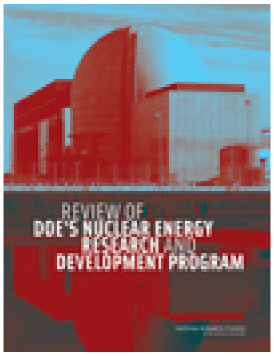

Review of DOE's Nuclear Energy Research and Development Program

Committee on Review of DOE's Nuclear Energy Research and Development Program, National Research Council

ISBN: 0-309-11125-0, 102 pages, 8 1/2 x 11, (2008)

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THE NATIONAL ACADEMIES
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REVIEW OF DOE'S NUCLEAR ENERGY RESEARCH AND DEVELOPMENT PROGRAM

Committee on Review of DOE's Nuclear Energy
Research and Development Program

Board on Energy and Environmental Systems

Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
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This report and the study on which it is based were supported by Contract No. DE-AT01-06NE64158 (Task Order No. 15) from the U.S. Department of Energy. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the organizations or agencies that provided support for the project.

International Standard Book Number 13: 978-0-309-11124-9
International Standard Book Number 10: 0-309-11124-2

Available in limited supply from
Board on Energy and Environmental Systems
National Research Council
500 Fifth Street, N.W.
Keck W934
Washington, DC 20001
202-334-3344

Additional copies available for sale from:
The National Academies Press
500 Fifth Street, N.W.
Lockbox 285
Washington, DC 20055
800-624-6242 or 202-334-3313 (in the
Washington metropolitan area)
http://www.nap.edu

Printed in the United States of America

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Preface

In January 2005, the FY 2006 President's Budget Request asked for funds to be set aside for a review by the National Academy of Sciences of the nuclear energy research programs and budget at the U.S. Department of Energy (DOE). Following passage of the FY 2006 congressional budget, the National Research Council (NRC) developed a statement of task (see Appendix F) for a "comprehensive, independent evaluation of the goals and plans of the office of Nuclear Energy (NE) at DOE, and processes for establishing program priorities and oversight (including the method for determining the relative allocation of budgetary resources)." The NRC established a committee to carry out the project, but the committee did not meet until August 24, 2006—over 18 months after the request for funds for the study.

During that interim period, DOE's nuclear research program changed significantly with the emergence in early 2006 of a major programmatic initiative—the Global Nuclear Energy Partnership (GNEP). If executed as envisioned by its advocates, the GNEP program would result in the construction of commercial-scale facilities for spent fuel reprocessing and disposal by consuming the resultant plutonium and minor actinides together in advanced burner reactors, thereby reducing the radioactive burden on the waste repository. The budgetary implications of this new program were very substantial; if appropriated, the President's Budget Request for FY 2008 would more than double the Office of Nuclear Energy research and development budget from its FY 2006 appropriations level, mostly as a result of the GNEP program.

These developments created two issues for the committee. First, the program for which the statement of task had been prepared changed significantly between the writing of the statement of task and the start of the committee's work. Second, the dominant new program, GNEP, lacked the technical documentation, program plans, and program management organization that would ordinarily form the basis for an evaluation of program content and budget priorities. Despite these difficulties, the committee decided that the issues surrounding the design and technical approach of the GNEP program were sufficiently controversial that they could not be ignored in its review. I commend my colleagues on the committee for taking this stand and thank them for being willing to deal with the resulting frustrations of crafting a balanced evaluation of GNEP in the absence of information that would normally be available.

I wish to thank all of the committee members for the exceptional knowledge and patience they brought to this assignment. Our work probably required more of these qualities than any of us expected when we set out on this task. The support we received from the NRC staff certainly met the high standards I have come to expect of them. My appreciation especially goes to Martin Offutt, Matt Bowen, and Jim Zucchetto. Panola Golson once again made the administrative support both effective and unobtrusive.

Robert W. Fri
Chair
Committee on Review of DOE's Nuclear Energy
Research and Development Program

Acknowledgments

The Committee on Review of the DOE's Nuclear Energy Research and Development Program is grateful to the many individuals who contributed their time and effort to the National Academies' National Research Council (NRC) study. The presentations at committee meetings provided valuable information and insights. The committee thanks the following individuals who provided briefings:

Jim Bresee, U.S. Department of Energy (DOE),
Richard Chandler, Office of Management and Budget,
George Davis, Westinghouse,
John Deutch, Massachusetts Institute of Technology,
Marvin Fertel, Nuclear Energy Institute,
Timothy A. Frazier, DOE,
Ray Ganthner, AREVA,
Eugene Grecheck, Dominion Energy, Inc.,
Susan L. Harlow, DOE,
Dave Hill, Idaho National Laboratory,
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Rebecca Smith-Kevern, DOE,
Dennis Spurgeon, DOE,
John Stamos, DOE,
Joe Turnage, Constellation Energy/UniStar, and
Gary Vine, EPRI.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of the independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

John Ahearne, NAE, Sigma Xi,
Jan Beyea, Consulting in the Public Interest,
Philip R. Clark, NAE, GPU Nuclear Corporation (retired),
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Richard Meserve, NAE, Carnegie Institution,
Kenneth Peddicord, The Texas A&M University System,
Neil Siegel, NAE, Northrop Grumman Mission Systems, and
Raymond G. Wymer, Oak Ridge National Laboratory (retired).

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Chris Whipple of ENVIRON International Corporation. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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Growing energy demands, emerging concerns about the emissions of carbon dioxide from fossil fuel combustion, the increasing and volatile price for natural gas, and a sustained period of successful operation of the existing fleet of nuclear power plants have resulted in a renewal of interest in nuclear power in the United States. The Office of Nuclear Energy (NE) in the U.S. Department of Energy (DOE) is the main agent of the government's responsibility for advancing nuclear power. One consequence of the renewed interest in nuclear power for the NE mission has been rapid growth in the NE research budget: it grew by nearly 70 percent from the $193 million appropriated in FY 2003 to $320 million in FY 2006.

In light of this growth, the FY 2006 President's Budget Request asked for funds to be set aside for the National Academy of Sciences to review the NE research programs and budget and to recommend priorities for those programs given the likelihood of constrained budget levels in the future (DOE, 2005). The programs to be evaluated were Nuclear Power 2010, the Generation IV reactor development program, the Nuclear Hydrogen Initiative, the Global Nuclear Energy Partnership (GNEP)/Advanced Fuel Cycle Initiative (AFCI), and the Idaho National Laboratory facilities program. The committee's evaluation of each is summarized below, along with its assessment of program priorities and oversight and its relevant recommendations.

All but two members of the committee concur in the assessments presented in this report, and their dissenting statement is presented in Appendix A. In particular, all committee members agree that the GNEP program should not go forward and that it should be replaced by a less aggressive research program. The authors of Appendix A would "hold DOE R&D spending [on the less aggressive fuel cycle research program] to pre-2003 levels, before AFCI," and they believe that "DOE is the wrong agent for developing commercial technologies beyond the early laboratory stage."

Separately, three other committee members who do agree with all the recommendations in the report expressed their preference for an alternative to the technology preferred for GNEP. They describe this preference in Appendix B.

NUCLEAR POWER 2010

The Nuclear Power 2010 (NP 2010) program was established by DOE in 2002 to support the near-term deployment of new nuclear plants. NP 2010 is a joint government/industry 50/50 cost-shared effort with the following objectives:

- Identify sites for new near-term nuclear power plants and obtain early site permits (ESPs).
- Complete detailed, first-of-a-kind design engineering on two advanced light water reactor (ALWR) plants and confirm the safety of the designs by obtaining design certifications (DCs).
- Obtain combined construction and operating licenses (COLs) in keeping with the Standardization Policy (10 CFR Part 52) of the U.S. Nuclear Regulatory Commission (USNRC).
- Develop an effective inspection, testing, analyses, and acceptance criteria (ITAAC) process to assure licensing compliance during construction.
- Implement the Energy Policy Act of 2005 (EPAct05) standby support provisions for the construction of new nuclear plants.
- Estimate the capital costs and operation and maintenance costs, construction time, and levelized cost of electricity for the two plants.
- Evaluate the business case for building new nuclear power plants and pave the way for an industry decision to build new ALWR nuclear plants in the United States. Construction would begin early in the next decade.

