IAEA GENERAL CONFERENCE

Nonproliferation remains main issue

Other issues addressed at the IAEA's 49th General Conference were the reemergence of nuclear power, the nuclear fuel cycle, and health and safety.

WHILE ABLE TO look forward to a reemergence of nuclear energy, the 49th General Conference of the International Atomic Energy Agency (IAEA) was held September 26–30 in Vienna, with proliferation issues, particularly involving North Korea and Iran, at the top of the agenda. The problem was made clear in the message presented for UN Secretary-General Kofi Annan by Nobuyasu Abe, UN under secretary-general for disarmament affairs, which described the World Summit in New York two weeks earlier as a failure for not meeting the challenge of strengthening the Nuclear Non-Proliferation Treaty (NPT). "States were not able even to reaffirm existing commitments, or find a way forward even at the level of principles," Annan's statement said.

Reflecting the difficult world environment, the statement continued, "We must also come to terms with the fact that developments in the nuclear fuel cycle have led to proliferation risks that were not fully envisioned when the NPT was established 35 years ago. In this context, I believe that the work of the Expert Group on Multilateral Approaches to the Nuclear Fuel Cycle must be followed up. Their February report suggested multilateral options for improved controls over the proliferation-sensitive portions of the nuclear fuel cycle while preserving assurances of supply and services."

One UN success Annan pointed to in his statement was the adoption by the UN General Assembly in April of the International Convention on the Suppression of Acts of Nuclear Terrorism. The convention details offenses related to the unlawful possession and use of radioactive material and the unlawful use or damage of nuclear facilities. Under it, countries are required to criminalize these offenses and to adopt appropriate measures to protect radioactive material.

Before the start of business, the General Conference first confirmed the appointment of Director General Mohamed ElBaradei to a third term, elected Horacio Bazoberry Otero, Bolivia's ambassador to Austria and resident representative to the IAEA, as general conference president, and approved Belize's application for IAEA membership.

ElBaradei: At the podium with General Conference President Horacio Bazoberry Otero (at right), Bolivia's ambassador to Austria (Photo: IAEA)

ElBaradei looks to the future

"Nuclear power is reemerging in a way that few would have predicted just a few years ago," said IAEA Director General Mohamed ElBaradei in his annual summary to the conference. Fast-growing global energy demands, an increased emphasis on the security of energy supply, and the risk of climate change—along with sustained improvements in performance—are driving a new consideration of this source of power in many quarters, he said.

Near-term nuclear growth remains centered in Asia and eastern Europe, which together account for 22 of the 24 units now under construction. Russia intends to double its nuclear generating capacity by 2020, China plans nearly a sixfold expansion in capacity by the same date, and India anticipates a tenfold increase by 2022. Some developing countries, such as Indonesia and Vietnam, are also moving steadily forward with plans for nuclear power investment.

In pushing the nuclear agenda, the IAEA has taken the lead in the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), which has close ties to the Generation IV program. Among other goals, INPRO is developing a methodology to assess the safety, security, proliferation resistance, and waste management capabilities of new designs. The methodology is now being applied, ElBaradei said, in many different contexts. For example, Argentina is using the INPRO methodology to evaluate the introduction of nuclear power in a system with limited grid capacity, India is applying it to analyze nuclear systems for hydrogen generation, and China, France, India, the Republic of Korea, and the Russian Federation are applying INPRO methods in a joint study of a closed fuel cycle using fast reactors.

Continued

ElBaradei also noted progress in other innovative projects, including the following:

- Several innovative and evolutionary approaches are moving toward implementation under the Generation IV International Forum.
- Russia has licensed the KLT-40, a 60-MW reactor design that can be floated and transported by barge, that takes advantage of Russian experience with nuclear-powered icebreakers and submarines, and that can also be used for district heating.
- The Republic of Korea intends to construct by 2008 a one-fifth–scale demonstration plant of its 330-MWe SMART pressurized water reactor, which will also include a demonstration desalination facility.
- South Africa recently approved initial funding for developing a demonstration unit of the 168-MWe gas-cooled Pebble Bed Modular Reactor (PBMR), to be commissioned around 2010.

Support is also growing for the development of multilateral approaches to both the front and back end of the nuclear fuel cycle, as ElBaradei has been advocating for many years. Since the expert group he established to explore options for multilateral control of fuel cycle facilities issued its report in February, a number of initiatives have been introduced. The uranium industry and the World Nuclear Association have set up a working group to explore the concept of fuel assurances. The United States has been developing a proposal on providing "reliable access to nuclear fuel," working with principal suppliers, for countries that agree to forgo independent enrichment and reprocessing facilities. And the Nuclear Threat Initiative is working on a strategy that would help the IAEA set up an actual fuel bank.

