

ANS ANNUAL MEETING

Looking to the future: The next 50 years

THE 2004 ANS Annual Meeting, held in Pittsburgh, included the official observance of the American Nuclear Society's 50th anniversary. The 2005 Annual Meeting, held June 5–9 in San Diego, took a logical next step by adopting the theme, *The next 50 years: Creating opportunities*. Developments in the industry since the Pittsburgh meeting seem to show an increased likelihood that new power reactors may be built in the United States during the next decade, and speakers at a number of sessions in San Diego addressed not only how to create such opportunities, but what to do once the opportunities arrive.

The opening plenary session indicated that some opportunities for nuclear power are coming from the top levels of political leadership. Jeffrey Clay Sell, sworn in on March 21 as deputy secretary of energy, told the attendees that nuclear power is the "cornerstone" of the Bush administration's energy policy. Later, in response to a question from the audience, he described President Bush as the "most pronuclear president since Eisenhower, and maybe more so than Eisenhower."

Sell described in detail the risk indemnification insurance plan proposed by Bush in late April (*NN*, June 2005, p. 25). According to Sell, owners of the first two new power reactors of each type (AP1000, ESBWR, etc.) would be eligible to obtain insurance to compensate for half of the cost of serious project delays from prolonged hearings, up to \$500 million per reactor. Under the plan, premiums would be waived for reactors ordered before the end of 2008. Sell noted, however, that the administration has proposed this insurance to *replace* the various tax incentives being considered for new reactors in congressional deliberations on the energy bill, not in addition to them.

To underscore the importance of reviving nuclear power, not just in the United States but worldwide, Sell cited a variety of demand growth projections. He said that the International Energy Agency foresees a 60 percent growth in world energy demand over the next 25 years, and that in 2030 there would still be 1.6 billion people in the world without electricity, according

Meeting session coverage:

- ◆ *Optimistic outlook for nuclear power continues*
- ◆ *Industry edges closer to reactor licensing*
- ◆ *The nonproliferation challenge in Iran*
- ◆ *Technology for proliferation-resistant fuels*
- ◆ *Personnel turnover and knowledge capture*
- ◆ *Alaska town studies small power reactor*
- ◆ *Robotics for remote and hazardous environments*
- ◆ *NRC's new engineering inspections*

to *USA Today*. Because nuclear power already exists, he said, it can be seen as a strong possibility to provide larger output, without greenhouse gas emissions, to meet future demand—more so than hydrogen, wind, solar, and carbon-sequestered coal, which either have inherent limits or are not yet proven to be practical. Sell predicted that in the next 25 to 50 years, power reactors will become unremarkable and non-controversial.

NRC's role

Peter Lyons, appointed by Bush earlier this year to the Nuclear Regulatory Commission, spoke on the agency's role in future nuclear energy utilization. He said that while the NRC's mission is to regulate nuclear applications, not to promote them, he

believes that the NRC should encourage fuel diversity by ensuring the availability of nuclear power. He stated that the United States would lose its technical capabilities



Lyons

in nuclear energy within 20 years without boosts in personnel and infrastructure in the near term. Lyons summarized the areas in which the NRC is involved with maximizing the potential of existing reactors (through license renewal and power uprates) and setting the stage for the possibility of new reactor orders (through ongoing activities in early site

permits [ESP] and reactor design certification, and readiness for construction/operating license [COL] applications). His slides illustrating the NRC's process for reviewing license applications drew attention to one area of potential regulatory uncertainty. While the NRC has set target time frames for reviews of ESP, design certification, and COL applications, it has set no such targets for reviews of the inspections, tests, analyses, and acceptance criteria (ITAAC) that must be completed to verify that a reactor has been built in compliance with its COL. To some extent, this is because the owner of the reactor conducts the ITAAC, on whatever schedule it chooses, and only later would the NRC review them.

Lyons listed a number of other issues that need to be addressed, to differing degrees, by the industry and the NRC. These include materials (such as in vessel head corrosion), the potential for clogging in pressurized water reactor containment sumps, the loss of experience as aging workers retire, the need to maintain safe operation, and the reliability of the nation's electricity grid.

The transformation of INL

Adm. John Grossenbacher (USN Ret.), director of the Idaho National Laboratory, spoke on the effort to transform what had been the Idaho National Engineering and Environmental Laboratory into a world-class, multiprogram facility for advanced reactor and fuel cycle development. He said that getting to that point would require overcoming a number of challenges, including the continuing cleanup of areas on the large tract of land in eastern Idaho, where radioactive materials had been buried with little or no confinement, to pre-

differing and sometimes conflicting cultures among scientists, engineers, and reactor operations personnel. As for making INL a focus of a nuclear renaissance through the development of Generation IV reactors and fuel cycles, he said, "If we're waiting for a better time . . . I don't know what we're waiting for."

Incentives needed

Andrew White, president and chief executive officer of General Electric Nuclear Energy, said he is lucky to be in charge of GE's reactor business at a time when the United States appears to be heading for new nuclear power and GE's top management is taking a more pronuclear stance. White, as other GE nuclear officials on recent occasions have done, stated plainly that former GE chief Jack Welch had not been especially positive about nuclear power as a major GE enterprise.

Contrary to what Sell had said earlier, White said he thinks incentives are needed to encourage the construction of the first few new reactors in the United States. As for his company's newest contribution to the potential new era of nuclear power, White said that GE plans to submit its application for the certification of its ESBWR advanced boiling water reactor design to the NRC this summer.



White

Overcoming barriers

Former NRC Chairman Richard Meserve, now president of the Carnegie Institution, agreed with White on incentives, noting that the Secretary of Energy Advisory Board had said that the federal government should provide \$250 million for the first two new reactors. He also called for the renewal of the Price-Anderson Act and echoed White and Lyons on the need for the nuclear field to attract new people to fill in for those nearing retirement. But in response to earlier speakers who cited polls showing as much as 70 percent backing for new reactors, Meserve said that he thinks such public support for nuclear is "soft" and would drop sharply if there were a serious incident at an operating reactor.

Meserve foresaw a number of barriers to



Meserve

the ordering of new reactors: unknowns in the never-used aspects of the licensing regime in 10 CFR Part 52, unknowns in ITAAC and the final approval for reactor startup, the coordination of regulations and licensing among several countries, and the enforcement of the International Atomic Energy Agency's additional protocol to bolster nonproliferation. In closing, however, Meserve said that he believes the barriers can be overcome.

The final speaker at the opening plenary session was Nobel Prize winner Samuel Ting, a professor of physics at the Massachusetts Institute of Technology. Because his presentation on the use of superconducting magnets in physics and space exploration effectively started off the embedded Space Nuclear Conference 2005 (SNC '05), it is covered in the separate report on SNC '05 that begins on page 55.

Nuclear Power 2010

With each passing meeting, the sessions devoted to the possibility of new reactor orders in the United States offer more precise details about the federal government's plans and funding and the nuclear industry's expectations and schedules. The session at the San Diego meeting was devoted specifically to Nuclear Power 2010, the Department of Energy's program to share costs with industry on early site permits (ESP), reactor design certification, and construction/operating license (COL) applications, so it did not include explorations being done by utilities without DOE support, such as those being carried out separately by Duke Power Company and Southern Nuclear Operating Company.

Tom Miller, of the Department of Energy's Office of Nuclear Energy, Science and Technology, gave a status report on Nuclear Power 2010, of which he is the program director. He said that the program has provided support for the licensing demonstration projects of NuStart and Dominion Energy, the feasibility study for possible construction of an advanced boiling water reactor at the Tennessee Valley Authority's (TVA) Bellefonte site, scoping studies for the use of federally owned sites for power reactor construction, and a study of siting prospects in Texas (requested by the Texas Institute for the Advancement of Chemical Technology). "I can't relay how much interest there is in new plants in this country," said Miller, calling the current situation a complete turnaround from two years ago.

Miller noted that the process still faces a number of challenges. Deployment issues

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vent their migration into the environment. Grossenbacher referred to this legacy as the site's "sins of the past"; under the new contractor arrangements at INL, cleanup activities will be performed by contractors other than those operating the laboratory.

Grossenbacher spoke of the need for culture change at the Idaho facility, citing the

include regulatory uncertainty (because the Nuclear Regulatory Commission's new licensing process in 10 CFR Part 52 has never been used), financial uncertainty (because potential investors are unsure of the actual costs of bringing new reactors to completion), and such long-standing concerns as high-level waste disposal and accident indemnification. Challenges for the industry include the formation of a qualified supply chain (including the provision of commodities such as concrete and rebar), the availability of personnel in all areas (technical, craft, and engineering), advancements in engineering and construction management to complete a project in about four years, and the integration of inspections, tests, analyses, and acceptance criteria (ITAAC) into the construction process and schedule.

NuStart activities

Dan Keuter, vice president of nuclear business development at Entergy Nuclear, summarized the activities of the NuStart consortium, which includes the owners of more than half of the nation's operating reactors, as well as the two most established reactor vendors. He said that there were jitters on Wall Street when Entergy bought Pilgrim in 1999, marking the first outright sale of an operating reactor, but after a while things calmed down. Keuter said he thinks the same will happen when new reactors are ordered: perhaps some early turmoil in the investment community, but then steady growth in confidence as new reactors enter service.

According to Keuter, NuStart itself would not build reactors, but a separate organization of one or more NuStart members would use the licenses issued by the NRC to build reactors. He spoke of the announcement in May of six candidate sites (*NN*, June 2005, p. 18), which will be winnowed down to two in September, for which NuStart will seek licenses. He said that the exclusion of Exelon's Clinton site from the group of six came at Exelon's request and did not indicate anything wrong with the site. (Exelon later announced that it withheld Clinton because it did not want new reactors there to be shared by NuStart; see *NN*, July 2005, p. 11.) Keuter then listed the other major milestones on the schedule: August 2006, request for proposals issued for constructors; July 2007, selections made from returned proposals; August 2007, COL application for AP1000; December 2007, COL application for ESBWR; 2008, application to the DOE for shared funding on final plant design; and in 2010, Keuter said, he thinks it is "probable" that some NuStart members will take the COLs and be ready for "potential construction."

