Nuclear Power in the West: White Paper

On October 28, the WIEB Board of Directors instructed WIEB staff to prepare a white paper on the future of nuclear power in the West. It has been suggested that the white paper also address subjects of interest to the WGA Staff Council. What follows is a working draft, incorporating additional topics identified by the Staff Council at their December 4 meeting. The draft focuses on the 11 western states that are part of WIEB, but can be expanded to cover all WGA states.

Overview

In the eleven western states, nuclear power currently accounts for 9% of total electric power generation, 21% of low-carbon power generation, and 64% of low-carbon generation excluding hydro. What is the future role of nuclear power in the West, where intensive efforts are underway to address climate change and to incorporate renewable generation into the power system of the Western Interconnection? Is the future for nuclear power 2% percent of total generation or 20%? At existing or new sites? Using Generation III technologies or Generation IV? For baseload power exclusively or for other purposes as well?

This *draft* white paper considers two broad factors, each with multiple components and uncertainties. First, what are the prospects for new nuclear power in the country as a whole? Second, given those prospects, how might nuclear power complement or contribute to the future energy mix in the West? After reviewing the current status of nuclear power, the paper discusses:

- The costs of nuclear power, compared to other sources of baseload power, or low-carbon baseload power. *Observation: The cost is relatively high; how much higher depends on the factors considered.*

- The water requirements (withdrawals and consumption) of nuclear power. *Observation: The requirements are relatively high, but the gap may be reduced by Generation IV technologies.*

- The security of nuclear power plants. *Observation: Since September 2001, the NRC has increased its emphasis on nuclear plant security. Nuclear plants may provide more attractive terrorist/sabotage targets than other power plants or regional transmission, but they are (arguably) more resilient and more fully defended.*

- Siting nuclear power plants. *Observation: New nuclear plants, particularly on new sites, undoubted pose siting difficulties. Yet, over the past two decades, operational safety has greatly improved while climate change concern has greatly increased, likely resulting in greater siting acceptance. Proposed nuclear plants on new sites in the south have not yet provoked extreme negative response.*

- Waste confidence. All components of the U.S. nuclear waste program (permanent disposal at a geologic repository, centralized storage, reprocessing, even the safety of extended on-site storage) are uncertain. Yet the Nuclear Regulatory Commission's (NRC) proposed waste confidence rule would effectively remove waste confidence as a factor in licensing new nuclear power.

- Generation IV nuclear technology and its fit with the western energy portfolio. *Observation: Generation IV technologies address many of the issues that have limited nuclear power in the West. The extent to which they may resolve these issues will unfold over the next decade, roughly the same time frame in which the results of current efforts to revise the western electric generation portfolio will unfold. As part of current efforts to reduce CO2 emissions through development and regional transmission of renewables, it may be useful to consider whether and how Generation IV technology complements the evolving western power system.*

WGA Staff Council expressed interest in several related topics, not yet developed in this paper:

- The safety of nuclear plant operations. *Despite recent problems at Palo Verde, the nation's fleet of nuclear plants is operated more safely than it did prior to the 1979 incident at Three Mile Island. In significant part, this is due to the industry-established Institute of Nuclear Plant Operations (INPO), which conducts independent evaluations, shares reactor operating experience and lessons learned, and helps develop and maintain a safety culture in nuclear plant operations. With license extensions, however, generally older plants will be operating at high capacity, posing continued safety challenges.*

- Uranium mining, milling and enrichment. *Over the past 15 years, most uranium purchased for U.S. nuclear power plants has been of foreign origin, and foreign uranium has been less expensive than U.S. production. These patterns are changing. Permitting for uranium mining and milling is very active in Wyoming and Colorado. Three centrifuges (in Eunice, NM; Atomic City, ID; and Portsmouth, OH) are under construction or planned. Total deliveries to U.S. reactors increased from 38 million pounds of U3O8 equivalent in 1994 to 66 million pounds in 2006.*

- Reprocessing. *In October 2008, the DOE Office of Nuclear Energy issued a programmatic assessment of reprocessing/recycling options, but the Obama Administration's FY'10 budget zeroes out the Bush Administration Global Nuclear Energy Partnership. Even so, reprocessing (a costly R&D effort with uncertain long-term results) will continue to be considered—perhaps less for its potential to economically produce nuclear plant fuel than for its potential contribution to HLW management.*