Nuclear security and verification

On the IAEA's verification activities, which provide assurances that countries are meeting their Nuclear Non-Proliferation Treaty (NPT) obligations, "We have clearly made progress on some fronts, but perhaps regressed on others," ElBaradei said. "The lack of agreement at the 2005 NPT Review Conference . . . put the spotlight on an unprecedented array of challenges to the nonproliferation and arms control regime."

But, he said, he believes that overall, the agency's system has shown great resourcefulness and resiliency in dealing with many of these challenges. "We have rapidly initiated intensive verification efforts in a number of countries and investigated the illicit procurement network. We have strengthened the verification system through enhanced use of satellite imagery, environmental sampling, and a variety of new technologies—as well as through the development of enhanced information analysis techniques, the introduction of integrated safeguards, and the transition towards a more qualitative, information-based system. And perhaps most importantly, in dealing with these verification challenges, we have maintained our objectivity and independence, and thereby strengthened our credibility. In short, the past few years have continued to underscore the central importance of the agency's role in combating proliferation."

ElBaradei also noted the July agreement by the parties to the Convention on the Physical Protection of Nuclear Material on major changes to strengthen the convention. These changes make it legally binding to protect nuclear facilities and material in peaceful domestic use, storage, and transport. They also provide for expanded cooperation among countries on measures to recover stolen or smuggled nuclear material, to mitigate the consequences of sabotage, and to prevent and combat related offenses.

Health and safety

A new approach to the way the IAEA works is having an important impact on a major health program aimed at helping developing countries where the number of cancer cases is rising more rapidly than in the West. Setting the scene, ElBaradei noted that access to life-saving radiotherapy is in many areas limited or nonexistent. By way of comparison, he said, consider that in Austria, there is approximately one radiotherapy machine for every 270 000 people, whereas in most African countries, the ratio is about one machine for every *10 million* people, and some countries have no such facilities. The agency's Program of Action for Cancer Therapy (PACT; *NN,* Dec. 2004, p. 47) includes the mobilization of resources from nongovernmental institutions, which is a new venture for the agency. Efforts have been directed at assembling needed expertise and seeking partnerships with key organizations. ElBaradei noted that he had received a letter from the director general of the World Health Organization (WHO) on beginning a discussion on the feasibility of developing a joint program with the IAEA in this area. Addressing the challenge of cancer is an intrinsically multidisciplinary effort, he said. "We seek to build a coordinated, holistic approach that would include all aspects of cancer control, including prevention, detection, diagnosis, treatment, and palliative care."

"We seek to build a coordinated, holistic approach that would include all aspects of cancer control, including prevention, detection, diagnosis, treatment, and palliative care."

ElBaradei noted several other achievements in the IAEA's safety and development programs:

- With India's ratification of the Convention on Nuclear Safety earlier this year, every country with operating nuclear power plants is now a party. The convention, now with 56 contracting parties, is becoming a forum for increasingly substantive discussions on safety issues.
- The use of the agency's safety review services continues to grow as more countries with developed nuclear programs, including Belgium, Germany, Japan, the Republic of Korea, Russia, and the United States, are requesting Operational Safety Review Team (OSART) missions. The publication of OSART highlights and the development of a Web site on OSART good practices have become new mechanisms for sharing technical information and lessons learned.
- Consensus has recently been reached on the safety requirements for the geological disposal of radioactive waste, and the IAEA Board of Governors approved the new safety standard at its meeting held September 19–23. The use of this standard and its supporting guidance will facilitate the licensing process for geological disposal facilities. The IAEA is continuing to work on harmonizing approaches and guidance on assessing the safety of disposal facilities for low-level radioactive waste.
- Public concerns about security have led to the refusal of shipping organizations to take medical radioactive materials. The secretariat is continuing its efforts to reverse this through meeting with commercial carriers, regulatory authorities, and relevant UN organizations.
- The IAEA's International Nuclear Information System (INIS) has been expanding at a record pace, with over 100 000 bibliographic records and more than 250 000 electronic full-text documents added last year alone. Students at 273 universities now have free access to the INIS database, and the system has grown to nearly 1 million authorized users.

A personal view for the future

This year, as he is to start a new term in office, ElBaradei said he wanted to outline his own vision for the next four years, which includes the following:

■ Expansion of the IAEA's capacity to offer energy assessment services, which help governments develop their own capacities for national energy analysis and energy planning. These services, which treat all energy options equally, are in especially high demand in developing countries and transition economies. The agency develops planning models tailored to each country's special circumstances. IAEA energy planning tools are now used in more than 100 countries around the world.

