At the 2011 ANS Winter Meeting's opening plenary session (from left to right): Session chair Joe Turnage; U.S. Rep. Steny Hoyer (D., Md.); Richard Lester (MIT); Michael Wallace and John Hamre (both CSIS); and Richard Meserve (Carnegie Institution for Science). (Photos in Opening Plenary and President's Special Session writeups: Brendan Hoffman)

ANS WINTER MEETING

The status of global nuclear deployment

Meeting session coverage:

- *The work of licensing board judges*
- *Fukushima Daiichi status and prospects*
- *Used fuel and the Blue Ribbon Commission's draft report*
- *New resources for nuclear engineering students*

EACH NATIONAL MEETING of the American Nuclear Society is given a theme, and while the theme seldom has much of an effect on the meeting's many technical sessions, it is often used by organizers to set the tone during the plenary sessions, which draw the largest attendance. For the 2011 ANS Winter Meeting, held October 30–November 3 in Washington, D.C., the theme was "The Status of Global Nuclear Deployment," something of a departure from the optimism and passion often expressed in the meeting themes.

At the opening plenary session, the first speaker was Rep. Steny Hoyer (D., Md.), who treated his appearance as congresspeople are wont to do: He delivered his prepared remarks, took no questions from the other panelists or the audience, and departed as soon as he was finished speaking. Talking first about the challenges that the federal government is facing in general (the sluggish economy, two wars), he then moved on to energy, noting difficulties such as U.S. dependence on foreign oil, the need to address climate change, and the bankruptcy of Solyndra, the solar energy company that had received a $535-million loan guarantee from the Department of Energy.

Hoyer said that the Fukushima Daiichi accident showed the importance of the Nuclear Regulatory Commission, adding that the major role of nuclear power is recognized in the United States, including by the Obama administration. He noted that in his home state of Maryland, there has been an effort to license a new reactor at the Calvert Cliffs site, although he inflated its potential somewhat, referring to it as 2 GWe of new capacity (the U.S. EPR reactor would be rated at about 1.6 GWe). He then moved on to the development of the domestic supply chain for nuclear power, which he said would be boosted by the "Make It in America" initiative that he and other congresspeople are backing. Also, he called for an infrastructure bank to support large-scale energy projects and for the expansion of the "smart" electricity grid, and he endorsed support for students in nuclear fields and university programs.

Richard Lester, head of the Department of Nuclear Science and Engineering at the Massachusetts Institute of Technology, began his talk by echoing Hoyer on the importance of supporting manufacturing in the

United States and nuclear education. He then expanded the scope, addressing in more detail the Fukushima Daiichi accident and its aftermath. He observed that nearly eight months after the event, there still had been no radiation-related fatalities, and perhaps there never will be. The nuclear accident has nonetheless been a major economic and industrial disaster, with more than 80 000 people uprooted from their homes, some of whom, he noted, will never be able to go back. Some power reactors in Japan are likely to remain closed indefinitely, he said, and in the Fukushima Daiichi vicinity there is now contaminated land and a large quantity of waste with no place to put it.

Lester added that the event was magnified by failures of governance and that the breakdown in public trust will be the legacy of the nuclear community in Japan. The problems encountered in a country with an advanced and mature nuclear industry showed that an accident of this magnitude could happen anywhere, but also that matters are made worse when certain principles—such as transparency and regulatory independence—are not upheld.

The effect of the accident on new reactor construction, Lester said, may be fairly small. In the group of countries that have responded the most negatively, the most prominent is Germany. Lester noted, however, that this is, in fact, a return to the planned phaseout that had been halted by the Merkel government. In a second group are countries that are still committed to expansion, among them China, Russia, India, South Korea, and the United Kingdom. More difficult to assess, he said, is a third group of countries that have not yet adopted nuclear power. Even so, he said, it appears that most of the countries exploring nuclear power will continue to do so.

Because nuclear power is likely to continue to expand and to be adopted by more countries, Lester said, it is important to uphold the principles of good nuclear governance. He said that it could be argued that even though currently operating reactors are already safe, new reactors could cause doubt to be cast on the safety of older reactors. He said that this is a serious argument, but he also said that he is not persuaded by it.

Lester reminded attendees that nuclear energy is still relatively young compared to other energy technologies—with the first human-induced nuclear fission having taken place within the past 75 years—and as a result, he said, it is difficult to project what will or can be done with nuclear energy out to the year 2100. Lester suggested that fuel cycles could be closed, advances in biology could remove fear from the public's attitude toward radiation, small modular reactors (SMR) could mesh well with the energy uses and needs of new nuclear countries, and high technology could lead to the development of better materials for nuclear applications. He said that work on these and other frontiers will be done by students from nuclear engineering programs who have entered the nuclear field in the last 10 years.

Next to speak was Michael Wallace, longtime top executive at Constellation Energy and its joint venture for new reactors, UniStar Nuclear Energy. He is now a senior advisor at the Center for Strategic and International Studies (CSIS), a consultancy. While much of his work in the early part of this decade was to establish in the United States a French power reactor design—Areva's U.S. EPR—his talk was primarily a lament about what he said is the lack of American industrial presence and leadership in the worldwide nuclear enterprise. He began with rhetorical questions: First, why is nuclear power successful? His answer: innovation, dedication, and perseverance. Second, have we lost root-cause analysis techniques? He did not answer this one, perhaps implying an answer of "yes" in what he said later.

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Wallace said that nuclear power is being aggressively deployed in much of the world, and that in his view, there is relatively little new reactor effort in the United States. He listed the countries already known to be building new reactors, with an assertion that China would have 200 reactor projects by 2030. By his count, there are 61 countries without nuclear power that want to introduce it. Wallace said that the United States has lost its capability to be the main supplier for the world's nuclear electricity generators, and as a result is "losing its voice" to influence nuclear deployment elsewhere. The United States, he said, needs to move aggressively to build nuclear power plants. "The path forward is ours to set," he added. "We need a new paradigm for nuclear energy in the United States."