- SNF/HLW Transportation. *In its 2006 report "Going the Distance?", the National Academies found "no fundamental technical barriers to the safe transport of spent nuclear fuel and high-level waste in the United States." However, DOE has not embraced many of the report's recommendations (e.g. full implementation of DOE's dedicated train decision; shipment of older fuel). Instead, DOE sponsored legislation that would have authorized DOT to preempt state transportation regulations and allow* *the Department to conduct transport exclusively under the Atomic Energy Act of 1954. DOE's recently released "National Transportation Plan" retreats from federal-state consultation in SNF/HLW transportation system design. Realization of the consultative process contemplated in WGA Resolution 08-6 (B-1) will require stout political support. Meanwhile, WIEB has developed several tools and capabilities that could contribute to a consultative transportation system design process.*

Much about nuclear power remains uncertain, both nationally and especially in its western applications. One can find strongly-held contending positions on each of the factors addressed above. The situation might lead one to ask why invest continued attention and interest in such an uncertain electric power resource. The most reasonable answer might be: "only if the resource has the potential to significantly contribute to a western energy strategy." Forecasts for electric power generation and greenhouse gas emissions provide a context for considering this potential contribution.

The U.S. Energy Information Administration was asked by Senators Lieberman and Warner to conduct a forecast analysis of the effects of their proposed Climate Security Act of 2007 (S.2191), applying the same model system used to produce EIA's reference "Annual Energy Outlook," but reflecting S.2191 provisions for regulating greenhouse gas emissions through market-based mechanisms, energy efficiency programs, and economic incentives. The results, considered on a regional basis, provide insight into the special energy and electric power challenges facing the West,[1] and into prospective roles for nuclear power. Comparing forecasts under S.2191 for 2030 versus 2006, the EIA estimates for the West indicate a:

- 40% <u>increase</u> in power generation from coal (vs. 85% <u>decrease</u> in the rest of the US);
- 14% increase in nuclear power generation (vs. <u>288% increase</u> in the rest of the US);
- 27% increase in renewable power generation (vs. <u>350% increase</u> in the rest of the US);
- 92% increase in non-hydro renewable power (vs. <u>280% increase</u> in the rest of the US);
- 40% <u>increase</u> in CO_2 emissions (vs. 24% increase in the rest of the US).

Even under cap and trade legislation, EIA expects coal power generation to increase in the West while decreasing elsewhere, non-hydro renewable power generation to increase much less than elsewhere, and CO_2 emissions to increase more than elsewhere. Moreover, the EIA expectation that nuclear power generation will increase by 14% may be optimistic. Without license extensions at California's Diablo Canyon and San Onofre reactors, almost half of the West's current nuclear generation capacity will be unavailable after 2025. While continuing to focus on the development and transmission of non-hydro renewable energy, it may be useful for the West to also consider the contribution of additional nuclear power (especially after 2025) in order to meet electric power needs and greenhouse emissions reduction goals.

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[1] EIA's "electricity market module" provides estimates for Region 13 (California), Region 12 (Arizona, Colorado, most of New Mexico, and southern Nevada) and Region 11 (Washington, Oregon, Idaho, Wyoming, most of Montana, Utah, and the remainder of Nevada).

The Future of Nuclear Power in the West

Question: What is the future role of nuclear power in the West, where intensive efforts are underway to address climate change and to incorporate renewable energy into the Western Interconnection?

The position of the U.S. Department of Energy under the Bush Administration was that "the expanded use of nuclear power in the United States….is critical to meeting our country's climate change and energy security goals." Analyses of most prominent climate change legislation in the the last Congress (the "Lieberman-Warner" bill) project that, in order to meet carbon reduction goals, nuclear power should increase from the current 20% of electric power generation to 30% by 2050. Given increases in total power requirements, the percentage increase requires a doubling of nuclear generation capacity.

Currently, nuclear power accounts for 9% of electric power generation in the eleven western states, compared with 22% in the remainder of the continental U.S.[2] Yet, low-carbon power sources[3] account for 42% of total generation in the West, compared with 27% in the remainder of the continental U.S. The explanation is the high portion of hydroelectric power generation in the West: 28% versus just 3% in the remainder of the continental U.S.[4] Nuclear power accounts for only 21% of low-carbon power generation in the West, compared with 81% in the remainder of the U.S. Excluding hydro, however, nuclear power accounts for 64% of low-carbon power generation in the West.