■ An increase in the nuclear community's creativity in developing regional approaches to energy needs. Such approaches could be useful in addressing many issues that have made nuclear energy impractical for developing countries, including electrical grid capacity, upfront capital costs, infrastructure and workforce needs, design certification, licensing, operation and maintenance, and safety regulation.

■ Benefits to the IAEA from partnerships for strategic or financial reasons. For example, in the PACT cancer treatment effort, establishing a partnership with WHO has been crucial—not only because of the added expertise and cancer-prevention emphasis WHO can provide, but also because the IAEA is far less known for its health programs, and a joint IAEA-WHO program would add credibility to the PACT effort as the agency seeks to attract funding from private foundations.

■ Stopping the dissemination of sensitive fuel cycle activities and developing a framework for multilateral management of such activities, which are key to strengthening the nonproliferation regime. ElBaradei suggested that an urgent first step would be to create an international framework for assuring the supply of reactor technology and nuclear fuel—for all countries, for use in nuclear energy generation—to be followed by a framework for multilateral management.

Another recent ElBaradei priority has been improving public awareness of the work of the IAEA. In 2001, he called for increased public outreach—with the media, nongovernmental organizations, and opinion leaders—to explain what the agency has achieved. "Little did I realize at that time," he said, "the degree of public exposure we were to receive." In the four intervening years, he noted, the agency's public image has been transformed—in large part because of emergent nonproliferation issues, but also because of the IAEA's successful efforts to raise public awareness of its important work. Besides stepping up its Internet presence, he said, "We have revitalized our public seminar program, holding fewer seminars but making them more dynamic and targeting a more focused audience. We have continued a series of public service announcements on television. And we have conducted a series of media campaigns on important topics, including nuclear security, radiotherapy, nuclear power, and—earlier this month—the Chernobyl Forum report" [*NN,* Sept. 2005, p. 46]. Regarding the last item, ElBaradei noted that the report, "Chernobyl's Legacy," issued in September, has gone a long way toward setting the record straight. Based on the best scientific analysis, it reflects the consensus achieved among the relevant United Nations agencies and programs and the governments of Belarus, Russia, and Ukraine.

ElBaradei said that the results of these efforts have been extraordinary. The IAEA has moved in the public domain from being a relatively unknown agency to a trusted institution that plays a crucial role in both security and development.

U.S.: An ambitious agenda

"My government," said U.S. Ambassador Gregory L. Schulte, "believes that nuclear power will—that it *must*—play an enlarged role to meet the global demand for clean, affordable, safe, and reliable sources of energy." Schulte was speaking in place of Secretary of Energy Samuel Bodman, who had to remain in the United States to deal with energy-related problems following the recent hurricanes.

The opening statement by Schulte focused on several critical issues, including Iran, the U.S. nuclear security agenda, and international cooperation. He also made some announcements, including one about the establishment of an enriched fuel reserve to ensure that states renouncing enrichment and reprocessing will have access to fuel for civilian nuclear power reactors. Schulte also announced that the United States will join the IAEA's INPRO project and put out an invitation from the U.S. Nuclear Regulatory Commission for other countries to join a multinational design approval program.

Iran, the ambassador said, has created a crisis by abusing the Nuclear Non-Proliferation Treaty (NPT) and concealing its nuclear ambitions. The recent resolution of the IAEA Board of Governors accusing Iran of noncompliance with its obligations under the NPT allows the board to bring the matter to the UN Security Council. This, Schulte said, sends a clear message that Iran's actions are isolating it from the international community and that Iran must take action to come into compliance with its international obligations and to give the world confidence that its nuclear programs are truly peaceful.

The United States stands behind the initiative of the EU-3 (Britain, France, and Germany) on Iran, he said. "Their proposal respects Iran's desire to use nuclear energy for civil purposes, as President Bush reaffirmed on September 14, but first requests that Iran agree not to pursue the development of enrichment and reprocessing capabilities. . . . These capabilities are neither necessary—given Iran's massive oil and gas reserves—nor are they legitimate—given Iran's long record of safeguards violations."

It is this long history of deception and concealment that forfeits Iran's right to peaceful nuclear cooperation, he said. "Iran is a special case that requires special measures to ensure the international community that Iran will not subvert so-called 'peaceful use' for military ends." Iranian leaders, he said, should take immediate steps to reimpose the suspension of its enrichment and reprocessing programs and return to negotiations with the EU-3.

Schulte stressed U.S. support for the IAEA in this. Iran must provide the IAEA proactive cooperation and transparency and choose a course of negotiation and confidence-building rather than continued confrontation, he said.

