The Role of Nuclear Power in Offsetting Global Warming

by John L. Roeder

With mounting concern about global warming from carbon dioxide emissions from fossil fuel combustion, the role of nuclear energy in America's energy future is undergoing a reassessment in many quarters. Although the accidents at Three Mile Island in 1979 and at Chernobyl in 1986 have held back further growth in the number of American nuclear power plants, existing plants have operated in recent years at greater capacity and have thereby increased the amount of electric energy they have produced, and they emit no greenhouse gases. It was against this backdrop that Washington and Lee University and The Council on Foreign Relations sponsored a workshop to examine "The Role of Nuclear Power" at the University on 20-24 June 2007, under the leadership of Washington and Lee Chemistry Professor Frank Settle and Charles Ferguson of the Council on Foreign Relations.

Ritch Characterizes Uranium as "Ubiquitous"

The opening night keynote address was given by John Ritch, Director General of the World Nuclear Association (also President Clinton's Ambassador to the International Atomic Energy Agency (IAEA)). Ritch chose as his title "The Necessity of Nuclear Power: A Global Human and Environmental Imperative."

It was as Clinton's Ambassador to the IAEA that he first saw the connection between nuclear energy and global warming, Ritch began. Today, he said, many nations are looking to nuclear energy not only as a way to meet the threat of global warming but also as a means to energy security. Ritch added that he sees global warming -- and pollution from unprecedented energy consumption -- as the greatest threat ever faced by planet Earth, and that the Kyoto Protocol, if fully enforced, would only make a dent in it. By 2050, we must reduce greenhouse gas emissions by 60% if we are to meet this threat.

The alternative, resulting from "business as usual," will be catastrophic climate change and rising sea level, Ritch went on, and both will fundamentally disrupt human civilization. Citing James Lovelock's *The Revenge of Gaia*, Ritch derisively observed that this "business as usual" was a spike in human population and activity over the past 200 years -- within a much longer timeframe for the universe, for life, even for humans. The explosion of this spike threatens humanity's future by counteracting the conditions that enabled it to come into being. And today's population increase exaggerates the difference in living standards, best indicated by access to electricity. A third of the world's population, Ritch lamented, has no access to electricity and is vulnerable to water shortage. Another third has only limited access to electricity and faces future water vulnerability.

The "middle third" of the world's population, Ritch continued, are accelerating their need for energy. In the future their energy demand will outstrip that of the wealthy who are now the largest energy consumers, and they will determine the degree of climate change. Ritch said that he could see only nuclear energy being able to meet this accelerating demand without increasing greenhouse gas emission to the point of inducing catastrophic climate change. Many nations, he said, are recognizing this, and he added his expectation that Italy would reverse its anti-nuclear course any day soon.

Yet, Ritch went on, nuclear energy is not yet growing fast enough to meet the world's environmental needs. And he said this with full knowledge of criticisms about the danger of nuclear proliferation, lack of safety of nuclear power plant operation, and the lack of permanent nuclear waste disposal. With regard to the last, Ritch pointed out that nuclear waste is both "minimal and manageable." With regard to terrorist radioactive releases, Ritch expects them to come from a hospital rather than a nuclear reactor, because of nuclear power plant security and physical strength.

Ritch was more concerned that nuclear opponents are now harping on shortages of nuclear fuel, operators, and fabrication capacity. Among nuclear fuels, Ritch included both thorium and plutonium (in addition to uranium), and he noted that operators can be trained as the reactor is being built; he also cited Asia's capacity to fabricate nuclear reactor parts. But a nuclear renaissance (a term that was to experience frequent use at the workshop) requires governmental support, Ritch added. This governmental support is necessary to 1) move beyond Kyoto in establishing a scheme to ward off global warming, while acknowledging equity in emissions rights, 2) elevate nuclear investment to a national and international priority (twenty-first century reactors have still not been built in sufficient numbers to demonstrate their economy of scale, he pointed out, adding that the United Nations needs to be "brought up to speed" on this), and 3) build the nuclear profession worldwide (Ritch's World Nuclear University stands ready to do this).

