Nuclear Energy: Policies and Technology for the 21st Century

Nuclear Energy Advisory Committee

November 2008

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November, 2008

Dr. Samuel Bodman
Secretary of Energy
U.S. Department of Energy
Washington, D.C. 20855

Dear Secretary Bodman:

We are pleased to send to you *Nuclear Energy: Policies and Technology for the 21st Century*. The report was prepared and adopted by the Department of Energy Nuclear Energy Advisory Committee. The committee was asked to prepare this report by Assistant Secretary of Nuclear Energy Dennis Spurgeon in the spring of 2008. To carry out this task, NEAC formed two sub-committees, one devoted to nuclear energy policy and one focused on nuclear energy technology.

The report calls attention to the role of nuclear power and its impact on energy security, the environment and non-proliferation. A strategy for nuclear energy policy and technology should be considered not in years but decades. This report identifies important benchmarks in both the policy and technology areas. Importantly, progress on nuclear energy will require bipartisan efforts and our members are representative of both political parties and are drawn from different professional backgrounds. The committee is composed of eminent scientists including a Nobel Prize winner, former senior officials of the DOE, the Nuclear Regulatory Commission, the US State Department, NASA and the National Security Council and distinguished professors in the field of nuclear energy including a university president, industry leaders and important non-governmental organizations such as the Nuclear Threat Initiative, the National Resources Defense Council, the Nuclear Energy Institute and the Eisenhower Institute.

The Department of Energy has played and will continue to play an integral role in securing safe nuclear power for our nation, including a very important and fundamental role in advancing the technology. Nuclear power is experiencing a dramatic expansion internationally that will require safe construction and operation as well as compliance with non-proliferation objectives. Our report emphasizes that a global approach is vital to ensure a sustained US nuclear program at home and international leadership abroad. France, the UK and Japan have important nuclear power and research programs. The report identifies mutually beneficial areas of cooperation with these nations and others.

Finally, the report also recognizes the importance of strengthening multilateral institutions such as the International Atomic Energy Agency and calls attention to its recently completed 20/20 Commission Report that identified a strategy for the strengthening of the nonproliferation agenda and nuclear energy development in an era of international nuclear expansion.

We would like to thank our colleagues Daniel Poneman and Burton Richter who joined us in the leadership of the sub-committees. We would also like to acknowledge our international colleagues who contributed to this report, Susan Ion of the UK and Kunihiko Uematsu of Japan.

William F. Martin
Chairman
Nuclear Energy Advisory Committee

John Ahearne
Vice Chairman
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- Chair – *William F. Martin* – Former Deputy Secretary of Energy and Coordinator, IAEA 20/20 project.
- Chair - *Daniel Poneman* - Principal, The Scowcroft Group and former Special Assistant to the President, National Security Council.
- *Henry Barron* – CEO and Chief Nuclear Officer, Constellation Energy.
- *Susan Eisenhower* – President, The Eisenhower Institute.
- *Corey Hinderstein* – Director of International Programs, Nuclear Threat Initiative.
- *Dr. Allen Sessoms* – President, University of the District of Columbia.

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- Chair - *Dr. Burton Richter* – Director Emeritus, Stanford Linear Accelerator Center Stanford University and Nobel Laureate for Physics.
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- *Marvin Fertel* - Sr. Vice President & Chief Nuclear Officer, Nuclear Energy Institute.
- *Dr. Darleane Hoffman* - Professor of the Graduate School, Department of Chemistry, University of California, Berkley.
- *Dr. Susan Ion* – Vice President, Engineering Policy Committee of the Royal Academy of Engineering, UK and former Group Director of Technology for British Nuclear Fuels.
- *Dr. Sekazi Mtingwa* – Senior Lecturer, Massachusetts Institute of Technology.
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- *Dr. Joy L. Rempe* – ENEEL Fellow, Idaho National Laboratory.
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- *Dr. Kunihiko Uematsu* - Japan Atomic Industrial Forum and former Director General of Nuclear Energy Agency of the OECD.
- *Dr. Dominique Warin* - CEA-Saclay, DEN/DDIN.

The Committees gratefully acknowledges the contributions made by:

- *Dr. Arnold Baker* – Chief Economist at Sandia National Laboratory and former president of the International Association of Energy Economics.
- *Dr. John Boger* – Former Designated Federal Officer of the Nuclear Energy Advisory Committee.
- *Jonathan Gillman* – Assistant to the Chairman and Energy Analyst, Washington Policy and Analysis.
- *Dr. Ray Kelleher* – International Atomic Energy Agency.
- *Dr. Joseph Perkowski* – Manager, Energy Initiatives, Idaho National Laboratory.
- *Kenneth Chuck Wade* – Acting Designated Federal Officer of the Nuclear Energy Advisory Committee.

Executive Summary

The Department of Energy (DOE) Nuclear Energy Advisory Committee (NEAC) formed two subcommittees to develop a report for the new Administration. The two subcommittee reports follow this brief summary.[1]

The mission of the Policy Subcommittee was to explore the critical choices and implications in US nuclear energy policy, with a view to framing options for the next President to consider.

Both in the United States and worldwide, nuclear power has the potential to curtail the dependence on fossil fuels and thereby to reduce the amount of greenhouse gas emissions while promoting energy independence. Therefore, retaining nuclear power as a key piece of the nation's energy portfolio strengthens US energy security and environmental quality. Given the stakes for the United States in the manner in which nuclear energy is used (and potentially misused) around the world, it is in US national interest to play an active role in global efforts to address the safety, security, environmental, and proliferation implications of nuclear power.

Currently there is substantial risk and uncertainty surrounding the ability and length of time actually required to license and build a nuclear power plant. This risk and uncertainty make it difficult to control the financial and material costs of building nuclear power plants and raises rates of return required by investors to commit capital to build them. Reducing such risk and uncertainty for new nuclear power plants with respect to other alternatives is the goal of US legislation authorizing loan guarantees in support of nuclear power plant construction.

Encouraged by the offer of federal subsidies under the 2005 Energy Policy Act, a number of US utilities are now seriously considering the addition of nuclear power plants to their portfolios of power generation assets.

NEAC reviewed a range of projections regarding the future deployment of nuclear power in the United States, and concluded that the uncertainties involved precluded any confident judgment regarding which projection or projections to use as the basis for our review. NEAC therefore chose three scenarios in order to bound the plausible nuclear futures for the United States:

Case A - Low Scenario: All reactors extend operating life to 60 years, but no new nuclear reactors are built.

Case B - Middle Scenario: All reactors extend operating life to 60 years, and over a dozen new reactors are built, contributing 17GWe of installed base-load power generation. This assumes no change in existing US policy, as described in the Energy Information Administration Reference Case**.**

Case C - High Scenario: Reactors contributing 45 GWe of additional base-load power generation are built, on the assumption that future power generation investment decisions will be based on a carbon-constrained legal and regulatory regime.

[1] This is a report by the Nuclear Energy Advisory Committee. It has been approved by the full committee, although not all parts are endorsed by all members.

The results of fuel cycle R&D could significantly change the challenges for the storage of nuclear waste at various locations, including Yucca Mountain. The US should complete the NRC licensing process for the Yucca Mountain project to determine its acceptability as a disposal site, while also exploring other options for waste management.

NEAC believes that the US Government should develop and articulate its nuclear energy policy to assure a uniform level of excellence that will provide global leadership, assure environmental and energy security, and protect our Nation's prosperity, while building on and extending its commitment to nuclear safety, security, repository science, and non-proliferation. Specifically, NEAC recommends the following steps to be taken by the DOE, under White House leadership and in cooperation with relevant agencies and stakeholders:

- The establishment and implementation of a nuclear energy R&D roadmap.
- The development of a workforce able to meet the human resource requirements of the US nuclear industry.
- Preservation of "safety first" as the guiding principle for all actions regarding the design, construction, and operation of all nuclear facilities.
- Integration of security as a top priority in US nuclear facilities.
- Improvement of NRC licensing processes and coordination with other affected agencies and stakeholders.
- Minimization of the risks of nuclear weapons proliferation through such measures as reform of the nuclear fuel cycle and provision of reliable assurances that users of nuclear energy worldwide will have their fuel requirements efficiently met by their suppliers so long as they adhere to international nonproliferation standards.
- Strengthening of the International Atomic Energy Agency (IAEA) and providing it with the resources required to do its job properly, in order to promote the safe development of nuclear energy globally as well as full compliance by all nations with non-proliferation norms.

The Technical Subcommittee reviewed the facilities available for nuclear energy programs starting from reports produced for DOE-NE.

The reports recommended:

- Further improvement of operations and extension of the lifetime of the fleet of current and future light water reactors.
- Assurance of a well-qualified and trained workforce.
- Development and demonstration of Generation IV reactors, such as the Next Generation Nuclear Plant (NGNP), to extend the applications of nuclear energy.
- The upgrade of domestic facilities and expansion of the collaborative use of international facilities for activities required to create a sustainable fuel cycle.
- Recognition of fast-reactor core competencies in critical areas, combined with a robust program of international collaboration.
- Development of a modeling and simulation capability.

Many high-priority facilities require moderate to significant investment before they could provide the capabilities needed by DOE-NE. NEAC believes that a strategic initiative is needed to ensure that the required facilities are available and ready to support these missions (especially those identified for multiple DOE-NE missions).

NEAC agrees on the importance of emphasizing international collaboration, especially with respect to longer-term, high-cost R&D goals, such as in developing recycling and fast reactor capabilities.

The DOE needs to provide an analysis for the next administration that reviews the current status and of programs and facilities, and suggests a multiyear program including consideration of facility upgrades and new facilities necessary for its several missions. The analysis should systematically examine which facilities need to be maintained, upgraded, abandoned, or built new. The goal would be to have the right mix of mission-driven modern facilities that can be kept up-to-date and operated safely.

Many high priority facilities require moderate to significant investment before they could provide the capabilities needed by DOE-NE.

A depressing story was revealed of decayed or decaying facilities that in most cases are not suited for their intended uses without significant and often expensive refurbishments. However, even if aggressive new power plants and advanced programs do not proceed, the United States needs a robust set of nuclear research facilities.

The DOE Office of Nuclear Energy should broaden its assessment of nuclear infrastructure needs to include the once-through fuel cycle used by the current fleet of light water reactors and the likely improved versions of LWRs that will evolve from them.

International collaborations should be increased, especially in the current climate of stringent budgets.

NEAC concludes that some R&D programs would be the same whether there are no new reactors, a few new reactors or many new reactors:

- R&D to keep current plants running well and avoid any surprises. This R&D will include efforts to mitigate aging phenomenon.
- R&D to encourage a new cadre of engineers and scientists to become involved in nuclear energy.
- R&D on waste management.
- R&D to maintain the US as a major participant in international nuclear power discussions.

To terminate our planning horizon at 2030 would be a serious mistake. New concepts can take many decades to go through lab scale and engineering scale development before getting to commercial scale.

NEAC Policy Subcommittee Report

I. Introduction

More than 50 years since the launch of the Atoms for Peace initiative, the implications of US nuclear policy -- in terms of our Nation's energy, environmental, and national security interests -- are greater than ever. The choices the next president will make regarding nuclear energy will substantially affect these interests. The mission of this Subcommittee is to explore the critical choices and implications in US nuclear energy policy, with a view to framing options for the next President to consider.