U.S. security agenda

In the wake of the conflict with Iran, limiting access to enrichment and reprocessing technology has risen up the U.S. nuclear security agenda. To ensure that states renouncing enrichment and reprocessing have reliable access to fuel for civil nuclear power reactors, Schulte said, "We are working with major suppliers and the IAEA on a back-up supply mechanism for states that forgo investment in indigenous enrichment or reprocessing capability. . . . With this in mind, we are pleased to announce that the U.S. Department of Energy will reserve up to 17 metric tons of highly enriched uranium for this effort." This will be done as an IAEA verifiable assured fuel supply arrangement from materials previously declared excess to national security needs. "We will also consider placing additional

"[The U.S.] government believes that nuclear power will—that it *must*—play an enlarged role to meet the global demand for clean, affordable, safe, and reliable sources of energy."

uranium that will soon be removed from our military stockpile in this reserve, and are examining other possible sources," he said. "We encourage other nations to join us in this initiative."

A further goal must be to phaseout the commercial use of high-enriched uranium (HEU). Nearly 40 U.S.-supplied research reactors have been converted from HEU to a low-enriched form of fuel (LEU) that cannot be used in weapons. The United States has also launched a similar initiative with Russia. Schulte also said that the United States is prepared to join with others in establishing new international guidelines on the management of HEU. Such guidelines, he said, should involve all HEU users and the IAEA, and they should incorporate requirements for the accounting and reporting of national stocks of civilian HEU, for strict standards for physical protection, for converting all remaining HEU reactors and isotope production to LEU, and for designing new civilian research reactors to use only LEU.

"[B]ringing India into the mainstream of the international nuclear nonproliferation community will strengthen the overall nonproliferation regime."

Another part of the nuclear security agenda holds that states must fully exercise their responsibility to regulate nuclear activities under their jurisdiction and control. That is a primary purpose of the recently adopted UN Security Resolution 1540, which obligates states to enact strict internal and external controls against proliferation and to secure facilities and weapons-usable materials. "The implementation of this resolution is an immediate priority," Schulte said.

International cooperation

Schulte also stressed the United States' commitment to helping responsible governments develop peaceful nuclear programs "without placing unreasonable conditions on them." If nuclear energy is to have a future, he said, all countries must have the capability to minimize the risks of an accident, or of terrorist sabotage or diversion.

It was in precisely this spirit that the United States entered into a new relationship with India that should, he said, make an important contribution to global stability, democracy, prosperity, and peace. Under this historic agreement, the United States will work to achieve full civil nuclear energy cooperation with India in return for India's reciprocal commitment to assume the same responsibilities and practices as other leading nations with advanced nuclear technology. "We all benefit from increased collaboration and cooperation with India's civil nuclear community. At the same time, bringing India into the mainstream of the international nuclear nonproliferation community will strengthen the overall nonproliferation regime."—*Dick Kovan*

U.S. to join INPRO

U.S. Secretary of Energy Samuel Bodman, in a videotaped message to the IAEA General Conference, announced that the United States would join the IAEA-led International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). The decision is expected not only to strengthen the project—currently made up of 22 country members and the European Commission—but also to further boost collaboration between it and the Generation IV International Forum (GIF) of 10 countries, which is led by the United States.

The relationship between INPRO and GIF has warmed considerably in the past months. Officials of the two and the agency discussed possible synergies at a brief liaison meeting during the IAEA's General Conference last year. In April of this year, agency officials attended the GIF policy group meeting, where it was agreed that a workshop-type meeting should be held to discuss collaboration on a larger scale. This meeting took place September 20–21, just prior to the most recent GIF policy group meeting on September 24 in Manchester, England. The meeting was attended by 12 GIF representatives and 20–25 from INPRO and IAEA programs concerned with nuclear technologies for the future.

"This was the first occasion when so many GIF members came to the agency specifically to discuss the collaboration issue," Akira Omoto, IAEA director of the nuclear power division and overall manager of INPRO, told *Nuclear News*. "On the first day, each side explained what it is doing, and the IAEA explained the relevance of its activities that could assist future reactor and fuel cycle technologies. We discussed issues of economic modeling, proliferation resistance, physical protection, nuclear safety, and sustainability and infrastructure, the areas in which GIF has working groups."

Omoto said that on the second day the meeting split into four groups—economics, proliferation resistance, security, and infrastructure and sustainability—and each group made specific recommendations on how the two projects might work together synergetically in the future. On a cautionary note, he pointed out that when it comes to technology development, a great deal is protected by international property rights.

"Basically, the results of IAEA activities are made available to the public through technical documents. But I don't think that detailed content will be disclosed in this area. GIF technological development results cannot be expected to be transferred to INPRO, and then disclosed. But in the methodology area, and in other areas such as infrastructure and sustainability, we think there are many things where we can work together. We found the two activities were very complementary."

