ANS WINTER MEETING

Nuclear and energy independence

WHILE ORGANIZATIONS HAVE canceled or altered conferences in the wake of the events of September 11, the American Nuclear Society attracted more than 1100 attendants to its Winter Meeting in November in Reno, Nev. “In light of recent events, that is a remarkable accomplishment,” ANS President Gail Marcus commented during the opening plenary.

The large gathering was due perhaps to the upbeat mood of the industry in general, thanks in part to the Bush administration’s support of the continued use and further deployment of nuclear power, and because any hope for reducing greenhouse gas emissions likely would include nuclear power in a national energy policy.

During the plenary Marcus paraphrased Charles Dickens by saying, “It is the best of times, it is the worst of times,” in reference to the terrorist attacks on the United States and the opportunity for nuclear power to stake a substantial claim in the nation’s energy future. “The recent events only point more strongly to the need for energy security,” she said, “and in my mind, energy security has to include a very strong component of nuclear power.”

Leon Walters, the meeting’s general chair and director of the Engineering Division at Argonne National Laboratory–West, noted during the plenary that before September 11 the world was coming to the realization that nuclear power could be the solution to global warming. But now, he said, after that dark day in September, “the contribution of nuclear energy to reducing the dependence on foreign fossil fuels has taken on added importance.”

A foothold for the nation’s energy independence was made 50 years ago, Walters continued, when on December 20, 1951, the Experimental Breeder Reactor-I became the first nuclear unit to produce electricity. On a large viewing screen set up in the plenary auditorium, an image was shown of an official proclamation, signed recently by senators, congressmen, and the governor of Idaho, honoring the EBR-I and the nuclear pioneers who developed it. The proclamation recognized the environmental benefits of nuclear power and feted those who worked to provide the world with “clean, sustainable energy for the benefit of humankind for centuries by making use of nature’s gifts of uranium and thorium.” A ceremony was held later during the Winter Meeting to celebrate the nuclear pioneers who participated in the EBR-I project and helped lay the foundation for energy independence. (For a history of the EBR-I project, see *NN,* Nov. 2001, pp. 28 and 30.)

Major themes of the plenary:

- ***H_2 power can be an application of nuclear***
- ***50 years since first electricity with EBR-I***
- ***A proposal for a continental supergrid***

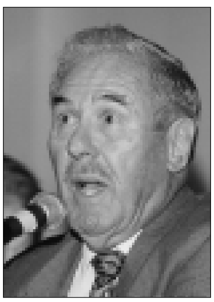
The Winter Meeting, titled *Nuclear Research and Development,* also hosted two embedded topicals and the ANS Student Conference. The topicals were *Practical Implementation of Nuclear Criticality Safety* and *Accelerator Applications/Accelerator Driven Transmutation Technology and Applications.*

History and hydrogen

The opening plenary, titled *Global Energy Perspectives,* was divided into two sessions over two days and provided a retrospective on where the nuclear power industry has been and a perspective on where it might go.

During the first session, Len Koch, one of the nuclear pioneers honored for his work on the EBR-I, reminisced about the early days of the industry. During his work career, Koch was associate project director of the EBR-I and project manager for another reactor, the EBR-II. He later became director of the Reactor Engineering Division at Argonne National Laboratory before moving on to Illinois Power Company.

“It is amazing the industry we gave birth to,” the 81-year-old Koch proclaimed proudly. “Today, there are 438 nuclear power plants operating around the world, producing about a sixth of the electricity that is generated.”


Koch

Koch explained that while the EBR-I was cooled by NaK (a liquid-metal alloy of sodium and potassium), the bulk of its reflector was air-cooled because of the uncertainty that the control rods could be operated in a high-temperature liquid-metal environment. The EBR-I itself had an 8-in. diameter core that was composed of 0.5-in. diameter pins of enriched U-235 in a single assembly. The vessel and piping all were doubly contained, a top inlet being provided to the vessel, going down through the blanket and up through the core. Fast control was provided by bottom–operated rods and reflectors; slow control by movement of the 5-ton bottom blanket.

Koch likened the now historical powering of four light bulbs at the EBR-I facility in Idaho, which represented the first nuclear–generated electricity on December 20, 1951, to the first flight of the Wright brothers' airplane. "This was our first generation of electricity," he said, "and on the next day we ran the reactor closer to full power . . . and all the electricity in the building was supplied from the reactor."

Those times developing the EBR-I were "the good old days," Koch said, when nuclear pioneers considered nuclear reactors "very interesting, fabulous new tools." With a nod toward energy security, Koch recalled that years before the EBR-I went into operation, scientist Enrico Fermi calculated that nuclear power plants could generate all the electricity needed in the United States for hundreds of years based on what were then the nation's known uranium resources. "Now, however, with the known amounts of uranium, nuclear could provide power for the United States for several thousands of years," he said.

Koch recalled a letter written in 1962 by President John Kennedy to Glenn Seaborg, then chairman of the Atomic Energy Commission. Kennedy's letter urged the AEC to look at the role of nuclear power in the nation's economy. Seaborg conducted a study and then responded to Kennedy. "For the long-term benefit of the country and indeed the whole world," Seaborg wrote, more emphasis needed to be placed on breeder reactors that could make use of nearly all uranium and thorium reserves, instead of the less than 1 percent of uranium and little of thorium that was used in present reactors. "Only by the use of breeders would we really solve the problems of having adequate energy supply for future generations," Seaborg's letter implored.

"Things have changed," Koch commented sardonically.

Koch called President Jimmy Carter's directive in the 1970s to eliminate reprocessing of spent fuel a "devastating decision," and credited Carter with founding a new field called "burial science."

If the future belongs to nuclear, Koch challenged, then new reactor designs should take advantage of the benefits of spent fuel. "The Generation IV program lacks the specifics we need," he said. In that regard, Koch called for a Generation V program that has a primary objective of using spent fuel and depleted uranium to power nuclear reactors.


Scott

Providing a perspective on how an energy system could be shaped through use of nuclear-derived hydrogen was David Sanborn Scott, vice president of the International Association for Hydrogen Energy. Scott opened his talk by declaring that nuclear is "probably the safest and cleanest of all energy sources," while hydrogen is "probably the safest and definitely the cleanest of chemical fuels." Together, he said, "they can deliver a brighter, cleaner 21st century."

The 21st century, though, is at peril, Scott claimed, because of a climate threat that is an "environmental juggernaut." Current levels of carbon dioxide in the atmosphere equal 360 to 370 parts-per-million, the highest amounts of CO_2 concentration in the past 400 000 years. "So when people say we are not putting our planet at risk, it reminds me of the tobacco industry saying smoking isn't dangerous to your health," he said.

If unabated, climate destabilization "could" lead to catastrophic events, Scott continued, such as the shutting down of the Gulf Stream and the freezing of the United Kingdom. These possible catastrophes could be avoided by using a two-pronged strategy, he said.

First, emphasis must be placed on oil independence, because a terrorist strike on Saudi Arabia's oil-production facilities would threaten our economy. Imported crude oil is "the commodity all democracies depend on," Scott said. Consider a few strategic factors: The average production rate of an oil well in the United States is about 12 barrels a day. In Persian Gulf countries, it is about 5000 barrels a day.

Second, the age of hydrogen-electricity, or "hydricity," must be ushered in to allow for the production of hydrogen fuel cells for cars, planes, and other transportation vehicles that currently are powered by fossil fuels. Since hydrogen and electricity are carbon free, hydrogen fuel cells manufactured by a nonfossil source such as nuclear power would release zero CO_2 into the environment, Scott said.

How does hydricity work? Both hydrogen and electricity are energy "currencies," not energy sources, Scott explained. Both can be harvested from any fuel source, fossil or nonfossil. The two currencies are mutually interchangeable: "Fuel cells convert hydrogen to electricity, and electrolysis converts electricity to hydrogen," he said.

Scott predicted that because hydrogen is storable, it will become the staple fuel of cars, buses, trains, and ships that employ fuel-cell engines. It also will power liquid-hydrogen aircraft that will fly farther (because hydrogen weighs about a third of what conventional fuels weigh) and fly cleaner (because the exhaust is water vapor).

The synergies inherent in hydricity systems will permit "extraordinary" technical, industrial, and regulatory flexibility, thereby improving efficiencies, reducing costs, adding security, and bringing environmental benefits, he said.

(A detailed review of hydrogen systems was given during the President's Special Session, covered later in this meeting report.)

Supergrid and infrastructures

Chauncey Starr, president emeritus of EPRI and past president of ANS, suggested on the second day of the plenary that the nation needs a continental supergrid based on hydrogen-cooled superconductivity and nuclear power. "It would provide a real-time electricity connection between the east and west coasts, and supply electricity and hydrogen fuel," he said.

Current-day national energy strategies are flawed, Starr noted, in that they are planned on projections that provide little guidance beyond a few decades. In contrast, the supergrid would be an example of century-long planning, and would be an alternative approach based on new research and development initiated at the applied science level.

A long-term national strategy is needed, Starr stated. In that regard, he called for a national "Energy System Advanced Research Project Agency" to stimulate new R&D.


Starr

"Let me be clear. We cannot expect leadership on century-long planning from our government process. If there is to be an effectively sophisticated direction of technical policy, it will have to come from the scientific and engineering community. Neither government nor the economy's market-based processes will do it for us. It's our job," he said.

The "unplanned, radical" innovations of the 19th and 20th centuries came from science-stimulated R&D, he said—electricity, telephone, petroleum engines, automobiles, airplanes, nuclear power, semiconductors, biotech, etc.

Following in that line would be the continental supergrid ("an old vision," Starr noted, but one that with new applied science would now be "marginally feasible"). It would supplement the existing grid, which is not feasible to send electricity supplies back and forth between "the coal-based east and hydro-based west" because the power losses are too great over such large distances, he said.

The supergrid, a "highly efficient energy corridor," would be an assembly of bipolar loops using a magnesium diboride superconducting transmission line (see figure, next page). Its core coolant at 25 K would be liquid hydrogen, with the hydrogen exiting as a fuel. The electricity and hydrogen both would be generated by nuclear power plants spaced along the corridor. Water vapor would be the only gaseous effluent. It would be a direct-current system, controlled by solid-state electronics. "The end result is a system free of fossil fuel and greenhouse gas emissions," said Starr, "with a relatively small ecological footprint and mostly buried under ground."

The supergrid would cost perhaps $1 trillion, at an average rate of $10 billion per year including R&D, superconductor cables, and power plants. It would be built mostly on public land. "To provide competition and save time, we would start at both coasts and at selected inland sites," Starr said.

It would take decades to complete, and many White House administrations would

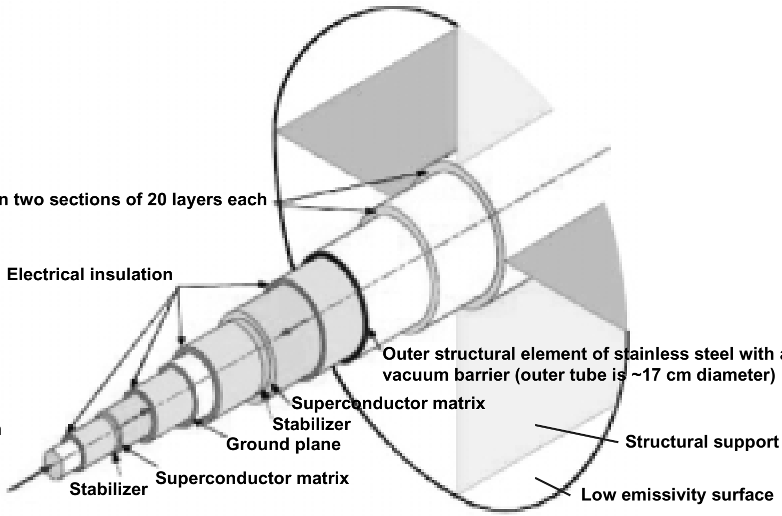


Fig. 1: Design of the MgB_2 DC superconducting transmission line in an evacuated pipe (Source: EPRI)

share in its progress. "I can picture the rhetoric and the symbolic switch-closings as we complete each milestone uniting the energy supplies of eastern and western U.S., and eventually the continent," he said.

The supergrid would be near invulnerable to terrorism because all major parts would be underground. It also would further the nation's energy independence. "If a hydrogen-fueled motor would gradually replace the internal engine, the reduction of U.S. dependence on oil imports might radically change our foreign policies and commitments," said Starr.

Another speaker, Hans-Holger Rogner, head of the planning and economic studies section within the Department of Nuclear Energy, International Atomic Energy Agency, wondered what effect energy infrastructure decisions made today would have on the coming decades.

"When we talk about global energy perspectives, what it really is about is the energy services needs of future societies," Rogner said. "Let us remind ourselves that there are still about 2 billion people out there [today] . . . who have no access to modern [electricity] services."

Thus, Rogner noted, choosing an energy infrastructure would have long-term, socio–environmental impacts on the world. Factors influencing the decisions on which energy generators to pursue would be the costs to build and maintain them, their quality, reliability, security, and convenience, their effect on the environment, and their social impact.

Rogner

Rogner presented scenarios of various energy infrastructures and concluded that the future would hold "enormous technical opportunities for nuclear power."

Hydrogen future

The potential importance of nuclear-derived hydrogen to the future of the nuclear industry was the driving force behind the well-attended "President's Special Session on Hydrogen Systems: An Overview." "I know in my agency, the Department of Energy, there's some interest in hydrogen generation, in general, from any source, including nuclear power," said ANS President Gail Marcus. "I think this is the next big sector that we can apply nuclear power to."

Speakers at the session covered a range of hydrogen applications and experience. Among the presentation highlights were discussions of the opportunities for nuclear power in the production of hydrogen for fuel cell applications and the role of nuclear-derived hydrogen in building a sustainable energy system. Also, the final speaker convincingly dispelled false lore surrounding the topic that inevitably comes up during any discussion of hydrogen as an energy source: the *Hindenburg* disaster.

"With hydrogen applications moving out into the general public arena, attention to safety is clearly paramount," said retired NASA engineer Addison Bain during his presentation on the *Hindenburg*. "It's not that it's any more hazardous than any other chemicals in fuel, but that its unique and emerging uses will be smaller in scale, less centralized, and more accessible to the public."

Fuel cells

Ged McLean, director of the University of Victoria's Institute for Integrated Energy Systems, pointed out that fuel cell technology is in its infancy. In fact, what is purported to be the world's first portable fuel cell generator—manufactured by Coleman, the camping equipment company—was scheduled to come to market before the end of 2001.

"This is a completely integrated, 2-kilowatt remote standby power system," McLean said. "It's quiet. It makes no noise and it generates very little heat. It's a premium product going after an early market—the early market being competing with those ugly, horrible gasoline generators that make a lot of noise and, by the way, have emissions. You could run this in your living room. You could run this right next to your frying pan while you're cooking. In fact, you could generate all the power for your electric stove from this."

McLean cited a study that said although the market for hydrogen fuel cells is minuscule today, it will balloon up to $32 billion by 2010. "Here's my question to you: Do you think that this is going to create some demand for hydrogen?" McLean asked. "The fuel cell is at the fulcrum of change. It's going to change the energy system."

By way of example, McLean said the California Air Resources Board said that there would be 2 gigawatts of installed generating capacity in automobiles by 2008. "Now, it's distributed. It's like sand. But what happens if you hook up with some other technology that I know about—embedded systems, the Internet, the chip—so that you can manage that? You can put electricity back into the grid. You can take electricity out of the grid. You can store that electricity in hydrogen. You can take hydrogen from fossil fuels and make electricity.

"So, you end up with a scenario like this: You generate hydrogen; that hydrogen is now in your hybrid or fuel-cell car, which can now provide transportation services and energy services."