"If history is a river, we have reached the white water," Ritch said, expressing by analogy his concern about the catastrophic effects of global warming which he felt would clearly ensue if there is no nuclear renaissance. He likened nuclear energy's ability to save the world to that which Winston Churchill attributed to nuclear weapons in World War II.

The ensuing question period elicited disagreements with Ritch based on Brice Smith's *Insurmountable Risks*, reviewed by Hugh Haskell (who was one of the workshop participants) in our Winter 2007 issue. Ritch responded with concern about emotive language opposed to nuclear energy. He felt there was no other non-emission energy source that could provide the world's needed emission-free energy. In response to those who cited the finiteness of nuclear fuel in the ground, Ritch said it was "ubiquitous."

I later asked Ritch, "Can nuclear energy alone ward off global warming?" In response, he admitted willingness to whatever non-emissive assistance he could get from conservation or renewables but appeared not to see any reason to depend on them. In fact, in response to another question, Ritch spoke about fielding 10,000 reactors worldwide rather than the 2500 talked about by Smith and Arjun Makhijani in a reading, "Nuclear is Not the Way," which we had been provided from the Wilson Quarterly. (The number 2500 had been determined by Smith and

Makhijani as the number of nuclear reactors needed by 2050 to keep pace with the growth in demand for electricity without increasing carbon dioxide emissions.).

When I cited Hoffert's group's assessment of being able to stave off global warming for only decades, at most, with known uranium deposits (*Science*, **298**, 981-987 (1 Nov 02), described in both Winter 2004 and Spring 2005 issues), Ritch responded that the supply of any mineral is always a matter of decades but that as time goes on, more resources are discovered, along with more efficient technologies for extracting them.

Williams Compares Nuclear with Carbon Sequestration and Wind

Clearly, Ritch had staked out one extreme of the spectrum of the degree to which nuclear energy can offset catastrophic climate change resulting from global warming. The remainder of the workshop would see many other speakers placed at more moderate points on that spectrum. The first of these was Robert Williams of the Princeton Environmental Institute, who spoke on "Nuclear Power and Alternatives in Mitigating Climate Change."

There is much evidence that climate change mitigation is now a high priority in most political circles, also interest in reviving nuclear energy because of its climate change mitigation potential, Williams began. He also noted the ability of the nuclear power industry to grow at the rate of 37%/year in the two decades prior to 1977 and added that such a capacity for rapid growth is key to instituting an alternative to coal -- now. Yet, Williams recognized, nuclear needs to overcome the loss of confidence from both the public and investors, also concerns about proliferation and terrorism. The latter, he felt, are more serious than the former.

Warding off climate change requires leveling off carbon dioxide emissions at 2005 levels (rather than doubling them by 2055) -- 7 gigatons of carbon (GtC) per year -- followed by a decline thereafter. In the language of Pacala and Socolow (*Science*, **305**, 968-972 (13 Aug 04), described in both Fall 2004 and Spring 2005 issues), this requires seven 25 GtC "wedges" -- and 700 gigawatts of nuclear power, provided by 14 1-GW plants per year over 50 years, for a total of 700 plants, would provide one wedge. (4900 plants would provide all seven wedges, about half the 10,000 envisioned by Ritch.)

Supplying wedges to offset global warming by nuclear power plants requires replacing an "unraveling nonproliferation regime," Williams noted, yet he also cited reasons for cautious optimism, including increased concern and awareness about nuclear proliferation, and more recent visions of a world without nuclear weapons, which in effect would resurrect the premise of the Acheson-Lilienthal Report, which Williams and Harold Feiveson (a later speaker at the workshop) advocated in Energy Policy (1990).