Not only is western power generation distinctive from the rest of the country, it also varies widely among the western states. Regarding nuclear power, 49% is generated in California, 37% in Arizona (which exports 25% of its total generation, mostly to California), and 14% in Washington. Eight other western states generate no nuclear power.

The future role of nuclear power in the West[5] depends on two broad factors, each with multiple components and uncertainties. First, what are the prospects for new nuclear power in the country as a whole? Second, given those prospects, how might nuclear power complement or contribute to the future energy mix in the West? This paper focuses

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[2] U.S. Department of Energy, Energy Information Administration, "State Electricity Profiles 2006," DOE/EIA-0348(01)2. The 11 western states" include AZ, CA, CO, ID, MT, NV, NM, OR, UT, WA, and WY.

[3] Using EIA statistics, "low-carbon sources" include nuclear, hydro, other renewables, other (except natural) gas, pump storage, and other (including geothermal). Nationally, carbon dioxide emissions from these power generation sources are about 13 tons per GWh. Due to its high proportion of hydro power generation (27.6% versus 2.6% in the rest of the continental U.S.), CO2 emissions from "low-carbon sources" in the West is only 3 tons per GWh. Nationally, carbon dioxide emissions from coal power generation is 992 tons per GWh, and emissions from natural gas power generation is 496 tons per GWh. Due to its lower proportion of coal power generation (30.3% versus 53.3% in the rest of the continental U.S.) and its higher proportion of natural gas power generation (27.6% versus 18.3% in the rest of the continental U.S.), CO2 emissions from fossil fuel power generation is 13% lower in the West than in the rest of the continental U.S..

[4] 76% in Washington, 71% in Oregon; 84% in Idaho.

[5] While this paper focuses on the "service" phase of the nuclear fuel cycle, it is important to keep in mind the front and back ends of the nuclear fuel cycle, which is reviewed in Section 9 below.

mainly on the first factor. As the prospects for nuclear power--particularly “Generation IV” nuclear power--become clearer, the focus may shift towards the second.

1. **The Current Status of Nuclear Power.**

Currently Operating Plants. Of 104 licensed and operating nuclear power reactors in the U.S., only eight (at 4 sites: Palo Verde, San Onofre, Diablo Canyon, and Columbia) are located in the eleven western states.[6] The 104 nuclear plants produce 20% of the nation’s electric power, and 66% of its low-carbon electricity. California’s San Onofre and Diablo Canyon plants are estimated to produce 15% of the state’s electricity supply, and perhaps 30% of its low-carbon electricity supply.[7]

License Extensions. About 95% of the 104 currently operating nuclear plants are expected to receive 20-year extensions of their 40-year operating licenses.[8] Forty-nine reactors (at 28 sites) have already received such extensions. Another 17 reactors (at 12 sites) have filed for 20-year license extensions, and 33 reactors (at 17 sites, including Palo Verde in Arizona, Columbia in Washington, Cooper in Nebraska, and South Texas in Texas) are expected to file. No reactors in the eleven western states have received or filed for license extensions.[9]

New Nuclear Reactors. (See Figure 1, below.) The NRC has received “combined license applications”[10] for 26 new reactors at 7 sites. None are in the eleven western states.[11] The new reactors use “Generation III” nuclear reactor technology, which includes passive safety features, design simplifications, and other improvements over current designs. The improvements are expected to increase operational safety, reduce operation costs (below the average for currently operating nuclear plants), and reduce material and construction costs (below the costs of new construction of currently operating plant designs).

Westinghouse’s “Advanced Passive 1000” (AP1000) PWR, with 1150 MWe capacity is proposed for 6 of the 17 current combined license applications; General Electric’s “Economic Simplified Boiling Water Reactor” (ESBWR) is proposed for five; Areva’s “Evolutionary Pressurize Water Reactor (EPR) is proposed for another four. These reactors would have capacities of 1100-1600 MW.

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[6] Another eight reactors (at 5 sites) are located in Texas, Kansas, and Nebraska.

[7] Based on DOE/EIA “State Electricity Profiles 2006.” A recent California Energy Commission Report (“AB 1632 Assessment of California’s Operating Nuclear Plants,” Oct. 2008, pg.1) suggests somewhat different percentages for California.