McLean described a situation in which consortia of consumers could sell back hydrogen reserves to utilities. "This is really interesting, because . . . it means you don't have to size your nuclear power above the peak. It means you can size your nuclear plant somewhere below the peak and rely on the hydrogen that you've produced . . . [to] get that hydrogen back to generate your peak."

McLean concluded that this integrated approach "will really change the way the energy utilities work."

Sustainable development

Hydrogen can be produced by splitting water into hydrogen and oxygen by way of electrolysis, or by stripping the carbon atom from fossil or biomass sources, noted Hans-Holger Rogner, of the International Atomic Energy Agency. With global climate change being the most critical environmental threat of the 21st century, and in the absence of environmentally sound carbon disposal routes, the only sustainable hydrogen production options are renewable sources and nuclear power, Rogner said.

Over the next three to five decades, Rogner said it is almost certain that only nuclear technologies could produce hydrogen in sufficient quantities, and at economically viable costs, to build up a substantial bulwark against carbon dioxide–induced climate risk.

In contrast to renewables, nuclear power is a highly concentrated source of energy, with minimal burden on land requirements, he explained. With continually increasing urbanization, concentrated energy supplies will become even more important, Rogner said. Service of peak energy demand densities of 1.5 kW per square meter will be needed, and nuclear power is well suited to densities several times that, at a high rate of reliability, Rogner said. Renewables, though, can supplement nuclear power by, for example, supplying energy needs in remote or low-demand density areas.

System considerations, especially of the expected energy service demand densities of modern metropolitan areas, set nuclear power as superior to renewable sources—especially in its ability to produce the very large quantities of energy that will be required without unacceptable environmental damage, Rogner said.

Hydrogen exonerated

Addison Bain, who designed hydrogen systems for the *Apollo* program in the 1960s, outlined the reasons for the crash of the *Hindenburg* dirigible in Lakehurst, N.J, in May 1937. At age 57, Bain embarked on a doctoral thesis on the subject. In the course of his extensive research, he spoke to an employee assigned to the construction of the *Hindenburg*, a surviving crew member, and approximately a dozen eyewitnesses of the crash, among others. He is currently at work on a book about the crash, which he said appears to have been caused in large part by the extreme flammability of the zeppelin's fabric, as opposed to the flammability of its hydrogen load.

"I started out reading books about airships. And the more I read and the more I studied, I ran across so many inconsistencies. One of the airship books I read said that they used a cellulose nitrate–powdered aluminum mixture for doping [the skin of the craft]. That sounded like a rocket fuel to me. That got me going and inspired."

Two boards of inquiry, an American version and a German version, into the disaster determined that one of the ship's 16 gas cells sprang a leak, causing the vessel's hydrogen to mix with air, which was then ignited by a St. Elmo's fire–type of brush discharge.

After much research, Bain reached a different conclusion.

He said one of the most enlightening moments of his investigation came when he obtained a piece of the *Hindenburg*'s fabric. He took that piece of fabric, as well as other samples that were donated to him or that he purchased, to the NASA Materials Science Laboratory at Kennedy Space Center. There, after conducting tests, he learned that the fabric consisted of cotton, iron oxide, cellulose fuel acetate, and powdered aluminum, as well as other materials. Bain said iron oxide and powdered aluminum can cause a thermite reaction, in which temperatures can reach 5000 °F.

Also, the configuration of the powdered aluminum was similar to that of the powdered aluminum configuration used in rocket propellant, which is "significantly sensitive to the flow of static electricity across its surface," Bain said. That, coupled with stormy atmospheric conditions, in which lightning could be seen around the time of the landing, as well as the debut of an unorthodox high-mooring landing procedure, appear to have doomed the vessel. "That's the first time the *Hindenburg* ever attempted a high mooring," Bain said of the procedure, in which the ship was moored at a high altitude and winched to the ground with cables. "The static electric buildup on an airship is a function of the altitude. The voltage potential that was built up on that airship that day was 250 000 to 300 000 volts."

Bain learned that the outer cover of the *Hindenburg*'s sister ship, the LZ130 Graf Zeppelin II, was of made of a different material. "It was a peak on sulfur and a peak on calcium [during testing of pieces of the outer cover] that would determine that the coating included a calcium sulfate. And that is a fire retardant used in the textile industry. So, the guys knew," Bain said.

He said he found likeminded testimony in an archive in Germany, which gave cause of the *Hindenburg* disaster to the fabric and doping process used in the manufacture of the vessel—and not hydrogen.

"The moral of the story is, Don't paint your airship with rocket fuel," Bain concluded.

Generation IV roadmap

Two sessions were devoted to the "Generation IV Roadmap," the Department of Energy's ongoing initiative to develop the next fleet of nuclear reactors. The roadmap, the basics of which were introduced during a morning session, has a goal of identifying and developing one or more systems that can be commercially deployed no later than 2030 and can offer significant advances in the areas of sustainability, safety and reliability, and economics. Also explained were the roadmap's technology goals and fuel cycles.

An afternoon session delved deeper into the specifics of the individual groups that are working in support of the roadmap's development.

Program direction

The need for a technology roadmap to guide the Generation IV initiative was proposed by the DOE in 1999, according to Rob Versluis, a nuclear engineer for the Energy Department. Initiated in October 2000, the roadmap has a completion goal of October 2002.

Research and development on Generation IV technologies "is expected to be advanced internationally," Versluis said. Accordingly, about half of the technical experts participating in the project are from outside the United States. "Once the roadmap is complete, it can serve as the organizing basis of national, bilateral, and multilateral R&D activities aimed at developing Generation IV systems," he said.

While the roadmap's international partners investigate the long-term aspects of developing new reactors, within the United States the DOE's Near-Term Development Group (NTDG) is studying the regulatory, technical, and institutional issues that need to be addressed to support the domestic deployment of a new reactor within 10 years.

About 100 experts are involved in the roadmap through the following groups, in addition to the NTDG:

■ *Generation IV International Forum:* The forum consists of senior policy officials from the countries of Argentina, Brazil, Canada, France, Japan, Korea, South Africa, the United Kingdom, and the United States. The Organization for Economic Cooperation and Development's Nuclear Energy Agency and the International Atomic Energy Agency are permanent observers. Each country and observer is providing technical expertise to the roadmap.

■ *Nuclear Energy Research Advisory Committee Generation IV Technology Roadmap Subcommittee:* This subcommittee will provide advice to the DOE on the preparation of the roadmap.

■ *Roadmap Integration Team:* This team is responsible for developing and integrating the roadmap groups and activities, and preparing the final roadmap using analyses and documentation prepared by the working groups.

■ *Evaluation Methodology Groups:* These four groups collect information on and evaluate the four broad classes of nuclear energy system concepts: water reactors, gas reactors, liquid metal reactors, and nonclassical systems.

■ *Fuel Cycle Crosscut Group:* This group reviews energy demand forecasts for the 21st century and develops the characteristics of fuel cycles for comparison.

The steps to developing the roadmap, Versluis explained, include establishing goals, determining how to measure concepts against goals, identifying the concepts to undergo initial evaluation, gathering detailed information for promising concepts, evaluating the promising concepts against Generation IV goals, and identifying and establishing R&D goals for the most promising concepts.

Technical goals for Generation IV energy systems were detailed by Ralph Bennett, director of Advanced Nuclear Energy at the Idaho National Engineering and Environmental Laboratory. In all, eight goals have been proposed, three in sustainability, three in safety and reliability, and two in economics.

Bennett

For *sustainability*, the three goals are: that the systems (including fuel cycles) will provide sustainable energy generation that meets clean air objectives and promotes long-term availability of systems and effective fuel utilization for worldwide energy production; that the systems will minimize and manage their nuclear waste and notably reduce the long-term stewardship burden in the future, thereby improving protection for the public health and the environment; and that the systems will increase the assurance that they are an unattractive and least desirable route for diversion or theft of weapons-usable materials.

For *safety and reliability*, the three goals are that the systems will excel in safety and reliability; that they will have a very low likeli-

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hood and degree of reactor core damage; and that they will eliminate the need for offsite emergency response.

For *economics*, the two goals are that the systems will have a clear life-cycle cost advantage over other energy systems; and that they will have a level of financial risk comparable to other energy systems.

The eight goals "will be a vital factor in building public confidence in Generation IV systems," Bennett noted.

Providing information about Generation IV fuel cycles was Charles Forsberg, of Oak Ridge National Laboratory. "Four generic fuel cycles that cover the spectrum of feasible technologies for conversion of ore resources to energy have been defined," he said.

The four fuel cycles are *Once through,* in which the fuel is fabricated from uranium and thorium, irradiated, and directly disposed of as a waste; *Partial recycle,* in which some fraction of the spent fuel is processed, the fissile material is recycled, and new fuel is fabricated; *Full recycle,* in which all spent fuel is reprocessed for recovery and recycle of plutonium and U-235; and *All-actinide recycle,* in which all spent fuel is reprocessed and all actinides are recycled.


Forsberg

Forsberg concluded that the four types of fuel cycles have common facilities—those for mining (uranium and/or thorium), milling (purification of uranium and/or thorium), and fuel fabrication—as well as power reactors and the repository. Some fuel cycles, he said, include isotopic separation facilities, reprocessing facilities to recover selected elements from spent fuel, and special facilities to burn minor actinides.

Roadmap specifics

Louis Long, vice president of Southern Nuclear Operating Company, offered a strong comment about the next generation of nuclear reactors. While the goal of the nuclear industry is to have new reactors on line by 2010, said Long, for that to happen a new plant must be ordered "by 2003."


Long

Long appeared during the second half of the "Generation IV Roadmap" session to explain the work of the DOE's NTDG, which is made up of representatives from nuclear utilities, industry, reactor vendors, national laboratories, and academia. While the Generation IV roadmap seeks to deploy new plants by 2030, the NTDG has been formed to identify and develop one or more of the next-generation nuclear energy systems that can be commercially built no later than the end of this decade.

"Selections of new projects must be market driven and primarily supported by private sector investment," said Long, "but government support is essential" in the form of leadership and effective policy, efficient regulatory approvals, and cost sharing of generic and one-time costs.

The NTDG has identified nine generic issues that could influence the viability and timing of any new nuclear plant project, according to Long. These are: nuclear plant economic competitiveness, business implications of the deregulated electricity marketplace, efficient implementation of 10 CFR 52 (the standardized licensing process), adequacy of the nuclear industry infrastructure, a national nuclear energy strategy, nuclear safety, spent fuel management, public acceptance of nuclear energy, and nonproliferation of nuclear material.

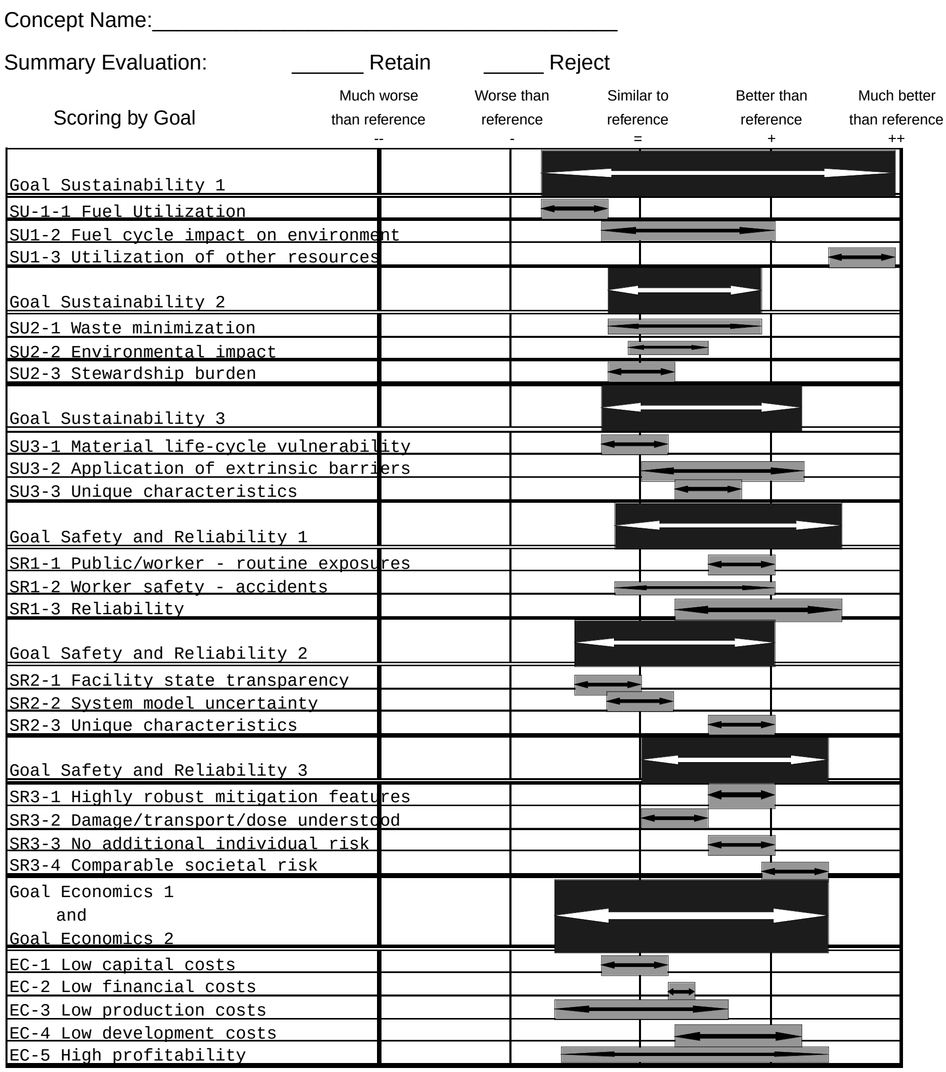
Right around the corner, however, is the date when a new plant must be ordered. "After reviewing all this, [the NTDG members] came to a conclusion," he said, "and that is that we think we can deploy new plants by the end of this decade. But in order to make it happen, the owners/operators have to commit by 2003."

Long reasoned that if construction on a new plant were to begin in early 2007 (in order for it to be operating by 2010), work toward securing the necessary permits and licenses would have to begin four years before that, in 2003.

Jordi Roglans-Ribas, a nuclear engineer for the DOE, explained the work of several groups that are evaluating specific areas of the Generation IV roadmap. Last February, the roadmap's Evaluation Methods Groups initiated the process for systematically evaluating the comparative performances of the roadmap's proposed goals. A component of that process is "Screening for Potential," according to Roglans-Ribas.

The Screening for Potential component identifies those nuclear energy system concepts that meet the purpose and principles of the Generation IV initiative and have the potential for significant progress toward established goals. "The basic philosophy for the Screening for Potential is to avoid discarding concepts with potential, even if associated with large uncertainty," Roglans-Ribas said.

Criteria used during the screening include system characteristics that provide an indication of a definitive future metric (e.g., facility size and complexity, as indicators of the capital cost). Evaluations are of a qualitative na-



Example of a Generation IV "Screening for Potential" score sheet ture, and a score sheet has been developed to help evaluate concepts against all the criteria (see accompanying figure). As additional concept information becomes available, Roglans-Ribas said, evaluations will become more quantitative.

Mario Carelli, manager of energy systems for Westinghouse Electric Company, explained the work of the roadmap's Water-Cooled Reactor Concepts group. A total of 37 advanced water-cooled reactor concepts are being investigated, each segmented into one of the following nine categories:


Carelli

■ *Integrated primary system reactors:* These light-water reactor concepts are characterized by a primary system that is fully integrated in a single vessel, which makes the nuclear island more compact and eliminates the possibility of large releases of primary coolant.

■ *Advanced loop pressurized water reactors:* These are modified loop-type PWRs with small water-filled containments.