Both "recognized ample scope for synergy," Omoto said, because GIF is focused on R&D (for selected reactors), and INPRO is focused primarily on the methodology and analytical tools to assess the viability of innovative nuclear systems. INPRO's aim is to prepare for nuclear power development and deployment to contribute to energy needs around the middle of the 21st century, with an emphasis on developing countries, rather than to develop new technologies itself, he said.

INPRO briefing

During the General Conference, Robert Facer, acting head of the nuclear power technology development section and an INPRO coordinator, briefed conference delegates on the project's activities. Facer said the key activity remains continuous refinement and upgrading of the INPRO methodology (developed and validated by the project two years ago) to assess innovative nuclear systems in a holistic way.

Facer explained that the aim of the methodology is to enable prospective users of innovative systems to study them in terms of each of six different areas—economics, safety, proliferation resistance, environmental impact, waste management, and infrastructure—and to identify how different designs match up against their conditions, and the advantages and difficulties that may be associated with the deployment of the designs. "The methodology . . . also may help future development of systems, that is, what research needs to be done and how the project can help coordinate and cooperate with others to do that," he added.

In the economics area, Facer said that plants must be affordable and financing must be available. When expressed in user-requirement terms, this means that the cost would be compatible with the user's needs and that finances could be raised. Also, important for those putting up the financing, the risk of applying the system must be acceptable in any of the many market environments relating to energy development around the world.

Continued

In the area of proliferation resistance, two basic principles were identified, he said. First, innovative power generation systems should be unattractive to would-be national proliferators, as they would be difficult to use to produce weapons. This is largely a technological feature. The second, recognizing that technology cannot solve everything, is that the designs support extrinsic systems that make it easy to monitor and supervise operations, with nonproliferation in mind.

In the safety area, Facer said that INPRO is not trying to replace the massive program and safety standards of the IAEA, but is looking at fundamental issues such as having many layers of protection and, where possible, systems that would be inherently safe. One target spelled out was that systems could be sited in very similar locations to those of other energy-producing systems. Another basic principle was that the level of confidence in safety should be demonstrable.

"In the area of the environment, we want to ensure that the adverse effects of operating an innovative nuclear system are still acceptable and, in terms of sustainability, that nonrenewable resources are used effectively," Facer said.

In terms of waste management, Facer pointed to the following four basic principles: waste generation is minimized, acceptable levels of environmental effects are achieved, environmental burdens are not carried over to future generations, and the implications of all the steps in the production of electricity or other energy are considered.

In the infrastructure area, the project had only one basic principle: that the design enable any country that wished to adopt it to be able to do so without an excessive extra investment in the national infrastructure. "Countries who are technology holders should have an interest to get the infrastructure [of buyer countries] organized so that they could sell with confidence, and the technology users would want to adopt systems without massive investment. So vendors and users must work together," Facer said.

Currently, the methodology is being applied to assess the viability of systems being developed in different countries. "In the future we will develop analytical tools to facilitate and coordinate cooperative development together with other international initiatives like GIF, and also with other activities within the agency such as with small and medium reactors, fast reactors, and nonelectrical applications that relate to and interface with INPRO. Then we will look to see cooperation between developed and developing countries, in research and development and potentially in deployment of different systems. The United States is interested in a study on infrastructure, because infrastructure can be just as innovative as any other part of the technology," Facer said. *—Gamini Seneviratne*

"...[W]e want to ensure that the adverse effects of operating an innovative nuclear system are still acceptable and, in terms of sustainability, that nonrenewable resources are used effectively."

IAEA SCIENTIFIC FORUM

Nuclear's scientific role: Beyond power production

The two-day Scientific Forum, now a regular event held alongside the International Atomic Energy Agency (IAEA) General Conference, this year focused on the theme "Nuclear Science: Physics Helping the World." Director General Mohamed ElBaradei noted that the subject commemorates the 100th anniversary of Albert Einstein's groundbreaking papers on the theory of relativity, the photoelectric effect, and the theory of Brownian motion, and forum chairman, Nobel Laureate Burton Richter, who is director emeritus of the Stanford Linear Accelerator Center, said, "Looking backward in time, there is no problem in demonstrating that physics not only has helped the world, but is fundamental to the world today." The forum's four half-day sessions covered the topics of meeting energy needs, developing advanced materials and technologies, advancing radiation medicine, and supporting nuclear safety.

In Richter's keynote address to the first session, "Meeting Energy Needs," he recognized a nuclear energy renaissance, which he said is being driven by two loosely coupled needs—to supply economic growth worldwide and to mitigate greenhouse gases from fossil fuels—which feed on each other to exacerbate climate change and global warming. Both of these point to the need for large-scale, carbon-free energy, he said, and nuclear energy is part of the solution.