Current Status

A good working relationship has been achieved between DOE and its contractors. The selection of the projects funded is appropriately market driven. There is a strong focus on demonstrating the regulatory processes, finalizing and standardizing the designs, and implementing the EPAct05 standby support provisions, all of which are essential front-end activities. Yet, other activities essential to ultimate success do not seem to have achieved that same focus in planning, let alone implementation.

Overall Progress

Although progress has been made on the licensing of demonstration projects, the pace is far slower than that proposed in the near-term roadmap, and there has been further slippage against the original NP 2010 schedules. This slippage does not suggest the high priority DOE has given to NP 2010.

Recommendation. NE should make the successful completion of the NP 2010 program its highest priority. It should take all necessary steps to ensure that guidance for the loan guarantee program authorized by the EPAct05 is finalized.

Licensing Demonstration

USNRC and industry need to improve the presently planned pace of COL reviews, avoiding review of already-settled issues and setting a more challenging schedule. In spite of the substantial effort that USNRC and the industry are devoting to preparing for the COL reviews, the planned schedules are still too long. Detailed milestones and schedules need to be established at the outset of the COL hearings and reflected in a binding order issued by the USNRC at the time each application is formally docketed. The ITAAC process needs to be defined fully and demonstrated to avoid construction delays caused by questions about licensing compliance or by litigation.

Recommendation. DOE should propose and support a joint DOE/industry/USNRC high-level working group to ensure that the following transpire:

- High-quality, complete applications are submitted and response times to requests for additional information are met as stipulated in USNRC's design-centered licensing review approach.
- The schedules for review of DC, ESP, and COL applications, including the legal review by the Atomic Safety and Licensing Board, are clearly established, complete, contain mechanisms for monitoring progress, show 3 years or less for review and approval of the initial COL applications, and show shorter durations for subsequent same-design applications.
- The ITAAC is being developed so that its implementation will minimize interruptions in construction and preoperational litigation delays.
- Common safety and licensing issues among the families of reactor designs are fully standardized.

Standardized Design Completion

While it is expected that a COL application could be standardized for each reactor design, it is not clear that common safety and licensing issues would allow the COL applications to be standardized among the families of designs. Schedules for completion of the full designs need to be accelerated to be consistent with the goal of estimating costs and construction times, and completing design before the start of construction. Design standardization efforts also need to be expanded to cover

- Construction, operational, and maintenance efficiencies,
- Protocols, such as form-fit-function, to permit competitive bidding on the great variety of smaller plant components, and
- Change processes and operational standards for the plant life.

Recommendation. DOE should work with the industry consortia to increase efforts to standardize safety and licensing issues across all families of reactor designs. DOE should also provide additional cost-shared funds to accelerate the schedules in the NP 2010 Five-Year Plan.

Deployment and Infrastructure Issues

DOE and the consortia have not devoted sufficient effort to critical deployment issues such as preoperational testing, advanced construction technology or processes, and operational training.

Recommendation. NE should immediately initiate a cooperative project with industry to identify problems that have arisen in the construction and start-up of new plants and define best practices for use by the industry.

The 25-year-long suspension of new plant construction in the United States has badly weakened the infrastructure needed to support a robust and growing nuclear power industry. So far, little effort in NP 2010 has been devoted to this issue.

Recommendation. DOE should include within the NP 2010 program a DOE/industry workshop to identify activities that would revitalize infrastructure for the construction of new nuclear plants, including the nuclear qualification of vendors and constructors; manufacturing capacity; and the availability of professional staff, skilled craftspeople and construction personnel. Additional tasks that merit further DOE support should be identified at this workshop.

Recommendation. DOE should fund a taskforce to work with industry groups on construction technology and planning to ensure that consortia construction time goals of 4 years or less will be met.

R&D Relevant to the NP 2010 Program

Neither DOE nor industry has proposed any R&D for the NP 2010 program.

Recommendation. DOE should evaluate the need for a reinvigorated R&D program to improve the performance of existing nuclear plants in a DOE–industry cost-shared effort separate from NP 2010. The estimated benefits to society should substantially exceed the government investment. In the event of funding constraints, NP 2010 funding for new plant deployment should have priority over this R&D for LWRs.

THE GENERATION IV AND NUCLEAR HYDROGEN INITIATIVE PROGRAMS

DOE has engaged other governments in a wide-ranging effort to develop advanced next-generation nuclear energy systems, known as Generation IV, with the goal of widening the applications and enhancing the economics, safety, and physical protection of the reactors and improving fuel cycle waste management and proliferation resistance in the coming decades. Six nuclear reactor technology concepts were identified in the DOE-initiated, international Generation IV Technology Roadmap completed in 2002. Each of the six technologies, as well as several areas of crosscutting research, is now being pursued by a consortium of countries as part of the Generation IV International Forum (GIF). Three concepts are thermal neutron spectrum systems—very-high-temperature reactors (VHTRs), molten salt reactors (MSRs), and supercritical-water-cooled reactors (SCWRs)—with coolants and temperatures that enable hydrogen or electricity production with high efficiency. In addition, three are fast neutron spectrum systems—gas-cooled fast reactors (GFRs), lead-cooled fast reactors (LFRs), and sodium-cooled fast reactors (SFRs)—that will enable better fuel use and more effective management of actinides by recycling most components in the discharged fuel.

From 2002 to 2005, the primary goal of the U.S. Generation IV program was to develop the Next Generation Nuclear Plant (NGNP), focusing on high-temperature process heat (850ºC-1000ºC) and innovative approaches to making energy products, such as hydrogen, that might benefit the transportation industry or the chemical industry. At the end of 2005, DOE shifted the fundamental emphasis of the overall Generation IV program, making spent fuel management using a closed fuel cycle the main goal of the NE program. This new GNEP priority led to reduced funding for the NGNP programs; phasing out of the SCWR, GFR, MSR, and LFR R&D programs, and refocusing of the SFR concept to near-term demonstration. With these changes, NGNP's VHTR remains the only major reactor concept that is not integrated into the GNEP program.

Next-Generation Nuclear Plant

Economic benefits of early commercialization of high-temperature reactors (HTRs) and VHTRs based on NGNP technology could be realized in four market segments where HTRs could make products at a lower cost than competing technologies: base-load electricity, combined heat and power, high-temperature process heat, and hydrogen. A long-term goal for the NGNP is to demonstrate hydrogen production as an energy carrier for a hydrogen economy. However, in each of those four segments, there are specific applications where HTRs will have near-term advantages. By directing NGNP and the Nuclear Hydrogen Initiative (NHI) R&D toward those specific applications, stronger near-term industry interest and investment is more likely, which in turn will support continued R&D investments for subsequent expansion of HTR technology into additional market segments and, in the longer term, support the transition to a hydrogen economy.

The NGNP program has well-established goals, decision points, and technical alternatives. A key decision point is the nuclear licensing approach. However, little planning has been done on how the fuel for the NGNP would be supplied. There is a particle fuel R&D program, but it will take up to two decades to complete the development and testing of this new fuel. To keep to the apparently preferred schedule, which has a FY 2017 plant start-up date, some of the technical decisions must be made quickly, so that detailed design, component and system testing, and licensing can be initiated. However, it is unlikely that the plant can begin operation by 2017 owing to the significant funding gaps that developed in FY 2006 and FY 2007 and affected the scope and schedule for testing fuel and structural materials as well as the heat transport equipment. A schedule that coordinates the elements required for public-private partnership, design evolution, defined regulatory approach, and R&D results should be articulated to enhance the potential for program success.

The main risk associated with NGNP is that the current business plan calls for the private sector to match the government (DOE) funding. So far, however, not a single program has been articulated that coordinates all the elements required to successfully commission the NGNP. The current disconnect between the base NGNP program plan and the complementary public/private partnership initiative must be resolved. DOE should decide whether to pursue a different demonstration with a smaller contribution from industry or, alternatively, a more basic technology approach for the VHTR.

Recommendation. In assessing NGNP conceptual designs, NE should favor design approaches that can achieve a variety of objectives at an acceptable technical risk.

Recommendation. NE should size the NGNP reactor system to facilitate technology demonstration for future commercial units, including safety.