It is important to remember that nuclear energy is just one element of the broader energy picture. One cannot effectively address nuclear policy without reference to its role in the overall energy mix both domestically and internationally, and without acknowledging the costs and benefits of different approaches as well as the tradeoffs that must be considered among them. This Subcommittee, however, is confined by mandate to the charter of the Nuclear Energy Advisory Committee. Thus, our report will focus primarily on nuclear energy. While we will be informed by alternative energy options, we will not analyze them in depth, nor will we attempt to make definitive judgments about the relative merits or demerits of nuclear energy compared to any other energy source. We do not believe these parameters will impair our work, since we accept the premise articulated in numerous studies (such as the 2003 MIT nuclear study, IEA WEO 2007, National Energy Commission[2]) that it is unwise to exclude any alternative -- including renewable energy sources, carbon sequestration, increased energy efficiency, and nuclear power -- in the quest to reduce carbon emissions while meeting future power generation requirements. It is not just an oil, gas, or nuclear issue, but rather an energy and environmental issue. The challenge is not merely domestic, but global.

II. The Emerging Energy Picture and the Role of Nuclear Energy

Projections reviewed by NEAC suggest that demand for electric power generation is likely to continue to rise in the coming decades, especially in the emerging markets of Asia, placing ever greater pressure on existing sources of supply. Many models were reviewed. All showed a trend toward increasing energy consumption and fossil energy-driven carbon emissions.

All potential contributors to bridging the gap between electricity demand and supply -- hydrocarbons, renewables, hydropower, nuclear, and conservation -- will be needed to avoid electricity shortfalls becoming a major brake on domestic and international economic growth. In addition, given the long lead times of energy investments and lengthy service life of power generation assets, near-term decisions largely will shape the balance among these various energy sources and technologies for decades to come. The impact of these near-term decisions upon energy security and national and global efforts to reduce carbon emissions may be dramatic. For example, China is adding the equivalent of at least one 1000 MWe coal-fired power plant weekly, a pace of deployment that will drive up carbon emissions significantly for most of this century.[3]

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[2] "Ending the Energy Stalemate", *the National Commission on Energy Policy*, 2004.
[3] "Can Coal and Clean Air Coexist in China?" David Bellio, *Scientific American* August 4th, 2008.

Like other nations, the United States is grappling with the challenges posed by energy security, climate change, and the continued reliance on costly hydrocarbons. Currently, fossil fuels account for over 80% of US energy consumption. Electricity is primarily supplied through large grids, with about half of that power coming from coal-fired plants, one-fifth each from nuclear and natural gas-fired plants, 7% from hydroelectric power, and 3% from renewables. Based on current trends and policies, between 2005 and 2030 US electricity demand could grow by over 30 % [EIA AEO 2008, 2008-2030], and the respective shares provided by fossil fuel, hydro/other renewables and nuclear power would be similar to today [EIA AEO 2008, 2008-2030]. But electricity demand growth could be much higher if, for example, there is a major move toward electric vehicles (either plug-in hybrids or fully battery-operated). The fuel mix for electricity generation also might be considerably different, depending on carbon policies, energy prices, and technology changes. For example, some have suggested that nuclear reactors might be used to produce hydrogen for the transportation sector, and smaller reactors might be used to produce process heat to be distributed off-grid for thermal applications and to offer more distributed nuclear-generated electricity.[4] At the same time, advances in wind and solar technologies could enable those sources to play an increasing role in the total share of electric power generation.

Given that US hydroelectric capacity is not expected to provide significant additional power beyond what is already installed**,** additional increments of base-load power will likely come from three sources, each with its advantages and disadvantages. Coal is plentiful, but its combustion releases the most greenhouse gases of all major power sources. In addition, coal prices have increased sharply over the past few years[5]. Significant research and development efforts on clean coal technology and carbon sequestration are under way to try to reduce coal's carbon footprint. Natural gas is cleaner than coal, but natural gas prices also have risen substantially in the past five years and continue to fluctuate.[6] It should be noted that natural gas developers have identified significant additional resources in the United States, which may help ease prices.[7] Natural gas is still viewed by utilities as being competitively priced versus coal or nuclear on a total installed basis. Combined-cycle gas plants have the additional appeal of relatively quick installation and overall flexibility of operation.

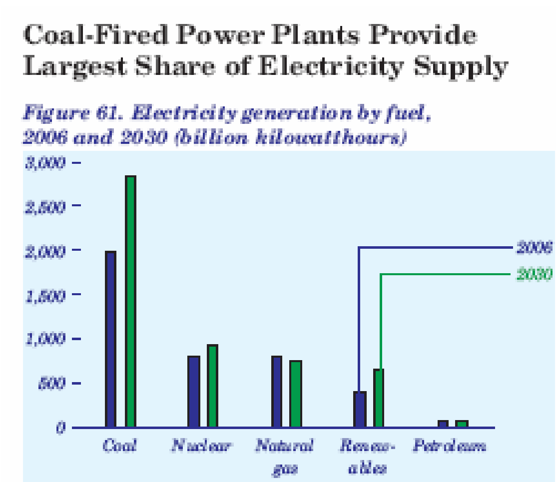


Figure 1 - EIA - AEO 2008

What about nuclear power? On one hand, nuclear power reliably provides large amounts of carbon-free base-load electricity, at a low cost once an existing plant has been amortized, drawing from reliable and plentiful supplies of relatively inexpensive fuel, with low health impacts from routine plant emissions.

On the other hand, nuclear power entails the risk of nuclear weapons proliferation and of a potentially catastrophic accident, while its chronic waste disposal problems remain

[4] "Alaska Town Seeks Reactor to Cut Costs of Electricity", Matthew Wald**,** *the NY Times***,** February 3, 2005.
[5] http://www.eia.doe.gov/cneaf/coal/page/nymex/nymex_chart.pdf
[6] EIA - http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_dcu_nus_a.htm
[7] Development of Alaska Gas Pipeline

unresolved. In addition, health and environmental concerns persist about nuclear power. Also, as noted above, it is unclear that nuclear can overcome the hurdles required to justify a multi-billion dollar commitment over the years it will require to build a new plant.

Consistent and predictable US public policy toward the electric power sector will be critical if that sector is to provide adequate generation capacity to reliably meet expected future demand. This is especially important with respect to nuclear power.

Currently licensing and building a nuclear power plant entails substantial risk and uncertainty, different in character and degree from that related to other electricity options. That said, recent experience suggests that climate concerns may make it almost as difficult to site and build a coal power plant as a nuclear powered one. This risk and uncertainty makes it difficult to control the financial and material costs of building nuclear power plants and increases the rates of return required by the private sector to invest in and build them. Reducing such risk and uncertainty is one possible role for US government policy.

The US government has assumed the responsibility for the disposition of civilian nuclear waste. Currently, because of the failure to date to build a US geological repository, the waste is being stored on-site at nuclear power plants. Fees have been and continue to be collected from nuclear generating utilities to pay for waste disposition. The US Government has successfully been sued by the utilities for its failure to fulfill its obligations under the 1982 Waste Policy Act.

In addition, in response to the March 1979 Three Mile Island nuclear accident in Harrisburg, Pennsylvania, the Nuclear Regulatory Commission tightened safety standards and regulatory requirements for nuclear power plants which, while increasing costs, also contributed to the absence of subsequent accidents. The NRC also undertook additional security measures following the terrorist attacks on the World Trade Center.

Encouraged by federal subsidies under the 2005 Energy Policy Act, a number of US utilities are now seriously considering the addition of nuclear power plants to their portfolios of power generation assets. They are attracted to the fact that amortized nuclear power plants produce electricity cheaply and reliably, and that such plants are not subject to the potential fuel supply issues and price swings posed by fossil fuels, whether domestically-produced or imported. They also see the nuclear option as providing the only widely-available and expandable base-load, carbon-free option for generating electricity. Utility executives realize that the likely introduction of a carbon tax or cap-and-trade regime will make nuclear an even more attractive alternative. To date, US utilities have filed applications for seventeen combined construction and operating licenses (COLs) with the Nuclear Regulatory Commission.[8]

Despite its attractions, nuclear power projects are too large in scale and too long in duration to be successfully managed without broad, bipartisan support at the local, state, and national level, patient and determined investments from public and private sources of capital, and a strengthened technical and scientific basis for our nuclear enterprise.

[8] Specific COL application information available at http://www.nrc.gov/reactors/new-reactors/col.html

III. US Nuclear Energy Future Scenarios - Three Cases

NEAC believes that it is both essential and urgent to mitigate the potentially disastrous consequences from climate change. The most economically efficient way to address this issue is to internalize the social costs imposed by greenhouse gas emissions, which have comprised an enormous unpaid burden (i.e. economic externality) associated with our extensive reliance on fossil fuels. That is why there is growing consensus in support of internalizing the costs of CO2 emissions through a carbon tax or cap-and-trade program, either of which would have the effect of limiting or reducing carbon emissions by leveling the playing field between carbon-emitting and carbon-free energy solutions.

As a carbon-free energy source, nuclear energy could benefit from putting a price on carbon. How great that benefit would be is hard to forecast, in light of the uncertainties regarding nuclear power *per se* as well as in comparison to the alternatives. NEAC reviewed a range of projections regarding the future deployment of nuclear power in the United States, and concluded that the inherent uncertainties precluded any confident judgment regarding which projection or projections to use as the basis for our review. Moreover, the nature of the challenges facing nuclear power are more qualitative than quantitative, i.e. no matter how many or how few nuclear power plants will be built, the same policy issues regarding waste, security, safety, and environment will need to be addressed. To be sure, the number of plants to be deployed *will* affect the marginal costs for each one, but that is an issue best left to utility executives and investors rather than to NEAC to consider.

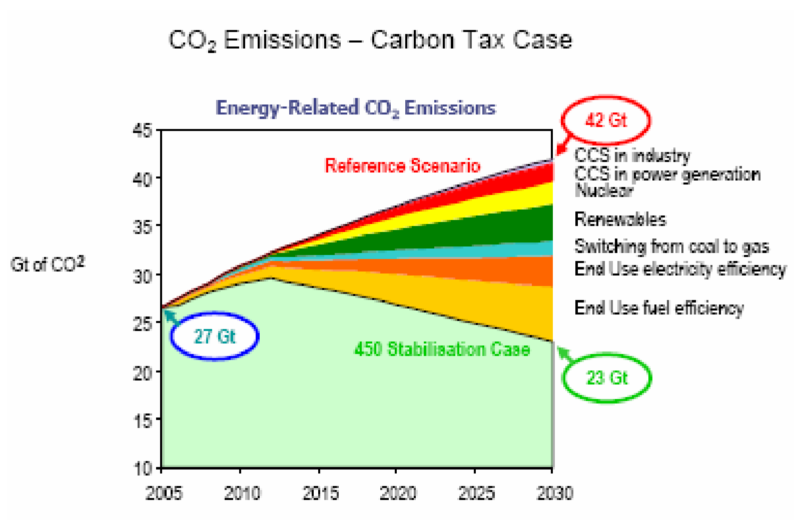
Case A - Low Scenario (0GWe increase): Even though public support for nuclear power has risen, utilities have filed applications for licenses, and politicians have demanded major greenhouse gas reductions, new build is *not* inevitable. Numerous hurdles remain, and no irrevocable commitments to new build have yet been made in the United States, unlike the dozen other countries where nuclear power stations are now being built. This scenario does assume all reactors extend operating life to 60 years. If the United States ends up in the Low Scenario, then the share of nuclear power as a percentage of total electricity between now and 2030 will decline from 19% to perhaps around 15%, depending of course on overall total market demand assumptions. Unless renewables and/or energy efficiency improvements can make up the difference, the likely consequence would be to worsen the US carbon footprint through increased reliance on coal and to marginalize further US influence in the international nuclear scene. In addition, depending on federal policies with respect to renewables and carbon emissions limitations, this scenario may also lead to increased electricity system failure and reduced economic growth, as well as potentially higher electricity prices as a function of declining nuclear-generated power supplies.