Keuter also showed what NuStart believes to be the best way to address the issue of first-of-a-kind costs. He said that an

80 percent federal loan guarantee would have the same effect on the federal budget as \$18/MWh, eight-year production tax credits, and less than half the effect of a 20 percent construction investment tax credit, but would meet more of the capital costs than any other option, would cover far more of the licensing and construction risk, would have the lowest dilution of earnings, and would be the only approach that helps obtain debt financing.

More focus, less commitment

Eugene Grecheck, vice president of nuclear support services at Dominion Energy, spoke next, saying that his company's involvement in Nuclear Power 2010 is more focused than NuStart's and thus far does not entail as much commitment. He said that Dominion plans to begin writing its COL application in September and have it finished two years later. The ESP for North Anna is expected in June 2006. Dominion will not decide on whether to seek a license, however, until that deadline in September 2007.

Grecheck said that Dominion would then apply for a COL if all financials are in place (government incentives, what he called "commercial risk allocation structures," cost estimates, power demand), if the NRC situation is clear (ESP in hand, ESBWR design certification at least at the point where outstanding technical issues are known), if there is local, state, and federal support, and if the industry is in fact able to build new reactors.

Steve Hucik, general manager of nuclear plant projects with GE Nuclear Energy, reported on two developments at his company, both expected during August: the completion of the Bellefonte feasibility study and the submission of the ESBWR design certification application. The former, which is based on the already certified ABWR, was still not ready for release, but Hucik said that GE has already had discussions with the TVA and the DOE on possible follow-on work to set the stage for a COL application. GE is referencing the ABWR as it is being built at Lungmen in Taiwan; Hucik said that Lungmen construction is serving as a test of building techniques that could be applied at Bellefonte.

Hucik said that GE hoped to beat its August target for the ESBWR application. GE does not expect to get final design approval from the NRC until December 2006, but Hucik said that the NRC has told GE that a COL application could be submitted then, and that it need not wait until the comple-

tion of the design certification rulemaking. GE is already having utilities review the design, and Hucik says that some of the tough issues to be addressed in a COL proceeding have already been taken into account in the design. The ESBWR has 25 percent fewer pumps, valves, motors, pipes, and cables than previous BWRs, thanks to its dependence on natural circulation. Hucik said that GE is aiming to make possible an ESBWR project that would go from first concrete to fuel loading in 36 months.

As for what the reactor's acronym actually stands for, he offered four choices for

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the first two letters: energy simplified, economic solution, expedited schedule, and energy secure.

NEI's efforts

Adrian Heymer, director of plant performance improvement with the Nuclear Energy Institute, covered the industry organization's efforts in support of Nuclear Power 2010. He said that based on developments thus far, the major issue in ESP deliberations is emergency planning. He believes that some progress has been made, but there needs to be an integrated plan, with action items. One area of uncertainty is whether the ESP will provide environmental finality, or if some of its findings will have to be revisited during a COL proceeding.

Heymer said that NEI is trying to work out exactly what ITAAC will entail and plans to release a proposed guidance document by the end of this year. He noted that the NRC is also considering a revision to 10 CFR Part 52 that would make the process clearer. NEI representatives have met with NRC personnel involved with site inspection, and Heymer said that they quickly reached a fair amount of agreement on what would be needed to get an ITAAC approved and what points the NRC would emphasize.

On the topic of federal incentives for new reactors, Heymer said that regulated and unregulated utilities would have different needs, so a single program might not work for everyone. He referred to the risk indemnification insurance proposed during the plenary session by DOE Deputy Secretary Jeffrey Clay Sell as a "starting point," saying that NEI appreciates the general concept but thinks it needs further work.

Heymer also observed that a nuclear revival poses infrastructure issues, such as the lead time for component fabrication if about 40 reactors are built worldwide over the next 10 years.

Building the plants

John Polcyn, vice president of Bechtel Power Corporation, declared that his firm wants to build the first new reactors. He said that Bechtel is involved in many activities connected with potential reactor orders, including some siting and construction cost studies for utilities that are not involved with the consortia. Polcyn said that projects that are going on right now, such as the restart preparations at Browns Ferry-1 and the waste cleanup at Hanford, show that Bechtel already has a supply chain in place that would be capable of reactor construction. He added that once new reactor designs are developed in greater detail, Bechtel plans to offer fixed prices on construction.

During a long and spirited question-and-answer session, an attendee noted that new reactors recently ordered in Europe and Asia are not tied in with the United States' push for standardization. Keuter said that if the passive-shutdown Generation III+ designs had been fully available when Finland was taking bids for Olkiluoto-3, they might have been competitive. Hucik noted that France will be covering the first-of-a-kind costs for the EPRs at Olkiluoto-3 and elsewhere, and that the EPR has been designed chiefly to meet the existing European utility requirements documents.

In response to a different question, Keuter addressed the concern about infrastructure adequacy by noting that in the first round of reactor construction in the United States, there had been little (if any) infrastructure or supply chain in place at the start, but more than 100 reactors were built over the next 20 years, and the infrastructure developed as needed. As he did earlier, recalling the reaction of the financial community to the Pilgrim purchase and suggesting that new reactor orders would get the same treatment, Keuter projected that history would repeat itself, and new reactor orders would spur the needed infrastructure development.

Nuclear power in Iran

In a session titled "The Development of Nuclear Power in Iran: Questions, Perspectives, and Impacts," a distinguished panel of experts provided a standing-room-only crowd with fascinating insights into the current effort to stop Iran from developing nuclear weapons, and, on a wider front, on the impact of this ongoing crisis on the future of the nonproliferation regime. The panel included people who have been involved in nonproliferation negotiations over many years, including those with Iran. The session, which was chaired by William Sutcliffe, se-

nior physicist, retired from Lawrence Livermore National Laboratory (LLNL) and now a consultant on various LLNL projects through M. H. Chew and Associates, looked at the current situation and how it might be resolved. The panel members gave their thoughts on what can and probably cannot be done. Sutcliffe asked the panel to consider some broader questions: How will what is happening in Iran affect the development of nuclear power? What may happen to the Non-Proliferation Treaty (NPT)? Will the development of nuclear power and technology in Iran make nuclear or radiological terrorism more likely?

Jon Wolfsthal, deputy director for non-proliferation for the Carnegie Endowment for International Peace, wondered why Iran might want nuclear weapons. Certainly the North Korean regime sees them as a means of survival, said Wolfsthal, and even Israel would seem to consider them an insurance policy. Given the Iraq war, the U.S. military strength in the region, and the military strength of Israel, Iran could see them as a deterrent, said Wolfsthal. Iran's leaders



Wolfsthal

also have strong domestic political reasons for a nuclear program. If asked whether Iran should be allowed to have a nuclear power program, most Iranians would say yes, of course. Iranians feel they are being prevented from becoming an advanced technological state by sanctions and other means employed by the United States to isolate the country and keep it down. And so, developing an advanced nuclear know-how has become a very desirable goal for many Iranians. On the question of nuclear weapons, however, there is not such a public consensus.

Wolfsthal said that he could devise all kinds of creative ways to help deal with most of Iran's concerns without needing nuclear weapons. "But any time [the U.S. dips its] toe in Iranian political waters, it backfires," he said. This may be an issue the West must let the Iranians work out for themselves.

Wolfsthal posed the question of how to gauge Iran's intentions. "Does Iran want something in return [for abandoning its nuclear plans] or not? Or are weapons the end itself? Is Iran just after nuclear power de-

velopment? Is enrichment just a trading chip? We don't know." And without knowing the answers to these questions, the negotiations will not produce the right results, he observed.

He said that he doubts that the United States can do much more than help on the margins. In many ways, he said, the battle with the United States is the last justification for the Iranian revolution. This means that it is very difficult for Iran's ruling conservatives to cut a deal.

Wolfsthal put forth several other questions:

■ *Can failure be prepared for without accelerating it?* By talking about learning to live with a nuclear Iran, will that become a self-fulfilling prophecy? Will discussing this possibility crack the existing united front?

■ *Could Iran be the last nail in the Non-Proliferation Treaty's coffin?* If Iran follows North Korea in going nuclear, will this mean the end of the "nonproliferation project," leaving only the "conflict resolution project" or the "war avoidance project"? The nonproliferation regime has not been perfect, but it has buttressed the nuclear power industry, he reminded the ANS audience. Without it, it will be difficult to maintain optimism about the expansion of nuclear power. Iran may be the linchpin on this. Otherwise, a whole new international system will have to be created.

■ *How can anyone influence the debate?* The more focus put on this issue, said Wolfsthal, the more it feeds back into Iranian domestic conflicts and the harder it will be for Iranian leaders to move away from their present course. This is a difficult political question, one that Western govern-

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ments have not been very good at dealing with.

Michael May, professor emeritus of management science and engineering and senior fellow with the Institute for International Studies at Stanford University, is one of the most experienced and prominent people in the nonproliferation arena. He described a safeguarded scheme, which he has been developing with his Stanford colleague,

Chaim Braun, for supplying fresh nuclear fuel to all countries. Their scheme focuses on strengthening the nonproliferation regime, not on the Iran problem, where it might not apply particularly well, May said. If, however, Iran really wants nuclear technology for energy purposes rather than military, he suggested that this may be the way forward.

May listed Iran's known nuclear sites and nuclear activities, including centrifuge enrichment operations, which are still frozen; uranium conversion facilities, where some 30 metric tons of UF₄, as well as some kilogram quantities of UF₆, are stored; and a heavy-water reactor under construction and a heavy-water production facility. There have also been laser enrichment experiments in the milligram range, and there are probably more activities that are not known about, he said.

May also posed a number of questions:

■ *Does nuclear energy make sense in Iran?* Although the United States government may not think so, May said that this is a tough question to resolve on behalf of another country. But, he noted, Iran has the second largest oil reserves and is sitting on the largest natural gas reserves in the world.

■ *Does enrichment make sense?* As long as the Iranians have to deal with sanctions and other supply concerns, they could believe that an independent enrichment capability is necessary for their power program. At the moment, their enrichment operations are pilot-plant scale, he said. The Iranians want to develop a production plant, starting with 3000 centrifuges and building up to 50 000, he said. The problem is that a weapons program needs much less in the way of separative work units from an enrichment plant than does a power program.