Even top environmentalists are becoming reconciled to nuclear energy's being less problematic to live with than global warming, noted Richter. Cost savings will come with series production, and will be competitive after a time, but there will be no significant growth until people are convinced that nuclear energy generation is safe and that it will not lead to weapons proliferation, and that radioactive wastes can be disposed of.

Safety is amenable to technology and regulation, said Richter, and the spent fuel problem is mainly with the last 1 percent,

Richter: Physics is fundamental to the world today (Photo: IAEA)

which contains plutonium and minor actinides. The two ways to protect the public from this high-toxicity long-life mix are isolation for a very long time and destruction by neutron bombardment. He noted that the "once-through" system, which relies on isolation, does not seem workable in a world of expanded nuclear power use, and the alternative, then, is reprocessing.

Richter described France's reprocessing system—separating plutonium from spent fuel, mixing it with uranium to make mixed-oxide (MOX) fuel, sending the leftover uranium for enrichment, and vitrifying the fission fragments and minor actinides for repository emplacement—as the most developed. Its plan, he said, is to keep the spent MOX fuel unreprocessed until there are commercial fast-spectrum reactors. In principle, only fission fragments, which must be stored for only a few hundred years, would go to a repository, Richter said. There are fast reactor (and fuel) problems that need to be resolved before this is made practicable, he noted.

Richter devoted much time to the issue of proliferation prevention, which will become more complex with nuclear energy expansion. Science and technology alone cannot solve the proliferation problem, he said, although it can produce the tools for better surveillance and detection. International safeguards need to be better funded to generate and apply them, and, he added, the only way to limit proliferation by nations is through binding treaties, effective inspection, deterrence, and, ultimately, effective sanctions.

The address of Yevgeny P. Velikhov, president of Russia's Kurchatov Institute, was confidently titled "Industrial Production of Fusion Energy Will Be the Next Step." The recent decision to build the International Thermonuclear Experimental Reactor (ITER) is a major step forward, he said, following more than 50 years of work by international researchers who started essentially from scratch. Controlled fusion's built-in advantages include abundance and accessibility of fuel resources, safety assurance that a noncontrolled excursion is not possible in the reactor, a low content of radioactive materials in wastes, and long-lived components.

Velikhov

Velikhov noted that ITER is expected to resolve, in an integrated way, all feasibility issues (other than materials) required to define a demonstration fusion power plant aimed to be operational in mid-century. ITER, he said, is not the only mode to fusion energy production, and others may be proved applicable in the next few years, meaning that several demonstration plants could be set up roughly in parallel. International collaboration in fusion has a long history and must continue. Velikhov called for the creation of an international organization to control fusion energy production, thereby reducing the risks of unapproved technology dissemination and proliferation.

Jiangang Li, of China's Academy of Science at the Institute of Plasma Physics, said that fusion is urgently needed for developing countries such as China and India, which have very few options for large-scale sustainable energy generation, and must be developed as quickly as possible, together with international efforts. World energy demand is expected to double in 40 years, he noted, and an even larger increase is needed to lift the world out of poverty. China's coal-centered energy structure will remain until mid-century, he said, and energy demand will quadruple, to 4 billion tonnes coal equivalent in the next three to four decades as China becomes a "moderately developed" country.

Li explained that hydropower has grown rapidly over the past five years, but the many hydrogen and renewable energy programs are too small-scale. Nuclear fission is regarded as a "transition solution," he said. Currently, six plants produce a total of 8.7 gigawatts. Social, safety, and environ-

mental problems, as well as technical difficulties, must be resolved quickly to install hundreds of gigawatts of capacity, he added, and fissile fuels will eventually be exhausted. "Therefore, it is crucial and urgent for China to realize controlled nuclear fusion energy for our long-term development as early as possible," Li said.

Advanced materials

Opening the second session, "Developing Advanced Materials and Technologies," the director of India's Bhabha Atomic Research Centre, Srikumar Banerjee, said that both achievement of better performance of the current generation of nuclear reactors and the realization of advanced reactor concepts demand better materials. Physical metallurgy and materials science principles are applied to meet the exacting requirements of fuels, structural materials, and many components of nuclear systems, he said, and the incentive to improve traditional fuels is primarily to achieve higher average core burnup. The development of advanced fuels such as mixed oxide, mixed carbide, nitride, silicide, and dispersion fuels should help better utilize fissile and fertile inventories via innovative fuel cycles, he added.

