Nuclear energy: Optimism about the future

IN AN ATMOSPHERE of optimism about the future of nuclear energy—and at an attractive and scenic site in Hollywood, Fla.—the 2002 ANS Annual Meeting provided an opportunity for intellectual stimulation, insights into nuclear industry trends, fellowship, and career networking for participants. The meeting, *The Revival of the Nuclear Energy Option*, held June 9–13, was chaired by Art Stall, from Florida Power & Light.

In the opening plenary session, Stall said that nuclear power in the United States has been on hold since the Three Mile Island accident. Construction programs were halted and plans for additional plants shelved, he noted, and public opposition became fierce, as many state and local officials fought against the plants.

Stall

Overreaction or not, the industry had some real problems at the time, he noted. Unit capability factors were below 63 percent, forced outage rates in double-digit percentages, and refueling outages averaging well over 100 days. In addition, operating costs were out of control, spending was high, and production was low. "We were not," he reminded the audience, "demonstrating excellence in nuclear operation."

Today, he told the participants, U.S. nuclear plants have a 91 percent industry average capability factor—an increase of more than 25 percent just since 1990. Refueling outages are now planned in days and hours rather than months, as the industry average dropped from over 100 days in the 1980s to 37 days today. Safety performance is also excellent, he observed.

These improvements, he said, have not gone unnoticed. They have generated an increase in acceptance of nuclear energy "both on wall street and on main street," he declared. Stronger public confidence also gives rise to stronger political support, he added, without which the industry cannot move forward. While any new nuclear plant must be market driven, continued government support is essential, he stressed, in the form of leadership, effective policy, and an efficient, stable, and predictable regulatory approval process.

Major themes of the plenary:

- *Better operations have increased acceptance*
- *A positive environment is developing*
- *It is necessary to convince politicians*
- *Security concerns must be clearly addressed*
- *The government is "4-square" behind nuclear*

Events during her term as President of ANS were "tumultuous," noted Gail Marcus (who finished her term in June), adding that she has spent a lot of time considering the right response for the Society to make to developments. Besides September's terrorist attacks, Marcus's list of events includes President Bush's National Energy Policy and his decision on Yucca Mountain, the plans for early site permitting, the DOE's Nuclear Power 2010 plan, and Generation IV activities. Many positive statements have come from the White House and from Capitol Hill, backed up by good results from public opinion polls and even in the news media, where talk of a revival of nuclear power is common, she noted.

Marcus

"All of these," she said, "are coalescing into creating a positive environment for us," and added that this has implications for ANS. She particularly wanted to address the Society's outreach activities. This year, ANS members were invited to join Society board members in one of ANS's days on Capitol Hill soon after the President's recommendation of Yucca Mountain. She said the effort was quite effective and hopes this will continue. Another activity was an aggressive campaign of letter writing to Congressional members in support of the Yucca Mountain decision. This continued during the Annual Meeting. She also mentioned the ANS public information Web site, which was being rolled out at this meeting in a revamped and expanded form, at <www.aboutnuclear.com>.

Finally, Marcus said she was highly pleased by the support of members who made this the biggest summer meeting in recent years. The total attendance was about 1150.

To inform the meeting's theme, the keynote address was given by U.S. Rep. Joe Barton (R., Tex.), one of the primary political movers of the nuclear revival. Having long understood the merits of nuclear energy, he set a personal goal of getting Yucca Mountain approved before he leaves Washington. Congressman Barton is currently the chairman of the House Energy and Air

Quality Subcommittee and a member of the Republican Steering Committee.


Barton

Barton focused on some of the main issues relevant to a nuclear revival, such as ensuring a secure supply of energy. U.S. oil production, he said, peaked at 11 million barrels per day in 1970 and is now down to below 8 million, and may really be only about 6 million. "We used to have big political debates about moving back to being energy independent," he said. "Oil imports are now over 60 percent and it is not a big political fight any more because we cannot win it."

But oil imports may not always be available. With world oil production to peak soon, within a decade, he reflected, and with the developing world wanting the same lifestyle as the United States, there may be nowhere to go to import oil. "We have not at my level really acknowledged or even thought about what the politics are going to be when you cannot say 'import more,'" said Barton. "It is a major issue that is looming, but it will probably not hit the political front pages maybe for 10 years. But it is going to hit."

Barton also gave his thoughts about some other major issues:

■ *On Yucca Mountain:* The biggest issue bedeviling the U.S. nuclear industry has been the disposal of high-level waste. While there was a lot of scientific basis for deciding on Yucca Mountain, "I do not want to kid you folks, there was a lot of politics in that," he said. Nevertheless, he said he does not think that it is a partisan issue, and expressed his belief that enough Democrats want to resolve it now.

■ *On new construction:* "Hallelujah," he cried, "when that becomes an issue." He noted that several companies are already expressing an interest in building new plants on existing sites. It will become more of a political issue in the next three or four years, when there are inquiries about building on a greenfield site, he predicted.

■ *On an aging workforce:* The country is about to undergo a big boom in nuclear plant construction, and of the 750 people in the session room, a show of hands indicated that only 19 were born after 1970. "We have got to do something to redress this," he said.

■ *On security:* Barton warned that society is already a little uncertain about just how safe nuclear power is, and a terrorist attack, emotionally and psychologically, could be devastating. While he shares this concern to a limited degree, he expressed his belief that terrorist groups go up against soft targets, not a difficult one like a nuclear facility.

While there are technical ways of dealing with these issues, the real problems are political, Barton stressed. For this, he said, it is necessary to get out and convince politicians. He called the audience the real "environmentally correct" people with the right message. But, he said, "you do not act like it." He told the audience members that they have a great story to tell but that it is no use only telling it at the meeting. His challenge was for them to get involved in their local area. The American people are basically where you want them to be, Barton said. Opinion polls show a real willingness to accept nuclear power now, he said, but democracy works only when you make it work.

Nuclear power, Diaz said, is not being portrayed in a balanced manner, particularly when the issues of risk and consequences are discussed.

Security takes NRC time

From the regulatory perspective, said NRC Commissioner Nils Diaz, many good things have happened over the last few years. He said that since the events of September 11, however, the Commission has spent most of its time on security, because it is important to allay and mitigate policy-makers' and the public's fears. This cannot be delayed, he added, as it could be a serious obstacle to the revival of the nuclear option. It must be addressed in a clear and transparent manner, he declared: "We must speak out loudly about what [the real risks] are, what we are doing about it, and what needs to be done about it," he said.


Diaz

Security at these plants is and will continue to be strengthened, Diaz noted. But he emphasized that there also has to be a strengthening of the response of government to make it even more difficult for any attack to succeed or any consequences to be felt, and to make sure that Americans feel they are properly protected.

Nuclear power, Diaz said, is not being portrayed in a balanced manner, particularly when the issues of risk and consequences are discussed, be it in Congress, state chambers, or public meetings, or especially in the media. "This is probably the fault of all of us," he said. "We do not address the issue of consequences very well." The industry prefers to talk about probabilities, he said, and right now, the issue of probability is secondary to the issue of consequences. But consequences, he observed, are the best thing that the nuclear regulators and industry has going for them. Even considering catastrophic releases at Chernobyl, nuclear consequences can compare favorably to other society risks, Diaz said.

He explained that while Chernobyl was costly in many ways, the consequences were and are still being distorted in terms of health effects. Leukemia, which was expected to be among the early primary latent health effects, based on the Japanese A-bomb survivor records, has not been detected, he noted. The 2000 UNSCEAR report said that apart from thyroid cancers, there was no evidence of a major public health impact attributable to radiation exposure 14 years after the Chernobyl accident. The incidents of thyroid cancer in children (about 1800) are particularly terrible because they were avoidable, Diaz observed. The failure was mainly that of the Soviet Union's inability to do what was needed to mitigate the consequences of the accident, particularly the latent effects.

As another example, Diaz explained, the doomsday scenario of a terrorist crashing a plane into a plant or spent fuel casks does not take into account very realistic analysis of the consequences of such an act. Nor does it consider the decisive and powerful resources that the country can put into play to prevent and mitigate any act against U.S. facilities.

Bill Magwood, the Department of Energy's director of the Office of Nuclear Energy, Science and Technology, said that the government is "four square" behind the idea that nuclear power will play a part in the future of the United States. "This is the first time that I have been able to say that since I have been in this position," he commented, "and I feel pretty good about it, and you should as well."


Magwood

The National Energy Policy says in very clear terms that the expansion of nuclear energy in the United States is something to strive for. "The opportunity is here," Magwood emphasized, "the paradigm has shifted . . . the window is open." It is now up to the industry to take the next

steps, he added, and that said, DOE will be working with industry to help make sure that building new nuclear plants is a decision that it can make very soon. For example, DOE is completing early site permit scoping studies and is looking for a COL demonstration project by 2004, which Magwood admitted is aggressive. The DOE and industry will be getting together soon to look at the possibility. The DOE is also working on a new nuclear business case study with industry and the financial community, looking at the economic barriers to nuclear power. In no case does anyone see a technical, environmental, or regulatory barrier to building a nuclear plant, said Magwood. The only serious problem, he noted, is making a business case.


Paul

The next speaker was Jerry Paul (R., District 71), a reactor engineer elected a Florida House Representative in 2000. Paul said he believes that there has probably not been a more important time for the industry to play a critical role in public policy since the Manhattan Project. Since September 11, he said, Americans have been exposed to the question: Is nuclear power part of the solution or part of the problem? He stressed to audience members that if they do not answer that question clearly, somebody else will.

Politicians are ready to hear the industry's message, Paul said. Those in the nuclear industry hold the key to unlocking the tremendous potential of nuclear energy to all Americans, but it should not be done defensively, he emphasized: In politics, there is no place for defense. The question is who has the better offense. That is what nuclear professionals must do better, he continued, and the message must be that this "beautiful" science can solve many energy and environmental problems. Policy-makers are intrigued by nuclear science, he explained; they should be indulged and helped to understand so they can make the case themselves. Paul urged those in the audience to show that this solution will help avoid an energy crisis like the one that occurred in California, help maintain low prices, and keep down greenhouse emissions. It also limits dependence on other countries, increasing America's security, he added.

This does not mean giving only the good news, Paul declared. Openly recognizing the legitimacy of those who have honest concerns is necessary, and, in fact, he suggested, those issues should be raised by those in the industry themselves. That helps build credibility and defuses the arguments against nuclear, he noted: "Hold the liabilities up to the light and make them assets."

Joe Colvin, president and chief executive officer of the Nuclear Energy Institute, was more optimistic than ever. "Every time you think things could not get much better," he said, "they do." He even called the theme of this meeting as being too modest. There is a growing recognition that nuclear is not just an option, it is an imperative, Colvin declared.

He emphasized that the industry's outstanding record has underpinned the renaissance. It is largely the focus on safety that has driven improved performance, Colvin said. Time and again the safest plants are also the most efficient plants. Statistically, he noted, it is safer to work in a nuclear power plant than in an office.


Colvin

The achievements have led to a change in public attitudes about the contribution of nuclear energy, Colvin noted. There is a growing appreciation that the country cannot simultaneously sustain the economic standards and do so in an environmentally friendly way without a substantial expansion of the nuclear capability. "About

60 000 MWe of new nuclear capacity, supplemented by an increase in electricity from renewables, will be needed [over the next 20 years] just to maintain the current level of 30 percent of U.S. power from emission-free sources," Colvin explained, which is about three nuclear stations a year. Echoing Magwood, he said that the problem is to make the business case.

The nuclear renaissance, Colvin said, has not happened by accident. It was the product of the dedication of a number of remarkable people who guided the industry. And to honor one of them, Colvin presented the Henry DeWolf Smyth Nuclear Statesman Award to Zack T. Pate, outgoing chairman of the World Association of Nuclear Operators and chairman emeritus of the Institute of Nuclear Power Operations.

To Zack Pate (see *NN* Interview, p. 25), excellence is a culture that he has helped to foster, said Colvin, and that today pervades the industry where safety and reliability are paramount. Pate led INPO for 14 years and in 1997 was elected chairman of WANO. A graduate of the United States Naval Academy, Pate commanded three nuclear submarines and served on the staff of Adm. Hyman G. Rickover at Naval Reactors headquarters in Washington, D.C. On the way, he picked up a Ph.D. in nuclear engineering from the Massachusetts Institute of Technology.


Pate

Pate said he accepted the award on behalf of the many people with whom he worked over many years, particularly at INPO and WANO, adding that he is especially proud of the way the entire industry shares and cooperates on matters of safety and reliability.

The award, established jointly by ANS and NEI some 30 years ago, has honored many of those most instrumental in developing the industry. Smyth, a chairman of the Physics Department at Princeton University, played an important role in the development of atomic energy beginning in the 1940s. He also served on the Atomic Energy Commission and was the U.S. representative to the IAEA.

Making plants ready for market

What will it take to bring a new power reactor on line in the United States? The question was asked during the ANS Annual Meeting/International Congress on Advanced Nuclear Power Plants (ICAPP) joint plenary, "Market-Ready Nuclear Power Plants." Steven Hucik, general manager of nuclear plant projects for GE Nuclear Energy, offered a detailed response. A new plant, according to Hucik, will have to meet an owner's financial objectives and needs, contribute to earning accretion, present no undue risks, have competitive capital costs, be licensed, have a proven technology and operating track record, and be backed by an experienced project and supply team.

For a utility to follow through with a new plant, Hucik continued, corporate earnings would have to be maintained during plant construction, cash flow and equity issuance would need to be managed, and the investment in the plant's construction would have to be recovered quickly. At its most basic, Hucik said, the project would have to be carefully controlled to avoid threats to budget and schedule.