Case B - Middle Scenario (17GWe increase): For the Middle Scenario, NEAC relied upon the Energy Information Administration reference case, which assumed no change in existing US nuclear or other energy policies. That would result in 17 GWe of new nuclear power stations entering service by 2030, which would hold nuclear roughly at its same share of US electricity generation, slipping only slightly from 19% to 18% of the total.[9] (This scenario also assumes that the lives of all currently operating reactors would be extended to 60 years.) It is important to recognize that "just replacing existing nuclear power" or "just holding

[9] Annual Energy Outlook 2008, EIA, Page 11

nuclear at its current share" of US electricity supplies will not happen by default. To the contrary, it would require over a dozen new reactors of one GWe or more to be ordered, reflecting major decisions by utility executives, investments by the financial community, regulatory and possibly commercial support from government, and an enormous effort involving thousands of engineers, manufacturers, technicians, and others. Even with that level of effort, however, this scenario would not itself make a significant dent on US greenhouse gas emissions, given the likely growth of fossil-fueled electricity and absent dramatic progress on clean coal technology, efficiency, and renewables over the same period.

Case C - High Scenario (45GWe increase): If a significant price were placed on carbon dioxide, either through a carbon tax or a cap-and-trade system, nuclear power expansion could be much greater assuming continued increases in GNP and electricity demand.[10] Under these circumstances, a new deployment of up to 45GWe by 2030 could be considered, although it is important to note that available forecasts vary regarding the potential increase of nuclear's market share as a function of carbon tax rates. Expanding nuclear power on that scale would begin to make significant inroads in the US carbon footprint, but the scale and pace of effort would substantially exceed that which the current nuclear infrastructure of the United States could support. Even with additional infrastructure, building 30 new GWe of new reactors by 2030 would be a major challenge. Note that in the EIA reference case, 176 GWe was added in total electricity capacity between 2008 and 2030, including the 17 GWe of nuclear capacity. For the EIA high case, 252 GWe was added in total electricity capacity between 2008 and 2030, including 31 GWe of nuclear capacity.



In this IEA Chart, by 2030, emissions are reduced to some 23 Gt, a reduction of 19 Gt compared with the Reference Scenario by enacting carbon restraints

[10] E.g. S.2191- The Lieberman-Warner Climate Security Act of 2007

IV. Domestic Policy Issues

NEAC considered eight major policy issues categories in the context of one or more of the three scenarios above:

- Waste management
- Research and development
- Human resources
- Supply chain management
- Safety
- Security
- Reactor licensing
- Policy environment

A. Waste Management

In June 2008, the Department of Energy submitted to the Nuclear Regulatory Commission (NRC) an 8,600 page license application to construct and operate a deep geologic repository for spent fuel and high-level radioactive waste at Yucca Mountain. On September 8, 2008, the NRC docketed the license application, and will now begin the process of evaluating technical and scientific issues to determine whether "DOE can demonstrate that it can safely construct and operate the repository in compliance with the NRC's regulations," a process likely to take three to four years.[11] The DOE in August 2008 reported to the Congress that the total system life-cycle cost to operate the repository from 1983 to 2133 would be almost $100 billion, including an expansion to accommodate 120,000 tons of waste, up from a previously planned capacity of 70,000 tons.[12] The earliest opening of the repository is estimated to be after 2020. Meanwhile the USG is paying up to $500 million per year in damages to utilities from which it was to have begun accepting waste in 1998. These court-directed damages could total over $60 billion. The continuing legal liability adds urgency to the need to address the high-level waste management issue. In addition to the spent fuel arising from commercial reactor operations, a repository is also required to store US defense waste.

Repository science is one of the areas of the nuclear enterprise in which the US is considered a world leader. Thus, proceeding with the NRC licensing process for Yucca Mountain is important to the US nuclear energy program and electricity sector, while supporting the US role in nuclear power globally.

In addition, it is important to examine the option of interim storage as a strategic component of the US waste management program, and to consider whether the US government should take title to the spent reactor fuel and tap the Waste Fund to pay for security of the fuel at volunteer locations or at existing plants, pending future use or final disposition.

In order for the United States to help mitigate proliferation risks, assure adequate fuel services to support the expanding number of nuclear reactors, and optimize the long-term efficiency of the

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[11] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-yucca-license-review.html
[12] See DOE Press Release on Yucca
http://www.ocrwm.doe.gov/info_library/newsroom/documents/8_5_08_FINAL_TSLCC_PR.pdf

nuclear fuel cycle, continued support for research and development efforts to improve the nuclear fuel cycle should be considered. NEAC notes that these objectives are currently addressed in an Advanced Fuel Cycle Initiative (AFCI). AFCI was launched in FY2003 and was required by statute "to conduct an advanced fuel recycling technology research, development and demonstration program" to evaluate fuel recycling and transmutation technologies to meet waste management needs "as an alternative to aqueous reprocessing technologies".[13] NEAC recommends that the AFCI program and alternative approaches be reviewed in terms of the ability to meet the objectives cited above.

Fuel cycle R&D could significantly change the challenges for the storage of nuclear waste at various locations, including Yucca Mountain. The integrated operation of various approaches to nuclear waste management also can affect the feasibility of fuel leasing over time, which could mitigate proliferation risks by reducing the incentives for more nations to acquire enrichment and reprocessing facilities that can be used to produce weapon-usable materials. Although the US is not currently reprocessing spent fuel and has not done so in over 30 years, many governments see the United States as a valuable partner in developing back-end technologies. Meanwhile Europe and Japan are implementing closed fuel cycles and looking to the US to collaborate on advanced R&D.

- NEAC believes that the US Government should complete the NRC licensing process for the Yucca Mountain project to determine its acceptability as a disposal site, while it also explores other options for waste management.
- NEAC believes that the United States should dedicate a significant research and development effort to improve the nuclear fuel cycle and minimize attendant proliferation risks.

B. Research and Development

The global nuclear marketplace is evolving, with a number of foreign suppliers now building new power reactors. The US has been a leader in nuclear safety, nonproliferation, security and, as noted above, in repository science. US research and development support for our nuclear program is not only necessary to continue to improve safety and waste disposition, but also to allow the US once again to play a meaningful role in reactor development and in other key elements of the global and domestic nuclear enterprise.

Establishing near- and long-term US nuclear R&D priorities must take our current domestic nuclear infrastructure as its point of departure. The Department of Energy, under White House guidance and in consultation with other key agencies and the Congress, should define and implement a roadmap of priorities for improving that infrastructure. Such a road map will help to inform the evolving missions for the DOE national laboratories and facilitate their modernization. In addition, this road map process should help to establish a consensus on the appropriate roles of government and industry. Some specific near-term R&D priorities for the United States in the field of nuclear energy should include the following:

- Safety, life extension, and decommissioning the existing fleet;

[13] P.L. 105-98, August 8, 2005, Sec 953

- Issues related to new build of Gen III+ reactors;
- Gen IV reactors; and
- Back-end solutions to the nuclear fuel cycle.

The consequences of a weakened nuclear infrastructure in the United States include reduced domestic capability to support the role of nuclear energy as well as the related problem of the reduced ability to attract and retain the talent at all levels -- from technicians to engineers to Ph.D.s -- needed to develop and sustain active US participation in the domestic and global nuclear marketplace. In that vein, NEAC recommends that both university and industry programs in nuclear R&D be strengthened, and that laboratories and facilities in the DOE complex be modernized and made more efficient. These programs should be developed in consultation with relevant government agencies and scientists, DOE national laboratories, private industry, and the academic community.

NEAC recommends that:

- The DOE lead the establishment and implementation of a nuclear energy R&D roadmap, in consultation with appropriate parties.
- University and industry programs in nuclear R&D be strengthened, and that laboratories and facilities in the DOE complex be modernized and made more efficient.
- The DOE review existing nuclear fuel cycle research and development to assure that it is meeting US needs in the nuclear fuel cycle.

C. Human Resources

The US nuclear workforce is aging and, as more and more head into retirement, it will become increasingly critical to recruit and retain technically qualified personnel. In order to assure an adequate workforce it is essential that students, technicians, and scientists see both intellectual challenge and attractive career paths in the nuclear field. Currently, satisfaction of neither criteria can be guaranteed. The current and projected pool of individuals with the qualifications to support the nuclear enterprise in the United States might be adequate to support the existing number of nuclear power plants and, thus, of the Low Scenario. A significant expansion of the nuclear workforce, however, would be required to support either the Middle or High Scenarios. (See American Physical Society, *Readiness of the US Nuclear Workforce for 21st Century Challenges*, APS Panel on Public Affairs, June 2008.[14])

Given the long lead-times in the development of human resources (longer still for faculty than for students, of course), in order to preserve the option for the Middle and High Scenarios, the DOE and NRC should review projected human resource requirements for engineers, technicians, operators, regulators, and scientists (physics, chemistry, radiochemistry) and develop options to promote career pathways in these fields. This would enable government, industry, and academia to work together to develop plans and programs to provide assurances that the US nuclear effort will be appropriately staffed by individuals qualified and motivated to support a successful growth of nuclear power, and to learn from existing programs to recruit and retain new talent.

[14] http://www.aps.org/policy/reports/popa-reports/upload/Nuclear-Readiness-Report-FINAL-2.pdf

Expanding US human resources sufficient to support an expanded number of nuclear reactors may be useful not only in terms of US domestic requirements, but also in light of the new-build already proceeding or planned abroad. For the individuals, it is likely that some of the new nuclear programs will generate substantial requirements for new talent that could easily come from US programs. For the Nation, it would be to our collective benefit if nuclear energy facilities the world over eventually could be staffed at least in part by US-trained personnel.

- NEAC recommends that the DOE and NRC take steps to promote the development of a workforce able to meet the human resource requirements for engineers, technicians, operators, regulators, and scientists (physics, chemistry, radiochemistry) on a timely basis, keyed to the deployment of new nuclear power reactors and other parts of the nuclear fuel cycle (e.g. waste management).

D. Supply Chain Management

It will be important to examine US domestic capabilities to support all links in the nuclear power plant and fuel cycle supply chain in order to identify any gaps that would need to be filled if utilities decide to build new domestic reactors. Recent studies have concluded that there are a number of potential chokepoints both in the nuclear fuel cycle and in the supply chain to support new reactor construction.[15] Potential fuel cycle chokepoints include fuel conversion and spent-fuel storage services. Reactor construction chokepoints include those that are material-related (heavy forgings) and those that are personnel-related (shortage of trained craftsmen with prior nuclear field experience). Expanding existing sources of supply and developing alternatives should both be explored in order to ease these possible chokepoints. The degree to which the US can rely on foreign suppliers for each of those gaps should also be analyzed.