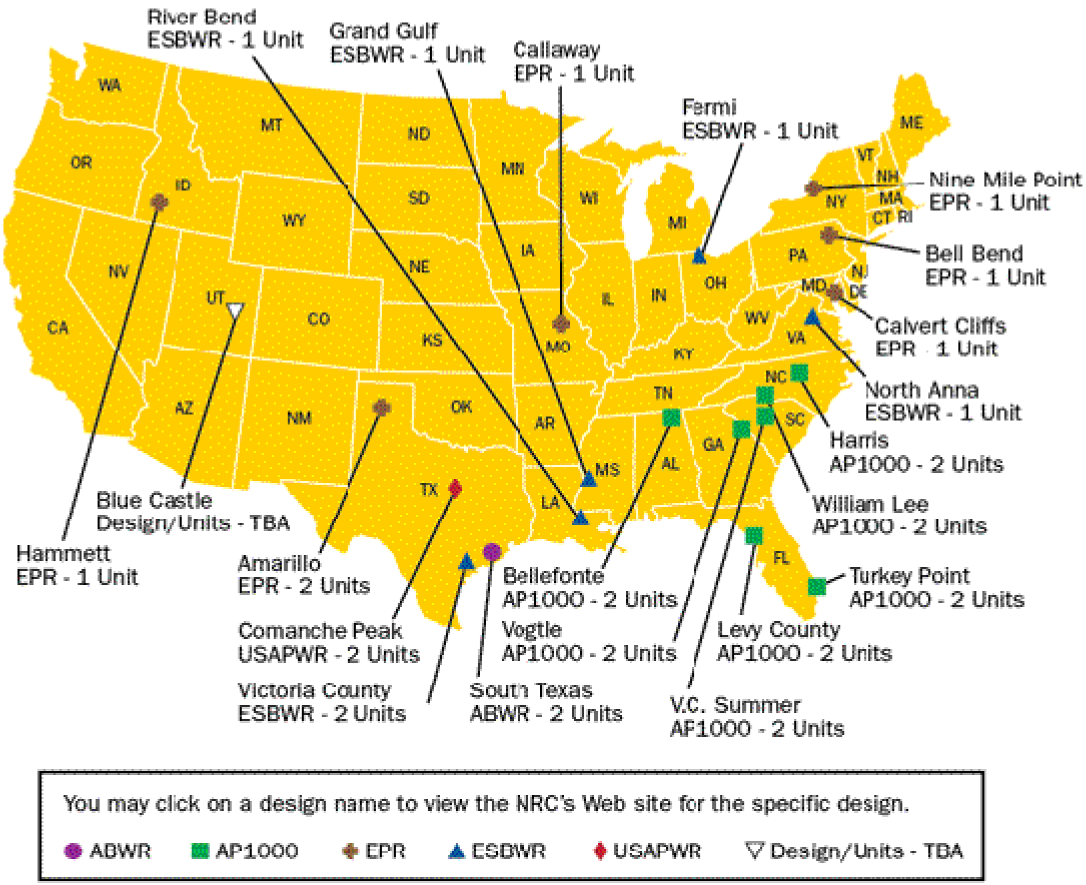
[8] Nuclear Energy Institute.

[9] Fort Calhoun in Nebraska received a 20-year license extension in November 2003.

[10] Part of the NRC’s effort to streamline the process for license review, the combined license application includes a (largely) pre-certified license design, and an application for its construction and operation at a particular site.

[11] Six of the proposed 26 new reactors are located at 3 sites in Texas.

Combined License Applications for New Reactors (NRC: Nov. 2008)



Note: NRC's November 2008 list excludes Hammet, Blue Castle, Amarillo and Turkey Point.

Loan Guarantees. Though they offer distinct improvements over currently operating reactor designs, the proposed new reactors would be large-scale projects, requiring investments of over $10 billion per plant before operations and electricity sales. In response to its June 2008 solicitation, DOE has received loan guarantee applications from 17 electric power companies for construction of 14 nuclear power plants.[12] The loan guarantees would apply to $122 billion of the $188 billion estimated construction cost of the 14 plants. It may be that DOE loan guarantee decisions determine which of the 21 new reactor combined license applications are implemented.