Recommendation. Because of the very high temperatures and severe material performance requirements for thermochemical water splitting, NE should maintain the flexibility to first operate the NGNP using high-temperature steam electrolysis.

Recommendation. DOE should focus on developing advanced materials for in-reactor operation at temperatures above 900ºC and fuel particles that can withstand high burnup and adverse transients. NE needs to ensure that sufficient funds are available to advance these technologies whether or not industry matching funds are available.

Recommendation. To ensure the good performance of hydrogen produced in an NGNP, NE should put more emphasis on the following:

- Conceptual integrated process development and optimizing plan flow sheets, before moving to engineering designs.
- Selecting the interface between the reactor and the hydrogen plant.
- Developing system performance tools to address unsteady conditions, such as plant start-up, plant trip, and maintenance needs.
- Assessment of total system economics.

Nuclear Hydrogen Initiative

NHI is DOE's research program for developing technologies to produce hydrogen and oxygen from water feedstock using nuclear energy. The program includes a small effort supporting advanced low-temperature electrolysis, but its primary focus is three methods that use high-temperature process heat to achieve greater efficiency. The high-temperature methods could realize 60-80 percent greater efficiency than conventional electrolysis. These methods involve challenging high-temperature materials problems, which are being addressed with laboratory-scale research at this time. Key technology downselections to allow testing at the pilot and engineering scales are scheduled for 2011 and 2015. The NHI program is tightly tied to the NGNP program to develop a reactor capable of producing high-temperature process heat. NHI activities are coordinated with the larger DOE hydrogen program, led by the Office of Energy Efficiency and Renewable Energy, as well as with NGNP.

NHI is well formulated to identify and develop workable technologies, but the schedules and budgets need to be adjusted to assure appropriate coupling to the larger NGNP program.

Recommendation. DOE should expand NHI program interactions with industrial and international research organizations experienced in chemical processes and operating temperatures similar to those in thermochemical water splitting. NE should also broaden the hydrogen production system performance metrics beyond economics—for example, it could use the Generation IV performance metric of economics, safety, and sustainability.

Other Generation IV Nuclear Energy System Programs

The second concept for development in the Generation IV program, the SFR, seems vague at this time and appears to involve selected studies of technology issues that are beneficial principally for commercialization rather than explicitly linked to the long-term technology needs of nuclear energy. The committee is concerned that the Generation IV concept evaluation criteria for reactor development adopted by the Generation IV Technology Roadmap were not applied in the selection of the VHTR and SFR. The Generation IV R&D priorities have been shifting despite minimal discussion of the criteria and the alternatives.

The program resources are barely adequate for basic studies related to NGNP and the VHTR design and entirely inadequate for exploring the SFR at a research level (unless the new GNEP program also includes basic research components), for investigating other reactor concepts, and for developing crosscutting reactor technology systems. The current program does not appear to be using the Generation IV program metrics to compare the high-temperature reactors and fast-reactor systems for dual missions—a process heat mission and a fuel cycle flexibility mission.

Recommendation. Within the Generation IV program, NE should modestly and reasonably support long-term base technology options other than the VHTR and the SFR, particularly for actinide management, using thermal and fast reactors and appropriate fuels.

Recommendation. Though NE currently focuses on the VHTR for process heat and the SFR for advanced fuel cycles, it should assess the cost-benefit of a single reactor system to meet both needs.

THE ADVANCED FUEL CYCLE INITIATIVE AND GLOBAL NUCLEAR ENERGY PARTNERSHIP PROGRAMS

Since 2002, the United States has been conducting a program for reprocessing spent fuel under the Advanced Fuel Cycle Initiative (AFCI). Then, in February 2006, it announced a change in its nuclear energy programs. Recycling would be developed under a new effort, GNEP, which would incorporate AFCI as one of its activities. If the recycling R&D program is successful and leads to deployment, GNEP would eventually require the United States to be an active participant in the community of nations that recycle fuel, because one aspect of the partnership is that some nations recycle nuclear fuel for other user nations.

GNEP has two key stated technical objectives:

- Develop, demonstrate, and deploy advanced technologies for recycling spent nuclear fuel that do not separate plutonium, with the goal over time of ceasing separation of plutonium and eventually eliminating excess stocks of civilian plutonium and drawing down existing stocks of civilian spent fuel. Such advanced fuel cycle technologies would substantially reduce nuclear waste, simplify its disposition, and help to ensure the need for only one geologic repository in the United States through the end of this century.
- Develop, demonstrate, and deploy advanced reactors that consume transuranic elements from recycled spent fuel.

Three facilities are key components of the GNEP program as currently planned: (1) a nuclear fuel recycling center, or centralized fuel treatment center (CFTC); (2) an advanced sodium-cooled burner reactor (ABR); a fast-neutron reactor; and (3) an advanced fuel cycle facility (AFCF). At the time of the writing of this report, the latest information the committee had was that the baseline separation process was UREX+1a, although some other comparable separation technology, most notably pyroprocessing, may be adopted at a later stage.

All committee members agree that the GNEP program should not go forward and that it should be replaced by a less aggressive research program. A majority of the committee favors fuel cycle and fast reactor research, as was being conducted under AFCI; however, two committee members recommend against such research, as described in Appendix A. The GNEP program is premised on an accelerated deployment strategy that will create significant technical and financial risks by prematurely narrowing technical options. Moreover, there has not been sufficient external input—in particular, no independent, thorough peer review of the program.

- The domestic need for waste management, security, and fuel supply is not great enough to justify early deployment of commercial-scale reprocessing and fast reactor facilities. In particular, the near-term need for deployment of advanced fuel cycle infrastructure to avoid a second repository for spent fuel is far from clear. Even if a second repository were to be required in the near term, the committee does not believe that GNEP would provide short-term answers.
- The state of knowledge surrounding the technologies required for achieving the goals of GNEP is still at an early stage, at best a stage where one can justify beginning to work at an engineering scale. However, it seems to the committee that DOE has given more weight to schedule than to conservative economics and technology. The committee concludes that the case presented by the promoters of GNEP for an accelerated schedule for commercial construction is unwise. In general, it believes that the schedule should be guided by technical progress in the R&D program.
- The cost of the GNEP program is acknowledged by DOE not to be commercially competitive under present circumstances. There is no economic justification for going forward with this program at anything approaching a commercial scale. DOE claims that the GNEP is being implemented to save the United States nearly a decade in time and a substantial amount of money. In view of the technical challenges involved, the committee believes that just the opposite is likely to be true.
- Several fuel cycles could meet the eventual goal of creating a justifiable recycling system. However none of the cycles proposed, including UREX+ and the sodium fast reactor, is at a stage of reliability and understanding that would justify commercial-scale construction at this time. Significant technical problems remain to be solved.
- The qualification of multiply-recycled transuranic fuel is far from reaching a stage of demonstrated reliability. Because of the time required to test the fuel through repeated refabrication cycles, achieving a qualified fuel will take many years.

The committee believes that a research program similar to the original AFCI is worth pursuing.[1] Such a program should be paced by national needs, taking into account economics, technological readiness, national security, energy security, and other considerations. As noted in Chapter 1, however, considerable uncertainty surrounds the technology and policy options that will ultimately satisfy these needs. For this reason, the committee believes that the program described below should be sufficiently robust to provide useful technology options for a wide range of possible outcomes. On the other hand, the program should not commit to the construction of a major demonstration or facility unless there is a clear economic, national security, or environmental policy reason for doing so.

Recommendation. DOE should develop and publish detailed technical and economic analyses to explain and describe UREX+1a and fast reactor recycle as well as a range of alternatives. An independent peer review group, as recommended in Chapter 6, should review these analyses. DOE should pursue the development of other separation processes until a fully fact-based comparison can be made

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[1] The dissenting view of two committee members is presented in Appendix A.

and a decision taken on which process or processes could be carried to engineering scale.

Recommendation. DOE should devote more effort to the qualification of recycled fuel because it poses a major technical challenge.

Recommendation. DOE should compare the technical and financial risks of such a program with the potential benefits. Such an analysis should undergo an independent, intensive peer review.

Recommendation. DOE should bring together other appropriate divisions of DOE and other federal agencies, representatives from industry and academia, and representatives from other nations well before any decisions are made on the technology.