- NEAC recommends that the DOE evaluate what actions the US Government could take to facilitate or enhance the adequacy of the U.S nuclear power plant and fuel cycle supply chain, in order to identify any gaps that would need to be filled if utilities build new domestic reactors.

E. Safety

The principle of "safety first" must guide all actions regarding the design, construction, and operation of nuclear power plants. In order to give that standard a practical meaning, it is necessary to ensure that nuclear manufacturers, operators, and regulators begin from the same basic analysis describing the kinds of risks that need to be mitigated. That analysis must be rigorous in order to hold the nuclear industry to an appropriately high standard, and realistic in order to ensure that safety efforts are focused on areas of practical risk. In order to maximize the safety of the nuclear enterprise, it is essential that a "culture of safety" be promoted among all personnel, from maintenance crews to control room operators to senior management. It must also apply to all actors in the nuclear arena, from government or the private sector, reactors or fuel cycle facilities, transportation and storage depots.

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[15] "The World Nuclear Industry Status Report 2007," Mycle Schneider, with Antony Froggatt, January, 2008.

- NEAC recommends that the principle of "safety first" continue to guide all actions regarding the design, construction, and operation of all nuclear facilities. (The DOE should lead by example and build upon the experiences US industry -- including nuclear manufacturers, operators, and regulators -- to begin from the same basic analysis describing the kinds of risks that need to be mitigated.)

F. Security

Security against potential hostile actions is critical to the successful operation of any nuclear facility. As with safety, the security plans and strategies for a nuclear facility should be premised on a solid threat analysis. The "design basis threat" (DBT) sets the standard against which security measures are evaluated. New plant designs contemplate a more severe threat than those from before 9/11.

Aspects of security that need to adapt and respond to security threats include material control and accountability, safeguards, and cyber-security. Following the tragic events of 9/11, industry and the Nuclear Regulatory Commission engaged in a wide-ranging effort to ensure that the threat regarding possible attacks on nuclear reactors, fuel-cycle facilities, and transportation facilities was properly analyzed and calibrated, and that the measures in place to confront those threats were adequate. These efforts, of course, must apply equally to both government and private-sector facilities. Additionally, all operators of nuclear facilities should adopt performance-based metrics for evaluating security system effectiveness, and not just rely on mechanical application of rules without reference to actual system performance.

- NEAC recommends that security be given top priority in DOE facilities, and be premised on solid threat analysis, which can be shared where appropriate with the US commercial nuclear industry. Security must be integrated into facility design, planning, construction and operation, not grafted on top of an existing program.

G. Reactor Licensing

In 1974, Congress reorganized the Atomic Energy Commission into two separate entities, on the theory that combining within the AEC the twin roles of promoting and regulating nuclear energy created an inherent conflict of interest between those two functions. Under the Energy Reorganization Act, the promotional mission of AEC went to the Energy Research and Development Administration, later to be absorbed into the newly-created Department of Energy. The regulatory functions were assigned to the Nuclear Regulatory Commission, an independent government regulatory agency, whose members are nominated by the President and confirmed by the Senate.

In 1979, the nuclear accident at Three Mile Island shattered US public confidence in nuclear power and led to a thorough review of NRC rules and procedures. While the intensified scrutiny was justified, the frequent revisions to licensing requirements and standards led to delays and confusion for operators of nuclear reactors subject to NRC jurisdiction. In recent years, the NRC and the nuclear industry have worked hard to improve the regulatory process. Standardization of reactor designs will help to support a more consistent approach to safety and regulation. That said, to date, the licensing process still leaves substantial room for improvement. For example, numerous amendments have been submitted during the COL and generic design reviews, leading to the initiation of multiple reviews to resolve different issues.

The question presented now is whether the NRC can further improve its licensing processes and, if so, how? The issue is complicated by NRC's status as an independent regulatory agency, not formally part of the Executive Branch. Thus issues of coordination and consistency of policy between NRC and other relevant agencies (such as DOE, EPA, DOS, DHS, 50 states) will be important in determining what role nuclear will play in the expansion of the US installed power generation base. At the same time it is, of course, critical that any such improvements not curtail effective public participation or in any way sacrifice the safety or security of any nuclear facility.

Regulatory reviews should be performed in a timely manner, while preserving the public's right to be heard in the process. Large investments in major base-load nuclear power plants are affected as much (or perhaps more) by length of time of exposure of risk capital as by total installed costs (i.e. "time is money"). Further, if deployment of smaller (and more easily operable) "modular" plants is important to certain markets either domestically or overseas, special (i.e. set-aside) resources may be needed for regulatory authorities to provide thorough, complete, and efficient licensing.

- NEAC recommends that the NRC, with support as needed from the Executive Branch and other parts of the US government, strive toward further improvement in its licensing processes, while coordinating with other affected agencies in a transparent manner open to citizens' participation.

H. Policy Environment and Financing Nuclear Power Plants

Nuclear power stations take years to plan, finance, and build. Once operating, they run for decades. Their development and safe, efficient, and economical operation therefore depends on a consistent and sound policy environment. That policy environment must be scientifically grounded, publicly supported, and informed by clear standards of safety, security, nonproliferation, and environmental stewardship.

From the 1950s until the 1970s the United States had a fairly consistent policy environment regarding nuclear energy. Then, a number of events -- including India's diversion of civil nuclear assistance to explode a nuclear device in 1974 and the Three Mile Island accident in 1979 – triggered a major reassessment of US nonproliferation and nuclear energy policies that infused the US policy environment with conflict and uncertainty. The United States, under Presidents Ford and Carter, abandoned a number of plans and policies (*e.g.*, those supporting recycle of mixed-oxide fuel in thermal reactors, pursuit of breeder reactors and commercial plutonium reprocessing), and sought to persuade other governments to follow suit. These efforts produced mixed results, at best.

Added to (and, to some degree, influenced by) this changing political environment, nuclear power lost public support, even as climbing capital costs eroded its competitiveness as a source of electricity. In 1981 the Washington Public Power Supply System (WPPS) abandoned plans to build two nuclear power plants and defaulted on $2.5 billion in bonds, the biggest municipal bond default in history. Today, whether nuclear power can be competitive in light of its large capital requirements remains among the biggest unanswered questions hanging over its future in the United States. This uncertainty raises the capital cost and the return required by investors to commit to financing nuclear power projects.

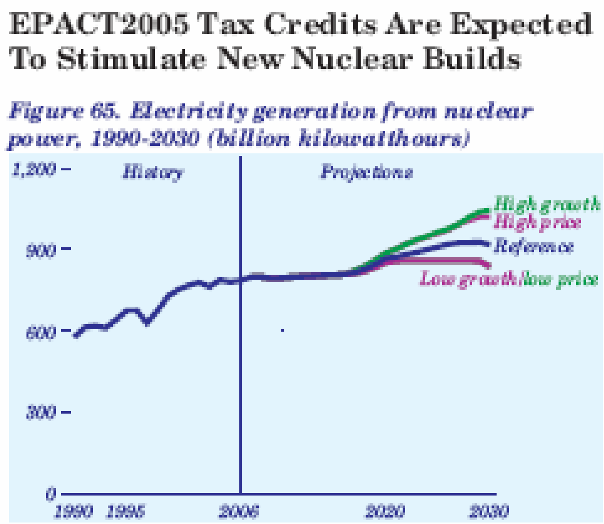

Figure 2 - EIA - AEO 2008

The Energy Policy Act of 2005 provides for loan guarantees and related additional financial provisions to support the construction of the first few new nuclear plants in the United States, but it remains unclear whether the guarantees provided will be sufficient to induce utility executives to commit to building those plants. Some believe that the loan guarantee program plays an important role in the building of any new nuclear power plants, especially in the deregulated states, as most banks won't invest in a new plant without it. Others believe that it is inappropriate for the federal government to subsidize the first few nuclear plants, since nuclear is a mature technology and the federal subsidies would not reduce the cost of new nuclear plants. Moreover, at the time of this writing it is not yet clear what effect the financial crisis of 2008 will have on investment decisions regarding nuclear power.

In addition to government, other major stakeholders must be actively engaged to ensure a clear, transparent and positive policy environment. This process must be inclusive for long-term deployment objectives to be achieved. Industry involvement, academic review, NGO activities, and citizens' participation will provide not only a thorough vetting of policy options but also the best opportunity to educate participants and to discuss institutional innovations as well as the trade-offs inherent in each of the three cases NEAC considered.

V. International Implications of Increased Reliance on Nuclear Power

Regardless of what course is taken on nuclear power in the United States, other nations are moving ahead to expand the number of new nuclear power plants. Today, 36 reactors are already under construction in a dozen nations. According to the World Nuclear Association, another 93 reactors have been planned, and 218 more have been proposed. On the other hand, some number of reactors will also be retired, though far fewer than are projected to be built.

The fact that these reactors are being built in other countries does not relieve the United States of its responsibilities regarding nuclear power. In fact, without a US presence, other countries will be setting the standards and expectations for the nuclear energy industry, as well as controlling nuclear energy science and the safety, and addressing environmental and security issues arising from the use of nuclear power. But the health and safety of US citizens as well as the ability of nuclear power to contribute to the US energy mix could suffer dramatically from any significant nuclear accident anywhere in the world.

Nuclear energy should only be pursued with full awareness of and attention to the need to minimize the risks of nuclear weapons proliferation. For example, if nuclear power plant expansion is accompanied by a linear expansion of countries engaged in enrichment and reprocessing, there will be an increased risk of proliferation. It is important to institutionalize fuel-cycle mechanisms to reduce that risk (*e.g.,* through multilateral arrangements, fuel assurances, leasing, and/or a fuel bank). It is urgent to finalize these mechanisms in time to encourage the establishment of a regime of restraint in fuel-cycle expansion. Life-cycle guarantees or nuclear fuel leases that offer cradle-to-grave fuel services, covering both front-end fuel assurances and stockpiles as well as back-end used-fuel management and disposal arrangements, may provide a number of governments sufficient confidence that they may forego the option of developing their own fuel cycles.

Without US leadership, it is far less likely that the international community will settle on international fuel-cycle arrangements that minimize the risks of nuclear proliferation. And if the United States is not itself engaged in building new nuclear power plants, including new reactor design and fabrication, it will be left with an ever-diminishing influence in international discussions relating to future nuclear power and fuel-cycle arrangements.

The USG has shown leadership in launching the Global Nuclear Energy Partnership. Since 2006, GNEP has codified principles agreed by over 20 nations to begin the long term process to bring this about. The partners share a common vision of the necessity to expand nuclear energy for peaceful purposes worldwide, to accelerate development and deployment of advanced fuel cycle technologies that do not separate plutonium and that reduce the risk of nuclear proliferation. The partnership includes the five permanent members of the U.N. Security Council, countries with significant nuclear programs or resources (*e.g.* Japan, South Korea, Australia, Kazakhstan), countries yet to operate a commercial reactor (e.g. Oman, Senegal, Jordan), as well as multilateral entities such as the IAEA and Euratom as permanent observers. Working groups have already been formed on reliable fuel services and infrastructure. An additional 42 countries attended the GNEP Ministerial meeting in October 2008.

