ANS ANNUAL MEETING

Nuclear has a lot going for it

THE USES FOR nuclear technology stretch to the extremes—from the subterranean realm to the stars. The opening plenary of the American Nuclear Society's 2003 Annual Meeting, in San Diego, Calif., June 1–5, offered talks on a range of topics, from storing spent nuclear fuel deep below Yucca Mountain to sending nuclear-powered spaceships to Mars, from developing a roadmap for new generations of advanced reactors to highlighting the benefits of nuclear applications for humankind.

This year's summer meeting—which had about 1000 attendees—was titled *The Nuclear Technology Expansion—Unlimited Opportunities.* After welcoming remarks at the opening plenary from outgoing ANS President Harold Ray, Nils Diaz followed with words of praise for those who attend ANS meetings for the pursuit and dissemination of knowledge. "You also gather and labor year-round to make a difference for your communities, and to improve and increase the global use of safe and beneficial nuclear technologies," said Diaz, chairman of the Nuclear Regulatory Commission.

Diaz

Quoting from Pope Leo XIII's Encylical Rerum Novarum (regarding the condition of the working classes), published in 1891, Diaz stressed the importance for the United States to retain its knowledge base in advanced technologies: "'In our time, in particular,'" quoted Diaz, "'there exists another form of ownership which is becoming more important than land: the possession of know-how, technology, and skill. The wealth of a nation is based much more on this kind of ownership than on natural resources.'"

The quote is even more pertinent now, in the days when the industry is claiming a nuclear renaissance while opponents claim nuclear obsolescence, "when a microchip can be worth much more than gold, and when services are more important than the production of goods for the U.S. economy," Diaz said.

It is a fact, he continued, that without abundant, reliable, and safe energy, there would be little of what is enjoyed today. "Energy, well distributed and affordable, is one of the indispensable and enabling components of the know-how era," he said. "And, obscured by achievements and gadgets, we have the working atoms; the protons and neutrons, the electrons, and quantum mechanics in action. The energy from the nucleus, and uses of radiation, are integral and necessary components of this day and age."

Major themes of the plenary:

- *Nuclear electricity is a stabilizing force*
- *First Gen IV plants to come about 2020*
- *YM goal: 400 tonnes of spent fuel in 2010*
- *Nuclear power needed for man on Mars*
- *Nuclear technology has many benefits*
- *Radwaste is greatest European concern*

Nuclear energy serves the needs of millions of people worldwide, safely and reliably, even as it is unheralded, he said. From an overall energy and economic perspective, said Diaz, "nuclear electricity supply can be a major stabilizing force in energy markets, and I believe especially so if coupled with hydrogen production."

How does the United States get to a hydrogen economy? Diaz explained it in three steps. "First," he said, "we should realize that unless the case is made by professionals in the field, governments and people will not have a full realization of how technology and energy got mankind to today's standard of living, and the particular role of nuclear energy and related technologies." He asked rhetorically whether opponents of nuclear are making a "better case" for their cause or are "just more dedicated." He declared that "Nothing will change in this respect unless you change it, and are as dedicated. The price is your time, and it has to be paid if you want results. This is an indisputable role of the American Nuclear Society: the pursuit and dissemination of nuclear know-how."

The second step, he said, is that the "productive and interesting world of the working nucleus and of radiation" needs to be brought to the classrooms where young people should be presented with balanced facts. "There might not be a more important class of people in this respect than science teachers," Diaz declared.

Third, connected to the above, is the need to bring "state-of-the-art know-how" to nuclear radiation technology and energy production, and to develop even newer and better techniques and applications. "If time keeps passing, lesser technologies than nuclear will fill the voids, with difficult-to-achieve claims of efficiency and economics," he said. "Who would have thought 25 years ago that nuclear power and radiation technologies could be called obsolete?"

Diaz continued by noting that many positive factors are converging to make possible a renaissance of nuclear power, based on the real and well communicated fact of its safety and reliability. But, he cautioned, the viability and probable growth of the technology is inextricably linked to its regulation. "There is no way, presently and in the foreseeable future, to maintain and to advance the use of nuclear power without a strong, predictable, and credible regulator," he said. "Therefore, it is essential that regulatory infrastructures be all that they can be: safety-focused, with state-of-the-art know-how in every important safety aspect."

Diaz offered a definition of a nuclear power plant safety construct: a hierarchical, techno-legal assembly of regulatory and operational safety systems ensuring the safe design, operation, and maintenance of nuclear power reactors for the benefit of the United States. This definition "is not complete," he said, "but is a good start for a much needed dialogue."

Diaz concluded by saying that the industry has "the skill to improve nuclear technologies so they are even more useful to society and, definitely, to implement a safety construct that leaves little doubt about requirements and responsibilities, for regulators and regulated alike."

Generation IV

In 1999 at an ANS meeting in Boston, Bill Magwood described the Department of Energy's vision for the long-term future of Generation IV nuclear reactors. Now, in San Diego, he offered what he called a "report card" on the Generation IV program's status today and its plans for the future.

Magwood

Magwood, director of the DOE's Office of Nuclear Energy, Science & Technology, was appointed under the Clinton administration, but he made a point of "giving credit where credit is due." None of Generation IV research would be going on, he stressed, if not for the leadership of the Bush administration in setting a national energy policy that "made it clear that nuclear technology has a clear part in the energy future. We're very, very excited about the fact that we have a president, a vice president, a secretary of energy, a deputy secretary . . . [all] saying very clearly that nuclear energy has a place in our world in the future."

The United States is expected to have an annual 1.5 percent growth in energy consumption through 2025, to a total of 139 quads, Magwood said. (By contrast, the U.S. total energy consumption in 1991 was 97 quads.) Most of the supply is expected to come from natural gas and coal, according to the DOE, but imports will increase to 35 percent by 2025 from 27 percent in 1991. The import of fuels for use in transportation also is expected to grow, Magwood said, from 66 percent imported in 1991 to 79 percent in 2025. A solution to meeting growing demand for both electricity supply and transportation use is nuclear energy, he said, but only if deployed in the near term.

Expected energy demand is a large part of the reason why the United States joined nine other countries—Argentina, Brazil, Canada, France, Japan, Korea, South Africa, Switzerland, and the United Kingdom—along with the International Atomic Energy Agency and the OECD Nuclear Energy Agency in a two-year effort starting in January 2000 to develop a technology roadmap for future nuclear energy systems. The roadmap defines and plans the necessary research and development to support Generation IV, Magwood said.

By the end of 2002, the roadmap led to the six most promising systems and their associated R&D needs. The systems are the gas-cooled fast reactor, lead-cooled fast reactor, molten salt reactor, sodium-cooled fast reactor, supercritical-water-cooled reactor (SWCR), and very-high-temperature reactor (VHTR). They all feature increased safety, improved economics for electricity production, reduced nuclear wastes for disposal, and increased proliferation resistance.

There are two stages of Generation IV, said Magwood. The first stage includes the VHTR and SCWR, reactors that could be deployed "in the 2020 timeframe," he said. The second stage includes the fast reactors, which could be built in the longer term, toward the 2040 timeframe.

In order to build Gen IV reactors, Magwood added, collaboration is necessary not only with international partners, but also with nuclear utilities that are willing to invest financially to make the reactors a reality. In addition, a Generation IV plant must demonstrate hydrogen production. "Long-term, a 30 million t/yr U.S. hydrogen supply would be able to replace one-quarter of our gasoline use," said Magwood, noting that the energy from 1 pound of nuclear fuel could provide the hydrogen equivalent of 250 000 gallons of gasoline without any carbon emissions.

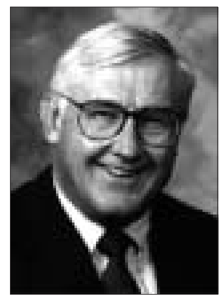
In conjunction with the Generation IV program, the DOE is working on an advanced fuel cycle initiative. The goal is to develop fuel cycle technologies that he said enable recovery of "the energy value from commercial spent nuclear fuel"; reduce the toxicity of high-level nuclear waste bound for geologic disposal; reduce the inventories of civilian plutonium in the United States; and enable a more effective use of the currently proposed geological repository at Yucca Mountain and reduce the cost of the geologic disposal.

Magwood said the DOE, starting in fiscal year 2004, also would be funneling a percentage of all nuclear energy R&D program funding to universities for research in such areas as innovative fuels and materials, advanced separation technologies, transmutation technologies, and computation and modeling capabilities. "This," he said, "is an essential step in assuring a new generation of engineers and scientists for the nuclear future."

Yucca Mountain

In 2003, 72 nuclear power plant sites in the United States and five DOE sites were storing 47 000 metric tons (t) of spent fuel in large pools of water or in aboveground dry casks. By 2035, 119 000 t of spent fuel will exist, according to projections from the DOE. Currently, there are more than 131 sites in 39 states storing spent fuel, high-level radioactive waste, and excess plutonium for which there is no complete disposal pathway without a permanent repository. As such, the federal government embarked on a long process that ultimately selected Yucca Mountain, in Nevada, as the possible home to a repository, according to Russ Dyer, assistant deputy director of the DOE's Office of Civilian Radioactive Waste Management.

Offering a history of the steps taken toward Yucca Mountain, Dyer noted that in 1982, Congress established the Nuclear Waste Policy Act (NWPA) for the disposition of high-level radioactive waste and commercial spent nuclear fuel. By 1987, the NWPA was amended to eliminate all sites except Yucca Mountain to be characterized for a potential repository. The NWPA required that an environmental impact statement be adopted by the NRC "to the extent practicable," according to Dyer.



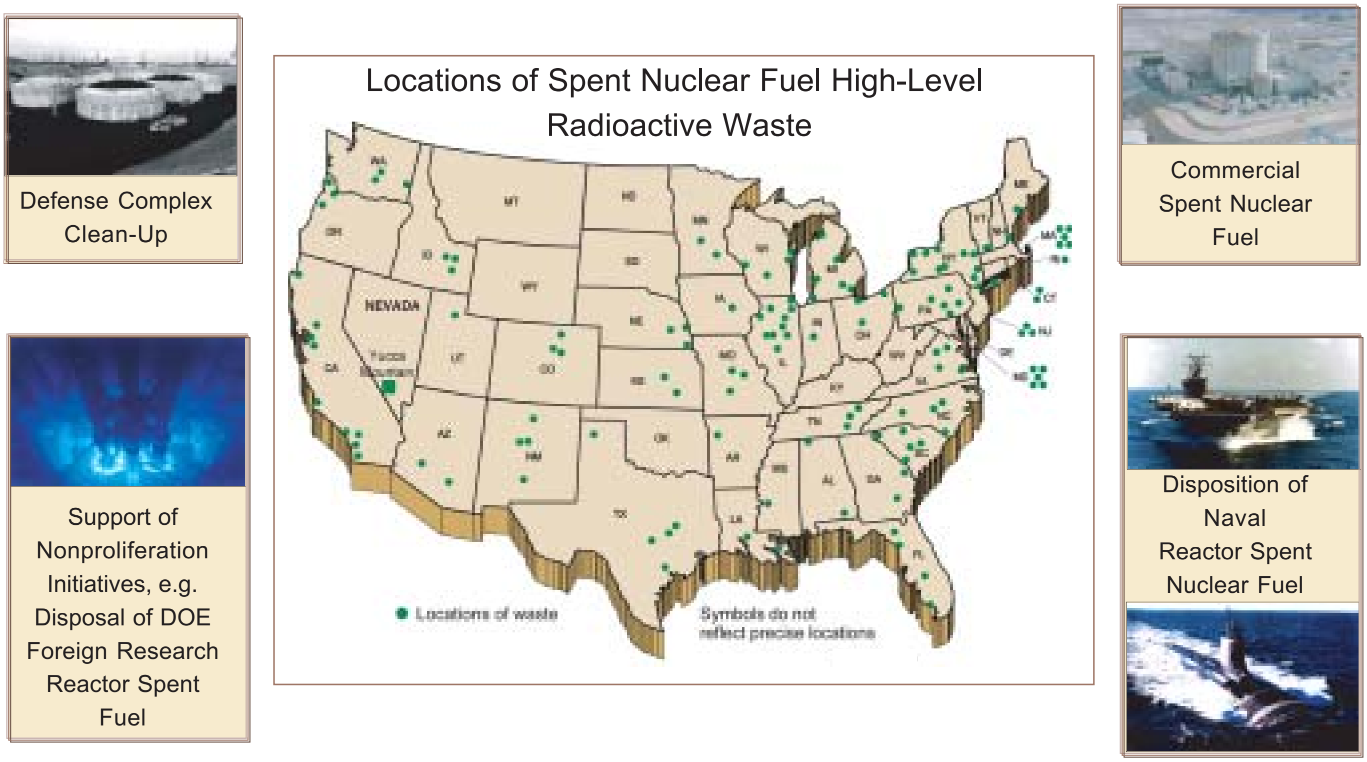
Dyer

In 1997, Congress directed the DOE, through the Energy and Water Development Appropriations Act, to prepare a report assessing the feasibility of developing a repository at Yucca Mountain. In 2002, a site recommendation was submitted and approved by Congress and signed by President Bush. Dyer said the DOE now expects to submit a license application to the NRC in 2004, with possible construction authorization coming by 2008 and an updated license application in 2010 to receive and process waste. "The goal is to accept a minimum of 400 metric tons of spent fuel in 2010," he said.

Yucca Mountain is about 100 miles northwest of Las Vegas, Nev., on land owned by the federal government. The area has a dry climate—receiving an average of about 7.5 inches of precipitation per year, according to the DOE. About 95 percent of this precipitation either runs off, evaporates, or is taken up by the desert vegetation.

A deep water table exists at Yucca Mountain, according to Dyer. If a repository is built there, it would be about 1000 feet below the earth's surface and 1000 feet above the water table. "So any water that does not run off or evaporate at the surface would have to move down nearly 1000 feet before reaching the repository and then another 1000 feet before it reached the water table," he said. The dry climate of Yucca Mountain is an attractive feature, Dyer said, because water is the primary way by which radioactive material could move from a repository.

Waste packages would be placed in tunnels that make up the repository. Storage would rely on a series of barriers that prevent or slow the movement of radioactive



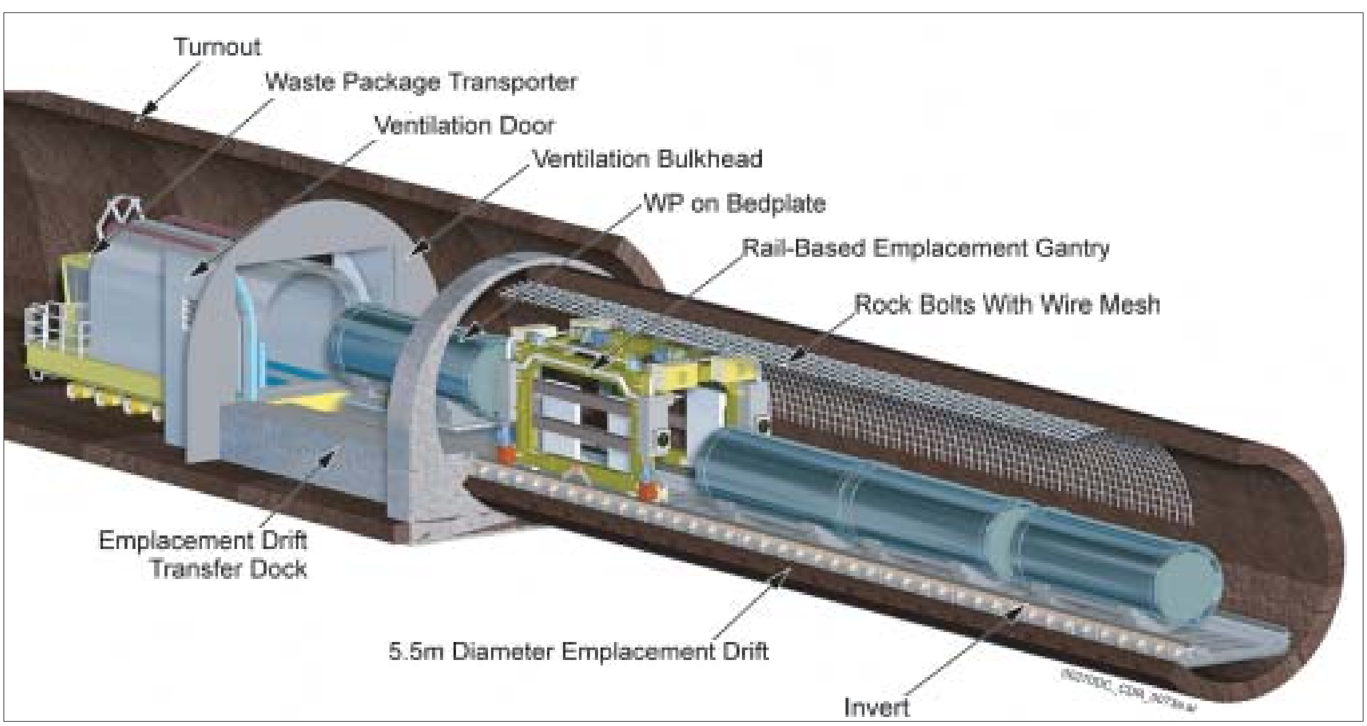
The multiple missions addressed by geologic disposal (Source: DOE)

materials out of the repository. These barriers include natural ones such as thick unsaturated rock, and engineered ones such as drip shields over the waste packages.