■ *Simplified boiling water reactors:* These are various-sized BWRs with natural circulation in the core region, no recirculation pumps, and, in most cases, more passive decay heat removal systems.

■ *Pressure-tube reactors:* These are Candu type reactors with light-water cooling and fuel that is slightly enriched.

■ *Supercritical water-cooled reactors:* These are a class of high-temperature, high-thermal-efficiency water-cooled reactors, each with a primary coolant system that operates above the thermodynamic critical point of water (374.12 °C, 221.2 bar).

■ *High-conversion water-cooled reactors:* These are various reduced-moderation reactor cores designed to use uranium more efficiently and minimize the reactivity swing.

■ *Pebble-fuel reactors:* These use a fluidized bed of ceramic or metallic fuel particles in sizes ranging from a few mm up to about 10 mm, which keeps the fuel at low temperatures, enabling higher core power densities.

■ *Thorium/uranium fuel cycles:* These are either homogeneously mixed thoria fuels or various seed and blanket arrangements using both oxide and metal fuels.

■ *AIROX fuel cycle:* This fuel cycle consists of an oxidation/reduction process to recycle spent LWR fuel into Candu reactors, or, with added enrichment, back into LWRs.

Finis Southworth, manager of systems, sciences, and engineering at the Idaho National Engineering and Environmental Laboratory, explained the work of the roadmap's Gas-cooled Reactor Concepts group. The group has divided each of 20 concepts into one of the following four categories:

■ *Pebble bed reactors:* These are all based on thermal neutron spectra, and generally offer the following features: They are "naturally safe," designed to maintain fuel integrity under all design-basis accidents with no active safety system requirements. They also exhibit high efficiency, generally based on direct-cycle gas turbine power conversion systems, with or without a bottoming cycle using the relatively high exit temperature (about 500 °C) helium from the turbine. The reference pebble bed reactor is 250 MW thermal and 115 MW electrical.


Southworth

■ *Prismatic modular reactors:* These also are thermal reactors. The potential benefits are similar to the pebble bed reactors regarding natural safety and high efficiency. The reference prismatic modular reactor power level is 600 MW thermal and 286 MW electric.

■ *Very high-temperature reactors:* These reactors have core exit cooling temperatures above 900 °C. Concepts for these reactors provide the potential for increased energy conversion efficiency and for high-temperature process heat applications such as coal gasification or thermochemical hydrogen production.

■ *Fast gas reactors:* These concepts offer "high fuel utilization, closed fuel cycles" through high conversion or breeding of fissile materials.

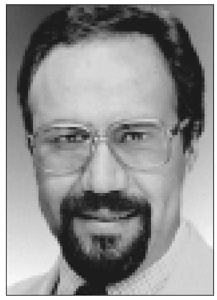
Michael Lineberry detailed the work of the roadmap's Liquid Metal Reactors Concepts group. Lineberry is a senior technical advisor at Argonne National Laboratory–West. Thirty-three concepts were reviewed by the group, and 27 of them were slotted into one of the following five categories:


Lineberry

1. Medium-to-large sodium-cooled mixed-oxide fueled reactors with advanced aqueous reprocessing and ceramic pellet or vibratory compaction fabrication (five concepts).
2. Medium-to-large sodium-cooled, metal-fueled (U-TRU-Zr metal) reactors with electrochemical fuel cycle technology (pyroprocessing) (six concepts).
3. Medium-sized Pb or Pb-Bi–cooled; MOX or Th-U-TRU-Zr metal alloy-fueled reactors; pyroprocesss fuel cycle for the metal-fueled concepts, advanced aqueous or unspecified "dry" process for the ceramic-fueled concepts (nine concepts).
4. Small Pb or Pb-Bi–cooled; metal- or nitride-fueled reactors with long-life "cartridge" or cassette cores; fuel cycles vary (three concepts).
5. Sodium-cooled concepts that eliminate the traditional secondary sodium loops by development of novel new steam generators (3 concepts).

In addition, five of the 33 concepts were evaluated as stand-alones (three direct energy conversion schemes, a concept involving the Candu burnup approach, and a concept that would develop Russian Pb-Bi submarine reactor technology for commercialization). A sixth concept was more a statement of fuel cycle principles, said Lineberry.

Samim Anghaie, professor and director of nuclear engineering at the University of Florida, explained the activities of the roadmap's Nonclassical Power Reactor Concepts group. Each of the concepts falls into one of five reactor categories: liquid core, gas core, nonconventional coolant, nonconvectively cooled, and direct energy conversion.


Anghaie

The liquid core reactor concepts include two subsets: molten salt fuel and eutectic metallic fuel. The molten salt reactors are fueled by uranium or thorium fluorides dissolved in a mixture of molten lithium and beryllium fluorides. Eutectic metallic fuel reactors use a mixture of uranium or plutonium and a low neutron absorbing metal.

The gas core reactor concepts comprise all reactors that are fueled by uranium tetrafluoride vapor.

Nonconventional coolant reactors use molten salts or high boiling point organic liquids to remove core power at low pressure and provide heat at high temperatures.

Nonconvectively cooled reactors include all designs that do not use bulk convective cooling to transport the core power.

Direct energy conversion reactors are built from very thin uranium dioxide foils fuel. Fission fragments carry most of their energy and electric charge out of the microns-thick foils to direct power conversion devices.

The Nonclassical Power Reactor Concepts group also is evaluating concepts with specific design features, including those with minimized waste fuel cycles, advanced fuel materials, and alternative power conversion cycles. In addition, the group is investigating diverse energy product reactors (which may provide hydrogen, hot water for district heating, seawater desalination, and other products, in addition to electric power) and modular deployable reactors, which are designed for long- period (5–10 years) single-cycle use and installation in locations that are not conveniently accessible for construction or refueling.

Early site permitting

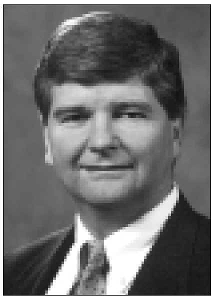
Three nuclear generating companies—Entergy, Dominion, and Exelon—have announced plans to examine the early site permit, which allows utilities, before actually deciding to build a plant, to obtain permission to build it on a chosen site. The advantage of the early site permit is that it resolves the licensing issues of a site for a given plant profile, which reduces the investment risk and allows utilities to clear many adjudicatory issues before constructing a nuclear power plant. A standard, certified plant design can then be plugged into the site.

The session "Early Site Permits: First Step to the Next Generation," featured three panelists variously involved in early site permit activities. Dan Keuter, vice president of Entergy Nuclear, provided an update of Entergy's early site permit plans: Ed Rumble, of the Electric Power Research Institute; and session chair Kyle Turner, CEO of McCallum-Turner, gave in-depth descriptions of what the early site permit process entails.

On the frontier

Entergy Corporation is the second largest nuclear utility in the United States, and "definitely the fastest growing," Keuter said. The utility has recently doubled its nuclear fleet, adding five plants in the northeastern United States. Furthermore, he said, the company's long-term vision involves building nuclear power plants. "We want to bank these sites, at the right time, with the right design . . . [and] start building new nuclear power plants."

Entergy is actively embarking on early site permits for "at least two of our sites; it could be more," Keuter said, not wanting to divulge sensitive information. He mentioned that Entergy is looking to add reactors where there are existing plants because "it's a lot cheaper to put up [plants at] an existing site than to greenfield a site," he said. Although all 10 of Entergy's sites are under consideration, Keuter mentioned that Indian Point and Waterford stations are unlikely candidates for hosting new units.



Keuter

Keuter said Entergy is interested in pursuing three reactor designs, GE Nuclear Energy's Advanced Boiling Water Reactor, Westinghouse's AP1000, and the Gas Turbine Modular Helium Reactor (GT-MHR). "Our early site permitting would be capable of taking those three designs," Keuter said. "But we want to keep those options open. At the right time, when the right economics come through, we'll have a site that can pick up the right design and place it in any of those sites."

Those "right economics" have much to do with being able to compete with natural gas. "A lot of people ask me, 'When are you going to build the next nuclear power plant?'" Keuter said. "And I tell them, 'You tell me what natural gas is going to be doing and what the cost of a nuclear plant is.' And I'll take that intersection and say, 'That's when we'll build it.'"

Application elements

Early site permits are a "real good deal," said Ed Rumble, of the Electric Power Research Institute, in that they are applicable for 10 to 20 years and can be renewed. Also, Rumble said, the public's ability to challenge an obtained permit is reduced. He described the three elements to the early site permit: the site safety analysis report, the environmental report, and emergency planning information.

The site safety analysis report requires information about the site such as a general site description; the meteorological and hydrological characteristics of the site; nearby industrial, military, and transportation facilities; the existing and projected population of the surrounding area; and a plan for site redress (i.e., for putting the site back into the state it was in when work started, if the work is not complete).

The environmental report is for information on the environmental effects of site preparation, station construction, and station operation, as well as reports on effluent monitoring. It is also to take into consideration the environmental effects of accidents and the economic and social effects of station construction and operation, and provide a summary cost-benefit analysis. Rumble said there is currently a petition to reduce the amount of alternative analysis—in which the applicant reports on considerations of other sites and other types of facilities—required in the environmental report.

Applicants pursuing an existing site for an early site permit will find significant advantages in the emergency planning information portion of the application, Rumble said. "If people use existing sites, it's probably a good idea. If they pick what they call a greenfield site, which is a brand new site, then they're either going to have to do a full-out emergency plan or propose the major elements of it," Rumble said. The emergency planning information must describe the physical characteristics unique to the proposed site, such as egress limitations from the area surrounding the site. It must contain contact information and descriptions of arrangements made with local, state, and federal governmental agencies with emergency planning responsibilities.

Rumble explained that the early site permit application also allows applicants to address the plant design in general terms of an envelope, without having to name the specific design. "You could envelope many different kinds of plants, or you could envelope only a few, depending on what you want to do. But you have flexibility there," he said.

"The plant parameter envelope is supposed to bound the plants that you would want to build for that site," he said. "Basically, the site is approved conditionally on the plant's being inside that envelope. If you have a site, the site has got to accommodate that envelope, and the envelope has got to bound the plant. So that when you actually go ahead and pick a plant and decide to build that plant, the plant parameters have to be within this envelope, so that the whole system works."

Rumble then described the three rules governing the plant-versus-site parameters in the early site permit application. The first is that the site capacity must be greater than the site needs. Using raw water as an example, Rumble said, "You have to have enough capabilities for water to exceed the needs of the plant and everything else that's at the site." Second, the site capacity to accommodate plant operations must be greater than the plant impact on site resources. Third, the plant must have the capability to withstand hazards greater than the site presents. "For example, in California it's going to be difficult to site plants because many plants aren't designed for the earthquake [challenges] that California presents. That's one case where plant design has to have certain capabilities to exceed the hazards on the site," Rumble said.

"I have to caution that this is pretty new stuff and hasn't been demonstrated," Rumble concluded. "It's going to be interesting to see how the plant parameter envelope situation really works out."

The steps involved

Kyle Turner provided more detail on how an applicant might proceed from thinking about pursuing an early site permit to actually obtaining one, and what the project entails.

When undertaking an early site permit program, utilities should expect it to last from 18 to 24 months, Turner said. At an existing site, the process may only require 12 to 15 months.

As far as the cost of the project, however, Turner invited the audience to speculate. "What I can tell you is the work that is equivalent to an early site permit application conducted for . . . plants like the existing fleet was about $5 million in the 1970s. You can apply your own escalation factor to that. And you can also take into account that the geologic and seismic challenges are somewhat greater today . . . because the burden of proof lies more directly at the hands of the applicant." Also, for a site investigation of a nuclear power plant, public relations programs are likely to have to be more active today than 25 years ago—a point he made several times throughout the session—so those costs will also have to be considered.

Turner

Turner said it is important for utilities undertaking an early site permit program to address it as a project, with definite schedule milestones, technical products, and budget constraints. "It is not a scientific investigation. It is not something where we're looking around for whatever answer may arrive. We do have an objective," Turner cautioned. "I say this only because it's very easy in one of these programs—and I've seen this in the past—to sort of run off. . . . Well, we can't conduct it that way and meet the schedule and budget objectives that may apply."

Also, a strong public information program will be needed. "You will, by virtue of the work you have to do to develop an early site permit application, come into contact with the public," Turner said. "You can't do it in secret and you shouldn't do it in secret. You're going to be in the process, as an applicant, of doing the things necessary to apply for an application. And the public is going to be interested, at a minimum. And the agencies, both regulatory and informational, are going to be aware."

Also, potential applicants need to be aware of unforeseen pitfalls owing to the novelty of the application process. The NRC review phase has not been tested, and neither the applicants nor the NRC itself knows how this is going to evolve. "Some of these uncertainties will be hammered out only in the forum of the actual regulatory review," Turner said. "And NRC is going to be fighting its way through that process just like the applicants would."

Having considered these points before embarking on an early site permit application, a utility must then, of course, pick a site. It helps to pick an existing site, or a parcel of land adjacent to an existing site, because regulators have already found them to be acceptable. The site should also satisfy the National Environmental Policy Act requirements for the consideration of alternatives. "You need to be able to demonstrate that you considered the environment—[that] you didn't just pick a site based on economics or engineering considerations without taking into account the impacts that the plant might have on that parcel of land and its surrounding area," Turner said.

Also, the site selection decision process should be replicable, Turner said. There is regulatory guidance from the NRC, as well as documented criteria, that can be used in the process. Any intelligent and informed person should be able to walk through the process and understand how the decision was made, Turner said. "You start, in general, with large areas, and you narrow those down until you've got individual parcels of land. And when you've done that, then you can compare those parcels of land to each other. And, based on those comparisons, you select the preferred site that you propose to NRC and on which you do the site characterization work."

Once the site is selected, the early site application project begins. Turner said the project is not any different than other projects in that data is collected, analyzed, and summarized in a report. In this case, the report is the application, whereby the utility explains to the NRC what they've done to satisfy the requirements of the license application.

In the instance of an early site permit application, field data collection is not an insignificant item, Turner noted. Some data for the application, which can be collected from sources in libraries, the Internet, and agencies like the Census Bureau, is obtained easily enough. The amount of onsite and near-site data that is needed for the application, however, "requires a significant amount of preplanning and approval," Turner said. "Field assessments in themselves require site access. This may mean legal agreements with people who own land on the site or, in the case of an existing site, land offsite. You may need permission to put on drilling rigs, to build roads, to run biological sampling. . . . You may need access to do geophysical testing." And for some field data collection programs, longer-term access will be needed for maintaining and calibrating meteorological tower instrumentation or accessing well water or surface water quality stations. And, in ecological studies, investigators may have to return to the site on a seasonal basis to gain a full understanding of a how a site's environment works over the course of a year.

Also, a plan for restoring landowners' property to its original state will be needed. "Normally, landowners don't like for you to go drill holes on their property, construct roads, install . . . mud pits, and just walk away from that. So, in addition to access for these field data collection programs, you'll also need . . . a redress plan," Turner said.

An advantage of applying for an early site permit on an existing site is that much of the information required for approval is already available. Because of changing regulations, however, one area in which this advantage is less certain is in seismology. Turner said the reason is simply the bases on which an applicant proves the adequacy of a site from a seismic perspective have been changed. "The applicant does have much more latitude, but the applicant does have much more in the way of a burden of proof. And it is not certain at this point exactly how much of a leg up existing data on seismicity at an existing site is going to help with the licensing of a new site. Clearly, it's an advantage. But how much of an advantage we simply do not know yet," Turner said.

"I would say that in the discussions within the industry and in the interactions with NRC . . . probably the area of most intense discussion and most detailed discussion has been in and will continue to be the degree to which existing site information provides you a leg up—or not—in applying for and obtaining an ESP application at a parcel of land that's adjacent to an operating unit."