Wallace's message was generally echoed by the next speaker, John Hamre, president and chief executive officer of CSIS. Based on statements made later in the question-and-answer period by other plenary speakers and audience members, however, the CSIS assertions did not seem to draw majority support from those present. Wallace's statement, "We do not make anything significant for nukes now," seemed to be contradicted by the presence elsewhere in the building of the ANS Nuclear Technology Expo, which was much larger than the one two years earlier. Even allowing for the presence of non-U.S. companies there, the U.S. industry lately has shown considerable vigor despite the lingering stagnation of the economy as a whole.

As for Hamre, he described himself as a "defense guy" with, by his own admission, not much expertise in nuclear power. As part of a discussion branching from an audience member's question about whether the World Association of Nuclear Operators (WANO) should become more like the Institute of Nuclear Power Operations, Hamre did state that the United States will have to negotiate a new nuclear cooperation agreement with South Korea and that it should be based on transparency.

Later, however, Hamre said that with U.S. expertise eroding in the area of nuclear weapons as well as in nuclear energy, the barrier between the civilian and military nuclear realms should be removed. He also said that ANS should not shy away from lobbying for nuclear energy. While it is possible for ANS and its members to *advocate* for nuclear energy, however, the society's legal status does not allow for *lobbying*—specifically seeking to influence legislators and government policymakers. As for the line between the civilian and military realms, ANS has long been dedicated to the peaceful uses of nuclear energy.

The final speaker was Richard Meserve, a former chairman of the Nuclear Regulatory Commission and now president of the Carnegie Institution for Science. Like Lester, he looked at the worldwide nuclear industry in the aftermath of Fukushima Daiichi. Meserve said, as many others have, that there could never be an international nuclear safety regulator along the lines of the NRC, because no nation would give up its sovereignty to allow such an organization to have that much influence.

Among the recent developments Meserve considers favorable are the extent to which the International Atomic Energy Agency is becoming involved with reactor safety (notably at this year's IAEA General Conference—*NN,* Nov. 2011, p. 56) and what he called "an unfolding exercise" at WANO's meeting in Shenzhen, China, where members began considering a stronger role for the organization. He also cited the effort of an organization related to his own, the

Carnegie Endowment for International Peace, to enlist nearly every power reactor supplier to adopt a code of exporter conduct principles (*NN,* Oct. 2011, p. 116), ranging from radiological safety and environmental protection to ethical issues such as the prohibition of child labor. Meserve said that the companies would meet, perhaps in December, to decide whether to set up a staff to oversee compliance with the principles.

Rather than place microphones in the audience, session organizers chose to have attendees write their questions on cards, which were then filtered and presented to the panel by the session chair, Joe Turnage. Responding to many of these questions, Lester and Meserve took a more positive view of the state of the U.S. nuclear industry and its role in the world than Wallace and Hamre did. Lester said that the technology is strong and innovative in the United States, and that he thinks it's good that there are centers of excellence in other countries as well. Just because innovation in nuclear energy is global, he said, domestic capability should not be underestimated. Wallace, stating a willingness to be "provocative," contended that the future market will not be only for SMRs, and that it would be a mistake to decide against building Generation III+ reactors.

Meserve, responding to a view that Wallace had expressed earlier, said that U.S. influence on the rest of the world's nuclear programs can come from a variety of sources—not just the recent profusion of SMR designs, but also the passive-shutdown reactor designs developed in the United States, the laser enrichment of uranium, and the skilled operation and high capacity of the current generation of reactors.

President's Special Session

Soon after being elected ANS President, Eric Loewen was asked to consider making the adjudication of licensing issues by Atomic Safety and Licensing Boards (ASLB) the topic for the President's Special Session at the Washington, D.C., meeting. Loewen soon realized that the work of ASLB judges is of critical importance to the industry and that the process should be of interest to many nuclear engineers in the society, like himself. The result was the ANS President's Special Session: Adjudication in the Licensing Process—Fact and Fiction.

Loewen

Licensing adjudication, Loewen said, is designed to provide openness and transparency in licensing nuclear activities. The process evolved from the Atomic Energy Act, which states that the public has a right to obtain a hearing on important legal matters.

NRC Chairman Gregory Jaczko opened the panel session with an overview of licensing adjudication. "In my experience," he said, "the hearing process has significantly enhanced our regulatory decision-making by focusing attention on issues of high public interest and bringing in outside expertise on matters of dispute."

Jaczko

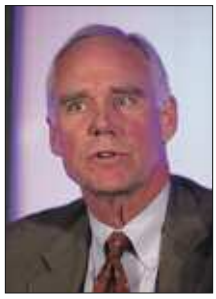
The licensing process provides a means for someone with concerns over a licensing matter to request a formal hearing. Over the years, Jaczko said, limits on the scope of the process have been introduced. Members of the public and other entities that are directly affected by any licensing action can put forward their concerns, however, and if they can make a suitable case, they can obtain a formal hearing in front of the independent judges of the ASLB. Generally speaking, these hearings are sought by those who reside or work near a licensed facility and who believe that a proposed action raises environmental or safety concerns. Participants include individuals, private citizen groups, businesses, and governmental bodies.

Jaczko added that this also allows the public to see how the NRC does its job, which ultimately helps build public confidence in the agency's decisions.

The hearings, he said, cover a wide array of licensing and enforcement matters and require judges to evaluate a broad range of safety and environmental issues. The judges that sit on ASLBs include lawyers and technical experts, both full and part time. The licensing boards are independent of the NRC, although the commission does select the panel members.

There is another type of hearing that does not necessarily involve disputed issues. For some major licensing activities, such as the licensing of new reactors, mandatory hearings are held, with no need for any issues to be raised by the public. The first mandatory hearings on new reactor license applications were held only a few months ago for the proposed Vogtle and Summer projects. Although the public doesn't actively participate in a mandatory hearing, it does have an opportunity to hear firsthand the bases on which safety decisions are made. Jaczko said that he found that the mandatory hearings left him much better informed about the work that went into the staff reviews, as well as the work that the applicants have done in preparing their applications.