Williams also considered two well-understood competitive alternatives to a nuclear renaissance to provide a "wedge" against climate change:

Carbon Dioxide Storage: Here Williams cited the injection of carbon dioxide into the Sleipner oil field in the North Sea. He said that 70 equivalents of this per year for 50 years are needed to produce one wedge. Much of this is already planned, Williams noted, including precombustion capture of carbon dioxide from gasification of coal for use in integrated gasification combined cycle (IGCC) systems (in which the carbon capture adds 2¢/kWh). Some of the carbon dioxide is to be stored in saline aquifers, and other carbon dioxide to enhance oil recovery. Already 30 MtC/yr have already been injected, accounting for 4% of US oil production, Williams added. To do this we have 3000 km of pipelines in the US dedicated to moving carbon dioxide, he said.

The cost of carbon capture in an IGCC system is equivalent to a tax of $106 for every ton of carbon vented, Williams continued, and nuclear power could be generated at the same cost. Carbon capture and storage, he added, can mitigate climate change up to 55% and reduce the mitigation cost by at least 30%. Williams said that it is estimated that the world can store more than 2000 GtC, about 80 times the 2002 emissions of 24 GtC.

He added that the recently-released MIT study on The Future of Coal indicates that carbon dioxide emissions can be stabilized with a sufficiently high carbon tax, largely through reduced use of coal. It is in the interest of the coal industry, he said, to pursue carbon capture and storage. There will, he conceded, be leakage of carbon dioxide stored underground, and we should also pursue learning about leakage and how to mitigate against it.

Wind Electricity: Williams observed that wind energy has grown at the same high growth rate as nuclear in its heyday. Seventy times the presently-installed wind power is needed to produce one "wedge." Unfortunately, Williams lamented, wind power is both intermittent and remote. Thus, it requires a backup energy source (compressed air, hydro, advanced battery, or flywheel, although compressed air "wins" by virtue of its lowest storage costs, and two are already operating, one in Germany, one in Alabama). Williams added that wind with compressed air energy storage backup is only slightly more expensive than the IGCC, and its dispatch costs are lower.

In determining which alternatives should be chosen for the seven "wedges," Williams felt that government should pick the "losers," but that the market should determine the "winners." Most technologies decrease in cost over time, he noted, but this has not been true for nuclear energy in France, where the government picked the "winner."

Wolfson Emphasizes "Nuclear Difference"

For those participants less initiated into the basic nuclear physics called "Fission Fundamentals," Richard Wolfson of Middlebury College provided them in a very engaging manner. Wolfson also emphasized what he called the "nuclear difference" -- namely, that while one fissioning nucleus of uranium-235 releases 200 million electron volts of energy, the combustion of one carbon atom to make a molecule of carbon dioxide releases only 4 electron volts in the burning of coal. Einstein's equation $E = mc^2$ is operative in both cases, he observed, but the reduction in mass from reactants to products is much greater in nuclear fission than in chemical reactions, so a lot more chemicals have to react to produce the same energy output. As a result, coal-burning power plants need to be "fed" two trainloads of coal a day, while a nuclear power plant requires only a couple of truckloads per year. A favorable by-product of this result is that nuclear fuel requires less mining and fuel transportation to meet the needs of a nuclear power plant.

Feiveson Cites Dual Use of Nuclear Materials and Technology

The next speaker, Harold "Hal" Feiveson, of Princeton University's Woodrow Wilson School, addressed "The Nuclear Nonproliferation Scheme." Feiveson began by observing that 3 kg of uranium-235 or plutonium-239 could energize a medium-size city for a day or provide a 50 kiloton nuclear weapon. That is to say, the same materials and the same technology are required for making nuclear weapons as for operating nuclear power plants. The gas centrifuges that can enrich uranium for a larger number of power plants to 3-4% uranium-235 can also enrich uranium to more than 80% uranium-235 for a smaller number of bombs. Feiveson also discounted the efficacy of "contaminating" reprocessed plutonium with highly-radioactive isotopes to make it "less attractive" to would-be nuclear proliferators: this "contamination" doesn't increase the plutonium's critical mass much, he said.