■ *Can any international supply scheme solve the problem of Iran?* In May's opinion, a successful outcome of negotiations will not come soon because of inadequate economic and security incentives and general mistrust; Iran has little reason to trust international assurances and, no doubt, the United States has little reason to trust Iranian intentions.

Any strategy designed to ensure fuel supplies, said May, should support and enhance nonproliferation measures, credibly guarantee fresh fuel, provide credible obligations for spent fuel control and monitoring, and be economically viable and nondiscriminatory in nature. Lease/take-back is the preferred option, said May. In fact, this is close to what the Russians and Iranians are negotiating—Russia wants compensation for disposing of the spent fuel, while the Iranians want credit for the remaining fissile content. When negotiations are at that point, he said, you know that it is only a matter of time before the agreement is signed.

May also commented on the position of Brazil, which is building an enrichment facility. Unlike Iran, the United States only wants Brazil to accept detailed inspections of the facility and accede to the Additional Protocol. At the moment, Brazil is insisting that some proprietary aspects of its program be shielded from inspection. Having Argentina as a partner in the project should help. In this respect, he noted, it might help if the Iranian enrichment program is partnered with a European company, but May doubts this would assuage the fears of the United States.

The Washington perspective

Mark Fitzpatrick, director of the Office of Regional Affairs in the State Department's Bureau of Nonproliferation, provided a Washington perspective of the Iranian situation, alerting the audience that he would be following the government script. The United States, he said, starts from the firm assessment that Iran is pursuing a clandestine program to make fissile material for nuclear weapons and has been doing so since at least 1985. Despite the international spotlight put on the program—and the efforts of the international community to stop it—Iran has not yet chosen to abandon its pursuit of nuclear weapons.

Iran's record of deception and denial of its program, Fitzpatrick said, has been reported in extensive detail by the International Atomic Energy Agency (IAEA) in the course of seven written reports and one oral presentation to the IAEA's board of governors since 2003. In general, the agency has reported the following:

1. Iran has pursued secret and ambitious programs to develop a uranium enrichment capability since the mid-1980s. It has used both gas centrifuges and lasers clandestinely to enrich uranium, to up to 15 percent in the case of its laser program.
2. Iran has undertaken secret uranium conversion activities since at least the early 1990s; these are aimed at developing the capability to produce feedstock for its centrifuge program, for experiments with uranium metal, and for construction of a conversion line designed to make enriched uranium metal.
3. Iran also conducted experiments separating plutonium from irradiated uranium targets and in other experiments produced polonium-210 by irradiating bismuth.
4. Iran failed to declare to the IAEA its import and use of nuclear material and failed

to declare and provide information about locations where nuclear material was stored or used. Iran intentionally misinformed the IAEA about its inventory of nuclear material so it could secretly use material that it had previously told the IAEA was lost in process.

5. Iran failed on many occasions to facilitate the implementation of safeguards as evidenced by extensive concealment activities.

The IAEA continues to investigate various unresolved questions. These regard the scope and history of Iran's P-2 centrifuge program, the timing and locations of its previously undeclared plutonium separation experiments in the late 1990s, and suspicious experiments involving polonium-210, which can be used in conjunction with beryllium as a neutron initiator in some types of nuclear weapons. Fitzpatrick described other discoveries that further indicate that Iran has not declared the full history and scope of its centrifuge programs.

Departing from his official text, Fitz-

Fitzpatrick said that Iran's continued failure to provide full information or access to inspectors after repeated requests has created a "confidence deficit" in Iran's assertions.

patrick said that Iran's continued failure to provide full information or access to inspectors after repeated requests has created a "confidence deficit" in Iran's assertions. Over the past two years, he said, each time the IAEA's secretariat has uncovered more evidence, Iran has backtracked, explaining that what it had said before was not quite true but that now it was providing the whole picture. "Well, the whole picture is still not out there, and there is increasing evidence of military involvement," he said. "So our assessment of a military plan for nuclear weapons remains very firm. . . . As the IAEA inspectors pull more threads, we are going to get more of this. We are not at the truth yet."

The U.S. view of the EU effort

Recently, said Fitzpatrick, the EU-3 (European Union countries France, Germany, and the United Kingdom) effort to offer Iran a negotiated diplomatic solution to this problem has been welcomed by Secretary of State Condoleezza Rice. "We believe that the EU-3 and others share our view of what would constitute 'objective guarantees,'"

he said. The EU-3 have offered Iran a range of incentives, including civil nuclear cooperation, political and security assurances, and economic and trade cooperation. The bargain to give up its unnecessary and uneconomic pursuit is quite generous, he observed, and there is no need to offer further incentives.

In Washington's view, said Fitzpatrick, the only acceptable "objective guarantee" that Iran has abandoned its weapons program is a full verifiable cessation and dismantling of all of its sensitive fuel cycle activities. Verification would require Iran to give IAEA inspectors full access to all locations and officials. Given the almost 20-year history of Iran's clandestine nuclear activities and the continuing confidence deficit created by its current lack of cooperation with the IAEA, only this can give the United States the assurance it needs, he said.

Despite the full support of the EU-3, Fitzpatrick said that the United States remains skeptical of Iran's commitment to maintaining its suspension over any length of time. It continues to challenge the terms of the suspension agreement. If Iran's leaders choose a more destabilizing course and carry out its threat to resume activities, the next step is clear: The IAEA's board of governors must meet immediately and report Iran to the UN Security Council.

An Iranian's view

At the heart of the issue is the domestic situation, explained Hadi Semati, associate professor of political science on leave from the faculty of Law and Political Science at the University of Tehran. Semati, a leading Iranian political scientist and a frequent commentator on Iranian affairs on major news media in the United States and Europe, is a visiting public policy scholar at the Woodrow Wilson International Center for Scholars.

The fundamental issue, Semati said, is trust. Iran does not trust the international community and feels extremely vulnerable and isolated. One reason for this is the lack of response after it was known that Iraq used chemical weapons during the Iran-Iraq war. Another issue is the intrusive inspections by the IAEA that go beyond the requirements of the NPT. Iranians believe they are being judged guilty without evidence, he said.

Semati explained that Iran is a nation still in transition, and that despite what many in the West believe, decisions are not simply made by a powerful leadership. The country has a complicated and sophisticated network of institutions and structures, he said, and decisions on all issues are subject to stiff competition among many parties. There is a mediation process that penetrates all aspects of life, providing a surprising level of adaptability, he noted. Furthermore,

despite severe legitimacy issues, the government and institutions enjoy a core backing, Semati said, adding that unfortunately, the coercive apparatus of the state still exists and retains significant power and control. Nevertheless, Iran exhibits a good degree of durability in the face of adverse social and political pressures. Generally, the state-society gap has widened in the face of mounting conservative backlash.

On the nuclear issue, however, the reverse is true. Any solution, said Semati, has to ensure Iran's sovereignty and independence. Increasingly, the public has identified itself with this issue, along with national pride and prestige. It finds the current attitude of the outside world discriminatory, looking particularly at the treatment of Brazil and Israel. The public is not interested in nuclear weapons per se, but any concessions by the leaders would be conceived as treason, he said.

The debate is undertaken in the context of the U.S. threat, said Semati, and is a clash of visions. Iranians believe that even if they accede to the EU-3 demands, the United States will not accept their country as a major player, let alone allow it to develop civilian nuclear power.

He stressed that unless there is an agreed upon political framework between the United States and Iran, in all likelihood, this issue will not be resolved. As long as the United States looks at Iran as only a proliferation issue, Semati declared, people will focus on this issue. He added that Tehran has a ferocious and vibrant political and cultural life—very much like that of Washington, D.C.

Limiting withdrawal from the NPT

The involvement in nonproliferation of Lawrence Scheinman, distinguished professor of International Policy at the Monterey Institute of International Studies' Center for Nonproliferation Studies, goes back to the Carter administration. Even more than the nuclear activities of Iraq and North Korea, said Scheinman—who is also an adjunct professor in the School of Foreign Service at Georgetown University—the discovery of Iran's nuclear program in 2002 called into question the whole nonproliferation regime. It brought into even greater prominence the specter of the "breakout" scenario that North Korea has pursued, as well as its involvement in clandestine activities. In the past couple of years, a number of proposals have been put

forward to limit the ability of countries to withdraw from the NPT as North Korea is doing, while maintaining their nuclear ca-

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pabilities for military purposes.

Two main approaches have dominated discussions on how to control the fuel cycle. One is the restrictive approach, focusing on the restraint or denial of the transfer of technology; the other is a more collaborative approach, centered on the idea of denationalizing the control of sensitive fuel cycle activities and bringing them under some form of multinational or multilateral arrangement.

Recently, President Bush proposed the following three ways to prevent the breakout scenario:

- The members of the Nuclear Suppliers Group must refuse to sell enrichment or reprocessing equipment and technology to any state that does not already possess full-scale functioning enrichment and reprocessing plants. Japan and Brazil immediately questioned what their status on this was considered to be. Both countries were assured that they could import equipment. Scheinman also suggested that Canada and Australia may want to develop these technologies in the future to give added value to the uranium they produce.

- The leading nuclear exporters must ensure that all states have reliable access to fuel at reasonable costs so long as they renounce enrichment and reprocessing.

- By 2005, only states that have signed the Additional Protocol will be allowed to import equipment for their nuclear programs.

Scheinman asked what is different today that requires revisiting the strategy for reconciling civil nuclear energy with nonproliferation. He listed the following four factors:

1. The cold war and the discipline that it imposed have been displaced by regional political security agendas. Many states, whose sense of security is more tenuous than before, see the prospect for obtaining a nuclear deterrent as being attractive. Scheinman thinks Iran may fit here. For others the aspirations of regional dominance and international standing are also motivations.

2. Over time, the possibility of obtaining nuclear technology and equipment has increased, in some cases through clandestine activities. Also, not all states adhere to the nuclear trade guidelines or exercise effective control.

3. The IAEA has discovered clandestine activities that state parties to the NPT have conducted. Previously, the challenge was from countries not party to the NPT; today, the more serious threat comes from those under the NPT that follow the breakout scenario.

4. National security and international stability are threatened by the possibility that organized transnational groups could attain access to nuclear materials. The greater the number of national facilities, the greater is this risk.