Hucik

From the regulatory side, what the industry requires for a market-ready plant is "a well-defined, stable, predictable licensing process" all the way through the combined operating license (COL) stage, Hucik stressed. The licensing process "also must be resistant to challenges," he said. "I think this is one of the key concerns that the utilities have, [that] some legal or non-nuclear challenge could come and disrupt the licensing." Hucik noted that while the Nuclear Regulatory Commission's 10 CFR Part 52 had come a long way, "it is not completely tested yet."

Concern about intervenors

Echoing Hucik's concerns was Michael Sellman, president and chief executive officer of Nuclear Management Company. Sellman said that it isn't just the construction schedule that needs to be worried about, "it's the intervenors." A sympathetic judge, he said, "could slow you down by a year or two, and price [construction of the plant] right out of the market. So that's going to be a critical issue."

The uncertainty of construction time could go a long way toward scaring off "buyers," Sellman warned. Besides intervenors delaying construction, there also is "potential for regulatory holds, and . . . U.S. electricity demand is down."


Sellman

A bar graph displayed by Sellman showed a large increase in the peak use of electricity in the United States during the 1996–1999 period. However, a projection through 2005 that he displayed called for a slump in peak demand because of the economic downturn. "In addition, there's been a lot of building [of power plants] going on the last couple of years, all natural gas," he said. Add up the expected slump and the existence of the new gas plants, "and the result is that for the next several years, there probably is not going to be a lot of construction started on any kind of plant," he said.

Whenever a new nuclear plant is built, it probably would not have a positive cash flow until the sixth year of operation, which is "what the investment community is looking at," Sellman said. "They're going to be asked to invest hundreds of millions of dollars . . . and get a rate of return in year six, if all goes well." He then added bluntly, "That's a hard sell to make."

Sellman did offer reasons why the industry should build new nuclear: It can help arrest global warming, eliminate U.S. dependence on foreign oil, eliminate long-lived radioisotopes by spent fuel reprocessing, and ward off the impending world shortage of potable water.

Spending to refurbish

Thomas Christopher, president and CEO of Framatome ANP, observed that any construction work in the industry in the near term would come from rehabbing the existing fleet of plants, not building new ones.

The industry will see a "new renaissance," Christopher said, but it will come in the form of existing plants receiving life extensions and through cost decreases in O&M and fuel spending in the coming years.


Christopher

The rehabbing of existing plants "is going to drive up the capital spending market dramatically," he said. "Two years ago if you would have asked me, I would have said the average nuclear unit in the United States spends about $5 million a year in terms of outside purchases. I wouldn't be surprised if that number, two years from now, is $30 million a year as the units rebuild."

A unit today embarking on a full-scale rebuilding program could be expected to spend more than $250 million in the next four years, Christopher said. The cost breakdown: $20 million on system replacements, $130 million on component replacements, $30 million for adding new systems, $40 million on equipment refurbishment, $25 million on system modifications, and $5 million for material condition upgrades.

Christopher agreed that construction of new nuclear plants in the United States would come, "not in the near term," but rather "in five to 10 years."

Future world statistics

Jim Fici, senior vice president of nuclear plant projects for Westinghouse Electric Company, presented an economic model of

the world in 2042, "because that represents the 100th anniversary of nuclear fission." In 2042, according to estimates presented by Fici, there will be a population of 9 billion people on earth, the acceptable standard of living will be about one-half ($15 750 GDP per capita in constant dollars) of what exists today in the United States, and conservation and energy efficiency will cut worldwide electricity use per unit of economic output in half to 0.2 kWh. This, according to Fici, will mean a need for more than double the current world electricity production of 12.5 trillion kWh.

The DOE will fund 50 percent of the cost for each utility's Early Site Permit (ESP) application submitted to the NRC.

Fici noted that worldwide population growth would mean an increase, specifically for the United States, in "new nuclear generation capacity equivalent to about fifty 1000-MWe plants," referencing the Nuclear Energy Institute's Vision 2020 plan.

Fici

The challenge, then, is "pure economics," Fici observed. But before new nuclear comes on line, existing plants could become better producers. Fici noted that the 10 top performing nuclear plants in the United States were approaching 1 cent per kWh (three-year average for O&M and fuel). If all 103 operating units in the United States were brought up to the performance (in terms of capacity factor) of the top 10 plants, about $50 billion of economic value would be created. If the operating lives of those plants were extended by 20 years, another $21 billion would be added. Increasing each unit's power output by 5 percent would add $10 billion in value. "The point is," said Fici, "there's over $80 billion of economic value that can be created from the existing fleet of reactors in the U.S. That's a very, very compelling economic story."

Fici said the industry and nation should take comfort in the performance of the existing fleet. U.S. nuclear plants generated more than 767 billion kWh in 2001, he said, offering the country both "energy diversity and energy security."

Looking ahead, what the industry needs for building new plants are cost-effective designs with low overnight capital costs that could be built in a short period of time "so that they can be an attractive alternative to combined-cycle plants using natural gas," he said. The stability of fuel prices for nuclear power is very predictable and very sound, and it's an "assurance against gas price volatility, going forward," he said.

Fici repeated words uttered by earlier speakers: "We also have to have manageable risk—financial risk that's manageable, and regulatory risk that's manageable."

Fici concluded that there is a need for a national energy policy that "levels the playing field and gives nuclear power its just due. In the United States today, there are studies that have been done that show the existing fleet of reactors literally underwrites fossil plants in the U.S. by tens of billions of dollars per year to meet Clean Air standards. We get no credit for that, and we should."

Nuclear Power 2010

The DOE's Tom Miller offered comments about the agency's Nuclear Power 2010 program, which is intended to facilitate the construction of new nuclear power plants in the United States by the end of the decade.

Miller noted that the DOE will support Dominion Energy, Entergy, and Exelon in evaluating and obtaining approval from the NRC for future nuclear plant sites as part of a new public-private initiative. The DOE will fund 50 percent of the cost for each utility's Early Site Permit (ESP) application submitted to the NRC. Over the next four years, the DOE expects to spend $17 million on the program.

Approval of an ESP is the first step in the NRC's new streamlined licensing process, which enables companies to evaluate prospective plant sites before committing financially to construction. The ESP is good for 20 years and can be renewed for an additional 20 years.

Officials from Dominion Energy, Entergy, and Exelon have said the companies expect to submit ESP applications by fall 2003, with NRC approval expected by 2005.

Miller noted that the DOE's monetary participation in the ESP program is separate from the $38.5 million the Bush administration is proposing for research and development in fiscal year 2003 as part of Nuclear Power 2010.

Generation IV roadmap

The long-term vision for nuclear power was discussed during the President's Session, "Advanced Reactor Programs—Generation IV Roadmap." Gail Marcus, then ANS president, gave a quick history of the development of nuclear power plants, from Generation I reactors (such as Shippingport in the United States and Magnox in the United Kingdom), to Generation II (current-day units), Generation III (advanced light-water reactors), Generation III+, and on through the hoped-for Generation IV reactors of 2030 and beyond. Marcus is principal deputy director of the Department of Energy's Office of Nuclear Energy, Science and Technology.

In order for Gen IV reactors to be deployed by 2030, Marcus said, the aim is to develop "something that looks not just at the reactor, but also at the fuel cycle; and not just at electricity, but at other products as well," she said. Those other products could include hydrogen production, process heat, and desalination.

Researchers from around the world are planning to work together to develop Gen IV reactors that would have "significant improvements in sustainability, safety, and economics" over present-day reactors, Marcus said. The Gen IV reactors also would be marketed internationally, to include "small countries and developing countries with not much infrastructure to handle nuclear" plants, she explained.

A "roadmap" was created by experts from the international community to identify the research and development needs for developing the Gen IV reactors. Researchers from 10 countries—United States, Argentina, Brazil, Canada, France, Japan, South Africa, South Korea, Switzerland, and the United Kingdom—collaborated in 2000 on developing the roadmap. Six reactor designs were selected for further development: a supercritical-water-cooled reactor, a very-high-temperature gas-cooled reactor, a sodium-cooled fast-spectrum reactor with advanced recycle technology, a lead/bismuth-cooled fast-spectrum reactor with cartridge core, a gas-cooled fast-spectrum reactor, and a molten salt reactor.

Marcus observed that it is unlikely that all countries would work on all reactor designs. Rather, each country would select certain designs and work with partnering countries. "But we don't know yet which countries will prefer which [designs]," she said.

Most likely to succeed

Ralph Bennett, director of nuclear energy at Idaho National Engineering and Environmental Laboratory, ranked the reactor designs in order, from nearest-term potential to longest-term potential.

Bennett

Ranked first is the very-high-temperature gas-cooled reactor, "which will be

developed in the earlie[st] time period," Bennett said. "This one strives for temperatures above what are being talked about in the . . . pebble-bed reactors today," he said. "Let's build on technology developed for that and reap some benefits by getting into hydrogen production in a reasonable time period."

Following, in sequence from nearest to longest term, are the sodium-cooled fast-spectrum reactor ("The focus here is not on reactor development, it's on fuel cycle development, which still has feasibility and performance issues to deal with," Bennett said); supercritical-water-cooled reactor ("several decades out"); gas-cooled fast-spectrum reactor; lead/bismuth-cooled fast-spectrum reactor ("a fairly small reactor"); and the molten salt reactor ("25 to 30 years out").

Bennett said the roadmap is expected to be completed by this October. It then will be reviewed by NERAC.

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Fuel cycle

Neal Todreas, professor at the Massachusetts Institute of Technology and cochair of a NERAC subcommittee, opened his remarks by stating, "My whole message is fuel cycle." Gen IV reactor designs, he said, should focus on "fuel cycle opportunities, and then fit reactor concepts within those fuel cycle directives."

Three fuel cycles were briefly discussed by Todreas: once-through, once-cycled, and full actinide recycle. "The problem," he said, "is with the spent fuel" and what to do with it. By 2050, with a fleet of reactors made up of once-through fuel cycles, the United States is "going to need a large number of Yucca Mountain equivalents," because Yucca Mountain is constrained by the "heat load, not the mass of fuel assemblies" that could be implanted there, he said.

Constraints continue with the other two fuel cycles, he added, namely through the cost of reprocessing the spent fuel.

The challenge, then, is to develop a Gen IV design that is "fuel cycle–based, drawing reactor-based elements into it that are needed to achieve and solve certain fuel-cycle programs," he said.

Todreas listed four R&D priorities toward development of a "fuel cycle–based" reactor. The first one is ore resources. "Let's go after and secure means to finding and exploiting additional ore resources," he said. "The more we secure of that, the more we defer our need for large new systems to handle the constraint on ore resource and fuel [reprocessing]."

The second priority is to "focus on waste management in the repository," Todreas said, "which means let's first get the highest energy from the ore, but without the cost of reprocessing."

Third is high-burnup fuel development, "but only if we could figure out a way around the decay heat constraint," he said. "We'd like to go to high conversion . . . systems."

Fourth is "through high thermal efficiency reactors, but reactors that can achieve low capital costs," he said.

To move the nuclear power industry into the future, the industry must "move from the past," Todreas advised. The Gen IV vision, "while it's very good long term, is 20 to 30 years out," he said. "We need a present. The bridge to the future has got to be on firm pilings . . . which in my mind [is the] light-water approach. If we can move to a thermal gas deployment early—by 2010—we might be able to [have] the pilings on which we could build the bridge to [Gen IV reactors]."

A foreign perspective

Providing foreign perspective on future reactor plans were Bertrand Barre, of France, and Kazuaki Matsui, of Japan. Barre, vice president of R&D for Cogema, noted that the European Union (EU) currently imports about half of all the energy for electricity it uses, and that figure "may peak to 70 percent by 2030 unless something is done."

Barre

Nuclear power is the EU's number one power source, providing 35 percent of the production (coal is second at 31 percent), Barre said. Yet, he explained, governments in some EU member states are against it, notably Austria, Belgium, and Germany. "In Germany," he added, "you are not allowed to say you work on nuclear energy. You must say you work on nuclear safety."

The debate over the technology, however, has been rekindled by the Green Book of the European Commission, which, Barre said, underlines the strategic risks linked to the worsening of the energy dependence upon foreign imports, and the inability of Europe to meet its Kyoto commitments without nuclear power.

Thus, France, the United Kingdom, and Switzerland became active in the Gen IV roadmap process, and, according to Barre, those countries will follow through with R&D activities.

Barre noted that gas-cooled high-temperature reactors "offer the prospect to open new segments for nuclear power: process heat, low-carbon fuels for transportation, and, later, hydrogen production by thermochemical water splitting."

Barre also commented that "at some point in the future, we shall need and rediscover" fast breeder reactors.

Matsui, director of the R&D division for Japan's Institute of Applied Energy, has worked since January 2000 on the Gen IV roadmap effort. Japan this year shut down its last coal mine, "so we have no more practical use of coal," he said. Thus, with limited natural resources, Japan has an aggressive plan for building new nuclear plants, Matsui noted.

Matsui

Japan's IVNET (Innovative and Viable Nuclear Energy Technology) program is the Japanese version of the DOE's NERI (Nuclear Energy Research Initiative). The IVNET program last year provided more than $12 million for 18 "themes" (reactor concepts), and two years ago, more than $7 million for 10 themes. In 2002, according to Matsui, more than $19 million is being provided for "16+" themes and for about five feasibility studies.

The themes must follow strict development directions. The designs must be economical, be socially acceptable with regard to safety and environmental impact, have sustainability, offer nonproliferation, and be flexible in application to nonpower uses.