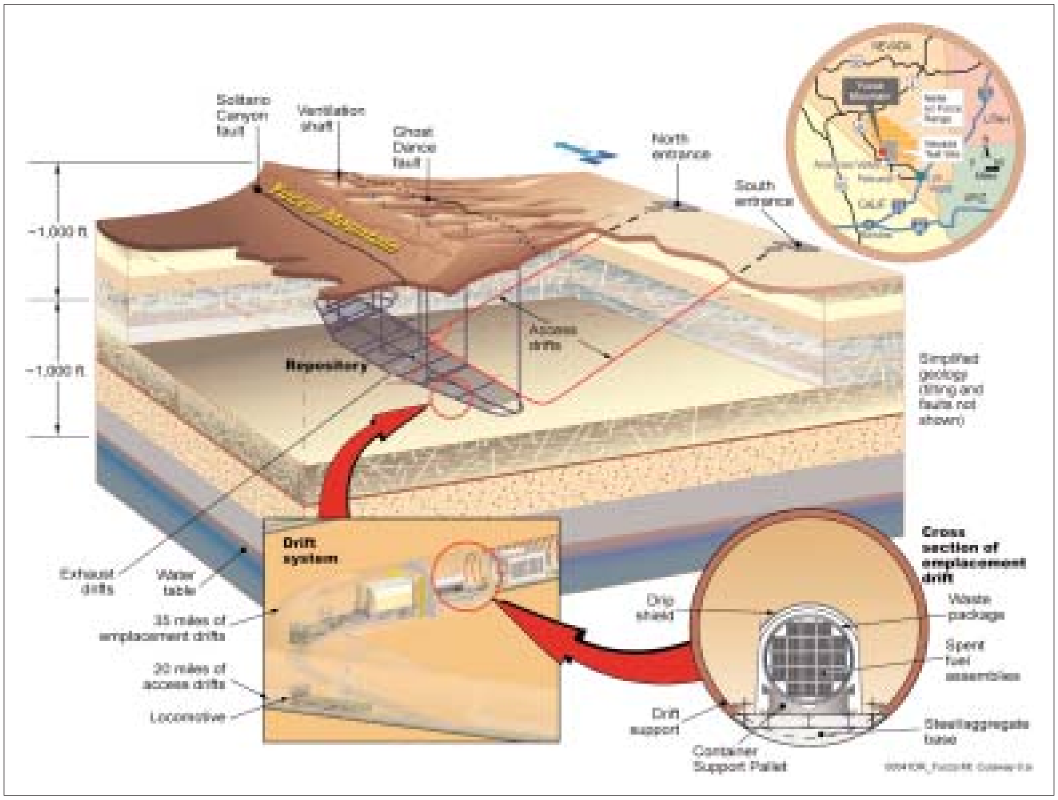
Only one tunnel—the Exploratory Studies Facility tunnel—has been excavated at this point. It is about 5 miles long, and there is a cross-drift tunnel of about 1.7 miles. Many miles of drift tunnels eventually would be developed if the project is successful in gaining an NRC license, Dyer noted. Even then, it is expected that the tunnels would be completed in a modular fashion, meaning not all at once, but as needed.

The waste would be stored in specially designed packages; the current thinking is that the packages would have an outer barrier made of Alloy C-22, an inner barrier of stainless steel, and a power limit of 11.8 kW.

A transportation plan to support waste acceptance is expected to be completed in short time. “Spent nuclear fuel shipments in the U.S. carry an impressive safety record,” said Dyer. More than 3000 shipments have been made in the United States in the past 30 years without a release of radioactive material harmful to the public or environment. In addition, the U.S. Navy has shipped 783 containers of high-level waste and traveled more than 1 million miles since 1957 without a harmful release. In Europe, more than 70 000 t of spent fuel already have been shipped through “densely populated areas,”



Cutaway showing proposed Yucca Mountain emplacement operations (Source: DOE)



The Yucca Mountain repository reference design concept (Source: DOE)

Dyer said, "and France and Britain average 650 shipments per year."

Dyer said the DOE would expect to receive a total of 70 000 shipments of waste at Yucca Mountain from 2010 to 2034. Over this 24-year period, the waste packages would arrive in 3215 train shipments (three packages per train) and 1079 truck shipments. Annually, 175 shipments would be made, consisting of 130 by rail and 45 by truck. To date, he said, no rail or highway routes have been selected.

To Mars

Astronaut Franklin Chang-Diaz has flown seven space missions from 1986 through 2002 and has logged more than 1600 hours in space. He is director of the Advanced Space Propulsion Laboratory at NASA's Johnson Space Center, in Houston, Tex.

With regard to missions to Mars and beyond, Chang-Diaz commented, "We might as well quit if we do not use nuclear power." Two of the necessities of space exploration, he said, are power and propulsion. The sun's rays are too weak to propel solar-powered rockets at distances beyond Mars, and chemical rockets, while important for getting from the surface of the Earth into orbit, don't provide the speed to travel to Mars. "So, nuclear fission reactors provide the only practical solution," he said.

Currently under development by NASA is the VASIMR engine, which is specifically engineered and designed for high-powered processing and thrust. The VASIMR engine relies on the technology of fusion, Chang-Diaz noted. "We do not have fusion power, obviously, but we do have tremendous technology that enables us to heat, vector, and exhaust a very high-density plasma through a module, which we call a magnetic nozzle," he said. "We use super-conducting magnets to create this magnetic duct and we inject propellent on one end, which we subsequently heat and accelerate through the use of vibrating frequency and electromagnetic radiation." The plasma then exhausts at a high velocity out of the other end of the engine, providing rocket propulsion.

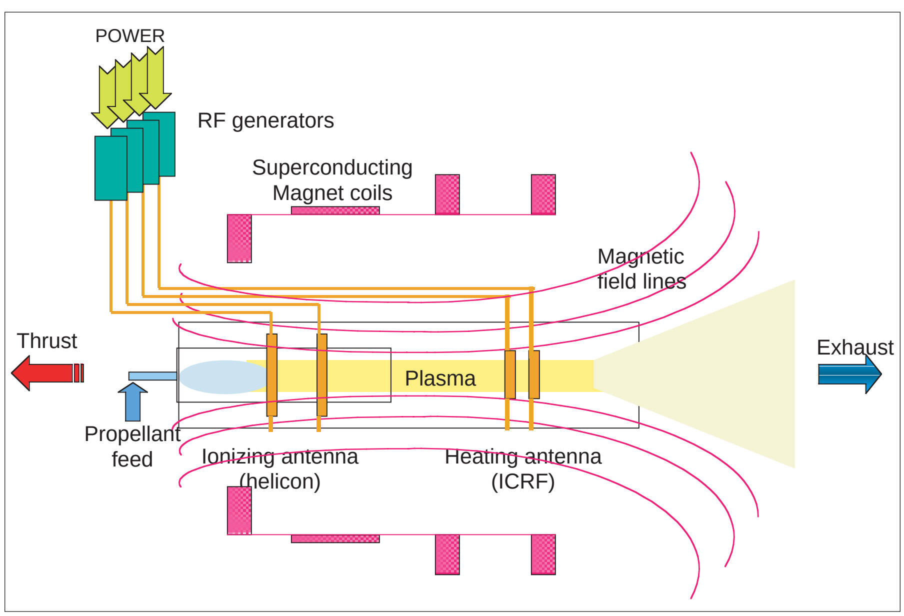
Chang-Diaz

The concepts NASA uses are well known, Chang-Diaz said, such as the use of radio-frequency heating of the plasma as described by Tom Howard Stix in his textbook, *Waves in Plasma*. The book explains that particles gain energy from incident waves, just as surfers ride the energy (waves) that moves ocean water.

The advantages of the VASIMR engine is that there are no electrodes or other materials in direct contact with the plasma. Therefore, he said, there is the potential for high power density, high reliability, and long life. There also is an assortment of propellants that can be used in the VASIMR, including helium, hydrogen, deuterium, nitrogen, argon, and xenon.

Two kinds of shielding are being studied for protection from reactor radiation and from radiation of the space environment, according to Chang-Diaz. "Number one, we want to consider the use of magnetic shielding," he said. "The engine itself can produce a kind of magnetic bubble that could potentially protect the crew from medium-energy solar flares." Second, he said, "we are also interested in the effect of hydrogen, which happens to be the propellent. So we would wrap the propellent tank around the body of the ship, and the hydrogen itself, in addition to being the propellent, will be a suitable shield."

How does humankind reach Mars? One potential schematic begins in lower orbit—with a rocket powered by "12 megawatts of



Simplified diagram of VASIMR thruster (Source: Advanced Space Propulsion Laboratory, NASA Johnson Space Center) solar power," said Chang-Diaz. "We would spiral around the Earth for about 30 days. This will get us out of the Earth's gravity field" using a low Isp, high-thrust mode. (According to NASA, rocket engine efficiency is generally defined by the parameter "specific impulse," Isp, which is effectively a measure of pounds of thrust per pound of propellent per second consumed. Isp is measured in units of seconds and is more or less analogous to miles per gallon, with higher values of Isp indicating higher operating efficiency.) The ship would then transition into the heliocentric portion of the trajectory powered by the VASIMR engine for about 85 days until orbit around Mars was reached. At that point, the ship would deploy a chemical-powered lander that would bring the crew to Mars. The mothership, however, would continue on past Mars to return four months later. By that time, "the crew has completed its service stay and is ready to come home," he said.

As NASA increases the power of its rockets, the farther beyond Mars that space exploration will go, and faster. "This is the potential of nuclear power," he concluded.

Nuclear's benefits

This year (in December) marks the 50th anniversary of President Eisenhower's "Atoms for Peace" speech and, according to Marvin Fertel, Eisenhower would feel pretty good about nuclear technology's progress if he were looking down on Earth today. Fertel, chief operations officer of the Nuclear Energy Institute, commented that lives are being saved throughout the world as a result of the use of nuclear medicine, that one out of every three Americans in a hospital receives either diagnostic or therapeutic treatment through nuclear medicine, and that 80 percent of the drugs that reach the market in the United States go through a Food and Drug Administration process that involves the use of radioactive tracers in getting the drugs approved. "So, we're seeing nuclear medicine actually save lives," he said.

Fertel

Also, nuclear isotopes are being used to make food supplies safer and, because radiation can be measured so precisely, nuclear technology is "ubiquitous in our industrial applications," Fertel said. "Everything from making sure a weld is safe to making sure we fill beer cans to the proper amount."

In the area of electric power generation, Fertel likened it to the San Diego marathon that was held the same day the ANS meeting opened on June 1. "I think we've come out of the gate pretty good, but it's not a hundred-yard sprint," he said. "We still have a long way to go."

Fertel noted that there are 2 billion people on Earth without electricity, representing one-third of the population, with projections calling for 9 billion people on Earth by 2050. "We'll certainly have to increase our use of electricity and energy in general," including nuclear, he said.

What might have been the greatest influence on the administration . . . is that nuclear is a major player in the U.S. voluntary program to reduce carbon emissions and greenhouse gases.

Currently, he said, nuclear reactors operating in 31 countries provide about 16 percent of the world's electricity. In 16 of those countries, nuclear power produces more than 25 percent of the electricity. Thus, he continued, nuclear has already penetrated the market as an important component of the electricity supply system. The question is, when will it take the next step?

Fertel recalled how the Bush administration came to embrace nuclear as an important part of a national energy policy. The first thing the administration did was find out that U.S. nuclear plants are operating well. "They didn't know that," he said. "The President and Vice President are oil people, they are not nuclear people."

What the administration discovered, Fertel continued, was that nuclear performance in the last five years was the equivalent of adding 13 new 1000-MW plants. "We're operating really well because we're focused on safety and we're focused on reliability," he said. "It's what gets us political support. It's what got us support from the Vice President and ultimately the President."

Fertel commented that the administration also learned that nuclear provides 20 percent of the nation's electricity supply, and that the industry was running at about a 90 percent capacity factor (including refueling outages) on a three-year average. They also learned that nuclear provides the lowest cost electricity available for production costs.

What might have been the greatest influence on the administration, Fertel said, is that nuclear is a major player in the U.S. voluntary program to reduce carbon emissions and greenhouse gases. NEI recently sent a letter to Energy Secretary Spencer Abraham telling him that the nuclear industry could by 2012 contribute 25 percent to the President's carbon-reduction goal through the addition of about 10 000 megawatts of "new" nuclear generation. "That new nuclear generation involves no new plants," he noted. "It involves the restart of Browns Ferry [Unit 1] and it involves about 8000 megawatts of upgrades and efficiency improvements at the other 103 plants."

Regarding construction of new plants, Fertel said that the Energy Policy Act of 1992 created a new oversight regime that "brings a lot more certainty to the regulatory process up front," such as through the NRC's efforts to establish early site permits and combined operating licenses. Unfortunately, he added, the industry now has "too many designs chasing too few customers, with about seven designs trying to get three or four customers." He pointed at industry consolidation as the reason for the shrunken customer base, saying, "The customers that are out there are real, but there aren't a lot of them." Still, when the time comes for that first new reactor order, "we have a process that can work much better than the old process and with a lot more certainty," he said.

View from Europe

A bad news/good news nuclear scenario for Europe was presented by Bertrand Barre, vice president of research and development for Cogema, of France, and vice president of the European Nuclear Society. While "one-third of Europe's lights are nuclear powered," he said, the bad news is that Germany is planning on phasing out nuclear power within 21 years, with a halt in spent-fuel reprocessing in 2005; Belgium is phasing out of nuclear power when the lives of the existing operating reactors reach license expiration (but the country will reverse this policy in the event of electricity shortages); and the United Kingdom has produced a white paper that advises the government to halt advancement toward new nuclear power construction, but keep the existing nuclear fleet as a backup in case renewables fail to reach their production targets.

Barre

The good news, however, outweighs the bad, according to Barre. In Switzerland, two pronuclear elections occurred in May, the first being a rejection by more than 66 percent of the voters of a nuclear phaseout, and the second being a rejection by 58 percent of voters of the moratorium on new plant construction. In France, Electricité de France is “poised to order one EPR” (European Pressurized water Reactor), Barre said. In Belgium, the anti-nuclear Green Party lost in the 2003 elections, gaining only 14 percent of the vote, a decrease of almost 6 percent from the previous election. In Finland, the likelihood of a fifth reactor being built in the country is being realistically discussed. In Sweden, the country is thinking about reversing itself on a decision to shut down 10 reactors by 2010. In the Czech Republic, a new reactor, Temelin-2, was connected to the grid in 2002. And the European Commission, in its “Green Book on Energy Security,” noted that without nuclear there would be “too much vulnerability” to energy security and “too much CO_2,” according to Barre.

A great misconception exists in Europe, Barre noted, in that across the continent (except for Scandinavian countries), a majority believes that “nuclear power contributes significantly to global warming and climate change.” In fact, for the European Union as a whole, more than 45 percent of respondents to a poll believe nuclear is detrimental to the Earth’s atmosphere, while only about 26 percent said it isn’t detrimental and 25 percent don’t know.

For the European Union as a whole, more than 45 percent of respondents to a poll believe nuclear is detrimental to the earth’s atmosphere.

Radwaste management remained the greatest concern among Europeans who were polled on nuclear power. By a healthy majority, however, according to polling data, “if all waste can be safely managed, nuclear power should remain an option,” said Barre.

Early site permits

An early site permit (ESP) represents the Nuclear Regulatory Commission’s approval of a particular site to build a class of nuclear power plant (or plants) independent of the facility review, explained Ronaldo Jenkins, ESP project manager in the NRC’s New Reactor Licensing Project Office. Primarily, the ESP process allows for early consideration of site suitability issues, specifically site safety, emergency planning, and site environmental, as reviews of these issues are conducted by the NRC as part of its three-part analysis. In addition, “litigation relating to these issues could be resolved before the applicant invests a significant amount of capital,” Jenkins said.

Jenkins, who led off the “Site Licensing Progress: Safety Impacts in the Early Site Licensing Process” session, noted that Dominion Generation, Exelon Generating Company, and Entergy Operations, Inc. have identified potential sites for ESPs and have stated plans to submit ESP applications to the NRC before the end of this year.

Industry views

Working toward an ESP provides challenges, said Spencer Semmes, lead engineer–technology for Dominion’s ESP project. Dominion has not yet selected a plant design for its ESP application, and in fact intends to propose a “surrogate plant that provides the NRC with the necessary design information,” Semmes said. The surrogate plant, called a “plant parameters envelope” (PPE), has been created by blending the design elements of several new reactor designs. By using a PPE, and because environmental guidance from the NRC and the Environmental Protection Agency require detailed information on a proposed plant’s operations, “it’s hard to provide that detailed information in a generic sense that covers multiple reactor designs,” he said.

Semmes

Semmes provided two examples where the case of not selecting a specific design is challenging. The first example relates to offsite dose calculations that are required for an ESP application. It might be easy to calculate the offsite dosage when a specific plant design such as the ACR-700 is selected, said Semmes, but it’s a lot harder to provide a calculation when multiple plant designs are considered, such as the ACR-700 (a heavy-water-moderated light-water-cooled reactor), a GT-MHR (a helium-cooled reactor), or an AP1000 (a conventional pressurized water reactor). “You end up with a very interesting mix of isotopes that makes the dose categories extremely difficult,” Semmes said.

A second example relates to the plant’s physical “footprint” on the land, in that some proposed plants are compact in size and some are not. Semmes said it was “a real challenge to figure out how you can put a plant footprint on site, to lay it out, and still provide coordinates as required by the regulatory guidance for the reactor itself, or reactors.” For example, for a 3000-MW plant, the footprint siting would require 16 Pebble Bed Modular Reactors, or four ACR-700s, or two ABWRs. “So the challenge of trying to specify where your reactor is [to be located on a site], when you’ve got anywhere from two reactors to 16, it’s kind of difficult and we’ve found that to be a big challenge,” he said.

Dominion’s ESP project was initiated in June 2001 with three objectives in mind: maintain a nuclear option for Dominion, evaluate new reactor technologies, and demonstrate the NRC’s 10 CFR Part 52 licensing process. The project was done in two phases, with Phase One completed last September. That phase analyzed sites for new nuclear deployment, including Dominion’s North Anna and Surry sites and the DOE’s Savannah River, Idaho National Engineering and Environmental Laboratory, and Portsmouth (Ohio) Gaseous Diffusion Plant. The sites were ranked using economic, engineering, environmental, and sociological criteria. “We determined that all sites were suitable, but North Anna was superior overall,” said Semmes.

Phase Two involves the ESP application’s development, with the goal of demonstrating the viability and predictability of the NRC’s regulation in governing ESPs. Semmes said that Dominion had a target date of this September for submitting an application for North Anna, with an expectation that the ESP could be issued by the NRC in May 2005.

Another ESP issue to be cognizant of is the public’s participation in the process and trust in the project, said George Zinke, project manager of nuclear business development for Entergy Nuclear. Zinke related the tale of what happened when Entergy and the NRC held an open meeting to inform the public about the company’s upcoming ESP application for the Grand Gulf plant, in Port Gibson, Miss. The meeting, which the NRC hoped would serve as an education vehicle for the public, attracted antinuclear activists who tried to rally support against a new plant. In fact, Zinke said, activists were “trying to convince the public that the only way [they] should participate in this licensing process is [through] civil disobedience.”