One solution could be to place all nuclear fuel preparation and disposal under international control. In this regard, Feiveson noted that Russia had expressed an interest in being an international enrichment center.

Ganthner Discusses Present and Future Reactor Designs

Speaking on "Reactor Fundamentals," Ray Ganthner of AREVA (formerly Babcock and Wilcox) noted that the world demand for uranium has now caught up to its supply. This, plus flooding of Canada's Cigar Lake uranium mine have caused the price to escalate to $130 per kilogram.

Ganthner also spoke to new "generation III" reactor designs (also reported in our Spring 2005 issue), aimed to improve safety, streamline design and operation, and reduce cost. Ganthner also noted that they updated technology as well -- that from generation II reactors currently in operation dates from the 1960s. Under the provisions of the 2005 Energy Policy Act, these generation III reactors (and their "generation IV" successors) stood to benefit, up to 6000 MW generating capacity, from a rebate of $18/MWh for all non carbon producing energy technologies that had not yet been commercialized. This act also promises government-guaranteed loans and insurance against inability to license a plant.

Keeping Track of "Generations" of Nuclear Power Plants

generation I: early small reactors, with less than 200 MWe generation capacity
generation II: nuclear reactors currently operating in the US
generation III: newer reactor designs which have been recently certified
generation IV: designs beyond generation III for improved safety and economy

Gordon-Hagerty Considers the "Before" and "After" for Nuclear Reactor Fuel

Discussing "The Nuclear Fuel Cycle," Lisa Gordon-Hagerty, now President of her own consulting firm, spoke about what happens to nuclear fuel before it enters a reactor and what happens after it leaves. Uranium enrichment is now done (by smaller and less energy-demanding gas centrifuges rather than the gigantic energy-hogging gaseous diffusion barriers that enriched our uranium in earlier years) by the United States Enrichment Corporation (USEC) in Paducah, KY; and the gaseous uranium hexafluoride input to the Paducah centrifuges is produced from "yellow cake" (U_3O_8) at a plant operated by Honeywell ConverDyn in Metropolis, IL. Uranium fuel fabrication is done by General Electric/Global Nuclear Fuel. Additional nuclear power plants would require additional conversion, enrichment, and fabrication facilities, Gordon-Hagerty noted.

The present world supply of uranium is sufficient for more than 85 years, Gordon-Hagerty stated. But at ten times the current price, she expected that 300 times as much uranium could be extracted. Gordon-Hagerty's final remarks concerned the Megatons to Megawatts treaty between the US and Russia. Under the provisions of this 20-year treaty, the US (via USEC) pays Russians to convert fissile material from nuclear warheads into reactor fuel. This employs Russian scientists and engineers and insures dismantling of the Russian nuclear arsenal. Half of US reactor fuel comes from the program, Gordon-Hagerty said.

Sproat Describes the Final Resting Place for Nuclear Waste

Next Edward "Ward" Sproat, Director of the Office of Civilian Radioactive Waste Management, US Department of Energy, addressed what is intended to be the last stop for spent nuclear fuel after it leaves a reactor, "The Yucca Mountain Repository for Nuclear Waste." After Sproat retired from Eskom in 2002 after working on gas-cooled pebble bed reactors in South Africa, Sproat told us that he wanted to make a bigger difference in enabling nuclear to be part of the future US energy mix. He described several ways in which pebble bed reactors differ from the light water reactors that are the staple of the US commercial nuclear power industry. Instead of being cooled by water, they are cooled by helium gas. And instead of encasing their fuel in zirconium rods, pebble bed reactors have their fuel present in 6 cm diameter carbon covered "pebbles," formed from "kernels" of uranium dioxide coated with carbon-containing substances, with carbon serving as the moderator. The same types of control rods as in light water reactors are also present. The heated helium coolant is used to turn a turbine directly, thus increasing the reactor's efficiency -- up to 47%. These pebble bed reactors are envisioned in 140 MWe modules. They do not melt down and require no cooling condenser, hence no exhaust towers. And since the helium coolant can be heated to 950^{o}C, the temperature at which water molecules can be dissociated, pebble bed reactors can also be used to produce hydrogen fuel.