These considerations are not amenable to solution by any one strategy alone, be it strengthened safeguards, counterproliferation measures, or new institutional arrangements, Scheinman said.

Fuel cycle activities

With the interest that has been expressed in the U.S. Congress regarding spent nuclear fuel storage and reprocessing, a session titled "Proliferation-Resistant Fuel Cycles" explored advanced fuel cycle options that have intrinsic proliferation-resistant features.

The Department of Energy's Office of Nuclear Energy, Science and Technology is leading the Advanced Fuel Cycle Initiative (AFCI), a program established through

of the currently proposed geologic repository, and reduce the cost of geologic disposal. The goal, he said, is to develop "proliferation-resistant spent fuel treatment, fuels, and transportation technologies to enable a transition from a once-through fuel cycle to a stable, long-term, environmentally, economically, and politically acceptable advanced closed fuel cycle."

AFCI researchers are investigating advanced separation technologies to recycle components of spent fuel in the current generation of light-water reactors, as well as in those reactors that may be deployed in the near term, including advanced light-water reactors and high-temperature gas-cooled reactors, which are under consideration in the DOE's Nuclear Power 2010 program. The AFCI office is also researching accelerator-driven systems for possible transmutation use in order to reduce the inventory of actinides that are accumulating in spent fuel, Savage said.

Savage cited an April 2005 report from the American Physical Society (APS) that evaluated the fuel cycle from a proliferation-resistance standpoint. The report concluded that nuclear power cannot be made "proliferation-proof," but advised that revitalizing safeguards research and development would be "the most significant technical investment that can enhance proliferation resistance of nuclear power within the next five years."

The APS report also recommended that the United States, in developing a spent fuel reprocessing technique, take its time, "a somewhat different" tack than the U.S. House Appropriations Committee is suggesting, said Savage, explaining that the committee wants a reprocessing technology selected by 2007. The committee, however, does recommend increasing financial support for proliferation-resistance R&D and improving the "technical support for institutional measures for the entire fuel cycle," he said.

Regarding international cooperation, Savage said that France is the United States's major research partner in proliferation-resistance work. "We are collaborating with them in the development of advanced aqueous and pyro-processing technology and advanced fuels," he said. "We have plans to irradiate transmutation fuels with a mixture of various transuranic elements in the Phénix fast reactor. We are also collaborating [on] a group actinide extraction process test at their Ottawa [Ont., Canada] facility." He added that

his office was also evaluating some of the advanced separations processes in collaboration with Japanese and Korean researchers.

James Laidler, national technical director of AFCI Separations Technology Development at the DOE's Argonne National Laboratory, commented that in order to preclude or significantly delay the need for a second geologic repository in the United States (assuming that Yucca Mountain becomes the first), no option exists except to process spent fuel in order to "recycle the things that are worth recycling and dispose of those that are not."

Laidler said that aqueous chemical processing is the initial method of choice. "It's a technology that has the maturity that makes it possible to deploy [on an] industrial scale in the next 15 to 20 years," which is as long as it would take to build and bring such a reprocessing plant into operation. The plant would have to handle 200 000 tons or more of spent fuel per year. "That would make it the largest commercial reprocessing plant in the world," he said.

Opponents of such a reprocessing facility, Laidler said, would complain that it



Laidler

would be a larger version of the Purex (Plutonium/Uranium Extraction) process, which was used in the United States in the 1950s for military purposes to extract plutonium and uranium from low-burnup fuel. The plutonium was then diverted for weapons production, and the uranium was reenriched and put into reactors. The remaining minor actinides and fission products went into waste tanks, he said, some of which leaked wastes into the ground at the DOE's Savannah River and Hanford sites.

The process has evolved considerably since then, Laidler continued, and it is practiced in France, the United Kingdom, and soon in Japan. "The process now is directed toward recovering plutonium for MOX fuel," he said. "There has been a significant effort over the years to reduce wastes and reduce processing costs. There is no liquid tank waste of any consequence being stored."

Because no fuel reprocessing plant exists in the United States, he said, "We can design a new fuel cycle facility from the ground up. We can do so in a way that establishes a new standard to which future fuel cycle facilities ought to be measured, including such things as advanced instrumentation, online measurements, and a design for physical protection to block all the potential pathways for attacks [by terrorists]."

Alex Burkhart, acting director of the Office of Nuclear Energy Affairs in the State

AFCI researchers are investigating advanced separation technologies to recycle components of spent fuel in the current generation of [LWRs], as well as in those reactors that may be deployed in the near term....

a recommendation of the Bush administration's National Energy Policy group in May 2001.

The AFCI mission, according to Buzz Savage, the program's director, is to develop fuel cycle technologies that enable recovery of the energy value from commercial spent nuclear fuel, reduce the quantity and radiotoxicity of high-level nuclear waste bound for geologic disposal, reduce the inventories of civilian plutonium in the United States, enable a more effective use

Department's Bureau of Nonproliferation, explained that proliferation resistance is in reality "a political concept." By definition, proliferation resistance is that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material or the misuse of technology by states in order to acquire nuclear weapons or other nuclear explosive devices.

According to Burkhart, the political tie-in comes from the fact that nuclear energy systems should be designed so that statesmen would be able to make the following assurances to the world: that nuclear materials in facilities constructed for peaceful purposes are not being diverted for use as instruments of war; that nuclear materials, technology, and equipment are not being misused; and that states' nuclear programs are not a threat to their neighbors or the global community, but are being used for peaceful intent. "These assurances constitute political goals," he said. "The technical features that we talk about in terms of enhancing proliferation-resistance are serving these political goals."

or inhibit the undeclared nuclear production of direct-use material and direct use as weapons material, and facilitate verification, including the tracking of materials from entry into a system to exit.



Zentner

Meanwhile, the extrinsics are those measures that result from a state's decisions. "They could be the state's commitments, obligations, and policies with regard to nuclear nonproliferation disarmament," he said. Other extrinsics could be the agreements between exporting and importing states that nuclear energy systems will be used only for agreed upon purposes, agreements that control the access to materials in the nuclear energy systems, and agreements that concern the application of the International Atomic Energy Agency's safeguards program.

The second group in which Zentner is active, the Gen IV Proliferation Resistance/Physical Protection (PRPP) Methodology Development program, came up with six measures to evaluate proliferation-resistance, to be used by designers of nuclear energy systems to improve the safety of facilities in the early design stage by identifying weaknesses. "We then work with the designers to improve the facility to minimize the chance that any weakness could be exploited," he said. The six measures are:

■ Proliferation technical difficulty: The inherent difficulty, arising from the need for technical sophistication and materials handling capabilities, required to overcome the multiple barriers to proliferation.

■ Proliferation resources: The economic and manpower investment required to overcome the multiple technical barriers to proliferation, including the use of existing or new facilities.

■ Proliferation time: The minimum time required to overcome the multiple barriers to proliferation, i.e., the total time planned by the state for the project.

■ Fissile material quality: The degree to which the characteristics of the material affect its utility for use in nuclear explosives.

■ Detection time (safeguardability): The time following the initiation of diversion or undeclared production for detection resources to detect irregularities and to provide adequate confirmation that diversion

or undeclared production has occurred or is occurring.

■ Detection resources: Manpower, technology, and funding required to apply international safeguards.

Zentner added that a study was under way by the PRPP to compare the proliferation-resistance of an enrichment facility with that of a reprocessing facility to determine if one or the other is more vulnerable to misuse. That study is to be released in September.

Manpower issues

When a sports team suffers injuries to key players, others must step up to fill in. Dusty Baker, manager of the Chicago Cubs, recently said, after injuries sidelined two of his star pitchers and news reports predicted gloom and doom for the team, "It's always been the end of the Cubs. But I don't listen to it. I don't read it. We think in terms of a new beginning for somebody else. Somebody always emerges."

Sig Berg, a self-professed Cubs fan, related the baseball anecdote during the ANS President's Special Session, "Manpower for the Nuclear Industry . . . A Continuing Need." Berg, executive vice president of the Institute of Nuclear Power Operations, equated the Cubs' need for emerging players with the nuclear industry's quest to bring in bright young professionals to replace an existing workforce that is nearing retirement.

When then-ANS President Jim Tulenko



Berg

opened the session, he quoted data that showed the industry would have a "severe shortage" of nuclear engineers and health physicists by 2011. Berg followed up with statistics showing that 16 000 nuclear workers in the United States are expected to depart the industry over the next five years, representing 28 percent of the nation's nuclear workforce, and that half of the nuclear workers are currently over 48 years old and only 7 percent are under the age of 33. "Stark numbers," Berg said, "but it's a part of where we are in the industry today."

Even as many in the workforce are preparing to leave the industry, so too have many of its leaders—such as Bill Lee and Virgil Summer—departed in the recent past. They will need to be replaced as well, Berg said.

These manpower changes represent a "new beginning" for the next generation of leaders, Berg said, as they will be responsible for "capturing the talent" the industry needs to work in the plants. He recalled his tour of new nuclear plants in China, where

Even as many in the workforce are preparing to leave the industry, so too have many of its leaders . . . departed in the recent past. They will need to be replaced as well, Berg said.

Burkhart commented that the designs of nuclear energy systems "should be about lengthening the amount of time a state has for a political response and about improving the early-warning process," meaning that the system's design and the political goal should go hand in hand. "It is the policymaker, after all, who will decide what level of proliferation-resistance and what combination of intrinsic and extrinsic features is acceptable in any given situation," he said.

Michael Zentner, an engineer at the DOE's Pacific Northwest National Laboratory, offered descriptions of intrinsic and extrinsic features of nuclear energy systems. Zentner is active in two different groups studying the issue of proliferation-resistance.

One of the groups, the Como Proliferation Resistance Workshops, held in Italy, defines "intrinsic features" as those that reduce the attractiveness of developing a nuclear weapons program, prevent or inhibit the diversion of nuclear material, prevent

control rooms were “filled with young engineers and operators the ages of 26 to 29.” These young professionals were “highly trained and highly energetic,” and it was impossible to “escape the kind of energy commitment that these people had” for running the plants, he said.

The United States is blessed with young people having this same vitality, he said. “They are talented, they are enthusiastic, they have a high degree of energy, and they are savvy. They have been to some of the

needed to maintain the weapons stockpile are at or near retirement age.

