would be more lethal to the target cell. The single-stranded break of a photon can be repaired. "It seems that there's going to be less sublethal damage repair going on with neutron irradiation, which is beneficial with tumor cells," Mahajan said.

The double-stranded DNA breaks are also less likely to cause cell mutation from radiation damage. "I'm led to believe that the double-stranded breaks that are occurring from the neutron irradiation are less likely to cause carcinogenic effects, because the cell will either die or survive," Mahajan said. "And once the cell is dead it cannot go through immunogenesis. Whereas in photon irradiation, with single-strand DNA damage, repairs can be done in an abnormal fashion and carcinogenesis is a high risk." She added that the procedure may be beneficial for pediatrics because of the possible decreases in carcinogenesis.

Several clinical trials testing the suitability of Cf-252 for cancer therapy have been conducted. One trial examined 82 patients treated between 1976 and 1979. They were treated one of three ways: external beam and cesium brachytherapy, external beam and californium brachytherapy, or californium brachytherapy then followed by external beam. The results show that in all cases, the Cf-252 given early in the course of disease achieved the best outcome. Overall survival was not very good, but much better than regular irradiation, Mahajan said. Another trial revealed the safety of escalating the dose in hypoxic situations.

For their clinical study, Mahajan and her group are planning on selecting patients with advanced cervical carcinoma, with bulky stage 2B, 3A, 3B, and 4 tumors. They will test standard external beam radiation, chemotherapy, and conventional brachytherapy, in which iridium will be replaced by HDR Cf-252.

"The use of the californium will have a radiobiological benefit, as theoretically suggested and which has been observed in the prior studies. The HDR brachytherapy will have a geometric benefit as well as a radiation safety benefit. And toxicity is going to be monitored closely because we're not quite sure what dose will be required. But dose escalation will be part of that protocol to optimize and characterize response," Mahajan said.

She said she does not expect the side effects of Cf-252 brachytherapy to be any different from those of photon therapy. "It's always a balance of side effects versus tumor control. And the situation where we are now, with conventional photon irradiation and photon brachytherapy, the control rates are suboptimal—as I suggested, there are . . . 70 percent relapse rates within the pelvis. And with that we still have about a 10 or 20 percent long-term side effect profile. . . . With the neutron brachytherapy I expect the same type of side effects. And we're going to be controlling our results, as far as toxicity, so that we're not going beyond what we expect in photon radiation. But the type of side effects should be the same."

## Space applications

The session "Space Nuclear Power II: The Future" covered near-term strategies to successfully develop and fly space fission power and propulsion systems. "Compared to other advanced systems," noted Mike Houts, of the Propulsion Research Center at NASA's Marshall Space Flight Center, "fission systems are really very simple: You put the right material in the right geometry and then turn it on. . . . To my knowledge there's no other energy system with that kind of energy density that's that conceptually simple to work."

Speakers noted throughout the afternoon that NASA (the National Aeronautics and Space Administration) has realized that conventional chemical systems are nearing their performance limits. The usefulness of solar power, which may perform well in some applications, degrades rapidly as the distance from the sun increases. Fission, however, appears to have tremendous performance potential and can allow for more robust spacecraft design. Conceivable near-term space applications for fission-based systems include power and propulsion for craft on the surface of Mars, as well as for ambitious outer planet missions and an exploratory mission to Jupiter's satellite Europa.

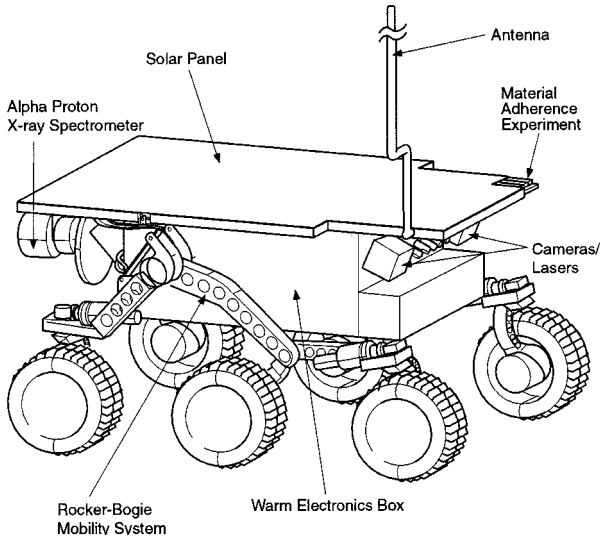
"We've demonstrated that these systems can be safe during development and operation," Houts said. They are "virtually nonradioactive at launch," and "even a large fission system would have an order of magnitude less onboard radioactivity than the little Sojourner rover on Mars," he said.

*Radioisotope systems*

Paul VanDamme, of the Jet Propulsion Laboratory, who spoke about the challenges of powering spacecraft and future space science missions using radioisotope systems, said that most missions use solar cells and batteries for power aboard a spacecraft. There are times, though, when it is impossible to use those resources, such as when a spacecraft is far away from the sun. Also, there are certain environments, like Jupiter's, that are extremely radiation-intense, and using solar cells is nearly impossible because of degradation concerns.

In a less obvious case, even if the spacecraft is going toward the sun or near the sun, solar power is still not necessarily easy to use, VanDamme said. If a mission requires launching the spacecraft into solar orbit, the craft may require a gravity assist from a Jupiter. "We [need] a spacecraft that has to work in two very different environments: one that's very cold and dark and radiation-intense, and then also [in one] very close to the sun. That becomes a very difficult technological challenge for power," he said.