Zinke

Zinke said the activists took language from Entergy and the NRC and misinterpreted it, and quoted things that were never said, hoping to alarm the public about the dangers of nuclear power. So, he added, it is easy to understand how members of the public could become alarmed by a proposed project. A solution to deflect the activists' tactics is for the ESP process to have "some kind of better public education, so that people understand how they can participate in the process," he said.

Regulatory process

The NRC's Jenkins said that after reviewing an application for a new reactor, the NRC can issue an ESP for approval of one or more sites, separate from an application for a construction permit or combined license. An ESP is a partial construction permit, Jenkins said, and is subject to all procedural requirements in 10 CFR Part 2 applicable to construction permits. ESPs are good for 10–20 years and can be renewed for an additional 10–20 years, while reactor design certification is good for 15 years. (The NRC's review of a reactor design addresses the safety issues of an essentially complete nuclear power plant design, independent of a specific site.)

The NRC encourages early discussions between the agency and potential ESP applicants, such as utilities and reactor designers—"before a license application is submitted," Jenkins said—so that the agency can provide ESP licensing guidance and resolve potential licensing issues.

During the pre-application period, the NRC holds public meetings with potential applicants to discuss advanced reactor designs. There are three specific reasons for these meetings, Jenkins noted. First, to identify major safety issues that could require NRC policy guidance. Second, to recognize major technical issues that the NRC could resolve under existing regulations or NRC policy. Third, to conduct the research needed to resolve identified issues.

A strategy for deploying new nuclear power plants was explained by B. P. Singh,


Singh

program manager in the Department of Energy's Office of Nuclear Energy, Science and Technology. The Bush administration's National Energy Policy development group in May 2001 recommended support for, among other nuclear initiatives, the licensing of new nuclear reactors and the development of nuclear fuel technologies and next-generation technologies. Following that recommendation, the DOE in February 2002 unveiled its Nuclear Power 2010 program, which has a goal of achieving an "industry decision by 2005 to deploy at least one new advanced nuclear power plant in the 2010 time frame," Singh said.

Singh defined the program as a public/private partnership to explore sites that could host new plants, demonstrate new NRC regulatory processes, develop advanced reactor technologies, and construct a business case for new nuclear plants.

To date, the program has issued a near-term deployment "roadmap," completed a business case study and site scoping study, helped initiate three ESP demonstration projects (at Dominion's North Anna, Entergy's Grand Gulf, and Exelon's Clinton), and started a schedule and construction assessment study.

The DOE will continue the program, Singh said, with the following activities through next year: a study of the economic policy benefits and impacts of new plant deployment, and financial risk mitigation strategies and implementation methods, among other things.

The key factors

A "convergence of key factors" will be needed for new plants to be built, according to Russ Bell, a senior project manager for the Nuclear Energy Institute.


Bell

Factors will include a need for power in the post 2010 timeframe, a collaboration by vendors and utilities to ensure competitive costs and predictable schedules, strong support for nuclear power from the White House and Congress, and strong support from the public "for nuclear in general and for new plants in particular," he said.

Regarding cost and schedule certainty, Bell said that vendors currently are working toward overnight capital costs in the range of $1000–$1200/kW and three-year construction schedules for new plants.

Environmental equity

The General Chair's Special Session, "Nuclear Power—Leveling the Environmental Playing Field," was chaired by Entergy's Carl Crawford, an ANS past president. Crawford noted that the environmental benefits of nuclear energy will be critical not only to its successful relaunch, but also to the nation's long-term economic well-being. This special session looked at how the industry can reduce unfair environmental constraints and exploit the support given by President Bush and congress, including money to develop the nuclear production of hydrogen.

The first speaker was Dan Keuter, Entergy's vice president for nuclear business development. Since his appointment in 2000, the company has doubled its nuclear fleet,


Keuter

adding five plants, all in the northeast. Besides buying existing assets, Keuter also looks at new nuclear construction. He said the question he is most asked is: What will it take to build a new nuclear power plant? Besides listing what is needed, Keuter tried to indicate how much has been done, and how much more there is to do.

The top requirement, he noted, is a supportive national energy policy with provisions to get nuclear power moving, including financial support, decommissioning funding reform, reducing the risk of regulatory or political delays to a construction project, technology development (for example, gas reactors for electricity and hydrogen production), support for the Yucca Mountain project, and others. A policy must also have good public and bipartisan support, he observed.

While the way forward on most technical issues is clear, said Keuter, it is on questions of finance and risk that new efforts are needed, particularly on ways to mitigate the risks to investors of first-of-a-kind costs, high initial capital costs, regulatory and political uncertainties, earnings dilution, and the market. He observed that a lead demonstration plant will certainly be needed before Wall Street will even think about providing debt financing. This, he added, will require industry and government working together to put into place all elements for building a plant, such as design validation and an efficient regulatory process.

The lowest risk and cost competitors are combined cycle gas-turbine and coal-fired generation, said Keuter. He showed a diagram of how the costs and risks of various options compare. For example, the advanced boiling water reactor (ABWR) has already been built (in Japan), and so has reduced risk, but still has a high cost, he said. Other designs have lower costs, but higher risk factors. He also listed the main financial risks and the measures being considered to

The environmental benefits of nuclear energy will be critical not only to its successful relaunch, but also to the nation's long-term economic well-being.

mitigate them. The number one risk, he said, is regulatory/political delays. To mitigate these risks, the DOE has proposed a two-part standby credit facility (a regulatory insurance policy) involving government interest payment during delay and a 100 percent repayment if delays cause a default. "This is essential before we can get any Wall Street support," he stressed.

After that, Keuter noted, comes the high capital cost of a nuclear project for which government loans or guarantees and accelerated depreciation has been proposed. To compensate for lack of earnings during construction of the first plant, there is a proposed 10 percent investment tax credit or government construction loan. To compensate for market risks, a long-term power purchase agreement (PPA) or a price guarantee has been proposed, or an emissions-free tax credit similar to what wind power gets. Finally, for first-of-a-kind costs, there is DOE support involving direct investment and government loans.

Keuter analyzed how such government incentives affect the cost of nuclear production. This will help determine where to concentrate the industry's efforts. After building lead plants, government support should diminish, said Keuter, but some will still be needed, such as regulatory risk insurance (although industry will pay the premiums), accelerated depreciation, and long-term PPAs. Finally, however, if the industry is going to be able to build beyond the initial few units, nuclear energy will need some form of environmental value based on avoided emissions, he added. He discussed the various options, including the Cap & Trade system (for NOx, SO_2, Hg, and CO_2) and emission credit allocations based on level of output or an auction system. Environmental legislation is coming, Keuter promised. There are now three bills in the offing: the so-called Jeffords Bill, the Clear Skies bill, and the Carper Bill.

The following is Keuter's list of what is needed to build that first plant:

- Consortium of four to five utilities.
- Common site with transmission to all owners.
- One reactor, with options for dual unit.
- Possible PPA with government.
- Ground-breaking by 2008 and operation by 2012.
- Competitive bid of at least two designs.
- Phased process with decision points to continue.
- Government support for first-of-a-kind costs, financing, and risk.

If the industry is going to be able to build beyond the initial few units, nuclear energy will need some form of environmental value based on avoided emissions.

Ted Marston, vice president of Science and Technology Development at EPRI, discussed the future deployability of new nuclear power under various market conditions using the National Energy Modeling System (NEMS). EPRI defined a regional power market of 85 000 MW load and examined possible scenarios and their consequences for nuclear energy. The market model took account of different generation mixes, environmental regulations, emissions allowance contributions, CO_2 prices, fuel prices, tariffs, technology, etc.

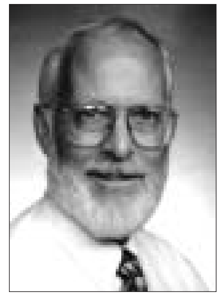
How greenhouse gas emissions are constrained in the future is critical, Marston said. EPRI looked at regulatory structure and concluded that CO_2 regulations turn out to be the dominant contributor to profitability. Given tough environmental regulations, the NEMS showed a deployment of large amounts of nuclear capacity.

Marston warned, however, that politicians are reluctant to do anything that will increase tariffs of individual ratepayers. This is a tricky subject, he noted, and he suggested that a possible way forward was to give emission allowances to large emitters to mitigate their asset value erosion due to environmental regulations. This should not have much impact on the asset value of nonemitters, which are more dependent on actual electricity prices, Marston explained. This should help avoid conflict between coal and nuclear, he added.

Going for hydrogen

In February, President Bush announced a hydrogen fuel initiative that includes a $1.2-billion budget to develop hydrogen production technology. While various offices in DOE have some responsibilities in the hydrogen program, the Office of Nuclear Energy, Science and Technology has responsibility for anything that is nuclear-driven. DOE's David Henderson said that $4 million was requested for FY 2004 to start the nuclear hydrogen program, with the aim of demonstrating hydrogen production with nuclear reactors by 2015. Following an initial workshop in March of this year, a roadmap for the R&D needed to meet the target date is being developed. It is to be ready in September.

The next speaker, Ken Schultz, reminded the session that the hydrogen economy will need a great deal of hydrogen. Transportation needs alone could take about 200 million t. Schultz is responsible for the development of General Atomics' program for hydrogen production, not only using GA's high-temperature reactor technology, but also solar and fusion energy sources. He noted that there is already an interesting hydrogen market in the United States, which consumes 11 million t of hydrogen each year. Almost all of this is produced by the steam reformation of natural gas and is used in the fertilizer, chemical, and oil industries. Besides exploiting an important energy source, this production releases 74 million t of CO_2 every year. This is a market that is very much suited to nuclear power—it is large scale and provides steady demand, Schultz said.



Schultz

Schultz described how nuclear energy might be used. Two general processes are available for producing hydrogen from water—electrolysis, which is not very efficient, and a thermal chemical water splitting process. In the latter, the chemicals are recycled: the only inputs are high-temperature heat and water, the outputs are low temperature heat, oxygen, and hydrogen. This is a developing technology which in theory can attain efficiencies of 60 percent if temperatures of about 1000 °C are available. At the moment, a sulfur-iodine cycle is believed the best one suited for a nuclear heat source.

A study done by Sandia National Laboratories, Schultz said, has indicated that by using a high-temperature reactor with the sulfur-iodine process, hydrogen could be produced at about $1.45/kg. And if the oxygen could be sold, the cost gets down to $1.25/kg, or about $9.30/million Btu. At this level, said Schultz, the system would be economical when the price of natural gas goes above $4/million Btu. Although in the past few years, the price has been $2–$3/million Btu, he said, today it is $6/million Btu. It is still necessary, however, to demonstrate the sulfur iodine process on a large scale, build an engineering loop to test prototype materials, temperatures, pressures, etc., and then to do it on a high-temperature reactor.

Reality v. optimism

The next speaker, Andrew Green, reminded the audience that policy-makers will look at all energy sources in developing strategies. Green, who has worked in state (Massachusetts) administration, where he was involved in environmental affairs, energy, utilities, and radwaste, is now with Navigant Consulting, a company that specializes in assessing the potential of nonemitting sources. Nuclear has a good story, he said, but there is a limit to the number of new plants and their associated facilities that could be built. Soon, he opined, a choice on how to use nuclear must be made—to replace fossil stations to produce power on the grid, or to displace transportation fuels, largely diesel and gasoline, in a hydrogen economy. Where, he asked, is the bigger "environmental bang for the buck"? Green said that it is likely to be in electricity production, so large efforts to develop a nuclear hydrogen capability may be a mistake.

Besides pushing [nuclear's] value as a nonemitting source, the industry must work on all the lingering issues such as early site permitting, the waste program, and other infrastructure issues.

He also reminded the participants that there are potential barriers in its way, such as the Kyoto Protocol, which denies nuclear energy nonemission credits that could support construction of nuclear plants in developing countries and in the polluted regions of the former Soviet Union. And until there is some tax on carbon, there is no advantage in not putting CO_2 into the atmosphere, he noted.

To bring nuclear power into hydrogen production, the industry has to get the fundamentals in place, Green said. Besides pushing its value as a nonemitting source, the industry must work on all the lingering issues such as early site permitting, the waste program, and other infrastructure issues. And, of course, it has to demonstrate that the technologies can be scaled up. He also advised the nuclear industry to reach out to other industries—such as the transportation, chemical, and agricultural product sectors, which will be a big part of a future hydrogen economy.

The next speaker, Ron Hagen, of the Office of Coal, Nuclear, Electric & Alternate Fuels in the DOE's Energy Information Administration, keeps track of developments in nuclear power in the United States and internationally. He made the point that because coal produces almost twice as much CO_2 as natural gas, switching to gas reduces greenhouse gas emissions significantly and also avoids ash production. This is a clear benefit and an attractive option. Furthermore, he noted that coal, like nuclear, is working to fix its problems by developing technologies to sequester CO_2, as well as coal gasification and the production of oil products.

Ultimately, Hagen noted, nuclear's advantage will depend on what value is placed on emissions, the cost of dealing with spent fuel, and the relative cost of building and operating the different power plants. He said that actually he doubted whether emissions will be a major determinant of which energy source is chosen. If nuclear power is much more expensive than the alternatives, there are probably other ways of getting environmental benefits than by using nuclear power. If nuclear power were much cheaper, then again the environmental benefit would not be a major determinant. If costs are about the same, however, then the environmental benefits may have a major bearing.

Following these cautionary contributions to the discussion, the final speaker, Finis Southworth, stated bluntly: "If nuclear is going to become a viable option again, we have got to build [a nuclear power plant]." Southworth, who is a department manager at the Idaho National Engineering and Environmental Laboratory (INEEL) and the U.S. product manager for Generation IV very high-temperature reactors, noted that the DOE's stated goal is to build a 600-MWt gas-cooled high-temperature reactor by 2015 and demonstrate full-scale high-temperature production of hydrogen. The program, he said, has a number of goals, including obtaining an NRC license, providing the basis for future behavior-based risk-informed licensing of a commercial version, and demonstrating hydrogen production and utilization technologies.

INEEL, noted Southworth, wants this to be the facility's 53rd test bed reactor. A site has already been identified about 3 miles from the Idaho Nuclear Technology Engineering Center (previously the Idaho chemical processing plant), that has already been well characterized (for a production plant project).

There has already been a considerable amount of analysis done of the design, the material, construction, licensing and environmental permitting, fuel supply activities, and hydrogen production to determine what is needed to make it work, he explained. R&D needed to meet the time frame includes priorities related to fuel, such as qualifying fuel to demonstrate the safety case, devising new fuel cycle initiatives, developing very high-temperature fuels, and demonstrating actinide management and transmutation. Also, since there is not time to develop new materials, the near-term objective is finding materials that are quantifiable. Suitable materials must be selected and their database built up. Scaling-up the various technologies is also necessary to meet the R&D timeframe. One critical date Southworth noted was 2007, when the pressure vessel has to be ordered. This, he said, does not leave much time.

Vessel corrosion

Dominion Energy's North Anna-2 was returned to service on February 2 following replacement of its reactor vessel head. It was the industry's first vessel head to be replaced after severe corrosion was found in February 2002 on FirstEnergy Nuclear Operating Co.'s Davis-Besse nuclear power plant, which resulted in industry-wide vessel head inspections ordered by the Nuclear Regulatory Commission. "This was an important step for the United States to show that this [vessel head replacement] could be done," said William Corbin, director of the nuclear projects department for Dominion Resources Services, Inc., at the session on "Reactor Vessel Corrosion: Prevention, Identification, and Replacement." He added, "Vessel head replacements are a viable alternative to continuous inspections."

Corbin gave a detailed presentation of Dominion's decision to replace the North Anna-2 head—and those of the North Anna-1 unit and the two Surry units—and about the challenges and lessons learned from the job. The North Anna plant, in Mineral, Va., has a pair of Westinghouse pressurized water reactors. Unit 1 is rated at 925 MWe (net) and Unit 2 at 917 MWe (net). The two Surry units, in Gravel Neck, Va., also are Westinghouse PWRs. Surry-1 is rated at 810 MWe (net) and Surry-2 at 815 MWe (net).

Corbin noted that the North Anna and Surry units ranked in the NRC's top third of U.S. pressurized water reactors in terms of susceptibility for vessel head cracking. "In fact," he said, "those four units [were] among the top 10 in the nation for susceptibility to the head cracking issues."

Before any decisions were made by Dominion to replace vessel heads, cracks were found in the North Anna-2 head's penetration tubes during an outage that began last September. Personnel started to assess "what it would take to make all the repairs, the [radiation] dose it was going to take, the time it would take, the money it would take," Corbin said.

In early October, another option was considered, which was to replace the vessel head with one purchased from Electricité de France, Corbin said. If Dominion purchased the French head, however, all of North Anna-2's control rod drive mechanism parts and related head components would have to be reused. "We also needed to consider how we were going to get the new head from the factory in France to North Anna," he said, adding that a hole would have to be cut into Unit 2's containment because the new head wouldn't fit through the existing equipment door. Also, the fact that the French head was not manufactured to ASME Code created another problem.

Dominion management decided that replacing the vessel head, although expensive in terms of time and money, would be a better alternative than continuing with head inspections. With the project under way, two robotic waterjets were brought in to cut away the containment concrete where the access opening would be located. "The location of the access opening [was] actually more or less on top of the original construction opening to the containment, but around the side from where the equipment hatch [is]," he said. "We didn't want to go in the area of the equipment hatch because the rebar pattern was very particular. There's lots of rebar there. By coming around about 30 degrees or so, we were able to create a place where we could get in and the rebar was not closed fast."

Corbin said that workers around the area during the concrete cutting had to wear double protection over their ears, "Earplugs and earmuffs," he said. "This [waterjet] is extremely loud to operate. I don't have a decibel figure for you, but it would be louder than jet engines at an airport."

Corbin noted that the new vessel head was too big by a mere few inches to fit inside the equipment hatch. "That's a consideration for future nuclear power plants," he said, "to make the equipment hatch large enough to get all the components in there. Just make it a little bit larger."