It is imperative that the United States strengthen and restore the international agreements and institutions that underpin the global nonproliferation regime, beginning with the Non-Proliferation Treaty and the International Atomic Energy Agency. Those cornerstones have been reinforced over the years by regional nuclear weapons-free zones (*e.g.,* in Latin America and Southeast Asia), multilateral initiatives (*e.g.,* Nuclear Suppliers Group, the Proliferation Security Initiative, and the Global Initiative to Combat Nuclear Terrorism), and other efforts. Overarching the nonproliferation regime is the UN Security Council, which has the authority to sanction governments that violate global nonproliferation norms. Those norms were strengthened in 2004 through the approval of Security Council Resolution 1540, which obligated member states to take effective steps to enforce nonproliferation commitments and to

> "…take and enforce effective measures to establish domestic controls to prevent the proliferation of nuclear, chemical, or biological weapons and their means of delivery, including by establishing appropriate controls over related materials..."

In addition, the issues of nuclear weapons proliferation and nuclear energy remain intertwined in a number of critical cases, most notably in Iran and North Korea. Significant proliferation issues persist as well among other states that have declined to accede to the NPT, such as India, Israel, and Pakistan.

In order to succeed in curbing nuclear weapons proliferation, the United States must coordinate effectively with the other nuclear weapon states recognized under the NPT: the United Kingdom, France, Russia, and China. Cooperation with the last two of these nations is essential, yet often elusive. Progress, however, has been made. China, for example, has shown increasing leadership in dealing with the North Korean nuclear challenge. Despite significant disagreements in other areas, Russia has often been cooperative on important nuclear initiatives (*e.g.,* US-Russia HEU deal, Cooperative Threat Reduction, Bratislava initiative, plutonium production reactor shutdown agreement, etc.). Russia has been a critical partner in international efforts to reduce the Iranian nuclear threat, including through insistence of a cradle-to-grave fuel arrangement for the Bushehr reactor (eliminating the need for uranium enrichment and plutonium reprocessing facilities to support that plant) and through offering Iranian participation in the Angarsk nuclear fuel initiative, to the same end. Further, the two sides committed to wide-ranging nuclear cooperation in April 2008 at Sochi. Despite significant disagreements over Georgia and other issues, US-Russian cooperation in combating proliferation and nuclear terrorism should continue, as it is strongly in the security interests of both nations and, indeed, of the entire international community.

A number of other proliferation issues need to be addressed, including the modernization of US and multilateral export controls, the development of discrete threat-reduction strategies for state vs. non-state actors, and the development of US policy toward specific nations.

In late 2007, the Director General of the IAEA established a Commission of Eminent Persons to review the Agency's current activities and make recommendations regarding future priorities in the light of recent and expected developments.[16] The report noted that a substantial increase in the use of nuclear energy would result in calls for the Agency to give priority to promoting the efficient, safe and secure use of facilities in states, including those new to nuclear power, as well as helping to prevent and mitigate nuclear accidents. IAEA activities were deemed likely to continue to include the establishment of authoritative guidelines, as well as the dissemination of experience, new knowledge and best practices, the provision of training, and the organization of peer reviews. A global expansion in the civil use of nuclear technology, the report noted, would bring with it increasing concern about the risk of accidents and the threat of nuclear terrorism. The spread of nuclear material, technology and know-how could also pose increased proliferation risks. The Agency would therefore continue to give high priority to strengthening prevention measures at both the national and international levels, and establishing measures to help ensure a coordinated response should prevention fail.

The IAEA is clearly likely to remain a major actor in preventing the spread of nuclear weapons.

NEAC recommends that:

- The US Government develop and articulate a nuclear energy policy that will minimize the risks of nuclear proliferation.

[16] Report available at http://www.iaea.org/NewsCenter/News/PDF/2020report0508.pdf

- The US should work urgently with the IAEA and other nations to institutionalize fuel-cycle mechanisms to provide assurances to governments hosting nuclear power facilities that their fuel needs will be met so long as they adhere to international nonproliferation standards.
- The International Atomic Energy Agency should be budgeted with sufficient resources to perform its mission properly.
- The USG should take concrete steps to preserve and strengthen the NPT.
- While the US is currently not engaging in commercial domestic reprocessing of nuclear fuel, the USG should respect the existing commercial programs in countries that adhere fully to global nonproliferation norms (e.g., Europe and Japan) and should work with international partners to research and develop the most safe and secure forms and use of materials.

VI. Conclusion

The policy issues that arise out of the use of nuclear power can be complex and daunting. Yet, ironically, the expansion of nuclear power may make some of these problems easier to solve. Why? During the many years that nuclear energy was consigned to the backwaters of energy policy and power generation, vested interests in the success and expansion of nuclear power stagnated and atrophied. Now the renewed interest in building nuclear power plants has reinvigorated efforts to ensure that the issues critical to the successful deployment of nuclear energy – including the supply chain, human resources, and regulatory infrastructure – are scaled properly to the task. The process of expanding the use of nuclear power also gives a wide variety of stakeholders – from ratepayers to equipment manufacturers to utilities to regulators – a far greater stake in the success of nuclear energy. Each stakeholder adds incrementally to the self-interested actions to increase the safe, secure and efficient operation of nuclear power plants, to adopt and execute a responsible waste management policy, and to minimize the risks that dangerous nuclear technology and materials may fall into the wrong hands.

Harnessing self-interest and the power of the marketplace to the interests of the commonwealth in the safe and secure use of nuclear energy is not a pipe dream. It is a reality that has been operating successfully for more than a decade in the form of the US-Russian HEU deal, under which the United States agreed to purchase 500 metric tons of highly-enriched uranium from Russia's nuclear stockpile – enough for 20,000 nuclear warheads -- to be blended down for use as commercial nuclear reactor fuel. Each year, one half of the uranium fuel consumed in US reactors comes from the HEU deal. Since nuclear power accounts for one-fifth of the power generated in this country, that means that one out of every ten light bulbs is powered by material that used to sit atop Soviet ICBMs in warhead form targeting American cities.

If nuclear power can play such a positive role in making America safer from the dangers of nuclear Armageddon, perhaps it can also play a more significant role than it is currently playing in efforts to limit greenhouse-gas emissions in the United States. As noted above, internalizing the costs carbon imposes on the planet could have a profound effect on promoting carbon-free energy sources, including nuclear.

It is important that international implications be analyzed and addressed since nuclear power is already present and in the process of expanding in other countries. If the United States does not expand the number of nuclear power plants on its soil but other nations do so, it will become increasingly difficult for the United States to carry significant weight in international efforts to manage global nuclear expansion. Given the stakes to the United States and the high US standards in safety, it is in US national interest to play a leadership role in global efforts to address the safety, security, environmental, and proliferation implications of nuclear power.

US decisions regarding nuclear energy may affect the global nuclear marketplace, both directly (through nuclear commerce in equipment, technology, and materials) and indirectly (as a product of the US example). In that sense, lack of US decisions will also affect the global environment surrounding nuclear power. In either event, it is in the US national interest that our government takes decisions cognizant of the impact of those decisions on other countries

In order to develop sound policies in the areas described above, it will be necessary for the US Government to engage not only with the relevant committees of the US Congress and with the relevant offices and bureaus within the Federal Government with expertise and responsibilities in this area, but also with the scientific community, industry, nongovernmental organizations, and citizens at large.

Framing all policy issues within the context of a Low, Middle, or High path for commercial nuclear power deployment provides a useful basis for understanding key policy alternatives. In order for either the Middle or High Case to become viable, significant progress would need to be made in all of the issue areas outlined in this paper. Before that can occur, extensive dialogue involving all stakeholders, from both public and private sector, will be required. At the same time, it is critical that domestic and international implications be analyzed and addressed if nuclear expansion is to be a viable option for the US and other countries. If the US does not expand the number of nuclear plants it has but other nations do so, it will become increasingly difficult for US to carry significant weight, on environmental, safety and security, and nonproliferation issues, in international efforts to manage global nuclear expansion. Given the stakes to United States, it is firmly in the US national interest to play a leadership role in global efforts to address safety, security, environmental, and proliferation implications of nuclear power. US nuclear energy policy has been analyzed and debated for years. Now is the time for thoughtful action.

NEAC Technical Subcommittee Report

I. Introduction

The NEAC technical subcommittee:

- Reviewed the facilities available for nuclear energy programs starting from reports produced for DOE-NE.
- Recommends R&D programs to match the scenarios developed by the policy subcommittee.

This report also identifies some issues relating to broader US interests relating to nuclear matters. The subcommittee report was approved by the full NEAC.

II. Facilities Review

The subcommittee reviewed the following references:

1. *Nuclear Energy for the Future: Required Research and Development (R&D) Capabilities – An Industry Perspective* (September 2008) - An effort led by Battelle documenting input from over 30 industry and university representatives on the capabilities and types of facilities needed to further research and development in support of the domestic nuclear power industry over the next 20 years.

2. *Required Assets for a Nuclear Energy Applied R&D Program* (September 2008) - An Idaho National Laboratory (INL)-led effort documenting current assets in the US and overseas that could be used to meet the facilities and capabilities identified in the Reference 1 Battelle study. In addition to identifying various assets, the INL study provides information about the adequacy, accessibility, and availability of these assets to meet anticipated nuclear R&D requirements.

3. *Executive Recommendations for Nuclear R&D Capabilities* (July 28, 2008) - This Battelle-led effort documents recommendations developed by a team of executives from industry, national laboratories, and universities and the basis for these recommendations.

4. *A Sustainable Energy Future: The Essential Role of Nuclear Energy* (August 2008) - A position paper from the Directors of Department of Energy (DOE) national laboratories recommending near-term and long-term actions for developing the nuclear energy strategy in the US

5. *Evaluation of Existing Department of Energy (DOE) Facilities to Support the Advanced Fuel Cycle Facility (AFCF) Mission* (August 2008) – A report issued by the GNEP program evaluating the capabilities and economics associated with using existing DOE hot cells for conducting an AFCF engineering-scale operation. Reference 2 incorporates input from various programs about facilities needs and adequacy for various missions. Reference 5 estimates the costs for renovating facilities for this program.

The DOE-NE effort is not yet complete. DOE-NE intends to issue a report with a priority list of funding recommendations with respect to maintaining, modifying, and developing facilities required to support the R&D needed for nuclear energy to remain a viable option in the United States. DOE-NE indicated that the Office of Science document, "*Facilities for the Future of Science: A Twenty Year Outlook*," should be considered as a model for this DOE-NE effort.

NEAC believes that this effort is much needed and very ambitious (with respect to schedule and budget). The subcommittee recognizes that schedule limitations precluded obtaining input from some owners of applicable facilities.

- NEAC recommends that efforts be continued to include additional university, industry, and foreign facilities of interest. NEAC also recommends that this effort be expanded to recognize the impact of other DOE missions on these facilities and the need for DOE-NE facilities to support missions outside of DOE-NE, including NNSA, NR, SC, and RW.

Although facility funding levels change each year, some indication of historical and current facility customers and required operating budgets should be examined as DOE-NE prioritizes facility funding allocations in their strategic plan.

All five references provide a list of recommendations for DOE-NE nuclear energy research (there are other areas of importance that are mentioned later). While there are some differences in the recommendations in the above five references, the prioritized goals listed in Reference 3 encompass the major components of the recommendations of all five.

- Further improve operations and extend the lifetime of the fleet of current and future light water reactors.
- Assure a well-qualified and trained workforce.
- Development and demonstration of Generation IV reactors, such as the Next Generation Nuclear Plant (NGNP), to extend the applications of nuclear energy.
- Upgrade domestic facilities and expand the collaborative use of international facilities for activities required to create a sustainable fuel cycle.
- Combine recognized fast reactor core competencies in critical areas with a robust program of international collaboration.
- Develop a modeling and simulation capability.
- Establish the Strategic Nuclear Energy Capability Initiative to assure that the proper resources are allocated to allow meeting the above objectives.