Some of the next-generation candidates, Matsui said, include a 300-MWe "resource renewable" boiling water reactor with a low-moderation core and hybrid safety system (possible commercial operation by 2030); a 600-MWe supercritical-pressure water-cooled reactor, with a closed compact system, adaptability of thermal power generation technologies, high efficiency, compatibility with a fast reactor core, and resemblance to a light-water reactor (2020); and a 50-MWe "super-safe" simple reactor, having a small, sodium-cooled fast reactor with inherent safety (date of commercial operation not yet determined).

Safety issues and the PBMR

Tony Baratta, professor of nuclear engineering at Penn State University, was asked to put together the session on "Safety Issues Associated with the Pebble Bed Modular Reactor (PBMR) Design" because of a growing interest in this system, particularly after Exelon requested that the Nuclear Reg-

ulatory Commission undertake a pre-application review of the pebble bed design developed by South Africa's Eskom company. While Exelon has dropped out of the Eskom project and has withdrawn its application, work carried out developing the licensing approach for this system will be of use to other advanced reactor applications. In fact, in the session, speakers covered licensing issues for advanced reactors in general, including Westinghouse's AP600.

Kadak

Andy Kadak, professor of the practice, nuclear engineering, at the Massachusetts Institute of Technology and a past president of ANS, outlined some of the problems in licensing advanced reactors, using the pebble bed as an example. Because existing regulations and the current licensing process are largely water reactor–based, he explained, several questions arise for gas reactors. For example, what happens if a system does not have an ECCS? Or if the fuel does not melt, when the regulations expect it to? Can we take advantage of all the innovation in the pebble bed concept when the technology is not water? How can a regulator license a reactor if he does not have a good understanding of the technology?

Kadak also pointed to what he called a basic weakness in the current DOE Generation IV Roadmap project: the development of only an R&D strategy and not a deployment strategy, which would require a licensing approach. He said that a critical element for success—getting a Gen IV reactor built—is missing.

A risk-informed approach

He said, however, that the NRC's move toward utilizing a risk-informed approach in regulating reactors will benefit advanced designs. At the minimum, this provides an exemption strategy—if the regulator can be convinced that there is little risk in a design, a requirement can be set aside. More difficult is a feature like "containment," which is important but different in gas-cooled systems and in water reactors, said Kadak. Containment, however, is a major element in the defense-in-depth (DID) concept, and a regulator is unlikely to set different criteria. Kadak said that another approach that would satisfy DID is possible.

To further demonstrate the problem, Kadak looked at the AP600. Despite its innovations, he said, the AP600 is still a water reactor "where there are no surprises." Nevertheless, Kadak declared, it took 10 years and cost half a billion dollars and all Westinghouse has is a certificate suitable for hanging. What would it take for a non-water reactor, Kadak wondered—double that time? "We do not want this for gas reactors," he stressed.

To develop a new approach, Kadak suggested starting with the fundamental safety objective of "do no harm," and working backwards—for example, establish a design basis of safety goals and risk, which involves a combination of probabilistic and deterministic thinking. A probabilistic risk assessment can be used to identify the key components, system, and structures that are important to safety, he explained. Next are the performance of detailed design, establishment of analytical tools, and definition of verification and validation processes.

Kadak proposed building a modular pebble bed demonstration facility on a research license. If possible, he said, it should be built to full size (250 MWt), but certainly with the balance of plant to be able to test the effect it may have on the primary system. This is particularly important for a direct cycle system, he added.

Kadak calculated that the whole program would cost about $2000/kW installed and be spread over six to seven years.

The demonstration plant would be used to confirm the computer codes and overall plant responses. It is hoped, said Kadak, that any remaining regulatory questions could be answered and the design modified as required. He favors including a full water reactor–type containment (with the hope of proving it unnecessary). Ultimately, in place of a lot of paper, he said, there will be a certified plant, demonstrating real performance and resolving real safety issues.

"I call this license by test," said Kadak. And because it has a research element to it, there would be "informed antinuclear community involvement" and the regulator would be engaged from the beginning, adding to its knowledge. The research permit could later be converted to an operating license or kept as a platform for future R&D work.

Kadak calculated that the whole program would cost about $2000/kW installed and be spread over six to seven years, so it should be possible to complete by 2010. He said that as a research demonstration project, the effort could get private funding, not just from utilities but also from the technology development companies, such as turbine manufacturers. His real intent, however, is that the project be constructed as a DOE facility with NRC oversight.

Exelon's perspective

The next two speakers were Kevin Borton, Exelon's primary contact with the NRC on the PBMR licensing effort, and the NRC's N. Prasad Kadambi, who spoke on the regulator's experience. As both explained, the level of agreement between applicant and regulator grew as each side increasingly understood the concerns of the other.

The hope of seeing a PBMR built in the United States within a few years received a setback recently when Exelon decided to drop out of the Eskom project and withdrew its application for a prelicensing review. The decision, explained Borton, was made on business grounds as the company decided not to become a reactor vendor. The company is applying for an early site permit and would consider the PBMR for the site, said Borton.

Since Exelon had wanted to bring a plant to market before 2010, instead of applying first for design certification, the company preferred to apply directly for a site/reactor design combined license. It believed the design would satisfy current regulations, arguing that the pebble bed is an evolutionary design, not a new concept. To proceed, said Borton, Exelon proposed an approach that took advantage of the work to develop licensing basis acceptance criteria for a modular HTGR in the early 1980s. To this, it added contemporary Probabilistic Risk Assessment (PRA) tools to help establish the PBMR design basis.

Exelon's licensing approach involves several elements. Most important, said Borton, it utilizes NRC's Top Level Regulatory Criteria: "They are already out there. We are not making them up. It is what the NRC uses today."

The approach also involves developing PBMR licensing basis events. He noted that a primary safety goal is to avoid the need for any offsite protective action beyond the site boundary. Borton explained that the design includes inherent features that made this very feasible, but also noted that some features, such as the use of helium as the heat transfer medium, and scenarios, such as air ingress into the primary circuit, are not covered in current regulations. A third element is to develop specific regulatory design criteria. This requires understanding how safety-related systems and components mitigate or prevent consequences of design-basis events.

Exelon looked at existing regulations and guidance criteria and found about 80 per-

cent of the regulations applicable, with little room for exemptions. The main difference is in the guidance material, he explained. "We found about 50 percent applicable and about 35 percent only applicable to light-water reactors, dealing with features such as ultimate heat sink for emergency core cooling systems and fire protection."

Exelon proposed a risk-informed approach for license amendments suitable for gas-cooled reactors. Its submission, said Borton, is consistent with the defense-in-depth philosophy and provides a good balance between prevention and mitigation. He noted, however, that there are a lot of preventive features, such as the layered fuel particles, the small slender core, and the use of passive means to remove heat so fuel will never melt.

Borton said that the NRC found its approach reasonable and also recognized the need to interpret certain regulatory terminology, such as loss-of-coolant accidents and containment, specifically for gas-cooled reactors.

The regulatory view

Kadambi explained that in conducting the preliminary assessment of the PBMR, the NRC staff did not try to build a whole new regulatory framework, particularly as Exelon proposed it be licensed on the basis of existing safety regulations. It did, however, take into account all the previous work that had been done by staff, including the licensing of the Fort St. Vrain HTGR and the modular HTGR developed by General Atomics. It also incorporated recent "directions, decisions, and policy statements" and other guidance released by the Commission to build a foundation for conducting a licensing review. This effort, he said, was "a first stab" at bringing it all together.

The most recent direction from the Commission is its Strategic Plan, which includes four performance goals: maintain safety; increase public confidence; increase effectiveness, efficiency, and realism; and decrease unnecessary regulatory burden. Also, the NRC has provided direction on its defense-in-depth philosophy and the White Paper on risk-informed and performance-based regulation.

To maintain safety, the statement says, the level of protection should be the same as for current light-water reactors. This provides at least a qualitative benchmark for conducting the regulatory review. Kadambi expanded this, noting that the Advanced Reactor Policy Statement adds that increased safety margins are expected, through simplification and the inclusion of inherently safe and passive features and other innovations. He said he would expect that the margins would be much more predictable and the range of variability narrower.

To maintain safety, the statement says, the level of protection should be the same as for current light-water reactors.

The second performance goal, to increase public confidence, means that the interaction with the applicant should begin early and the staff should provide timely and independent assessment of the technical material submitted. NRC should also provide opportunity for comment from all stakeholders.

For reducing unnecessary burden, Kadambi mentioned that if a performance-based approach is found to be appropriate, then the regulatory burden could be mitigated as the licensee can be given flexibility to achieve specified safety objectives as long as the safety objectives are gained.

The bottom line, he said, is that the approach that Exelon was proposing could work if it were properly implemented and took everything into account. There remain, however, many challenges to achieve this, he added.

Good enough is good enough

In describing some of the lessons he learned, Jim Winters, who managed the Westinghouse AP600 licensing effort, warned that engineers, both those of the applicant and regulator, often tried to "run away" with issues "to make it better." He said, however, that this is one time when "Good enough is good enough."

Winters added that although the AP600 is a water reactor, it differs significantly from existing reactors and the thought processes of both the applicant and regulator had to change. In particular, the AP600 does not have any pumps to go into operation after an accident, and, he said, engineers have been known to say, "It sure would be better if we had just one pump!" "We had to restrain ourselves from going down that path because then it would not be the AP600 any more," Winters said.

Another lesson related to the good work of the regulator. In particular, Winters endorsed the NRC's focus on quality and commitment to safety. At the end of the day, he said, that is what the AP600 application was judged on—the quality of the submittals, the quality of the design, and the fact that it is safe. He added that these are strictly his own personal opinions, not necessarily those of Westinghouse.

A lesson both sides had to learn was the importance of understanding fundamentals, because many of the disagreements were really about the fringes of safety, Winters said. Once both began to focus on the safety fundamentals, the problem usually went away.

Despite being a water reactor, the AP600 did not fit the requirements very well because existing criteria are basically for active systems, he explained. Furthermore, the NRC certification process was well established and both the Advanced Boiling Water Reactor and System 80+ had been successfully through it. The arrival of an application involving passive systems—without pumps or fans—was very novel. "The regulator was uncomfortable and we were uncomfortable on how to present it," Winters said.

When starting, he said, the AP600 team thought that if it could manage the paper and the process, it would all come together. He explained that the paper only defined the starting point; the process was then to manage the issues: "Do you need a containment spray? Well, there are arguments for and against. Do you need a pump for post shutdown cool down? For a passive plant, we claim you don't; others say you do. How big does the containment have to be to suck up all that energy in a LOCA?" The paperwork explained the issues and put them into context, but resolving them has to be managed, he said. "And if our engineer was not talking to the regulating engineer, we did not get very far. We really had to have those two individuals understand what each was driving at."

Related to this was the need to have a particular individual responsible at either end to drive the process to conclusion. "The process will stall if both sides are not keeping it going," Winters observed. He mentioned the adage: "If there is not one person responsible, there is no one responsible."

Another requirement is to have the same tick-off list. The whole process took about six years (he refuted Andy Kadak's estimate of 10 years), but for the first three years, the two sides did not have the same list and "we were in trouble." Once there was a common list of what the real questions were and whether or not we answered it, it became a lot easier to attack the issues and manage them, Winters explained.

When approaching the end, he said, more discipline was required. It had to be remembered that the goal is not necessarily the search for truth, or even of making it better. The license is based on criteria that must be met in order to be sure that the plant is safe.

Reactor vessel corrosion

Some anger was evident among audience members during the question-and-answer period that followed the "Reactor Vessel Head" session. At issue was the discovery in February of severe vessel head corrosion at the Davis-Besse nuclear power plant. Audience members questioned why the plant's management—FirstEnergy Nuclear Operating Company (FENOC)—never investigated warning signs, such as the daily replacing of clogged ventilation filters, that would have led to earlier discovery of the corrosion. No one from FENOC was available at the session to answer that question.

Davis-Besse, in Oak Harbor, Ohio, is an 873-MWe (net) Babcock & Wilcox pressurized water reactor that started commercial operation in July 1978.

Because the Davis-Besse corrosion had gone undetected for perhaps two years, according to reports from the Nuclear Regulatory Commission, a 7-in.-long × 5-in.-wide cavity caused by leaking boric acid had been carved deep (about 6 in.) into the head, leaving only a thin layer of stainless steel to contain coolant in the reactor vessel. The incident, said one audience member, had left the industry with a black eye, one that it could ill afford.

One panelist, the NRC's Brian Sheron, noted that NRC Chairman Richard Meserve had called Davis-Besse's severe corrosion the industry's "most significant event" since the Three Mile Island accident. In that regard, discovery of the corrosion "was a wake-up call, for the NRC and the industry," said Sheron, associate director for project licensing and technical analysis in the NRC's Office of Nuclear Reactor Regulation. "I don't think the NRC or this industry could tolerate another plant coming in with a Davis-Besse type of situation."

Sheron explained that the NRC first started checking into boric acid corrosion on pressure boundary surfaces in 1988, when a Generic Letter was sent out asking PWR plant operators to inspect and monitor for the presence of boric acid on reactor vessel externals. Later, in August 2001, after some control rod drive mechanism (CRDM) nozzles were found cracked and leaking at the Oconee-3 plant in South Carolina, the NRC issued a bulletin requesting PWR plant operators to inspect their nozzles. It was while Davis-Besse workers were performing visual inspection of nozzles, in compliance with the NRC's bulletin, that the severe head corrosion was found last February.

Sheron

The NRC then in March issued another bulletin requiring PWR plant operators to submit results of vessel head inspections and to describe boric acid corrosion prevention programs. Results of those inspections were "pretty encouraging," Sheron said. The results showed that no other PWR in the United States was in the same category as Davis-Besse regarding head corrosion.