Sproat told us that he wanted to get Congressional approval to build a pebble bed reactor in the US to produce hydrogen fuel, but he failed to get it. Instead, he came to his present position, appointed to it by President Bush, in 2006, clearly another way in which he could "make a bigger difference in enabling nuclear to be part of the future US energy mix."

There are presently 121 sites storing 53,440 megatons spent nuclear fuel or high level radioactive waste as of December 2005, all of which is supposed to end up at the eventual Yucca Mountain Repository, which is to house commercial spent fuel, radioactive waste from defense complex cleanup, naval reactor spent fuel, and spent fuel from DOE foreign research reactors. Unfortunately, the present design for the Yucca Mountain Repository has a legal limit of 70,000 megatons, which Sproat said would be reached by 2010, although he added that an amendment has been submitted to Congress to allow the NRC to decide the limit).

Sproat pointed out that the origin of the Yucca Mountain Repository dates back to the 1982 Nuclear Waste Policy Act, which established that nuclear waste generators should fund the disposal of their waste and required DOE to make contracts with power plant owners to accept responsibility for it in 1998. Clearly, this deadline has not been met, and this failure has already been the basis of a suit that Exelon has won against DOE in court. The earliest that Yucca Mountain can begin accepting nuclear waste is 2017, Sproat said, and he feels that it may be as late as 2021.

Sproat continued his chronology by observing that in 1987 Congress eliminated other potential nuclear waste sites in favor of Yucca Mountain, and in 2002 they overruled the veto of the governor of Nevada to make Yucca Mountain the "official" site of the nuclear waste repository. Still, Sproat added, the site must be licensed, and the license application will go to the NRC by the end of June 2008. After that, the NRC has three years to act, with a fourth if needed. Sproat said that he anticipated a seven-year process, to include time for litigation. He noted that much of this time will be needed, because this type of licensing has never been requested before. He added that the host county, Nye County, favors the project because of its economic benefits.

The waste to be stored at Yucca Mountain, Sproat explained, will be in solid form, in containers with inner and outer barriers, at a depth of 1000 feet, which is also 1000 feet above the water table. Most of the transport would be by rail, he added, since the casks are too massive for truck transportation.

A continuous stream of future nuclear waste is assured by the number of reactor license renewals. Already 39 have been renewed, and applications for an additional 12 plants are under review, with the owners of 27 more expressing intention to file similar applications. This could assure continued operation of 78 of the present 104 nuclear power reactors in the US, and US utilities have also expressed interest in constructing around 30 new plants. Sproat acknowledged that many consider the opening of Yucca Mountain to be the key to a nuclear renaissance, but he would like to see the repository open before a nuclear renaissance occurs.

Sproat added that the emplacement of waste at the Yucca Mountain Repository is required by law to be retrievable for its first 50 years and that the Repository is being evaluated for several eventualities over the next million years -- with models of monsoon rains, glaciers, and water injected under the repository.

There was also a time for participants in the workshop to share some of what they have done regarding nuclear issues. Janie Johnson from Los Alamos National Laboratory described an activity which modeled the assembly of drums for storage at the Waste Isolation Pilot Project

(WIPP) in New Mexico. Hugh Haskell made a PowerPoint presentation advocating a resurrection of the Acheson-Lilienthal report: there are no threats to use nuclear weapons against, he asserted. And Kai-Henrick Barth, mindful of the problem posed by Iran regarding the proliferation of nuclear weapons, presented his thesis that Iranian scientists are the drivers of Iranian nuclear enrichment.

NRC Historian Recounts Three Mile Island Accident

The next speaker was NRC historian Sam Walker, who focused on the "History of the Three Mile Island Accident," the subject of a recent book he had authored (*Three Mile Island* (U. Cal., Berkeley, 2004)). Although Walker joined NRC just after this accident, he spoke about it with a great deal of knowledge, characterizing it as a watershed event that divided the history of commercial nuclear power in the US into two distinct eras. He emphasized that we needed to stay mindful of this if there is to be a nuclear renaissance in the US.