Recommendation. DOE should defer the Secretarial decision, now scheduled for 2008, which the committee believes is not credible. Moreover, if it makes this decision in the future, DOE should target construction of new technologies at most at an engineering scale. DOE should commission an independent peer review of the state of knowledge as a prerequisite to any Secretarial decision on future research programs.

IDAHO NATIONAL LABORATORY

NE is the lead program secretarial office (PSO) for the Idaho National Laboratory (INL), and, as such, a significant part of NE's management responsibility and budget is devoted to INL. This responsibility will continue to be a major one for NE, since the management of INL's physical facilities presents two challenges.

First, new or rejuvenated facilities are required to support the new mission and vision for the laboratory. The laboratory envisions that within 10 years, INL will be the preeminent national and international nuclear energy center with synergistic, world-class, multiprogram capabilities and partnerships. To achieve its ambitious goals, INL must attract and retain world-class scientists and engineers in a multiplicity of engineering and scientific disciplines. INL must have a budget allowing it to acquire and maintain the state-of-the-art facilities and equipment that will be used by researchers of superior technical competence to lead the development of nuclear power as a valued energy option nationally and internationally.

The second challenge is to maintain the remaining infrastructure in good condition. NE/INL is the landlord for a large, multitenant site in deteriorating condition. DOE employs several metrics to assess the condition of infrastructure. Overall, the INL facilities are rated adequate and the overall utilization, good. However, the backlog of deferred maintenance is high in relation to the value of the assets. In FY 2004 the ratio stood at 11.8 percent for INL's nonprogrammatic assets; the DOE target for this ratio is 2 to 4 percent.

The committee considers that INL is an important facility and provides important capabilities to support NE's mission, which is to use nuclear technology to provide the United States with safe, secure, environmentally responsible and affordable energy. INL has developed a strategic vision and a long-term (10-year) plan on this basis. However, the funding being provided to INL by NE is substantially less than what is needed to fulfill that vision.

Recommendation. NE should set up and document a process for evaluating alternative approaches for accomplishing NE-sponsored activities, assigning these tasks appropriately, and avoiding duplication.

Recommendation. NE should set up a formal, high-level working group jointly with the Idaho Operation Office (ID) and INL (Battelle Energy Alliance [BEA]). Consideration should be given to also having one or more knowledgeable outsiders participate on an ongoing basis to provide a wider perspective.

Recommendation. For INL to accomplish its expected mission, a number of large, sophisticated and unique facilities will be needed. These could include large hot cells and associated laboratories for postirradiation examination of materials and test reactors such as the Advanced Test Reactor (ATR). The intent is for INL to have magnet facilities attracting researchers and industrial users. For these facilities to attract users, the full costs cannot be charged, and the user would pay only the justified incremental costs associated with use. This arrangement is typical of user facilities in the Office of Science laboratories.

The NE/INL budgeting system and the budget documents themselves are opaque and hard to understand. It is difficult to trace budget amounts to particular projects and programs or to specific activities within the INL subbudget. The committee concludes that a much more transparent, structured planning and budgeting process is needed.

Recommendation. NE, ID, and INL (BEA) should agree on a multiyear, resource-loaded, high-level schedule and plan for the INL facilities, such as the Primavera Project Planner (P3).

Recommendation. NE, ID, and INL (BEA) should improve the form and content of the INL facilities budget documentation. They should support a much more transparent, structured planning and budget process. Budget items should be readily traceable to specific items in the overall plan and schedule.

NE has limited experience of being the PSO for a national laboratory. As such, its procedures and processes for this responsibility are not yet well defined or developed.

Recommendation. NE should meet with DOE and National Nuclear Security Administration organizations that are PSOs for other laboratories to review and discuss their practices and processes. Based on the lessons they learned, it should develop and document its own internal processes and procedures for discharging its responsibilities as the lead PSO for INL.

PROGRAM PRIORITIES, BALANCE, AND OVERSIGHT

The NE budget has experienced wide swings in both size and content over the past 10 years. The committee has reviewed the current NE budget process for annually allocating limited resources among programs. Like the federal budget process in general, the NE process tends to subordinate long-term commitments to more immediate needs. The result of this conflict between the annual budget process and the long-term nature of much of NE's research has resulted in program goals, schedules, and budgets that are inconsistent. For that very reason, the committee is convinced that NE should set up an internal system to allocate resources consistently over time and among programs.

Program Priorities

To prioritize NE programs, the committee examined their relevance to NE's mission. The committee's judgment about priorities is summarized in Table S-1.

Program Balance

Based on these priorities, the committee's programmatic recommendations that have budget consequences are as follows:

- *Nuclear Power 2010 (NP 2010).* DOE should augment this program to ensure timely and cost-effective deployment of the first new reactor plants. Of particular importance is the need to address industrial and human resource infrastructure issues. Although increases in the NP 2010 budget are likely, they do not account for a large fraction of the total NE funding. The NP 2010 requirements should be fully supported.
- *Research in support of the commercial fleet.* The committee does not recommend a large federal research program, because most of this research should be industry-supported. However, some specific projects have sufficient public benefit to warrant federal funding, for which DOE should share about 20 percent of the costs and support user facilities at incremental cost. These elements of the program should be fully funded when the NP 2010 licensing and design completion efforts come to an end.
- *University infrastructure support.* A sizeable buildup in nuclear energy production, research, and development necessitates strengthening university capabilities to educate a growing number of young professionals and scientists in the relevant areas. DOE should include this program in its budget at the levels authorized by the Energy Policy Act of 2005.
- *Generation IV.* NE should sustain a balanced R&D portfolio in advanced reactor development. The program requires predictable and steady funding, but its goals can be more modest and its timetables stretched. A revised program can be conducted within levels recently appropriated for Generation IV and for SFR-related R&D under GNEP.

TABLE S-1 Relative Priorities of NE R&D Programs and INL

Priority	Program	Comment
High	NP 2010 and research in support of the commercial fleet	Unless the commercial fleet of LWRs grows, nuclear power will be a diminishing energy resource for the United States and there will be little need for all of NE's longer term research programs. NP 2010 and selected commercial research projects should be fully funded as a matter of highest priority.
High	University infrastructure support	University support is largely a government responsibility in the committee's view.
Medium	Generation IV, NGNP, NHI, and AFCI	These are all longer term research programs with defined downselect decisions that could change the course of research as more is learned. These programs will perform best with research budgets consistent with steady progress toward these decision points.
Medium	INL programs to reduce deferred maintenance and to build a capacity that will sustain a useful scientific capability	These activities require steady progress but can evolve over a reasonable time. Construction of user facilities and program facilities should be carefully evaluated on a case-by-case basis to validate the need and to avoid duplication with facilities at other national laboratories.
Low	Major facility deployment (large demonstration or initial commercial plants) in GNEP	U.S. industry does not urgently require the construction of such facilities.

- *AFCI.* NE should pursue the AFCI program with some modifications, as recommended in Chapter 4, but not including construction of large demonstration or commercial-scale facilities. The committee recommends a more modest and longer term program of applied research and engineering, including new research-scale experimental capabilities as envisioned for the Advanced Fuel Cycle Facility, although the program would differ somewhat from the AFCI program before GNEP.
- *Major fuel cycle facilities.* The committee recognizes that major engineering and commercial-scale facilities will ultimately be required to test and deploy fuel cycle technology. However, it concludes that DOE should not go forward with early deployment of such facilities. These facilities should be funded only when clearly needed, and then as increases to the NE base budget.
- *INL.* It is essential to provide reasonable and predictable funding to support the PSO responsibility for site condition and capacity building. DOE should create a strategic plan based on concepts laid out in Chapter 6 (see Table 6-2) to establish the target funding level for the Idaho Facilities Management account.

Program Oversight

Recommendation. As a counterbalance to the short-term nature of the federal budget process, NE should adopt an oversight process for evaluating the adequacy of program plans, evaluating progress against these plans and adjusting resource allocations as planned decision points are reached.