The following addresses several questions that will arise in considering the future of nuclear power, in the country and in the West.

2. Comparative Costs

What are the costs of electricity generated from nuclear power compared with the costs of alternative sources? For most currently operating nuclear power plants, construction costs greatly exceeded projections. But these are now sunk costs; utility sales and

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[12] USDOE, Press Release, October 2, 2008.

consolidations over the past decade or so have removed construction cost overruns from the current financial equation. For currently operating plants, the cost question focuses on the operating costs of nuclear power generation versus other sources, specifically other sources of baseload power or of low-carbon baseload power.

Regarding operating costs, current nuclear plants compare well. Due to its relatively high capacity factors, nuclear power generates 20% of the U.S. electricity supply with only 13% of its generating capacity. At about 1.9 cents per kilowatt hour, the average operation expenses (fuel plus O&M costs) of existing nuclear power are less than those of fossil steam plants (3.0 cents per kWh) or other fossil fuel plants (5.8 cents per kWh).[13] Only hydro plants (which have no fuel costs) have lower operating expenses. Their relatively low operating costs explain the very high percentage of currently operating nuclear plants that have filed or are expected to file for 20-year license extensions.

Looking forward, however, the cost comparison must also consider capital costs (equipment, material and labor required for plant construction), financing costs, and "owner's costs."[14] A recent assessment by the Nuclear Energy Institute[15], an industry organization, concludes that "even at capital costs in the $4,000/kWe to $6,000/kWe range, the electricity generated from nuclear power can be competitive with other new sources of baseload power, including coal and natural gas. These results are absent any restrictions on carbon dioxide emissions. With….programs that put a significant price on carbon emissions, nuclear power becomes even more competitive."

The NEI white paper presents the results of an analysis by the Brattle Group. At $4,038 per kWe, the capital costs of nuclear power are well above the costs of supercritical pulverized coal ($2,214/kWe) integrated gasification combined cycle ($2,567/kWe), or natural gas combined cycle ($869/kWe). With carbon capture and storage, however, the differences are much reduced: SCPC ($4,037), IGCC ($3,387), NGCC ($1,558). In this analysis, the levelized costs[16] of nuclear power ($83/MWh) are comparable to the levelized costs of SPCC, IGCC and NGCC, and significantly lower if the alternatives include carbon capture and storage.

3. Water Requirements

What are the water requirements in generating electricity by nuclear power, compared to alternative sources? One of the advantages of many renewable generating technologies (e.g. wind, photovoltaics) is that their water requirements are much less than of traditional baseload sources of electrical power. Coal-fired, natural gas combined cycle and nuclear plants all require water (high-pressure steam) to turn the

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[13] DOE EIA, Electricity Power Annual: 2006.

[14] Other infrastructure (e.g. transmission upgrades, cooling towers, water intake and treatment systems, administrative buildings, warehouses, roads and switchyards) and project management and development costs (permitting, taxes, legal costs, staffing and training).

[15] Nuclear Energy Institute, "The Cost of New Generating Capacity in Perspective" (White Paper), August, 2008.

[16] Levelized cost is the cost of an energy generating system over its lifetime, including initial investment, operations and maintenance, cost of fuel and cost of capital.

turbines that drive the generators. In “closed cycle” systems, water is used to cool the steam in cooling towers resulting in the evaporation of large amounts of water. Once the steam is cooled, it is recycled Into the power plant Nuclear plants consume more cooling water than fossil-fired plants because the steam is at lower temperatures and pressures, making it less efficient at using the heat from the reactor, thus requiring more water for cooling.[17] Conventional nuclear plants consume about .62 gallons of water/kWe, compared with .49 gallons/kWe for coal-fired plants and .25 gallons/kWe for combined cycle gas plants.[18]

Water requirements (withdrawals and/or consumption) are an increasing issue for many forms of power generation. Drought reduces hydro generation; nuclear and coal-fired generation increasingly compete for freshwater with residential, commercial, agricultural and industrial uses—particularly in rapid growth areas and/or areas plagued by drought. Section 316(b) of the Clean Water Act grants the U.S. Environmental Protection Agency authority to require facilities with cooling water intake structures (e.g. nuclear, coal-fired and natural gas combined cycle power plants) to use the “best available technology” for minimizing adverse environmental impacts of water withdrawal and consumption.[19] Projections (by DOE EIA and DOE NETL) of thermoelectric capacity and its water requirements indicate that water consumption in electric power generation will increase twice as fast in the West than in the country as a whole.[20] “Generation IV” reactors could reduce water use for nuclear power generation.