Roy Hawkens, the chief administrative judge of the Atomic Safety and Licensing Board Panel, described licensing boards as "trial courts" that ultimately issue a decision to resolve questions that arise during hearings. A licensing board generally consists of three individuals: an attorney who acts as the chair, and two members who have advanced training in a technical area such as physics, engineering, or environmental science. The members of each board are selected from the licensing board panel, which currently consists of 17 full-time judges, 10 of whom are attorneys, and 25 part-time judges, 23 of whom have technical expertise and two of whom are lawyers.



Hawkens

The adjudicative process is divided into three stages: the hearing request, the NRC staff review, and the evidentiary hearing. During the hearing request stage, those who want to participate—or intervene—in the process must submit a written request that includes an explanation of their interest in the licensing action and their specific concerns. The licensing board will then assess whether the intervenor has offered up at least one suitable issue. If the board decides that at least one issue has merit, the hearing process will go forward.

The review stage involves the NRC staff's preparation of safety and environmental review documents. Once these are issued, the board must schedule the hearing within 175 days. Following the completion of the hearing, the board is required to issue a decision within 90 days. The hearings are informal—that is, the judges themselves question the witnesses. The participants provide written, direct, and rebuttal testimony, as well as relevant documentary evidence prior to the hearing.

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Continued

Hawkens stressed that transparency and public access are critical to the process if public confidence in the adjudicatory process is to be maintained. To achieve transparency, the public must have access to the same information that the licensing board has, and it also needs to understand the analysis and decision-making process. To those ends, he said, the boards have to create an adequate record, provide access to the hearings, and craft decisions that can be well understood by the parties who appear before them, and by the general public as well. He added that a lot ultimately depends on the quality of the hearings and their perceived fairness and professionalism, as well as the quality of the decisions.

Kathryn Sutton, leader of the Energy practice at Morgan Lewis, discussed the process from the perspective of the applicant—that is, the organization submitting the license application. She noted that the intervenors must first demonstrate that they meet the acceptance criteria to petition the board, and second, that they proffer at least one specific concern—or "contention"—that is deemed admissible for the board to undertake a full hearing. At this point, an applicant must ensure that the intervenor meets these two prerequisites and adheres strictly to the NRC's procedural rules.


Sutton

If one or more contentions are deemed suitable for consideration, then a disclosure process begins that involves making all relevant information available to all parties. The burden of the process at this point shifts to the applicant, who hopes to establish that the contentions are without merit. An applicant can also address some or all of the contentions made by the intervener. If satisfied with the measures taken, the applicant may request that the particular contentions be dismissed. The objective for the applicant, she said, "is to narrow the scope of issues as we proceed through the hearing process." This is fair, Sutton said, because at the same time, the intervening parties also have an opportunity at any time to bring forward new or amended contentions, which could be in response to new material information, such as relevant lessons coming from the Fukushima Daiichi accident. If contentions remain, the actual hearing will begin once the NRC staff completes its environmental and safety reviews.

In general, Sutton said, applicants view the process as fair, thorough, and transparent, while stressing that it is governed by rules that they believe should be applied with rigor, particularly at the beginning of the process, when the admissibility of contentions is being determined. She also noted that there are very stringent standards regarding an applicant's ability to appeal ASLB rulings, and that opportunities to appeal are rare.

Stephen Burns, the NRC's general counsel, spoke about the commission's role in the process. He first noted that having both technical and legal members on an adjudicatory board, which was introduced in 1962 in the Atomic Energy Act, was truly innovative. Before that, only judges who were lawyers could decide cases, with the help of technical advisors.


Burns

Burns also referred to another role of the NRC, which is to act as the appeals board for ASLB decisions. Furthermore, the commission decided a few years ago that in the case of mandatory hearings for new reactor licensing, it would initially assume the role of the licensing board. This will provide an opportunity for the commissioners themselves to probe the staff on their evaluations and then make the final determination.

Burns also discussed a concern often put forward by critics that the NRC staff is effectively an advocate for the applicant and should not be a party in the proceedings at all. This concern is taken seriously by the commission, Burns said. The staff's position is that it is not an advocate for any party but is there to explain its assessments and other actions. The commission's view is that the staff's participation helps to inform the decision process. Another argument in favor of the staff's position, he said, is that the staff's participation ensures the openness and transparency of its work. Ultimately, the staff is there as a representative of the public interest, Burns stressed, adding that it does not have "a zealous will to win," as has been suggested. The most recent example of its role being challenged was in connection with the Yucca Mountain proceedings, when the state of Nevada asked that the staff be removed as a party to the hearing, which the NRC denied.

Richard Webster, of the Group for Public Justice, a public interest law firm that represents intervenors, listed a number of what he considered weaknesses in the hearing process. These include the extent of the restrictions on who can intervene and the issues or contentions that are allowed, and the limited accessibility to data and other information from the applicants. Greater accessibility, he said, would allow the public to better assess the projects themselves. He also expressed his belief that applications for operating license extensions should be subject to mandatory hearings, just as new reactor license applications are.


Webster

Webster explained that under the current approach, intervenors have to engage in a guessing game regarding the possible inadequacies in an application, since they don't have the needed information until the discovery part of the process. He called this a "catch-22" situation.

He also posed a question to the audience: "Why should you engineers care about this process?" The basic reason, Webster said, is that if the public doesn't trust the nuclear establishment—basically the industry and the federal government—plants won't be built. Furthermore, if distrust is high, a lot of plants will close, as is happening in Germany. The public has lost trust in the nuclear establishment in many areas, he said. For example, people living near nuclear power plants thought they had an understanding with the U.S. government that the nuclear waste would be taken away. This has not happened.

Webster said that the licensing process is really about building public trust, and that allowing the public to participate vigorously in licensing proceedings would be good for the industry. Those in the industry, he said, should want to make the process even more effective.