The new head was transported from France in one of the largest airplanes in the world for the tonnage it can carry (*NN*, Mar. 2003, p. 32). Ukrainian made, the Antonov-124-100 dwarfs other aircraft in size comparisons. According to Corbin, the airplane's nose lifts up and the new head was rolled in on rails. Once in the United States, the new head was set on a flatbed truck measuring 192 feet in length, and then it sailed "down the highway at 60 miles per hour" to North Anna, he said.

Once the old head was taken out of containment and the new head brought in, the access hole had to be closed up. Each piece of rebar that had been cut away was welded back in its original location. Then new concrete—4 feet thick—was put in place, all in a single pour.

The new vessel head fit on the reactor without problems, Corbin said, as all the CRDM penetrations aligned as they should. There was a slight hindrance with some of the lifting mechanisms that aligned the head properly, but that proved to be a small hurdle.

Corbin listed some issues regarding the head replacement project: mobilizing a team that included Dominion personnel and contractors; getting the French head (with its code written in French) approved to NRC requirements; meeting certain welding requirements for the rebar and the vessel head; conducting a stress analysis of the reactor, since the new head had a thicker flange and considerably increased weight; and dealing with safety issues for the new concrete that were resolved when North Anna "borrowed" qualification records from Davis-Besse, which had just previously qualified a similar safety-rated concrete mix. "We literally trucked down the material from northern Ohio to Virginia and used [Davis-Besse's] material, used their mix, used their design, used their back plan, used everything," he said. "We just brought the whole thing down to Virginia and set it up in the yard. That's how we've got the safety-rated concrete in one day's time."

A nuclear plant undertaking vessel head replacement should take "firm control" of all documentation, Corbin noted. "We really stumbled early and learned later how important it is to get the documentation packages absolutely right."

Regarding lessons learned, a nuclear plant undertaking vessel head replacement should take "firm control" of all documentation, Corbin noted. "We really stumbled early and learned later how important it is to get the documentation packages absolutely right," he stressed, adding that Dominion personnel traveled to France to be part of the team that prepared the new head and its documentation for the trip to the United States.

A second lesson learned was the importance of using company personnel for the job. "Don't rely on the contractors entirely," he said. "There is too much going on. It interferes with the way you run your facility to think that you could put a couple of people on this out of your own shop."

Third was getting the lines of communication in order. Leaders must be identified for the project team and for the operation of the plant. "We had some issues on that," Corbin noted, but "we worked through them."

A fourth lesson learned was project planning. For the replacement job, North Anna had set up a planned organization that included personnel from Dominion and from such contractors as Bechtel and Framatome. "That whole team worked together and mapped out our outline of what we were going to be doing all the way through the outage," he said. "That was a big success."

Since North Anna-2's job was completed, Dominion has also replaced the head at North Anna-1. The replacement work on Surry-1 was ongoing (since completed in June), and Surry-2's replacement job was scheduled to begin this fall.

Corrosion work

Stephanie Coffin, of the NRC's Materials and Chemical Engineering Branch, reviewed the agency's actions in light of the industry's recent experience with reactor vessel corrosion. These actions, she said, included the issuance of three bulletins, one order, some ASME Code work, and the codifying of 10 CFR 50.55a requirements.

Bulletin 2001-01, Coffin explained, highlighted the potential for cracking in control drive rod mechanisms (CRDMs), questioned the adequacy of visual examinations, categorized PWRs based on susceptibility to primary water stress-corrosion cracking (PWSCC), and requested plants to provide the NRC with information about future vessel head inspection plans, past inspection findings, and vessel head insulation design.

The next bulletin, 2002-01, highlighted the corrosion found on the Davis-Besse reactor head, questioned the industry's practices for identifying and resolving reactor coolant pressure boundary degradation, and asked how plant operators were assessing boric acid corrosion. A second bulletin in 2002 explained the potential weaknesses in current examination requirements and suggested the need for nonvisual, volumetric nondestructive examinations (NDE).

The NRC then issued Order EA-03-009, which imposed inspection requirements based on susceptibility to PWSCC, "and allowed for consideration of relaxation of inspection requirements for good cause," Coffin said. The order, she added, applied to Alloy 690 materials as well as Alloy 600 materials.

Coffin said that the NRC was undertaking a program to evaluate "crack susceptibility models" for Alloy 600 materials and for "Alloy 600 crack initiation and growth rates" in a borated water environment. The NRC also is running tests to correlate leak-age of vessel head material with its time to failure, evaluating corrosion rates due to failure, and researching how to improve NDE techniques.

Chris Wood, senior technical manager in the Nuclear Sector for EPRI, in explaining advances made in water chemistry to mitigate corrosion issues, noted that continuous injection of 20 to 35 parts per billion of zinc acetate "is currently the most promising" chemistry technique for PWSCC mitigation. The addition of zinc, he said, showed that corrosion rates and PWSCC susceptibility were lowered in tests, and, in addition, had shown in Atomic Energy of Canada Limited testing that zinc addition had lowered shutdown radiation dose rates.

EPRI conducted its zinc program, Wood said, to evaluate the long-term effect of zinc in mitigating Alloy 600 PWSCC and radiation fields, and to "ensure that zinc does not have an adverse effect on fuel performance and other components."


Wood

Wood continued that there is "strong laboratory evidence" supporting the position that zinc inhibits "the initiation of PWSCC in Alloy 600," while less conclusive laboratory evidence suggests that zinc "may be effective in inhibiting the propagation" of PWSCC.

Also, testing done at the Farley, Diablo Canyon, and Palisades nuclear power plants have shown significant reductions in PWR shutdown radiation fields with zinc additions, and that no adverse effects of zinc additions were observed on Zircaloy or Zirlo fuel cladding. Wood concluded that EPRI was recommending that PWRs "should consider" implementing an addition of 5–10 ppb of zinc to "reduce radiation buildup" and to prepare the plant "to gain benefits of zinc to mitigate PWSCC" if it is shown to be "effective."

Post-9/11 protection

The panel on "Physical Protection of Nuclear Materials and Facilities Post-9/11" was chaired by Alex Burkart, who noted that U.S. nuclear trade has always required the recipient to maintain physical protection. Since the horrific acts of September 11, 2001 (9/11), however, physical protection has taken on a real urgency and a new global political significance.

International solidarity has remained firm, said Burkart, who is deputy director of the Office of Nuclear Energy Affairs at the State Department. Only the day before, the G-8 countries had reiterated their commitment to combat terrorism at their summit in Evian, France, where an action plan was approved.

Since 9/11, the International Atomic Energy Agency (IAEA) has been an important partner in these efforts, said Burkart. The agency's work on security was the subject of the first three presentations at this panel session, starting with an overview of agency activities given by Anita Nilsson, head of the new IAEA Office of Physical Protection and Materials Security.

September 11, 2001, Nilsson said, was a wake-up call and IAEA Director General Mohamed ElBaradei lost no time in urging member countries to strengthen the agency's programs and other security activities. Besides the threat of theft of a nuclear device (whose security remains the responsibility of the weapons states), the other threats include the acquisition of nuclear or other radioactive materials to make a so-called dirty bomb, malicious acts against facilities (sabotage), and illicit trafficking (smuggling). The agency maintains a database with almost 500 confirmed cases of trafficking since 1995, demonstrating that greater protection at the source is needed, Nilsson observed.

The drafting group also hammered out new cooperation and confidentiality obligations and reached consensus on several new criminal offenses, including smuggling.

In March 2002, the agency secretariat went to the board of governors with a program of activities to protect against nuclear terrorism. Nilsson noted that this program highlighted a number of areas of concern that had not received as much attention as the agency would have liked, such as research reactors and radiation sources. Besides providing more protection at the source, there needs to be a second line of defense, as well as measures in place to respond to an event, she added.

Nilsson described the "international platform" for dealing with terrorism, with the Convention on the Physical Protection of Nuclear Material (CPPNM) at the top. She explained there are now efforts to revise the convention, looking at nuclear security in a more comprehensive way, as well as identifying weak links. She also noted the conceptional link between this convention and the Non-Proliferation Treaty (NPT). Although there are no physical protection requirements in the treaty, taken as a whole, it does contribute to the infrastructure that keeps nuclear material under control and protected.

There is not yet anything similar for radioactive sources, which was the subject of a major conference last March. But there is INFCIRC/225/Rev.4, a comprehensive document containing measures for physical protection, and the basic safety standards that contribute to overall security. There is also an ongoing work on the code of conduct on the safety and security of radioactive sources.

In addition, the agency operates the International Physical Protection Advisory Service (IPPAS). Under IPPAS, at the request of a country, the agency can assemble expertise to assess physical protection and regulatory systems and how they are implemented at facility level, and then give recommendations of upgrades.

Nilsson mentioned other agency priorities, including developing new security measures for nuclear transportation, ensuring that states and their agents know how to respond should an incident occur, and developing methods for taking forensic evidence.

Revising the Convention

A more detailed discussion of the effort to revise the CPPNM was provided by Patricia Comella, who is in Alex Burkart's office and played a key role in the work.

When the convention was drafted in the 1970s, she explained, many states were reluctant to give up any sovereignty over physical protection. This led to a very limited convention covering only the protection of nuclear material during international nuclear transport, and "storage incidental to such transport." The convention, which entered into force in 1987, imposes obligations on states to cooperate on physical protection matters, while protecting confidential information. It also sets out a broad criminal regime including offenses and prosecution/extradition procedures for the unlawful use of nuclear material that states must incorporate into their national law.

In the late 1990s, the United States began to push for a revision of the convention not only to expand its scope for greater security wherever the material is, but also to include verification and compliance powers, conditions that many countries found unacceptable. Finally, in 1999, IAEA Director General Mohamed ElBaradei was able to convene an expert meeting that concluded that a revision was necessary. It also set up a working group that came up with a set of "physical protection objectives" and "fundamental principles" that should be included in a revised convention. As a next step, the director general convened a drafting group of legal and technical experts to prepare amendments. This group produced a set of amendments in March 2002, but there was not a full consensus. According to Comella, there was virtual unanimity on the scope of the new obligations, which now includes domestic use, storage, and transportation, and the protection of nuclear material and facilities from sabotage. The revisions also call for additional measures, including further obligations to respond to incidents. The drafting group also hammered out new cooperation and confidentiality obligations and reached consensus on several new criminal offenses, including smuggling.

The knottiest of the unresolved problems, which is linked to the sabotage offense, is a provision that would place beyond the reach of the convention's prosecution/extradition regime the activities of military forces in the exercise of their official duties. Comella said there were even suggestions that this provision was intended to permit attacks on nuclear facilities used for peaceful purposes to be made with impunity. She made clear, however, that those activities, as the military exclusion provision makes clear, would be governed by other international law.

Comella said that the next step is to complete the revision work through some sort of consultative process, not under IAEA auspices, but by the parties themselves who will have to resolve the outstanding questions, including the sabotage/military exclusion question, and finally decide if their proposal is robust enough to be adopted in a diplomatic conference.

Stressing how critical the revision process is at the moment, Comella said that, "in the post 9/11 time frame, there is concensus that this [revision] must be accomplished. But we are not there yet and if that opportunity is lost, in my view we will not see a revised convention."

Kirsten Cutler, who is in the Office of the Senior Coordinator for Nuclear Safety at the State Department, discussed the threat of a radioactive dispersion device (RDD), the so-called "dirty bomb." While the conventional weapon of an RDD would likely lead to the greatest number of injuries, she said, the dispersed material could lead to radiation exposure of those in the vicinity, to widespread panic, and to high cleanup costs.

The main problem, Cutler noted, is the lack of control, as well as security, of radioactive sources throughout the world. Furthermore, she added, there is too little regulatory oversight or tracking of exports of sources and little done to verify whether the recipient is authorized to receive the source. She observed that even in the United States, an average of 300 sources are reported lost or stolen each year, according to the Nuclear Regulatory Commission. To address this threat, the U.S. government has intensified its efforts to improve security of radioactive sources, both at home and abroad.

A particular problem is faced by Russia and other former Soviet states, she said, where, after the collapse of the Soviet Union, many sources used in civilian and military applications were simply abandoned. To assist in locating, recovering, and securing high-activity sources that have become "orphaned" (lost, stolen, or abandoned), a tripartite initiative was established in June of last year among the United States, Russia, and the IAEA.

Tabletop studies have been used to test different attack strategies and defense capabilities with scale models, maps, and figures.

Cutler said that to widen the effort, the United States and Russia cosponsored the IAEA International Conference on Security of Radioactive Sources, held March 10–13, 2003, in Vienna. Some 750 government officials from more than 120 countries attended, and the six conference sessions resulted in pages of nonbinding "findings." This included endorsing two international initiatives under the IAEA's aegis. The first aims to facilitate the location, recovery, and securing of high-risk radioactive sources worldwide, using the tripartite initiative as a model, and the second is to assist governments in formulating national plans for managing radioactive sources through their life cycle, including disposal, based on the IAEA's *Code of Conduct on the Safety and Security of Radioactive Sources.*

The findings also pointed to other priorities, Cutler said, including:

- Identifying those sources that pose the greatest risks.
- Promoting public awareness of real threats and the appropriate responses in the event of a radiological emergency.
- Developing standards for the design of sealed sources that are less suitable for malevolent purposes.

Cutler also noted that in April, the IAEA held a meeting of radioactive source manufacturers and suppliers to discuss methods of manufacturing sources that are less suitable for malevolent purposes, and possible arrangements for the disposal, return, or reuse of spent sources.

Last orders from NRC

The NRC's efforts to enhance physical protection were outlined by Barry Westreich, chief of the Security Oversight Section of the agency's Office of Nuclear Security and Incident Response, which has been in place for a little over a year. Prior to 9/11, safeguards and security programs were run by the offices responsible for licensing—Nuclear Reactor Regulation, for reactors, and Nuclear Material Safety and Safeguards, for materials. There was rather little interaction between them, he noted. After 9/11, the commission directed that the security programs across the agency be integrated into one organization.

Westreich described the new organization and discussed orders and other actions taken since 9/11. For example, he said, on February 25, 2002, the NRC ordered security at power reactors and other licensees to be enhanced. Detailed guidance has been developed for implementing and inspecting licensees' responses. Several orders have been issued related to security officers: on training and qualifications, to address inconsistent standards; on fatigue concerns, to ensure that licensees do not overwork their security officers—an action that followed discovery of the large number of overtime hours clocked up by officers at some facilities; and on concerns of low pay and working conditions that may be having an impact on the high turnover of officers.

Immediately after 9/11, Westreich said, the NRC suspended force-on-force exercises and started to develop new ones. Tabletop studies have been used to test different attack strategies and defense capabilities with scale models, maps, and figures. A force-on-force performance testing process was developed involving actual drills using adversary forces performing mock attacks on a facility.

Another major activity, he noted, is vulnerability assessments to determine the risks and consequences of threats and to assess the adequacy of the existing regulatory framework. These assessments will identify mitigation strategies and help inform decisions and the development of national strategies.

The NRC has been conducting onsite threat assessment on cyber-terrorism at several sites to establish a self-assessment methodology, Westreich observed, and penetration testing is performed by NRC experts to determine the adequacy of the protection.

The commission is also concerned that these orders, besides being a burden on licensees, may be causing regulatory instability, said Westreich. It intends to complete realignment of the baseline security program and return to normal rulemaking procedures as soon as possible.

Ron Cherry is the director of the Office of International Safeguards, which is located in the National Nuclear Security Administration (NNSA), a semi-autonomous organization within the U.S. Department of Energy and headed by Ambassador Linton

Brooks. Cherry’s presentation covered the DOE’s International Physical Protection Cooperation (IPPC) program, which has for decades focused on protecting nuclear materials exported under the Atoms for Peace program. When established in 1974, he said, the IPPC involved bilateral consultations on security. In 1978, the nuclear Non-Proliferation Treaty mandated that the DOE, along with the State Department and the IAEA, operate a program on physical protection for training officials and facility operators from other countries. In recent years, he noted, it has expanded to include protection of materials not necessarily of U.S. origin. He described the current program as flexible and operating on a bilateral level and multilateral level through the IAEA, which has become an increasingly important channel for international collaboration on security matters.

The U.S. has been a long-standing supporter of the IPPAS program, said Cherry. “We have also supported improvements to physical protection programs as a result of the IPPAS missions. . . . These may be simple improvements in procedures and training, but they can also be extensive, from room entry upgrades, to working with partners to install perimeter intrusion, detection, and assessment systems, to upgrading central alarm stations, access control procedures, improving delay and target.” He added that “from the point of developing programs that are self-sustainable, it is always in our interest that the state undertakes the activities itself if possible.”

As for the future, Cherry said he particularly supports the concept of integration, “having one foot in the international safeguards world and one in the physical protection world. . . . I think it is critical for the notion of a comprehensive framework for security and certainly one that my program is going to continue to explore,” said Cherry.

View from the old country

“It is with special pleasure that I provide a perspective from France—or old Europe,” explained Denis Flory, of the Institut de Radioprotection et de Surete Nucleaire. Flory is deputy head of the institute’s radioactive material security department and chairman of the working group negotiating the amendment package for the CPPNM.

The first concern in the hours immediately following the 9/11 attacks was the security of the nuclear material being transported, he noted. As shipments are normally considered to be less vulnerable while en route, it was decided to let them continue to their destination where they could be protected. The next decision, Cherry said, was that all nuclear operators were to implement emergency procedures that included strict access controls at nuclear facilities, a ban on all visits, etc.

Flory was thrown into the deep end on September 24, 2001, when the government’s Nuclear Security Authority (HFD) ordered his department to inspect all large nuclear sites as soon as possible. These were to be done simultaneously, with no notice given. Flory immediately summoned his closest assistants to organize, in strict secrecy, 26 inspections on one day. They identified 36 inspectors and seven physical protection specialists to take part, who all agreed without any hesitation. An inspection guide was prepared with the aim of verifying that sites complied with the requirements of the national emergency plan, called Vigipirate.

At 7 a.m. on September 28, continued Flory, the inspectors undertook the first phase: to observe, unnoticed, the site near its entrance. Their presence, though discreet, did not always escape the notice of certain guards. At 7:45, all inspectors presented themselves at the site entrance. At all sites, he said, the reaction was quick and courteous, and by 3 p.m., all inspections were complete. The following Tuesday morning, the HFD had all 26 inspection reports, accompanied by a letter with the initial results of the mission.