Lyons added that studies from the Oak Ridge Institute for Science and Education have shown “alarming trends.” For example, in 1975 there were 77 nuclear engineering programs in the country, but by 2003 there were only 33, as universities responded to reduced student interest. Also, the number of university research reactors has fallen by about half since the mid-1980s, as evidenced by the fact that in 1995 there

were 812 students who attained degrees in nuclear engineering, including B.S., M.S., and Ph.D. levels, and by 2001 that number had dropped to 345, although it did increase to 448 in 2004.

This shortage in the nuclear arena is proving to be a sub-

set of a much larger national issue, Lyons noted. “We should have serious concerns with the current state of our nation’s workforce preparation for science and engineering [S&E] in general,” he said. The reason for concern is that since 1980 the number of S&E positions in the U.S. workforce has grown at almost five times the rate of the U.S. civilian workforce as a whole, but the number of S&E degrees earned by U.S. citizens is growing at a rate below the growth of the total U.S. civilian workforce. He further warned that the nation’s preparation of qualified S&E graduates is falling further behind other nations each year. For example, regarding the ratio of first university S&E degrees to the population of 24-year-olds, in 1975 the United States exceeded most of the surveyed nations, except Finland and Japan. By 2000, however, the U.S. ratio was exceeded by 16 nations, including (again) Finland and Japan, plus France, Taiwan, South Korea, the United Kingdom, Sweden, Ireland, and Italy, to name a few.

Lyons added that foreign students with temporary visas represent about half of all graduate students enrolled in U.S. universities in engineering, math, and computer science, and almost 70 percent of U.S. post-doctoral researchers in engineering and the physical sciences are foreign-born. Another point of concern for U.S. universities, he said, is that about 30 percent of the faculty in S&E disciplines are 55 and older.

Lyons said that while the NRC is meeting its recruiting goals today, it may be far more challenging to do so in the future. “Factors such as retirements, optimism for a rebirth of construction of new nuclear plants, continuing cleanup of the legacy of past weapons work, and expanding applications of nuclear technologies in the medical fields

will lead to immense competition for the small number of qualified students available,” he said.

Thus, the challenge of workforce development is faced by every sector of nuclear technology, including academia, government, and industry. “From today’s scientists and engineers, to our universities, to all of our companies that depend on advanced technologies, and to our nation’s elected leaders, the message of workforce development needs to be heard and acted upon,” Lyons concluded.

Leading nuclear in the U.K.

The task of putting nuclear technology back on the map in the United Kingdom is the job of Richard Clegg, director of the newly created Dalton Nuclear Institute. The United Kingdom, as evidenced by its Energy Policy White Paper issued in 2003, is lukewarm on the issue of nuclear power, Clegg noted, even as its aim is to create a “low carbon economy.” According to Clegg, the white paper doesn’t heartily support nuclear energy, nor does it condemn it.

That leaves nuclear to muddle along, with the United Kingdom on the road to losing its nuclear skills base. That’s where the Dalton Nuclear Institute comes in. The institute is being established this year at the University of Manchester to become a “cutting-edge” player in advancing nuclear technology. “It’s going to lead the U.K. in nuclear and be one of the leading players internationally,” said Clegg, who is also director of science for British Nuclear Fuels plc.

The Dalton Nuclear Institute will integrate and expand research in reactor technology, radiation chemistry, decommissioning engineering, nuclear physics, radiochemistry, fusion, materials performance, the environment, and policy and regulation. “I’m making sure that the pipeline is put back in place to supply trained graduates into the industry for the future,” Clegg said.

The Dalton Nuclear Institute will also, through its Nuclear Technology Education Consortia (NTEC), seek to expand the student population coming to nuclear technology. “It will put back on the map post-graduate level education in the U.K.,” Clegg said. NTEC will teach “the full banquet of everything from decommissioning to reactor fuel cycles, environment and safety, things to do with policy and regulation, and things to do with project management,” he said.

The NTEC will comprise 11 different learning institutions in the United Kingdom, coordinated by the institute. “No single university could deliver this,” he said. The NTEC’s first student intake is scheduled for later this year.

Continued

...the challenge of workforce development is faced by every sector of nuclear technology, including academia, government, and industry.

best schools in the world.” Although they are ready and eager to work, these young people see the world in a different way, he cautioned. “They would like to have a healthy balance between their professional life and their private life. They’re not interested in working 12 hours a day, seven days a week.”

Berg also said that training programs at nuclear plants should fit the expectations of young professionals. “I would suggest we put them together in clusters so they can have the power of their own vitality and their own ideas, and then take them out to our plants to work in groups,” he said.

Berg said that underscoring the task of refreshing the nuclear workforce is the concept of “protecting the core,” something he first learned when he joined the nuclear Navy years ago. “My job was to protect the core, no matter what, and this concept has never left me,” he said. “So the idea of nuclear safety and what it means for all of us is absolutely essential.”

The aging workforce

Peter Lyons, a commissioner on the Nuclear Regulatory Commission, emphasized the industry’s shortage of “human capital”



Lyons

by listing statistics for two government agencies with nuclear ties: Regarding the NRC’s staff, almost half are 50 or older, and 36 percent are eligible to retire within the next five years, and at the National Nuclear Security Administration’s weapons facilities, about 37 percent of the workers who have sets of critical skills

Reversing the aging trend

Andy White, president and chief executive officer of GE Nuclear Energy, opened his talk by pointing out that those countries that are actively pursuing new nuclear plants—France, Finland, Korea, Taiwan, and China—have vibrant workforces, while those countries that are not—the United States, Canada, Sweden, and Germany—have aging ones. This illustrates the correlation between the building of new plants and the coming of new resources and people to the industry. Or, said White, as another speaker had declared during an earlier session, “Build it and they will come.”



White

When White took his position with GE Nuclear two and a half years ago, 40 percent of his engineering staff was within five years of retirement. He then started an evaluation of every individual function in-house, with a matrix drawn up to show where shortages would be, where sufficient employee depth existed, how many employees each individual function would have in five or 10 years, and so on. Through aggressive recruiting at universities and in the industry, GE Nuclear has brought in 220 new employees since the evaluation began.

The recruitment of new employees has helped to reverse the aging trend at GE Nuclear. When White joined the company at the end of 2002, the average age of its nuclear engineers was 52.2, and it was increasing by about one year every year. At the end of 2005, however, the average age will be 49, and the company’s target over a 10-year period is to get to an average age of 45 or less.

GE Nuclear is also trying to bring in executives who will lead the company in “new growth” generation, White said. The company is looking for leaders with the following attributes:

- People who have an external focus, who think the way GE Nuclear’s customers think, who find success in market terms, and who operate outside the bounds of the company’s walls.
- People who are clear thinkers, who can simplify a strategy into simplistic and specific actions, and can make decisions and communicate priorities.
- People with imagination and courage, who are creative and challenging, and who can take tasks to the next level.
- People having inclusiveness and connection, and who can energize the various teams in the company.
- People with expertise, who are functional, and who have depth and confidence to drive change.

White concluded that there is no better time than now to build a new nuclear plant in the United States, with the support of the Bush administration and leaders like Sen. Pete Domenici (R., N.M.), and that the new build is likely to happen. “We really are going to need more people in this industry,” he said. “We need to strengthen the ties to schools with interns, co-ops, and some of the feeder programs that are most vital to our future. We need to invest in training programs and facilities. Everybody needs to believe and needs to think that a nuclear career is worth having.”

A reactor for Galena, Alaska?

A unique reactor project being pursued by the village of Galena, in rural Alaska, was the subject of a panel session. The reactor, known as 4S—for super-safe, small, and simple—is being developed by Toshiba. It is a sodium-cooled, fully sealed, passively safe, transportable reactor that would be factory fabricated and shipped to the site for installation. It is designed to run for 30 years with one fuel load. Galena, which has a population of 700, is interested in the 10-MWe version, which should provide all of its electric power and much of its heating needs.

At the 2004 ANS Winter Meeting in November, participants were given a brief introduction to the 4S reactor by Christopher Lapp, who also participated on this panel. The session was dedicated to the memory of Lapp’s father, Ralph Lapp, a nuclear physicist, lecturer, author, and radiation safety pioneer, who died last year. The session chairman, Garry Randolph, noted that among his many achievements, Ralph Lapp took on opponents such as Ralph Nader and Jane Fonda in public debates on nuclear energy.

Randolph, who became president of the Small Power Reactor Association (SPRA) after retiring as senior vice president of generation and chief nuclear officer of Ameren Corporation last year, said that he believes these small systems will form an essential part of the renaissance of nuclear power in the United States.

The session began with a video presentation by Sen. Larry Craig (R., Idaho), who is a member of the Committee on Energy and Natural Resources. “Nuclear power must be an ever-increasing component of our energy production,” Craig said, before describing the main features of the energy bill coming out of his committee.

These include reauthorizing the Price-Anderson legislation and authorizing \$3 billion for nuclear research and \$2.5 billion for next-generation reactors through 2015.