The majority of the subcommittee concurs with the above general recommendations as high priority capabilities for DOE-NE R&D investment (although some members disagreed with the prioritization of some items). The subcommittee has clarifications for several of these recommendations. For example, as discussed in Section IV of this report, the committee recommends strongly that the modeling and simulation capability be established adhering closely to the guidance stated in Reference 3 and supports initially developing the modeling and simulation capability by using existing capabilities procured by the Office of Science or NNSA and by demonstrating its worth with a pilot program that illustrates the economic benefit of this effort.

Although Reference 2 is still a draft, facility status information in this document clearly shows the following:

Many high priority facilities require moderate to significant investment before they could provide the capabilities needed by DOE-NE. (Reference 2 assessments of facility adequacy and costs to prepare for various missions were qualitative. As assessments similar to that documented in Reference 5 are conducted, required investments should be quantified).

- NEAC agrees that a strategic initiative is needed to ensure that the required facilities are available and ready to support these missions (especially those identified for multiple DOE-NE missions).

As noted in Reference 3, an integrated, time-phased and user-driven approach should be used for allocating funding for this initiative.

- NEAC agrees on the importance of emphasizing international collaboration, especially with respect to longer-term, high cost R&D goals, such as in developing recycling and fast reactor capabilities.

As noted in Section VI of this paper, significant capabilities in these areas currently exist in other countries (e.g., such as the operating JOYO reactor in Japan and reprocessing capabilities in France and the United Kingdom). As the US strives to regain its capabilities in these areas, the financial benefits associated with such collaborations should be explored to the fullest extent possible.

III. R&D Facilities

Reference 2 above assessed the state of all the significant facilities that are required to carry out a world class program. The assessment covered facilities needed for LWR development, irradiated fuel separation, advanced fuel development, and advanced reactor R&D.

- A depressing story was revealed of decayed or decaying facilities that in most cases are not suited for their intended uses without significant and often expensive refurbishments. Although several superior facilities were identified, even these facilities were not as good as needed for conducting the missions assigned to the US nuclear energy program. Neither DOE nor Congress has been willing to supply the necessary funds to maintain the R&D complex in good working condition.

The DOE's nuclear facility needs have to be ultimately determined by the mission and the budget. NEAC has laid out three options for the expansion of nuclear energy in the US ranging from no new power plants to many new plants between now and the year 2030. There also are advanced programs in progress related to GEN IV and GNEP.

- However, even if aggressive new power plants and advanced programs do not proceed, the United States needs a robust set of nuclear research facilities. There are basic needs for R&D facilities in a country with 104 currently operating plants, a major high temperature gas cooled reactor program, thousands of tons of spent fuel to ultimately be disposed of, a vital interest in safeguards and security for nuclear plants all over the world, and an even more vital interest in limiting the proliferation potential from both the front and back ends of the nuclear fuel cycle.

In addition, there are issues relating to homeland security, space missions, and nuclear medicine that are independent of the projected growth of new nuclear power reactors. Current Department facilities to support all of these missions are in many cases inadequate without upgrades and refurbishments that will have significant costs. The lack of modern facilities also affects the ability to attract nuclear experts needed to support world class research.

- The DOE needs to provide an analysis for the next administration that looks at the current status and suggests a multiyear program including facility upgrades and new facilities necessary for its several missions. The analysis should systematically examine which facilities need to be maintained, upgraded, abandoned, or built new. The goal would be to have the right mix of mission-driven modern facilities that can be kept up-to-date and operated safely.

IV. Modeling and Simulation

Huge advances in computer power are available today that allow science to be incorporated in simulations at a scale from smallest to largest much greater than previously conceived. This is a potentially high value-added activity but there are obstacles to overcome to make effective use of the available computer power. Many of the existing codes are not written in a fashion that allows them to be run on the massively parallel computers that give the greatest increase in computer power. Also many of these codes have science gaps that are bridged by perturbation analyses that may not account properly for nonlinear effects that dominate in some applications.

Advanced simulation programs can benefit LWR programs for life extension as well as advanced new reactor programs by shortening design and testing processes.

An example is what has happened in the last several decades to aircraft design. As the computer codes have gotten better and have been tested against real world systems, aircraft design has gone from incremental steps followed by flight tests followed by more incremental improvements, etc., to a mode where most of the design is done in the computer and the final flight test verifies the design. Aircraft design times have been greatly shortened, and costs have been greatly reduced.

- An advanced modelling and simulation effort can lead to better understanding of nuclear energy systems and has the potential to resolve long-standing uncertainties associated with the deployment of these systems.

Among these long-standing problems are the uncertainty associated with plutonium recycle in United States LWRs[17], qualification of new fuels, extending the burn up of existing fuels and the

[17] To date nearly 2000 t HM (tonnes of heavy metal) of MOX fuel have been fabricated for LWRs in Europe and over 150 t HM for FBRs in Europe, Japan and Russia. In 2007, the ESA reported, 8.6 tonnes of plutonium were loaded into European reactors in MOX fuel, displacing some 1035 tonnes of natural uranium and 690 tSWU. In total, 104 tonnes of plutonium has been used in MOX fuel in the EU since 1996. Irradiation experiments, experience in commercial reactors and post irradiation examinations all indicate that LWR MOX, despite being irradiated in reactor cores designed specifically for UO_2 fuel, not MOX, behaves as

uncertainty associated with developing an unambiguously demonstrable economic Liquid Metal Reactor.

- However, NEAC believes that it is essential that the modelling and simulation program focus on major problems impeding the rapid deployment of advanced nuclear systems and concurs with the modelling and simulation recommendations suggested in the July 2008 version of Reference 3 and the September 2008 version of Reference 2. This effort should increase gradually, utilising existing advanced modelling and simulation capabilities at NNSA and the Office of Science, and, to demonstrate the value that can be added by this effort, focussing on a pilot program that emphasises areas where experiments are long and difficult.

The modelling and simulation program has to be accompanied by an experimental program that can validate the codes. Without an experimental validation program, the modelling program will never be trusted, especially on safety issues

Some examples of important areas for consideration in this pilot program are:

- Extrapolating previous in-reactor fuel tests to higher burn up for those cases in which prototypic in-reactor tests are time-consuming, expensive, or no longer possible.
- Extrapolating results from existing small-scale separations tests to applications essential to the development of economical, safe, proliferation-resistant, large-scale advanced separations systems.
- Developing designs and design configurations for lower-cost high- temperature nuclear steam system designs for advanced reactors using, for example, high-strength chromium-molybdenum steels.

To ensure a sound foundation, modeling and simulations must be tested against real reactor designs and experiments and be used to predict the results of tests to be run and already run using test and operating data gathered from separate effects and integral tests as well as data and other information gathered from earlier and current reactors, both foreign and domestic.

While this may be called "post diction" it is a necessary prelude to prediction.

It is recognized that data needs and gaps in data availability may very well emerge from the modeling and simulation effort, and the identification of such gaps is encouraged. Upon identification of such gaps, the information should be used to develop well-designed experiments that clearly verify key physical and chemical mechanisms. If done successfully, confidence will be gained in using such simulations to reduce the need for empirical experimental data in nuclear energy systems and to focus those experimental efforts that must be undertaken.

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predicted and its performance can match that of the UO_2 fuel along side it in the core. LWR MOX is able to meet the licensing and operational requirements of the large commercial stations. There are however, some constraints on the fraction of MOX fuel that can be loaded into an LWR core at any one time in order to avoid compromising original safety margins. Most European reactors licensed for MOX will use it as one third of the core loading but some reactors can load up to 50%. Designing a reactor for a whole MOX core is significantly easier than trying to adapt existing reactors types and recent evolutionary PWR and BWR designs now offer possible 100% MOX cores e.g. ABWR, System 80+, AP600/1000, EPR.

Some staff in NE seem to be looking at a modeling and simulation program that moves to the $300-$500 million per year level within 5 or so years (the level of the NNSA Stockpile Stewardship program). NEAC believes this is too ambitious and too rapid a build up, considering the need to develop a programmatic focus on realistic problem solving and the state of reactor codes today.

A more appropriate goal in that time frame is $50-$100 million per year. Even at this reduced level a detailed multi-year plan with specific experimental and simulation activities and objectives should be the basis for establishing the annual and long-term budget requirements.

V. Problems that Inhibit DOE Nuclear Energy Programs

A. Insufficient Internal DOE Couplings

- Several DOE programs related to nuclear energy would benefit from stronger links between different parts of the DOE. Links to RW (Office of Radioactive Waste Management), NNSA, and SC (Office of Science) are important to maximize the effectiveness of work on various phases of the nuclear energy program.

Links between RW and NE would benefit both RW's and NE's programs.

NE's work on advanced fuel cycles, at least in theory, can have a major impact on radioactive waste disposal. For example, an objective of the GNEP program is to change the required isolation time of the highly radioactive reactor waste stream from the hundreds of thousands of years characteristic of the once through fuel cycle to only a thousand years or so. Fuel elements from the High Temperature Gas-Cooled Reactor now under development can stand much higher temperatures than the fuel elements from our workhorse LWRs. Both of these could have significant impact on repository design.

NNSA is responsible for safeguards and security and proliferation prevention programs. Stronger coupling would benefit both programs.

For example, as originally proposed the COEX process that NE is looking at for producing plutonium based fuel for thermal or fast spectrum systems had the plutonium-uranium mix set at 50% of each at the end of the reprocessing cycle. Closer interaction with NNSA would have led to an earlier change to a mix with less than about 10% to15% of plutonium. NNSA regards that mix as no more risky from a proliferation perspective than uranium enriched to less than 20% U-235. Closer coupling would have let NE start down a different road considerably earlier.

New fuel forms and new kinds of reactors will need more basic science input for such things as nuclear cross section determination and development of advanced materials. Much of this kind of work goes on in the Office of Science's programs. Coupling with SC is improving and this will help the energy mission.

Development of advanced nuclear energy programs with waste streams that are easier to handle and are more proliferation resistant would benefit from a system that included closer cooperation of all the parts of the DOE.

NE appears to be effectively involving the Office of Science. However, there are other offices that should be involved. An integrated program involving RW (waste forms and desirable characteristics for a repository), whether for long-term (once through) or shorter term (long-lived components destroyed in an ABR), would produce a stronger long-range plan.

NNSA is responsible for Safeguards and Security, and its input is needed as well to realize the NE vision of a solid 20-year plan.

B. Programmatic Options

The subcommittee did not do a detailed review of NE's advanced fuel cycle programs but did a limited examination of facility needs if programs go forward. Therefore recommendations in this report should be read as conditional, i.e., if this program is pursued, then these are the subcommittee's recommendations on how facility needs might be met.

An NE near-term objective is to close the fuel cycle by using MOX in thermal reactors and the longer-term plan is to burn actinides in fast reactors. Both elements are controversial and have not received widespread support by the Congress or by outside review committees. Moreover, it is unclear whether the next administration will support these programs.

A political-budgetary consensus to close the fuel cycle or launch a multi-decade effort to develop and deploy fast reactors for actinide burning does not exist today. Even if it did, it would be difficult to sustain the fast reactor development and deployment program over the multiple-decades and administrations needed to construct and commission actinide-burning reactors.