It is not as if the industry has suffered from too much adjudication, Webster said, adding that it has suffered from too little, as public participation in the process has been shown to lead to better safety. After all, in the real world, neither the applicant nor the NRC will get it right all the time. In this respect, he noted, the process has identified

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and rectified problems that had been missed. For example, there are now more frequent checks on corrosion in the containment at Oyster Creek and better pipe-leak detection at Pilgrim, while intervenor concerns led to the discovery of oversimplified corrosion calculations at Vermont Yankee. If safety is the most important concern, Webster said, "then those in the industry should be very happy that there are contested hearings."

The BRC and used fuel

The Blue Ribbon Commission on America's Nuclear Future was established about two years ago by Energy Secretary Steven Chu, who was asked by President Barack Obama to set up a board to conduct a comprehensive review of the back end of the nuclear fuel cycle and to make recommendations for a new path forward.

In July 2011, the BRC issued its draft recommendations, which include, among other things, centralized interim storage, the development of a new entity with the single purpose of handling the waste management program, and the possibility of more than one geologic repository (*NN,* Sept. 2011, p. 43). The final report is scheduled to be submitted to the energy secretary by January 29, 2012.

At the session titled, "Path Forward for Spent Fuel Management: Blue Ribbon Commission and the Next Step," the panelists commented on various aspects of the BRC's draft report.

Charles Forsberg, the session cochair and a research scientist in the Department of Nuclear Science and Engineering at the Massachusetts Institute of Technology, opened the session by posing questions about the BRC's draft recommendations. Among them: Does a new federal management entity have to be created before centralized interim used fuel storage is implemented? How does the BRC propose to assure access to the Nuclear Waste Fund to finance an integrated used fuel management program?


Forsberg

Forsberg explained that the issue of waste management is not a new one. He quoted from a 1982 report of the Office of Technology Assessment (OTA), an arm of the U.S. Congress, that laid the basis for the Nuclear Waste Policy Act. From the report's executive summary, Forsberg read, "The greatest single obstacle that a successful waste management program must overcome is the severe erosion of public confidence in the federal government that past problems have created. Federal credibility is a question on three main grounds: Whether the federal government will stick to any waste policy through changes in administration; whether it has the institutional capability to carry out a technically complex and politically sensitive program over a period of decades; and whether it can be trusted to respond adequately to the concerns of states and others who will be affected by the waste management program."

Forsberg said that the OTA's report suggests that "if history is not to repeat itself and the current stalemate on nuclear waste is not to continue, a comprehensive policy is needed that addresses the near-term problems of interim storage as part of an explicit and credible program for dealing with the longer-term problem of developing a final waste isolation system."

Such a policy, he said, must adequately address the concerns and have the support of all major interested parties, and it must adopt a conservative technical and institutional approach, one that places a high priority on avoiding the problems that have repeatedly beset the program in the past.

Thomas Cotton, a public policy consultant working with the BRC, said that in the United States there is now about 65 000 tons of used fuel, about 75 percent of which is in reactor pools and the rest in dry storage. There is also about 2500 tons of DOE defense waste that needs to go to a national repository.

Cotton said that the BRC took a hard look at all of the siting experiences for nuclear waste facilities in the United States and abroad, and its conclusion was that a new approach to siting and developing waste management facilities would be appropriate.

"Let me quickly add that the commission was not asked to—and it did not—say anything about Yucca Mountain and render anything about the withdrawal of the license application," he said, adding that the BRC recommendations are aimed at being relevant, whatever the fate of the legal process regarding Yucca Mountain.

The BRC concluded that a consent-based approach involving a willing and informed host community and state for a waste program would be the best solution. "The commission believes that such a process can work, based on what it's seen in other countries and based on what we've heard from various communities and states in the United States," he said. "It needs to be a transparent process based on clearly defined safety standards and the scientific process."

The BRC also concluded that it is time for a new single-purpose organization that is focused only on radioactive waste management. Cotton said that the BRC recognized that the DOE's high-level waste program at its peak had an appropriation of about $500 million a year, while the DOE had a $25-billion annual budget "and a lot of other distractions."

The BRC also found that it is very important for the new single-purpose organization and waste management program to have assured access to the funding that is now being provided by utilities and the ratepayers for the sole purpose of accepting and disposing of their high-level waste and used fuel, he said.

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Brian O'Connell, director of Nuclear Waste Program Policy at the National Association of Regulatory Utility Commissioners (NARUC), explained that NARUC represents the state public service commissions that regulate utilities in the United States. "Our interest in this activity is primarily to ensure that the government fulfills its statutory and legal contractual obligation to remove the waste from where it is—presently at 72 sites around the country—and dispose of it in accordance with the Nuclear Waste Policy Act," he said.

NARUC is also interested in protecting the ratepayers' investment in the Nuclear Waste Fund, which has about $27 billion in it, O'Connell said. "If I fault the [BRC's] work so far, it's [that the report is] a policy document, where some of us were expecting at least a ballpark estimate for what some of these activities were going to cost," he said. The BRC report calls for consolidated interim storage and perhaps multiple repositories, yet there is no mention of the cost for these things, he added.

O'Connell also commented that NARUC has a different view of consolidated interim storage "because we suspect that not all holders of used fuel will have their fuel sent to the interim storage facility, yet they will all be expected to pay for it" if it comes out of the Nuclear Waste Fund. He continued, "I would suggest that instead, a fee-for-service

charge be assessed to only those who use the facility."

Everett Redmond, director of nonproliferation and fuel cycle policy for the Nuclear Energy Institute, said that interim consolidated storage could be created even before a new management entity is set up. "Consolidated storage is something we know how to do right now," he said. "We do dry cask storage at over half of the facilities in the United States. Eventually, we'll do it at all of the reactors."