In the meantime, the government ordered a review of the existing levels of protection of all nuclear facilities and nuclear materials, in light of the attack. Threats and vulnerabilities were identified and assessed and measures to strengthen security developed. But there was a catch, Flory said: Giving advice is easy, as is ordering measures when they fall within the license conditions. Operators, however, rightfully want to be sure that measures, particularly expensive ones, will be effective and to know who pays for them. Certainly, he said, easy fixes were fixed, and the not so easy ones were also, on the understanding that they were necessary in the present extraordinary situation.

Since then, said Flory, the legal robustness of the authority’s orders has been debated quite seriously, although not very publicly. He noted that it became apparent that the regulatory system should be updated to clarify the relationship between the authority and its technical support on the one hand, and the operators on the other hand. A particular issue is to identify for a given threat situation what is the responsibility of the state and what is to be addressed by the operator. Unfortunately, Flory said, the number of players in the discussions has grown and it will take a long time to resolve.

Flory also had a message about communicating to the public. There is a need, he said, to make available some information about our job. “We owe the public a fair, unbiased view of its protection level against terrorism. At the same time, we owe the public a strict protection of sensitive information. The path is narrow. . . .”

A particular issue is to identify for a given threat situation what is the responsibility of the state and what is to be addressed by the operator.

The final speaker was Charles Ferguson, of the Center for Non-Proliferation Studies at the Monterey Institute, who is co-directing a project that is systematically assessing all major aspects of nuclear and radiological terrorism. He said that the center intends to publish a lengthy monograph on the best way to use resources, which now include the $20 billion pledged under the G-8 Global Partnership for dealing with nonproliferation over the next 10 years. But, he said, a strategic plan is still a long way off and with no international standards for providing protection, it will be difficult to develop spending priorities. To deal with this issue, Ferguson outlined five physical protection standards, two of which are somewhat novel:

■ *Spent fuel standard.* To make weapons plutonium roughly as inaccessible for weapons use as the much larger growing stock in civilian spent fuel. Highly radioactive fission products, particularly Ce-137 (30-year half-life), provide a lethal barrier against theft.

■ *Stored weapons standard.* Weapons-usable materials should be guarded as securely as stored nuclear weapons. In 1997, the DOE officially adopted this policy.

■ *Radioactive source security standard.* Enhanced security is needed for those sources that can be used in radioactive dispersal devices. The DOE and NRC published a good report on this, but a threshold of radioactivity levels (curie content) that would trigger a federal response was not included. At the March meeting on sources in Vienna, Ferguson said, the NRC and IAEA indicated that the threshold level will depend on the type of radiation emitted, but would not be less than about 20 Ci. This means that only a small fraction of millions of sources in use throughout the world pose an inherently high risk if used in a dirty bomb. This is encouraging, he said, because it shows that the problem is manageable if the resources are put in.

■ *Hardened nuclear facility standard.* To ensure that all nuclear fuel bearing elements, including reactor cores and spent fuel, are protected inside hardened structures, such as containment buildings and dry storage casks, to prevent offsite radioactive release should an attack occur. In general, U.S. nuclear power plants tend to meet these standards, Ferguson said. A recent study, however, suggested that terrorist attacks on some types of spent fuel pools could cause the release of materials. Outside the United States, the Chernobyl-type reactors, which lack a containment structure, would not meet this standard. Ferguson wondered how willing the United States is to shut down these plants. Do they pose enough risk to spend the billions for replacement power? A compromise will be difficult to reach, as Russia does not think these plants are unsafe.

■ *HEU elimination standard.* There should be a global effort to eliminate high-enriched uranium (HEU) by phasing out the civil commerce of HEU, downblending existing stocks, and prohibiting enrichment to these levels.

Improving Yucca Mountain

The proposed Yucca Mountain high-level radioactive waste repository is such an enormous undertaking, involving so many disciplines—climatology, hydrogeology, radioecology, volcanology, to name but a few "-ologies"—as well as the need to consider the earth's geological moods 10 000 to 1 million years into the future, that it is easy to overlook the one thing that its success depends on: water—or, specifically, the lack thereof.

"The performance of Yucca Mountain, the performance of the waste package and the whole system depends on water, depends most strongly on water," noted Bo Bodvarsson during the Technical Program Chair's "Special Session on Science and Technology for Yucca Mountain." Bodvarsson is director of the Earth Sciences Division at Lawrence Berkeley National Laboratory, heading a team of geophysicists, reservoir engineers, geochemists, microbiologists, and atmospheric scientists. "Because if you don't have any water seeping into the drift . . . then the corrosion rates of the waste packages are going to be very, very small. If you don't have any water going into the drift, the waste package doesn't corrode, then no water can actually transfer the waste down."

Overall, speakers at the session were concerned with getting more out of Yucca Mountain—better performance, less expensive operation, less uncertainty. A speaker from the Department of Energy outlined a new science and technology initiative with just these goals in mind. Another, from a national laboratory, reviewed the contributions advanced fuel cycles could make to lessening the burden the radioactive waste makes on a repository. And a representative from EPRI discussed the problems of modeling—hundreds of thousands of years into the future—the performance of a facility the likes of which the world has not seen.

Science and technology initiative

In its 2004 budget request, the Department of Energy earmarked funds for a new science and technology initiative to improve waste management. With the DOE on track in the next seven years to pursue a license to operate the proposed Yucca Mountain waste repository, to construct it, and to begin operations, the time to make small improvements here and there is running out.

The baseline design of the repository is about to become "frozen" for licensing purposes, said Thomas Kiess, of the DOE's Office of Civilian Radioactive Waste Management, who is working on the science and technology initiative. "We've got to fix upon a plan so that we can do all the analysis necessary to submit an application to our regulator. And because a lot of resources go to that, a lot of my colleagues just have to put on blinders and pick something that's tried and true, using present-day technology that we know will work, and write it up," Kiess said.

The science and technology initiative was launched to keep abreast of technical advances that occur in the meantime that could make the repository less expensive and may improve operations.

For instance, in the baseline design, tungsten arc welding is to be used for the final closure weld on the waste packages, Kiess said. The process uses a lot of metal, takes a long time, and requires multiple passes. An alternative may be to use electron beam welding, which uses thinner metal, takes less time, and can be done in a single pass. "We might save money if we could ever make an electron final closure weld on those waste packages perform as well as tungsten arc welds. So, we're exploring that," Kiess said. He and his colleagues are also looking into different corrosion-resistant coatings for the waste packages, as well as exploring the efficacy of decay heat from the spent fuel to drive water from the waste packages and waste forms.

Next year, with what OCRWM hopes will be a bigger budget than its modest \$2-million allotment this year, the department will look into tunnel engineering improvements, among other plans. "We have to dig approximately 100 kilometers of these underground drifts," Kiess said. "That is a very rote, repetitive operation. Is there any way you can improve efficiencies on that? Drift engineering captures a topic where there are technical advances that we might reasonably expect to take advantage of and incorporate. . . .

"We hope to spend the money wisely on a suite of projects, some of which are aimed at savings from operational efficiencies or actual engineered improvements, and others of which aim at enhanced understanding of the repository and other system components."

Advanced fuel cycles

The main goal of advanced fuel cycles is not to eliminate the need for repositories like Yucca Mountain, but to reduce the amount of waste generated per unit of energy production, explained Hussein Khalil, deputy director of the Nuclear Engineering Division at Argonne National Laboratory. Such a waste reduction will help with the challenges associated with siting and developing repositories, as well as with reducing the cost and uncertainties associated with licensing and operating them. "I think it's accurate to say that attaining these goals is extremely important to continue—certainly to expand—the use of nuclear energy in the future in the U.S. as well as internationally," Khalil said.

One of the ways advanced fuel cycles can

Yucca Mountain: An enormous undertaking improve waste management is through reducing the volume of waste, Khalil said. It can be done by eliminating some of the bulkier constituents from the waste, such as uranium. An advanced fuel cycle can also lower decay heat as a function of time by eliminating the long-lived heat-emitting waste constituents, primarily the transuranic actinides. "It's this long-term heating that ultimately limits how densely the waste can be loaded in the repository," Khalil said.

> **Speakers at the session were concerned with getting more out of Yucca Mountain—better performance, less expensive operation, less uncertainty.**

Advanced fuel cycles can also mitigate waste isolation requirements by eliminating sources of long-lived radiotoxicity from the waste. Such a system can recover the transuranic actinides from the spent fuel and consume them in a reactor transmutation system, which then has the additional benefit of recovering the energy value they possess, Khalil explained. "Then, of course, the residual waste is essentially fission products, and these would be managed by incorporating them into durable waste forms, which are also ideally very compact. And to the extent that these waste forms are durable, this can also contribute to meeting the waste isolation requirements," he said.

Advanced fuel cycles can also contribute to reducing long-term safeguards requirements by eliminating fissile materials and weapons-attractive materials from the waste. Such materials can be consigned to the reactor fuel cycle, where they are used to produce energy and are ultimately consumed by fission, Khalil said.

There are two major programs in the United States that are aimed at developing advanced fuel cycle systems. The first, the Advanced Fuel Cycle Initiative, is focused on developing fuel cycle technologies. The main goal of the so-called Series 1 technologies, which are intended for use in the near- or mid-term, is to reduce the volume of waste and its plutonium content, Khalil said. Some examples of these technologies include aqueous processing, mixed-oxide fuel technology, and recycled plutonium using thermal reactors. Series 2 technologies would be used with dedicated transmutation systems—most likely fast-spectrum transmutation systems—as well as with Generation IV reactors and reactor plants. The objectives for these are to achieve reductions in long-term decay heat and radiotoxicity on the way to realizing some of the targeted repository benefits, Khalil said.

The other major program involving work on advanced fuel cycles, albeit indirectly, is the Generation IV Nuclear Energy Systems Initiative, which is focused on development and demonstration of complete nuclear energy systems. Among other goals, the program calls for Gen IV systems to manage their waste effectively and look to reducing the stewardship burden to future generations, Khalil said.

The art of abstraction

As high-level waste and spent fuel program manager at EPRI, which has been conducting an independent assessment of the Yucca Mountain repository total system performance, John Kessler has the "luxury," as he put it, of predicting what will happen inside the remote California mountain over the next 10 000 to 1 million years. And, because the repository is the first of its kind in the world, that task must be accomplished with limited data.

"You worry about water dripping into the container and [if] you have some sort of leak at the bottom," Kessler said. "You're concerned about how much gets in. What's the flow through it? How much gets released from the waste form and heads down through the lower part of the unsaturated zone [of the earth's crust] into the saturated zone? . . . How much groundwater contacts how many containers? And when does that occur? How fast do the engineered barriers fail? That's going to affect when the release begins and the rate of release. How long does it take then for the groundwater to get the waste out to the biosphere?"

These sorts of questions have led Kessler and his colleagues to become intimate with the categories of uncertainty that are appropriate to use in the probabilistic modeling of the system's performance over hundreds of thousands of years. One category, natural variability, involves trying to fully understand and characterize the variability of, say, rock properties. "Randomness" and measurement error also need to be taken into account in these models. Last, uncertainty in the modeling process itself is a consideration. "You may have more than one model as to how you could envision something to evolve over 10 000 to a million years. And you may not have enough data to rule them all out. So, we have potentially more than one model that needs to be carried along here," Kessler explained.

As an example of the difficulty of keeping track of uncertainty in a total system performance assessment, Kessler gave details on the questions involved with when and where waste can be exposed to groundwater.

Start with rainfall: "We have atmospheric models with climate change built over 10 000 to a million years that need to be pulled in, with all the uncertainties associated with that, plus distributions of rainfall that are seasonal. All of those affect evaporation and run-off, which also have uncertainties and variabilities in how you calculate what evaporates and what would run off. That then feeds into a net infiltration model: How much percolates deeper into the rock? So, you have soil and rock properties, again with uncertainties. That's the first set of models."

Kessler proceeded to outline other possible factors in waste being exposed to groundwater, including rock properties, radioactive decay and decay heat, groundwater chemistry, drip shield and container failure rates and geometries, in-package chemistry, spent fuel cladding properties, and cladding failure rates—each of which "has many aspects of uncertainty."

There are two approaches used for probabilistic modeling, Kessler explained. The more familiar one is Monte Carlo sampling, in which every parameter and model of importance is assigned an uncertainty, or variability distribution. Then the dice are rolled—hundreds to thousands of times. "You randomly select from the entire suite of distributions and calculate the result . . . and determine statistics to get your means, correlations, everything."

Another course, which EPRI uses, is a logic-tree approach. A limited number of probability "branches" are assigned, each with a discrete value of probability. "You calculate for each individual branch as you get out to the end [of the tree]. And then you weigh these probabilities. . . . This requires significant abstraction and more complex models to get to this approach. But you can hardwire in some very low-probability branches if that is what you want to do," Kessler said.

Quantifying uncertainty, Kessler said, remains a "somewhat controversial" but active area of study. "I think I counted three or four papers given just at this conference that get to how one quantifies uncertainty and carries along those uncertainties for diverse scenarios."

Swords-to-plowshares: Update

For half a dozen years the Department of Energy has been processing legacy uranium-233 stores into a promising radioisotope for cancer treatment, bismuth-213, a rare emitter of high-energy alpha particles. Much of the nation's inventory of U-233, originally produced in the 1960s at DOE nuclear defense production plants, is stored at Oak Ridge National Laboratory in Building 3019, which dates back to the Manhattan Project. Approximately 1.5 tons of uranium, containing 450 kg of U-233, have been stored at the lab for more than 30 years, according to ORNL. The material had once been intended for use in molten salt breeder reactors and tests for other reactor concepts.

Two of the speakers at the session, "Safety Program to Achieve Beneficial Uses of U-233 in Medical Applications," have worked directly with the project at ORNL. They reported on a program to inspect the old packages of U-233, and the process ORNL uses to produce actinium-225, a parent radionuclide of Bi-213 that customers use to produce Bi-213. Currently, ORNL workers are producing up to 50 millicuries (mCi) of Ac-225 per customer shipment, said Dairin Malkemus, a radiochemical process development engineer at ORNL. "The current demand is much greater than that and is expected in the future to climb even higher. So, there's a definite need for this isotope," Malkemus said. A third speaker reviewed a commercial effort to turn U-233 into Bi-213.

Storing U-233

The U-233 material at Building 3019 is contained in approximately 1100 packages of various designs, most of which are highly radioactive. The material is stored in double-walled containers in shielded vertical tube vaults, which vary from 8 ft deep to 30 ft deep, with packages stored one on top of the other, said Jim Rushton, U-233 program manager at ORNL. More than 50 different types of package types were used.

In the late 1990s, the Defense Facilities Nuclear Safety Board identified some potential vulnerabilities in the U-233 storage. As a result, ORNL decided to embark on an inspection program. "We had decided that we wanted to look at about 10 percent of the inventory—a representative cross-section of a lot of these different package types. We had many package types, different geometries, different ways that they had been stored in terms of how they were handled. So, there were a lot of mechanical design challenges," Rushton said. There were also questions about the quality and reliability of the packaging records, since they had accumulated over several decades, Rushton said.

Adopting a systems approach, Rushton and his colleagues assumed that there were container integrity problems and designed systems to access and retrieve the packages in a shielded and confined mode. They also set out to develop a suite of nondestructive inspection capabilities.

They first inspected the tube vaults, conducting in-vault radiation smears to check for contamination outside the packages. They also lowered video cameras into the tube vaults and inspected the tops of packages to determine if they could actually handle them, Rushton said.

If a package were deemed retrievable, the workers remotely pulled it up and placed it into a converted portable hot cell that acted as a shielded and ventilated inspection chamber. A more detailed smear was taken and the package was again checked with a video camera. Workers then made dimensional measurements of the container ("this was the area where we found the records were particularly bad," Rushton noted) and moved it to a gamma imaging system for gamma spectroscopy. They then made a final decision on whether the material could be restored or had to go for destructive examination.

In his abstract, Rushton noted that 41 packages, representing 79 percent of the stored packages, have been nondestructively inspected. Eighteen packages were then sent to a laboratory for recovery of thorium-229, a parent radionuclide of actinium-225. Those 18 packages have added approximately 60 mCi of Th-229 to the ORNL inventory that is available to produce alpha isotopes for medical research, or an increase of about 50 percent.

"A sample of the containers inspected showed that the inventories can be accessed and handled safely," Rushton concluded. "The sample tube vaults that we have been into are all uncontaminated. We expect that to be a general condition. The outer containers have good integrity, and [our] radiography confirms the integrity of most of the inner containers."

Producing Ac-225

With relatively low gamma emissions, which is notable for limiting the dose to personnel producing and working with it, and a 10-day half-life, Ac-225 is an ideal generator to produce and ship to customers, explained Malkemus. "The long half-life of the parent material, thorium-229, makes it very useful as a stable cow from which we can milk the actinium," Malkemus said. "And, most importantly, [Ac-225] produces the 45-minute-half-lived daughter bismuth-213, which is what's used for the alpha radioimmunotherapy."

ORNL has two main stores of Th-229, totaling approximately 150 mCi. About 90 mCi of that was extracted from the material in Building 3019 in the mid-1990s. More recently, ORNL has separated another 60 mCi of Th-229 from U-233, with a much higher specific activity, Malkemus said. And the potential remains for another 8 mCi of Th-229 to be recovered.

The first step in recovering Ac-225 is to remove the actinium and radium daughter products from the thorium-229, Malkemus said. The radium and actinium are then converted to 10 molar hydrochloric acid and run through a 5-mm MP-1 resin column to remove any iron. "We have to remove iron from the process because of not only interference with the subsequent processing steps, but also because when we send it to the customer, Bi-213 is going to end up [linked to a monoclonal antibody] . . . and any trace of iron that is left in the material will interfere with that. So, we clean it up as much as possible," Malkemus said.

After the iron is removed, the material is evaporated and converted to nitric acid. The actinium is then separated from the radium and processed further before being moved to a glovebox, where benchtop-scale final purifications are performed. The radium is set off to the side as a "radium pool," from which additional actinium can be harvested. "A few weeks later we can run this process again, grow in more actinium, separate it again, and send more actinium to customers," Malkemus said.

One process improvement Malkemus and his colleages have made over the years was to install new gloveboxes for the final product preparation. The decision was made out of a need for better shielding due to the more potent 60 mCi in additional batches of thorium that were extracted from U-233 in recent years. These batches contain a higher concentration of Th-228, which yields the high-dose daughter thallium-208. The higher Tl-208 content requires more tightly controlled and timed separations, coupled with more shielding to protect personnel, Malkemus noted in his abstract.