The senior advisory body for NE has been the Nuclear Energy Research Advisory Committee (NERAC). A modified NERAC seems the obvious starting point for reestablishing oversight of the NE programs. In the committee's opinion, the key will be to ensure its independence, transparency, and focus on the most important strategic issues. The committee has not attempted to design a specific oversight capability, but the following characteristics would be appropriate for the body it has in mind:

- Encourage objectivity by recognizing that knowledgeable persons have different points of view and that balance is therefore best achieved by diversifying the membership of the oversight body.
- Avoid conflicts of interest by requiring public disclosure of members' connections with study sponsors or organizations likely to be affected by study results. Persons directly funded by sponsors are rarely appointed to such bodies.
- Ensure transparency by requiring that both the statement of task and the final report for each project are routinely made public in a timely fashion.

REFERENCE

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1

Introduction

Growing energy demands, emerging concerns about the emissions of carbon dioxide from fossil fuel combustion, the increasing and volatile price of natural gas, and a sustained period of successful operation for the existing fleet of nuclear power plants have resulted in a renewal of interest in nuclear power in the United States. The Energy Policy Act of 2005 (EPAct05) advanced this interest by authorizing a number of initiatives intended to both accelerate new nuclear plant construction in the near term and spur longer-term research and development (R&D). Partly as a result of EPAct05, the nuclear power industry is considering applications for the construction of new light water reactor power plants in the United States. The U.S. Nuclear Regulatory Commission (USNRC) reports that it expects 21 applications for 32 new units between 2007 and 2009.[1]

The government plays a significant role in guiding the future of nuclear power. The nuclear industry in the United States is closely regulated to promote safe and secure power plant operation. The Nuclear Waste Policy Act of 1982 and its 1987 amendments make the government responsible for long-term management of spent reactor fuel. In addition, because power plant construction can be an expensive and lengthy process with substantial uncertainties, particularly those associated with regulatory and environmental permitting, the industry looks to government for assistance in managing the risks of investing in the first new reactors ordered in the United States since 1973.

The Office of Nuclear Energy (NE) at the U.S. Department of Energy (DOE) is a major agent of the government's responsibility for advancing nuclear power. Specifically, NE takes its mission to be as follows:

> . . . to lead the DOE investment in the development and exploration of advanced nuclear science and technology. NE leads the Government's efforts to develop new nuclear energy generation technologies; to develop advanced, proliferation-resistant nuclear fuel technologies that maximize energy from nuclear fuel; and to maintain and enhance the national nuclear technology infrastructure.[2]

One consequence of the renewed interest in nuclear power for the NE mission has been a rapid growth in the NE research budget: by nearly 70 percent from the $193 million appropriated in FY 2003 to $320 million in FY 2006.[3] The turnaround over a longer period was even more dramatic; in FY 1998 the NE research budget had collapsed to $2.2 million. In light of this growth, the FY 2006 President's Budget Request (PBR) asked for funds to be set aside for the National Academy of Sciences to review the NE research programs and budget and to recommend priorities for the programs given the likelihood of constrained budget levels in the future (DOE, 2005). Following passage by Congress of the FY 2006 budget, the National Research Council (NRC) developed a statement of task (Appendix F) for a "comprehensive, independent evaluation of DOE's nuclear energy program's goals and plans, and processes for establishing program priorities and oversight (including the method for determining the relative allocation of budgetary resources)."

At the time the statement of task was approved, the scope of the project focused on five elements of the NE program, which were described in the prospectus for the study approved by the National Academies:

- *Nuclear Power 2010.* This is a joint government/industry cost-shared effort comprising technology development and demonstration activities that advance the National Energy Policy goals of enhancing energy independence and reliability and expanding the contribution of nuclear power to the U.S. energy portfolio. Its current focus is to demonstrate the revised licensing process by which the next generation of

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[1] From the September 11, 2007, version of http://www.nrc.gov/reactors/new-licensing/new-licensing-files/expected-new-rx-applications.pdf.

[2] From the statement of mission available at http://www.ne.doe.gov/. Last accessed January 28, 2007.

[3] These are totals only for programs within the scope of this project.

nuclear power plants would be governed and to finalize the licensed designs to a point that project and private investment decisions on new plant constructions can be firmly based.

- *Generation IV.* This nuclear energy systems initiative addresses fundamental R&D necessary to ensure the viability of future nuclear energy systems. The initiative is intended to address concepts that excel in safety, cost effectiveness, sustainability, and proliferation resistance and that will be attractive to the private sector for commercial development and deployment. With international participation, the initiative developed a technology roadmap that identified the six most promising nuclear energy systems, paying attention to the complete fuel cycle, power conversion, waste management, and other nuclear infrastructure issues. The concepts it identified are (1) the very-high-temperature reactor (VHTR), (2) the supercritical water-cooled reactor (SCWR), (3) the gas-cooled fast reactor (GFR), (4) the lead-cooled fast reactor (LFR), (5) the sodium-cooled fast reactor (SFR), and (6) the molten salt reactor (MSR). The roadmap also serves as the basis for organizing national, bilateral, and multilateral research and development activities for the development of Generation IV systems.
- *Nuclear Hydrogen Initiative.* This initiative conducts R&D on enabling technologies, demonstrating nuclear-based hydrogen production technologies and studying potential hydrogen production approaches in support of the President's Hydrogen Fuel Initiative. The objective is to develop technologies that will use nuclear-generated heat to produce bulk hydrogen at a cost competitive with that of other alternative transportation fuels. Approaches such as high-temperature electrolysis and various thermochemical water-splitting cycles are being considered.
- *Advanced Fuel Cycle Initiative (AFCI).* This initiative develops and demonstrates fuel cycles that could have substantial environmental, nonproliferation, and economic advantages over the once-through fuel cycle. Specifically, it is investigating (1) the development of separations technologies for spent nuclear fuel; (2) the development of advanced, proliferation-resistant reactor fuels that will enable the consumption of plutonium from accumulated spent fuel, thus extracting more useful energy from spent fuel materials; and (3) transmutation engineering for minor actinides and long-lived fission products from spent fuel. The initiative is also developing systems analysis tools to formulate, assess, and guide program activities and a transmutation education activity that includes support of young U.S. scientists and engineers studying science and technology issues related to transmutation and advanced nuclear fuel cycle systems.
- *Idaho Facilities Management.* This program maintains DOE facilities at Idaho National Laboratory (INL) that are related to the above-mentioned R&D programs. (The FY 2006 PBR specifically asks that the relationship between the Idaho facilities management program and NE's R&D program be evaluated.)

EVOLVING PROJECT SCOPE

In response to the FY 2006 PBR, NRC established the Committee on Review of DOE's Nuclear Energy Research and Development Program. The statement of task for the committee closely matched that of the effort described in the above-mentioned prospectus, except that it introduced two issues that somewhat extended the scope. One was the appropriate federal role relative to that of "public, nongovernmental (including universities) and international efforts." The other charged the committee with examining program management and organization, among other things, that might be "key[s] to success of the [technical] program."

Following the required appropriations and procurement cycle, the committee first met on August 24, 2006, more than 18 months after the request for the study first appeared in the FY 2006 PBR. During the interim period, however, NE's research program changed significantly. EPAct05 authorized expanded initiatives for the nuclear program and also resulted in the establishment of a new position, assistant secretary for nuclear energy, within DOE. Even more important was the public emergence in early 2006 of a major programmatic initiative—the Global Nuclear Energy Partnership (GNEP). GNEP's stated technical objective is to develop, demonstrate, and deploy technologies to reprocess spent reactor fuel in a way that minimizes the risk of fissile material being diverted, reduces the volume of waste in long-term storage, and recovers the energy available in the unused portion of the spent fuel. If executed as envisioned by its advocates, GNEP would result in the construction of commercial scale facilities for spent fuel reprocessing and disposal by burning[4] the resultant plutonium and minor actinides together in advanced burner reactors, thereby reducing the radioactive burden on the waste repository. As proposed, GNEP would cost billions of dollars over several decades.

The GNEP initiative had major budgetary implications in the nearer term as well. To accommodate GNEP, the FY 2007 PBR proposed to increase the AFCI budget[5] by $154 million, from $79 million to $243 million, while increasing the total NE budget by only $98 million. This proposal would thus have resulted in $56 million being drawn from other NE programs to fund GNEP. However, the Congress did not pass a FY 2007 appropriation for NE; instead it authorized a continuing resolution for the full year, which contained $167 million for the GNEP program through the AFCI account. The FY 2008 PBR includes $395 million for GNEP and $672 million for research and development. Between the FY 2006 appropriation and the FY 2008 request, the NE research and development budget would rise by more than 150 percent (this does not include funding for the Idaho Facilities Man-

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[4] In this context, "burn" does not mean to incinerate or combust; it means to convert heavy elements into lighter elements through the process of nuclear fission.