One solution is to use a radioactive power system. Radioisotope thermoelectric generators (RTGs) can convert heat into electricity using thermoelectric converters. The heat is produced in modules that contain plutonium



Mars Pathfinder's Sojourner rover (NASA)

dioxide, a ceramic form of plutonium. There are typically 18 such modules in an RTG. The unit will produce, at first, about 280 We. Over time, as the plutonium decays and less heat is available, the power output decreases.

NASA is currently working with the Department of Energy to improve the design, VanDamme said. "Ideally, we would like a device that is smaller, has less mass. And most people involved would also like it to use less plutonium, for lots of different reasons—one of which is, of course, plutonium-238, which is the main ingredient here, is a limited resource and one not currently produced in the United States," he explained.

Radioisotopes can also produce thermal heat in space applications. Radioisotope heater units (RHUs) are small—about the size of a large marshmallow—and produce about 1 Wt of energy. The Sojourner rover on the Mars Pathfinder mission had three RHUs onboard to keep the electronics warm enough to survive the cold Martian nights. Without them the electronics would not have been able to operate for more than a day, VanDamme said.

He outlined space science missions that are in the planning stages. Between now and 2005, there are 22 space science missions being planned—none of which, however, require a radioisotope power system. Two of the missions—the recently announced rover missions to Mars—may require RHUs. For the 2006–12 time frame, five potential missions are being studied that may require radioisotope systems. Two other missions to Mars are planned for the 2007–13 time frame.

One interesting mission in the 2006–12 time frame, which is still in the conceptual phase, is the Europa Orbiter mission. NASA would send a craft to the Jupiter satellite, which is believed to be encrusted with an ice layer—underneath which is believed to be a liquid ocean. "We want to send a probe there, get it in orbit, get an idea of how thick the ice is [there] and all around the moon," VanDamme said. "Maybe find, ideally, a thin spot in the ice, which could be a potential landing site. . . . We [would] actually land on Europa, melt the ice, and get some kind of scientific instruments down into that liquid ocean, which would be an amazing feat."

There are, however, many technological challenges for the Europa mission, not the least of which is generating the 400 or 500 W of power that would be needed. "Spacecraft power is a challenge," VanDamme explained. "You're going around a satellite of Jupiter where there's a very harsh radiation environment. You're in the dark a lot of the time because you're [blocked] from the sun because of Jupiter or the satellite itself. And it takes a while to get there, so you need something that can live a long time. . . .

"Even though this is in advanced study, NASA is always faced with competing [projects]. We have scientists that say they want to do a lot of science, and science requires more power."

*Fission-based systems*

George Schmidt, deputy manager of the Propulsion Research Center, spoke about future nuclear space applications and the advantages that fission-based systems offer over chemical- or solar-based systems. "Ultimately, if we want to really realize the full potential of nuclear systems for space, we have to evolve to fission-based systems," he said. From a performance standpoint, there are many advantages to using fission, especially when looking at very ambitious deep space exploration, he noted.

The extent and sophistication of future robotic and human exploration is ultimately limited by propulsion and power technology. Chemical energy sources both for power and for propulsion are now near their theoretical limits. "The specific impulse that you can get with the best propellant combination . . . is about as good as the chemical technology is going to get," Schmidt said.

Natural energy sources, such as solar energy, are highly dependent on the location of spacecraft. Radioisotope sources, which have great advantages and work extremely well for some applications, are ultimately encumbered by low efficiencies and lower power densities. Other more speculative energy concepts, such as fusion or the beamed-energy concept, remain immature.

"When we really look at it in terms of all the different types of energy or resources that we have at our disposal, the one that clearly surfaces that has the most potential is nuclear fission," Schmidt said.

An appeal of nuclear fission is that there are multiple ways to utilize the energy source. One is to produce electrical power for very high performance electric thrusters, a concept that has been studied for decades. Much higher power densities would then be achievable, compared to those of a radioisotope or solar power system.

More important, Schmidt said, "some of the more advanced forms of nuclear thermal propulsion have an incredible evolutionary potential. They can really evolve to perform the missions that we have heretofore been assuming for fusion and some of these real advanced nuclear energy sources. We can do a lot of that with nuclear fission. So, it really has a lot of potential for the future."

The rationale for using fission systems is a function of the power that is needed for spacecraft applications and the duration of use. The chemical energy supplies, such as the auxiliary power units used on the space shuttle, are useful for high powers, but are going to be constrained to very short durations. Solar energy holds appeal for extended durations, but places limits on the amount of power because of the massiveness of the systems and the low efficiencies for conversion. Even within foreseeable technological improvements to that, there are still going to be constraints. And radioisotope sources are certainly going to be good for low-power applications.

"But when we start talking about high powers and long durations, that's when fission really comes into play," Schmidt explained.

"Also, and I think this is probably most important, if you look at solar flux as a function of distance from the sun, you see [on a graph] that [the slope] drops off very steeply," Schmidt explained. "And because of that, even though solar for electric propulsion and other forms of propulsion has a lot of appeal around earth orbit—possibly up to Mars—beyond that it doesn't really make sense, not only for the spacecraft power supply but also for the propulsion. It just does not provide the adequate power density."