"In addition to having simply more room to work with, and being newer, fully compliant gloveboxes, there are also a couple of features built in to help streamline the process:

"We put in a transfer elevator, sealed at both ends, running from the alpha cell on the floor below up to these new gloveboxes so that we can transfer counting samples, we can transfer product up easily without having to bag the samples out of the glovebox, bag them back into another glovebox. . . . So, that greatly streamlines the process," Malkemus said.

"We have all these changes, all these process improvements to enable us to achieve the three objectives of increasing the actinium production, minimizing the costs involved with this process, and minimizing the dose rate to personnel."

One process improvement Malkemus and his colleagues have made over the years was to install new gloveboxes for the final product preparation.

U-233 into Bi-213

Both the Food and Drug Administration and radioisotope customers place a number of restraints on the commercial production of medical radionuclides, noted Andrew Bond, a senior chemist at the PG Research Foundation, who described a flowsheet for production of Bi-213 from U-233. (The research was sponsored in part by Oak Ridge, Tenn.–based MecActinium, Inc.)

Perhaps most critical is high radionuclidic and chemical purity, Bond said. The Bi-213 is eventually going to be coupled with a biolocalization agent and an antibody in most cases, forming the radioimmunoconjugate that is then introduced to the patient. "Chemicals like iron can interfere with the formation of that radioimmunoconjugate. And it's an inefficient use of the Bi-213. It's also an inefficient use of a very expensive antibody. So, you want to form as much of the radioimmunoconjugate as you can. That, ultimately, should get more people treated with higher clinical efficacy," Bond explained.

The production of Bi-213 involves three fundamental chemical separations. First is the partitioning of milligram quantities of Th-229 from U-233, a relatively rare process. Second is the separation of Ac-225 from milligram quantities of Th-229, which would be done a few times per month. "This is going to be recurring over and over and over again in the production facility, so it has to be a robust process that's reproducible and cost-effective." The last step is the purification of Bi-213 from Ac-225, which would take place several times per day, potentially, at a medical center.

For these steps to have maximum chemical and economic efficiency, the processes must be integrated, Bond said. "Begin with the end in mind. We want complete vertical integration. The output from Step A has to be an acceptable feed into Step B.

"What that gets us is overall chemical efficiencies, so we get maximum yields. We get some economic efficiencies there. We also get a whole bunch of safety efficiencies. We minimize handling in operations, which minimizes defect opportunities. . . . It just minimizes the number of glitches," Bond said.

He reported that their studies have indicated Step A—Th-229 from U-233—is a safe, efficient, cost-effective process. In Step B, there have been no detectable losses of thorium or radium resource materials and they've been getting good recoveries of Ac-225, Bond said.

And in Step C, they've been recovering more than 98 percent of the Bi-213 in as little as 2 milliliters of solution. "At this point, when you start separating the bismuth from actinium, the clock is really ticking. With the 45-minute half-life of Bi-213, you want to absolutely minimize the number of operations," Bond said. "And that's why we felt it critical to be able to strip the bismuth into a solution that could just be dumped right in at the end."

Spent fuel P&T

Most of the work in the United States on "Spent Fuel Partitioning and Transmutation Studies to Enable Efficient Use of the High-Level Waste Repository"—the title of this session—is done under the Department of Energy's Advanced Fuel Cycle Initiative (AFCI), explained session chair Emory Collins, of Oak Ridge National Laboratory. A primary aim of the AFCI program, he said, is to explore means for extending the lifetime of the Yucca Mountain repository to more than 100 years, delaying the need for a second repository as long as possible.

The first speaker, Holly Trellue, of Los Alamos National Laboratory, explained how the existing nuclear plants in the United States can be utilized to reduce the amount of waste that will have to be put into Yucca Mountain. Although they would not be as efficient as fast reactors for this purpose, it will still be possible to achieve some real reductions in the amount of material that must be sent for disposal, she said, adding that the ultimate goal would be not to have to put any plutonium into Yucca Mountain.

There is already extensive experience with mixed-oxide (MOX) fuel, Trellue said. Currently, many reactors in Europe take about a third of a core of MOX fuel, which contains about 6 percent plutonium. Only one recycle is used, which means that only 30 percent burnup is achieved.

To make real inroads in the plutonium stocks, multicycle fueling strategies are needed, said Trellue. She discussed some of the problems that this brings: the fissile content of reprocessed fuel is reduced and has to be compensated for; facilities to handle reprocessed fuel, such as gloveboxes and hot cells, are needed because of the higher activity; MOX fuel fabrication for the second recycle requires additional blending, dry instead of wet grinding of powders, etc. If a full MOX core strategy is chosen, there are additional safety problems due to the higher actinide buildup and a harder thermal neutron spectrum, which decreases the efficiency of the control rods, of the soluble boron, and of other control mechanisms. Basically, additional shutdown capability is needed.

A primary aim of the AFCI program is to explore means for extending the lifetime of the Yucca Mountain repository to more than 100 years.

Trellue described calculations to determine how efficient systems were in burning plutonium using the Monteburns code. Parameters included: percentage of MOX used in the core, numbers of control and shutdown rods, numbers of cycles, etc. Benchmarking with burnup data from a San Onofre reactor showed relatively good results with most isotopes.

Of particular interest was Trellue's proposed strategy of using currently operating reactors in the United States, pointing particularly to the System 80 reactors, such as at Palo Verde in Arizona, which were designed to have full MOX cores. She described a scenario using all the Westinghouse reactors with 17×17 fuel and the System 80 reactors, with one-third MOX cores, fuel with 10 percent plutonium, two recycles each of four years, and six years of cooling. She calculated that all the legacy plutonium, about 110 000 metric tons (t), could be burned over 30 years, starting in 2010. She also discussed some other possibilities, such as using full MOX cores. For this to be feasible, several things would have to be done—for example, plutonium separation must be technically established and politically approved, a MOX fuel fabrication plant must be built, and reactors must be relicensed.

Trellue concluded that reprocessing strategies can significantly reduce the amount of material to be disposed of in Yucca Mountain and may prevent the need for another repository.

Session chair Emory Collins presented the second paper, on an economic assessment for the AFCI program. The study was done late last summer as part of a report on the program prepared for Congress. The aim was to provide some perspective on the economics of reprocessing and MOX fuel fabrication and whether it made sense compared with constructing a second repository, which is now expected to cost $35 billion. Although the study was done rather quickly, Collins said, he thought it came up with fairly good values.

The study assumed that industrial-scale facilities could be put into operation by 2015 to process spent fuels for the current U.S. generating capacity of 100 GWe. Three cases were evaluated for comparison with the costs of once-through spent fuel disposal. These were:

1. Base case: reprocessing only, 2000 metric tons per year, which is the rate of spent fuel generation at the moment.
2. As base case, with two cycles of MOX in a light-water reactor.
3. As base case, with one cycle of longer burnup in a gas-cooled high-temperature re-

actor (GHTR) using plutonium-neptunium fuel. (First reactor would be built under the DOE 2010 program and converted to a plutonium burner in 2020; after that, gas reactors would be added as fast as possible.)

Among other things, said Collins, the study determined the amount of waste generated that would require repository storage. In all cases, the largest effluent stream is the uranium, which can be decontaminated sufficiently to meet Class C low-level waste limits—or can be reenriched and reused. The second largest mass is the Zircaloy cladding hulls, which will contain a small amount of residual fuel and long-lived activation products. This waste will require repository storage unless a method of decontaminating them sufficiently can be developed.

For cases 2 and 3, about 90 percent of the plutonium and neptunium would be separated in the reprocessing plant and recycled in "transmutation" fuels, while the remaining actinides (predominantly americium) would be converted to "transmutation" targets. The heat-generating fission products, primarily cesium and strontium, would be isolated and solidified to permit more efficient storage in the repository. The remaining fission products (predominantly lanthanides and noble metals) would be encapsulated, possibly as glass, for storage in the repository. In all cases, the volume of wastes requiring repository storage could be significantly reduced and the heat-generating wastes more efficiently managed so that a second repository would not be required for perhaps 100 years, or more.

Collins warned that the 2015 target would be very difficult to meet, given the time required for completion of supporting research and development, environmental impact analysis, site selection, acquisition of capital funding, licensing, design, construction, and startup operations. He noted that a number of decisions and actions must be initiated as soon as possible. Capital funding for licensing, design, and construction of some $12 billion must be ready by 2007. Operating costs would be about $350 million per year. The bottom line on cost of design, construction, and operation of a combined reprocessing and fuel fabrication plant, he said, is about $24 billion over a 30-year period. This is about 65 percent of the cost of a second repository. Furthermore, he thinks there are other opportunities for cost reduction. For example: collocation and integration of the two plants, improving and simplifying the process, maximizing the use of automated processes and robotic techniques, and more flexible use of Yucca Mountain.

New processing options

The next two papers described work undertaken at Savannah River under the AFCI to improve repository performance by separating out as many of the "worst offending" constituents of spent fuel as possible.

Tracy Rudisill, of the Westinghouse Savannah River Co., described a new process specifically aimed at producing a plutonium product stream for conversion to MOX fuel and multiple recycling; separating technetium-99 and iodine-129, the principal long-lived fission products, for conversion to targets for transmutation; and generating a uranium product stream that meets criteria for disposal as a Class C low-level waste (unless there is incentive for recycling).

The team, Rudisill said, started with the Purex process, a mature solvent extraction method for irradiated nuclear fuel that was designed to recover plutonium and uranium. They conceived a variation called Urex (uranium extraction) that could still deal with large quantities of spent nuclear fuel and provide the necessary selectivity. With Urex, uranium and technetium are extracted in one stream, and the isotopes, such as americium, neptunium, and curium, are rejected to the aqueous raffinate with the fission products.

With Urex, uranium and technetium are extracted in one stream, and the isotopes are rejected to the aqueous raffinate with the fission products.

Three tests of the Urex process were performed with a feed solution using old Dresden reactor fuel. The demonstration was very effective, said Rudisill. It showed that all goals for recovery and decontamination could be achieved. The uranium product was class C or lower, meeting low-level waste criteria. The process allowed recovery of greater than 99.9 percent of uranium and 95 percent of technetium.

Glenn Kessinger, of the Savannah River Technology Center, described work to demonstrate the use of the chop-leach process, using nitric acid, to produce a feed solution for the Urex process. The secondary goal was to see if this treatment could leach out enough of the actinides from the Zircaloy cladding for it to be categorized as low-level waste. The team had access to Dresden fuel that had been stored in shielded cells at Savannah River for about 20 years. It consisted of 4.5 kg of fuel—including 3.9 kg of uranium and 24.5 g of plutonium.

The results demonstrated that this approach is appropriate to produce the feed, he said. An analysis of the cladding, however, showed that actinides were present at a concentration about 50 times greater than the limit for low-level waste. Kessinger said there are possible solutions. They also found a relatively large amount of insoluble residue with actinides recovered from the dissolver. Kessinger suggested that future development work on this method be aimed at addressing these two issues.

Processing Triso fuel

High-temperature reactors are attractive, said Barry Spencer, of Oak Ridge National Laboratory, because they can be used in deep-burn strategies, as a transmutation device to burn long-lived actinides and fission products, and can run with a full plutonium core. Nevertheless, he said, to get rid of all fissile materials, it is necessary to reprocess and recycle the fuel. Laboratory studies on the processing of high-temperature gas-cooled reactor (HTGR) fuels were performed in the United States in the 1960s and 1970s, but no engineering-scale processes were demonstrated. Spencer described preliminary studies of how to improve the processing of spent fuel, but unfortunately, he noted, no experimental work was done.

The fuel assembly considered was a graphite block with fuel rods containing fuel particles (carbon-based tricoated—Triso—particles), referred to as fuel compacts or "sticks." The particles can contain uranium and plutonium, in oxide or carbide form, or other "targets" such as minor actinides. An advantage of this is that a block can accommodate different types of compacts—for example, normal uranium/plutonium oxides (driver fuel) and others containing nuclides to be transmuted (transmutation fuel).

The fuel is challenging to reprocess because, as Spencer explained, it consists of "small islands of oxide fuel in a large sea of carbon." What is wanted, he said, is a way to separate the oxide from the carbon and feed the fissile fuel into an existing light-water reactor fuel reprocessing plant.

The traditional process, he said, involved a "crush-burn, crush-burn, and dissolve" operation. The initial crushing was to reduce the blocks and separate the coated fuel particles from the graphite. The first burn removed the filler carbon and the outer carbon layer of the particles, leaving behind the silicon coatings, which require a crushing to get at the next layer of carbon which is then burned off. That should leave uranium and plutonium oxides that can be sent into a standard dissolution process.

One problem with this approach is that the carbon dioxide produced has a considerable amount of C-14 (due to the irradiation) and cannot be dumped to the atmosphere. That means using an expensive off-gas treatment system to sequester the carbon dioxide, usually by reaction with calcium hydroxide. This produces a large mass of waste, compared with the original elemental carbon.

Spencer then described some promising options. First, an efficient mechanical head end process is needed to remove the compacts from the carbon block, grinding them to expose the fuel kernels, then separating the lighter carbon particles from the heaver fuel particles, and leaching or dissolving the fuel components from the remaining carbon fines.

Previous work, explained Spencer, shows that cutting away the top and bottom of the block allows the sticks to be pushed out with minimal force. One constraint is that the material produced from these mechanical operations must be suitable for further aqueous or pyrochemical processing. The team identified two promising processes: a preliminary aqueous process, which uses a counter-current system to leach the oxide fuel from the carbon, allowing the fuel to enter a conventional aqueous solvent extraction process; and a process called carbochlorination, which will produce a chloride salt that can be further processed by pyrochemical methods. The carbon waste produced by these can be formed into a compact and durable waste form.

In summary, said Spencer, the project identified several new processes that could be used with minimal trouble. The waste-reduction goals make processes that retain carbon in an elemental form the most attractive one. The exact details need to be developed and demonstrated; the significant industrial experience related to carbon processing, however, should shorten and simplify this endeavor.

I&C research and technology

Sukesh K. Aghara opened the session "Instrument and Control for Security, Operations, and Decommissioning" with a presentation on fast neutron damage to digital-to-analog converters. For the past three years, Aghara has worked on developing and characterizing fast neutron irradiation facilities at the Nuclear Engineering Teaching Laboratory at the University of Texas at Austin.

One of the areas where radiation-tested hardware is needed most is in the space industry, Aghara said. Trends to decrease spacecraft power consumption, weight, volume, and cost have resulted in less effective shielding against external radiation. In addition, increased spacecraft performance and data-handling requirements have created the need for state-of-the-art radiation-tested technology. "Space is more interesting recently primarily because of the change or paradigm shift in NASA going towards using the state-of-the-art instead of using two-generation-old technology and trying to design their own radiation-hardened circuits," Aghara explained. "So, the new concept that NASA is relying on is they want to go out and pick up the commercially available, off-the-shelf technology and circuits and go out and test them."

The radiation effects industry, including military and commercial aspects, added up to about $1 billion in sales in 2001, Aghara said. Of that, about $20 million was spent commercially on radiation testing. "That's a pretty small number. But, still, it's a big industry and growing," Aghara said.

The radiation effects industry, including military and commercial aspects, added up to about $1 billion in sales in 2001.

Aghara and his colleagues decided that a quick and effective radiation test facility could provide an attractive service for this market, and set out to characterize a mixed neutron and gamma-ray test facility. They chose to center their research on digital-to-analog converters (DACs) in part because they are the kind of high-precision devices that would be needed by NASA and other organizations looking for complex radiation-hardened technology. In addition, the knowledge base of radiation effects on DACs is limited, with most of the studies having been performed using gamma rays only.

Aghara and his colleagues irradiated 48 Phillips 8-bit DACs. The devices were irradiated at the UT TRIGA reactor at a level of 1 kW. Pre- and postirradiation performance testing was performed at Texas A&M University's semiconductor test facility.

The results indicated a strong correlation between radiation damage through neutrons and device performance, Aghara said. Further work into detailed analysis of the more sensitive electrical parameters is in progress, he noted.

In all, the work demonstrated a methodology to perform a detailed performance characterization of mixed signal processing devices in a mixed radiation environment, Aghara said.

"We have successfully characterized a fast neutron radiation facility, which can be used by any end user. They can come in, give us 500 chips, and we can just put them in there and irradiate them, depending on what kind of fluences they want, and do that within a span of a few hours," Aghara concluded.

Spherical imaging

Founder and chief technical officer of Portland, Ore.–based iMove, Inc., David Ripley provided an overview of his company's new spherical imaging technology, which can be used to secure nuclear facilities and monitor building interiors.

The remarkable full-sphere field of view displayed by spherical video cameras is captured by five wide-angle lenses, with overlapping fields of view, and a telephoto lens on the bottom. The upper five lenses can capture most of the immediate sphere of view, from 45 degrees below the horizon to the zenith, with 360-degree accessibility. The bottom lens is pointed at a computer-controlled pan-tilt mirror, and can be used to provide close-up views of items of interest captured by the upper five lenses.

The all-digital system captures about 15 frames per second, and resolves to 9 million pixels per spherical frame, Ripley said. Video can be captured on CD and DVD, distributed over a local- or wide-area network, or streamed over the Internet. Also, software is available to compare every frame of video with the one preceding, and in doing so detect motion, track objects, and alarm. "It turns out a spherical camera is a nice thing, because it sees an entire area," Ripley said. "It's quite important if you're really concerned about people going in and out of an area or parts of an area."

iMove has been working with a defense contractor on a use of the technology for naval defense, Ripley said. The contractor is looking to put the cameras into unmanned undersea vehicles (UUVs) for reconnaissance. This particular UUV would be the exact size of a torpedo and would exit from the submarine's torpedo tube, travel 150 miles or so into places too shallow for submarines, and then put up a 6-ft sensor-containing mast. "At the top of the mast is our camera and below that is a sensor for radar," Ripley explained. "These things are all squirreling away data onto hard drives on the UUV, which will eventually go back to the submarine." Ripley said the Canadian military is also looking into using the camera on its next-generation armored vehicle, as well as using a smaller, modified version of the camera on top of the helmets of soldiers.