Turner then once again emphasized the importance of public information programs. "I want to harp on this subject again, because it's one that I think applicants find very difficult," he said. "If you're planning on doing something as controversial as siting a nuclear power plant, at the same time you'd like to keep your stock prices as high as you could and you'd like to keep your existing plants operating efficiently and without interference. So, what you have here is the classic question of who do you tell and how much can you tell and how do you tell it.

". . . Whenever you start with this process, this program of developing an ESP—this data collection, analysis, and reporting project—has to be integrated into that [a public information program], so that every interface that's conducted as a part of the ESP application is consistent with the existing institutional relationship program.

"This becomes acutely a problem when you have contractors working on your ESP application," he continued. "They have to be trained. They have to know what the applicant's position is. And they have to know to whom to refer any questions that they may get about things like, 'What kind of plant are you going to put here?' 'When are you going to start building?' 'I've heard that you guys have already started laying the foundation.'

"So, it becomes not only an institutional planning issue, but also a communication issue, so that everybody working on this program—[who are] not always an employee of the applicant—knows how to handle these kinds of questions."

HTGR designs

Among the most exciting prospects for the nuclear power industry is the high-temperature gas-cooled reactor, and the audience for the panel session "HTGR: Innovative Designs" heard from some passionate advocates for this technology from Germany and the United States. Panel chair Mark Reinhart, of the Nuclear Regulatory Commission, unfortunately had to tell the audience that two presentations were withdrawn—one on China's 10-MW reactor, which began operating in December 2000, and the other on Eskom's Pebble Bed Modular Reactor project.

This gave the three other speakers additional time to present their thoughts about a technology that they have been committed to for most of their careers. The first speaker was Hubertus Nickel, from the Jülich research center in Germany, where the pebble bed concept was first developed.

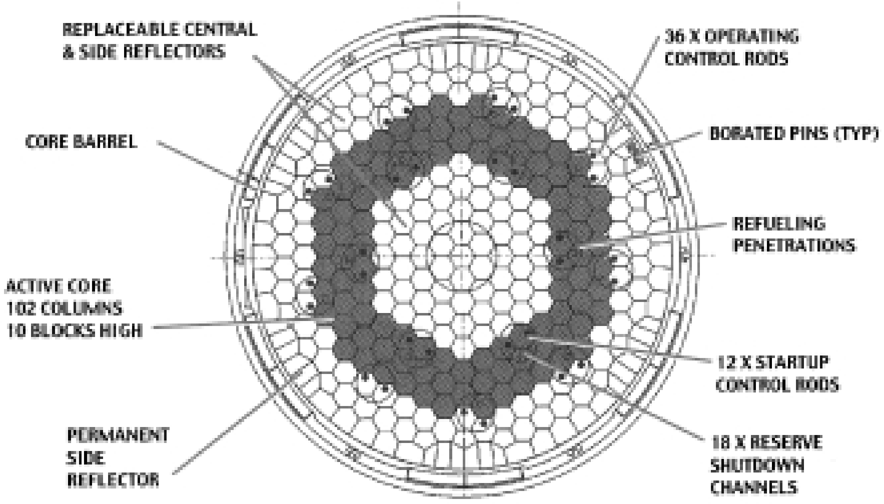
Nickel, who had also been a member of Germany's Reactor Safety Committee (equivalent to the NRC's Advisory Committee on Reactor Safeguards) for 26 years, ran through some of the history, as well as the main features, of the HTGR. The HTGR utilizes an all-ceramic core with a graphite core structure, ceramic-coated particle fuels and complete ceramic fuel elements. Combined with the helium coolant, the system provides a high level of inherent safety while allowing very high operational temperatures. Reaching outlet temperatures of around 950 °C provides a number of advantages, including high thermal efficiency and usable process heat for industrial applications.

Nickel

Current designs

The latest designs of relatively small, modularized reactors with steel pressure vessels provide what Nickel called "catastrophe-free" operation through passive decay–heat removal during any loss-of-coolant accident. The fuel temperatures during a full loss-of-coolant accident would remain below 1600 °C, ensuring no catastrophic releases of radioactivity.

Nickel described the two types of HTGRs: the pebble bed concept and the prismatic core–type reactor developed by, among others, General Atomics in the United States. For the pebble bed reactor, the fuel elements consist of tennis ball–sized spheres containing tiny coated particles in a graphite matrix. In the prismatic core, the fuel elements consist of hexagonal graphite blocks in which are inserted fuel rods containing coated particles



The GT-MHR core (Source: GA)

bonded in graphite matrix. The basic coated particle is essentially the same in both concepts, and present designs can achieve very high burnup.

In the 1960s, several high-temperature research reactors were built to study this reactor concept: In Germany, the AVR (Arbeitsgemeinschaft Versuchsreaktor), with a pebble bed core; in the United States, the Peach Bottom-1 reactor, with a prismatic core; and in Britain, the Dragon reactor, with a prismatic core (an international project sponsored by the OECD Nuclear Energy Agency).

These led to the construction of two commercial reactors operating on a conventional steam cycle:

- The 300-MWe Thorium High-Temperature Reactor (THTR) at Schmehausen, built by a German consortium.
- The 330-MWe Fort St. Vrain reactor, built by General Atomics for the Public Service Company of Colorado.

Neither of these was commercially successful.

Nickel described some of the achievements of the AVR reactor, which operated for more than 20 years, including 10 years at over 900 °C. Two particular concerns of the HTGR are the ingress of water or air into the core. The scientists at AVR were able to study the effect of a water ingress first hand when a steam generator tube failed during reactor operation, allowing more than a ton of water into the core in about 20 hours. According to Nickel, nothing much happened. It took some months to complete a dry-out of the core, but the fuel performed well at full power afterward. As to air ingress, when AVR operations finally ended, an air ingress accident was created in the reactor. The effect on the fuel was relatively minor. It took about 36 hours for the helium to be purged and oxidation affected only 1–3 percent of the fuel.

He also explained why a thorium-based fuel cycle was chosen. Basically, the decision was taken at a time when there were still concerns about uranium supplies and before the passage of nonproliferation legislation in the United States (during President Jimmy Carter's administration), which led to the ending of the use of high-enriched uranium—which drove the THTR fuel cycle—in many countries, including Germany.

A vendor perspective

The next speaker, Walter Simon, senior vice president at General Atomics, told the audience that there was a time when GA had an order book of 10 large HTGRs. Unfortunately, this was before the first oil crisis. One of them was canceled the day it received the construction permit; all others were also soon canceled.

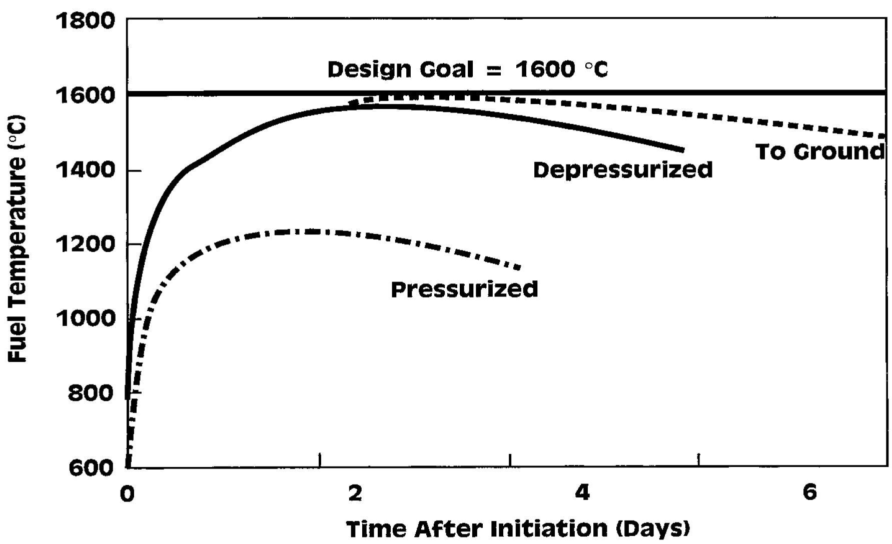
Simon explained some of the reasons for the new interest in the HTGR, which have to do with both new technology and changing attitudes, and described some of the more interesting features of the its new design, the 285-MWe gas turbine modular helium-cooled reactor (GT-MHR).

One fortuitous development was the coming together of two technological developments: gas turbines were becoming larger and reactors smaller. There is now a good match between the two. The move to smaller reactors, previously ruled out because of their perceived poorer economics, came from growing demands for safer reactors. In 1984, GA received a letter from Congress asking it to look at reactors that were safer. This resulted in a design that looks very different from the previous "short and fat" HTGR design. The new ones are long and skinny.

The new design is largely determined by two constraints imposed by safety requirements. First, there were to be no control rods in the core, only in the periphery; second, to avoid a catastrophic failure, fuel temperatures could not exceed 1600 °C in a loss-of-coolant accident. These constraints basically define the limits of the core diameter and power density to levels that ensure adequate decay heat removal to prevent fuel failures. It does, however, allow some increases in core length, and by going to an annular configuration with pure graphite in the central region, some increase in power was possible.

Simon described how decay heat is removed following a full depressurization. While there is a passive reactor cavity heat removal system, if this fails, heat from the reactor, which is built underground, will flow through the containment and dissipate through the earth to ensure that fuel temperatures will not go above 1600 °C.

A major development came in 1993, when GA and Russia's Minatom signed a Memorandum of Understanding on the joint development of a GT-MHR. At the time, they also approached the U.S. government for assistance, but it still had a no-nuke policy fully in force and, "as usual in those days," said Simon, they got no answer. GA then told Minatom that it would put in $1 million to start the project if the Russians would also. Minatom, which had already proposed building a unit at Seversk to burn Russian weapons plutonium from dismantled nuclear weapons, agreed. Despite not having U.S. government support, there was enough interest in this concept that in 1996, two commercial companies, Framatome and Fuji Electric Corp., joined the project.



GT-MHR fuel temperatures during a loss-of-coolant accident (Source: GA)

In 1998, the position of the U.S. government changed. As part of its plutonium disposition agreement with Russia, it decided to fund the GT-MHR program (in parallel with the MOX disposition program) with the condition that the Russians match it. The Russians have done that ever since. In fact, this is quite a unique situation, said Simon, because it is the only nonproliferation effort in which the Russians actually share the costs. The project is now sponsored jointly by the DOE and Minatom, and receives support from the Japanese government and the European Commission.

The program calls for a prototype GT-MHR module to be in operation by 2009 in Russia and the operation of a power station containing four modules, each of 285-MWe capacity, by 2015; each module will burn 250 kg of plutonium per year. The fuel for these reactors will contain only plutonium—there will be no fertile component. This can be done, said Simon, by including an erbium poison. Another advantage, said Simon, it that it is extremely difficult to extract any remaining plutonium from the spent fuel.

The development costs in Russia are a quarter to a third of what they would be in the United States, said Simon. Of course, a few design changes would be required to convert the design for strictly commercial use. For example, under the present agreement with the U.S. government, the first unit will have a conventional type of containment system. Simon explained, however, that such a high-pressure containment is not needed by this reactor to meet safety requirements, and for the commercial product, it would be converted to a low-pressure vented structure.

The project now has an advisory board consisting of representatives from a number of large U.S. utilities interested in the technology. In December 2001, a first meeting with the NRC was scheduled to set the licensing process into motion. Simon said that the projected "nth-of-a-kind" plant costs are now about $1120/kWe, with generation costs of 3 to 3.5 cents. The first plant would be about 25 percent higher.

A view of the future

The third speaker was James Kendall, who recently retired from the IAEA, where he led the gas-cooled reactor technology development unit. Before moving to the agency, Kendall had gained extensive HTGR experience in the U.S. No longer an IAEA official, Kendall felt free to speak his mind, and he had a lot of messages for those wanting to develop HTGRs.

Generally, he said he was quite encouraged. His experience at the agency, working on projects involving safety issues, including heat transfer and fuel performance, gave him confidence that this is a relatively robust technology and that the safety case will be made. Another positive development was that China and Japan, which both have operating high-temperature reactors, have successfully replicated German experience. He is also encouraged by the technological developments in other fields important to HTGR development, notably in gas turbines, advanced protection and control systems, and materials.

One strong point for Kendall is that the renewed interest in this technology has been driven by the marketplace, where credibility is so vital. He carried on this line to discuss some of the risks. For example, today's operating power reactors—which he called nuclear's golden goose—provide the financial basis for developing new technology. He warned this must be taken advantage of now, as this situation will not last forever.

Another concern he expressed was the capability of vendors to deploy a new technology like HTGRs. There are a lot of skills that will be needed, he observed, in activities such as designing, contracting, fabrication, and construction, as well as licensing, etc. He also said that it would be necessary to find suppliers willing to take on some of the risk in developing many components, which they would do only if they were to find the product credible.

Pebble bed reactors

Immediately following the second panel session on HTGR Innovative Designs, a technical session on the Pebble Bed Modular Reactor (PBMR) was held.

Andy Kadak, Professor of the Practice, Nuclear Engineering, at Massachusetts Institute of Technology, opened the proceedings with an overview of an MIT version of a PBMR, which, he believes, provides some improvements to the South African PBMR version (*NN*, Sept. 2001, p. 35). "We have gotten good press. People are captivated by this idea."

"We wanted to develop a demonstrable 'product' that could compete with natural gas and coal. . . . It had to be demonstrably safe and the waste could be easily disposed of and does not create any additional proliferation concerns," Kadak explained.

Kadak

The project was initially started in early 1998 under the American Nuclear Society's Economic and Environmental Imperative initiative to see if students can develop a nuclear energy technology that can compete with natural gas. Research is aimed at developing a conceptual design of the complete plant. Ultimately, it is hoped that a full-scale, dual-purpose research and demonstration plant is built based on this design. The work is now largely supported by the Idaho National Engineering and Environmental Laboratory (INEEL) and DOE Nuclear Energy Research Initiative (NERI) grants. The project has proceeded to the point that serious consideration is being given to building a full-scale dual-purpose research and demonstration plant at INEEL under a university-led consortium that will include national labs, other universities, utilities, and suppliers.

Kadak acknowledged that they are not plant designers, but do want to get involved in building the demonstration reactor. "We will license it as a DOE facility on a DOE site. We hope to have NRC work with us to develop a risk-informed licensing basis in the design and we want the design to be certified." The plan is that the facility will provide the test-bed for licensing purposes and then continue to be used to develop the concept.

The MIT reactor, rated at 250 MWt (l10 MWe), is similar to the Eskom PBMR in its core design but radically different in the balance of plant.

Concept overview

The pebble bed reactor core, he said, contains approximately 360 000 uranium-fueled pebbles about the size of tennis balls. Each pebble contains 9 grams of low-enriched uranium in tiny grains of coated particles within a hard silicon carbide shell. These microspheres are embedded in a graphite matrix material in the shape of a spherical pebble. The unique feature of pebble bed reactors is the on-line refueling capability, in which the pebbles are recirculated with checks on integrity and burnup. It is projected that each pebble will pass through the reactor 10 times on average in a three-year period before discharge. Because of the on-line refueling capability, plant maintenance outages are projected to be carried out every six years.

MIT chose an indirect cycle to allow for more flexibility in process heat applications and easier layout configurations. Kadak said they want to focus on the total modularity concept. True modularity, he said, will facilitate factory fabrication, simplify site assembly, and, most important, on the maintenance side, allow replacement rather than repair.

For a new type of reactor, licensing will be a major item. Issues to be considered include containment and the possible impact of accidental air and water ingress into the system.