4. Security

Are nuclear plants substantially less secure than other sources of baseload or renewable electric power? After the terrorist attack on September 11, 2001, the physical security of nuclear power plants and their vulnerability to deliberate acts of terrorism were elevated to a national security concern. The NRC issued Advisories and then Orders that required licensees to provide enhanced capabilities to detect and respond to a nuclear attack. The NRC also conducted engineering studies at representative nuclear plants to assess the likelihood and potential consequences of various types of sabotage or terrorist attack, including, of course, the type demonstrated on 9-11. The NRC concluded that nuclear plants are generally robust, but that various initiatives are warranted for greater assurance.

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[17] Australia Department of Parliamentary Services, Research Note, December 2006: “Water Requirements of Nuclear Power Stations.”

[18] AWEA website.

[19] In 2007, the 2nd U.S. Circuit Court of Appeals invalidated both the use of restoration as a compliance option and site-specific variances based on cost-benefit analyses. Until the EPA can revise their “Phase II Rule,” state agencies must continue to rely on their best professional judgment. In April 2009, the Supreme Court overruled the 2nd Circuit decision, stating that the government can weigh costs against benefits in deciding whether to order power plants to make upgrades to protect fish. Such assessment could enable some 500 power plants (including nuclear plants) to avoid the costs of “closed-cycle cooling,” which relies on recycled water to cool machinery.

[20] DOE NETL, “Water Supply for Sustainable Thermoelectric Power Production,” June 26, 2007. The projected percentage increases (2005-2030) are 32% in the U.S., 66% in WECC/NWPP, 74% in WECC/RM, and 352% in WECC/CA.

Supplementing the NRC's own initiatives, the Energy Policy Act of 2005 (Title VI) added new provisions requiring background checks of plant security personnel, conduct of "force-on-force" security exercises, and revision of the nuclear power plant "Design Basis Threat."[21]

Still, critics contend that industry implementation has been slow. They find shortcomings in the performance of security contractors, and advocate that further measures are needed. [22] It is reasonable to presume that nuclear plants are more secure than they were before 9-11. Whether they are as secure as they could or should be is (quite obviously) arguable. Nuclear plants may provide more attractive terrorist/sabotage targets than other power plants or regional transmission, but they are (arguably) more fully defended. There may be no precise way to determine whether the uncertain difference in security of nuclear plants and other modes of power generation should be a determinant of the future of nuclear power.

5. Siting

Of the 17 combined license applications thus far received by NRC, only four propose nuclear plants on new sites. Thirteen would add one or more new reactors at existing nuclear plant sites. Any major new power plant, nuclear or otherwise, will raise difficult siting issues. Water requirements and security concerns could make these greater for nuclear than for other types of power generation. On the other hand, transmission corridors from nuclear plants to load centers are likely to be fewer in number than required to move regional renewable sources.

6. Waste Confidence

NRC is currently seeking comment on its proposed revision of the "waste confidence" rule, preventing the licensing of new nuclear power plants absent confidence in an assured path for permanent disposal of its waste. While the current rule requires confidence that a permanent repository will be available for operation in 2025, the proposed revision would require confidence that permanent disposal would be available within 50 years after the shutdown of all licensed nuclear plants. The proposed rule also proposes confidence in the safety of on-site storage for 60 years after license expiration.

Thus, while the prospects at Yucca Mountain are uncertain, and the prospects for centralized storage (perhaps co-located with reprocessing facilities) are even more so, NRC proposes confidence based on the inherent safety of on-site storage systems and the institutional vigilance of nuclear utilities, even beyond economic operations.

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[21] NRC's implementing rule: a) clarifies that physical protection systems are required to protect against diversion and theft of nuclear material, b) expands the assumed capabilities of adversaries, c) assumes that adversaries are knowledgeable about their targets and are willing to kill or be killed, and d) revises the threat posed by insiders.

[22] CRS Report for Congress: "Nuclear Power Plant Security and Vulnerabilities," January 18, 2008.