[5] The GNEP funds are carried under the AFCI budget line since there has been no such line for GNEP itself.

agement account, which would increase from $99 million to $104 million). Table 1-1 summarizes the budget history of the NE program.

THE COMMITTEE'S APPROACH TO EVALUATION

The above-mentioned developments created two issues for the committee. First, the program for which the statement of task was written changed significantly between the time of the statement of task and the start of the committee's work. Second, the dominant new program—GNEP—lacked the technical documentation, program plans, and program management organization that would ordinarily form the basis for an evaluation of program content and budget priorities. The committee believes that it has adapted to these developments in a way that is consistent with the statement of task and the structure of today's NE program.

In the case of GNEP/AFCI, the committee relied on the Mission Need for GNEP, the GNEP Implementation Strategy, and the GNEP Strategic Plan documents for its evaluation (see Chapter 4 for further discussion). Although these appear to be the authoritative descriptions of the GNEP program, the GNEP Implementation Strategy and the GNEP Strategic Plan documents were not made public until well after the committee started its work. The committee believes that these documents provide an adequate basis for its overall assessment of GNEP but recognizes that they fall far short of the documentation needed for a detailed review. The GNEP Technology Development Plan was released late in the report process, but because it included a disclaimer that the plans it contained did "not necessarily reflect the views and decisions of the Department of Energy," the committee could not accept it as DOE policy.

The other elements of the program were evaluated in more conventional terms, although each required its own approach:

- Nuclear Power 2010 is not a research program but is designed to help mitigate the risk that industry will decide to build the first new nuclear power plant. The committee has evaluated it using the elements of the statement of task as the principal criteria.
- The scope of the Generation IV program and the Nuclear Hydrogen Initiative (NHI) program has changed as a result of GNEP. Within the Generation IV program, the committee has focused on the Next Generation Nuclear Plant (NGNP) research effort because the fast spectrum reactor research that was part of this program has been considered in GNEP. While hydrogen production remains a goal of the NGNP program, a number of process heat applications are

TABLE 1-1 Office of Nuclear Energy Budget History FY 2003 to FY 2008 (thousands of dollars)

	Comparable Appropriations			Actual Appropriations		
Program	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007 CR	FY 2008 Request
Nuclear energy plant optimization	4,806	2,863	2,412	0	0	0
Nuclear Energy Research Initiative	17,413	6,410	2,416	0	0	0
Nuclear Power 2010	31,579	19,360	49,605	65,340	80,291	114,000
Generation IV	16,940	26,981	38,828	53,263	35,586	36,145
Nuclear Hydrogen Initiative	2,000	6,201	8,682	24,057	19,265	22,600
Advanced Fuel Cycle Initiative	57,292	65,750	66,407	78,408	167,484	395,000
Subtotal, R&D	130,030	127,565	168,350	221,068	302,626	567,745
Idaho facilities management	62,983	75,534	122,320	99,358	100,358	104,713
Total reviewed accounts	193,013	203,099	290,670	320,426	402,984	672,458
Radiological facilities management	62,928	63,431	68,563	54,049	46,775	53,021
Safeguards and security	52,560	56,654	58,103	71,285	72,946	72,946
University programs	18,034	23,055	23,810	26,730	16,547	0
Program direction	57,909	60,256	60,076	60,498	62,652	76,224
Total energy supply	271,307	291,186	393,339	430,565	482,191	801,703
Total NE budget	375,441	402,804	521,903	532,988	601,904	874,649

NOTE: CR, continuing resolution. Budget history for selected NE programs. NE is funded primarily from the Energy Supply and Conservation appropriations account, but the total NE budget for each year includes some funding from other accounts. The FY 2003 to FY 2005 columns are comparable appropriations, which means that they include funding from other accounts, but for similar activities. Revised updated budget numbers, which were not available to the committee during its study, can be obtained from Patrick Holman, DOE NE.

SOURCES: DOE (2004, 2005, 2006, 2007); the FY 2007 CR appropriations and some FY 2006 appropriations were supplied to NRC staff by DOE on March 9, 2007.

possible as well, and these have been considered. Because this is a well-documented research program, the committee has used appropriate criteria from the Program Assessment and Review Tool (PART)[6] process in its evaluation, as well as the elements of the statement of task.

- The committee focused chiefly on the Idaho Facilities Management program because it is a major line in the NE budget—on the order of $100 million annually. This program is only one element of the Ten-Year Site Plan for INL. It supports chiefly the building of infrastructure at INL as well as technical programs that are not funded through program channels. The committee has used DOE's criteria for the quality of laboratory infrastructure to evaluate this program and has examined whether the proposed program is consistent with its recommendations for other programs.

THE COMMITTEE'S PERSPECTIVE ON THE NE RESEARCH PROGRAM

Despite the changes in program and budget experienced by the NE research program, there are some constant features that set the context for the committee's evaluation approach, which was influenced by two observations. One is that while the details of the NE program have shifted considerably, its high-level goals have changed little if at all. While stated in somewhat different words in various reports, the committee believes that a reasonable summary of the goals for technology development in support of the NE mission is as follows:

- Assist the nuclear industry in providing for the safe, secure, and effective operation of nuclear power plants already in service, the anticipated growth in the next generation of light water reactors, and associated fuel cycle facilities.
- Provide for nuclear power at a cost that will be competitive with other energy sources over time.
- Support a safe and publicly acceptable domestic waste management system, including options for long-term disposal of the related waste forms. (The principal DOE responsibility for this function lies with its Office of Civilian Radioactive Waste Management.)
- Provide for effective proliferation resistance and physical protection of nuclear energy systems, both at home and in support of international nonproliferation and nuclear security regimes.
- Create economical and environmentally acceptable nuclear power options for assuring long-term nonnuclear energy supplies while displacing insecure and polluting energy sources; such options include electricity production, hydrogen production, process heat, and water desalinization.

The committee's second observation is that predicting the course of nuclear technology development over the next several decades entails substantial uncertainties. Indeed, the committee heard presentations from several respected analysts about how this development might take place. Their views of the technological future differed in important ways. An important reason for this divergence is that the development of new nuclear technology requires a planning horizon measured in decades, in no small part because of the capital intensity of the commercial nuclear energy sector. Over such a time period, the committee believes that the success of various candidate technologies will depend on policy and other forces outside the control of any NE technology development program. For example,

- Waste management options and associated regulatory regimes and their likely acceptance by the public range from long-term storage at reactor sites or centralized interim storage, to direct disposal of all spent fuel in geologic repositories, as well as reduced waste forms envisioned by GNEP.
- As yet unformulated environmental policy, especially regarding climate change, could have decisive impacts on the attractiveness of nuclear power.
- Opinion on the cost and availability of natural uranium and associated enrichment capacity varies widely: some say it will be abundant, others say it will be "limited."
- If the near-term reprocessing options being pursued by other countries were to become established commercially, the resulting waste management regimes would compete with the GNEP concept.
- Other countries might succeed in the development of next-generation nuclear technologies.
- Nonproliferation and physical protection regimes are in flux, especially as international agreements continue to evolve.
- Success of competing energy sources, such as clean coal, would affect the need for nuclear power.
- The rate of near-term expansion of nuclear power plants, both domestically and internationally, would matter since it drives the timing and need for advanced reactors and fuel cycle technology.

How these uncertainties affect the elements of the NE program is discussed at the appropriate place in the balance of this report. In general, however, the committee's view is that to select the winning technology path from among the options known today would be very premature. This conclusion is especially relevant for research that serves long-term objectives, such as GNEP/AFCI, Generation IV, and NHI.

Chapters 2 through 5 summarize the committee's evaluation of each of the programs within the statement of task. A concluding chapter presents recommendations on program balance and priorities among the programs, as well as mecha-

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[6] PART is used by the Office of Management and Budget to assess the management of federal programs and contains specific criteria for that purpose.

nisms for maintaining oversight of the programs as external conditions inevitably change.