There are three applications for nuclear fission on a spacecraft. The nearest-term application would be to provide electric power to support operations of a spacecraft in-flight or stationed on the surface of a planet. Such a system would consist of a nuclear energy source, some type of solid-core reactor delivering heat to a power conversion system, along with a waste-heat disposal system.

Another space application for nuclear fission is for electric propulsion. The setup would be similar to power provision, except most of the power taken out of the system would be delivered to a thruster. "That would allow us to [achieve] very high specific impulse propulsion that we could use for deep space missions," Schmidt noted.

Third, in a considerably different approach, nuclear energy could power thermal rockets. "Here we're utilizing direct heating of a working fluid or propellant, and expanding that propellant out in some form to produce thrust," Schmidt explained. "The appeal of the nuclear thermal rockets is it can deliver very high power densities. But you are going to have lower exhaust velocities and specific impulses than you would with electric propulsion. But for missions where you're really concerned about acceleration, where time is going to be a key concern, then nuclear thermal is the appropriate type of system to use."

The payoff of a fission-based nuclear electric power system becomes apparent in light of the different types of missions, Schmidt said. Looking at a piloted Mars mission, for instance, fission can provide a substantial reduction in the amount of propellant that is needed, which can greatly reduce the flight-time of the trip.

"Now, you're going to ultimately be constrained by your specific impulse and the various structural fractions in your vehicle," he said. "But, overall, you get a tremendous advantage over chemical-based systems."

Looking at other ambitious missions, such as a Neptune orbiter, there is still a tremendous performance advantage: a two- to ten-fold reduction in propellant when using nuclear electric propulsion.

"Finally, it becomes apparent, . . . [when] compared to chemical systems, nuclear fission now becomes an enabling technology—something that you really can't do with chemical-based systems. . . . From a straight performance [standpoint], fission is certainly superior, at least for most of the missions that we're considering."

The problem, however, is that the United States has conducted only one flight demonstration with a fission-based system. And technology without flight heritage, Schmidt pointed out, has little or no impact on space programs. The U.S. has conducted considerable research and development in this area,

but of all these efforts, only one reactor-powered craft has ever flown, the SNAP-10A in the mid-1960s. "Even though the U.S. has invested the resources and has developed the technology to a large degree, really, in terms of flight, we haven't really done that much."

If it hasn't flown, it doesn't count, he said. "Unless you have a fully mature technology that's flown, most of the time [NASA] won't consider it in the program. And I think that's what's critical about this."

The inactivity, however, is not for lack of safety. "When we start looking at all the different issues, these types of systems can be made almost absolutely safe—certainly as safe as other alternative types of approaches to power and propulsion," he said.

Current studies are centered around a three-phase program that will allow the space program to incrementally build capability toward realizing fission's potential.

Phase one is aimed at using existing facilities and technology, focusing on applications for near-term scientific exploration. With this approach, NASA researchers are looking at very small systems—300-kW energy sources using electrical resistance heating. Schmidt said most of the design issues can be worked out using nonnuclear elements, and that the nuclear material would be incorporated in the final stages of development. "What this does is it minimizes the amount of environmental concerns . . . and ultimately we're focusing on small applications that have a near-term benefit to scientific exploration," Schmidt said.

The phase-two studies are the more advanced operations using developed technology. This would be focused on technology that would relate to human exploration, and would involve technology work in nuclear thermal propulsion, advanced fuels, and also advanced nuclear electric systems. For that reason it would likely be more of a developmental challenge, but something that certainly could be done extremely safely and with no impact to the environment, Schmidt said.

And, finally, phase three is "where we realize the full potential of fission." This phase concentrates on extremely high-performance concepts for rapid interplanetary space flight, building on technology and infrastructure from phase one and two. "Here we're looking at gas-core reactors—also using gas-core rockets, perhaps. Various advanced forms of fission that could be used to realize . . . specific impulses in the range of 5000 to 10 000 seconds, even greater perhaps. But, with that kind of capability we're really talking about supporting very ambitious, possibly human, exploration of the solar system, and even beyond."—*Dick Kovan, Rick Michal, Patrick Sinco, and Gregg Taylor*

TOPICAL MEETING

# Licensing issues for advanced I&C technologies

A SESSION CHAIRED by Douglas Chapin at the Embedded Topical Meeting on Nuclear Plant Instrumentation, Control and Human-Machine Interface Technologies (NPIC & HMIT 2000), at the ANS/ENS International Meeting in Washington, D.C., looked at licensing issues for advanced I&C technologies.

Arndt

Steven Arndt, leader of the I&C team of the Nuclear Regulatory Commission's Office of Nuclear Regulatory Research, introduced the NRC's proposed five-year research plan for digital I&C technology. The purpose of the plan, now in draft form, is to provide a "road map for completion of current research and identification of new research needs," Arndt said.

Digital equipment issues currently under review by Arndt's team include environmental qualification, defense-in-depth and diversity, verification and validation, interfacing with plant equipment, real-time performance, commercial-grade dedication, and configuration management.

Common problems found during review of digital systems, Arndt continued, include software engineering (which is not yet a mature discipline), the lack of standardization, and the current inability to quantify software reliability.