- NE should broaden its assessment of nuclear infrastructure needs to include the once-through fuel cycle used by the current fleet of light water reactors and the likely improved versions of LWRs that will evolve from them.

The Draft GNEP Programmatic Environmental Impact Statement (PEIS) has just been released for public comment, and but there is no Final GNEP PEIS record of decision (ROD). The NE Staff is moving forward on GNEP as if the ROD will adopt the proposed program, NE also should have a base R&D program option that assumes that the US will continue to rely for the foreseeable future on the open fuel cycle use by the current fleet of LWRs, and the likely successive fleet of LWRs, for power production, such as the LWR Sustainability effort proposed by industry and DOE-NE.

One member of the committee indicated that relative to the existing open fuel cycle the closed cycle for MOX use in thermal reactors is more costly, less safe, leads to greater routine releases of radioactivity into the environment, greater worker exposures to radiation, greater proliferation risks, larger inventories of nuclear waste that must be managed and does not appreciably reduce the geologic repository requirements. Some members do not agree with all of these statements and other members believe that one reason to advocate a closed cycle is that in the long term Pu

and other higher actinides dominate the radiotoxicity in a repository and that, on sustainability grounds, failure to recycle a valuable energy resource is not really sustainable.[18]
However, all members agree that, if GNEP is to be pursued, it makes sense to develop or identify an existing fast reactor for fuel testing.

C. Down Selections

DOE-NE should emphasize the need to expedite technical decisions and down-selections so that funding can be wisely allocated. Specific examples include: pebble-bed versus prismatic fuel for the HTR (high temperature reactor) and oxide versus metallic fuel for the fast spectrum test reactor (which in turn may allow GNEP/AFCI to down-select to only aqueous processing). Although the lack of these down-selections is partially due to the fact that industries preparing responses to RFPs are considering both options, DOE-NE should find a way to accelerate these down-selections so that R&D costs can be reduced.

VI. International Collaboration

- International collaboration should be increased, especially in the current climate of stringent budgets.

A. Interim Fast Spectrum Test Reactor (FSTR)

- NEAC is skeptical that the GNEP program can achieve its long-range goals without an FSTR before the proposed ARR prototype is available. Thus, if GNEP is pursued, the US will need the services of a fast spectrum test reactor; hence, NE should investigate a shared funding model to support work at a foreign facility until the ARR prototype is commissioned.

There is no FSTR in the United States and few in the world. Currently, Phoenix in France is scheduled to begin decommissioning in summer 2009. There are plans to construct a new demonstration fast reactor probably in Marcoule during the 2020s, with a decision on the path

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[18] Dissenting Opinion by committee member Dr. Thomas Cochran

The GNEP vision of reducing repository requirement and risk by recycling selected actinides in fast reactors requires that a substantial fraction of the operating reactor fleet be fast reactors
"Large numbers of fast reactors for actinide burning is unlikely to occur because—to borrow observations made by Admiral Hyman G. Rickover more than 50 years ago— fast reactors have proven to be more costly to build, more complex to operate, susceptible to prolong shutdown as a result of even minor malfunctions, and difficult and time-consuming to repair. Plutonium is a valuable resource for weapons, but is not for energy production. It has a negative economic value for this purpose and there is little prospect that this will change in the foreseeable future because there is no evidence that uranium resources are likely to become scarce in the world, or even in those countries that are closely allied with the United States. Plutonium recycle and the introduction of fast reactors will contribute nothing toward the de-carbonization of global electricity supplies for many decades, while consuming valuable capital resources better spent on less costly and more practical energy alternatives for climate change mitigation.
The GNEP R&D effort could encourage the development of hot cells and reprocessing R&D centers in non-weapon states of concern, as well as the training of cadres of experts in plutonium chemistry and metallurgy, all of which pose a serious proliferation risk. Moreover, were NE to pursue less risky open fuel cycle alternatives, all of the large, costly facilities in NE's current or recently proposed program, namely, the Advanced Burner Reactor (ABR), Advanced Recycle Reactor (ARR) prototype, Interim Fast Spectrum Reactor (FSR), the Advanced Fuel Cycle Facility (AFCF), and commercial reprocessing and MOX plants, would be entirely unnecessary or, at a minimum, could be deferred indefinitely."

forward by 2012. JOYO in Japan currently is shut down but scheduled to restart around 2011. After being shut down in 1995 due to a leak in its secondary cooling system, Japan's Monju reactor is scheduled to restart in February 2009. Russia has two operating fast reactors, BOR-60 and BN-600. BOR-60 is old and politically and functionally challenging for the US to use. However, both Japan's Monju and Russia's BN-600 are power reactors and are not designed to accommodate efficiently extensive testing of fuels and materials.

- JOYO appears to offer the most likely opportunity for conversion to an international FSTR user facility, to irradiate fuel elements and other materials, in partnership with a limited set of countries, including France, Japan, and the UK.

If existing or currently planned facilities are not adequate or not available a new international FSTR should be constructed, based upon such international models as ITER and CERN's Large Hadron Collider (LHC). In both of these examples an international consortium contributes to both construction and operating costs. The experimental program of the fast reactor user facility would be best determined by an international committee of the participating nations.

B. International Reprocessing Facility

- Rather than launching an expensive program to construct an engineering scale AFCF immediately, it may be faster and less costly to demonstrate UREX reprocessing technologies on an engineering scale at a foreign facility such as AREVA's LaHague facility in France or the THORP facility in the U.K.[19]

Also, there may be some interest in Japan to convert its Recycle Equipment Test Facility (RETF), which was designed to reprocess spent fuel from the JOYO and Monju reactors, to an international reprocessing user facility. Since RETF is currently under construction, this is an excellent time to explore this idea. However, if the decision is made for the US to pursue a closed nuclear fuel cycle, eventually the US should construct its own reprocessing facility along the lines of the Advanced Fuel Cycle Facility.

Based upon R&D needs, AFCF's program priorities should be established among the different modules (aqueous, electrochemical, fuel fabrication, waste form) leading to a phasing of buildings. Consideration should be given to using existing foreign facilities, looking at some complementary capabilities between such facilities and AFCF. In particular, throughput should be studied carefully.

C. AFCF if International Engineering Demo is Possible

A recent study on the use of the AFCF identified engineering scale, or production scale, throughput as a key development parameter necessary to provide a sound engineering basis for larger future facilities. The preferred throughput rate for establishing an engineering scale process in the facility was 25 tonnes/year of heavy metal, which is equivalent to a product output of four Lead Test Assemblies (LTA) per year. As a possible means for reducing the capital cost of the facility, an alternative case based on 4 tonnes of heavy metal per year and a product output

[19] Any proposal would be subject to both availability of the plant and the willingness of the UK or French government to support such an initiative.

of one LTA per year was also examined. In either case, the authors found that it is difficult to fit the entire capability into a single existing facility in the DOE complex and a Greenfield facility would be the best-fit possibility.

Given the current budget situation, it appears unlikely that funding sufficient to build a Greenfield facility at either the higher or lower rates is likely to be available. Therefore it behoves the program to change the assumption basis and to determine what use can be made of those existing large facilities within the complex. With this as the assumption basis, it is unlikely that full capability can be established in a single facility at the preferred throughput levels.

A full demonstration at the laboratory scale of the UREX process has not yet been done; though all pieces have been done separately.

The possibility of a single Integrated End-to-End demonstration, that is, all process steps from receiving to final production of the product carried out by a single operating organization in a single facility at a lower throughput rate should not be dismissed.

Given this starting point, it may be possible that the entire process can be demonstrated in an Integrated End-to-End manner with some of the key process steps at the engineering scale. The subcommittee believes that this possibility should be examined as it may be the only means of carrying out the AFCF program in a reduced budget scenario.

D. Possibility of User Facility Based in the US

- It is not sufficient for the US to use facilities in other countries without establishing a reciprocal international user facility at home. There are many possibilities. One is a transient test reactor of the ilk of the Transient Reactor Test Facility (TREAT).

TREAT is a large air-cooled thermal test reactor that was constructed in the late 1950s at Idaho National Laboratory and operated for almost 40 years. There continues to be a need for a TREAT-type reactor that is capable of studying the transient response of materials to severe reactor conditions.

It must be demonstrated that restarting TREAT is the best path forward for getting a state-of-the-art facility for transient testing. Since 1994 it has been in standby mode and the cost for a restart is estimated to be on the order of $100 Million. NEAC, however, cautions that independent verification is needed to ensure that all the required upgrades to obtain an appropriate state-of-the-art facility are included in this cost estimate. A TREAT upgrade may be the way to proceed.

However, the main point here is that there are important, unique facilities that could be built on US soil as the US contribution to the set of international user facilities.

E. Fuel Development

It takes a very long time to develop and supply a sufficient amount of stable, reliable, and licensed reactor fuel. Furthermore, the amount of fuel now needed for an HTR is limited. (It also would move the program forward if the HTR program had a clear mission.)

- Therefore, it is recommended to find ways to develop the fuel jointly between the US and Japan, including industrial cooperation. Japan is the only country that has fabricated a large amount of HTR fuel and successfully operated it at very high temperatures.

The US might save in development costs by working with Japan, although the licensing requirements for US fuel may be more stringent than the Japanese requirements (run to failure). NE also should explore possible joint work with South Africa, related to the work on the PBMR (pebble bed modular reactor), and with China, which has an operating HTR.

France, Japan and the United States should make a survey of available and useful hot laboratories, and setup a joint program based on cost sharing.

For example, the potential for using JAEA's RETF (Recycle Equipment Test Facility) should be explored for wet type LWR fuel reprocessing technology. This survey should include the brand new UK facilities which are pending full commissioning and the labs of the European Commission, e.g., the Institute for Transuranium Elements in Karlrsruhe Germany

VII. Scenarios

NEAC considers three scenarios: no new builds, about 17 GWe new nuclear reactors by 2030, the EIA base case, and about 45 GWe new nuclear reactors by 2030. In all three scenarios, current reactors operate for a lifetime of 60 years.

NEAC concludes that some R&D programs would be the same for all three scenarios:

- R&D to keep current plants running well and avoid any surprises. This R&D will include aging phenomenon.
- R&D to encourage a new cadre of engineers and scientists to become involved in nuclear energy.
- R&D on waste management.
- R&D to maintain the US as a major participant in international nuclear power discussions.

For both the 17 GWe and 45 GWe scenarios, R&D will be necessary to address issues related to new builds, including manufacturing and inspection. Also required will be R&D on separations chemistry and scaleup and on possible transmutation options. For the third scenario, which is the most aggressive, particular R&D should address new reactor concepts, GEN IV and advanced LWRs, and the testing and design work necessary for these concepts.