Banerjee talked about development of zirconium-based alloys, for cladding and pressure tube applications in terms of their metallurgy, fabrication methods, and in-reactor degradation mechanisms, as well as in-service inspection. Regarding radiation embrittlement of reactor pressure vessels (RPV), he compared Western and Eastern specifications for RPV steels. The search for new materials that can withstand higher rates of radiation-induced atomic displacement has led to swelling-resistant austenitic and ferritic stainless steels—such as the D-9 steel for India's fast breeder reactor—for fast reactor applications.

In summing up, Banerjee spoke of "increasing demands on materials with respect to higher operating temperatures, higher fuel burnup, structural integrity at higher fluence, and reduced radiotoxicity. He said that research and development in physical metallurgy and materials science—to optimize manufacturing routes, identify and understand aging degradation, and establish structure-property correlations—is key to developing more forgiving materials.

Sueo Machi, of the Atomic Energy Commission of Japan and a former IAEA deputy director general of nuclear sciences and applications, said that the economic scale of radiation applications in industry, medical care, and agriculture is as significant as nuclear power in Japan and the United States. The major application tool for industry and health care is now the electron accelerator, he said, the reliability of which has greatly improved in recent decades. Some 13 000 machines have been installed worldwide, he noted, with about 1200 used for industrial applications. Their use for sterilization of medical products and food packaging, as well as for cleaning exhaust gases and wastewater for environmental protection, is also growing, he observed.

The major application tool for industry and health care is now the electron accelerator, the reliability of which has greatly improved in recent decades.

The upgrading of polymers by radiation cross-linking and grafting by electron beams is used extensively, mainly for producing high-quality automobile tires, heat-resistant wires, and heat-shrinkable materials, Machi said. Electron accelerators are used to produce functional polymers such as battery separators, deodorant fibers, and hydrogel wound-dressing, he added, and very low-energy (20–100-keV) electron accelerators are used for the curing of surface coatings, with no organic solvent emissions.

More than 1000 ion accelerators are now widely used in Japan for ion implantation for semiconductor production and surface modification, and the world's first medical ion accelerator, located in Japan, has proved, with more than 2000 clinical tests, that it could provide highly effective radiotherapy for cancer. Synchrotron orbital radiation is used for materials research, he said, and new accelerator-based spallation neutron sources, which produce extremely high-flux neutrons in pulsed mode that are not available from reactor-based sources, are now under construction in Japan, the United Kingdom, and the United States.

Ralph Eichler, of Switzerland's Paul Scherer Institute, suggested that the most commonly perceived benefits to society from nuclear and particle physics derives from particle beam technology. Charged particle accelerators play an increasingly larger part in industrial and medical applications, he said, and neutrons produced with high-power proton accelerators in a spallation process are used in applications ranging from basic research, to radiography in the automotive industry, to transmutation of highly radioactive fission products. Eichler said that acceleration of ultra-cold neutrons provides intense and almost monoenergetic neutrons to study soft matter, and that detailed understanding of ion physics at low energy has allowed the design of compact—almost tabletop-size—accelerator mass spectroscopy. He noted that such a compact device, able to measure concentrations of specific radioactive isotopes even below natural radioactivity, is close to commercialization.

Roland Schenkel, acting director general of the European Commission's Joint Research Centre, said nuclear measurements play a fundamental role in the development of nuclear technology. A recent highlight in basic physics is related to nuclear fission and transmutation with high-intensity lasers, he observed, and ultra-fast high intensity lasers could produce high-energy protons and accelerate them so that they can in turn produce high-energy neutrons. These laser experiments, he said, have opened up new possibilities for making nuclear measurements in the laboratory without using nuclear reactors or particle accelerators.

Radiation medicine

The third session, titled "Advancing Radiation Medicine," focused on the diagnosis and treatment of cancer with the use of ionizing radiation. Wolfgang Schlegel, of the German Cancer Research Center in Heidelberg, spoke of the introduction over the last 30 years of three-dimensional imaging with X-ray computerized tomography and magnetic resonance imaging to characterize tumor morphology and improve delineation of target (tumor) volumes. He noted that the need to assess and correct temporal alterations in the volumes is leading to image-guided radiotherapy (IGRT), aiming to detect deformations and movement during radiotherapy fractions (interfractional IGRT) and beam delivery (intrafractional IGRT). He said that the need to gate or track the radiation beam to correct for the changes has in turn led to time-adapted radiotherapy, a technical challenge now being explored.

Another emerging innovation that Schlegel discussed is biological adaptive radiotherapy, the response to the knowledge that a tumor is not homogeneous tissue that requires homogeneous dose delivery, as had previously been supposed. It is now known that a tumor may consist of various subvolumes with different biological properties, he said, and new methods to characterize these properties and enable delivery of appropriate inhomogeneous dose distributions are being developed, such as functional magnetic resonance imaging using new traces for positron emission tomography (PET) and functional magnetic resonance imaging.