For site security, the system is not intended to replace but to supplement conventional security devices, Ripley said. "It does a really good job of augmenting. It overcomes the shortcomings of conventional sensors, which are typically blind and have extremely narrow detection bands.

"And, most important, it enables remote inspection of alarmed sites. Typically, what happens is one of these devices goes off and you have an inspection team go and check it out. That's expensive and time-consuming and not as responsive as you would like it to be." The spherical camera system can provide a coherent live picture of an entire scene, reducing the need for "another group of people that have to pop in the Humvee and come out there and see what's going on," he said.

Besides being ringed around a site perimeter for intruder detection, the spherical camera system can be used inside a building, where Ripley imagines the nuclear power industry may find it especially useful. It can be used to monitor personnel exposure during shutdown periods, as well as for monitoring other "large evolution processes," Ripley said. "The assumption here is it would be useful to have that camera running during this entire hours-days-weeks process, whether it's refueling or steam generator replacement or for training purposes. If there was a problem, you can go back and look at how that developed. And, at least for training purposes, you can have people watch the whole scene as it's going on."

360-degree photography

On a similar note, Greg LeBaron, who has worked at the Department of Energy's Hanford site for 26 years, described a fairly simple method of using 360-degree still photography as a decommissioning tool. About $2500 in off-the-shelf equipment—including software, a digital camera, and other hardware—can allow a person to take 360-degree photos and embed in them sound files, other photos, and text useful for documenting facility configurations and conditions, LeBaron said.

The system is particularly useful for decommissioning because a room or facility can be viewed remotely. Using the system, personnel are also able to conduct planning and training without additional risk of radiological or other occupational exposure. LeBaron showed an example of a 360-degree photo that was taken in preparation for some work to be done in a hot cell at Hanford. "We went into and we took this layout of photos. They were able to sit down in the office, go through, put together the plan [using the 360-degree photos]," LeBaron said. "It saved having to run into the facility to look . . . and try to scribble lots of notes, run back to the office and figure out what they were going to do, and go take another set of notes. Getting into this area was not something that you just casually walk into. You have to prepare to go in. You have to have escorts. There's other work going on. So, it avoided quite a bit of effort and difficulty in getting in and out and putting together the plan."

In another example, LeBaron described using the 360-degree photography system to preclude the need to enter a dangerous area. Two people from the Defense Nuclear Facilities Safety Board had wanted to take a look at some cells at Hanford. "The cells were cells where you have to dress up in special clothing, you have to have your whole entourage of health physics people, your operations folks. Everybody goes in to look," LeBaron explained. "We said, 'Well, we have this virtual tour here on the computer.' We took them through the virtual tour. At the end of it they said, 'We're happy with it. We're not interested in going in.'

"So, we were able to minimize waste by not generating the clothing that would later have to be washed and [decontaminated], and also time, because we didn't have to pull people off of a job to take them on this tour.

"We've been able to use this technique in several areas to save money and increase efficiency," LeBaron concluded.—*Dick Kovan, rick Michal, and Patrick Sinco*

EMBEDDED TOPICAL

Decommissioning and spent fuel

Major points of the session:

- *There still are lessons to be learned*
- *Transportation remains a major issue*
- *Make pad lap joints as long as possible*
- *Underwater videos are essential*

THE SUN HAS come out on the dry cask storage side of the industry after years of vendor bankruptcies and quality assurance problems, according to Michael Lackey, organizer and chair of the "Dry Cask Storage Facilities—Sharing Our Experience and Updating Project Status" session. The session was part of the *Embedded Topical Meeting on Decommissioning and Spent Fuel Management.* "It wasn't too many years ago you could look back and there were a lot of dark clouds over this part of the business," said Lackey, general manager of the decommissioned Trojan nuclear power plant (owned by Portland General Electric Co.) in Prescott, Ore. "We had some performance problems in the field," he said. "So, I think we've come a long way. I think the sun has come out."

There are, Lackey continued, still a lot of lessons to be learned in this business of building independent spent fuel storage installations (ISFSIs), where spent fuel is stored on sites "temporarily" until its hoped-for relocation to a permanent repository such as that proposed for the Yucca Mountain locale. Stories need to be told about pouring concrete for the massive pads upon which the ISFSIs rest and about the experiences in building them, he added.

Leading off the session to share the regulator's experiences was Bill Brach, director of the Nuclear Regulatory Commission's Spent Fuel Project Office. The past year has been "a very active" one for spent fuel storage and transportation, he said. Among the activities, the NRC has conducted its first inspections of a foreign-based cask fabricator (in Japan), while six new ISFSIs in the United States have become operational—"that is, loading their first cask on site," Brach said. Currently, there are 27 ISFSIs operating in the United States.

Transportation of spent fuel continues to be a "major issue," Brach declared, recalling the Baltimore train fire of 2001 during which train cars derailed in a two-mile-long tunnel in downtown Baltimore. One of the cars, containing an accelerant, ignited and a major fire raged. The NRC asked itself, "What would have been the consequences had a spent fuel cask been on that train and been subjected to that fire environment?" The agency worked with the National

ISFSI pad with loaded casks at the Trojan plant (PGE)

Transportation Safety Board, the National Institute of Standards and Technology, the Center for Nuclear Waste Regulatory Analysis, and Pacific Northwest National Laboratory. "The bottom line of our analysis," said Brach, "concluded that had a spent fuel cask been on that train in the fire in the tunnel, there would not have been any breach of canisters, nor would there have been a significant challenge to the canister."

Brach

That analysis has been challenged by opponents of the proposed repository at Yucca Mountain, who have claimed through their own investigation that a Baltimore tunnel fire would have challenged or breached a spent fuel canister. The two sides have met to discuss their analytical differences, Brach said.

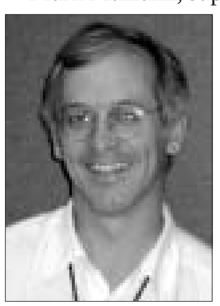
Limited space

On a small patch of real estate in San Clemente, Calif., sits the San Onofre nuclear power plant. The site size is limited by the Pacific Ocean on the west and natural cliffs and a highway to the east. As such, space for an ISFSI is tight, explained Jorge Morales, dry cask storage project manager at San Onofre. The plant is operated by Southern California Edison Co.

Space was made available for the ISFSI by the decommissioning of San Onofre-1 (which was permanently closed in November 1992) and by the demolition of various buildings on site. The site's ISFSI is now being constructed in two stages. The first stage will support storage of fuel from the retired Unit 1, which will allow decommissioning of the unit's spent fuel building and associated pool cooling and water processing systems. Once the Unit 1 fuel is in dry storage, Morales said, further decommissioning of Unit 1 will allow for expansion of the ISFSI to accommodate the second stage, which will store spent fuel from the site's two operating units, San Onofre-2 and -3.

Morales explained that "San Onofre elected to fabricate the fuel canisters in-house, which was done under ASME N-Stamp criteria," and that the components for fuel movement were custom-ordered, including a transfer cask made by a Spanish company, a wheeled transfer trailer from a German firm, and concrete storage modules from a domestic fabricator. Morales said that the fuel movement to the ISFSI is on target to start in August this year.

Mark Malzahn, supervising project management engineer for the construction of San Onofre-1's ISFSI, its storage modules, and its security systems, said the first order of business for constructing the pad on which the ISFSI would sit was finding a supplier of "safety-rated concrete." The dimensions of the pad are 293 ft long, 43½ ft wide, and 3 ft thick. Since more than 1400 yd^3 of concrete were required for the ISFSI pad, the "only option was to qualify a local commercial batch plant under a testing regimen," Malzahn said.



Malzahn

Another challenge, Malzahn continued, was the coordination of searching a large number of concrete delivery trucks, given the site's enhanced security requirements post-9/11. "We shut down one of the main entrances to the plant in one of our security decisions [following 9/11]," he said. "We had to open it up again to help ensure that the trucks were not going to be delayed by any traffic problems—we have nearly 2000 people coming to work every day who start at 6 a.m. We went ahead and opened this gate that was previously shut down in licensing. We notified the NRC that we were going to do that and no one had any problem with it. It was just another detail to take care of to ensure the success of the project." More than 140 trucks brought loads of concrete into the site, and 114 tons of rebar ranging from ¼ in. in diameter to 1⅜ inch in diameter were delivered.

Also, the pad's "flatness and levelness" were an important issue. "Maximum surface area contact between the pad and the storage modules is desirable in a high-seismic region" such as where San Onofre is located, Malzahn said. Analysis has shown that the ISFSI modules may slide a short distance during a design-basis earthquake.

A lesson learned, Malzahn noted, involved lap joints. "If anyone is in the process of building [an ISFSI pad], I would recommend that for those of you who will use lap joints, make them as long as possible," he said. "We had them made right on the design length and we spent a lot of time going back and forth a half inch, making sure it was what the design called for on the overall lapping lengths. We should not have had to go to all that trouble if we had thought it out a little more."

When completed, the pad will be able to hold 31 ISFSI modules.

Rancho Seco

The Rancho Seco nuclear power plant, in Clay Station, Calif., started commercial operation in April 1975 and was retired prematurely in June 1989 after the state's voters passed a referendum to close it down. Jack Boschoven, of Transnuclear, Inc., is manager of the plant's spent fuel dry storage project. He explained that because Rancho Seco was closed down prematurely, its operator, Sacramento Municipal Utility District (SMUD), had little time to collect sufficient decommissioning funds. SMUD then made the decision to put the plant into SAFSTOR to allow radionuclides to decay and to increase the funds for decommissioning. (SAFSTOR, according to the NRC, is a method of decommissioning in which "a nuclear facility is maintained and monitored in a condition that allows the radioactivity to decay; afterwards, it is dismantled.") The dismantling of the site was scheduled to begin in 2008, "although it looks like that is being accelerated somewhat," Boschoven said.

Boschoven

SMUD realized it could save $5 million in plant operation costs per year if it could eliminate the maintaining of the spent fuel pool. Based on the reduced risk from removing the spent fuel out of the pool and because of the large projected savings, SMUD decided to place its fuel in dry storage, which would allow the plant to go into a SAFSTOR condition and permit a smaller staff.

The plant needed to store all 493 of its fuel assemblies, including those that contained damaged fuel. The canisters used for dry storage had to be approved by the NRC to hold the damaged fuel, as well as licensed for transportation and storage. "Rancho Seco was probably the first to make that decision for a decommissioning plant to pursue a dual-purpose NUHOMS™ MP187 storage and transportation system" manufactured by Transnuclear, said Boschoven.

The canisters used for dry storage had to be approved by the NRC to hold the damaged fuel, as well as licensed for transportation and storage.

Twenty-one dry shielded canisters (DSCs), 22 horizontal storage modules (HSMs), one transfer/transportation cask, and associated transfer equipment were supplied to the plant. Rancho Seco's ISFSI is made up of those 22 HSMs, arranged in a back-to-back configuration that houses the 21 DSCs on a concrete slab about 225 ft long, 170 ft wide, and 2 ft thick.

Boschoven said the HSMs are "low-profile, reinforced concrete structures designed to withstand all normal condition loads as well as off-normal condition loads created by earthquakes, tornadoes, flooding, and other natural phenomena." They also are designed to withstand conditions postulated to occur during design-basis accident conditions such as a complete loss of ventilation. The last of the 493 spent fuel assemblies that were stored in the spent fuel pool were placed into dry storage on August 21, 2002, according to Boschoven.

Joe Witte, principal mechanical engineer at Rancho Seco, offered advice from his experience with the dry fuel storage project. "We had a very long, involved project," he said. "It was more than 10 years long to get this done. It involved the bankruptcy of a vendor, and some fabrication problems. So, intrusive vendor oversight is critical."

For the movement of the spent fuel canisters, Rancho Seco decided to use a "cask drop mitigation program" instead of upgrading to a single failure-proof crane, Witte said. The complexity of the cask drop mitigation program, however, was "underestimated," Witte said. Depending on site-specific factors, such a program may have a smaller capital cost than a crane upgrade, but it could require extensive cask tip/drop analysis and NRC licensing. Numerous modifications were required, including cask drop limiters in the fuel pool, steel bridges across sections of the elevated concrete floors, a moveable "no-topple span" to eliminate the potential for a drop on the edge of the pool, removal of railroad tracks, and installation of an engineered sand pit under the area where the cask was lowered 40 feet onto the transportation vehicle.

Other site modifications, Witte explained, included increasing the load rating of the fuel cask crane, installing a crane radio control system, enlarging the fuel building hatch, installing cask access platforms, adding a jib crane to handle cask components, providing the support infrastructure for the canister automatic welder, installing video capability with several monitors convenient for the crane operator, and upgrading the load rating of the underground utilities on the heavy-haul path to the ISFSI. "Integrated training and testing also resulted in numerous modifications and procedural changes" related to controlling contamination, tool control, communication, and crane operation, he said.

In addition, for the spent fuel pool work, "underwater videos are essential," Witte said. "They saved us numerous kinds of problems. Occasionally we weren't sure what was going on and we viewed the tapes and it saved us a lot of time."

Hanford project

The Department of Energy's 324 Building at the Hanford Site, near Richland, Wash., is being deactivated. During its lifetime, the building hosted destructive and nondestructive examinations in hot cells of spent nuclear fuel. The building's inventory consisted of seven fuel assemblies and 32 loose, intact fuel rods from one boiling water reactor and two pressurized water reactors.

Explaining the spent fuel removal and transfer was Bob Rasmussen, general manager of engineering at Mid Columbia Engineering, Inc., in Richland, Wash. Last fall, the entire spent nuclear fuel inventory from the 324 Building was successfully reconfigured and packaged into six modified NAC-1 transport casks. Each of the casks was transported to Hanford's interim storage pad, with the final shipment occurring last November, Rasmussen said. The project spanned about an 18-month period.

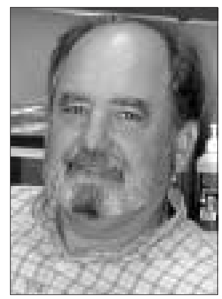
As a cost-savings measure, project managers elected to purchase the available fleet of six formerly licensed NAC-1/NFS-4 Type B single element transport casks and matching ISO containers to be used as the shipping and storage packages. The casks and containers had to undergo extensive decontamination and upgrades, Rasmussen said, and were retrofitted with internal fuel storage canisters.

Six inner canisters were designed, fabricated, and loaded into the casks. The inner canisters acted as the containment boundary for the onsite shipment of the spent fuel, and included a remotely installed, manually welded shield plug and cover plate closure system. A dose study was conducted, Rasmussen said, to validate the thickness of the shield plug and to ensure the dose to workers was within acceptance criteria.

Rasmussen said a "significant" challenge was the need to design the packaging system to accommodate three different fuel configurations into a single storage cask design.

Trojan work

Portland General Electric's Trojan nuclear power plant began commercial operation in May 1976 and closed down in November 1992. Steve Nichols, manager of decommissioning projects at the plant, explained that Trojan's ISFSI fuel loading campaign started last December and is scheduled for completion at the end of this year. A total of 34 multipurpose canisters (MPCs) will be loaded and stored in the site's existing concrete casks.


Nichols

Trojan's ISFSI pad, he said, is designed to hold 36 concrete casks, but will hold only 34 of them. Holtec was the supplier of the MPCs.

Nichols offered the following schedule for typical MPC loading:

■ Prep work on an MPC and placing it in a cask load pit (CLP) so it is ready for fuel loading—10 hours.

■ Loading fuel to the MPC and videotaping the job—12 hours.

■ Installing lid on the MPC, draining the CLP, transferring the MPC to the decontamination and assembly station, and preparing the MPC for welding—12 hours.

■ Lid welding and pressure testing on the MPC—17 hours.

■ Hydro, nondestructive, and helium leak testing, and partial closure ring installation on the MPC—6 hours.

■ Blowdown and vacuum drying—about 42 hours.

■ Helium backfill, installation of cover plates, welding of remaining sections of closure ring on the MPC—8 hours.

■ Transferring the MPC to the crane bay, then to a concrete cask, and moving to pad—10 hours.

■ Preparation of transfer cask for next MPC loading—8 hours.—*Rick Michal*

EMBEDDED TOPICAL

Risk management—now more than ever

Major points of the plenary:

- *Risk of core damage has dropped*
- *Further improvement is necessary*
- *A big future uncertainty: regulation*
- *Safety is self-imposed in best plants*
- *Behavior-based method lifts safety*
- *Marine Air lowered risks in Iraq*

WHILE THE SUBJECT of risk management owes a lot to the Three Mile Island-2 accident, the title of the *Embedded Topical Meeting on Risk Management—Now More Than Ever,* came out of the events of September 11, 2001, explained the general chairman Ron Knief, of XE Corp., during the meeting's plenary session. Back in 1988, Knief took part in a risk management project, set up by GPU Nuclear, the original operator of TMI, to spend about a year traveling in and outside the United States to talk to people about risk management. Afterward, a symposium was set up to share the lessons with GPU Nuclear and the people interviewed.

Ted Marston, EPRI's vice president, science and techology development, gave an overview of the subject and answered some basic questions: Why do we need risk management more now than 25 years ago? Why hasn't it been further embraced than it is? What do we have to do to drive it forward?

Marston believes fundamentally that risk management provides the framework for improvements in existing plants and the deployment of next generation plants. Marston noted that since 1992, average core damage frequency (CDF) has dropped by a factor of three, while productivity increased dramatically. There had also been a drop in the NRC's significant events figures through 2000. These results, he said, demonstrate that productivity need not be damaged by measures to improve safety. A lot of this improvement is attributable to formal risk assessment/risk management techniques, but, he warned, "We can and must do better. . . . Manage [risk] or it will manage you."


Marston

Risk management provides a way to optimize the use of resources, not only of the plant but of the regulator, to ensure that the most significant safety issues are addressed. A risk management program involves identifying the hazards and risks and then quantifying and prioritizing those risks; only then can you begin to manage them, he said. Marston defined some of the characteristics of an effective risk management program, which would include appropriate indicators for identifying and monitoring risk and would have functions in place to prevent risk-important challenges to safety. It would also pursue the causes of risk significant degradations and ensure that actual risk-significant events are evaluated and corrected immediately. Furthermore, stressed Marston, a risk management program should be a living one, which adapts as plant, personnel, and regulations change.