But Sheron admitted he had "questions about the lower vessel penetrations" for PWRs at large. (Lower vessel penetrations are for instrumentation to monitor fuel behavior, etc., and are smaller than CRDM penetrations, according to the NRC's John Zwolinski.) Sheron wondered how often the industry inspected the lower vessel, and whether these penetrations would be susceptible to boric acid corrosion. From a risk standpoint, he said, a hole from corrosion in the lower vessel would be much worse than one located in the head. Sheron explained that although removal of a 4-in. nozzle off the head would produce a small loss-of-coolant accident, analysis had shown that the plant would shut down safely and the core would not melt. In contrast, a 2-in. hole in the bottom of the vessel "would melt the core," he said.

Sheron explained that the NRC first started checking into boric acid corrosion on pressure boundary surfaces in 1988.

The problem is that a small hole in the lower vessel would not depressurize the reactor enough to get the accumulators and low-pressure pumps to kick into operation, Sheron said. The result would be a "slow drain down" of coolant from the core. The hole would remain covered by coolant (until after the core was uncovered), so that there would be no steam discharge.

Although the lower vessel has a lower temperature than the reactor head and is less susceptible to cracking, "you can't rule it out," Sheron said. And while risk of a hole's developing in a lower vessel is small, the consequences of such an event are "much higher," he said.

The NRC is now asking PWR plant operators what plans are in place to check for corrosion of lower vessel penetrations.

As for the Davis-Besse incident, the NRC and FENOC concluded that the vessel head degradation found at the plant was caused by primary water stress corrosion cracking, and that susceptible material was present, namely Alloy 600 in the nozzles and Alloy 82/182 in J-groove welds. The fact that Davis-Besse operates at the highest vessel head temperature in the industry, more than 600 °F, according to Sheron, added to the plant's higher-risk operating environment.

With the NRC's approval, Davis-Besse has plans to replace the head with an unused one from the canceled Midland plant in Michigan. Davis-Besse also has cut out the degraded area from the original vessel head and sent it for study to Framatome.

Davis-Besse's root cause evaluation of the incident, Sheron said, determined that it was hard to put a finger on exactly when the sequence of events started that eventually led to the corrosion. "They think the actual [nozzle] cracking may have started as far back as 1994," he said. "When the corrosion started may have been somewhere around 1998 to 2000. But there's really no hard evidence to point to when the corrosion started and why."

A challenge now for the NRC, Sheron admitted, is determining for PWRs how much corrosion is acceptable before a vessel head would have to be replaced or repaired. "We don't know yet," he said. "That's still an open question."

An update on a materials reliability program (MRP) for vessel head degradation was presented by Larry Mathews, chairman of EPRI's MRP Alloy 600 Issue Task Group. Mathews, of Southern Nuclear, provided details on the results of vessel head inspections that were submitted to the NRC by PWR operators following the Davis-Besse incident.

Of the 31 CRDM leaks identified, there was no evidence of significant corrosion or wastage on the top of the head adjacent to the leaking nozzles, Mathews said. Also, no evidence of significant wastage adjacent to through-wall defects (i.e., in the head annulus) "has been observed during nozzle repairs at plants that were repaired with the temper-bead weld method," he said.

Mathews added that the industry has developed an inspection plan—which predicts probability of leakage based on industry experience and through use of a Probablistic Fracture Mechanics model—that would provide "adequate protection against nozzle ejection." He concluded that investigations are under way to improve estimates of corrosion development to "ensure ample opportunity to discover leakage before significant wastage," such as what happened at Davis-Besse, occurs.

Early site permits

Several U.S. utilities have embarked on the early site permit (ESP) process with the NRC to bank a few sites for future nuclear plants. These all have operating reactors, which should avoid many of the problems

associated with greenfield sites. The speakers at the Early Site Permit session panel were familiar with greenfield issues, having been involved in the original environmental studies of current operating plants. Licensing times then were lengthy and driven by seismologic and geologic issues. An aim of the present ESP program is to shorten the time significantly.

The ESP process involves various environmental disciplines, such as meteorology, geology, ecology, and seismology, whose aims are to support the conclusion that a reactor can be constructed and operated without undue risk. In this case, an ESP should provide a plant parameter envelope encompassing everything that might be put on a site with no specific design in mind.

Jim McWhorter, of Schnabel Engineering Associates, focused on seismic, geologic, and geotechnical issues. Earthquakes are a major driver of plant design at the early stage of the process, he said, and as much information as possible about the geologic structure and seismic history is needed. A good database is essential.

The ESP process involves various environmental disciplines, such as meteorology, geology, ecology, and seismology.

McWhorter noted that an optimistic schedule for a geoscience program would be 13–15 months, starting after the initial planning stages. This would include literature surveys of the region right on through field work. The preparation of a field data collection plan is important for preparing geologic and seismologic source maps, he said, and the program will also involve such activities as preparing a geotechnical lab testing program, a drilling program, site seismic analysis, and other analytical studies.

Some of the challenges that will be faced in the future are very similar to the ones faced 20 years ago, McWhorter observed. There are still geologic structures in the eastern United States that are difficult to pin down as to their age and relationship to large earthquakes. He noted that in April this year, there was a moderately large earthquake in Plattsburg, N.Y., that was not associated with a known geologic structure. This, he said, creates uncertainty in seismic hazard analysis for this region. On the other hand, he pointed out, in mid-continent, such as Oklahoma, it is difficult to pin down the age of the last major movement. The long return periods between events adds substantial uncertainty in seismic analysis.

McWhorter noted, however, that good progress is being made. Geologists and seismologists are getting to the point where they can model the relationship between earthquakes and local structure and its impact on a design. They are helped in the present situation in assessing existing nuclear sites where a good database exists, he said. Nevertheless, given the difficulties in this science, utilities need to put a good team together to move forward, he added. It is also vital to establish good relations with the regulators.

Meteorology and climatology

George Howroyd, of CH2M Hill, is involved in the ESP process at Exelon's Clinton site, in Illinois. The requirements that apply to his specialty—meteorology and climatology—are set forth in NRC Regulatory Guides and NUREG technical reports issued years ago. As there is yet no precedence for the ESP process, he said, applicants expect to rely on NRC staff guidance, as well as guidance from the Nuclear Energy Institute (NEI).

Meteorological and climatic information will be required in all aspects of an ESP process, said Howroyd, notably for the Site Safety Analysis Report (plant design basis, environmental evaluations, and dispersion of routine and accident releases), the environmental report, and emergency planning (for hazardous chemicals, as well as radiation).

Howroyd noted that the information required includes the climatology of the region (e.g., air flow patterns, temperature, precipitation, severe weather) and the local meteorological conditions (e.g., snow and ice loading, wind speeds, frequency of severe conditions) to assess its potential impact on a facility and the impact the facility may have on the meteorology (construction of buildings, removal of trees, creation of a lake, etc). Information from other sources (weather stations and industrial plants) will be collected, he added, and a complete topographical description prepared of the area to a distance of 50 miles.

In addition, he said, an onsite meteorological measurement system will be set up that will continue to function during plant operation to collect data needed for characterizing atmospheric dispersion. All this information will be used to make short- and long-term diffusion estimates in the event of an accident. The NRC will review the models used and the relevance and applicability of data.

Another point Howroyd made is that there is a need for many more experts for these activities, mentioning in particular equipment siting, equipment specification and accuracy, calibration oversight, data reduction and analysis, and end-use data formatting.

The environmental side

Jim Oliver, with Tetra Tech NUS, is a certified fishery biologist whose experience goes back more than 30 years when, working at the U.S. Fish and Wildlife Service, he was concerned with heated effluent released from nuclear power plants, starting with Oconee. In 1984 he moved to the other side, joining NUS, where he has been involved in preparing environmental impact statements and looking at different ecological issues. Tetra Tech is heavily involved in license renewals, and found that many environmental issues are just as pertinent today as they were 30 years ago. Oliver explained that the Environmental Report (ER) provides a guide to the ESP process.

Oliver put a useful perspective on the licensing process as it evolved from the National Environmental Policy Act (signed into law by President Richard Nixon in 1970). He explained that despite what many people think, NEPA is not a protection statute. It provides for an analysis of environmental impacts relative to their significance. It does not require the project to be stopped on environmental grounds, and although it is likely to lead to "appropriate" mitigating actions, it does not require the applicant to look at every single option or to take all measures suggested.

In addition, NEPA provides an opportunity for the concerned public to know what is planned. It is important to note, said Oliver, that this also provides an opportunity for industry to get the public on its side. Through NEPA public meetings, industry can explain what it is doing and get the public's buy-in, by making them stakeholders involved in the process. While interveners will be looking to stop projects, he believes that the industry can gain credibility against the interveners at these meetings. For Oliver, that is what it is about.

Oliver described an ESP as being similar to the ER, which requires an environmental assessment of the project. This will include, for example, examining how the environment interfaces with site preparation, construction, and operation, undertaking environmental monitoring programs, and looking at alternative energy sources and sites.

The areas covered by an ER include ecology (aquatic, critical habitat, threatened or endangered species), geology/soils, hydrology, meteorology, demographics (including environmental justice), land use, cultural and archaeological resources, traffic/transportation, and others.

Oliver gave a number of examples of what has been learned from this work. For

example, on threatened and endangered (T&E) species, he noted that it will not look good if the cooling system chosen wipes them out.

Demographics and land use provide interesting insights of how things have changed. As an example, he mentioned environmental justice (EJ) which relates to any disproportionate impact on a minority population, such as siting all dirty landfills in a "minority" community or making all trucks drive through it so as not to bother an affluent community. EJ has to be assessed in a 50-mile radius around the plant.

The license extension work has often revealed large changes, observed Oliver. Some areas around nuclear plants have developed large retirement communities. Even more changes could occur for a new plant built on a greenfield site, which could see boom growth that the local infrastructure could not handle.

To do these investigations, there are many information sources out there, including state and federal agencies, university and research institutes, studies funded by the applicant, internet resources, and GIS mapping. After the terrorist attack last September, said Oliver, a lot of useful Web sites were shut down, showing how much the Internet is relied on.

Regarding studies funded by the applicant, noted Oliver, interveners will accuse them of bias. One way to counteract this is to get them independently peer reviewed. This heads off other questions, he said, and gives credibility with public and the NRC.

Oliver said that he learned a lot of lessons about handling documentation—for example, to coordinate the development of the various application documents early to ensure electronic compatibility, thereby making the NRC's job much easier. Also, he said, he learned that it is useful to coordinate analyses to save time and money and to ensure that conclusions of different application documents are not at odds, and to maintain a backup of support documentation. Remember, too, he warned, that litigation lawyers are out there. "They are going to look at everything we do to stop it, to divert it, or, if they are on our side, to push it forward."

Update on plant security

Through the marvels of good design and good regulation, nuclear power plants are already robust and secure facilities, as one speaker in the session "Nuclear Power Plant Security" pointed out. The events of September 11, however, have cast renewed attention on plant security. Instead of being designed primarily to protect against vandalism, disgruntled employees, civil disturbances, and small groups of adversaries, plant sites now have to be prepared for a new enemy whose skills and methods have not yet been necessarily revealed, and whose threat potential is beyond that described in any plant security plan. The session was held to present an update on the ongoing efforts to defend against these new threats.

"We didn't just wake up on September 11 and say, 'Oops, we've got to worry about security,'" said John McGaha, president of Entergy Nuclear South. "We have been worrying about security and doing things on security for a long time. For better than half of my nuclear career, I've been somehow or another involved with making improvements in the security program.

"Yes, September 11 is forcing us—and rightly so—to take another hard look at making some additional improvements."

All plants already have in place a robust containment dome, noted Don Mothena, manager of plant services for Florida Power & Light. It consists of 3–4 feet of concrete, several inches of steel, and air space followed by more concrete and steel. "We're not going to have people coming through that willy-nilly," Mothena said. "It's going to have to be something that's very bad—acts of war, enemies of the state."

Having reliable personnel is also among the protective measures. Mothena noted that the plant seeks to hire and maintain trustworthy people through the use of background checks, substance abuse and psychological screening, and a continuous behavior observation program. "Quite frankly, that's one of the strengths of this industry. You can't have people coming in and working for days, weeks, months at a time, working long hours, under the challenge of nuclear power plant operation, and not be sensitive to what their behavior is and whether they're acting in a manner consistent with what you expect," Mothena said.

Through the marvels of good design and good regulation, nuclear power plants are already robust and secure facilities.

On average, plants have 80 security personnel per site, two-thirds of whom have previous military, law enforcement, or security experience, Mothena said. They typically receive 270 hours of initial training, and go through 90 hours per year in requalification, and 30 hours per year in antiterrorist tactical exercises.

Since September 11, plants have increased patrols of sensitive plant site areas and increased the safe standoff distance from vital equipment. Plants have also improved communication with offsite organizations, Mothena said. "We know that the number of security guards at a nuclear power plant is a finite number. Our job is to provide sufficient delay, so we can get local law enforcement support to aid us. This is not meant to be a long-term battle. It's meant to be something where you recognize that you have a problem, you yell quickly, you yell loud, and you get additional resources to help you perform the important task of protecting the power plant."

Mothena called for the federal government to develop an integrated response for the country's energy infrastructure, and to improve intelligence. "We are sensitive and important because of our quantities of radioactive material. We are also extremely hardened. But there are a lot of things that can be very devastating to society and community if you lose electricity for long periods of time.

"We need to improve communications and intelligence. In a perfect world, protection should be done in an intelligence arena instead of at the power plant fence."