Redmond noted that the NRC's regulatory structure for dry cask storage and away-from-reactor independent spent fuel storage installations (ISFSI) is already in place and has been exercised, citing the Private Fuel Storage ISFSI in Utah that was licensed by the NRC but was never built. "So the regulatory structure exists, the cask design exists, and transportation is something that we've also done successfully in the United States," he said. "In general, we have all of the tools necessary to do a consolidated interim storage facility, and we have the capabilities. We could have a facility up and running in less than 10 years."

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In order to make centralized interim storage happen, he said, legislation instructing the DOE to implement it would be "extremely beneficial, if not necessary." A willing host community would also be needed.

Sven Bader, an advisory engineer with Areva Federal Services, questioned the lack of timelines in the BRC report. He said that the report often mentions "intergenerational inequity," which can most simply be defined as something left behind by one generation to be dealt with by the next generation. He quoted the report: "The generations that created this waste and benefit from the activities that produce it have an obligation to insure that the entire burden for providing for the disposal does not fall on future generations."

Bader added that there is a disconnect in the report in that it often mentions intergenerational inequity and the need to expeditiously develop a geological repository and a consolidated interim storage facility, but at the same time it claims that such actions will take time to fully implement, that the adaptive approach is particularly slow and open-ended, that patience will be required in every aspect of a program's implementation, and that implementing the BRC's strategy will not be quick. "So, you ask all these questions and follow them up with all these reservations—we're going to get a timeline that's going to be very unfortunate," he said. But, he added, "I think the BRC acknowledged that."

Forsberg, who opened up the session, wrapped it up as the final speaker by asking whether the BRC had focused on the right things. The BRC tackled the issue of how the United States could site a geologic repository, he said, but it should have looked at how to make repositories attractive industrial facilities and at how to design a fuel cycle as if starting from scratch.

"The fuel cycle as we know it is an accident of history," he said. "It was not designed. It just happened. The traditional fuel cycle implies separate facilities and locations. This is a legacy of World War II and the Cold War."

He explained that the United States built the Savannah River Site in South Carolina, on the opposite side of the continent from the Hanford Site in Washington state, "because we worried about the possibility of common-mode failures, earthquakes, and Russian bombers. These are not appropriate site criteria to be concerned about today."

Forsberg's message was that siting a reprocessing plant alongside a waste disposal facility would improve the economics, efficiency, and public acceptance of both (see article, *NN,* Nov. 2011, p. 40).

Fukushima Daiichi review

John Gunning, of Oak Ridge National Laboratory (ORNL), organized and chaired the panel session titled "Fukushima Daiichi—Event Sequence, Dose to Public, Current Status, and Proposed Decommissioning Path." The session focused on the accident sequence, which started with the magnitude 9 earthquake of March 11 and the tsunami that followed an hour later, and the current status of the three main damaged boiling water reactors at the site. Descriptions of and insights on the events were provided by U.S. specialists based on what is known about the accident progression, including the responses of the plant and the men and women working there, who were greatly admired for what they achieved and how they went about it.

The first speaker, Larry Ott, also of ORNL, focused on the defining characteristics of the accident: station blackout (SBO) and the loss of the "ultimate heat sink," which at the Fukushima station was the ocean. This meant that even though station crews were able to get power back and to start up vital systems, the inability to restore a connection to the ultimate heat sink made it extremely difficult to recover control of the reactor and prevent core damage.

Ott described what occurred at the plant as the accident unfolded, providing information on the condition of the most important systems and components and the consequences when they failed. He made use of the work on severe accidents at BWRs that was undertaken at ORNL after the Three Mile Island-2 accident in 1979, noting that most research efforts focused on pressurized water reactors. The events that unfolded at Fukushima, Ott said, are consistent with the well-developed understanding of the consequences of an SBO, along with the loss of functioning systems caused by the tsunami and the difficulties that ensued in bringing the reactors under control. An SBO, he said, is the most probable BWR accident sequence resulting in a loss of water injection. "It is not like this accident came totally out of left field," he said.

Following reactor scram and the loss of off-site power, the emergency diesel generators started and other emergency equipment—including the isolation condensers (Unit 1 only) and the reactor core isolation cooling (RCIC) pumps—operated as intended. The earthquake caused switchyard damage and the collapse of transmission lines leading into the plant, but did not significantly damage the units. It was the tsunami's 14-meter-high waves that did the real damage. Essentially all of the electrical motor-driven pumps, including the emergency core cooling system pumps, became inoperable. This left only some of the steam turbine–driven RCIC and high-pressure core injection (HPCI) pumps available, and they were expected to operate for only a few hours. Somehow, Ott said, the crews were able to operate these pumps at Units 2 and 3 for a few days. Eventually, however, reactor pressure built up and it was necessary to vent the reactor vessel. Then began the fight to achieve and maintain low-pressure water injection into the core to prevent further damage to the reactor and to contain radioactivity as much as possible.

The post-TMI BWR severe accident research done at ORNL continued until 1999. Ott described particular BWR features relevant to a severe accident. For example, BWR cores contain about three times more zirconium metal than a PWR core, with the potential for significant hydrogen production during a severe accident. Because the

outer 25 percent of a BWR core is at a much lower power level than the center, he said, the outer section will still be below Zircaloy oxidation temperatures when core debris from the middle portion could already be relocating to the bottom of the reactor vessel. Actually, he added, the first of the core structures to relocate in a BWR accident are the cruciform control blades. There are also significant steel structures in the bottom head of the reactor vessel where the control blades are withdrawn, requiring at least 3.7 m of depth below the core. There are about 100 tons of steel just in the control rod structures, as well as a huge amount of water filling up the large volume—enough, Ott said, to quench three completely molten cores. And so, as this material drops to the bottom of the reactor vessel, there will be a considerable blow-off of steam before it can attack the bottom head.