The latest estimate of capital cost is about $2000 per kW. While this is high, said Kadak, the cost per unit sent out is estimated at only 3.3 ¢/kWh (net), and that includes decommissioning and waste disposal. The total project cost will be roughly half a billion dollars to bring the first demonstration unit on line with certification.

Modularity concept

Marc Berte, an MIT graduate student, next described the total modularity concept used for the reactor. In the MIT approach, the whole plant—reactor, intermediate heat exchanger, and the balance of plant—is packaged to be transportable via low-cost means (truck as opposed to barge) and easily assembled. This reduces capital, construction, and maintenance costs, and makes them attractive for use in developing countries, which do not have an extensive rail network and are not capable of large onsite construction. Another advantage of modularity is that it can reduce maintenance costs and downtime since the modules can be replaced rather than requiring online repair.

The fabrication of the modules, including all complex assembly and welding, will be done in the factory. All pipes are included in the modules with their own support structure—no additional support structures are needed on site. No single module exceeds 60 000 kg, well below the 100 000 kg which should be transportable. Shielding of modules for transporting active modules will also be possible.

On site, the modules will be aligned and flanges and piping bolted together. The only large machinery needed is a crane to emplace the top-level modules. The amount of site preparation for the balance of plant, on-site tooling, and machinery requirements is minimal. Overall, this layout requires the use of 21 modules (not including command and control or power processing units), each of which is truck transportable.

The goal is minimum time and labor and zero welding between modules. Whether the codes allow it has yet to be determined. "We are taking all the code compliance issues from the beginning so we do not run down a dead end," explained Berte. As an aside, he also said that the possibility of air transport was being considered, particularly because there are large Russian air transporters available now.

Multi-pass fuel cycle

In addition to its inherently safe design, a unique feature of the pebble bed reactor is its multi-pass fuel cycle, in which the graphite fuel spheres are randomly loaded and continuously cycled through the core until they reach a typical end-of-life burnup of about 80 000 MWd/t. Not all the spheres, however, have fuel. In the South African PBMR design, approximately a quarter of the core will consist of pure graphite "moderator" spheres, the rest being fuel spheres of varying burnup. To get the distribution right, the pure graphite spheres are dropped into the central region of the core at a single position, while the fuel spheres are dropped into an annular region at the edge of the core at nine positions. All spheres are removed from one central location at the bottom.

It normally takes about three months for a sphere to traverse the core. The reactor has a fuel handling and storage system that regulates the input and extraction of the spheres. When a sphere leaves the core, the first requirement is to distinguish if it is damaged or not. The good ones are transferred to an identification block to distinguish between fuel spheres and the pure graphite spheres. If it is a pure graphite sphere, it is sent to a second block where the identification is verified and then it is transferred back to the core. If it is a fuel sphere, it goes to another measuring block where its burnup is measured. If it has reached the planned burnup level, it is sent to storage; if not, it goes back into the core.

David Chichester, of Thermo Gamma-Metrics, described the on-line activity measurement system (AMS) his company has developed for Eskom's PBMR to differentiate between irradiated pure graphite and fuel spheres. The system measures the gross photon activity of a sphere and compares this value with a predetermined threshold value. These measurements are done using an ionization chamber. The instrumentation was going through acceptance testing at the time of the Reno meeting and should be on its way to the Pelindaba Nuclear Institute near Pretoria, South Africa, in 2002.

The unique circulating fuel of the pebble bed reactor makes in-core fuel management much trickier than for conventional light-water reactors for which computational methods allow highly precise in-core fuel management. For the pebble bed, an on-line measurement approach becomes the only accurate method to assess whether a given pebble has reached its burnup limit and is sent to storage or is returned to the core. Prof. Ayrnan Hawari, of the University of Cincinnati, described possible on-line burnup monitoring using passive gamma-ray and neutron detection methods to establish a power-history and cooling-time independent burnup measurement. These methods rely on radiation from selected fission products and heavy actinides that have built up.

Hawari's group determined that Cs-137 and Eu-154 provided the best correlations between activity and burnup, and they believed that both methods could be developed for accurate on-line burnup measurements. Hawari explained, however, that a usable system must take into account other considerations, particularly its ability to meet the requirements of throughput. The preliminary analysis indicates that using either method for the expected measurement time is sufficient to meet a circulation rate of one pebble every 30 seconds. Several detectors and detection systems are currently under evaluation.

Optimizing the design

According to C. Y. Wang, an MIT graduate student, the development path of the MIT reactor concept began with a design that although not necessarily optimized from an efficiency or plant cost point of view, could in theory actually be built using current technology. "Once the initial, buildable design is established," he said, "we will then determine key limitations to this design, and develop a path to removal of these limitations." Then, a final design of a more efficient and cheaper plant will be developed that has a reasonable chance of being buildable.

The most significant constraints on the designers are having to comply with all existing codes and standards and avoiding any significant additional R&D effort that would extend construction times and costs. For example, the use of an indirect heat exchanger has the advantage of preventing radioactive contamination of the secondary plant and reduces "to incredible" the probability of a water or air ingress accident; this restriction, however, which is due to ASME code requirements, severely limits the allowable intermediate heat exchanger temperatures, and, therefore, the plant efficiency. Avoiding any significant extension of existing technology limits the allowable size of the turbines and compressors, and by using the pressure vessel design of South Africa, coupled with the indirect cycle design of the MIT concept, a separate cooling system will be required for the pressure vessel.

The current goal for the "next-generation" plant is to achieve an overall plant efficiency of above 45 percent, compared to the current 40 percent. This will require extending current technology, which may involve advances in materials performance to allow higher intermediate heat exchanger temperatures, increases in turbo machinery efficiency, and many other options. At the moment, the optimum "mix" of technology development that minimizes overall cost and/or risk is not clear. A model is now being developed to do this.

J. M. Martinez-Val, of the Spanish company UPM, discussed the possibilities of using pebble bed reactors to transmute transuranics and long-lived fission products from light-water reactor fuel. The key is the strength of the Triso fuel particles, which can achieve burnup levels of more than 700 000 MWd/t. He described several variants, including the use of an accelerator-driven subcritical pebble bed reactor in tandem with a critical reactor.

Various fueling strategies that meet different final goals were discussed, including:

1. Once through strategy—LWR fuel is reprocessed once and all the actinides are encapsulated in Triso fuel, which is circulated in the reactor until high burnup levels are achieved.
2. Nonproliferation strategy—Irradiation and reprocessing of Triso fuel are repeated until targets of 99.9 percent transmutation of fissile material are achieved.
3. Minimization of long-term radiotoxicity strategy—Low-level fission products, such as Tc-99 and I-129, are added to the actinides.

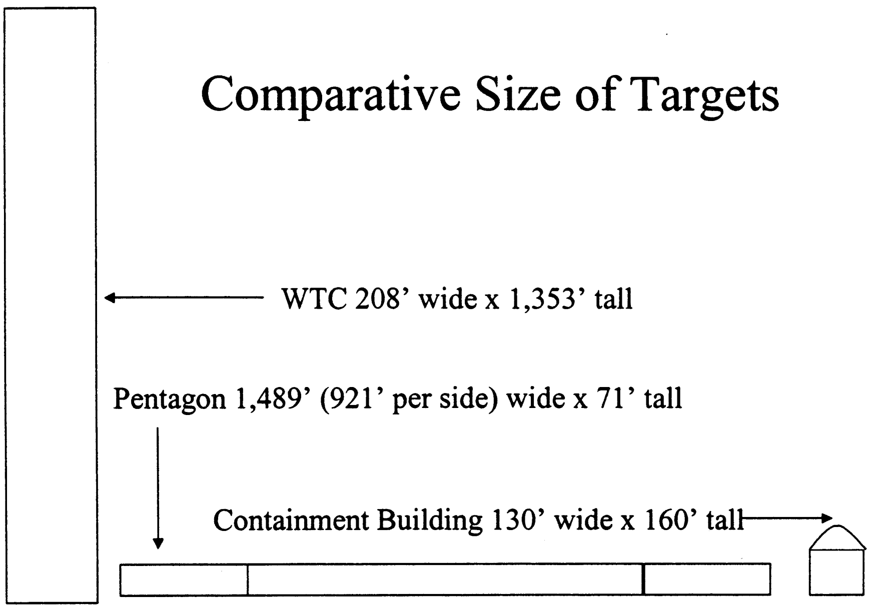
He warned, however, that to reduce the long-lived isotopes to a level that will allow the activity to decay to the natural uranium level in about 400 years, it will be necessary to virtually eliminate all transuranics. But to get close to 100 percent, the pebbles will have to be reprocessed, which would be very expensive to do.

Security measures

With homeland security issues making news, a special session chaired by ANS President Gail Marcus was organized to examine "Nuclear Plant Safety." Since the September 11 terrorist attacks, the public has had a more active interest in nuclear issues, said Brian Grimes, an industry consultant from Mukilteo, Washington. For the first time, for example, the general public seems concerned about perceived hazards from the transportation of spent fuel, he said.

Also new is the interest of "mainstream media" in talking with people about nuclear issues, Grimes continued. "Of course, there is the usual reporter technique of seeking judgments from local sources," he said. "Unfortunately, some of the antinuclear people have more pungent quotes than the nuclear people."

Overall, the general public has a greater concern for nuclear safety because an attack on a nuclear target could lead to perceived worst-case consequences, such as radiation exposures and land contamination. This concern exists "because there is a general radia-



Relative sizes of a World Trade Center tower, the Pentagon, and a nuclear power plant’s containment building (Source: NEI)

tion phobia [that is] enhanced by antinuclear folks trying to advance their agendas,” Grimes said.

It is up to the industry, then, to put nuclear threats in perspective. For the short term, Grimes explained, emphasis must be placed on communicating the capabilities of nuclear plants, such as their hardened structures and the separation of equipment on site. The industry must trumpet that each site has an armed and active response force and an energy plan for evacuation of an area. Also, the public must be made aware that if an attack occurred on a nuclear plant, the likelihood of radiation release would be low. Even in a worst-case scenario, Grimes said, the result from a large accident would likely be “a bad day at the plant and [maybe] some local land cleanup.”


Grimes

For the longer term, the industry must inform the public that as the world battles terrorism, nuclear plants always will have their protective measures, Grimes said.

Hardened structures

Marvin Fertel, senior vice president of the Nuclear Energy Institute, reviewed the security capacities of nuclear power plants. “Nuclear plants in our country and basically anywhere in the world are generally hardened structures,” Fertel noted. “Also, all the commercial plants have security plans and programs in place in our country. So, security was here before September 11, it will be here after September 11, and it’s changing [for the better through improvements].”

All nuclear plants in the United States have stayed at their highest levels of alert since the September attacks, and the Nuclear Regulatory Commission continues with around-the-clock staffing at its Emergency Operations Center and regional Incident Operations Centers. “So the entire [nuclear] infrastructure has been at its highest security level,” Fertel said.


Fertel

Regarding security specifics, Fertel remarked that perimeters have been extended outward around nuclear plants, so that visitors are farther away before they gain access. Some states have National Guard troops supplementing the security forces at the plants. Existing safety measures include thorough background checks of employees, vehicle barrier systems in place at sites, and security exercises conducted by plant personnel.

The NRC and the industry have independently undertaken “top-to-bottom” reviews of the security infrastructure. “We’re looking at every aspect,” Fertel said. “Comments have been made, particularly in the media, about [plant security] weaknesses, and we’re looking at those to see how real they are.”

Fertel stressed that a nuclear plant’s containment has about 12 feet of concrete and a foot of steel, in various segments, between the reactor core and the outside of the building. “So we have a relatively robust structure,” he said.

As to the question about aircraft attacks on nuclear plants, Fertel said that “only three of our facilities have looked at airplane crashes” during design consideration, but that is because those plants are located near airports. Those plants—Seabrook, Limerick, and Three Mile Island—were designed to protect against what could be perceived as possible threats or risks (aircraft crashes), the same way a plant in Kansas would design to protect against a tornado but probably not a hurricane, he commented.

Are nuclear plants in the United States robust enough to survive an aircraft hit? “We think generally the answer for containments would be absolutely yes,” Fertel said. But the real danger would be a plane engine’s rotor, not the body of the aircraft itself. “The plane doesn’t do much damage except to itself,” he said. “But the rotor becomes a missile and could penetrate to some depth into concrete.”

While containments seem secure, there is some concern for other structures on site, including the auxiliary buildings and spent fuel pools, Fertel said. Spent fuel pools of pressurized water reactors are below ground level and so there is less worry about threats of air strikes. But the spent fuel pools of boiling water reactors are elevated. “The question there is, would a plane be able to crash into it, breech it, and drain it?” Fertel offered. “If it’s not drained, there is no problem. There would be no radiological releases and the situation would be controlled.”

For security of auxiliary buildings, “there are concerns there,” Fertel said. A plane could penetrate them and make safety systems inoperable. In that regard, the industry is looking at probabilistic safety assessments and working with EPRI to see that protections are in place in the event of aircraft accidents.

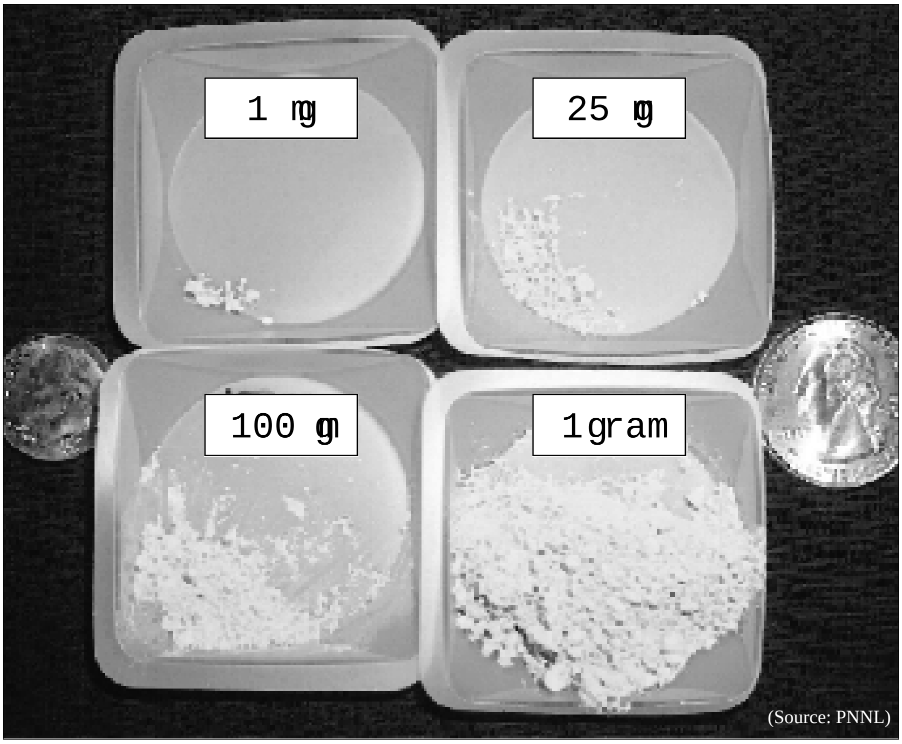
Much of the security issue comes down to the likelihood of an aircraft making a direct hit on a nuclear plant, Fertel said. The World Trade Center towers were very tall vertical targets, and the Pentagon, while large horizontally, was not easy to hit and in fact was struck indirectly on September 11. “So a nuclear plant’s profile”—a fraction of the size of the buildings attacked on September 11—“makes it difficult to hit from the air,” he said (see illustration above). “A plane hitting the plant is something that should be looked at and is being looked at, but it is not, at least upon the first assessment, the threat that it is made out to be by some of the antinuclear groups.”

Fighting anthrax

Also discussed during the session was a nuclear safety issue as related to the use of radiation to kill anthrax spores.