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2

Nuclear Power 2010

BACKGROUND

The Nuclear Power 2010 (NP 2010) program[1] was established by the U.S. Department of Energy (DOE) as a budget line item in 2002 to support the near-term deployment of new nuclear plants in accordance with the roadmap (NERAC, 2001) prepared for DOE by its Nuclear Energy Research Advisory Committee (NERAC). The overall purpose of NP 2010 is to help achieve the goals of the National Energy Policy Development Group (NEPDG, 2001):

- Enhance long-term energy independence and improve the reliability of electricity generation, with minimal air pollution and greenhouse gas emissions;
- Increase diversity in the U.S. energy portfolio;
- Expand the contribution of nuclear power to the U.S. energy portfolio; and
- Address technical, safety/regulatory, and institutional challenges to the deployment of new nuclear plants.

NP 2010 is a 50/50 government/industry cost-shared effort with the following objectives:

- Identify sites for new near-term nuclear power plants and obtain early site permits (ESPs).
- Complete detailed, first-of-a-kind design engineering on two advanced light water reactor (ALWR) plants and confirm the safety of the designs by obtaining design certifications (DCs).
- Obtain combined construction and operating licenses (COLs) in keeping with the Standardization Policy (10 CFR Part 52) of the U.S. Nuclear Regulatory Commission (USNRC).
- Develop an effective Inspection, Testing, Analyses and Acceptance Criteria (ITAAC) process to assure licensing compliance during construction.
- Implement the standby support provisions of the Energy Policy Act of 2005 (EPAct05) for the construction of new nuclear plants.
- Determine the capital costs and operation and maintenance costs, construction time, and levelized cost of electricity for the two plants.
- Evaluate the business case for building new nuclear power plants and pave the way for an industry decision to build new ALWR nuclear plants in the United States. Construction would begin early in the next decade.

DOE's responsibilities end with the issuance of the COL by the USNRC, completion of first-of-a-kind engineering for the AP1000 and Economic Simplified Boiling Water Reactor (ESBWR) standard plant designs, and implementation of the standby support and loan guarantee financial incentives of EPAct05.

Based on these results, responsibility for the procurement and construction of new nuclear plants rests solely with the nuclear industry.

Program Background

The NP 2010 program is the culmination of a cooperative research, development, and deployment (RD&D) effort in the 1980s and 1990s between DOE's Office of Nuclear Energy (NE) and industry to develop improved light water reactor (LWR) systems for initial expansion, making them safer, smaller, and simpler, standardized and prelicensed by the USNRC, and competitive with nonnuclear alternatives. The program was initiated in the early 1980s by the U.S. utilities under the technical management of the Electric Power Research Institute (EPRI) and grew into a broad cooperative effort, the ALWR program[2] (Taylor and Santucci, 1997). Participants included DOE, the U.S. utility members

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[1] Department of Energy, Office of Nuclear Energy, Nuclear Power 2010 Plan Overview, January 2006. Available at http://www.ne.doe.gov/np2010/neNP2010a.html.

[2] G. Vine, EPRI, "DOE's light water reactor R&D program: An industry perspective," Presentation to the committee on October 17, 2006.

of EPRI, major international utilities in Europe and Asia, and qualified reactor suppliers, all of whom cofunded the program. DOE established cooperative agreements with industry by which their management responsibilities could be discharged. USNRC was kept fully informed of progress, commented on the results of the program, and performed independent confirmatory analyses and experiments. A prime utility goal was to oversee the development of the utility requirements documents (URDs) (EPRI, 1990) to provide owner-operator guidelines to the designers of the new plants. A key purpose of the URDs was to apply the lessons learned in the first worldwide deployment of nuclear power, focused on increased safety, reliability, design, and operational simplification and integration. In 1992, a National Research Council (NRC) report on nuclear power encouraged continuation of that R&D effort on ALWRs (NRC, 1992).

Testing was completed on two 600-MWe designs featuring passive emergency core and containment cooling systems: the Westinghouse pressurized water reactor (PWR) AP600 and the General Electric (GE) simplified boiling water reactor (SBWR), on which the power-upgraded Westinghouse AP1000[3] and the GE ESBWR[4] are based. Design certifications were obtained from USNRC for the AP600, the evolutionary advanced BWR (ABWR),[5] and the advanced PWR System 80+.[6]

With rising concern over global warming, rapidly increasing energy prices, greatly improved performance of existing LWR plants with average capacity factors exceeding 90 percent, and the stimulation of U.S. energy policy (NEPDG, 2001), DOE sponsored the NP 2010 program, cost-shared with U.S industry. The principal focus of NP 2010 was to move beyond R&D to the deployment of new nuclear plants.

Approach to Evaluation

The criteria used in the evaluation of NP 2010 were those provided in the committee's statement of task. The remainder of this chapter contains three main sections:

- Overall program description,
- Goals, timetables, and progress, and
- Committee recommendations.

The areas covered under program description include primary milestones, licensing demonstration, costs, management responsibilities and organizations, standardization, ITAAC, infrastructure needs, setting priorities, oversight methods and metrics, cooperative industry–government R&D, economic issues, and EPAct05. The program descriptions are derived from DOE and industry documentation, presentations by DOE management, nuclear consortia leaders, and industry representatives from the Nuclear Energy Institute (NEI) and EPRI. The penultimate section brings the goals and timetables up to date and assesses progress. The final section presents the committee's recommendations.

OVERALL PROGRAM DESCRIPTION

Primary Milestones

The NP 2010 program includes the following technical goals[7,8]:

- Demonstrate key untested regulatory processes.
  —ESPs
    - Obtain three ESPs.
  —DCs for new reactors
    - Obtain approval of AP1000 design certification amendments.
    - Complete ongoing design certification of the ESBWR.
  —COLs
    - Provide guidance on COL generic issues.
    - Obtain USNRC acceptance of AP1000 and ESBWR COL applications.
    - Complete ITAAC demonstrations.
    - Obtain two COLs.
- Complete first-of-a-kind engineering (design finalization) of new standardized nuclear plant designs to provide improved safety, reliability, and economy.
- Determine the plant's capital and O&M costs, construction time, and levelized cost of electricity.
- Provide technical support for risk insurance definitions (standby support) for the first six new U.S. nuclear plants (legislated in EPAct05).

Licensing Demonstration

Status

DOE solicited proposals from industry for New Plant Licensing Projects and design completions that would dem-

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[3] G. Davis, Westinghouse, "The certified AP1000 standard design," Presentation to the committee on November 8, 2006.

[4] R. Kingston, GE, "New units: ESBWR and ABWR," Presentation to the committee on November 8, 2006. See also D. Hinds and C. Maslak, The next generation of nuclear energy: The ESBWR, Nuclear News, American Nuclear Society, January 2006: 35-40.

[5] See Nuclear Energy Institute, New Reactor Designs: General Electric Advanced Boiling Water Reactor, 2006. Available at http://www.nei.org/keyissues/newnuclearplants/newreactordesigns/.

[6] See Energy Information Administration, New Reactor Designs. Available at http://www.eia.doe.gov/cneaf/nuclear/page/analysis/nucenviss_2.html/.

[7] R. Smith-Kevern, Acting Associate Director, Office of Nuclear Power Technology, DOE, "Nuclear Power 2010," Presentation to the committee on August 24, 2006.

[8] T. Miller, Deputy Director, "Light water reactor deployment," Presentation to the committee on October 17, 2006.

onstrate the validity of the USNRC 10 CFR Part 52 process and its related standardization policy in assuring a reasonably predictable path to completion of design, construction, and start of operation of new nuclear plants. Two consortia of utilities responded to DOE's request for proposal, accepting the primary goals stated above. DOE subsequently entered into contracts with the two consortia. USNRC committed to the licensing reviews required. Congress provided incentives through EPAct05 to enable the utilities to make prudent investments to build the first six plants.

The NuStart Consortium[9] is made up of utilities, which include Constellation Energy, Duke, EDF-INA, Entergy, Exelon, FPL, Progress Energy, SCANA, the Southern Company, and the Tennessee Valley Authority (TVA) and the reactor suppliers GE and Westinghouse. The NuStart cooperative agreement provides for the preparation of two COL applications and the submission of one application to the USNRC following a down-selection process for one technology at one site. NuStart is currently preparing COL applications for the ESBWR at Entergy's Grand Gulf, Mississippi, site as well as the AP1000 at Exelon's Clinton, Illinois, site and TVA's Bellefonte, Alabama, site.