The first BWR accident sequence studied at ORNL was of an SBO at Browns Ferry-1, a BWR 4 with a Mark-1 containment. According to Ott, some of the findings of this and other studies concerning accident progression included many of the events that occurred at Fukushima, such as water levels dropping to uncover the core, steam pressure building up and requiring the reactor vessel to be vented, and the generation of hydrogen. The timing seemed consistent with the events in Japan. In one ORNL example, Ott described significant hydrogen generation starting about 80 minutes into the sequence and generating over 600 kg of the gas, adding that about 200–250 kg of hydrogen was thought to be enough to do the damage seen at Fukushima Daiichi-1 and -3. He also made the point that when injection is lost, a clock starts ticking for the operators to get low-pressure injection into the reactor started after the steam blow-off to avoid core damage.

The team was called on to answer questions from other BWR customers, the national labs, the NRC, and the media. It received over 100 questions the first day alone.

Curt Robert was part of GE Hitachi Nuclear Energy's response team that was set up the day of the event with the primary task of supporting Fukushima Daiichi's owner, Tokyo Electric Power Company (Tepco). Robert, with a background in reactor operations (he had been a licensed senior operator), took on a role that he described as being similar to a shift technical advisor, since he would have an understanding of what the workers would be doing at the Fukushima units to respond to the emergency. The team was also called on to answer questions from other BWR customers, the national labs, the Nuclear Regulatory Commission, and, eventually, the media, and it received over 100 questions the first day alone.

Besides having to deal with a great deal of misinformation coming out of Japan the first few days after the accident, the GE Hitachi team lacked up-to-date data about the plants and their designs and modifications. The available drawings showed the units "as-designed," not "as-built." The team also lacked the latest operating procedures, notably the Emergency Operating Procedures and the Severe Accident Management Guidelines, that would provide information on what the staff at the plant would be trying to do. Nevertheless, the team was able to develop models of the plant and other tools to help it understand and assess the conditions at the plant and to consider how to mitigate the consequences of the accident. As more data came in, the team was able to build up the models and see more clearly what could likely happen. Considering the limited information available, Robert said, he was quite proud of what the team accomplished.

The team ran many simulations to trend the data, he said, stressing that during an emergency like this, mitigating the event was more important than diagnosing exactly what had happened, and understanding the data trends would help in determining the best emergency procedures to implement.

Robert acknowledged that while his team was working to help and advise its colleagues in Japan, Tepco was ahead of his team most of the time. Nevertheless, the information the team provided validated what Tepco was doing and likely gave Tepco's people a sense that they were doing the right thing.

He described some of the emergency procedures that Tepco staff undertook, such as scavenging batteries from cars in the parking lot and connecting them to the RCIC pumps after the tsunami had rendered all of the plant batteries inoperable. Robert mentioned that as an operator he had been trained to get air-operated valves working using portable air compressors—the kind that are available at stores such as Home Depot—to vent a primary containment during an emergency. He noted that it was likely that this would have to be done in the dark with alarms going off and workers wearing rain gear. But more important, Robert said, Tepco has depositions from operators of exactly what happened at Fukushima, providing a chilling account of the accident.

A baseline MELCOR model of the accident was put together in order to begin to understand what had happened at Fukushima and to answer questions such as what fraction of the core was damaged.

The last speaker, Randy Gauntt, worked in reactor safety and severe accidents for 29 years at Sandia National Laboratories. He was involved in developing the MELCOR severe accident modeling code, which he said he found extremely useful during the month he spent at the American Embassy in Tokyo providing advice to U.S. interests and the Japanese government. At the time, he said, the emphasis was on the security and safety of American citizens and assets. People had been evacuated, and the embassy wanted to know what to tell them about when they could return. He also had regular visits from U.S. Navy personnel, as the aircraft carrier USS *Ronald Reagan* was off the coast of Japan. Having measured elevated radiation levels, they wanted to know what the potential risks were. Gauntt also noted that he spent a lot of time explaining what a severe accident is.

With his team back at Sandia, Gauntt noted, a baseline MELCOR model of the accident was put together in order to begin to understand what had happened at Fukushima and to answer questions such as what fraction of the core was damaged and how much fission product was released. As an

example, he mentioned the time when a big aftershock cut off power to the plant, halting the tenuous system for injecting water into the damaged reactors and spent fuel pools. The team later modeled the consequences of water injection being completely lost as a result of such an event and how long it would be before the situation would seriously degrade.

Gauntt said that the TMI-2 accident prompted about $500 million in severe accident research and resulted in the development of sophisticated codes that are able to model all facets of reactor accidents, including thermal hydraulics, core melting, fission product release, hydrogen generation, and the transport and behavior of fission products.

Gauntt described the Mark I containment system toroidal suppression pool as a small lake that also functions as a large heat sink. When the reactor scrams, the power quickly drops by over 90 percent, he said. The decay heat is relentless, however, and at Fukushima, being cut off from the ultimate heat sink leaves the suppression pool as the last meaningful cooling source available until further cooling capability is provided. He then explained how the RCIC steam-driven pump worked to maintain water level in the core. Unfortunately, these pumps lose their pumping power as the suppression pool water temperature nears the boiling point. By the time the pumps could no longer work, he said, "you're approaching 'game over' if you haven't connected to another heat sink."

Using a diagram of the accident timelines for each of the units, Gauntt showed when certain events occurred, such as the start of core damage and the hydrogen explosions. Core damage began first at Unit 1, which lost all cooling capability quite soon after the tsunami hit. Units 2 and 3 made it farther, as workers were able to cool the cores using emergency systems for some time. Eventually, however, an unexpected event—such as a hydrogen explosion—would end that capability, with core damage following.

Gauntt explained the procedure for hooking up a low-pressure injection system when the emergency cooling pumps are no longer operating, including venting the reactor vessel to relieve the pressure so that low-pressure pumps, such as on fire trucks, can be hooked up. Even so, he explained, the pressure inside the reactor was working against the low-pressure pumps and making it difficult to maintain injection.

Next, he compared MELCOR modeling of the accident against actual results. His first example was to model water levels during the depressurization of the reactor and initial injection of water. The modeling followed the actual event quite well, he said, noting that it was clear from the actual data, as well as from the model, that the whole core had been uncovered at some point.