Gail Marcus made the presentation for Ray Durante, who had planned to attend the session but was unavailable at the last minute. Durante is head of the Food Irradiation Council. “As far back as the 1960s, radiation was successfully used to destroy anthrax spores in imported goat hair used [in] making carpets,” Marcus read from Durante’s statement: “While only a limited amount of research has been done specifically on the anthrax bacillus spore, there is enough data on work related to similar pathogens to be confident that radiation would be very effective for this application.”

Further research needs to be done, Durante’s statement continued, to determine what level of radiation would be most effective since an organism’s sensitivity to irradiation depends on the size of its DNA and the rate at which it can repair DNA damaged by irradiation.



Relative amounts of anthrax, to scale

"When it was first learned that anthrax spores were being sent through the mail and affecting postal workers and others, there was an understandable rush to find an immediately available method to counteract the health threat," Durante's statement noted. Press releases and articles stated that food irradiation equipment could be used to sterilize mail. Unfortunately, Durante lamented in his statement, a mature and viable food irradiation industry does not exist today, although experience on sanitizing medical supplies shows that the machines do work.

Durante noted that it would "seem logical" to use electron beams to irradiate large batches of mail.

Barbara Seiders, manager of chemical and biological defense programs at Pacific Northwest National Laboratory (PNNL), explained technologies being studied for obtaining mail safety. In examining the anthrax threat, researchers at PNNL have found that the size of an anthrax particle is important because "not all particles are problematic," Seiders revealed. "The only particles you have to worry about are the ones that find their way into the lungs and cannot find their way back out." So if a particle is too large, it may deposit on the tongue before it gets to the lungs. If it's too small, it will be breathed in and breathed out.


Seiders

Anthrax particle sizes range from 1 to 10 microns in diameter, with one to two anthrax spores per particle. The bottom line, though, is that there are more than 1 million infectious doses in a few milligrams of anthrax spores. "That's kind of grim," she commented. (See photo above for visual depiction of relative amounts of anthrax, to scale.)

Seiders noted that while irradiation has been used for medicine and food safety, "those usually have been done in liquid mediums or in meat tissue, and it is a very different problem trying to sterilize a dried powder as compared to a liquid-based organism." Limited information is available about irradiating dried foods such as spices, she said.

Based on a number of studies dealing with the anthrax spore and from information provided by experts, the radiation dose would have to be greater than 10 kGy to kill anthrax, she said.

PNNL researchers have looked at a number of methods for killing anthrax contained in sealed envelopes and parcels. These methods include irradiation using electron beams, gamma-ray irradiation using cobalt-60 or cesium-137, beta irradiation using strontium, and irradiation using X rays.

All methods are affected by the volume of mail to be handled, the amount of time the mail would need to be irradiated, operational feasibility concerns and constraints, human health concerns, and availability of equipment to do the irradiating. For example, using electron beams at an existing facility, a conveyor belt could carry boxes of mail through an irradiation machine, and PNNL researchers have estimated it would take less than 10 minutes to kill the anthrax, depending on the size of the box of mail. On the other hand, for gamma-ray irradiation using Cs-137, pallets of mail (4 ft × 4 ft × 4 ft) could be irradiated in up to five hours using low doses of about 3 million curies or 15 minutes at a dose of 50 million Ci. No facility for this gamma-ray method yet exists, Seiders said.

Work is also being done at PNNL on the use of holographic imaging to aid in detection of anthrax in mail parcels.

Seiders would not comment on the work that PNNL is doing to kill the smallpox virus.

California energy crisis

The quick answer to the question posed in the session's title, "California Electricity Crisis: How Can Nuclear Help?" is, of course, that it can't, because it is currently illegal to build nuclear power plants in California. Furthermore, session chair and former ANS president Bertram Wolfe, a California resident, said he suspects that the state's governor, Gray Davis, is antinuclear. Wolfe said he sent a letter—twice—about nuclear power to Gov. Davis, signed by 15 leading experts, that went unanswered. "So, we don't have . . . a governor in California today that is looking generally . . . at the energy situation and what nuclear power can do," Wolfe said.

Nonetheless, speculating on the impact nuclear power could have had during the California energy crisis—which led to high energy prices and recurring rolling blackouts throughout the state over the past two-and-a-half years—or could have in the coming decades, was the subject at hand.

Although the state's energy problem has abated somewhat, several speakers during the session emphasized that it has not been solved. "In the future and in the present in California, 95 percent of all our generation being built is natural gas," commented 1998–99 ANS President and California resident Ted Quinn. "Governor Davis has been very proud to announce the opening of natural gas generating stations. And it's really a benefit to help us. But, certainly in the long term, it's not the answer."

California legislators, however, appear to think that it is. Nuclear Energy Institute member outreach director Dave Modeen illustrated that point when he recalled a trip he made to the state a year ago. "I happened to be in California last January. And the week I was there there were two decisions," Modeen said. "Two large plants, 600 megawatts each, were voted down by the authorizing agencies because of concerns by the not-in-my-backyard participants. . . . So, even while this issue of the doubling, the tripling, the factor-of-10 increase in energy costs was going on, there was still really a reluctance to try to address, at least from my perception, some of the imbalance, on the part of the policy-makers."

Part of the problem, Modeen said, is that two-thirds of California's current energy mix comes from less than reliable sources. Natural gas, which accounts for 46 percent of the mix, according to Modeen, can suffer from drastic price swings. And hydroelectric sources, accounting for 22 percent of the energy supply in California, Modeen said, are not always available. In other words, California appears to be setting itself up for more problems in the future.

"We realize that the electricity business will continue to experience significant price and supply volatility," Modeen said. "It's just natural. I know in the last five or six months, as the economy has eased, the weather has eased also, and things look a little better in California. That could be a short-term situation. There's really nothing to say that we can't swing back to much of the same situation, even with the restructuring of some of these laws and market rules."

Fast reactors

Carl Walter, a longtime staffer at the University of California's Lawrence Livermore National Laboratory—who now calls himself "a retiree working at Lawrence Livermore"—said the crisis could have been avoided if firm steps had been taken in the 1970s to construct an appropriate sustainable electric power infrastructure. He also added his voice to the chorus, warning that "we must not be led astray by only short-term approaches to the so-called electricity crisis in California. The problem is of vastly greater scope and duration, and no less urgent."

Walter outlined what he believes can be a long-range solution, once the spent fuel disposal problem is solved and California again permits nuclear power plants to be built within its borders. He said the advanced fast reactor with fuel recycling—or FR/FR—is "the solution to our problem in California."

Work on the reactor has been done by GE Nuclear Energy, Argonne National Laboratory, and Burns and Roe Company. GE's design for the Super-PRISM, a liquid sodium-cooled fast reactor, comes closest to fulfilling the vision for the reactor, Walter said.

The FR/FR is passively safe, with a low probability of severe core damage. All the actinides are fissioned, and the long-lived fission products can be transmuted, which means its disposal would not require safeguards, Walter noted. The reactor utilizes uranium two orders of magnitude more efficiently than light-water reactors. And, at anticipated costs of $28 per megawatt-hour, the cost of power is competitive, Walter said, "particularly when you compare it with Governor Davis's secretly awarded contracts of $69 a megawatt hour."

Crisis nonintervention

During his presentation, which drew a hearty round of applause at its conclusion, attorney Dan Fessler, who was president of the California Public Utilities Commission from 1991 to 1996, provided an analysis and timeline of the California energy crisis.

When he took over as president of the CPUC in 1991, energy prices in California were about one-and-a-half times higher than the national average. There was a question, Fessler said, of how long California could sustain its economy—with its higher taxes and high cost of living—especially as its neighbor states enjoyed energy prices below the national average.

At one point, following the end of the Cold War and subsequent "screeching halt on all defense procurement," after which California "began to hemorrhage jobs," it was decided that California could not sustain its economy, Fessler said.

The job of the CPUC has always been to deliver safe, reliable, reasonably priced and environmentally responsible provision of energy. The issue that then faced the state legislature was "the question of reasonable pricing," Fessler said.

"It was decided that . . . it would be in the interest of all consumers, particularly to consumers in California—which was and remains a state that imports the great bulk of its energy during peak periods, either in the form of fuels that are brought in . . . or in the form of electrons over the high-voltage transmission grid from the other western states—to try to promote a transparent competition in generation, wherein a marketplace would be created that would give evidence of what would be the least costly set of generators that could run at any hour and satisfy the demand in California and, more broadly, in the West," Fessler explained.

A spot market for electricity, the first of its kind in the western U.S., was created, called the Power Exchange. "The idea was a fairly simple one," Fessler said. "We would take the transmission assets of California, place them in the hands of a central grid operator, whose responsibility would be to operate the transmission assets so as to facilitate the physical delivery of electricity from the least costly set of generators that could be identified in . . . the Power Exchange."

It was a day-ahead and hour-ahead market for electricity, in which electricity generators would see a day ahead the projections of the state's demand for electricity spelled out over a 24-hour clock, and then they could bid, in one-hour increments, the price that they would charge to supply electricity during that hour, Fessler said.

One of the features of the California Power Exchange, Fessler explained, was that all bidders would be paid the price that was to be awarded to the last increment of supply needed to meet demand. "That was thought to be the real marginal cost of electricity. And with that price signal being sent seven days a week, 24 hours a day, it was thought that over time those price signals would alert individuals as to where opportunities were to build new generation, where transmission constraints were being discovered. And it would focus, therefore, the science plus the economics of our profession . . . upon the true problems in building out an infrastructure that would match a supply needed to meet demand in an efficient manner."

Rather than expose the state to the true movements of supply and demand, however, the state legislature—comprising "very nervous" elected officials—decided that it would order a 10 percent price reduction to be given to all household users of electricity, as well as small industrial, small commercial, and small agriculture users. In other words, voters," Fessler said. "[The] voters would have an immediate 10 percent reduction, sort of as a decree of Caesar Augustus, even as the government was speaking about giving up command and control of price regulation and moving to forces of supply and demand."

According to Fessler, the legislation also capped the amount of money that the utilities could charge for electricity prices during this period, and fixed them at the electricity rates prevailing on January 1, 1996. "They could not charge a higher rate no matter what happened," he added.

In March 1997, the Power Exchange became operational. And during 1997 and 1998, prices on the wholesale market for electricity fell dramatically, not only in California but across the West. "It appeared that our fondest hopes for deregulation and the commitment to market forces was paying substantial dividends," Fessler said, "because one of the provisions that we had put through was that the utilities would have to pass through the wholesale costs of electricity, as found in the Power Exchange, to all California citizens, which meant that the benefits of competition would reach every citizen, from an individual living on a pension alone in a small apartment to the largest user of electricity. That was, to me, one of the prides of what had been accomplished, because it devised a delivery scheme to deliver the benefits as well as the risks of competition to all, on an equal basis.

"Well, obviously, the story, if it had ended there, would be a happy story. But it didn't end there."

In June 1999, on one day, in one hour, a very strange thing happened, Fessler said. The price on the Power Exchange shot up to an astronomical level for the hour-ahead market, and the market cleared at that very high price. But the market receded within the two hours, and thereafter, for about 7 months, there was no problem.

But by spring 2000, price spikes were becoming a persistent problem. Prices in California on the Power Exchange were going up, and they were not just going up during the peak hours of electricity usage. "Peak prices were going up and they were not coming down during periods of the day in which it was thought that electricity prices would normally recede dramatically," Fessler said.

By May, the high prices began to be an endemic problem in California. "Indeed, it can be argued, that by May of the year 2000, what was wrong with the system was fully evident to anyone with public and private sector responsibilities, not only in California, but in Washington, D.C.," Fessler said.

The market had become dysfunctional. Somehow, Fessler explained, significant segments of supply were not bidding into the Power Exchange. "It wasn't that the physical generation was physically disabled. It wasn't that it had picked up and left the Western part of the United States. But it was not being bid in the Power Exchange. Instead it was being bid into the secondary market, which was operated in real time by the independent system operator. The mission of the independent system operator was to keep a constant physical equilibrium between supply and demand, *cost being no object.*"

Its normal function would have been to fill in if there had been a loss of a generator through a physical calamity. But now it was taking up an increasingly large sector of the market—5, 10, 15 percent. "By the time the prices reached their full maturity, nearly 40 percent of the market had moved from the Power Exchange into the last-minute desperate scramble for electricity. Sometimes the scramble wasn't fast enough, and for the first time in 15 years, Californians began to experience blackouts.

"That was May.

"And June," he continued.

"And July."

"And the government did nothing," Fessler whispered.

Consumers were not seeing the price consequences of the high prices being paid in the wholesale market because the legislation had capped the retail rates for electricity. "California therefore moved into this crisis with the consumption of electricity virtually unabated," Fessler said.

Also, Fessler noted, 2000 was, of course, an election year, in which California was a major prize in the election. "And it seemed to me, as a civilian, to be the primary goal of elected officials to make certain that no prices were communicated to the public until after the sixth of November in the year 2000.

"It was on the eighth of November that Governor Davis discovered that California had a problem with electricity."

The difference between what the electric utilities had paid for electricity in the first 11 months of the year, and what they had been allowed to recoup from ratepayers through frozen rates had gone from a $1-billion problem in May to an estimated $14–$16-billion problem, Fessler said.

In response to an audience question, Fessler made the session's most striking point: "We will debate for years what actually went wrong in the last 26, 28 months in California. . . . But here is a solid fact, and it haunts me. At no point in California during the period of time in which the [energy] market was reacting with these grotesque price signals, or in which we were shutting people off from the consumption of electricity, was the imbalance between supply and demand ever in excess of 600 megawatts.

"Now, if SONGS-1 [San Onofre nuclear generating station] had been operating, we would not have had a problem. If Rancho Seco had been on line, we would not have had a problem. If Trojan had been functional—and if you assume that there was adequate transmission capacity, which can be a problem—we would not have had a problem."

Someone in the audience immediately asked, "Have the folks in California been told this?" to which Fessler responded, "No."

50 years of fast reactor knowledge

The session "Passing on Fifty Years of Fast Reactor Knowledge to a New Generation on Nuclear R&D" provided an opportunity to discuss what needs to be done to preserve knowledge in this technology and motivate it to happen. Opening the session, Leon Walters, of Argonne National Laboratory, reminded participants that the decline in fast reactor research and development began with the Carter administration in the mid-1970s. "If we want to recover the information generated over several decades, it would be very difficult," he said. And to compound matters, experienced people have been leaving the workforce, taking a lot of knowledge with them. The only way to reverse the situation would be with a vigorous program and this is not possible, he remarked, at least for some considerable time.


Walters

One impetus for this session was the discovery, during research undertaken on the technical history of EBR-II, that much of the information was on the verge of being lost. Several billions of dollars was spent getting this information, noted Walters, and for a few million more, "we can put it in a state that can be passed on."

Walters had recently made two important contacts, the International Atomic Energy Agency and the DOE's weapons program. With the help of IAEA's Alexander Stanculescu, an Agency "consultancy" (a preliminary meeting to define the scope of a problem and how to approach it) is planned for next spring in Idaho Falls, Idaho, to develop a worldwide plan for preserving fast reactor knowledge. In the meantime, the Reno meeting provided an opportunity to get some of the people together to start exchanging ideas and set the stage for the consultancy.


Stanculescu

Another important discovery was that a knowledge preservation program for weapons technology is already in place. One of the consequences of the ending of both U.S. nuclear weapons testing and weapons development in 1992, was that this community has been experiencing a continuing loss of expertise. But it was able to convince the administration and Congress that this should be viewed as a national security issue, and funding has been made available to undertake a preservation program.