"Safest place to be"

Upon notification by the Nuclear Regulatory Commission last September 11, all nuclear power plants in the United States immediately increased security to Level 3, which is the highest level, noted John McGaha. Today, all commercial reactors in the country remain at Level 3. "With that, I would say that maybe the nuclear industry is the only industry, or the only critical assets in the country, that is still at the current highest level of readiness."

As a result of the initial notification and the few dozen or so advisories that the NRC issued between September 11 and this past February, there were a number of compensatory actions taken to shore up security at nuclear plants, McGaha said. They included measures such as controlled area checkpoints, increased overtime and increased staffing, additional armed responders, additional patrols, and National Guard support. The industry is now engaged in interim compensatory measures to address waterborne threats, increased threats from vehicles, land assault threats, and additional actions to mitigate the consequences of a terrorist attack.

"I always tell our folks that if you hear rumors that there's going to be a terrorist attack, let me know, because I'm going to head out to a nuclear plant, which is probably the safest place to be," McGaha said.

In terms of post–September 11 improvements, he called for congressional representatives to be well educated on the current capabilities of the nuclear industry. The threat of a terrorist attack should not be used as an excuse by nuclear power opponents to come up with legislative approaches to derail the nuclear power industry, he added.

McGaha also said that the industry needs to work with the NRC and the Office of Homeland Security to institute whatever additional measures are needed to improve meaningful interactions regarding security at all levels of federal, state, and local governments. "The fact is, the industry cannot do it alone. The NRC can't do it alone. Homeland defense cannot do it alone. The federal, state, and local governments can't do it alone. We all have to work together."

The expense of the new security measures, however, still needs to be reconciled. Entergy Nuclear South has spent more than $6 million this year in response to September 11, and Entergy's northern plants have spent even more, McGaha said. The spending will keep increasing if a clearly defined boundary is not established between the threat the industry should be routinely protecting against and the threats posed by an enemy of the state, McGaha said. "We cannot . . . turn nuclear plants into paramilitary organizations, with antiaircraft guns and tanks," McGaha cautioned. "We cannot turn nuclear plants into that. If we do, not only will the costs be exorbitant, but, in my opinion, if we had to go to those measures then we'd have to look for alternative sources of energy . . . and there aren't a whole lot of other sources of energy out there."

McGaha said the industry has been working on improving nuclear plant security for a long time, and will continue to do so.

McGaha said the industry has been working on improving nuclear plant security for a long time, and will continue to do so. The industry will maintain the necessary vigilance to protect its plants. "My hope is that our hardened facilities will cause potential terrorists to target other facilities. I'm not wishing anything bad on another facility . . . but it's my understanding that a terrorist wants to go after an easy target, where they can make a statement, cause death, and grab the limelight," McGaha concluded. "The last thing they desire is to fail in creating terror. So, it should be our goal to ensure that that is exactly what happens when they think about attacking a nuclear plant."

View from the regulator

Before September 11, it was a well-accepted fact that nuclear power plants were, and continue to be, among the best-defended and most hardened facilities in the nation's critical infrastructure, said Glenn Tracy, director of the Division of Nuclear Security for the NRC. In the aftermath of the attacks, despite there being no single credible threat against an NRC-licensed facility, all facilities remain at their highest security posture.

On September 11, the NRC, like several other agencies responsible for the oversight of critical infrastructure, activated its emergency response center, Tracy explained. The commission issued an immediate threat advisory to notify the licensees of the state of affairs and to describe all information that it had obtained from the FBI and all intelligence agencies during that day. The NRC also contacted the licensees directly through its regional offices to discuss the actions that were pertinent to take, and answer any questions that they had. The agency evaluated the general and specific threats, and developed a monitoring assessment and trending methodology for use in the various activities that were ongoing at the various NRC sites across the nation, Tracy said.

Changes in NRC security policy since September 11 have been numerous. The commission has ordered security enhancements for power reactors. In notifying its licensees of any information received from the intelligence community, the NRC has updated its original threat advisory more than 30 times. The NRC has contacted state governors regarding the deployment of the National Guard and state police, and has coordinated with the Coast Guard. The agency has also coordinated with the Federal Aviation Administration on flight restrictions and, Tracy said, "acted more than once to protect the air space above nuclear power plants."

Tracy described, in general terms, the NRC-directed interim compensatory measures that are in place and are being taken at various plant sites. Without being too specific, Tracy said the measures call for increased patrols, additional security posts, additional physical barriers, vehicle checks at greater standoff distances, greater coordination with local law enforcement, and more restrictive site access for all personnel.

The NRC is also currently involved in legislative initiatives to improve security, Tracy said. For one, the NRC is trying to federally criminalize sabotage of nuclear power plants. For another, the agency is seeking deadly force authorization. "We would want the ability for our licensees to be able to apply deadly force for those who are trying to sabotage a nuclear power plant," Tracy said. Currently, a plant guard has to be in a detrimental situation before such force can be used. Last, the NRC would like access to the National Crime Information Center. "We want to try to get access to those databases and all the other databases for not only our licensees, but for the NRC itself, in order to better enhance our access programs and be able to get the background checks, all with keeping in mind the principles of privacy," Tracy said.

"The bottom line," he concluded, "is the goal of providing a coordinated . . . and fully integrated response—that is, all the assets of the state, the federal government—to protect public health and safety."

Tabletop fusion

One certain highlight of the 2002 ANS Annual Meeting was the "Technical Program Chair's Special Session: Breakthrough in Fusion Research." The session centered around the notable and controversial paper published in the March 8 issue of *Science* magazine, in which the authors claimed to have used sonoluminenscence techniques to produce thermonuclear fusion in a jar of bubbling acetone. "The fundamental implication of this discovery, folks, is that for perhaps the first time in history, we've got the ability to utilize simple mechanical energy to initiate and control nuclear fusion forces," commented Rusi Taleyarkhan, co-lead author of the study, at one point during the session.

He estimated that the research group has received nearly 5000 inquiries about the work, including from the international and American media, in the three months since publication. The ANS session marked the first time the principal researchers accepted an invitation to speak at a public meeting since the paper was published.

Whether nuclear fusion actually occurred, however, has been a bone of contention since the paper was published. Two Oak Ridge National Laboratory physicists recreated the experiment, but with negative results. The two were not in attendance to defend their methods and results, which were referenced several times during the session. Nonetheless, a distanced member of the fusion community did conclude the session with comments—both encouraging and skeptical—on the experiment.

The sonofusion work arose out of research conducted over the past several years at Rensselaer Polytechnic Institute (RPI) and Oak Ridge National Laboratory, said Taleyarkhan, a program director at ORNL. The researchers had identified a means of intensifying the energy in collapsing bubbles in liquids by a factor of a trillion over conventional approaches. They then ob-

tained funding to see what would emerge from the discovery.

"The first major indicator that something interesting was going on was when, after characterizing our system, we started using deuterated liquids," Taleyarkhan explained. In January 2001, the group began seeing the first signs of deuterium-deuterium fusion induction in the collapsing cavities. "And, believe me, we've not slept well since."

Growing bubbles

Sonoluminescence, in which sound energy is converted to light energy, has been known for almost 70 years, explained Richard Lahey, an engineering professor at RPI and co-lead author of the study. It is a phenomenon in which a bubble is excited to oscillate so that when it implodes it gives off an extremely short, 100-picosecond-or-so light flash, which can be seen with the naked eye. It has been widely used by chemists for high-temperature chemical reactions and to produce exotic materials for commercial purposes.

In the early 1990s, a Ph.D. student discovered a way to levitate single bubbles and to have them achieve sonoluminescence. Lahey explained that the method begins by filling a cylinder with liquid—in the student's case it was water—and a gas—air, in the student's case. A piezoelectric transducer is then used to oscillate the walls of the chamber. A standing wave will be created, which has a node at the top and the bottom. If done correctly, there will be an antinode in the middle. The pressure will then vary extremely quickly between high pressure and low pressure, which will freeze the bubble in place. The bubble would like to rise due to natural buoyancy, but the pressure freezes it in the antinode. Every time the bubble collapses, a light pulse is emitted.

This acoustically forced, noncondensable gas bubble, however, has an inherent limitation on what size it can grow to. It can grow only by a factor of 10 before instabilities will break it apart. "People have been trying to beat that for quite awhile," Lahey said. "Rusi [Taleyarkhan] and I for a number of years worked on ways to try and beat it. It's a very difficult thing to do. . . .

"We recognized that if we ever were going to get sonofusion, it was going to take a new approach to achieve this super compression."

Taleyarkhan added, "We said, 'Maybe if we can find a way to increase this particular ratio by several orders of magnitude, rather than just be a factor of two or five or 10, we might be able to get some interesting phenomena taking place.'"

Collapsing bubbles

The test system was simple enough. The chamber was about the size of three coffee cups, at the base of which was a piezoelectric transducer. Other equipment included a couple of microphones to monitor shock waves, a plastic or liquid scintillator (both were used) to monitor for nuclear emissions, a photomultiplier to detect flashes of light, and a neutron source to generate 14-MeV neutrons.

"People have from time to time been criticizing, saying 'Why have you been using neutrons in an experiment like this?'" Taleyarkhan said. "Well, I'm a nuclear engineer. That's how nuclear engineers work. We use the mindset, 'Use a thief to catch a thief,' or a neutron source to produce neutrons."

Neutrons were used to strike individual target nuclides in the liquid, which would recoil and cause supercritical vapor pockets, Taleyarkhan explained. The nanometer-sized bubbles would then grow to about 5 mm, significantly greater than previously achieved growth ratios. "What that really implies," Taleyarkhan said, "is that I've got a slingshot that has been extended all the way from earth to the sun and let go. You can certainly imagine that a lot of damage can take place when you let go and you are at the receiving end. And the receiving end is going to be the particles, or the molecules, that are going to be compressed. . . .

"We recognized that if we ever were going to get sonofusion, it was going to take a new approach to achieve this super compression."

"And when [the bubbles] implode, they really mean business. The rate of collapse and the velocities that you get are in the range of 10, 20, 30 kilometers per second. It's like falling off a cliff."

At this point during the session, the lights in the conference room were dimmed and a short video was played. The television screen showed a jar of clear, bluish liquid in which there were continual small white flashes accompanied by a barrage of muted popping sounds, which sounded like packs of firecrackers going off a few blocks away.

Neutron detection

One of the points of dispute between the results of the Taleyarkhan and Lahey team and those of Daniel Shapira and Michael Saltmarsh, the ORNL physicists who recreated the experiment with different results, was the type of neutron detectors used in the experiment.

Robert Block, professor emeritus at RPI and director of the university's Gaerttner Linear Accelerator Laboratory, explained that one of the results of a deuterium-deuterium, or D-D, fusion reaction is the emergence of a helium-3 atom and a neutron with an energy of 2.45 MeV. What is difficult is measuring the energy of the neutrons while rejecting background gamma rays. "Let's face it. You're putting off a blast of 14-MeV neutrons. They rattle around. They hit the walls. They hit the ceiling. They thermalize. You get gamma rays. You get all sorts of background events, which can be detected," Block said. "Now, the question is, how do you see the neutrons and reject the gammas?"

Thermal neutron detection methods have excellent gamma suppression, but cannot separate the D-D neutrons from the source neutrons, Block said. Organic scintillators with pulse shape discrimination, however, can reject more than 99 percent of gamma rays and quickly detect neutron signals, whose pulse height is related to neutron energy. "By using this type of detector . . . you have a very fine way of separating the gammas from the neutrons and getting information about the energy of the neutrons causing the events," he said.

Taleyarkhan, et al., used both plastic and liquid scintillators to detect neutrons. The plastic scintillator responds to both neutrons and gamma rays, but cannot distinguish between the two. "You get a scintillation pulse, but you're not quite sure where it comes from," Block said. The liquid scintillator responds to both neutrons and gammas and, by using pulse shape discrimination, can separate the neutrons from the gammas. Block said they were getting 98–99 percent rejection of gamma rays.

"Our detector, which is 2 in. by 2 in., is the standard size recommended for our energy range," Block said. "The Shapira-Saltmarsh team used a detector 30 times larger in volume. It was a big monstrosity. I think it was designed for 14-MeV neutrons. They had it on hand, that's what they used. The area of the detector was an order of magnitude greater than ours.

"If you calculate the number of neutrons from the generator striking the detectors in the amplifier overload, our detector recovers with no problem from amplifier overload. Theirs gets saturated. So, they have a very high counting rate just from the fact it's big, it's thick, it interacts with the 14-MeV neutrons quite strongly. . . . They had such a big detector they had a lot of gamma

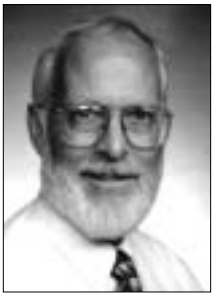
ray background [interference]. They had a huge background rate—very difficult to do coincidence measurements."

Perspective

Ken Schultz, a fusion engineer with General Atomics who was not involved with the project, but has been involved with fusion research for 25 years, commented on the experiment in his presentation titled "A Perspective from the Fusion Community." He divided his comments into four areas.

Did this team do the right thing? Schultz had asked himself, and concluded yes. "Unlike the debacle of cold fusion, where a couple of very good scientists got in over their head . . . this team did it right," Schultz said. They obtained peer review. They went through the publication process, and in that publication they acknowledged the contrary positions of Shapira and Saltmarsh, to the extent that their rejoinder is a key part of their paper, Schultz said.

Did they do the thing right? The research team has made an "excellent start," Schultz said. The experiment is challenging, however, a fact pointed out by both teams. "There are very low signal-to-noise ratios in what is being seen, both in the neutrons and in the tritium, in that there turned out to be tritium in the laboratory and tritium in their fluids," Schultz said. "There are distractive phenomena going on—neutron scattering around the room, events in the scintillator that may be caused by extraneous events. And the analysis is difficult." He said he didn't think the experiment was finished yet, by either team.