Two especially noteworthy aspects of Walker's presentation were his citation of errors in documentaries about the Three Mile Island accident and the interjection by Peter Bradford that the accident at Chernobyl (which didn't have a containment like that at Three Mile Island) would have breached the containment at Three Mile Island. (Bradford, invited as a speaker at the workshop, was a Nuclear Regulatory Commissioner at the time of the Three Mile Island accident.)

The French Nuclear Energy Program

Speaking next was Christian Nadal, President of Electricite de France International, on "History of Nuclear Power in France." Although France's Superphénix fast breeder reactor was shut down in 1998, France still reprocesses spent reactor fuel to produce mixed (uranium and plutonium) oxide fuel for second use in its reactors (in order to reduce the amount of plutonium in the final waste product). The site of the repository for waste from French spent nuclear fuel has been selected in the eastern part of France, Nadal told us, but it has not yet been implemented. The storage there will be retrievable, he added.

Fetter Presents Nuclear Energy Economics

While other speakers had addressed the other three "canonical" issues related to nuclear energy -- safety, nuclear waste, and nonproliferation – Steve Fetter, Dean of the University of Maryland School of Public Policy, spoke to the economics of nuclear energy. A histogram he presented of costs (in $/MWh, the same as ¢/kWh) for 99 US reactors showed a peak at $45 with a "standard deviation" of $15, a maximum of $140, and an average of $50. But the first plants were not the most expensive, Fetter noted, as one might expect. Fetter stated that the MIT Study, *The Future of Nuclear Power* (cited by Hugh Haskell in his review of Brice Smith's *Insurmountable Risks* in our Winter 2007 issue and available at <http://web.mit.edu/nuclearpower/pdf/>) forecasts $40 (per MWh) for construction, $15 for non-fuel operations and maintenance, and $5 for fuel for a new US nuclear reactor. But since the last nuclear power plant to be ordered and built was ordered in 1974, we have no recent experience in constructing nuclear reactors in the US to serve as a test of the licensing process. (Fetter also emphasized that construction time is key to construction costs. The cheapest plants were built in four years, the most expensive in 20 years.)

Fetter showed the following comparison of electric energy costs from various sources (all in $/MWh):

Energy source	Nuclear	Coal	Gas	Wind	Solar
Capital	50	30	12	60	250
Operation and maintenance	15	5	3	10	5
Fuel	5	10	25-50	0	0
Total	70	45	40-65	70	255
$100/ton Carbon tax	0	25	12	0	0
Total w/Carbon tax	70	70	52-77	70	255

Clearly, with a carbon tax in place, both wind and nuclear are competitive with coal and gas for generating electricity. And with the added $18/MWh rebate for not previously commercialized technologies for noncarbon sources under the 2005 Energy Policy Act, they could be made even more competitive. However, Fetter noted that for intermittent renewable sources like wind and solar, backup must be added and included if they contribute more than 10% to the total energy mix.

Reprocessing and recycling nuclear fuel -- as is done in France and intended in Japan -- is more expensive, Fetter said, costing between $1.50 and $4 per MWh, but this added cost could reach "break even" if the cost of uranium increases enough. In fact, he said, increased uranium costs could also justify fast breeder reactors, but he felt that the benefits would be more than offset by higher construction costs. In any case, he said, the cost of uranium would have to exceed the present price of $140/kg. He cited a "red book" figure of 2.1 megatons available for $40/kg. If a price doubling provides a tenfold increase in availability, he observed, we should expect 21 megatons at $80/kg, upwards of 150 megatons at $130/kg. (Earlier Gordon-Hagerty had indicated that a tenfold price increase would multiply availability by 300. A tenfold increase is more than three doublings, which would, according to Fetter, lead to three tenfolds, or a thousand fold, in availability, greater than the 300 multiplier of availability cited by Gordon-Hagerty.)