The following four areas are among many targets of research for Arndt's team:

- *System aspects of digital technology,* which include "environmental stressors," Arndt said, such as electromagnetic interference/radio-frequency interference (EMI/RFI), temperature, humidity, smoke, and lighting.
- *Software quality assurance,* which entails the development of objective software engineering criteria.
- *Risk assessment of digital I&C systems,* using digital failure assessment methods applied by defense and aerospace industries to determine types of failures and their impacts on overall safety, which "can be useful in nuclear applications," Arndt said.
- *Emerging I&C technology and applications,* such as smart transmitters, that will offer information for providing compensating measures for instrument error or control functionality.

"Understanding and measuring reliability of systems is the most important issue," Arndt said. "If not the most important, then certainly the most challenging."

Implementation of the plan, which Arndt said might come in late December 2000 or soon after, would involve contractor assistance, cooperative programs at universities, participation in international programs, and continued NRC research.

Robert Uhrig, distinguished professor of the Department of Nuclear Engineering at the University of Tennessee, reviewed various types of intelligent systems. "In the past decade, artificial intelligence–based soft computing technologies, specifically neural networks, fuzzy logic systems, and genetic algorithms, have been investigated for application to nuclear power plants," he said. "However, actual use of systems incorporating such technologies, often called 'intelligent systems,' to nuclear power plants has been minimal."

*Continued*

### *Major points from the session:*

- *Digital I&C software engineering is not yet a mature discipline.*
- *Future I&C upgrades are to include advanced computer technology.*
- *I&C modernization is under way in Ukraine.*
- *Several types of analyses of I&C software by special tools are needed.*

Uhrig explained the characteristic behaviors of the three soft computing technologies: Neural network models, he said, are created by training the networks by using data from the system to be modeled; fuzzy systems are concerned with encoding *a priori* knowledge in the form of fuzzy rules rather than learning from rules; and genetic algorithms use a "survival-of-the-fittest" approach to optimization based on a process analogous to natural evolution.

Within the next decade, Uhrig said, I&C upgrades at nuclear plants should include fuzzy systems to control reactor power levels, optimization systems in the non-nuclear balance of plant, fuzzy logic systems embedded in plant safety systems, and self-adaptive systems using neural networks and/or genetic algorithms.

Jung Soo Koh, principal researcher for the Korea Institute of Nuclear Safety, presented a safety evaluation of the digital protection system at the Ulchin-5 and -6 nuclear plants in Korea. Construction of the plants was started in 1997, and the first commercial operation is scheduled for 2004 for Ulchin-5.

A review of the digital plant protection system (DPPS) and digital safety feature actuation system at Ulchin focused on safety classifications related to software quality control, defense-in-depth and diversity analysis, equipment qualification of electromagnetic environment, and independence of data communication.

During licensing of the Ulchin site's construction permit, several design changes occurred. "The major change was modification of the DPPS architecture," Koh said. "One processor each for the bistable processor [BP] and local coincidence processor [LCP] in the original design was changed to two processors for BP and four for LCP." This redundant architecture provided what Koh called effective features for improving tolerance of single failures while simplifying testing.

Mikhail Yastrebenetsky, head of the Safety-Significant Systems Division of the Ukraine Institute of Nuclear Safety, ticked off reasons why many of the older I&C systems in Ukrainian nuclear power plants need to be modernized: The systems have a low level of reliability, nonsatisfactory diagnostics of hardware and software, low-quality man-machine interfaces, discrepancies in seismic and other environmental requirements, low fire resistance, the useful lives of most types of instruments have been expired for as long as 10 years, and there is an absence of spare parts for many types of equipment.

The good news, Yastrebenetsky continued, is that "an I&C modernization program is under way in Ukraine, supported largely by the U.S. Department of Energy." The program was started in 1996 and led by Ukraine's State Scientific Technical Center on Nuclear and Radiation Safety. Various upgrades already have been implemented, including those to the computer information systems at the South Ukraine and Rovno plants; the safety parameter display systems at the Zaporozhye, Khmel'nitskiy, Rovno, South Ukraine, and Chernobyl plants; and the control rod system at South Ukraine.

Current assessments are now being done on various I&C systems at the plants, including the automatic power regulators at South Ukraine and Rovno, and reactor protection systems at Rovno and Khmel'nitskiy.

Arndt Lindner, of the Institute for Safety Technology (ISTec) in Germany, presented a paper on conducting assessments of various I&C systems at nuclear units, including the FRM-2, which is the high-flux research reactor in Munich, and on I&C systems at the Bohunice plants in Slovakia and the Paks plants in Hungary.

For the FRM-2, a 20-MWt light-water-cooled reactor, IStec performed the failure mode and effect analysis (FMEA) of the I&C system (hardware and software); conducted the reliability analysis based on the FMEA, including a sensitivity analysis for software failures; did an assessment of a vendor's factory acceptance test, including assessment of the test specifications; and verified an application software.

At Bohunice, which has four 408-MWe (net) pressurized water reactors, ISTec conducted assessments of backfits done at the units during the past few years, including the reactor protection systems.

At Paks, which has four PWRs of about 430-MWe (net) each, assessment work included vendor and utility factory acceptance tests, the Paks-specific concept for periodic testing, and verifying the reliability of the reactor protection systems.