7. Generation IV

Might at least some of the questions raised above be addressed by emerging "Generation IV" plant technology? The answer is "very possibly, yes." Of particular interest are the "pebble-bed" reactor (PBMR) being developed in this country by Westinghouse and the Gas Turbine-Modular Helium Reactor (GT-MHR) being developed by General Atomics. Both are high-temperature gas reactors, which operate at significant higher efficiency than Generation III reactors. Both lend themselves to modular development, reducing the lead time between capital investment and operations and sales. Both greatly reduce the complexity of cooling systems, a major contributor to the cost of conventional plants. Both reduce thermal discharge to the environment. The GT-MHR can use air cooling, thus reducing water use and consumption, and permitting more siting options. Both can "follow load" more effectively than current nuclear plants.

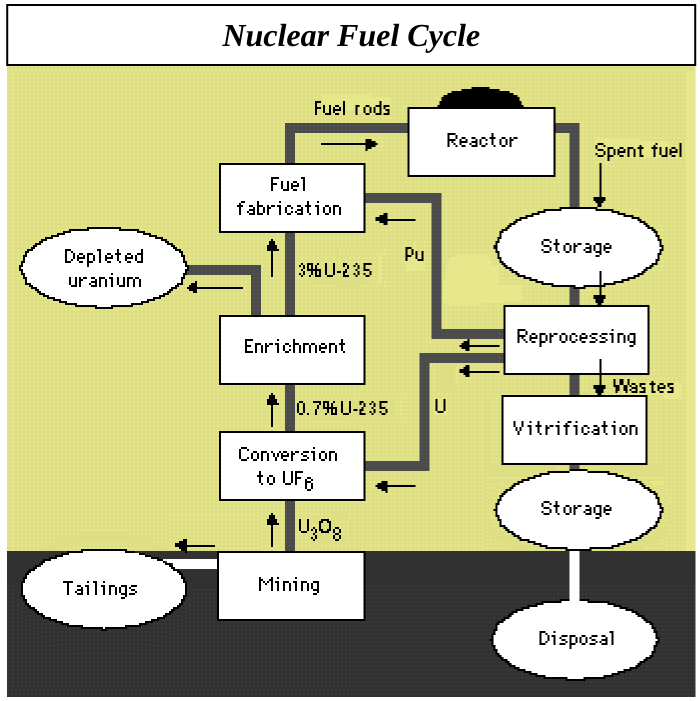
8. Fit with Western Generation Portfolio

As wind and solar generation expand in the West, the value of flexible generation that can ramp up and down to complement the variability in those resources increases. Additionally, wind integration studies have found that the greatest challenge to operating a reliable power system with large amounts of wind generation is during times when demand is low. This is because for technical and economic reasons the relatively inflexible generation in the system cannot be backed down far enough to accommodate the wind generation during low demand periods. Generation III nuclear power plants are not flexible generators, thus their output is less valuable than the output from flexible generators such as some hydro and natural gas power plants.

No Generation IV technology is likely to be ready for deployment before 2017—a time-frame at which the results of current efforts to revise regional generation portfolios will be more evident than they are today. As part of current efforts to reduce CO2 emissions through development and regional transmission of renewables, it may be useful to consider the degree to which Generation IV technology can complement the new portfolio of generation in the West.

9. The Nuclear Fuel Cycle

Nuclear power has raised issues at each phase of its cycle. This section reviews the three phases. The description applies to the cycle for light-water reactors used in the U.S.; the cycles for other reactor technologies differ in various details.



The Front End. Uranium ore is mined using open pit and underground methods including solution mining. The uranium in ore generally contains less than 1% U-235 and over 99% U-238. U-235 is a fissile[23] isotope of uranium, while U-238 will nearly always absorb the neutron. To produce reactor fuel from uranium ore requires milling (grinding the ore to a uniform particle size, and treating it with chemical leaching to extract the uranium, in the form of U3O8 "yellowcake," conversion of the yellowcake (by heating) to uranium hexafluoride (UF6), a form suitable for enrichment by gaseous diffusion[24] or centrifuge[25], and fabrication of the enriched uranium hexafluoride into uranium dioxide powder, which is processed into pellets, which are stacked in zirconium tubes and assembled into bundles which separate the tubes by precise distances, as required by the specifications for the reactor core.