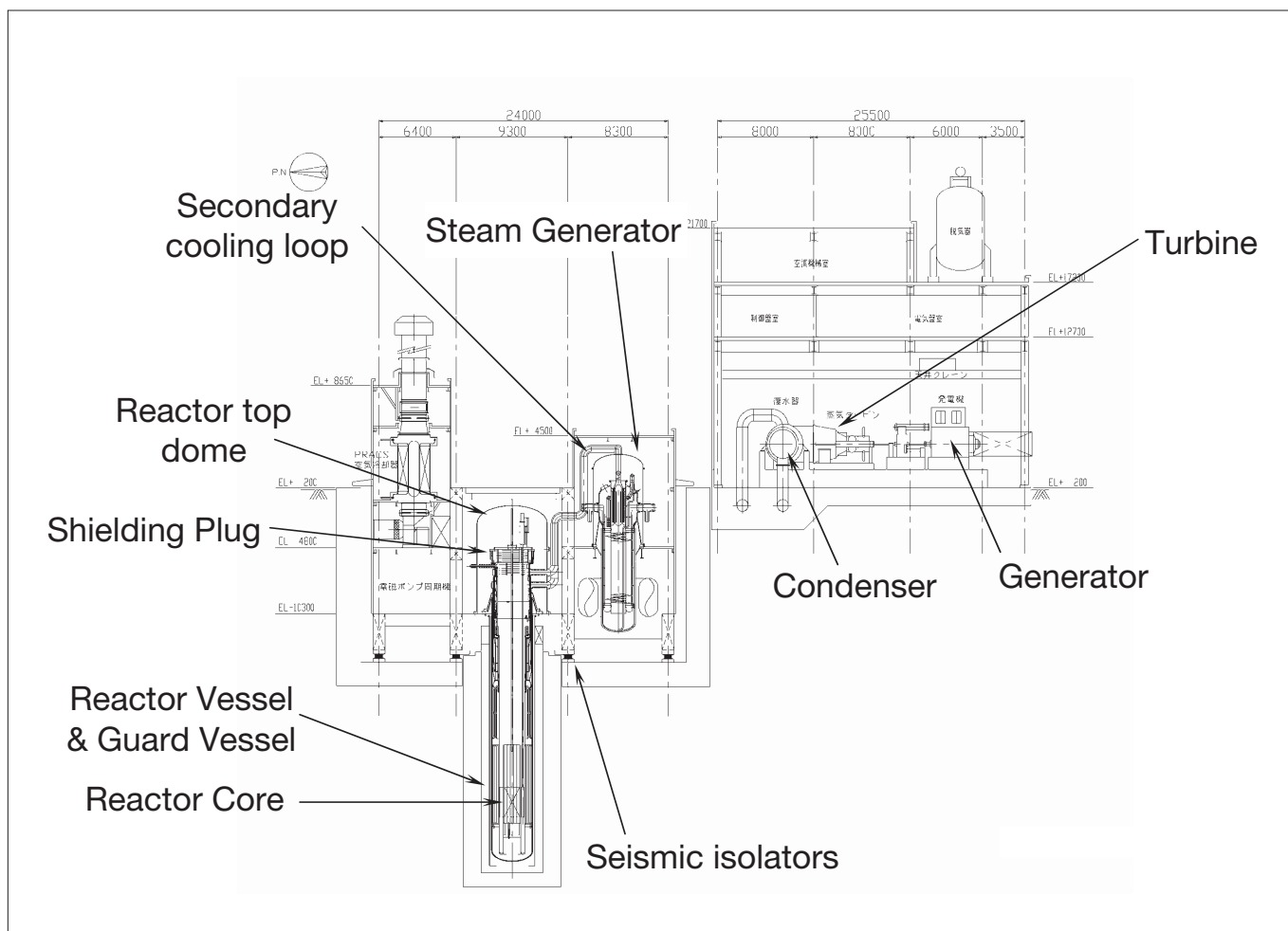
Many in the industry probably did not think that this day would arrive, Craig said, but real money is now being put into nuclear. Many new developments are driving the industry into a new era that will be tremendously positive and productive for the United States, he said. The new conditions include changes in attitudes of many who previously spoke out against nuclear power, now realizing that they cannot save the world simply by asking people to turn things off. There is certainly a role for small reactors, Craig said.

Galena was represented by Marvin Yoder, its city manager. In introducing him, Randolph said that the advocacy of this nuclear reactor requires someone like Yoder, whom he called a truly dedicated leader and a great spokesman.

Yoder explained that like many other communities in rural Alaska, Galena, which includes a U.S. Air Force base, has to supply its own energy. Temperatures at Galena vary from -64 to +92 °F. Located 270 air miles from Fairbanks, the town is isolated from the rest of Alaska, with no electrical grid or roadway connection. Galena’s links to the world are its large year-round airport and the Yukon River, which during the summer months provides the only access for delivering fuel supplies. “In May,” said Yoder, “we got our first fuel shipment since last September. We still had 10 days of fuel left.” The town gets 700 000 gallons of fuel oil in the summer months to fill its tanks. With fuel getting more expensive, Galena decided to look at alternatives. Developing the area was also an important consideration, he noted, as growth cannot happen with energy at the price it is now.

Toshiba said that its reactor could deliver power at 10 cents/kWh, as opposed to the over 30 cents Galena is now paying. . . . The reactor has been developed in 10-MWe and 50-MWe versions.

Contacts between Toshiba and Galena came about by a few accidental but fortuitous meetings of different people, Yoder said. Toshiba said that its reactor could deliver power at 10 cents/kWh, as opposed to the over 30 cents Galena is now paying.



Toshiba's 4S sodium-cooled reactor, being considered for energy production in Galena, Alaska

Subsequent meetings between Toshiba and community leaders have gone well, he said. "They looked us over, and they felt that we were a community they could work with."

Yoder also contacted the Department of Energy, which agreed to sponsor a Galena-specific study of long-term energy supply options and also looked at environmental issues. The team included people from the University of Alaska, Science Applications International Corporation, and the Idaho National Laboratory. The conclusion was that nuclear power would be the best alternative, providing the cheapest power. It will also allow the city to sell power to the U.S. Air Force, provide district heat to local buildings, and make possible other activities, including food and hydrogen production.

The next step is to develop several white papers to answer various "threshold" questions, such as security requirements, spent fuel disposition, environmental impact (particularly on the river), where to site the plant, and others. Because other Alaskan communities have shown an interest in what Galena is doing, the state legislature committed a half-million dollars for this. In addition to the white papers, the city council must also prepare an early site permit application, which it wants to complete by 2008.

In February, Yoder and other council members met with the Nuclear Regulatory Commission to discuss safety issues and the licensing process.

Toshiba's 4S development

A detailed description of the 4S development was provided by two people who are directly involved, Yoshiaki Sakashita, of Toshiba, and Izumi Kinoshita, from Japan's Central Research Institute of Electric Power Industry (CRIEPI).

The 4S is a totally enclosed unit—the core and the primary coolant loops are sealed in the cylindrical structure. There should be no emissions (other than steam), no release of radioactivity, and minimal chance of radiation exposure. The core is designed to use fuel with enrichment below 20 percent, which meets nonproliferation requirements.

The reactor has been developed in 10-MWe and 50-MWe versions. The main components are located within the reactor vessel, which is also surrounded by a "guard vessel," forming a secondary boundary for the primary sodium, which is circulated by electromagnetic pumps located above the core. There are three heat transport systems: a primary sodium circuit, a secondary sodium circuit, and the steam

turbine-generator.

The system sports six main features:

- *No refueling*—Avoiding refueling provides the following benefits: no transportation of fuel, low maintenance requirements, high proliferation-resistance, design simplification, and no activity emissions during the plant's lifetime.

- *Passive safety*—Passive safety features include the following:

- A negative temperature coefficient achieved by the core design means that the fission reaction will slow down if the core temperature gets too high.

- Primary sodium coolant operates at basically atmospheric pressure.

- The reactor vessel auxiliary cooling system provides heat decay removal using natural air circulation.

- *Transportability*—The reactor and plant buildings are modular and transportable.

- *Low maintenance requirements*—With no mechanical systems within the reactor vessel (the primary coolant is circulated by electromagnetic pumps), the potential for equipment problems is very small; the secondary side of the plant is modular, allowing for easy replacement.

- *Security*—The reactor is placed in an underground shaft with a concrete cap. This provides a nearly impenetrable barrier that

cannot be lifted/removed by any heavy equipment available in Galena.

■ **Standardization**—Standardizing helps most aspects of a reactor, including design, licensing, shop fabrication, transportability, and costs.

Fuel and other special features

The Galena 4S will have 18 fuel assemblies. The fuel composition is enriched uranium (less than 20 percent) alloyed with zirconium. Burnup is about 35 GWd/t. Fuel is based on the Run Beyond Cladding Breach (RBCB) designs developed at Argonne National Laboratory for EBR-II. An advanced “longer and larger diameter fuel pin” was developed to contain all fission products produced during the reactor’s 30-year lifetime.

Reactivity is controlled by a unique neutron reflector system surrounding the core that slowly moves upward from the bottom of the core to compensate reactivity loss from burnup. An electromagnetic impulse system was developed to drive the reflector at a rate of 1 mm per week. If an accident should occur, the reflector would drop

9Cr-1Mo steel, which has good swelling resistance in fast neutron fluxes.

■ A seismic isolation system was developed that will ensure site flexibility.

■ The steam generator has double-wall tubes to prevent a sodium-water reaction accident.

The Galena panel

Following these presentations, a panel discussion brought together representatives of other organizations with an involvement or a particular interest in the project. These included Christopher Lapp, president of Lapp Consulting and a founding member of SPRA; Doug Rosinski, a lawyer at Pillsbury Winthrop Shaw Pittman; Don Carlson, from the NRC’s Office of Nuclear Regulatory Research; Neil Brown, of the Lawrence Livermore National Laboratory; and Akio Minato, of CRIEPI.

Lapp said he originally investigated the use of the 4S reactor for a company developing gold mining operations in Alaska, which, coincidentally, was looking at a 30-year lifetime. The mining company needed about 70–80 MWe of continuous power, so two 50-MWe 4S plants could have been a good option. In the end, the company could not wait long enough to license a reactor. Nevertheless, Lapp believes that there is a large market for the 4S for mining operations in remote areas. It was also pointed out that the availability of a power source for mining operations could help promote other activities in the area.

Rosinski pointed out that Galena would be the 4S reference plant for establishing the design basis for certification and would serve as a model for the construction and licensing of additional commercial plants. The certification process would be backed up by the analysis and research work done at Argonne from the 1950s through the 1980s on EBR-II, which can be directly related to this design.

Carlson explained that the NRC’s Office of Nuclear Regulatory Research will be responsible for licensing activities of the 4S, as this is not a light-water reactor. The NRC does not have any activities involving this design now awaiting a request. He stressed that the NRC encourages interactions to get staff up to speed and to make sure the applicant puts forward a complete submission.

Brown has done a lot of work on liquid metal reactors. At General Electric during the 1980s, Brown worked on the PRISM re-

actor, which initially was not so different from the 4S, although it was designed as a breeder. Brown explained that economies of scale led to a large size increase. LLNL is involved in security and proliferation matters and has worked with CRIEPI to make the 4S reactor more proliferation-resistant.

Minato mentioned that CRIEPI is investigating application strategies for small reactors, such as desalination and hydrogen production, which would be of particular interest to Galena, helping it to supply other energy needs.