In his paper (coauthored with D. Wach), Lindner observed, "In addition to the essential functional tests of the I&C system, several types of analyses are necessary to grant an acceptable minimum of residual software failures in the I&C software. The tool-based comparison of redundant software structures will also help to detect specification and design errors. Our experiences have shown that analyses like software analysis by special tools (e.g., RETRANS), FMEA, reliability analysis, etc., are extremely important."—*Rick Michal*

TOPICAL MEETING

# Current developments in best-estimate methods

THE EMBEDDED TOPICAL Meeting on "Best-Estimate" Methods in Nuclear Installation Safety Analysis (BE2000), held during the ANS/ENS International Meeting, provided a forum for the exchange of information on current developments in the area of best-estimate (BE) analysis methods.

The advancement of such methods in achieving reactor safety may be linked to a *Federal Register* entry from 1971, notably the Atomic Energy Commission's "Interim Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Power Reactors." That document, which was highlighted by the Nuclear Regulatory Commission's Jared Wermeil during BE2000's opening plenary, stated: "Ideally, one would have available analytical methods capable of detailed realistic predictions of all phenomena known or suspected to occur during a loss-of-coolant acci-

***Major points from the meeting:***

- *The NRC has just released a new draft Reg Guide with detailed guidance for developing best-estimate codes.*
- *An effort is needed for international harmonization and practical applicability of uncertainty methods.*
- *Although BE methods are complex, they provide a nuclear utility with a margin that otherwise would not be attainable.*

dent, supported in every aspect by definitive experiments directly applicable to the accident. In the absence of such perfection, adequate assurance of safety can be obtained from an appropriately conservative analysis based on available experimental information. In areas of incomplete knowledge, conservative assumptions or procedures must be applied. When further experimental information or improved techniques become available, the conservatisms presently imposed will be reevaluated and a more realistic approach will be taken."


Long

Robert Long, former ANS president, led off the opening plenary by announcing that session chairs and speakers from 19 countries were present at BE2000, along with representatives from eight universities from the United States and overseas. Participants from more than 40 national and international laboratories, research institutions, and industrial organizations also were on hand.

"A full spectrum" of BE elements were subjects of scheduled sessions, added Long, of Nuclear Stewardship, LLC, and honorary chair of BE2000. The sessions included licensing and regulatory requirements, methodologies, validation, applications, and simulators.

## A history of BE methods

Gary Wilson, technical program cochair of BE 2000 (along with S. Michael Modoro), followed with a BE-methods history lesson. Wilson, a consulting engineer with Bechtel BWXT, gave a presentation that highlighted the accomplishments of BE efforts done by U.S. researchers. He stressed, though, that "this should not be interpreted as non-recognition of the considerable and important work accomplished internationally."

Wilson noted that initial licensing procedures that govern analysis methods were formed in the United States in 1974. Those procedures established the primary "safety criteria," he said, for peak cladding temperature, cladding oxidation, hydrogen generation, coolable core geometry, and long-term cooling. These particular safety criteria remain unchanged today in the United States.


Wilson

In the 12 years that followed formulation of the original licensing requirements, an effort by U.S. and international researchers was conducted. The result was the development of a number of advanced computer codes for reactor safety, including RELAP, RETRAN, TRAC, and COBRA-TRAC.

Based on research results through 1986, the NRC initiated an effort to develop and demonstrate a licensing-acceptable BE method, Wilson continued. This method was successfully completed in 1989 and was supported by a revised rule for the acceptance of emergency core cooling system (ECCS) performance. In the years since the NRC implemented its rule, the international community has continued to develop alternate and refined approaches to BE analysis, Wilson concluded.

Review and approval of analytical computer codes that are used for licensing applications in U.S. nuclear plants are the responsibility of the NRC's Wermeil, chief of the reactor systems branch of the agency's Office of Nuclear Reactor Regulation. Wermeil announced that NRC staff has just released a new draft regulatory guide (DG-1096) that provides detailed guidance for use by industry in developing BE codes.

These codes offer "advantages," Wermeil said, in that they characterize accident scenarios with greater assurance; reduce unnecessary conservatism and constraints on operations, thereby reducing risk from narrow operating windows, such as reducing potential for operator error; and allow a better understanding of actual plant behavior and sensitivities of this behavior to various perturbations, thereby improving safety.

Giving an international perspective on BE methods was Horst Glaeser, of GRS Forschangesgelände, in Germany. He briefly noted BE methods that were used on the Angra-2 plant's licensing process in Brazil and on a plant's upgrade renewal license in the Netherlands.

Yet, he commented, while there exists a "great deal of communality of practices of safety analysis," details of BE methods may differ because the process to evaluate uncertainties in licensing procedures are not yet settled in most countries. He said, for example, that some countries prefer the results of BE calculations supplemented by an uncertainty statement of the code, rather than conservative evaluation model calculations. "An effort is needed," he said, "toward harmonization and practical applicability of uncertainty methods."

Robert Tsai, of the Nuclear Fuel Management department of Exelon Nuclear, commented that BE methods had the potential to improve fuel economics of nuclear plants. Impacts would come through improved "bundle design for energy extraction, for a longer and higher energy cycle," he said; through improved core loading patterns for energy extraction; and by increased operating flexibility through less restrictive technical specifications.

Further, Tsai added, incorporation of BE methods plant-wide would "support relaxing equipment performance requirements, increase plant availability, reduce maintenance, and reduce O&M costs." These increases would come from extended emergency diesel generator and ECCS injection valve stroke times and ECCS start times; relaxed requirements for instrument setpoints and system flows; reduced surveillance frequencies, person-rem exposures, and equipment specifications; and extended equipment life.