Schultz

Is this really useful anyway? Schultz was dubious that the work could be scaled up to eventually generate energy for electricity (not that Taleyarkhan, et al., disagree). The energy balance, he said, would almost surely be negative, particularly with constraints such as that the work must be done at a very low temperature to avoid vapor pressure in the bubbles. "From an energy point of view, I am not optimistic at all that this actually leads to a useful product. I think we should keep on pressing on with ITER [the International Thermonuclear Experimental Reactor] and the National Ignition Facility and the other large-scale fusion approaches." Having a picosecond timescale modulated neutron source, however, could be an interesting tool in a variety of physics experiments.

What should be done next? Schultz said he did not think that sonofusion had been proven, but neither had it been disproven. He called for more analysis of the same experiment, with more sophisticated instrumentation, and for the two teams to continue to cooperate.

"All of the issues that Professor Block presented are technical issues. They can be worked out with the two teams sitting together and going through them one by one.

"When the dust settles, we may need yet another more exacting experiment, given the challenge of measuring these things and the small signals that are obtained."

And the scientific process should continue, Schultz concluded. "I know that science grinds slowly, but it grinds exceedingly fine."

In setting up a new business relationship, workers at Comanche Peak have attempted to fuse the values of the plant and the vendor.

Collaborating in the industry

The session "A Collaboration of Resources in the Nuclear Industry" featured three speakers, each outlining a different collaboration approach in the industry. Teaming efforts at a single site, between similar companies, and across the industry were all covered.

Randy McCamey, assistant to the vice president of engineering at TXU Electric's Comanche Peak, discussed collaborative efforts within a single company at a single site, among the company and a number of vendor organizations. He described an arrangement at his plant, in which contractors are paid based on plant performance, that has helped improve the safety and reliability of the plant.

A few years after the Comanche Peak units came online in the early 1990s, McCamey said, workers at the plant found themselves duplicating a lot of work. "Every time an outage came around, we were re-creating these contracts with various vendors to do these certain services. We would follow through with those and the next outage would come around . . . and we would re-create the contract," he said. "We just felt that there was a better way to do that, to optimize these things—safety, performance, and cost."

McCamey described the inherent conflict between the priorities of a power plant and those of vendors. The plant continually strives for excellent records of safety and performance. Vendors, on the other hand, stand to make more money if the plant is not performing well because more services will likely be needed. "If our plant operates poorly, then the vendor has more to do, and so their revenues increase," he said.

In setting up a new business relationship, workers at Comanche Peak have attempted to fuse the values of the plant and the vendor and to come up with a common set of goals. Building performance measures into the contract, and sharing the costs and rewards based on performance, has been a useful technique toward this end, McCamey said. The indicators are looked at on an annual basis, and the results shape profits for both TXU Electric, which operates the plant, and the vendors.

"If we have a bad year," McCamey said, "where [contractors] have to work hard to get us back to better performance, then not only are they spending money in efforts to do that, but, contractually, they don't get as big a piece of the pie. So, it's in our best interest to run safely, efficiently, and have higher reliability. And now, in this teaming arrangement, it's also to the best interest of our teaming partners for the plant to run safely, efficiently, and reliably."

McCamey said the utility has found, almost by accident, that there is a greater sense of ownership for equipment among the contractors with this arrangement. "With this broader ownership base between the companies, we found it to be much more productive as a teaming effort on plant ownership and on equipment ownership. And when we come to the table in groups, even though our badges may be from different companies, we really are much more effective as a team together because each of the companies is looking for the best options in terms of safety, performance, and cost, rather than only TXU employees . . . creating the best scenario and then dropping that off to the contractors."

Companies collaborating

In 1999, five nuclear power plants—Monticello, Prairie Island, Duane Arnold, Kewaunee, and Point Beach (and later Palisades)—decided to form an operating company, with the goal of one day becoming a generating company, explained John Paul Cowan, senior vice president of operations for that organization, Nuclear Management Company. "They felt by . . . getting more nuclear expertise, being able to get expertise shared across multiple similar units, that they could improve their safety, cost, and production," he said.

Under NMC's business model, each plant owner continues to own its nuclear units, and each owner remains financially responsible for its nuclear units' operating and maintenance costs. NMC operates nu-

clear units with existing employees, while a small headquarters staff in Hudson, Wis., provides direction and oversight for the site-based employees. "If you go to any one of our stations, half of the employees belong to the Nuclear Management Company, half of the employees belong to the owner," Cowan explained. "So, we have 3600 people split among six companies: NMC, and the other five owners."

All the sites have put together an "excellence plan," with four centers of attention: operations, equipment, training, and organization. "That's different than the plants had before. The plants had improvement plans that were very narrowly focused. We have a standard set of fleet indicators that we compare the plants to. We have standard definitions . . . so we can compare the plants' performance," Cowan said, adding that there are about 75 indicators for each plant.

Plants that are interested in joining NMC, which they can do without selling their nuclear assets, are subjected to what Cowan called a gap analysis. "We tell you where you are relative to the rest of the industry, where you are relative to cost structure, where you are relative to your organizational size, where you are relative to processes," Cowan said. "We then take the gaps—those items we want to fix . . . and build them into the excellence plan. From those come the budget. And after we have that, we start measuring the performance indicators."

The greatest benefit in joining NMC, Cowan said, is newfound clout in the industry. "Instead of being one little entity among a big sea, you are now part of NMC, where there are eight [reactor units] similar to you.

"So, when we go somewhere, we have some clout to make things happen in the industry. Each of the owners never had that before. We have what we call a place at the table."

Plant configuration

Future owners of nuclear power plants need to ensure that the integrity of the license basis for the plant will be maintained over the course of its operational life. Michael O'Connell, manager of process improvement at Stone & Webster, Inc., discussed a methodology to achieve those ends. He described the development, which was sponsored by the Electric Power Research Institute, of an advanced information management system, or AIMS, that can be used to control configuration of a nuclear power plant throughout its life cycle.

"EPRI was concerned that if future owners didn't have confidence in the ability to maintain the configuration over the life of a plant, that was a barrier to adoption of new technology," O'Connell said. AIMS allows for collaboration because it can link all the necessary organizations involved in the operation of a nuclear power plant, even though they may be working different schedules, in different time zones, or may be trying to achieve separate ends.

The concept has been used by Westinghouse in its design of the AP1000 reactor, an outgrowth of the design for the AP600, which is already certified by the NRC. The two share about 80 percent in common. "As a result, there's a lot of material that would be transferred over to the AP1000 design space, as well as creating new space," O'Connell said. "This was a unique opportunity, we thought, to implement the AIMS concept at the reactor-vendor side, with the eventuality that an owning utility—whoever bought the plant— . . . would then be transferred a complete configuration management package, assuming they wanted it, that would support plant operations for 60 years."

One of the challenges in developing the system was allowing for data integration between what O'Connell called "islands of information"—the disparate databases, some with duplicate information, on modification and operational activities that are maintained by a plant. Some examples include equipment data sheets, process flow diagrams, logic diagrams, purchase orders, safety data sheets, and instrumentation and control diagrams.

Once the plant is built, there are four abstract domains of the plant that need to be maintained concurrently: the analytical plant, which includes calculations and analyses; the licensed plant, which includes licensing documents, 10 CFR 50 requirements, and codes and standards; the record plant, which includes drawings and procedures; and the physical plant, which includes the as-built configuration, components, and structures.

Future owners of nuclear power plants need to ensure that the integrity of the license basis for the plant will be maintained over the course of its operational life.

"In most views of the world right now, we've got four separate boxes of information. And we have a somewhat tedious and rigorous modification process or design change process to try to make sure that what's out in the field matches what our records say, matches the analysis basis for the plant, and hopefully matches what we told the [NRC]. And if they don't, then we all know the consequences of those disasters. They are many and expensive," O'Connell said.

So many pieces of information are stored electronically that it is difficult to find everything that is on hand, O'Connell said, as well as to ensure the right information is used. "When you retrieve something, the current revision would be handy, as well as knowing the life cycle of where the other revisions are at and what happened before and what is pending," O'Connell explained. "Any time you answer a licensing question, you're going to say, 'What's our current configuration? What's on record?' We need to know that without spending a great deal of time retrieving it."

Also, AIMS attempts to reduce unneeded data migration and leave database files in their native format. "I've been engaged in those data migration efforts, and they're not fun. They're expensive. And they produce more errors," O'Connell said. "Anytime you start massaging a lot of information like that, you generate more problems than you started with."

One of the benefits of AIMS is that it can shorten plant delivery time by streamlining communication. That can be accomplished by taking out what O'Connell called non-value-added time, and noted the automotive industry as the inspiration. Automobile companies used to take three weeks for design decisions to be made on a new car, O'Connell said. They then worked the decision process down to three days. "The actual decision process is relatively quick. But communicating it, having it ripple through the organization, making sure all the documentation is changed to reflect the organization's decision-making was taking three weeks. We took our cue from what we saw in Detroit, because, based on our research . . . Detroit went from 60 months down to 36 months for design of automobiles. And a lot of that time was taken out of the process by taking out non-value-added time. Well, if we're going to deliver plants in 36 months from first concrete to fuel load, or even shorter, we need to take out as much non-value-added time as we can."

The actual AIMS software application launches in a common Web browser. A vendor in Japan, a vendor in Korea, and a project management team in North America can access the information without needing a custom suite of software.

O'Connell then showed a screenshot of the software configuration that has been used in the design of the Westinghouse

AP1000. It contained headings such as marketing, product design, purchasing, system administration, business administration, service support, etc. "All of those people will have access to the same data set, whether they're design folks, licensing folks. . . . People can click on their view and see what works best for them."

What we attempted to do in this document is present everything you can do in a research reactor and to provide all the criteria necessary to do it," Dodd said.

Research reactor survival

The need for research reactors to survive and become increasingly responsive to commercial needs were the primary themes expressed in the session, "Research Reactors: The Next Generation Used for Industrial and Medical Applications." Some reactors, in fact, should not even remain in operation if they do not hold up under rigorous economic analysis, noted Brian Dodd, of the International Atomic Energy Agency.

"If you've got good reason to be open, then I think you'll be open. If you can't make the case, then I would support that you shut down. It sounds a little heretical," Dodd said. The session also featured an overview of the the Canadian MAPLE medical isotope reactors, which are scheduled to begin production next year.

The idea of a business model for a research reactor may sound unusual because research reactors do not necessarily exist to turn a profit. In order, however, to survive, they must be valuable to their stakeholders, noted Michael Spellman, who opened the session and discussed the business model for the Texas A&M Nuclear Science Center (NSC), for which he is the technical services coordinator. Besides ensuring safe operations, he said he considers his job to be making the center more valuable.

"The whole idea of a business plan is to figure out how to add economic value," Spellman said, "and then figure out how to capture some of that value to help pay your bills and to make your facility valuable to enough different people in enough different ways to survive."

The first aspect of developing the NSC's business model involves a "SWOT" analysis, in which the facility's strengths, weaknesses, opportunities, and threats are assessed.

Among the strengths of NSC are that it is a low-cost source of neutrons, Spellman said, and that it has an experienced and small core staff. The supply of smart and inexpensive labor readily available on a university campus is an advantage and helps keep costs down. The center also keeps running smoothly through written procedures for many aspects involved in running the facility, such as billing, operations, and shipping. NSC also enjoys strong moral support from the university: "As long as we don't cost too much money, [university administrators] are very happy to leave us alone," Spellman said.

NSC receives weak *financial* support from the university, however, Spellman said, enumerating the weaknesses. It is also an old facility with low flux levels, and is poorly utilized by university researchers.

Marketing itself better to the university researchers is among the opportunities that Spellman sees for the center. There is also an opportunity to produce some medical isotopes, such as iodine-125.

The continual changeover in university administrations is one of the threats that Spellman identified for NSC, because good relationships may last only during the five-year term of an administration. Radiation mishaps, however, remain the greatest threat, Spellman said, especially because they use those inexpensive student workers to handle high-level isotopes on a regular basis. "It's all systematic, it's all a process at this point, but it's still a concern," he said.

"We bring about 2000 junior high and high school students through our facility every year. And they walk right by our handling facility, which is open to the air and is always contaminated—always. We clean it once a week and it's [still] contaminated.

"Now, the students don't go in there, but they go right beside it. We frisk them on the way out and make sure that they're not contaminated. But we lie awake at night thinking about the idea that [for instance] a fifth grader came in and got contaminated, and we had to take his shoes because we couldn't get it cleaned off. And then he goes home and tells his mom. You can see the fear there."

At the end of the SWOT analysis, Spellman said, the next step is to identify core competencies, which fall out of the analysis. Identifying what the organization does well, what it could do well, and what activities earn income and add value are some of the goals of this step.

NSC can add value, Spellman said, by being challenged by its user base to continually learn new processes and techniques. He cited an example of a request in which someone had asked for a mile-long piece of wire that was uniformly radioactive. "He asked us to develop a process, and we did. It's taken us a couple months and it's cost us a few thousand dollars, and we haven't charged him a penny, yet. . . . He's guaranteeing us that if we learn a new skill, he'll pay us to use it. So we spent $3000 to learn how to make this long wire, and he's promised to pay us to do it. And this week we're doing it for the first time for money. We've been doing it for free. Now we start getting paid.

"It's pretty simple, it's not very high-tech, and anybody can do this in six weeks," he continued. "But what it does is incrementally make the Nuclear Science Center at Texas A&M more valuable. We don't know how much yet, because we don't know how much of this we're going to do. But we're a little more valuable, and we've got one more user. And we're a little less likely to go away over the next few years."