Gauntt also showed an analysis of the Unit 2 drywell pressure. The first simulations showed much higher pressures than in the actual event. The team then did a forensic analysis, determining that a hole somewhere in the primary containment would account for the lower pressure (in fact, a 2-inch hole successfully simulated the situation), and speculated that it could have been in the bellows connection between the wetwell and the drywell. He also noted that the hole provided a pathway for hydrogen to escape. The codes performed pretty well overall, Gauntt said, adding that he hopes that they will be used to map out better responses to a serious accident. Codes are key to managing risk, he noted, and the Fukushima accident is going to be an invaluable reference point in further developing and validating them.

Gauntt summed up by saying that efforts to remove decay heat to avoid core damage failed at Fukushima Daiichi. Furthermore, the reactor depressurization and low-pressure water injection weren't altogether successful. At times, efforts to maintain adequate cooling appeared to be having some success, but some unforeseen event—a hydrogen explosion, running out of cooling water, an earth tremor forcing the site to be evacuated—would eventually occur, halting the recovery. The same could be said of mitigation efforts, he said, although the releases of radioactivity are believed to be modest, about 1 percent per reactor (although some members of the audience indicated that they thought it could be more). The response to the accident, Gauntt said, has required inventing a lot of *ad hoc* measures. Sometimes, however, no good solutions are available.

Codes are key to managing risk, and the Fukushima accident is going to be an invaluable reference point in further developing and validating them.

Workforce development

A general session sponsored by the Education, Training and Workforce Development Division covered a variety of topics, including the university-laboratory partnership program at the Advanced Test Reactor (ATR) at Idaho National Laboratory, a rotational program for early-career nuclear engineers at Pacific Northwest National Laboratory, and a nuclear training program at the Jožef Stefan Institute in Slovenia.

In 2007, the Department of Energy designated the ATR a national scientific user facility (NSUF). This designation made test space and post-irradiation examination (PIE) equipment at the ATR available for use by researchers, according to ATR Manager Frances Marshall, with the goal of providing them access to the most advanced test capability.

The ATR NSUF has established a partnership program with seven universities and Oak Ridge National Laboratory (ORNL) that has added reactor-testing space, additional PIE equipment, and ion beam irradiation facilities to its capabilities. "With the addition of these capabilities," Marshall said, "irradiation can occur in multiple reactors, and post-irradiation exams can be performed at multiple laboratories."


Marshall

The partnership program has allowed materials to be analyzed at the Advanced Photon Source at Argonne National Laboratory, the National Institute of Standards and Technology's Center for Neutron Research, the Los Alamos Neutron Science Center, and the Shared Research Equipment user facility at ORNL. In addition, because ORNL is a partner facility, ATR NSUF users have access to the High Flux Isotope Reactor and related facilities.

Marshall said that to date, 11 experiments have been performed at the partner facilities. (For more details on the ATR NSUF, see *NN,* Aug. 2011, p. 42.)

Ryan Boscow, university recruiting program manager at Pacific Northwest National Laboratory, described a pilot program launched in 2009 at PNNL to prepare graduates with nuclear-related master's degrees for career positions in research and development. The candidates complete three rotations in nuclear-focused R&D teams across several project areas, which to date have included safeguards and nonproliferation, nuclear systems engineering and analysis, radiological sciences, and risk and decision sciences.


Boscow

Although only a few candidates have gone through the program so far, Boscow said, "significant value has been created for the development of the candidates entering the workforce, as well as for the technical teams within the laboratory."

Sama Bilbao y Leon, director of the nuclear engineering program at Virginia Commonwealth University, detailed the school's Visible Nuclear Reactor, which was designed and built entirely by VCU undergraduates.

VCU does not have its own research reactor to provide students with hands-on experience in the operation of a nuclear reactor, and so the Visible Reactor was developed to fill the void. The reactor is a 3-kW design patterned after a full-scale pressurized water reactor. The various components of the reactor are transparent, allowing students to visualize the thermal hydraulics and heat transfer phenomena taking place in the system. The Visible Reactor is equipped with a human-machine interface that allows operators to control and regulate the actuation of the various components and to monitor pressure, temperature, and flow throughout the system.

Bilbao y Leon

"The VCU Visible Reactor is a valuable asset to the VCU engineering program," Bilbao y Leon said. "It serves as a useful and unique tool in classroom instruction, as well as a practical avenue for new senior design projects each year."

Steven Krahn, a professor of the practice of nuclear environmental engineering in the Department of Civil and Environmental Engineering at Vanderbilt University, described a new master's degree curriculum in nuclear environmental engineering that will bring together students from varying industry backgrounds who will move together through the program. Each cohort class is expected to have students from the DOE, the NRC, the Environmental Protection Agency, state regulatory agencies, and the private sector, such as the DOE's site operators, utilities, and major suppliers.

Krahn

Krahn said that the new program will be offered in a format that provides several advantages to the participating students because of the nature of the curriculum delivery, which is designed to be convenient to mid-career professionals, and the locations, which in addition to Vanderbilt will include hands-on experience at major nuclear sites and facilities. For example, it is planned that the nuclear chemistry course will take place at a national lab, while the course in life cycle management of nuclear fuel cycle facilities will likely include a detailed walk down of a nuclear power plant and its support facilities.

Krahn said that students will develop an understanding of thermodynamics, kinetics, and mass transfer applied to chemical processes; hydrology; health physics and nuclear measurements; nuclear chemistry and associated chemical processes; life cycle management of nuclear fuel cycle facilities; nuclear waste storage, processing, and disposal; environmental performance assessment; nuclear and chemical process safety (including reliability insights); and nuclear environmental regulations and standards.

Admission guidelines have been developed and the new courses have been approved by the Vanderbilt School of Engineering faculty and its curriculum committee, Krahn said. The launch of the program is planned for January 2012.

Igor Jenčič, of Slovenia's Nuclear Training Center (its abbreviation in the Slovenian language is ICJT), discussed the training and public information activities being conducted at the center.