Rockwell Mackie, of the University of Wisconsin, discussed treatment delivery methodologies that have emerged in the past two decades, the first of which is stereotactic radiosurgery, or stereotactic radiography, based on multiple beams focusing on a single location. He said that intensity-modulated radiation therapy (IMRT), which uses computer optimization to determine beam delivery intensity maps to maximize target coverage and minimize damage of critical tissues, is the newest. Variability in the setup of the patient and movement of organs is probably what has limited radiation therapy success in the past, he observed, but with the newfound ability of IMRT to put high dose gradients between the tumor and critical tissue, these issues are being addressed with the installation of imaging systems in the treatment room itself.

Mackie said radiation therapy is a bargain compared with other types of therapy, such as surgery or chemotherapy, in the developed world. The cost of the treatment delivery equipment is about 15–20 percent of the treatment budget, and only 10–15 percent in a comprehensive cancer center.

Maria-Ester Brandan, of the Instituto de Fisica in Mexico City, said the practice of medicine today is intimately tied to technological developments. Adoption of advanced techniques such as digital radiology, PET, or IMRT involves investments that some institutions are willing to pay, she noted, but the essential human resources are not always taken into account. Efficient use of medical equipment demands a new generation of medical physicists, she declared.

Fidel Diaz-Balart, Cuba's presidential adviser on atomic science, addressed the interface of nuclear science and biotechnology. He noted that Cuba has developed pharmaceutical drugs, vaccines, and diagnostic and therapeutic agents by combining the two, notably in the form of a specific cancer vaccine licensed by the U.S. Food and Drug Administration.

Supporting nuclear safety

"Supporting Nuclear Safety" was the title of the fourth session of the forum, which was moderated by former NRC Chairman Richard Meserve, president of the Carnegie Institution in Washington, D.C., and chairman of the IAEA International Nuclear Safety Group. In a keynote address to the session, Meserve argued that it is time to revisit and rethink the global safety regime. Nuclear energy is contributing a great deal to human well-being, he said, and promises to grow in response to climate change. But growth is hindered by public concerns about safety, he noted, even though the recent safety record is good and plant-based safety indicators are impressive and reassuring.

Continued

Nonetheless, Meserve said, confidence-sapping events continue to occur worldwide, even in countries with extensive operating experience and strong regulatory capabilities. Every country's nuclear program is effectively hostage to safety performance elsewhere, he noted, and construction and servicing of nuclear power plants is becoming a global enterprise. The inherent efficiencies and safety advantages of this should not be undermined by needless national limitations, he said, adding that there is also the "simple reality" that everybody has plenty to learn from each other. Meserve spelled out in some detail his suggested five possible changes to the existing safety regime, as follows:

1. Be more effective, open, and universal in sharing experience, not just about design deficiencies and "near-miss" events but also about low-level operational events, the analyses of which could show how serious accidents could be avoided.

Every country's nuclear program is effectively hostage to safety performance elsewhere, and construction and servicing of nuclear power plants is becoming a global enterprise.

2. Harmonize national safety regulations so that minimum requirements are met everywhere. IAEA safety guidelines would be the acceptable norm to be applied where practicable and at the same time the guides themselves would evolve, on the one hand to promote global consensus on fundamental principles, and on the other hand to provide unambiguous guidance on safety goals for new plants and improvements for old plants.
3. Encourage essential characteristics beyond standards, primarily a cluster of organizational and individual elements that make up safety culture.
4. Strengthen the obligations under the international convention on nuclear safety. The current peer review process needs to be more probing, Meserve said, and perhaps the IAEA should be given authority to verify that recommendations of its safety missions are implemented.
5. Establish multinational design approval programs.

"These are not revolutionary changes," Meserve said. "They build on both current international cooperative efforts and national systems that have served us well."

Comments from two other speakers were also noteworthy. Jacques-Emmanuel Saulnier, senior vice president of communications for Areva, described his organization's position on safety and communication with the public, noting that Areva's corporate attitude in essence is to "take full responsibilities, listen and reach out to the public, dialogue without avoiding any issues, [and] be transparent." And Jim Ellis, president and chief executive officer of the Institute of Nuclear Power Operations (INPO), spoke about safety from the operator's perspective, quoting a Cameroonian proverb to synthesize his message: "Rain does not fall on one rooftop alone"—meaning that "we are all in this together." He said that ensuring that safety has the overriding priority is woven into the fabric of all INPO activities.—*Gamini Seneviratne* NN