*Continued*

### A BE method overview

Wanting to "stir things up a bit" was L. E. Hochreiter, professor of nuclear and mechanical engineering at the Pennsylvania State University. Hochreiter's presentation was on whether the licensing procedure for BE methods makes life simpler or more complicated for nuclear utilities.

Hochreiter

Hochreiter opened with a brief review of BE methodology, which has the objective, he said, of modeling true physical phenomena as accurately as possible; modeling plant transients in a realistic manner; understanding the performance of ECCS; and determining realistic plant limits for specific accident scenarios.

The flip side, he added, are very complex computer codes and models that are difficult to understand; long running codes that are expensive to use; and high expectations.

Meanwhile, Hochreiter continued, the NRC developed the code scaling and uncertainty (CSAU) methodology. CSAU qualified and provided the licensing framework for BE codes; developed a phenomena identification ranking table (PIRT) to identify the most important models and to guide assessments; provided a method to access model/plant uncertainties by ranging; and provided a sample plant calculation.

This CSAU methodology "did provide a means or path for BE codes where no path had existed," Hochreiter said, and it raised "the difficult issues" that needed to be addressed, such as complete documentation, frozen code assessments, model/modeling consistent with BE, scaling, propagation of uncertainty period-to-period, and compensating errors.

But while CSAU did provide some simplification, the licensing process remains complex, Hochreiter affirmed. This is because, for CSAU, there are no specific models in the NRC's Appendix K; reviews require "a very knowledgeable reviewer," he said; reviews can be very reviewer dependent; complete documentation is required, at a level that is difficult and expensive; and there is a much wider range of assessments to address, such as model uncertainties, ranging, and scaling.

Hochreiter pointed to a Westinghouse review as an example of BE complications. Westinghouse started the licensing process for its COBRA-TRAC code in 1989. It compiled five volumes of code qualification documents, standing three feet high, and submitted them to the NRC. The NRC's detailed review of the documents took four years, during which time the agency asked more than 600 questions of Westinghouse. Responses to the questions from Westinghouse back to the NRC were contained in documentation piling six feet high. In the end, the original documentation was rewritten, and Westinghouse received final approval for COBRA-TRAC in 1996.

With all of this difficulty and all the time and effort spent, was Westinghouse's effort worth it? Yes, Hochreiter answered resoundingly. With approval of BE methodology, Westinghouse can offer plant upratings, improved fuel designs with higher peaking factors, improved fuel cycle designs to aid plant extensions, and relaxation of diesel start-time requirements—all of which provide economic benefit to Westinghouse's customers: utilities.

And so although BE methods are complex, Hochreiter concluded, use of them will gain a utility a margin that otherwise would not be attainable.—*Rick Michal*

TOPICAL MEETING

# Overview of accelerator applications

THE RAPIDLY GROWING ANS Accelerator Applications Technical Group traces its beginnings to 1996. Several people at Los Alamos National Laboratory were convinced that recent developments in high-intensity proton accelerators meant there were new applications for which there was not a forum to present technical results or to conduct technical interchange, explained Warren Funk, project services manager for the Spallation Neutron Source project office at the Thomas Jefferson National Accelerator Facility. In 1997, an ANS technical group for accelerator applications was formed, with 29 charter members. By last year, the group had ballooned to 267 members—a more than ninefold increase in three years.

Funk

The level of interest in the group was apparent in the plenary session for the embedded topical meeting, "Nuclear Applications of Acceleration Technology" (sponsored by the ANS Accelerator Applications Technical Group), for which participants were poised elbow-to-elbow in the meeting room.

*Congressional actions*

Peter Lyons, science policy advisor to Sen. Pete Domenici (R., N.M.)—perhaps the nuclear industry's strongest advocate on Capitol Hill—gave a presentation describing the congressional actions that affect high-power accelerator systems and the nuclear industry in general, and where the senator fits in to those actions. He expressed the frustrations attendant with a presidential administration that opposes many of these efforts to move the field forward. And he detailed some of Domenici's plans for accelerator production of tritium and advanced transmutation of waste, including the senator's proposal for a new accelerator facility.

Domenici chairs the Subcommittee on Energy and Water Development of the Senate Committee on Appropriations, which oversees funding for most Department of Energy

***Major points from the meeting:***

- *The neutron community in the United States has decreased to fewer than 1000 scientists, versus some 4000 in Europe.*
- *The Spallation Neutron Source being built could mark a change in reliance—for neutron scattering—from reactors to accelerators.*
- *A proposed high-current accelerator could be a backup to the DOE civilian reactor-based tritium program, and a means for ATW pilot studies.*

programs—including all accelerator programs. The senator is "very committed" to maintaining nuclear energy as a viable option for the future, Lyons said. Domenici, however, sees that the largest single issue related to the viability of the nuclear energy industry is a credible resolution of spent-fuel issues. "Senator Domenici is simply not convinced that the current open cycle is the best choice," Lyons said. "He is not convinced that Yucca Mountain, as envisioned, is ever going to open. He is not convinced that we know enough today to say that spent fuel should be equated with waste. He's not convinced that the public will accept wastes with extremely long-lived toxicities."