One reason risk management has not been embraced to a greater extent is because there is concern that risk management cannot be quantified. Marston said, however, that a combination of "current risk metrics, such as cdf and lerf (large early relief frequency)," with the existing plant performance indicators that industry and the NRC have put together does provide an effective way for assessing risk management performance. Another concern is that the approach cannot be structured in a format amenable to compliance. But Marston thinks the fundamentals are there for acceptable regulatory scrutiny.

One of the biggest uncertainties for the future is the regulatory process. The current prescriptive regulatory structure, said Marston, is not conducive to achieving economic competitiveness and required levels of safety. The structure is focused on design basis, which, he said, can be counterproductive in some cases, focusing on the wrong kind of transients and the wrong safety-significant events. Restrictive structures can also lead to focusing on low safety significance and even on plants that are already doing a very good job. This means scarce resources are not being utilized as effectively as possible, he added.

To go forward, Marston said, there is a need to enhance the regulatory acceptance of risk-informed performance-based regulations. He observed that this can be done through a phased systematic process. "He thinks that moving away from the current prescriptive structure can be done through a phased systematic process." An assessment of the use of risk management at Duke's Catawba plant supports the idea that risk management is the key to improving operation, he noted. In the future, Marston said, new uses of risk techniques, such as risk-informed tech specs and risk-informed asset management, will be available for operators in the nuclear business.

Risk lessons learned

Dick Taylor was one of the people Knief interviewed during his GPU Nuclear grand tour. Taylor is currently head of environment, health and safety, policy, and strategy at British Nuclear Fuels plc (BNFL) and a visiting professor on risk studies at Cranfield University. He also speaks as a member of the International Nuclear Safety Advisory Group (INSAG), the committee that provides safety advice to the International Atomic Energy Agency's director general. Taylor said that much of his presentation is included in the recent INSAG 15 report on key practical issues for strengthening safety culture. INSAG 15 is the successor to the 1992 INSAG 4 report, which reflected the lessons learned from the Chernobyl accident, and which coined the term *safety culture,* defined as a rigorous approach with good communication and a questioning attitude.

Taylor said that in his experience, he can always sense something different when going into a plant that has reached excellence in safety performance. Not only is the housekeeping so much better, but "tap people on the shoulder and ask them what are the [safety] issues—they could actually tell you. They were interested and involved in the issues."

Continued

This led him to ask how nuclear safety, particularly regarding the people element, has improved over time. He identified several phases. The first phase is marked by the attitude "accidents go with the job." Here safety is compliance driven. This began to change in the late 1980s and early 1990s, when many nuclear organizations went through a rapid improvement phase that he attributed to "picking low-hanging fruit." Companies soon found, however, that the level of safety began to fall, leading management to take action to raise them again. This would then be repeated in what Taylor called the "roller coaster" effect. In this phase, explained Taylor, there is commitment, but it is largely imposed by management and safety professionals, and is difficult to sustain.

In behavior-based safety, the process is management-facilitated and -supported, but it is not management-driven, except at the early stages.

Finally, for those who entered the next phase, "the companies who really cracked it," safety was no longer imposed by management—"it was self-imposed," Taylor said. "Employees on their own wanted to achieve better environmental, health, safety, and quality performance."

INSAG 15 came out of a request to pull out behavior that really made a difference in terms of human performance. Some simple diagnostic questions were also included so people could check out their safety consciousness. Taylor discussed a number of lessons, including:

■ Are fine words matched by reality? People are acute in detecting the difference. They will need real evidence that safety is given high priority when managers are on site. Is safety the first thing they ask about? When safety and production come into conflict, which wins?

■ Is compliance with procedures an absolute? Taylor notes, however, that procedures have to be respected—that is, workable, intelligible, and relevant to the person doing the job. There should not be a two-tier system—with some rules not viewed as necessary.

■ Are conservative decision-making and a questioning attitude evident? Assessing risk is the key, not simply adhering to safety concepts like STAR (stop, think, act, review).

■ Are safety first decisions supported by leaders? If somebody stops production for what they believe is a valid safety concern, are they positively supported?

■ Is there a good reporting culture? Are near misses being captured?

■ Do the people who report an event see something being done about it?

■ Does the workforce have confidence to challenge the way things are being done?

■ Is the company a learning organization? Does an audit meet with "a cringe" or is it considered a learning opportunity?

In the field

Dennis Ruddy, general manager of the Y-12 plant at Oak Ridge, explained how safety culture can be improved. There was a seminal study during World War II, he said, that led to a theory called "deviation toward the norm," which explains the cyclical changes in safety described by Taylor. The study found that when safety was improving—for example, with aircraft carrier landing and takeoff—inevitably, the rate would fall back until it found a "norm" which he called a cultural basis upon which people felt comfortable." The safety levels would swing around this comfort zone, he said.

For Ruddy, that was the beginning of "behavior-based safety." By embedding good behavior, such as that discussed by Taylor, the norm—that fundamental comfort level—changes, driving safety to a new level.

In behavior-based safety, Ruddy noted, the process is management-facilitated and -supported, but it is not management-driven, except at the early stages. The process, he said, is owned and operated by the employees who live day to day in the environment and are the best placed to see what the risks are. It is the workers who see the faults, such as frayed cords, tripping hazards, equipment deteriorating to the point that it would put an employee at risk. Having employees observe the behavior of others is the key component of the system. Observations need to be fed back to staff as soon as possible. This has to be done in a constructive way, with positive aspects of their work emphasized to reinforce the safe things they are doing.

Ruddy emphasized that unsafe behavior is more likely to change if pointed out soon after it is done, rather than through the use of safety instructions or warnings given before work starts. A lot of data are recorded and analyzed, and lessons put back into the work place. Reports have to be acted on quickly, he said, and "we fix things on the spot—we do not just leave it as data." The investment is big in terms of the number of people engaged in the process, explained Ruddy. Some employees have to be trained to a high level of expertise to teach the process to everybody in the plant.

To demonstrate the success of behavior-based safety, Ruddy described the results at two facilities, the Pantex plant, in Texas, and Y-12, in Tennessee, which were both taken over by BWXT at about the same time. The behavior based safety process was implemented at Pantex immediately, said Ruddy. Within a year, Pantex began to show more improvement than Y-12. At Pantex, the view that the safety level was acceptable changed.

Another example of risk management in action was given by Col. Randy Alles, with 27 years in the U.S. Marine Corps, an F-18 pilot who commanded Marine Aircraft Group (MAG) 11 in Operation Iraqi Freedom. MAG 11, composed of more than 80 aircraft, is one of five that the Marine Corps employed in the Iraq operation. Alles described how Operational Risk Management (ORM) was used in planning operations.

The aim of ORM was to put each risk in a "low" value category, adding mitigators if needed. Whenever the risk was higher, that is medium or high, Alles had to go to the next level of authority (his commanding general or the expeditionary force commander) for a final decision.

The three activities he discussed were deployment; preparations for combat operations; and combat operations. Deployment involved moving some 80 aircraft and 2300 marines and sailors from various locations, mostly in the United States, to a location in Kuwait. Many factors had to be considered in planning this operation, including margins for error and backup plans (route diverts). Since his F-18s were crossing the North Atlantic in January, weather was a consideration if a pilot had to eject. The mitigators included flying in pairs, limiting flying to a 12-hour crew day, scheduling flights when circadian rhythms of pilots were optimal, normally in the middle of the day. Refueling was a particular concern, with the possibility of the hooking-up gear being ripped off. During Operation Desert Storm, landing during the night was wrongly considered a greater risk than refueling during the night. The one serious accident occurred during a nighttime refueling operation. Daytime refueling was set as standard.

Preparing for operations involved setting up the living quarters, the flight parking area, the flight line area, maintenance and operations services, training in nuclear/biological/chemical (NBC) weapon response, etc. Because planned criteria on how close together planes could be when parked could not be met, mitigators had to be put in place to prevent or minimize consequences of accidents. For example, the magazine area was separated from the flight line, barriers were placed between planes, an ordnance safety officer was always on the flight line, and weapons loading was not allowed at the parking area.

The combat operations phase involved different challenges than Operation Desert

Storm. For example, collateral damage was of greater concern in Operation Iraqi Freedom and various go/no go criteria were put in place to limit it. As clouds limit the ability to see threats, weather and altitude criteria were set for missions, although these would be suspended if there were troops to protect. To prevent civilian casualties, criteria were set for target identification purposes before weapons were used. Collateral damage evaluation criteria were also established and a software program that predicts the effects of weapons in a built-up area was used to determine whether a specific weapon was acceptable for a mission. A mission would be canceled if the payback were assessed not to be worth the risk. These measures were effective, said Alles. None of his aircraft were shot down, damaged by enemy fire, or lost by accidental mishap. *—Dick Kovan*

EMBEDDED TOPICAL

Applications of accelerator technology

Major points of the plenary:

- ◆ *Be mindful of operating costs*
- ◆ *Ahead: Rare Isotope Accelerator*
- ◆ *Technologies help defend homeland*

IN ALL, 160 papers were accepted for the *Embedded Topical Meeting on Nuclear Applications of Accelerator Technology,* noted session chair Eric Pitcher during the plenary session. About a quarter of those were submitted by non-U.S. participants.

Highlights of the seven papers presented at the well-attended plenary included an overview of the qualities that separate good accelerator facilities from not-so-good ones, as well as a review of radioactive beam facilities and an update on the U.S. Rare Isotope Accelerator project. Also, a national laboratory researcher offered that homeland security is providing a new area of applications for accelerator technologies. "As long as the terrorist situation continues . . . the whole mindset of the way we do address things, the way we do research and develop new technologies, are different. And they're going to stay different," said James. L. Jones, who discussed applications of accelerator technologies for national security.

Running a good accelerator facility

Stanley Schriber, a professor at Michigan State University who also works in the school's National Superconducting Cyclotron Laboratory, outlined the requirements of a productive, smoothly operating high-power accelerator facility.

Taking a cue from the business world, well-run acclerator facilities should be mindful of operating costs. A good guideline, Schriber said, is that operating costs should form 10 to 15 percent of what it would cost to replace the facility. More complex facilities, however, should have an operating cost of 6 to 8 percent of the replacement cost. For less expensive facilities, the operating cost should be 18 to 20 percent. "You can go through all the data that's available both in the business world and our business and you'll find that that is a good rule of thumb," Schriber said.

The consequences of inadequate operating budgets are noticeable. Short facility lifetimes, poor availability and reliability, an unhappy user community, and poor future sponsor support are all potential results of not including enough funding for operations, Schriber said.

Also important for good operations are facility upgrades—which are often eliminated because of budget constraints. The minimum yearly investment guideline for facility improvements is 5 to 8 percent of the facility operating budget, Schriber explained. "You've made an investment. You've bought a house. Do you just let it sit there and fall apart for 20 years? Or do you actually fix the hole in the roof? Do you actually fix the gutters? Do you paint it now and then? . . . This is an extremely important item, but many times it's eliminated because of funding constraints or other reasons."

By not adequately funding for upgrades, a facility runs the risk of again running into reliability concerns, being unable to keep up with advances that can improve user programs, and eventually losing out on an important investment. "The cogent question is, who would invest in a company that doesn't improve its processes?" Schriber said.

The other major area in need of extra attention is staffing. A typical facility's $100-million operating budget will allow for 300 staff members, including about 22 operators, Schriber said. Assuming that 30 percent of the staff will spend 10 years at the facility on average, and that the remaining 70 percent spend 20 years at the facility, about 20 new employees will be needed each year. "That means you have to have an effective training program. There has to be good coaches and good mentoring that's going on," Schriber said. In his paper, he noted that this hiring requirement needs to be carefully planned and should involve "hiring in advance of need to permit smooth transitions with useful information transfer." He also mentioned that good connections throughout the physics community are required to obtain the needed staffing resources.

Radioactive beam facilities

Radioactive beam facilities, which use a driver accelerator to produce short-lived radioactive isotopes for nuclear physics experiments, have not been greatly covered in accelerator applications conferences, noted Jerry Nolen, who works in the physics division at Argonne National Laboratory. Nolen outlined the basics of how the facilities work and reviewed where development stands on the nation's next-generation radioactive beam facility, the Rare Isotope Accelerator.

There are two traditional types of radioactive beam facilities. In fragmentation, or "in-flight" facilities, the driver accelerator accelerates heavy ion beams. The heavy ion beams go through low-Z targets, such as carbon, and fragment into secondary beams, which continue on at the energy that they were created and are quickly delivered straight to experiments, Nolen said. There are four such facilities in the world today: the National Superconducting Cyclotron Laboratory at Michigan State University, the

GANIL facility in France, the GSI facility in Germany, and the RIKEN facility in Japan.

The other, "isotope-separator on-line" type of radioactive beam facility differs in that the driver accelerator typically accelerates light ions. Light ions are directed to a high-Z spallation target, and radionuclides are produced as reactions on the high-Z target. Isotopes must then be extracted and then post-accelerated to deliver beams for research. Examples of this type include the Holifield Radioactive Ion Beam Facility at Oak Ridge National Laboratory, the ISOLDE facility at CERN, and the ISAC-1 facility at TRIUMF in Canada.

Current-generation radioactive beam facilities use 1 to 4 kilowatts of driver beam power. Next-generation facilities, which include several projects in the works around the world and the Rare Isotope Accelerator in the United States, will use hundreds of kilowatts of driver beam power, Nolen said. "The whole purpose of these kinds of facilities was to do basic research in nuclear physics. But there are several qualitative statements that you can make about the science of nuclear physics that can be answered by these next-generation facilities. And this justifies the large amount of activity in this field around the world," Nolen said.

The Rare Isotope Accelerator was recommended as the highest priority for major new construction in nuclear physics in an April 2002 report by the Department of Energy's Nuclear Science Advisory Committee. It will utilize both standard isotope-separator on-line and fragmention methods with new approaches for handling high primary beam power. "From a nuclear physics perspective, it's really a dreamworld for looking at any aspect, any open question in low-energy nuclear physics. You can have basically whatever target, whatever beam you would desire to answer a particular question," Nolen said.

Besides the isotope-separator on-line and in-flight methods, the facility will use an entirely new mechanism. It will be able to use heavy-ion fragmentation but then slow down the fragments and stop them down to room temperature in a helium gas, where they stay ionized, Nolen explained. "It's a method that rounds out the capabilities of the facility."

There is currently a federal R&D program for the facility, involving nine laboratories and universities in the United States. Two organizations, Michigan State and ANL, have expressed interest in hosting the site and have indicated they will begin work on conceptual design reports for the facility in the coming year, Nolen said. The project is expected to cost around $800 million, with an operating budget of about $75 million per year.

What inspectors need are very good imaging resolution along with good penetration into the large objects of interest, like cargo containers.

"The most optimistic scenario for RIA is that, in DOE language, we will have [critical decision] zero this year, followed by three years of design and four years of construction," Nolen said. "We could begin a two-year commissioning period in 2010. So, it should be complete by 2010 in this scenario."

Homeland security

The United States has 301 ports of entry, through which 16 million cargo containers are carried annually. "If we were to have an incident with a cargo container . . . it would shut down the United States commerce for the better part of four months in terms of checking all the containers and making sure there isn't going to be a subsequent event. It's a serious problem," said James L. Jones, of the Idaho National Engineering and Environmental Laboratory. Jones gave an overview of the role accelerator-based technologies utilizing ionizing radiation play in nonintrusive inspections for national security.

Active, noninstrusive technologies use externally applied sources to image or stimulate emissions from inspected objects, Jones said. What inspectors need are very good imaging resolution along with good penetration into the large objects of interest, like cargo containers.

There are two such radiation-based systems in use today. Science Applications International Corp.'s (SAIC) Mobile Vehicle and Cargo Inspection System, used internationally, relies on a radioactive source of gamma rays such as cobalt-60 or cesium-137 opposite an imaging detector. "The system works reasonably well for items that you can penetrate with about 1.3 MeV photons, max," Jones said. Advanced Research and Applications Corp.'s (ARACOR) Eagle system, in use in the Port of Miami, uses a 6-MeV electron linear accelerator. The system can be driven over a row of containers for imaging, and produces images in about a minute and a half, Jones said.

With explosives being the weapon of choice for terrorists in the last two decades, there are several radiation-based explosives inspection systems in use. SAIC's portable Pulsed Elemental Analysis with Neutrons system uses a neutron generator and fast/thermal neutron activation analysis, Jones said. ANCORE's Vehicular Explosive Detection System (V-EDS), which is used on cars and trucks, utilizes thermal neutron activation and uses a californium-252 source. "What it really focuses on is looking at the 10.8-MeV [gamma ray] . . . that comes off a nitrogen capture event inside explosives," Jones said. The ANCORE Cargo Inspector (ACI) uses pulsed fast neutron activation analysis with high-energy neutrons. "It looks at the fast and thermal neutron characterization and characterizes the explosives. . . . You can also get other materials out of the spectroscopy, in addition to the explosive nitrogen indicator."

INEEL has developed two explosive detection systems. The Pulsed Photoneutron Activation system uses a transportable, high-energy pulsed electron accelerator to induce photoneutrons at the converter source. It can be coupled with a conventional X-ray imaging source to provide a more complete image of the inspected object. The other is the Portable Isotopic Neutron Spectroscopy system, which can use a Cf-252 source and do thermal neutron activation analysis. The system has been in considerable use for the Department of Defense for characterizing chemical munitions. "Every chemical munitions facility in the United States has some of these systems," Jones said.

INEEL is also working on a system for nuclear materials inspection. The Pulsed Photoneutron Assessment Technology system is transportable and uses a pulsed linear accelerator to produce highly penetrating photons, which induce photofissions in nuclear materials. Telltale delayed neutrons can also be measured. "For the delayed neutrons . . . you measure between each accelerator pulse. If you see those, then you have a good indication that there's nuclear material in there," Jones said. And the system can be integrated with the ARACOR Eagle inspection system for cargo containers. "Not only can you do the imaging of the complete container within less than about a minute and a half, you can also now characterize the high-Z material that it sees in the real-time image."

Jones said that INEEL is planning to continue fundamental R&D of nonintrusive standoff inspections of shielded weapons of mass destruction, as well as continue its focus on homeland security applications and demonstrations. In fact, the laboratory is developing what it is calling the Center of Nonintrusive, Active Interrogation for Research and Applications. "We are and want to continue to stay a nuclear science leader in homeland defense, nuclear energy, and waste management," Jones said.—*Patrick Sinco* NN