When asked why Toshiba is aiming for an NRC pre-application review, Sakashita explained that the U.S. regulatory system is much more suitable for assessing and certifying new designs than the Japanese system.

The question was raised about using the 4S for plutonium burning. The panelists explained that any issue that could have an impact on licensing—including any, such as plutonium burning, that could involve proliferation—would be better avoided. Also, this would require having another fuel manufacturing line.

According to information from Toshiba that was presented during the session and discussed by the panel, the projected capital cost to build the 4S on a commercial basis is \$2500/kW, or \$25 million for a 10-MW unit. The economics, however, are highly sensitive to the number of plant personnel required. Toshiba considers that about 20 or 30 people will be needed to operate the plant, but the final number could be much higher, depending on security requirements, although with experience, the numbers could be quite low. A detailed safety and security risk assessment, required by the licensing process, will determine the necessary staffing levels.

The reactor operators will primarily function as monitors, and the monitoring capability will be extensive, certainly for the first reactor. The panel noted that the technology is available and there is a lot of experience with monitoring sodium-cooled reactors.

During the discussion, it was also noted that the licensing process for the 4S will be a major undertaking since it is a new system. Licensing should be somewhat easier, however, since many problems that plague water reactors—notably corrosion and other materials problems—do not occur in sodium-cooled systems, and since this design should not be prone to severe accidents. The approach taken by the designers was to look at what sort of core is needed to avoid having to include engineered safety features. Nevertheless, it was pointed out, these issues will have to be thoroughly dealt with during the licensing process. EBR-II experience will be relevant to many aspects of the 4S, providing confidence that it will get through the process.

Rosinski pointed out that Galena would be the 4S reference plant for establishing the design basis for certification and would serve as a model for the construction and licensing of additional commercial plants.

down to make the core subcritical. A gravity-driven neutron absorber rod located at the center of the core provides a second independent shutdown system.

Reactor power control, including load following, is achieved by controlling the water flow to the steam generator. This causes a change in the coolant temperature, which affects the core inlet temperature, altering the reaction rates in the core. Since the core reactivity has a negative temperature coefficient, the lower water flow rate (lower load) lowers the core thermal output (consistent with lower load) by raising the core temperature. This feature greatly simplifies operation of the 4S power plant.

Other special features include the following:

■ The conductivity of the sodium makes it possible to use electromagnetic pumps, which means that there are no rotating mechanical components in the reactor.

■ The reactor vessel is made of Modified

Robotics research

A real live snake uses an undulating motion to move itself from one location to another. Robotic snakes will never duplicate that exact movement, according to Johann Borenstein, a research professor in the University of Michigan's Advanced Tech-



nologies Laboratory, because a snake's entire body is covered with touch sensors, something that would be almost impossible to copy in a robot. "My personal opinion about undulated snake robots is that it can't be done, at least not in the foreseeable future," said Borenstein, who spoke at the session titled "Robotic Research: The U.S. Department of Energy University Research Program in Robotics."

Researchers throughout the world are working to develop snake-like robots equipped with wireless cameras that could be used to traverse such terrains as the rubble of a collapsed building. Many DOE applications require inspections and surveillance in hard-to-reach, and sometimes hazardous, areas, and even NASA (National Aeronautics and Space Administration) is experimenting with snake robots that could be used to explore distant locations in space. But a lot of robotic snake designs won't work well, Borenstein stressed, because traveling along an asphalt parking lot is a lot easier than moving across a rocky environment. "In nature, snakes do as well as they do because they have about a gazillion years of fine-tuning sensory systems," he joked.

Instead of trying to capture a snake's undulating motion in a robot, Borenstein and other University of Michigan researchers are working on a mechanism called a "serpentine robot," which is a slender, multi-segmented vehicle designed to provide greater mobility than wheeled or tracked robots.

Two models of a serpentine robot have been developed by Borenstein's crew. The first, the OmniTread-8 (OT), consists of five segments that can fit through an opening that is at least 8 inches in diameter. The newer model, the OT-4, consists of seven segments that can pass through a 4-inch opening. The segments are connected by joints operated by pneumatic bellows, which produce sufficient torque to lift the segments up and over obstacles. More important, pneumatic bellows provide natural compliance with the terrain, ensuring optimal traction on most terrains, according to Borenstein.

Also common to both OT models are the tracks on all four sides of each segment and on the edges where the sides meet, so that an OT's surface is entirely covered by tracks. "We aimed at a design that maxi-



The OmniTread-8 serpentine robot (top) during testing in 2004, and the newer OT-4 moving over a desert location.

mizes coverage of the whole robot body with moving tracks," Borenstein said. "This feature is tremendously important, since because of the long, slender body of a serpentine robot, it is very common that it rolls over in difficult terrain. We found, in fact, that this happens very often."

Borenstein noted that a third design feature is the single drive motor, located in the center segment, that powers each OT. Through an articulate, so-called "drive shaft spine," rotary power is passed through all segments. Gear trains inside each segment then drive the tracks that surround the sides of the segment.

For powering the serpentine robots, he said, the OT-8 requires a tether that provides compressed air and electric power, while the OT-4 can be operated without a tether, using onboard compressed gas and electric power for about one hour of operation. It also can be equipped with a fiber op-

tic tether for remote control operation.

The OT-4 also has the ability, by using "graspers," to latch on to and travel along linear small-diameter objects such as water pipes, electric overhead wires, and on-wall electric conduits.

Borenstein said that the OT-4 has been tested by independent researchers and that it traversed difficult terrain without problems, performing like no other snake-like robot is capable of performing. Borenstein's work at the University of Michigan is partially funded by the DOE.

Brad Grinstead, of the University of Tennessee, described his work on the Mobile Scanning System, which consists of a variety of sensors—laser range scanners, video cameras, global positioning satellite (GPS) equipment, and an inertial navigation system—mounted on a van and used to digitize large-scale environments.

Continued

The research work is being conducted because traditional robots have trouble working in a variety of environments, according to Grinstead. An outdoor robot, for example, measures its location directly, through use of scanning instruments, while an indoor robot commonly must use “pose estimation” from video to determine its location. “For a robotic system that may be traveling back and forth between indoor and outdoor environments, neither of these systems is optimal,” he said.

To optimize the ability to capture an object’s location, the Mobile Scanning System uses a GPS with an accuracy of up to 2 cm and an inertial measurement unit with a measurement rate of 100 Hz. Grinstead said the data from these devices are combined through a filter that uses redundancies to provide an optimal estimate of a robot’s position in relation to objects around it.

While the GPS is the only sensor that makes absolute position measurements, when the Mobile Scanning System moves under vegetation, near buildings, or indoors, the GPS positional quality degrades to the point where the uncertainties involved in estimating the robot’s position become too great. When this happens, the system switches over to its video localization mode, and the robot uses the images captured by the system’s onboard video camera to perform pose estimation.

Also at the University of Tennessee, (UT) work continues on developing intelligent three-dimensional sensing for the robotic inspection of hazardous facilities. According to UT’s Sreenivas Sukumar, researchers there have deployed laser scanners



Sukumar

on a robotic platform to provide high-fidelity 3D details about shapes and structures. The goal is to develop a tool that could assist users, such as inspectors, in checking out areas that are hard to see under normal viewing conditions, such as the underside of an automobile. “In addition to the increased confidence for manual inspection,” he said, “3D sensing is not influenced by illumination and lighting, as is the case with most other visual surveillance systems.”

In one scenario involving the scanning of an automobile’s underside, the UT researchers “collected” images by using two different types of 3D laser scanners (one was a time-of-flight scanner and the other a triangulation model) that were mounted on a mobile platform. The researchers then interpreted the images by using a mesh model, where surface shape analysis was used based on curvature. The idea, Sukumar explained, was to output the actual im-

ages as a graph network of patches. With prior knowledge about the images—for example, knowing what an automobile muffler looks like as a mesh model—understanding the scene is reduced to a comparison of patches with similar “curvature variation measures,” he said.

The DOE University Research Program in Robotics supports the work of both Grinstead and Sukumar.

Engineering inspection

A session on hot topics in reactor licensing was devoted to the NRC’s new engineering inspection process, which has thus far been used on a pilot basis at four operating power plants, one in each of the NRC’s four regions. The session included analysis of the inspections at Diablo Canyon, Kewaunee, and Summer, but the most significant from the “hot topic” standpoint was probably the inspection at Vermont Yankee because of the controversy surrounding its pending application for a 20 percent power uprate.

Jeff Jacobson, an inspection team leader at the NRC, mentioned the “enormous amount of public interest” in the Vermont Yankee uprate request, and he noted that the inspectors specifically chose areas that would be affected by the uprate, and so the inspection at Vermont Yankee was slightly different from the other three. Jacobson said that the most interesting finding is that Vermont Yankee takes credit for the availability of a hydroelectric station downstream of the plant as an off-site power source to meet station blackout requirements. This was acceptable while the hydro plant was staffed at all times, but it has since been automated, has changed ownership a number of times, and is no longer directly wired to respond in case of a blackout at Vermont Yankee. Jacobson said that the uprate request will not be approved until this matter is resolved in a way that provides Vermont Yankee with acceptable station blackout coverage.

Another issue at Vermont Yankee concerned the reactor coolant system integrity (RCSI) system, which has an air-operated valve and thus is dependent on the air instrument system. The valve would have failed open, which was not acceptable. Jacobson said that since the inspection, the RCSI issue and two other findings have been corrected, leaving station blackout as the only open issue.

Another engineering inspection that had a significant effect on a plant was at Kewaunee, where a problem with auxiliary feedwater discharge pressure switches prompted a shutdown in February that lasted until early July (see page 14, this issue). Jon Pollock, long-term programs manager at Kewaunee, said that the inspection revealed that specific operator actions had been assumed in relevant calculations, and this did not agree with plant technical specifications. Restart became possible only after Nuclear Management Company requested, and the NRC approved, a license amendment to change the tech specs accordingly.

Thomas Baldwin ... gave some advice to other plant staffs awaiting engineering inspection: Be ready to identify and produce plant licensing and design basis source documents and standards, with all superseded versions and revisions.