International research reactors

The struggle for research reactors to survive is not peculiar to the United States, said the IAEA's Dodd. Worldwide, he observed, missions have been accomplished and old research reactor applications have now become obsolete. The international stagnation of nuclear power has decreased demand for nuclear applications as well as training, which was once a mainstay of many research reactors, he added. "Now it's become really a matter of survival of the fittest," Dodd said, "not just in the U.S., but worldwide." As a result of these factors, Dodd helped develop two IAEA technical documents—TECDOC 1212, "Strategic Planning for Research Reactors," and 1234, "Applications for Research Reactors"—which he described in his presentation.

Developing a strategic plan helps a facility justify continued operation and can allow for appropriate commercialization development. It is also a means to effectively manage changes in culture, Dodd said. Workers at many facilities, especially in the countries of the former Eastern Bloc, have a more lackadaisical mindset that would not work well in the capitalistic markets their countries may be heading toward, he said. A strategic plan can help that. "The strategic plan helps to communicate the priorities of the facility, secure budgets, justify recruitment of staff and infrastructure upgrades, and it enables stakeholders to see the benefit of their support," Dodd said.

First, a research reactor facility must examine its capabilities, which is where TECDOC 1234 comes in. "What we attempted to do in this document is present everything

you can do in a research reactor and to provide all the criteria necessary to do it," Dodd said. "The document gives you the flux level needed, the facilities needed, the equipment necessary, the space, the personnel, and the funding—all the things you need to be able to do to specific types of applications."

Then, the facility must identify its potential applications. Speaking with stakeholders and identifying potential stakeholders is one way to do this, Dodd said. For example, if a facility has been doing neutron activation analysis for agricultural purposes, are there more agricultural users out there? Also, identifying local and national issues can help in identifying new applications for a research reactor. This step is particularly useful in developing countries, Dodd said. He cited an example of a reactor in Ghana, a country rich in natural gold resources. "You start looking at the industries: What's important to the national industry? Gold mining is. So, screening for mineral ore is an obvious application. . . .

"Be proactive in your interaction with the stakeholder. What are their needs? What do they want?"

The last task is to identify four or five major objectives for the reactor. Out of that process come specific objectives—the specific tasks that will allow the major objectives to be accomplished. They should be smart, specific, measurable, achievable, relevant, and timely, Dodd said. "Specific objectives will have a responsible person, a deadline, some performance indicators," he explained.

"If your major objective is to increase utilization [of the reactor], then your specific objective is to increase utilization hours of, perhaps, the neutron diffraction facility by academic institutions 30 percent within the next 18 months. It's pretty easy to tell if you've met this or not," Dodd said.

Once specific objectives are identified, then the responsible person develops an action plan. "What will get me a 30 percent increase in neutron diffraction users in the next 18 months? What specific things do I need to do? This becomes the task of that particular person—the detailed implementation steps of those specific objectives."

MURR overview

Charles McKibben, associate director of infrastructure for the University of Missouri Research Reactor Center (MURR), discussed the history of MURR and how it has been utilized.

MURR is a 10-MW reactor with a higher peak thermal flux per megawatt than Oak Ridge National Laboratory's High Flux Isotope Reactor facility, he said. Except for shutting down for half a day each week, the reactor is in operation 24 hours a day. With a peak flux of 1×10^{14} for the P-tube system and reflector irradiation positions, MURR has a strong neutron activation analysis program, McKibben noted. Several leading epidemiology programs rely on MURR's neutron activation analysis program to quantify trace-element concentrations in epidemiology investigations, McKibben said.

MURR has played a role in the development of three radiopharmaceuticals approved by the Food and Drug Administration. Ceretec, a technetium-99m agent, was approved in the early 1980s for diagnosis of abnormalities in brain blood flow. TheraSpheres, which were approved in 2001, are microspheres measuring 20–30 microns in diameter that contain yttrium-89 that is activated to Y-90. They are used to ease the symptoms of liver cancer and extend life. And Quadramet, a samarium-153–laced radiopharmaceutical for treating bone cancer, was approved in 1997.

Researchers at the facility are currently testing a holmium-166–labeled agent for treating multiple myeloma, a form of leukemia. Ho-166 is a beta-emitter with a 26-hour half-life, and the actual pharmaceutical that goes into the patients comes from the MURR facility. Twenty-three out of 83 patients tested have experienced complete remission of cancer during phase I/II trials, McKibben said.

"MURR is dedicated to conducting high-quality research in this radioisotope, radiopharmaceutical area," McKibben concluded. "Once we do that research, we're dedicated to commercializing those to useful products in treating cancer and providing the technology to other people.

"As we talk about keeping research reactors viable, you take those funds generated from commercialization and use them to further both your independent and collaborative research."

New medical isotope production

The MDS Nordion Medical Isotope Reactor project (MMIR), which centers around a pair of AECL-operated MAPLE Reactors, was the subject of Jean-Pierre Labrie's presentation. MDS Nordion already supplies the radioisotopes for about 34 000 nuclear medicine procedures each day. About 80 percent of those procedures use molybdenum-99, on which the production capabilities of the MAPLE reactors will be focused. MDS Nordion currently supplies Mo-99 out of AECL's NRU reactor, which has been in operation since 1957. The radioisotopes are shipped to about 5000 hospitals in North America, as well as to more than 2000 other hospitals around the world.

In 1996, MDS Nordion and AECL announced an agreement to build new facilities for the production of medical isotopes. The agreement provided for the construction of two 10-MW MAPLE reactors and a high-volume, commercial, first-stage processing facility at AECL's Chalk River Laboratories, in Canada. The arrangement called for AECL to build and commission the reactors, and then operate them on behalf of MDS Nordion. The commercial production of the isotopes will be managed by MDS Nordion. "To make it more simple, we will operate, essentially, as MDS Nordion asks us to supply isotopes to them," said Labrie, who is general manager for the MMIR project.

At the time, the objective was to start commercial production of medical isotopes in the facilities in 2001. Active commissioning of the facilities, however, has been on hold since July 2000, due to recurring problems with the operations of the shutoff rods in the MAPLE-1 reactor. In investigation of the problem, workmanship issues

MAPLE reactors: Unit 2 (white building on left) and Unit 1 (white building on right)

from the construction phase of the project also started to surface. "Since we have a problem with one system and it was related to a construction deficiency, it has raised doubts about all the other systems in the reactors. Which means that for about the past two years we have been working the systems, generating reports, and assuring ourselves that every system is ready to go," Labrie said. Now, the project is expected to begin isotope production in 2003.

The MAPLE reactors are open-pool reactors fueled by silicide fuel dispersed in an aluminum matrix. The reactor core measures about 400 mm in diameter and 600 mm in height, and contains about 5 kg of uranium-235. The core has 19 fuel sites, 13 of which are hexagonal and six are circular. The core is cooled with forced water, at a rate of 300 kg/s.

"Going to lower enriched uranium means that we have to process roughly five times more uranium for the same quantity of isotopes being produced."

Each reactor has two independent safety systems. The first safety system, which is the one that has caused problems, consists of a set of three hydraulically actuated shutoff rods, only two of which are required to shut down the reactor. The second safety system consists of three electromagnetically actuated control absorber rods, which drop into the core, and a hydraulic actuated reflector dump. "On an event, we activate both safety systems," Labrie explained. "Only two of the six absorber rods, whether they be shutoff rods or control absorber rods, are adequate to shut the reactor down. So, there's an ample margin of error in terms of shutting down the reactor. The reflector dump also shuts down the reactor, but it's a bit of a slower system. That's why we drop the control absorber rods."

The reactors have been licensed to irradiate high-enriched uranium targets, which have been obtained from the United States and are subject to American laws requiring AECL to make a significant effort toward converting the facilities to handle irradiation of low-enriched targets. MDS Nordion launched a three-phase feasibility study in 1999, and completed the initial phase in 2000.

"Our main issue is the management of waste that comes from the chemical processing of uranium targets," Labrie said. "Going to lower enriched uranium means that we have to process roughly five times more uranium for the same quantity of isotopes being produced. That pushes the facilities toward the limit of their design capability. They were designed for highly enriched uranium, and if you have to process five times the same amount of uranium, you cannot use necessarily the same techniques to do your extraction of isotopes."

Work is under way on the second phase, the Conversion Development Program, which will attempt to improve management of the waste so that a conversion to low-enriched uranium is feasible. This will be followed by an assessment of the economic impact of the conversion. "As I said, this is very simply a commercial activity. It has to generate profits to the shareholders. This is why we need to have the shareholder assess the business impact of this conversion. And if the business impact is acceptable to the shareholders, then there will be a conversion implementation process," Labrie said.

Before that can happen, however, the reactors and the processing facility will have to be relicensed for low-enriched uranium targets, which is a three-year process, Labrie said. AECL will also have to make some changes in processes in the processing facility in order to handle the low-enriched uranium targets. "We will not be looking at a conversion before sometime in 2007," Labrie said.

Dry cask storage update

Mike Floyd, of RIO Technical Services, chaired a panel, the Dry Cask Storage update session, which looked at what remains one of the growth sectors of the industry. This has put pressure on the regulators, as well as the plants.

About three years ago, the Nuclear Regulatory Commission asked for ASME codes to be adapted for use in the fabrication of transportation and storage containment systems to ensure third-party oversight. The issue for ASME, explained Garrick Solovey, of WPI (Worldwide Performance and Innovation)/Virginia Tech, was that its nuclear codes are primarily concerned with pressure boundaries and container structure. For these casks, the focus is on leak-tightness and issues such as the neutron-absorbing material, whose inspection and evaluation must be included in the code. Solovey said helium leak tests are more useful than pressure tests.

The ASME committee is trying to maintain as much flexibility in the code as possible to allow for new designs to develop, he said, and added that it will try to be responsive and not hold up cask design development. "The group was open to anything that makes sense and that is good design practice," he said.

Under the new code, the main onus has shifted from the owner to the designer. For components such as reactor pressure vessels, the owner participated in signing off data sheets. For the new code, the owner is provided a copy of the data sheet but is not required to be part of the sign-off process, which will include the designer, the fabricator, and the ASME-authorized nuclear inspector. The NRC felt that the owner had been too much involved in the approval process.

Some lessons learned

Michael Lackey, of Portland General Electric, is manager of decommissioning projects at Trojan. Part of the plan was the construction of the Independent Spent Fuel Storage Installation (ISFSI), for which Sierra Nuclear was awarded a contract in 1995 to provide dual-purpose casks. Loading operations began in July 1999, but it was soon discovered that the internal coatings in the casks' transport baskets had begun to fail. It turned out to be an adhesion problem. PGE eventually terminated the contract and awarded Holtec International a contract to provide an all-stainless-steel canister. The utility was able, however, to salvage the concrete cask from the Sierra Nuclear design, which saved some $7 million. Lackey anticipates license approval this October.

This experience has provided PGE with a number of lessons, he said. For example, he said, although a significant burden on utilities, Lackey says they must provide significant quality assurance oversight of designers, fabricators, and all their subcontractors. They must be prepared for all eventualities in a major project like this, which was the first pool-to-pad contract for Holtec.

He also stressed the importance of getting things done early, including shakeout operations. For example, do not weld just one lid during a dry run, make sure staff are proficient in it. Also, communicate early and often with both the NRC and state regulators, and adhere to strict rules of engagement on quality, timeliness, completeness, and accuracy. Once submissions are made, do not make changes.

For good vendor performance, Lackey said, the contract should carefully spell out incentives and penalties. "I think it would be hard to do it without incentives . . . [contractors] like them and we like them." But, he warned, incentives will set a contractor's priority tasks, so make sure they are not tied just to schedules—they have to be linked to

some measure of quality as well. Remember also that your project is likely to be competing with others, he added.

Yucca Mountain

Assuming the Yucca Mountain project gets the go-ahead, the DOE's Paul Harrington said, an application should be submitted in late 2004. The NRC then has three years by law to review it, but can request more time. DOE is now looking at what is necessary to begin emplacement in 2010.

Harrington mentioned the planned construction of a "blending facility," which includes a series of storage pools in the fuel handling building that could accommodate 5000 tHM [tonnes of heavy metal]. Its intent, he said, is to allow the mixing and matching of hot young fuel and older cooler fuel assemblies to make up packages with a maximum of 11.8 kW thermal output. Outside will be a pad capable of holding storage cylinders to take up to 40 000 tHM of hot fuel, which will not meet the thermal goals for pre- or post-closure. This will act as an "aging facility," where heat will be rejected to the atmosphere rather than underground.

Because of the variation in the waste streams, he noted, there are different versions of waste packages, although conceptually they are the same: basically a dual-wall cylindrical vessel with end caps. They will need to accommodate uncanistered commercial fuel and canistered loads of "classified" fuel coming from the Navy. Canisters will be fabricated to maximize long-term integrity (the Environmental Protection Agency set a 10 000-year lifetime criterion), which involves minimizing contact with other objects and avoiding any other potential corrosion mechanism. There will be no lifting trunions or weldments on the containers, which will sit on emplacement pallets that are V-shaped to ensure that there are only four surface contact points. There will also be a drip shield over the package to protect it from water or falling rocks after the closure of the repository.

There are not yet design criteria for real multipurpose canisters (for transport, storage, and disposal). A program to do this had started some years ago, but was stopped because a development contract had been given to one company (Westinghouse), which Harrington said would have given it an unfair advantage. DOE will get back to this issue later.

The NRC perspective

John Monninger, chief of the spent fuel licensing section in the NRC's spent fuel project office, warned applicants of its increased work load since the September 11 terrorist attack. The number one priority now is evaluating security and safeguards, he said, and the NRC has diverted resources to perform vulnerability assessments of storage designs, transportation, etc.