In addition to being economically competitive, Fetter said, nuclear power plants can be built to operate safely, and the waste can be safely disposed of. But the risk of proliferation is uncertain, he felt; and, unless this can be brought under control, the justification for a nuclear renaissance may be severely limited.

Regarding modular designs, Fetter observed that no one has yet experimented with mass production of modular reactors on a large scale. They are like passenger airliners, Fetter said -- expensive, with profits not materializing until after the first 100 are made.

Bradford Sees No Evidence of Nuclear Renaissance

Peter Bradford, a Nuclear Regulatory Commissioner at the time of the Three Mile Island accident and now president of his own consulting firm, talked about the difference between actual and perceived risk posed by the Three Mile Island accident. The actual risk at Three Mile Island was initially high and decreased with time, while the perceived risk began low and increased with time.

In spite of all the talk about how the threat of global warming will spark a renaissance of nuclear power, Bradford observed that he has yet to see such a renaissance. He added that licensing is not a problem: no applications to build a nuclear power plant were denied. Recalling the wedges proposed by Pacala and Socolow and cited by Williams at the workshop to stave off global warming, Bradford noted that Pacala and Socolow presented 15 possible wedges. Only seven of them are needed, and the extent to which nuclear energy is needed depends on which seven wedges can be implemented with greatest cost effectiveness, he said.

Ferguson Discusses Proliferation and Terrorist Risks

The next speaker was Charles Ferguson, workshop co-organizer, whose paper, "Nuclear Energy: Balancing Benefits and Risks," was basic reading for the workshop participants. Ferguson began his discussion of "Proliferation and Terrorist Risks" by observing that uranium-235 weapons spin off the nuclear fuel cycle at the enrichment phase, and plutonium-239 weapons spin off the nuclear fuel cycle with reprocessing of spent fuel. How can one assess whether and/or when a nation or group decides to spin off the nuclear fuel cycle to develop nuclear weapons?

About three quarters of present nuclear power reactors are in the G-8 nations, Ferguson observed. Other types of reactors are designed to provide propulsion, produce specific isotopes, and perform research, with more reactors providing propulsion than power. But the reactors with greatest proliferation potential are heavy water, light water, or graphite-moderated research reactors with a capacity of more than 25MWt (megawatt thermal output). A megawatt-day, he said, can produce a gram of plutonium if the uranium is enriched less than 20% in isotope uranium-235.

Iran has more than three research reactors, Ferguson went on. One is from the US Atoms for Peace program, and other is from the Chinese, but none has more than 25 MWt output. Iran's expressed need to enrich uranium is for a Russian reactor to be completed at Bushir -- but the Russians are prepared to supply the enriched uranium fuel for their reactor under their contract with Iran.

Under the NonProliferation Treaty (NPT), nonnuclear state signatories like Iran are entitled to peaceful nuclear technologies, Ferguson observed, and nuclear state signatories have a responsibility to pursue nuclear disarmament. If one counts North Korea, which recently renounced the NPT, there are now four nuclear states who have not signed it (the other three are India, Pakistan, and Israel, the last not a declared nuclear state but believed to be one).

Can we manage the risks of proliferation with a major expansion of nuclear energy, Ferguson asked. Answering his rhetorical question, he said that it depends on where the expansion occurs, with greater risks in more unstable areas. The IAEA has not yet been able to inspect frequently enough to detect clandestine bomb manufacture, given the following times to make a bomb: 7 to 10 days from plutonium or uranium, 1 to 3 weeks from mixed oxide fuel, and 1-3 months from irradiated fuel (if these materials are purchased from a supplier rather than produced on-site in a reactor). Another problem cited by Ferguson is material unaccounted for (MUF): 30 kg plutonium at Sellefield, UK, and 200 kg plutonium at Tokaimura, Japan.