The other inspections have generally drawn less attention. Mike Kammer, design supervisor at South Carolina Electric and Gas Company’s (SCE&G) Summer reactor, stated that the inspection produced three findings, one of which remains an unresolved issue, and while he noted the demands that the inspection placed on SCE&G (3100 utility staff person-hours were devoted to it), what disturbed him most was that all of the findings were on issues that had been known to the utility at one time or another, but SCE&G had not taken advantage of opportunities to resolve them long ago. Kammer said that a temporary correction was made to diesel generator protective relaying in 1996, but it was never made permanent. The unresolved issue is on tornado missile vulnerability of safety-related equipment, and Kammer said SCE&G is modifying the final safety analysis report where it concerns tornado missiles.

Thomas Baldwin, an engineer with Pacific Gas & Electric Company (PG&E), gave some advice to other plant staffs awaiting engineering inspection: Be ready to identify and produce plant licensing and design basis source documents and standards, with all superseded versions and revisions. The NRC, said Baldwin, has access to only the regulations and standards now in effect. He said that the inspection at Diablo Canyon turned up two findings, one of which re-

mains unresolved: the lack of an engineering evaluation of the effects of a tsunami on the discharge system and structure. (The plant is sited along the Pacific coast.) Baldwin said that the staff time devoted by PG&E to the support of the inspection to-

taled 3600 utility person-hours. (Diablo Canyon is the only two-unit plant of the four included in the pilot inspections.)

Jacobson said that the NRC now believes that this level of inspection is preferable on all power uprate applications. He added that

he was working on a draft paper that would go before the commissioners this summer, proposing revisions to the schedules based on what was learned from the time spent during the pilot inspections.—*E. Michael Blake, Dick Kovan, and Rick Michal*

TOPICAL MEETING

Space Nuclear Conference: Adjusting to a “change of course”

PREPARATIONS FOR THE Space Nuclear Conference 2005 (SNC '05) were at an advanced stage when the embryonic space nuclear program within the National Aeronautics and Space Administration (NASA), Project Prometheus, underwent two sudden changes. First, when the proposed federal budget for fiscal year 2006 was made public in late January, the proposed Jupiter Icy Moons Orbiter (JIMO), which would have been the first new spacecraft to use nuclear energy not just for on-board power but also for propulsion, was deferred indefinitely, leaving Prometheus with no connection to a formally planned spacecraft (*NV*, Mar. 2005, p. 62). Then, in April, NASA's new administrator, Michael Griffin, gave Prometheus a new assignment: to develop surface-based power systems for support of a proposed lunar colony and for processing of lunar materials for use in the colony.

During the plenary session of SNC '05, conference co-chair Raynor Taylor, of the Nuclear Systems Initiative at NASA headquarters, described the developments as “a slight change of course,” and asserted that the work done thus far within Project Prometheus could transfer almost completely to the new mission and maintain the option for further development of nuclear propulsion as future missions arise. Nonetheless, the Prometheus-related work reported at the conference was tied to JIMO or other aspects of propulsion, an inevitable consequence of the time lag in the preparation of papers for meetings.

Samuel Ting, the Thomas Dudley Cabot Professor of Physics at the Massachusetts Institute of Technology and winner (with Burton Richter) of the Nobel Prize, spoke

Major themes of the plenary:

- ◆ *Superconducting magnets in spacecraft propulsion*
- ◆ *Progress in Project Prometheus*
- ◆ *Redirection of Prometheus for lunar power plants*

at the main plenary sessions of both the ANS Annual Meeting and SNC '05, and in the course of both presentations he covered the potential uses of superconducting magnets in space exploration, physics research, habitat power, spacecraft propulsion, and radiation protection. As an example of a propulsion system, he cited a pulsed-power design employing superconducting magnets and magnetohydrodynamic energy conversion. Each pulse would come from an injection of uranium tetrafluoride, imploded to criticality and fission at a pinch point in the magnetic field. Ting said that the time for each pulse would be short enough so that the plasma would not have to be controlled continuously.

In the area of physics research, Ting spoke of a superconducting magnetic spectrometer called AMS, which will operate for three years on the International Space Station (ISS). At that altitude, cosmic rays are not deflected by Earth's magnetic field and atmosphere, and a wealth of particles can be analyzed. The movement of these

charged particles through the superconducting detector will allow for precise determination of the nature of these particles, all the way up the periodic table to ions of iron. He said that the apparent absence of antimatter in large quantities in the universe calls the current big bang model of creation into question, and that if the AMS does not find significant amounts of antimatter, the big bang model would be shown as fundamentally flawed and in need of revision.

Radiation protection will be a major concern in any space program that involves



Ting

long-term habitation of humans and other terrestrial life-forms. Ting noted that in the immediate vicinity of Earth, space radiation would produce a dose to a human of 90 rem/year, and solar flares could boost the dose unpredictably. Supercon-

ducting magnets could be configured to provide shielding by diverting charged particles. Ting said that in a round trip to Mars, the cumulative dose could be reduced from 130 rem to 45 rem with either 1000 tonnes of aluminum or a 30-tonne superconducting magnet. At the ISS, the dose could be brought down to 50 rem/year.

Ting noted that superconductivity has been known to exist for nearly 100 years, and the main problem with its applications has been quench, the condition in which the temperature of the material rises to the point where the material can no longer supercon-

aftermath of the Indian Ocean tsunami in December 2004, the main needs of the survivors were food, water, and electricity, while in past ages they were food, water, and shelter. Citing a message from a more recent pope—John Paul II, responding 100 years later to Leo XIII's encyclical—Diaz said that technology and skill were becoming more important possessions than natural resources or land. He added that in the modern era, not only do the underclasses have great needs, but television shows them what they don't have.

Diaz noted that the needs of ambitious

In zero gravity, ordinary liquid helium forms bubbles, interfering with the cooling necessary to maintain superconductivity. [Ting] said that this requires even more cooling, so that the helium becomes superfluid, and that the system therefore must be tested in space.

duct. Nearly all known superconductors exhibit the property only at very low temperatures, and Ting noted a further demand for superconductivity in space: In zero gravity, ordinary liquid helium forms bubbles, interfering with the cooling necessary to maintain superconductivity. He said that this requires even more cooling, so that the helium becomes superfluid, and that the system therefore must be tested in space. He also noted, however, that from his experience in particle physics (he won the Nobel as co-discoverer of the J/psi particle), many times one looks for one thing and finds something else instead. "If you know what you're doing," he said, "you don't have to do it."



Diaz

Nils J. Diaz currently chairs the Nuclear Regulatory Commission, but has spent most of his working life in nuclear academia. He spoke at SNC '05 on the evolution of the nuclear testing and regulatory environments, but began on a more philosophical note. He quoted Pope Leo XIII, from 1891: "Man's needs do not die out, but forever recur." Diaz said that in the

nuclear projects in space start with materials able to withstand high temperatures. He projected that this might lead to developments tried out first in space, and then applied to terrestrial applications. He also foresaw as the next challenge the inefficiency of the thermodynamic cycles employed in power plants, noting that even in the Brayton cycle, vast quantities of energy are essentially thrown away. He asked rhetori-

cally whether direct, total energy conversion could ever take place, and whether this challenge couldn't be taken up at least as much as the pursuit of fusion is.

On regulation, Diaz said that it is becoming more quantitative, and less based on presumed hunches. He also raised an issue that he has promoted in other venues recently: the development of a multinational system for reactor design approval. As Diaz envisions it, regulators in the world's major nuclear nations would develop a consensus on design and safety analysis, while environmental and site-related issues would remain under the oversight of each nation's own agencies.

Franklin Chang-Diaz, director of NASA's Advanced Space Propulsion Laboratory at the Johnson Space Center in Houston (and a seven-time astronaut), presented test results on the Variable Specific Impulse Magnetoplasma Rocket (VASIMR), updating a presentation from SNC in 2003. VASIMR employs a series of plasma chambers to heat and ionize hydrogen and then direct it by magnetic fields as a rocket thrust medium. The process is not nuclear itself, but Chang-Diaz has said that he favors a nuclear power source to start the process. The process employs a number of techniques known in magnetic fusion development, such as neutral beam injection to supply fuel and radio-

frequency heating to add energy. Chang-Diaz said that a key feature is the capability for impulses of varied power levels to provide maneuverability on long flights (such as to and from Mars, where in theory hydrogen could be harvested for fuel).

Tests have been carried out thus far on a ground-based test bed called VX-20. Chang-Diaz said that plasma output has been shown to increase linearly with magnetic field strength, but increases in the field strength have been limited by the tendency of the magnets to arc at certain power levels.

Samim Anghaie, of the Innovative Nuclear Space Power and Propulsion Institute at the University of Florida, reported on developments with carbide and cermet (ceramic-metal) fuels. Space reactor fuel, like the materials needed to line and shield the rocket chambers, must be able to maintain physical structure under extremely high heat. Anghaie filled in for Evgeniy D'yakov, of Russia, who was unable to attend; Anghaie combined the information from Russia with that from U.S. labs, noting that the space reactor fuel programs have had long interruptions in both countries. Calculations predict that some of the fuels could provide eight hours of steady operation at around 3000 K; Anghaie found that spherical encapsulated fuel pellets of three carbides—uranium, zirconium, and niobium—have been able to withstand 3300 K.

James A. Dewar, author of the book *To the End of the Solar System: The Story of the Nuclear Rocket*, traced some of the history that went into his book and cited what he saw as lessons to be learned from it. Among other things, he warned against what he called "mission-itus" thinking, in which a requirement for a mission is set and work is then done to meet the requirement. Citing examples dating back to the 1960s, Dewar argued that NASA would achieve better results by developing hardware on its own, and then assembling a space program with reasonable goals and objectives from that hardware.

During the question-and-answer period at the end of this session, Taylor responded to a question by providing more detail on NASA's current plans for Project Prometheus. He said that the first priority is power production for lunar-based installations, the second priority is nuclear thermal propulsion, and the third priority is nuclear electric propulsion. The second and third priorities would await the evolution of new missions that are not currently foreseen.

In response to another question, Chang-Diaz said that the target thrust for VASIMR would be 200 kW in a three-year deployment on the ISS, with an eventual upgrade to 4 MW, which he said could send a ship to Mars in 115 days.—E. Michael Blake