To remedy this, Domenici led legislation that would create a new office within the DOE on spent nuclear fuel research, with a specific focus on advanced reprocessing and transmutation technologies. He wanted to emphasize international cooperation, because he sees that many other nations have a great deal to contribute, Lyons said. This proposal was passed by large margins in both the House of Representatives and the Senate, but was vetoed by President Clinton. A subsequent veto override vote was successful in the House, to fail only by one vote in the Senate. "So, again, the administration, as they've done many times, succeeded in blocking any attempts to move more rapidly on dealing with spent fuel in the country," Lyons said.

The senator has been interested in the potential of transmutation and its impact on spent-fuel strategies, Lyons said. In the fiscal year 1999 budget, he set aside $4 million for study of waste transmutation, and last year, $9 million. "It's interesting to note that any funding that's been put in for ATW . . . has always been zeroed by the administration," Lyons said. "And, in general, certainly in my view, the administration has demonstrated repeatedly that they have no interest in doing anything to enhance the future prospects for nuclear energy."

Last year, Sen. Domenici wanted to explore what he saw as a number of opportunities for synergism between accelerator production of tritium and accelerator transmutation of waste, Lyons said—despite the DOE's having made a clear decision to produce tritium in light-water reactors.

The proliferation concerns with the Civilian Light-Water Reactor (CLWR) Program may or may not be as benign as many think. "I found it interesting, at a meeting in Europe just within the last few weeks, to hear very very serious concerns from a number of the nuclear energy leaders in Europe with the decision in the U.S. to make tritium in civilian reactors," Lyons explained. "They saw that as an extremely unfortunate coupling of military and civilian programs. I'm frankly a bit surprised—I think the senator has been surprised—that there has been less of an outcry here about that, frankly, than he anticipated. But, in any case, we're waiting to see how CLWR will progress."

*Accelerator facility*

Lyons closed with a description of Domenici's proposal for a new high-current accelerator facility. By providing tritium production, the facility could serve as a backup to the CLWR program. It could provide a location for pilot studies of accelerator transmutation of waste and a place to study many other issues related to the use of fast spectrum systems for transmutation studies, Lyons said. The facility could also include a national production capability for radioisotopes, and would have a strong nuclear engineering component.

There is, however, a catch.

"The senator has indicated that he would include, as another requirement . . . that whatever site that would like to take this accelerator also agree to take interim storage of spent fuel," Lyons explained. "In other words, there's a carrot—and something 'not a carrot.'

"There have been several sites that have come in to talk with us on this. And this might get very interesting over the next year. I see the AAA [Advanced Accelerator Applications] program as laying the groundwork for the types of decisions that might go into a future decision on whether such a complex might be a sensible thing for the country."

Los Alamos National Laboratory's Paul Lisowski discussed the status of the $600-million Accelerator Production of Tritium program, and provided an overview of the project's missions, what it has accomplished, and where it is heading.

The United Sates requires tritium for its nuclear weapons. Because it decays with a half-life of about 12 years, it has to be replaced relatively frequently. For well over a decade, the Department of Energy has tried to find a new source of tritium, Lisowski said.

He explained that in December 1995, the DOE decided on a dual-track plan to produce the isotope, and considered both commercial light-water reactors, which were the lowest capital cost option, and an accelerator system, which would have the lowest impact on the environment. In December 1998, the DOE opted for the commercial light-water reactor path as primary tritium production option, and decided that the accelerator path would serve as the backup. The DOE also allowed various engineering development and preliminary design of important elements for the accelerator system to be completed. "[That] was meant to allow us to move fast if it turned out that the Commercial Light-Water Reactor Program became derailed," Lisowski said.

In order to meet the demands of the project, Lisowski said, they would have to build what would be the world's highest-power proton linear accelerator. The machine they designed would accelerate protons to about 1000 MeV at 100 mA, for 103 MW of proton power. It was designed to begin with an injector, and have normal conducting accelerating structures pass through a superconducting accelerating structure. It would then deliver the beam to a tungsten target where neutrons are produced, moderated, and then captured in helium-3—the decay product of tritium.

"Helium has a very high capture cross section for thermal neutrons, therefore it very efficiently produces tritium and avoids the waste form that would result if you were producing tritium from a metal matrix, the way it is done in nuclear reactors," Lisowski explained.

Lisowski said the group was concerned about spallation neutron products and other materials that were made in the coolant and in helium. They conducted experiments to examine spallation products and all aspects of production of radioactive gases into tritium, and how they could separate the material out so it was not put it into the tritium processing facility.

"We were concerned about what might happen when the beam was turned off and the material heated up from natural radioactive decay," he explained. "And so we made a whole series of decay heat measurements to confirm . . . predictions. As you know, in reactor physics decay heat is an important safety aspect, and it was an important aspect for us to investigate so that that worked."

They constructed a prototype of a low-energy accelerator, which will eventually be completed to 8 MeV, and performed an integrated operations test. The project met its milestone, operating the low-energy demonstration accelerator to an energy of 6.7 MeV. The facility is the third most powerful operating proton accelerator in the world, Lisowski said.

Over the past five years they have completed about 30 percent of the preliminary design of the accelerator plant, and much of that information, Lisowski said, is going to be valuable to the AAA program in their design work for the Spallation Neutron Source.

"We went at this because we thought—I think a lot of people in this project thought—that we would be the people who supplied the tritium for the country, that this would be the technology that the administration would choose, and that national defense was on our shoulders—that maintaining the nuclear deterrent was our responsibility. And so we took this very seriously."