The NPT does allow nonnuclear states to make highly enriched uranium for research or propulsion reactors, but -- after doing so -- a state could change its mind and bolt the NPT. By allowing nonnuclear states access to peaceful nuclear technologies, the NPT could also encourage countries in a quest for weapons capability, Ferguson argued. He added that new types of terrorist groups, like Aum Shinryko and Al Qaeda, are more likely to use nuclear materials, because they are interested in causing deaths as well as destruction.

Yet Ferguson also felt that nuclear power plants are unlikely terrorist targets, because containment buildings are lower than cooling toward and difficult to target. Ditto for spent fuel, he said, because it is held in pools in boiling water reactor buildings and buried in pools outside power water rector buildings. Very little spent fuel has been put into dry cask storage, he said.

Quillian Compares Energy from Nuclear and Other Sources

Mary Quillian of the Nuclear Energy Institute, the trade group for the nuclear industry, presented an excellent collection of visuals on timelines on the evolving use of energy and patterns of energy production and consumption. Power plants are put into operation in order of ascending fuel cost, she said -- wind, hydro, then nuclear, coal (for base load), then gas (for peak load). Yet, she noted that the intermittency of wind and water availability yield relatively low capacities for renewable energy sources -- 18.8% for solar, 30.3% for wind, and 31.8% for hydro, compared with 89.9% for nuclear and 71.1% for coal. Land requirements (in acres per GWh) are highest for hydro and biomass, least for nuclear, she added. Water requirements are highest for geothermal, least for solar and wind. And the range of greenhouse gas emissions (in grams of carbon dioxide per kilowatt hour), according to five different references, is 755 to 1309 for coal, 546 to 1190 for oil, 389 to 991 for natural gas, while only 13 to 731 for solar photovoltaic, 15 to 156 for biomass, 2 to 237 for hydroelectricity, 7 to 124 for wind, 14 for geothermal, and 2 to 59 for nuclear.

Quillian cited some polling results. An April 2007 poll of 1000 adults, she said, found 41% feeling that climate change is a problem, with 27% feeling that most electricity would come from solar in 15 years, while 24% felt most electricity would come from nuclear by that time, and 18% from wind. Between 56 and 63% of those interviewed in three other polls indicated favorability toward nuclear energy.

Quillian's chart of cost comparisons for electricity from various energy sources was consistent with Fetter's but more detailed. But regardless of whether new nuclear power plants are built, Quillian pointed out that our current fleet of about 100 US nuclear reactors, by avoiding carbon dioxide emissions from the equivalent of coal-burning power plants, offsets the carbon dioxide emissions from 96% of US passenger cars.

To keep the same percentage contribution to US electricity in 2030 as in 2006, when 45% more electricity will be needed, Quillian observed that we would need to build 50 new 1000 MW nuclear plants, 261 new 600 MW coal plants, 279 new 400 MW natural gas plants, and 93 new 100 MW renewable plants. (Note that this is considerably less than the 2500 reactors cited above that had been determined by Smith and Makhijani as the number of nuclear reactors needed by 2050 to keep pace with the growth in demand for electricity without increasing carbon dioxide emissions -- Smith and Makhijani have a longer timeframe and a stronger constraint on carbon dioxide emissions.) Quillian showed a list of up to 34 nuclear plants presently under consideration (consistent with Sproat's figure of 30), but she was uncertain how many would actually be built. Building a coal-fired plant today is also uncertain, she noted, because of uncertainty about imposition of a carbon tax.

Quillian listed Texas, Iowa, Wisconsin, Georgia, South Carolina, Virginia, Florida, and Louisiana as states that have passed legislation or regulations to help secure financing for constructing new nuclear plants.

Also speaking at the workshop were William Reinke, Executive Director of the SERC Reliability Corporation, on "Electricity Generation and Distribution," and Henry Sokolski, Executive Director of the Nuclear Policy Education Center, on "Educating Students and the Public on Nuclear Energy Issues."

Many of the presentations at the workshop and other related documents are available on-line at http://npw.wlu.edu/materials/index.html.