IAEA work

Walters then asked Stanculescu to describe the potential role of the IAEA. He explained that the agency appreciates the need to preserve information and knowledge when, as it expects, the world comes asking for more nuclear power plants. It already has useful resources available, including the International Nuclear Information Systems (INIS) and several nuclear databases. And provided member countries are in favor, said Stanculescu, the agency can provide a number of other services. "We can look around and identify what is being done and act as a catalyst and facilitator," he added. "And we can try to integrate these activities and initiate specific projects with strong member state participation."

The IAEA is already involved in preserving fast reactor data. In 1999, it invited experts to meet to discuss what should be done to start an initiative. The agency is also now working with the OECD Nuclear Energy Agency (NEA), which has a similar activity under way for preservation of experimental neutron physics benchmark data. Generally, NEA will concentrate on thermal reactors and IAEA on fast reactors.

The session then heard presentations on the approaches being taken and the activities under way in several other countries.

Roland Soule, of France's Commissariat à l'Energie Atomique (CEA) described a major project to preserve fast reactor knowledge that began after the government decided to close the 1200-MWe Superphenix reactor. He now has several people working on what appears to be a very user-friendly information system. It was constructed to cover the entire scientific and engineering information requirements of the fast reactor. He mentioned several databases operated by CEA, including SNEDAX, which covers integral fast reactor experiments in zero power facilities. SNEDAX was originally developed at Forschungszentrum Karlsruhe (FzK), in Germany, and includes experimental data from facilities in France, Germany, Japan, Russia, the United Kingdom, and the United States.

A German contribution by Roland Boehme, of FzK (presented by the session co-chair, as the author could not attend), described the history of fast reactor development in Germany, beginning in the 1960s with the zero-power SNEAK facility at FzK. SNEAK was shut down in 1985 when a decision was taken by France, Germany, and the United Kingdom (which operated the ZEBRA facility) to keep only France's Masurca facility going as an international project.

Immediately after the shutdown of SNEAK, work on preserving documentation started. This was completed in 1996 and then transferred to the CEA. Information from the country's fast reactors, including details from the experiments undertaken at the KNK-2 reactor at Karlsruhe, and publications on the Kalkar SNR-300 fast reactor (which was built, but never received an operating license) are stored in the archives of Siemens, now Framatome ANP. No manpower is available for scrutinizing these.

The Japanese situation was described by Yoshio Yokota, of JNC (Japan Nuclear Cycle Development Institute), which still has a very active fast reactor program, although its two power generating plants, Joyo and Monju, are not presently in operation. It also has a comprehensive knowledge preservation program that includes collecting "human" knowledge. This is done by recorded interviews with key staff as they reach retirement and through the preparation of individual "memoirs." Based on this, a computerized "FBR plant design planning system" is being constructed that will include an explanation of each design decision and how the decisions affect each other. Since it is difficult to select what to retain, it preserves all information.

JNC is also proposing a major international knowledge preservation program to be called ISAN, which, besides being an acronym for International Super Archive Network, is, appropriately, Japanese for "legacy." The company hopes that this will provide other countries whose staff have been redeployed or retired with an incentive to put some resources into this activity. It will use the World Wide Web as a means of sharing nonproprietary information.

The Russian program

Visa problems meant that the Russian contributors were unable to attend, and John Graham, of ETCetera Assessments LLP and a past president of ANS, summarized the paper they sent. Russia has an active fast reactor program, which includes plans to extend operation of its BN-600 station to 2020 and to construct an 800-MWe version (BN-800), for which some funds have been raised.

As with other countries, however, its experts are leaving. Some work preserving knowledge is being done—for example, post-irradiation experience has been gathered from the country's three critical facilities and construction of a database is in progress. In addition, some work is under way to gather experience directly from experts. This includes interviews with older specialists and having them produce their memoirs, focusing on specific problems.

Unfortunately, this work has stopped due to lack of funds. This is an activity that would appreciate support from the West. The Institute of Physics and Power Engineering, in Obninsk, has also begun to preserve the private archives of famous scientists (photos, letters, drafts of scientific papers, etc.).

In his own contribution, John Graham imagined it being the year 2050 and the fusion program having just been terminated. "What does it take to recreate a fast reactor technology?" he asked. To get an idea of how big a job this would be, he provided a long list of the types of work that would have to be undertaken. For example, the basic knowledge categories he listed were: R&D, design, fabrication and construction, operation, and decommissioning. Under design, he included general design system criteria and standards; core physics information (through core life); dynamic analysis (normal and off-normal); system design descriptions; safety analysis and reports; beyond design-basis protection; project costs.

Graham then discussed a couple of specific topics of vital importance to fast reactors—thin-walled piping for loop-type fast reactors and sodium boiling—where information and knowledge has been lost. After the Clinch River Breeder Reactor Program was canceled in 1984, the files on the development work done by Westinghouse along with Argonne National Laboratory were boxed and sent for storage in caverns below Pittsburgh with a notation to destroy them in 10 or 15 years. As by that time there was unlikely anyone around to say that the files were worth keeping, he doubts that anything survived. On sodium boiling, he asked the expert in this country, who happened to be in the audience. Graham was told that "his own published papers were stored in his garage, but the Westinghouse files of analysis and data had been destroyed."

Graham concluded that he knows "of no technology which has been fully lost without being superseded by better technology. Fast reactor technology is in danger of being lost just in that way—presently, the compendium of knowledge exists only in Japan and Russia. If those programs are terminated without the knowledge being preserved, then the world will have lost a vital resource. . . . To reconstruct the technology again 50 years hence will cost us 10 to 50 times what it cost 25 years ago, even at modest escalation rates. It is almost already too late to act."

Weapons knowledge preservation

An actual nuclear knowledge preservation program that is in progress was described by William A. Bookless, of Lawrence Livermore National Laboratory. In this case it concerns the DOE's weapons technology program. Bookless remarked that when early-retirement incentives were first offered by the DOE, there was one day that 700 people left the laboratory. This represented more than 10 000 person-years of nuclear weapons experience.

In about 1993, he and a few others got together to consider how to keep the technologies robust for future use, following the dramatic changes that were occurring in the weapons program as production facilities closed and consolidation was in full swing: in 1989, the Rocky Flats plant was closed, and in 1992 all nuclear weapons testing and development stopped. In response, these few people created the nuclear weapons information group, an ad hoc group of experts from different organizations, to discuss the work already going on independently in each. Because it is now seen as a national security issue, this work also gets financial help from government agencies.

In his presentation, Bookless discussed many problems and issues that they had come across. Trying to understand how to transfer knowledge to later generations is a bit more complicated, he warned, than data management. "Data does not represent understanding of anything," he said. Above data, he listed "information," which computers can capture fairly effectively. But that does not capture "knowledge," he said. This requires an understanding of patterns. "Our database systems today cannot understand patterns the way a human being can. Perhaps some day."

In his view, the final goal is the ability is to apply the knowledge to a project—such as building a reactor. The application of that knowledge requires the kind of connectedness that computer databases will not be able to do for a long time. "The only method that has been proven, as far as I am concerned, is the mentoring of people, which involves the actual exercising of our people. We have implemented this at our lab. . . . I believe a constant program is needed that applies the knowledge to real projects, real things to do or we will lose it," he said. This is why sending people to take part in Russian and Japanese programs seemed a good idea to him.

Bookless also talked about the need to create an environment where people feel comfortable to induce them to impart their knowledge. Some people love to talk and hate to write, he said, and others would rather isolate themselves until they have finished writing. "We have had people provide 500-page tomes on one specific design approach where they attempted to write down what we never captured in the past—why we did it," he said. He gave an example of a particular alloy that was chosen for some purpose. While there was good documentation about the alloy, there was no record of why it was chosen—was it because it was ductile, or strong, or cheap, or have minimum of a material that should not be included? "What was the reason we used it?" Only those involved in deciding had those answers, he said. In another case, the key designers of a particular item were brought together. With a model in front of them, they spent many hours discussing each design feature allowing the thought processes involved in coming up with the design to be extracted.

He also provided a lot of other advice. He mentioned that a group at Sandia has captured a structured way of extracting knowledge. They have explored a lot of techniques, such as the use of panels, methods of motivating people, how to ask questions, etc. Regarding information storage, they use formats that are considered "migratable," such as pdf, ASCII and html, which should be available generation after generation. Another thorny issue is sharing proprietary information. "We have been working on this for many years and feel we are getting close," Bookless said.

An FBR session postscript

At the end of the session, the chair told the participants that given the interest shown, he was inviting everyone to join him and several of the speakers on the final day of the meeting to continue the discussion. This extra session provided an opportunity to examine where to go now.

Bookless had more useful advice based on the weapons technology knowledge preservation program. To attract funding, he said, it is necessary to get the message across that it is vital to preserve fast reactor knowledge, as one day it may be needed. He said it was vital to talk to members of high-level commissions and panels—particularly congressionally mandated ones—not only to convince, but to familiarize them with the idea that it is a national security issue and that without it, billions of dollars of knowledge will be lost. This will take many years and a lot of effort. His advice led to a proposal to produce a "white" paper that puts the arguments together. A convincing story is needed with a strong justification, he said. That there are other countries that want to share the burden was considered helpful, he added.

It was generally agreed that preserving the knowledge found in the heads of experts—who know what has been done, why it was done, and what the results are—should have priority, since this sort of information is seldom included in reports and is perishable. It was suggested that there are probably only about 500 people in the world that have the type of experience and knowledge that should be preserved.

The IAEA's Stanculescu also noted that some people want to get a clear vision of what is to be done. "I am afraid we cannot have a clear vision," he said. "If we wait to know how to do it, then we will not get started." The important thing is to get started, he added, and then what needs doing will come out. He was confident that the consultancy meeting, which was tentatively scheduled for the first week of April 2002, will be a step toward a real international effort to preserve fast reactor knowledge. NN

TOPICAL MEETING

Accelerating the transmutation program

A significant roadblock to development of additional nuclear power capacity is the concern over management of the nuclear waste produced by the plants, which requires disposal. Authorized by Congress to begin in fiscal year 2001, the Department of Energy's Advanced Accelerator Applications program was created to address this and other pressing nuclear issues facing the United States, including declining U.S. nuclear infrastructure and global nuclear leadership.

The *Embedded Topical Meeting on Accelerator Applications/Accelerator Driven Transmutation Technology and Applications* was held to discuss many of these concerns. Technical program chair Warren Funk, of the Thomas Jefferson National Accelerator Facility, said the program committee received between 170 and 180 papers, nearly double what they had in the largest previous meeting.

Major points from the session:

- ◆ *Accelerator transmutation can address the waste issue*
- ◆ *Spallation Neutron Source to operate in 2006*

AAA history

The AAA program is developing the technology base for waste transmutation—the nuclear transformation of long-lived radioactive materials into short-lived or nonradioactive materials—and aims to demonstrate its practicality and value for long-term waste management. Both acting associate director for the program, John Herczeg, and director of the AAA program at Los Alamos National Laboratory, Bruce Matthews, provided histories and overviews of the program.

Although there was work on transmutation in the early 1990s at LANL, the actual AAA program did not begin until 2000, Herczeg noted. The program was formed by Congressional directive as a combination of the Accelerator Production of Tritium and the Accelerator Transmutation of Waste programs. The organization over the last year has included several DOE laboratories and sites, including Los Alamos, Argonne, and Savannah River.

"We were required to put a report to Congress in place," Herczeg said. "That report defined that we were to build a facility within 10 years that would cost around $2 billion. Congress looked at that report and decided that that was a little too expensive."

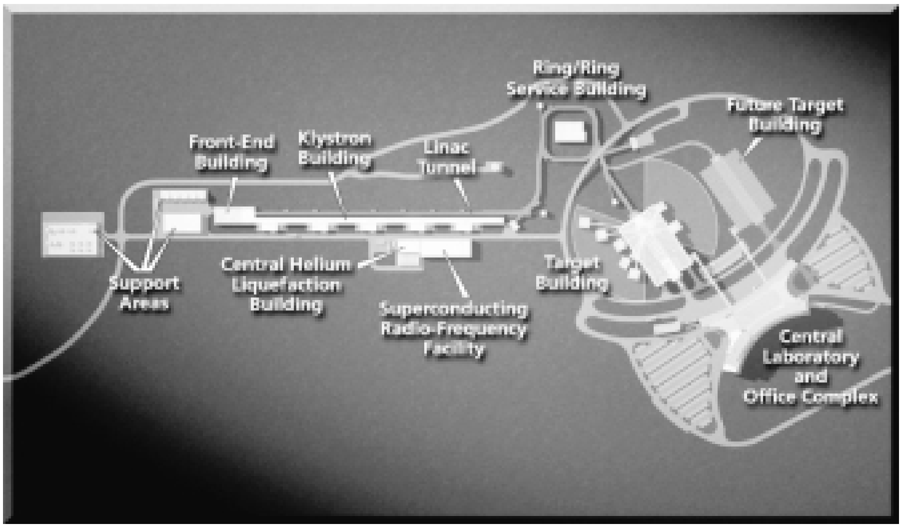
The AAA program has decided to hold back on accelerator development for now, Herczeg said. "We're going to focus on transmutation separations technology. We're still going to maintain the [accelerator] technology. That is, we're going to still do some work in the design of the [accelerator] facility, even if it's preconceptual and at a very low level."

Matthews noted that transmutation is needed because Yucca Mountain would quickly be filled to its statutory limit. "Somewhere—we're guessing 2015—policy-makers in this country are going to have to make a decision whether we go to an alternative strategy or build a new repository if we are going to have nuclear energy as an option. That's really, I think, what the key driver is for this program is and where we fit into the future," he said.

SNS update

The associate laboratory director for the Spallation Neutron Source, Thomas Mason, provided an overview and update of the Spallation Neutron Source, an accelerator-based neutron source that uses spallation, which is under construction in Oak Ridge, Tenn., and set to begin operation in 2006. At 1.4 MW, it will be the world's leading pulsed spallation source and the world's leading facility for neutron scattering, Mason said. "We believe that the capability of this machine will outstrip anything that's currently available, and it's our intention that SNS will be the world's leading facility for neutron scattering."

One of the unusual features of the project, Mason pointed out, is that it is being developed by a consortium of Department of Energy labs. The front end, which includes the ion source and some of the low-energy components of the accelerator, is being developed by Lawrence Berkeley National Laboratory. The linear accelerator, which accelerates H-minus ions up to 1 GeV, is being developed by Los Alamos National Laboratory. The accumulator ring is being developed by Brookhaven National Laboratory, and the mercury target



Site plan of the Spallation Neutron Source (DOE)

by Argonne National Laboratory.

The funding request for the project in FY 2002 was $291.4 million. The bill that has been passed by the House and Senate includes the full request of $291.4 million. “This is a reflection of the fact that the project has very full congressional support,” Mason said. “This is our peak funding year. In ’03 we drop off to $225 million and flatten out. Our eventual operating budget will be about $150 million a year. So, from a political funding point of view, we’re over the hump. . . .

“We still have an awful lot in front of us in terms of getting it done. Nevertheless, the fact that we’ve now finished off a year where our funding was $278 million, going into a year with $291 million means there’s an awful lot going on now in terms of procurements for hardware, awards for construction of buildings, real tangible stuff that gives us confidence that we’re going to get done.”

The project design is about 70 percent complete. Overall, the project is about one-third complete, and that includes all the R&D activities and the design work. In terms of the actual construction, though, the project was about 15 percent complete through the end of September, Mason said. The total project cost is $1.4 billion.

Mason said that significant site construction activities are under way, with good progress on all of the technical components from the front end through the superconducting linac, ring, target, and instruments.

Initial cost and design estimates have been accepted for the last two instruments (a small-angle neutron scattering instrument and a powder diffractometer) of five total that are being built as part of the construction project. “Each one of those [five instruments] has outstanding performance that easily outstrips anything, typically by factors of 20 to 100 in terms of raw throughput,” Mason said.