To end at 2030 in planning will be a serious mistake. New concepts can take many decades to go through lab scale and engineering scale development before getting to commercial scale. In particular, if the closed fuel cycle is to be pursued, with new concepts for (recycling, reprocessing, regeneration), ten years of lab work, ten years of engineering work, and ten years of further testing will be necessary, leading to the conclusion that 2030 is too short a time horizon for a healthy R&D program.[20]

Unless the United States government aggressively changes its policy of neglect, a review in the future may find what is described in a recent UK report:

"[T]he current crisis of skills in the area of nuclear engineering, and the uncertainty regarding the UK's capacity to forge ahead with a new generation of nuclear new-build, could have been avoided if a nuclear strategy had been put in place 10 years ago. The need is now pressing for a strategic Government policy on nuclear engineering." [21]

"It would be wholly unrealistic to consider the possibility of sustaining a new nuclear power programme in the UK without UK expertise and engineers. Whilst the design of a new build will be procured from overseas vendors, its deployment will be local, requiring UK engineers to complete detailed design and site specific works, regulate, build, commission, operate, maintain and support a fleet of new nuclear power plants over their projected 60 year lifetimes."[22]

VIII. Nuclear Education and University Programs

- Regardless of whether the scenario for utilization of nuclear energy involves the status quo, modest growth, or an ambitious and enhanced program that includes developing recycling, transmutation, and new reactor and fuel technologies, university programs will be essential in educating and supplying the required next generation of scientists and engineers.

Even in a status quo scenario, our preeminence in frontier nuclear science areas[23] has earned us a "place at the table" in international discussions.

Nuclear science and engineering personnel are urgently needed, not only for utilization of nuclear energy, but for other aspects of the nation's security and well-being in the broadest sense.

These include homeland security, nuclear forensics, production of radioisotopes for nuclear medicine and other applications, minimization and safe storage of nuclear waste, environmental monitoring, defense programs, and sectors of government responsible for regulation, safety, or emergency response, to name but a few.

- Currently, the pipeline in the US is insufficient to furnish the required personnel for all these areas, especially with the increased emphasis on homeland security, detection and assessment of terrorist activities, and other radiological threats.

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[20] "The deployment of a new nuclear option takes a long time: 30 to 40 years…." Electricite de France presentation by J-M. Delbecq/J-L. Rouyer, Micanet Meeting, April 7, 2005.
[21] *Nuclear Engineering,* The Royal Academy of Engineering, March 2008, p. 1.
[22] *Ibid.*, p. 2.
[23] *The Future of U. S. Chemistry Research: Benchmarks and Challenges 2007*, Committee on Benchmarking the Research Competitiveness of the United States in Chemistry, Board on Chemical Sciences and Technology, Division of Earth and Life Studies, National Research Council of the National Academies, The National Academy Press, Washington, D.C.

A recent APS study[24] of nuclear workforce needs considered the following three scenarios for nuclear power: (1) maintaining the current number of nuclear reactors (about 100) without reprocessing their nuclear fuel; (2) doubling the number of reactors without reprocessing fuel; (3) doubling the number of reactors and closing the fuel cycle by reprocessing and recycling spent fuel. The report drew attention to "critical shortages in the US nuclear workforce and to problems in maintaining relevant educational modalities and facilities for training new people".

The sub-disciplines of nuclear chemistry, radiochemistry, and actinide chemistry were found to be in a crisis situation, with nuclear chemistry on the verge of extinction. University chemistry departments have not replaced retiring professors and fewer than two Ph.D.s in nuclear chemistry were awarded in 2004. Even though there is strong student interest, there are only a few remaining universities with programs awarding Ph.D.s in nuclear chemistry. The situation is exacerbated by the absence of a single funding home for the three related sub-disciplines of nuclear chemistry, radiochemistry and actinide chemistry as each must seek support from a different, or even multiple funding agencies[25].

The APS Panel recommended establishing a cross-cutting workforce initiative to address the needs for trained nuclear chemistry and radiochemistry personnel, including fellowships and scholarships. The Panel also concluded that prestigious faculty fellowships (such as awarded by NSF) for new professors in these areas and increased research funding would demonstrate that significant opportunities existed and would help convince university chemistry departments to consider hiring new faculty.

The "feast or famine" DOE support for nuclear engineering programs and university reactors has led to considerable uncertainty and has resulted in more than a factor of two decrease in the numbers of nuclear engineering departments and university reactors between the 1980s and the present.

- The current university funding is too tightly tied to the existing NE programs. A funding program for universities similar to the earlier Nuclear Energy Research Initiative (NERI), should be established.

As recommended by PCAST (President's Committee of Advisors on Science and Technology), DOE established NERI to provide research funding not necessarily tied to ongoing R&D at the national laboratories. Thus, any new program should use caution in appointing members of any committee that reviews university funding proposals to ensure that they are not too heavily weighted toward national laboratory R&D interests.

Another recommendation of the APS Panel was that the federal government should assume significant responsibility for education of the next generation of nuclear scientists and engineers by naming a single Federal agency to act as steward for an ongoing, robust university-based

[24] *Readiness of the U. S. Nuclear Workforce for 21st Century Challenges*, Report of APS Panel on Public Affairs, June 2008: http://www.aps.org/policy/reports/popa-reports/index.cfm.

[25] In 1978 when the DOE Division of Nuclear Science was eliminated, portions of the program went to Chemical Sciences and other portions to the Office of High Energy and Nuclear Physics. Nuclear chemistry went to nuclear physics, actinide chemistry to Chemical Sciences and Radiochemistry was left to try to attain funding from various applied programs such as in RW, Nuclear Medicine, etc. None of these subfields could apply to NSF for funding due to prior agreements that DOE was responsible for all nuclear and energy related activities. Only recently has this ban been lifted.

nuclear and chemical science and engineering education program. NEAC has not discussed this recommendation and takes no position on it. In the short term, while the pipeline from the universities is being refilled, nuclear technician training programs and retraining programs at community colleges or at reactor sites should be established. Collaborative programs and internships with nuclear industry and national laboratories also should be implemented.

As suggested by the recent National Academies report[26], DOE-NE should fund nuclear science and engineering education at the levels authorized by the Energy Policy Act of 2005, namely $56 million for FY2009.

This would support the development of the needed workforce to address the large wave of retirements in government, national laboratories, and industry and the additional workforce needs for homeland security, detection and attribution of nuclear events, and nuclear forensics to combat nuclear and other forms of radiological terrorism. As part of the educational funding, there should be adequate support for university training and research reactors, such as was provided previously by DOE's Innovations in Nuclear Infrastructure and Education (INIE), a program last funded at $9.41 million for FY 2006 that encouraged partnerships among the university reactors, national laboratories, and industry.

Quoting from the *July 2008 Letter of Executive Team member James Duderstadt to Paul Kearns of Battelle*, "Long ago DOE (AEC-ERDA) was assigned the primary responsibility for developing the engineers and scientists necessary to sustain the nation's nuclear energy capabilities. Yet DOE's support of these educational programs has been at a token level for years – actually amounting to less than 10% per student or faculty member of other areas such as nuclear physics and high energy physics." Although individual program leaders have sometimes tried to eke out some support for various student training programs, significant amounts of money for faculty grants and student training never seem to materialize.

The recent reports generated by Battelle and INL have listed Workforce Issues and Nuclear Education and related facilities among their top priorities, but it is not yet clear what the funding mechanisms will be for university faculty and student research and training support.

IX. Lessons to be Learned

- Lessons can be learned from past foreign situations both in a negative way (decline of the nuclear sector as in the UK) and in a positive way (world leadership of nuclear research and industry as in France and Japan).

The UK presents a case history of relevance to the US in terms of rapid decline of skills supporting the nuclear sector in the absence of a coherent policy from the Departments of Government which should have recognized the need for them to be nurtured.

During the late 1980's and early 1990's successive privatizations of parts of the UKAEA and CEGB (Central Electricity Generating Board) led to a catastrophic fall in R&D supporting the

[26] *Review of DOE's Nuclear Energy Research and Development Program*, National Research Council, National Academies Press, Washington, DC, October 2007.

nuclear sector. Most of the major laboratories of the CEGB closed and R&D associated with new nuclear systems ceased to be funded by the then Department of Energy with the Department of Trade and Industry. Some 8000 technical posts were lost to the sector. This in turn had a catastrophic effect on the University base which had supported UK and international nuclear endeavors. The UK had only ever had one course in Nuclear Engineering and this was at Masters level. The supply of graduates historically came from nuclear modules within mainstream science and engineering degrees and it was these which disappeared as students failed to take an interest in an industry perceived to be in decline and experienced academic staff retired. Absent government funding it was almost impossible to encourage new academic appointments. By the mid 1990's the only investment of any significance was being made by BNFL through four targeted research alliances with top UK universities. This encouraged leveraged investment by the UK's main research council as Government realized it needed to have a science base capable of 'keeping the nuclear option open'. It took nearly a decade to regain internationally competitive research groups targeted at the nuclear sector and a resurgence of taught modules at undergraduate and masters level. Failure to sustain an active program over the last five years has made it almost impossible to sustain the UK's knowledge base in fast reactors. A Generation's valuable work has been consigned to an archive but valuable know how of relevance to the systems still under consideration internationally has probably been lost.

An additional unforeseen consequence of reduced funding for R&D and no coherent plan to sustain nuclear competence was an increasing shortage of trained technicians and top end blue collar skills required to service a sector over the coming two decades of existing plants and very significant shortages in skilled personnel available to join the nuclear regulator.

In the former case in 2007 the UK Government launched a National Nuclear Skills Academy to provide training of technicians and modules up to foundation degree level but recognizes it will take over a decade to remedy the situation.

In the latter case the under resourcing of the regulator is of significant concern to the Industry trying to engage in a new build endeavor with internationally available designs and to the UK Government who now want a new generation of reactors deployed by the end of the second decade of the 21st century.

The Royal Academy of Engineering (the UK's equivalent of the US National Academy of Engineering) has strongly recommended that the UK Government fund a targeted research program.

The UK through BNFL invested $400M in new active R&D facilities at Sellafield to enable 21st century fuel cycles to be explored and underpinned. These have yet to be exploited but the capital investment has at least been made.

On the other hand, countries like France and Japan have succeeded in the past to develop world class Nuclear R&D facilities, and to upgrade them constantly at the needed level up to a point where ageing can no longer be overcome for technical or safety reasons. Even if long lasting and difficult, a time-phased approach as used in these counties to anticipate shut down of ageing facilities allows making decisions to build new and adapted R&D capabilities. For example, in France nuclear hot cells built in the Paris area in the sixties have been shut down, while the new Atalante facility was progressively built in Marcoule in 1990-2000. This facility is now recognized as a leading world class laboratory for supporting reprocessing and waste form studies.

X. Conclusions

Many high priority facilities require moderate to significant investment before they could provide the capabilities needed by DOE-NE.

A depressing story was revealed of decayed or decaying facilities that in most cases are not suited for their intended uses without significant and often expensive refurbishments.

However, even if aggressive new power plants and advanced programs do not proceed, the United States needs a robust set of nuclear research facilities.

NE should broaden its assessment of nuclear infrastructure needs to include the once-through fuel cycle used by the current fleet of light water reactors and the likely improved versions of LWRs that will evolve from them.

International collaborations should be increased, especially in the current climate of stringent budgets.

However, the main point here is that there are important, unique facilities that could be built on US soil as the US contribution to the set of international user facilities.

NEAC concludes that some R&D programs would be the same whether there are no new builds, a few builds or many builds:

- R&D to keep current plants running well and avoid any surprises. This R&D will include aging phenomenon.
- R&D to encourage a new cadre of engineers and scientists to become involved in nuclear energy.
- R&D on waste management.
- R&D to maintain the US as a major participant in international nuclear power discussions.

To end at 2030 in planning will be a serious mistake. New concepts can take many decades to go through lab scale and engineering scale development before getting to commercial scale.