Service Period. Generally, the nuclear reactor core is designed to contain several hundred assemblies or bundles. However, burn-up rates in the reactor core are not spatially uniform, and it is not efficient to place new assemblies in the same locations from which a spent fuel assembly has been removed. A nuclear reactor cycle involves replacement of generally about one-third of the assemblies in the core, and the rearrangement of old and new assemblies to maximize fuel burn-up and minimize fuel costs per unit of electric power generated. Current nuclear reactor operating practices achieve higher burnup (the amount of energy produced per ton of fuel irradiated, or "burned") than in the 1970s and 1980s, but higher burnup increases irradiation, requiring increased care in spent fuel management.

Spent fuel removed from the reactor core is "discharged." Under the Standard Contract authorized by the Nuclear Waste Policy Act (NWPA), for each discharge the utility receives a slot in the queue for DOE acceptance and removal.[26] Meanwhile, however, the utility is responsible for interim storage. NRC regulations require that assemblies removed from reactor cores be stored in spent fuel pools (circulating water with boron) for at least five years. Thereafter, the utility may retain the spent fuel in pools, or remove it for storage at an NRC-licensed Independent Spent Fuel Storage Installation

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23 That is, it will nearly always fission when struck by a free neutron.

24 Huge facilities at Oak Ridge (TN) and Portsmouth (OH), now shutdown.

25 Facilities are under construction in Portsmouth (OH) and in southeast New Mexico.

26 The queue slot is for the metric tonnage of fuel discharged, and can be applied to any 5-year old fuel at the site in question or at the utility's other nuclear plant sites.

(ISFSI), or (if available) at an off-site centralized storage facility. As pools approach their capacity limits, utilities have loaded assemblies from pools to dual purpose (aging and transportation, not disposal) canisters for “dry” storage. As of May 2008, about 37,000 assemblies (10,500 metric tons) have been stored in a wide variety of dual-purpose canisters for dry storage.

Utilities are finding it economic to use larger dry storage and transportation canisters, with capacities of up to 37 pressurized water reactor (PWR) or 87 boiling water reactor (BWR) assemblies. Meanwhile, however, DOE has adopted the smaller (21 PWR, 44 BWR) TAD (Transportation, Aging, Disposal) system as intergral to its Yucca Mountain license application. The TAD has not yet been certified by the NRC, and DOE has not yet persuaded industry to download to TADs for dry storage rather than to larger dual purpose canisters. It may be that reloading to TADs will be required at the destination site, or that repository drifts may need to be redesigned to accommodate waste packages containing the larger dual purpose canisters.

Back End. Spent fuel removed from reactor cores is highly irradiated and contains reactor poisons, but it retains much of its fissile U-235 and Pu-239, as well as fertile U-238. If, after whatever period of interim storage, the next step is permanent disposal, the overall cycle is termed “once through” (a reactor). If the next step is chemical reprocessing or transmutation, the cycle is termed “closed.” However, the much discussed reprocessing in France and Great Britain generally achieves only one additional “pass” of MOX fuel (a blend of reprocessed uranium and plutonium) through a reactor that has been adapted to accept it.

Spent fuel from light-water U.S. reactors contains about 95% U-238, about 1% unfissioned U-235, about 1% plutonium, and about 3% highly radioactive fission products, including long-lived actinides. The PUREX process (used at Hanford to separate plutonium for weapons production, and currently in France for separating the ingredients for mixed-oxide[27] reactor fuels), has been rejected in the U.S. due to nuclear proliferation concerns. Alternative reprocessing technologies are under consideration, and are the subject of a current Programmatic Environmental Impact Statement issued by the DOE Office of Nuclear Energy. The purpose of the PEIS is to focus ongoing research and development on one or two of 10-12 competing options.

Reprocessing at a commercial scale would require very costly facilities at one or more sites. About 13 communities (3 in New Mexico, 3 in Idaho, one in Washington) have expressed interest in the economic development opportunity, but state governments have been less committal.

The technologies presented in the PEIS have a wide range of effects. Some would drastically reduce the volume of high-level waste requiring permanent disposal while generating large volumes of Greater-Than-Class C” waste, for which a disposition path has not been determined.[28] The PEIS assumes that substantial industry support will be

[27] “MOX”: a blend of Pu and U-238.
[28] A current EIS will examine the options, which include the Yucca site.

required to implement a selected reprocessing technology, and industry appears to be unprepared to make any such commitment any time soon.