"The VCU Visible Reactor serves as a useful and unique tool in classroom instruction, as well as a practical avenue for new senior design projects."

Slovenia operates one nuclear power plant, Krško, a 666-MWe Westinghouse PWR located in the southeastern part of the country. The nuclear share of electricity production in Slovenia is about 38 percent.

Jenčič said that the training of future plant operators begins with the theoretical part at the ICJT, which is located in Ljubljana, the capital of Slovenia. The training continues on nuclear power plant systems, the simulator, and hands-on experience at the Krško plant. The ICJT is an organizational unit of Jožef Stefan Institute (JSI), which is the largest national research lab in Slovenia.

"In addition to professional expertise from research departments," Jenčič said, "this setup enables easy inclusion of the TRIGA research reactor in the training process, and also public trust arising from the academic reputation of JSI."

He added that the vision of the ICJT is to be a respected source of knowledge about nuclear technologies in Slovenia and internationally. In addition to the training of plant operators, it offers classes in nuclear technology and radiation protection. It also welcomes foreign students for international training courses.

A few years after the Chernobyl accident in 1986, the activity of the ICJT expanded to include public information. Jenčič said that ICJT lecturers proved to be quite effective in presenting relatively complex nuclear issues in a simple manner to the general public.

Public information is provided through live lectures, a permanent exhibition on nuclear energy, several publications, and a Web site (<www.icjt.org>) that includes information on energy and electricity, nuclear physics, the greenhouse effect, nuclear plant technology, and radioactive waste disposal.

I&C upgrade planning

The trend toward digital instrumentation and controls is driven in large part by the aging of power reactors' original analog equipment and the growing difficulty in obtaining replacement parts, which in many cases are no longer being manufactured. The project undertaken in recent years at Pacific Gas and Electric Company's (PG&E) Diablo Canyon plant is somewhat different: Digital I&C has been brought in to replace an earlier digital I&C system, which had replaced an even earlier analog system.

The Eagle 21 digital process protection system (PPS) was installed in 1994 to replace Westinghouse's original analog 7100 PPS. John Hefler, principal engineer/technical manager at Altran Solutions Corporation, said that the Eagle 21 PPS had to be replaced because of long-term obsolescence and maintenance issues.

Hefler noted that diversity and defense-in-depth (D3) was a major issue when Eagle 21 was installed, and remained a major issue regarding its replacement. In 2006, when the replacement was being planned, the regulatory guidance for D3 was considered unclear. The license amendment request for the replacement requires an advanced stage of design, but the D3 approach determines the replacement's basic architecture. Hefler said that PG&E did not want to commit funding for the design without a reasonable assurance that the selected D3 approach would be approved.

PG&E met with the Nuclear Regulatory Commission twice in 2006, and Hefler said

that while the dialogue was useful, there was no system in place whereby the NRC could review a part of a design (such as a D3 assessment) separately from an amendment request. The NRC could not even provide formal comments or concurrence without an amendment request in hand from the applicant. Eventually, the NRC worked through the conundrum by replacing its interim staff guidance on digital I&C (ISG-02) with new guidance, designated ISG-06. During the development of the guidance, it was possible to determine that the intended replacement for the Eagle 21 system—the Triconex PLC—could meet NRC requirements. Hefler said that ISG-06 was issued in January 2011 and PG&E applied in July for pilot plant status for the use of ISG-06, which the NRC approved in October.

Ken Schrader, of PG&E, described lessons learned by the company from using Phase 0 of ISG-06, in which an applicant can have formal meetings with the NRC to get an early indication of a proposed system's acceptability prior to submitting an application to use that system. The lessons include the importance of a team's covering many disciplines (software, I&C, maintenance) to develop Phase 0 documents, and the need for a tool to manage those documents, which come from a variety of sources and serve a variety of purposes. Schrader said that while the system planned for Diablo Canyon was on a smaller scale than the upgrade being carried out at Duke Energy's three Oconee reactors in South Carolina, the Diablo Canyon application was 250 pages, plus about 500 pages of enclosures and several vendor documents.

Richard Stattel, senior electronics engineer in the Electronic Instrumentation and Control Branch of the NRC's Office of Nuclear Reactor Regulation, pointed out that the word "interim" is used by the agency in ISG-06 and similar guidance because it began as a separate entity but will eventually be incorporated into formal NRC regulations. He noted that ISG-04, on digital I&C communications, has been almost entirely incorporated into IEEE standard 7432, and once the NRC endorses that standard, ISG-04 will no longer be in effect.

The NRC held four Phase 0 meetings with PG&E on the Diablo Canyon upgrade. Stattel said that the view within the agency is that in the future, the NRC and applicants are likely to arrive at the same results with fewer meetings.

Stattel also said that the Diablo Canyon project, like the one at Oconee, is more than just an effort to address obsolescence. A digital upgrade is a safety improvement for the plant as a whole. As for the ISG-06 pilot project, Stattel said that the goals are to reduce regulatory uncertainty and to establish and maintain technical consistency.

Gregg Clarkson, of Rock Creek Technologies, spoke about his experience as a consultant to Wolf Creek Nuclear Operating Corporation when the main steam feedwater isolation system at the Wolf Creek pressurized water reactor in Kansas was upgraded from analog to digital. He noted that as analog equipment ages, so do the people who understand it, raising another major concern for the industry: capturing the knowledge of a workforce approaching retirement age.

Clarkson advised that anyone considering a digital upgrade start with a study of the current status of a plant's major safety systems, a detailed investigation of vendor offerings (deeper than what is included in marketing brochures), and an effort to gain an understanding of what the plant needs and when it will be needed. Once all that is done, he said, a plan should be developed that includes an overall safety system architecture and strategies for licensing, vendor and platform, and implementation.

Asked whether the view of Wolf Creek's management has changed since the upgrade, Clarkson said that the fear of the unknown is now gone. Wolf Creek is now at work on upgrades to more systems, with others in the planning stages, and management is backing the work.—*E. Michael Blake, Dick Kovan, and Rick Michal*