On the site, the linac tunnel, which is the first accelerator structure, is now greater than 75 percent complete, and the target building foundation is under way. “The target building is the most complicated building on the site,” Mason noted. “The target is a nuclear facility, so it’s complicated from that point of view. It’s also got to accommodate all the experimental apparatus. And it’s the most expensive structure that we’re building, certainly.”

Mason said the facility staff have recently shifted their planning focus from design, which is now fairly stable, to planning for the installation and the hand-off from partner labs to Oak Ridge. He said he expects this next phase to begin next spring.

The need for transmutation

Nobel laureate Burton Richter, chair of a Nuclear Energy Research Advisory Committee group on accelerator transmutation of waste, and director emeritus of the Stanford Linear Accelerator Center, said that transmutation is important and worth researching because of the energy problems throughout the world. “The world’s energy problems are not solvable in an environmentally tolerable way if we keep the same pattern of carbon-based energy supplies as we’re using now. That is totally unsustainable,” Richter cautioned. His presentation focused on why transmutation is needed.

Richter

Richter said carbon-based energy supplies cannot be scaled up to meet the growing world population or the projected increase in per capita gross national product in the developing world, nor can they prevent drastic global climate change. “Without a change in how we get our primary power, we’re heading for an economic catastrophe, an environmental catastrophe, or both,” said Richter, who won the Nobel Prize for physics in 1976.

Much of the problem is due to developments occurring in the underdeveloped world, he said. Only industrialized societies, however, have both the technology and resources to carry out the essential research and development for carbon-free energy alternatives.

Richter noted that the United Nations estimates the current world population to be 6 billion. The U.N. predicts that figure will increase to 9 million in 2050 and to 10.5 billion in 2100. In turn, the world’s primary energy demand grows by a factor of two by 2050, and 3.5 by 2100. “The global environment can’t stand a 350 percent increase in emissions from the world’s existing primary energy sources,” he cautioned.

The energy demand in the developed world or the reforming world (such as the Eastern Bloc) will not be increasing as much as energy demand in the underdeveloped world, Richter said. “We have to take steps in the industrialized world to make carbon-free power practical and available. Because if we don’t, we’re going to see average world temperatures go up. The latest estimate is [an increase of] 6 °C. And while we don’t know what the environmental consequences are going to be, it’s been several hundred million years since the temperature was that high. And the environment is certainly going to be different.”

So, what are the options? The first is nuclear power, Richter said. The second is conservation and efficiency, particularly in the United States, which is the least energy efficient of the industrialized societies. (Richter said the United States uses twice as much energy per dollar as Japan, and one-and-a-half times as much as Europe.)

He noted that nuclear power is the only source of electricity that can immediately start replacing large amounts of carbon-based power. “We can have reliable baseload systems with the current generation of light-water reactors. You could, if you wanted, expand the total amount of energy by 2050 by a factor of five. That requires a coordinated effort to design simple, modular, medium-sized, next-generation reactors, and that is going on now. The Generation IV program I hope is going to come up with something that’s economic and efficient.”

Richter, however, pointed out the usual stumbling block of the public’s irrational fear of radiation. “Every time I show this, people are startled,” Richter said, showing a new view graph. “You get 240 millirem per year from natural radiation, but 40 millirem of that comes form the radioactivity in your own body. . . . There’s a significant amount of radiation that comes in the radioactive potassium and carbon that’s used to produce *you.* On the average, you get 60 millirem from medical [procedures]. You get practically nothing from nuclear power plants. You get about the same amount from coal-fired power plants, but nobody ever expresses any concern about [radiation from] coal-fired plants.”

Richter cited a study from the journal *Risk Analysis* that detailed the public health impacts of various forms of power generation. Nuclear power was ranked second to wind power in having the fewest public health impacts—and both were far better than coal and oil. “If you want to deploy renewable power and have a minimum impact on human health, you either work on wind power or you work on nuclear power. And if you work on anything else, you're working on things that have a bigger health hazard."

Turning to transmutation, Richter said there are four goals that the process has to fulfill in order to be useful and acceptable.

Transmutation has to improve public safety in terms of helping meet both the Environmental Protection Agency's drinking water standard and the Nuclear Regulatory Commission's dose standard. Transmutation can help meet these goals by reducing toxicity of the waste. "But I like to put it in a little more colloquial way: You want to reduce the potential hazards from spent fuel to less than that of uranium, from which it comes, in less than the lifetime of the pyramids," Richter said. "The pyramids are manmade structures. They've been sitting there for 6000 years. I think you can convince the general public that we can build [facilities] at least as good as the ancient Egyptians can."

Transmutation must provide benefits for the repository program. It can do so by potentially simplifying the design of future storage sites, reducing the number of storage sites needed per unit energy, and reducing the volume of waste that goes into the repositories. "I think that people should pay attention to this because it's part of the very important financial question that is going to continue to plague nuclear power," he said.

Transmutation must reduce the risk of proliferation. "In any system that involves transmutation, there is in-process plutonium that has been separated and is in transit, from fabrication to being burned someplace. And you really have to look at how much the increase in short-term risk is balanced by the reduction in long-term risk. That's a policy issue. And nuclear engineers and physicists are not going to make that call. There are other people who are going to make that call, and we have to give them all the information they need."

Last, transmutation must improve the prospects for nuclear power. The public's fear of long-lasting radioactive waste is justified, Richter said. "The general public has good reasons to be skeptical about [long-term radioactive waste]. Nothing has lasted hundreds of thousands of years that we know of. The climate's not the same as it was a hundred thousand years ago. Everything's different. And that's one of the driving forces for transmutation."

Indecision and the excess of methods available for transmutation remains the biggest problem for the technology. "This program cannot afford to pursue all of those options. There are far too many of them," Richter cautioned. "And one of the challenges you face, whether you're worrying about a European or a Japanese or an American R&D program, is to reduce that number of options to something that can be pursued in more depth and doesn't spread everybody too thin. That really has to be an important focus of the next six months to a year."

Entering into a broad-scale international collaboration is the most beneficial step the transmutation community can take right now, Richter said. "It's of interest to everybody to solve this waste problem. Everybody is facing the same funding limits and the same shortage of test facilities. It's to everybody's benefit to share the workload until commercialization of the program. . . . It doesn't make a lot of sense for Europe, Asia, and the United States to duplicate or triplicate the full spectrum of test facilities that are required to go from where we are to a demonstration. I think we have to get together and we have to get a sensible international program going.

"So, a final word. Nuclear power, and possibly wind power, is the only carbon-free system that can make a big impact on CO_2 production in the next 20 years. If the waste disposal is not addressed in a way that's acceptable to the public, nuclear power cannot and will not expand.

"Any plans for handling waste have to go through a lot of R&D. They have to develop an international context because nobody can afford this. . . . And they ought to be integrated into the next-generation reactors.

"What that says is that transmutation R&D is not a sandbox for the science and engineering community," he concluded. "There is a problem that has to be solved, and transmutation is a very important possibility to solve that problem." NN

TOPICAL MEETING

Nuclear criticality safety: Past, present, and future

After opening the *Embedded Topical Meeting on Practical Implementation of Nuclear Criticality Safety*, meeting general chair Stephen Bowman, of Oak Ridge National Laboratory (ORNL), turned the plenary session over to honorary chair Francis Alcorn, senior advisory engineer at BWX Technologies' Nuclear Navy Fuel Division. At 67 years of age, 36 of which he has worked in criticality safety, Alcorn said he still enjoys what he does, although he promised to retire some day.


Alcorn

The plenary looked to the roots of the profession, as well as at current issues and future challenges. Alcorn used the opportunity to name and thank 70 people for their contributions to criticality safety. This very personal nod to the past led him naturally to the first speaker, Norm Pruvost, of the Criticality Safety Information Resource Center (CSIRC), who described the making of a set of videos that recorded the discussions during two special conferences devoted to the heritage of criticality safety. The first, the Criticality Heritage Video 2000 Conference, was held September 18–20, 2000, at Los Alamos National Laboratory (LANL), and the second at ORNL, May 21–23, 2001. He also showed two 10 minute excerpts from the many hours of taped discussions.

Pruvost explained that they were not just interested in preserving records and papers. "We decided it was also time to capture some of the people involved [and] . . . we wanted to have them in 'three dimensions,' particularly for some of the young people who will not have a chance for a direct contact with these people." So he and several colleagues organized the heritage conferences at which pioneers of criticality safety were videotaped, discussing subjects of interest in the field.

To explain what was meant by heritage, Pruvost said: "I took the arbitrary starting date as February 11, 1939, and ending at January 19, 1975. The first . . . corresponds with the publishing in *Nature* of the letter titled 'Disintegration of Uranium by Neutrons: A New Type of Nuclear Reaction,' by Lise Meitner and Otto Frisch, in which the word fission first appeared in nuclear science context. The ending point . . . was the last day of the Atomic Energy Commission."

The past versus the present

One of the particular aims of the conferences was to contrast the criticality safety accomplishments of the Heritage period with developments since. For example, some senior experts believe that current criticality safety finds itself addressing insignificant concerns while serious concerns go unattended. This is partly due to an over-reliance on regulations and regulators, as opposed to the more practical efforts of experts whose experience and know-how have provided high standards of safety for decades.

The pioneers selected were Hugh Paxton and Dave Smith, of LANL, and Dixon Callihan, of ORNL, who joined their respective labs in the 1940s, and Joe Thomas, who only came to ORNL in 1953. Some young specialists were included at the conferences to ask the pioneers to elaborate on specific issues that interested them. The sessions covered a range of topics, including major events, like the 1958 criticality accidents at Los Alamos and Oak Ridge, and areas where the pioneers felt some confusion existed, such as the distinction between reactor safety and criticality safety and the double-contingency principle.

Following some interest from medical people, sessions were added to the Los Alamos conference in which specialists with experience or medical knowledge of criticality accidents—including the JCO incident in Japan where two people died—discussed how to proceed in assessing the treatment for victims of criticality accidents. Another session focused on the development of the American Nuclear Society standards for criticality safety. Other topics covered included the interaction between criticality experts and operational personnel, changes in the regulatory structure, and early calculational methods used before big computers were available.

While the video project looked at heritage, the next presentation, by the Department of Energy's Jerry McKamy, took the subject to the next phase, explaining how over the past two decades, criticality safety arrived at its current position. In his talk, the "Evolution of Criticality Safety Requirements," he began by noting that there is really only one requirement: Avoid criticality.

To explain why the regulatory requirements have expanded so much, despite there not being a criticality incident in the United States since 1978, McKamy described how other drivers, including public attitudes, national nuclear policies, and external events, have affected the regulatory environment.

McKamy listed the main criticality events in the U.S.:

- In 1945, the first criticality incident (at Los Alamos).
- In 1958, the first fatality due to a criticality accident.
- In 1964, the second and last fatality due to a criticality accident.
- In 1978, the last criticality incident.

In 1964, McKamy said, the development of national consensus standards began, and as there have been no further fatalities in the United States and no criticality incidents since 1978, the application of the standards has been quite successful.

Other events, however, have led to more regulation, notably the TMI accident in 1979 and Chernobyl in 1986, and the publication of a 1986 report by the National Research Council that criticized the DOE's handling of reactor safety. According to McKamy, criticality safety, although not identified as a particular concern, was swept up along with those that were, and, unfortunately, featured quite prominently in the development of new rules.

He described the shift from the time when experienced criticality experts drove safety through the national consensus standards, to when the regulators led it. During what he called the expert period (which is close to the Heritage era), the specialists tended to have long careers at sites that would all have their own critical mass laboratories for testing. These experts, he said, applied their test results and experience creatively to the processes in hand. And they shared their experiences.

The shift was particularly noticeable with the introduction of new regulations, as well as of legal, civil, and criminal penalties for violation of requirements. He gave examples of "shoulds" used in guidance documents being changed into "shalls." Regulations also became more complex and required more criticality controls. "This despite the fact that there were no criticality incidents since 1978," he reminded the audience. Another environmental change was a growth in the number of people and agencies needing or wanting to be informed about criticality safety procedures. McKamy said he now has to coach his staff on how to present its work to various stakeholders. The level of paperwork needed has grown by a factor of about 100. There was also a growing compliance mentality.

"We are now trying to manage everything reactor-like," he said. "We were safety driven, now we want to minimize liability. Then we had risk acceptance, now we are risk averse." In the past, the goal had been to do something

Major points from the session:

- *A concern to preserve records and expertise*
- *Insignificant concerns vs. serious concerns*
- *A shift from being expert-driven to more regulation*
- *Challenges: Risk assessment, communication, technical competence*

productive—e.g., operate a reactor, move and process fuel. Criticality safety was then defined, explained McKamy, as the art and science of operating fissile systems while maintaining subcriticality under all reasonably credible conditions. The processes are not safer in this new era, he said, but they are all more expensive.

The next speaker, Christa Reed, also registered her concern about the regulation culture. While some criticality safety controls are in place to protect against a criticality, she said, "some, quite frankly, are in place because we want to avoid regulatory violations, some are in place because of regulations or license requirements." When these kinds of controls go wrong, nuclear criticality safety (NCS) managers can find themselves in the "awkward position of trying to explain why a control wasn't really important to criticality safety."

New challenges

Reed, manager of NCS at BWXT's Naval Fuel Division, described the new challenges faced in criticality safety and how best to respond to them. The ones she featured were assessing risk, communication, and maintaining technically competent staff.

An increase in understanding of risk and how it is assessed is essential, Reed said, as regulation shifts from being compliance-based to risk-informed and performance- based. She particularly pointed to the difficulty in reconciling an approach to safety based on a risk-informed assessment and the use of the double contingency. "As we move more and more to the risk-informed paradigm . . . we are challenged to ensure that different approaches, especially quantitative in nature, are meaningful, are capable of being consistent with double contingency, and do not distract our limited NCS resources from other more valuable duties, such as walking the process floor."

Commercial demands are also presenting challenges for NCS. As an example, she pointed to the drive for improved economic performance, which has led to a demand by process companies for more operational flexibility (such as the use of bigger tanks, increased throughput, etc.), and reduced margins; these present challenges to criticality experts to support and justify such measures with the current experimental data available. Another example is the push to introduce new and better reactor technologies, such as the pebble bed modular high-temperature reactors, which requires parallel efforts for demonstrating criticality safety.

She also pointed to the challenge of improving communication, which is not there just to frustrate the expert. Her favorite illustration of how times have changed is the report of an assessment that she came across in some old files. The assessment, which had been carried out by a criticality expert, consisted of two sentences: "The evaluation is complete. Call me for the limits." Jargon is also an obvious issue. Explaining that the analysis "applied the double contingency principle" is unlikely to improve understanding, she remarked. Nor is the explanation, "I incorporated sufficient factors of safety to require at least two independent, unlikely, and concurrent changes in process conditions before a criticality would be possible." One of today's challenges is "to close the understanding gap between an NCS expert and regulator, or an NCS expert and plant management, or an NCS expert and operator, or even an NCS expert and the public."

On human resource issues, Reed said that "technically competent staff is the single most important factor affecting success." The statistics are startling, she said: The supply of undergraduate nuclear engineers is at a 35-year low. This is coupled with an outflow of experienced workers. Current projections indicate that 76 percent of the nation's professional nuclear work force can retire within five years. She also noted that 30 percent of BWXT's NCS engineers could retire today. "The bottom line is that we are losing expertise, and along with it, valuable institutional knowledge. This is a reality."

She also warned about the difficulty of training people in criticality safety: It cannot be done by checklists. "Learning criticality safety takes time, with guidance from an experienced engineer."

But she was not totally disheartened. Reed told the audience that like Alcorn, she also has a list of 70 people. "They all have 10 or less years of experience and are willing, capable, and eager to face the challenges of today and the future." NN