With its work program pushed to the limit, the NRC is now applying stricter attention to the rules and tightening up on the quality and completeness of the applications it accepts. Monninger also mentioned the effort spent on growing congressional, media, and other stakeholder interest in storage and transportation.

With only about 10 percent of spent fuel stored in dry casks, there is a growing demand for storage and transportation reviews and requests for license amendments and exemptions. Monninger said he was particularly concerned about a failure on the part of some licensees pursuing a general license to do an adequate fuel characterization or a thorough site characterization. He noted that some discovered, just as they were preparing to load fuel, that they had damaged fuel or the enrichment was wrongly documented, or the certified seismic load limits of the cask design were less than the seismic loads at the site, and so there have been many requests for exemptions. He said these are all time consuming and take NRC staff away from other work, such as processing site-specific licenses and amendments to certificates of compliance.

Storage and transport of high-burnup fuel is another issue, Monninger observed. More amendment requests are coming in for this, which adds to the work load. Guidance on high-burnup fuel is scheduled to come out this summer and draft guidance on burnup credit is in the works.

The Idaho Falls facility

Dean Tolberg, engineering manager of Foster Wheeler Environmental Corp., gave an update of its privatized modular-vault dry storage facility at Idaho Falls. It has 55 t of fuel contracted, including fuel from Peach Bottom-1 and -2, the Shippingport plant's reflector modules, and about 1600 Triga elements. This is about 20 percent of the DOE's inventory at the site. Wanting to use proven technology, the starting point was the existing Fort St. Vrain vault facility, he said. The design is easily expandable without affecting operations.

A license is expected in March 2004, Tolberg noted. Fuel will arrive in the "Peach Bottom" cask that the DOE is providing as government-furnished equipment. The fuel will be removed, packaged in DOE standard multipurpose canisters, and put into storage tubes, which provide secondary containment. These are backfilled with helium to inhibit corrosion. Tolberg admitted, however, that it makes little difference because the fuel is "old and cold." The contract stipulates that this procedure has to be completed within 48 hours.

To meet criticality safety conditions, he said, absorber tubes are placed in the canister. No burnup credit is taken, so the safety analysis assumes beginning of life enrichment values. For the Shippingport and Peach Bottom fuel containing thorium, however, the actual amount of U-233 generated at end of life has to be determined.

Finally, Tolberg said, because the DOE is considering getting out of storage activities at the site, a proposal has been made to take the rest of the fuel stored there.

Key issues

The final speaker was Juan Subiry, of NAC International, which will be loading 64 of its vertical concrete casks in the next 18 months at Maine Yankee. Subiry described some of the key issues NAC is working on, including: high-burnup spent fuel, damaged fuel, burnup credit, and "militant acts of destructiveness."

While the NRC does license transport of high-burnup fuel, he said, full guidance is available only for licensing casks for low-burnup fuel (below 45 000 MWd/t). Above that level, there is a lack of guidance, and vendors are not willing to invest in designs.

Subiry made the point that most high-enrichment fuel was discharged in the 1990s, and only now are substantial data becoming available to develop the guidelines. NAC has submitted a Topical Report on relevant technical issues such as the level of creep strain, oxide thickness limits, cladding temperatures etc.

He also mentioned the possibility of improving the condition of the fuel by a type of annealing treatment. The current interim guidelines are very conservative, he noted, but the NRC has recently said that new guidelines being developed will likely be based on temperature rather than creep strain, which Subiry said is good news for industry.

He noted that there is an urgent need for some burnup credit, particularly for spent pressurized water reactor fuel, which is rapidly accumulating. A particular concern is that some transportation systems may become de-facto storage-only systems. The industry needs assurances that whatever is licensed now will be licensed in the future, Subiry declared. Technical issues include assuring what the burnup is and that it is uniform throughout the fuel.

NAC has also looked at the potential threat from terrorists to storage facilities, noted Subiry—in particular, aircraft crashes and missile impact. In the worst case, its analysis concludes that an engine rotor could [damage] an overpack, but not the canister. Fire, he said, would degrade the system, but not affect the cask, so there would be no release of activity. More details on this work were published in the May/June 2002 issue of ANS's *Radwaste Solutions* magazine.—*Dick Kovan, Rick Michal, and Patrick Sinco* NN

TOPICAL MEETING

New plant construction and design: Myths and realities

THE MYTH IS that the general public opposes new nuclear plant construction in the United States. Not so, said Marvin Fertel, who led off the plenary session of the *International Congress on Advanced Nuclear Power Plants* (ICAPP). Fertel, senior vice president of the Nuclear Energy Institute, noted that contrary to myth, 64 percent of all U.S. adults feel it is "acceptable" for new nuclear plants to be built (if those new units are located next to existing nuclear plants), according to a poll conducted by Bisconti Research.

Fertel explained that myths abound about nuclear power: That the market can support only one new reactor design, that uncertainties in the Nuclear Regulatory Commission's processes make it impossible to build new plants, that Wall Street would never finance construction of a new plant, and that government support is an unnecessary subsidy to the industry.

Fertel

The truth, Fertel continued, is that realities shatter the myths. These realities include the "strong" support from the Bush administration and Congress for new nuclear plants, the electricity demand and the need for new baseload capacity that will exist later this decade, the fact that new nuclear plants are critical to reducing greenhouse gas emissions and meeting other Clean Air Act requirements and could be critical to transitioning to a hydrogen economy, and the interest by a number of generating companies in new plants.

One reality hammered home by Fertel is the need for new plants to be competitive in the U.S. electricity market. "[Building a new nuclear plant] is not going to happen because you think it's a good idea," he said. "It's going to have to be competitive. You're going to have to look at it from a business decision. You're going to have to convince your boards of directors that it's a good business decision."

Part of that business decision will be based on the time duration to bring a new plant to market—it must be short and certain, according to Fertel. "'Certain' is absolutely essential," he stressed. "If you say it's four years [to build a plant], it better be four years."

Fertel said the industry believes that new nuclear capacity can be built at a capital cost of $1000–$1200 per kilowatt, which is competitive with gas-fired combined cycle plants at $600/kW with gas delivered at $4–$5/million Btu. He said new nuclear also would be competitive with new baseload coal-fired capacity, i.e., conventional pulverized coal with full environmental controls ($1000–$1200/kW), and "clean coal" technologies ($1200–$1500/kW).

Competitiveness of nuclear is what makes it an attractive generating source for Japan's Tokyo Electric Power Company (TEPCO), according to Akira Omoto, general manager of TEPCO's nuclear engineering department and engineering research and development division. Omoto reviewed TEPCO's nuclear power history, specifically its commitment since the late 1970s to advanced boiling water reactors. Currently, TEPCO operates 17 nuclear units.

Omoto

Omoto said the ABWRs were competitive with Japan's gas-fired combined-cycle units, and that "it wouldn't be surprising" to see new ABWRs built at a capital cost of $1200–$1300/kW. In comparison, Omoto noted, TEPCO's Kashiwazaki Kariwa-6 and -7 (Japan's two existing ABWRs), which went commercial in 1996 and 1997 respectively, were built at a capital cost of $2250/kW.

A new nuclear power plant is planned for Finland, explained Ami Rastas, executive vice president–engineering for Teollisuuden Voima Oy (TVO). TVO is the Finnish utility that operates the two Olkiluoto nuclear plants.

Rastas

The design of the new TVO unit is not yet determined, Rastas observed, but its output will be in the 1000–1600-MW range. It will be built at the Olkiluoto site (which has two ASEA-Atom BWRs) or at the Loviisa site, which is home to two units (Soviet-design VVER pressurized water reactors) operated by another Finnish company, Fortum Corporation.

Rastas said that a university study had indicated that the generating costs of nuclear in Finland are "the lowest in comparison with baseload generation using coal, natural gas, or peat." No dollar figures were offered, but Rastas said the

Major themes of the plenary:

- *Pronuclear realities shatter myths*
- *ABWRS are competitive with gas*
- *Nuclear costs in Finland are favorable*
- *South Korea will increase nuclear share*
- *Nuclear is a solution to the trilemma*

"cost structure of nuclear production is favorable from the cost stability point of view."

Rastas said that because nuclear plants produce power at low cost in Finland's deregulated electricity market, coal-fired plants have been in operation less than half the time and gas-fired plants only occasionally, due to volatile market prices.

Finland today imports 72 percent of its energy needs, primarily from Russia. Rastas said TVO's goal is to have a new nuclear unit in operation by 2010.

In South Korea, nuclear today provides more than 28 percent of electrical generation. The projection is to have more than 37 percent from nuclear by 2015. Ki-In Han, vice president of nuclear steam supply system (NSSS) engineering and development for Korea Power Engineering Company, Inc. (KOPEC), explained that nuclear has been a major electric power source in his country since 1986. Sixteen units are in operation, with four more under construction and six more on order.

Han

Because South Korea "is very poor in energy sources," Han emphasized, nuclear is "not an option, [it is] a necessity."

Two units of the advanced KSNP+ (Korean Standard Nuclear Plant) pressurized water reactor design—Shin-Kori-1 and -2—should be deployed by 2008 and 2009, respectively. Two more—Shin-Wolsong-1 and -2—are expected by 2009 and 2010. Two more units, of the next-generation APR1400 design (see details further below), are expected by 2014.

Han surprised the audience by giving low marks to the likelihood of near-term deployment of new nuclear plants in the United States. Negatively affecting the role of new nuclear in the United States, he said, are the "abundant" energy sources of the United States, the deregulated electricity market, the fact that the national nuclear energy strategy is positive but not strong, the large number of nuclear operating companies in the United States (in comparison, South Korea has one), the fact (regarding the Nuclear Regulatory Commission) that "many elements of 10 CFR 52 (the regulations for the simplified and streamlined plant licensing process) are not demonstrated," the slow economic growth rate, and the "additional" megawatts of nuclear coming on board through power uprates and license renewals.

To deploy a new plant in the United States, Han recommended that a joint venture be formed by nuclear utilities and the government. The venture should receive support from the government in the form of tax benefits and incentives, he said.

Explaining the likelihood of the coming "trilemma" (crisis) and nuclear's role in helping struggle out of it was William Naughton, manager of research and development for Exelon Nuclear. The trilemma is defined as a potential convergence involving economic growth, consumption of energy and resources, and conservation of the environment. Driving the trilemma will be a world population increase to almost 10 billion by 2050, the need to stimulate economic activity to four or five times that of what it is today, the disparity of resources and living standards between the northern and southern hemispheres, and the environmental impact of a second Industrial Revolution.

Naughton

Nuclear is a solution to the trilemma, Naughton explained, because it could meet global energy demand and spur economic development, it has minimum environmental impact, and it minimizes consumption of valuable resources such as oil, wood, and gas. "In my opinion," said Naughton, "nuclear power is . . . the only currently available non-fossil energy source that has the potential to meet the global energy demand of the trilemma in the 21st century."

Plant designs

Following the plenary, another ICAPP session was held on "Plant Designs and Programs for Near Term Deployment." Malcolm LaBar, of General Atomics, described his company's Gas Turbine–Modular Helium Reactor. The GT-MHR couples a gas-cooled modular helium reactor, contained in one vessel, with a high-efficiency modular Brayton cycle gas turbine energy conversion system contained in an adjacent vessel. "The GT-MHR is meltdown-proof and passively safe," LaBar said.

LaBar explained that the GT-MHR's safety is achieved through a combination of safety characteristics and design selections that take "maximum advantage" of the inherent coated-particle fuel, helium coolant, and graphite-moderated gas-cooled reactor characteristics.

The GT-MHR currently is being developed in Russia under an agreement with the United States, LaBar said. The U.S. Department of Energy and Russia's Minatom are jointly sponsoring the development work, with support from Japan and the European Union.

Construction of the first commercial GT-MHR in the United States, once regulations are satisfied, would take about three and a half years, according to LaBar.

Another design on the horizon is the ESBWR. "The E in ESBWR might stand for economical," joked Atambir Rao, ESBWR project manager for GE Nuclear Energy, who added that E really just means E.

The ESBWR's simplified boiling water reactor design uses natural circulation and passive safety systems, Rao explained. The use of simplified systems "yields a plant design that is significantly simpler and smaller than traditional BWR designs, while producing approximately 1380 MWe," he said.

Rao

The ESBWR, which relies on "extensive utilization of the 670-MWe SBWR basic system and structural design," said Rao, has evolved as a result of multiple reviews involving European utilities, designers, and researchers, over a period of six years.

Dong-Su Kim, vice president of the NSSS engineering and development division for KOPEC, provided detail on the APR1400 design. It is a two-loop, 4000-MWt PWR that is based on South Korea's KSNP design that references the [Westinghouse] System 80+, according to Kim. It includes hot-leg temperature reduction to provide additional core thermal margin, a larger pressurizer to better accommodate transients and reduce challenges to the plant's safety system, and an increase in steam generator secondary water inventory to "smooth out" normal operating transients, Kim said.

Kim

The APR1400, which received regulatory approval in South Korea in May, has a design life of 60 years. KOPEC plans to have APR1400 units in operation in South Korea soon after 2010.

Bob Twilley, of Framatome ANP, explained the SWR (German for boiling water reactor). The design was developed by Framatome in cooperation with a number of European utilities. Development began in 1992 with a concept based on experience gained from the current fleet of BWRs.

Twilley said the incorporation of passive safety systems into the SWR design had improved it so that there would be no need for external power for several days following a postulated event. There would be "a three-day grace period," he said, meaning that "no operator interaction" is needed for up to three days after an accident, and "the core remains okay."—*Rick Michal* NN