*Spallation Neutron Source*

There has not been a new neutron source in the United States built from scratch in 30 years, said David Moncton, executive director of the Spallation Neutron Source (SNS) project. Consequently, the neutron community in the United States has shrunk to less than 1000 scientists, compared to approximately 4000 in Europe. Moncton, whose enthusiasm for the project was contained only by professional reserve, provided an overview of the facility—currently the largest civilian science project in the country—which is expected to lead to a renaissance in the study of pulsed neutron beams for scientific research and industrial development in the United States.

"It's our hope that the SNS facility will reclaim for the United States the lead that was effectively yielded to Europe . . . in the 70s," Moncton said. "I've been impressed, in my little under two years of association with this project, how strongly [and] unanimously supported this project has been by the science community, and by the administration and the department."

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The technical facilities of the SNS—now prepared for the first concrete pourings—consist of what will be the world's most powerful proton linear accelerator when it is commissioned. The 2-MW linac will accelerate H-minus ions, which are produced in an ion source at one end of the site. As the ions enter the accumulator ring, they are passed through a foil, which strips off each ion's two electrons, converting it to a proton. The 1-GeV protons will have a pulse length of about a millisecond. They will be injected into the accumulator ring, and each pulse will wrap around the ring about 1000 times. They are then compressed from a millisecond to just under a microsecond: As the particles are injected into the target, the pulse length is 950 nanoseconds.

"[This is] very innovative technology that, in the beginning, going back five or so years ago, seemed quite bold and maybe even characterized as risky by many," Moncton said.

They plan to use liquid mercury as the spallation target, because of the heat loads and the thermal shock that are deposited by such an intense beam. All spallation sources that have previously been built use solid targets, Moncton said. It wasn't believed, however, that solid targets could be effective above about 1 MW in power. So the project took the initiative to develop a research and development (R&D) base for mercury targets. "And that's been very successful over the course of this four- or five-year period, both in the United States as well as in Europe and Japan," he said.

A number of active efforts to resolve a number of the critical R&D issues associated with the use of mercury have met success. "I don't think there's a person now who's familiar with this technology that doesn't believe that this is quite low risk, at this stage. So, this is a very exciting development, that we've moved from something which was considered five years ago to be quite risky to something that we believe now is very well in hand. And it bodes very well for the future of spallation sources, because I think mercury would certainly be the target of choice for future sources, going up to even higher powers," Moncton said.

Studies on magnetism have been uniquely the province of neutrons, he explained. Certainly some information can be gleaned from electrons by studying X rays and the weak coupling between X rays and the magnetic moment. But nothing elicits the kind of information on magnetism from matter like neutron diffraction, Moncton said.

"With a source as powerful as the SNS, it will be possible to go to much smaller samples and very exciting opportunities in the study of the structure of thin magnetic films, for example, [which] simply isn't possible with the weaker neutron sources that we have today," he said.

"We believe that neutrons are poised to make an even bigger contribution in the next 50 years. And that's why it's so important to have new neutron sources."

Synchrotron radiation is popular now in the structural biology community. People are following on the work of the human genome project with very active plans to determine rapidly the three-dimensional structures of as many proteins as possible. This enterprise, Moncton said, is now developing at exponential rates at the X-ray facilities in the country.

"But that has a finite end to it, and it doesn't lead directly to the understanding of how the molecules themselves function," Moncton said. "Molecular function is directly connected to molecular dynamics. And as we understand the three-dimensional structures of the proteins which underpin life, it's going to become increasingly important to understand their dynamics. This is where I think neutrons are going to play the next role." The interest of the biological community in neutrons is not nearly as high as it is in the X-ray field, but that may change in the next 5 to 10 years. Moncton said he would not be surprised to see the growth of the biology community in neutrons very strongly stimulated by the existence of the SNS.

One field that is recognizing the use of neutrons is engineering. Moncton said some interesting pilot experiments have been undertaken using neutron scattering to determine the strain distribution in engineering materials. "We're working with a group that's very interested in the development of an engineering instrument—an engineering diffractometer—that will have pretty impressive characteristics for analyzing strain and helping to optimize the development of various kinds of engineering materials. So, we look forward to this being a growing community as well with the new source."

If funding proceeds as scheduled, the project will be completed in early FY 2006. It will then require two years of operation to achieve a highly reliable, 2-MW performance.

There are two exciting aspects for the future of neutrons from the construction of this facility, Moncton said. "One is that there's a great deal of upside to the development of neutron scattering instruments based on spallation sources. We're at a relatively early stage in our understanding of how to make optimal use of pulsed sources. And so there's a tremendous learning curve in front of us. I think we're going to learn a lot about how to better optimize instruments. . . . And there will be many more types of instrument technologies that are invented for spallation sources over the next decade or two than for reactors, which are a very mature field.

"We hope that the SNS and the design that we have will be able to stay competitive with any facility that Europe or Japan will build over the next decade. Both communities are actively pursuing designs which they hope will exceed the SNS. But I think we have the basic technology here, and with the advancements possible—the superconducting technology—to be able to stay competitive with anything that might be built over the course of the next 10 or 20 years.

"And so if the SNS is as successful as we believe," Moncton concluded, "I think it's going to mark a turning point in the field of neutron scattering, from a reliance primarily on reactor sources, which has been the case for the last 50 years, to emphasis on accelerator-driven sources, which I think have a very exciting future."—*Patrick Sinco* NN