The Dominion Consortium[10] comprises Dominion, Constellation Energy, GE, and Bechtel. Its cooperative agreement includes preparation and submission of a COL for the North Anna, Virginia, site with the GE ESBWR as the selected reactor design. The designs of both the ESBWR and the AP1000 are being funded with direct cost-sharing agreements between DOE and the companies producing the reactor designs.

A TVA-led consortium has completed a study,[11] under NP 2010 sponsorship, of cost, schedule, and design changes needed to deploy the GE design-certified evolutionary ABWR at the Bellefonte, Alabama, site (TVA, 2005). The consortium is not active at this time. Another consortium, Unistar, made up of Constellation Energy, AREVA, and Bechtel Power Corporation, is not participating in NP 2010 but is planning to submit an application to USNRC for a COL and the design certification of the French 1,600-MWe evolutionary pressurized water reactor (EPR) from AREVA (DOE, 2004).

Timetables

The overall schedules call for obtaining the ESPs this year, the DC for the ESBWR by April 2010, the DC amendment approval for the AP1000 by July 2008, the COLs by early FY 2011, and finalization of the two designs by mid-FY 2011. The milestones for completion of the new nuclear power plant licenses by the consortia are shown in Table 2-1. The USNRC has adopted as a planning assumption that the required public hearings on ESP and COL applications will take up to 1 year to complete, following the issuance of the Safety Evaluation Report (SER) for a COL, before an ESP or a COL can be granted. This additional year is not included in the dates for USNRC approval of COLs in the DOE estimates shown in Table 2-1.

As of August 2007, a total of 14 companies, including those in Table 2-1, had announced their intent to seek a COL for a new nuclear plant: TVA, Progress Energy, Duke, South Carolina Electric and Gas, Southern, Dominion, Entergy, Constellation, Ameren, PPL, Amarillo Power, Alternate Energy Holdings, NRG, and TXU. Four of these companies are seeking, or have received, an ESP that could be referenced in a COL proceeding.

Design Finalization

A substantial portion of the plant designs will be completed to obtain a COL, but much more remains to encompass all features of the entire plant. The 5-year program plan of DOE's Office of Light Water Reactor Deployment for NP 2010, issued in January 2007, schedules completion of the full ESBWR design early in FY 2011 (DC in mid-FY 2010) and completion of the AP1000 first-of-a-kind engineering design in mid-FY 2011 (DC in early FY 2006). Start of construction is set at the end of FY 2010 for both designs, before design finalization.

Costs

The funding levels of the DOE cost share of NP 2010 for FY 2005, FY 2006, and FY 2007 were $49.6 million, $65.3 million, and $80.3 million, respectively. The FY 2008 budget request for NP 2010 is $114 million. As of March 2007, the DOE estimated cost to complete NP 2010 was $550 million, leaving $240.8 million for FY 2009 and FY 2010.[12,13]

This funding is matched by the Dominion and NuStart consortia, including both GE and Westinghouse. The level of funding is about equal for each consortium and includes the payments to the USNRC to cover their licensing work. The largest portion of the funding supports the design engineering effort. DOE reports that industry is current with its contributions.[14]

Industry has testified that NP 2010 funding will not maintain the program's momentum, recommending that DOE FY 2008 funding be increased to $183 million (Bowman, 2007).

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[9] M. Kray, Exelon/NuStart, Presentation to the committee on October 17, 2006.

[10] E. Grecheck, Dominion Energy, Presentation to the committee on October 17, 2006.

[11] See also R. Ganthner, AREVA, Presentation to the committee on November 8, 2006.

[12] R. Smith-Kevern, Acting Associate Director, Office of Nuclear Power Technology, DOE. "Nuclear Power 2010." Presentation to the committee on August 24, 2006.

[13] T. Miller, Deputy Director, "Light water reactor deployment," Presentation to the committee on October 17, 2006.

[14] Communication between the DOE and a committee member on September 11, 2007.

TABLE 2-1 New Nuclear Plant Licensing Demonstration Project Milestones (as of April 15, 2007)

Utility/Site	Early Site Permit	Design Certification	Construction and Operating License
Dominion/ North Anna, Va.	USNRC approval[a] May 2007.	ESBWR application in; USNRC approval April 2010.	Application submittal November 2007; USNRC approval April 2010.
NuStart-Entergy/ Grand Gulf, Miss.	Permit[a] granted April 2007.	As above.	Application submittal February 2008; USNRC approval April 2010.
NuStart-Entergy/ River Bend, La.	USNRC approval December 2007.	As above.	Application submittal November 2008; USNRC approval February 2011.
NuStart-Exelon/Clinton, Ill.	USNRC approval August 2006; permit granted March 2007.	Westinghouse AP1000 DC received December 2005; USNRC approval of potential amendments July 2008.	Application submittal February 2009; USNRC approval September 2011.
NuStart-Duke/TVA-Bellefonte, Ala.	Not determined.	As above.	Application submittal October 2007; USNRC approval July 2010.

[a] After USNRC approval of the ESP application, the Atomic Safety and Licensing Board holds a public hearing; upon satisfactory completion of the hearing, the USNRC commissioners grant the permit.

Industry further recommends (Bowman, 2007) that the total NP 2010 funding be increased by $354 million to enable completion of the full NP 2010 scope in a timely manner, requiring a $177 million increase by both DOE and industry to maintain the 50 percent cost-share agreement.

Management Responsibilities and Organizations

Office of Nuclear Energy

The Office of Light Water Reactor Deployment at NE provides overall management of the NP 2010 program, including program planning and development, program management and monitoring, preparation and approval of procurement solicitations, contractor award selection, conduct of program reviews and corrective action completion, program funding authority to the operations offices and the national laboratories, and dissemination of program information to DOE management and stakeholders. NE staff serve as project managers for specific projects, where they are responsible for overall oversight, performance monitoring, and management of functions related to the projects.

NE has assigned NP 2010 staff to interface with their project counterparts from the power companies and reactor vendors as well as other subcontractors during the course of their project management and oversight duties. As part of their management and oversight duties, NE-NP 2010 staff periodically meet with USNRC staff to advise them on the status of NP 2010 and to be advised on USNRC plans for handling the licensing load. NE staff also participate in various industry committees and task forces coordinated by the NEI to assure that industry concerns are fully addressed.

Industry Consortia

The industry consortia have responded to the DOE solicitation, proposing projects, activities, and funding requirements as partners on the licensing demonstration projects for ESPs, DCs, and the COLs. Pursuant to contracts with DOE, the industry consortia selected by DOE are responsible for the management and completion of project activities, including those activities subcontracted, interfacing with and reporting to DOE on project progress and financial status. DOE also entered into a cooperative agreement with the EPRI to develop generic COL application guidance and resolve generic issues that would affect the licensing demonstration projects.

U.S. Nuclear Regulatory Commission

USNRC can issue an ESP for approval of one or more sites for one or more nuclear power facilities separate from filing an application for a construction permit or a combined license. The review of an ESP application may address site safety issues, environmental protection issues, and plans for coping with emergencies, independent of the review of a specific nuclear plant design. An ESP can be referenced for up 20 years and can be renewed for up to 20 years. USNRC review of a DC application addresses the safety issues surrounding a new nuclear power plant design independent of a specific site. Once issued, the DC can be referenced for up to 15 years. It can also be renewed for an additional 15 years.

The USNRC will docket and, subsequent to satisfactory review and comment on all safety aspects of the applicant's power plant design and site, issue a COL to the applicant to build and operate the plant. The COL will be consistent with the relevant ESP and design certification. USNRC reports that it expects 21 applications for 32 new units in the 2007-2009 time period.[15] In addition, four companies are pursuing ESPs at seven sites; GE, Westinghouse, and Areva are pursuing DCs or amendments to existing DCs; and Mitsubishi is planning to apply to USNRC for a SER and a DC.

This surge of interest in new plants arises from

- Financial incentives in EPAct05, including
  - —Requirement for first concrete by 2013 in order to be eligible for production tax credits,
  - —Limitation of the risk insurance to the first six plants, with a higher level of support for the first two plants than for the next four plants, and
  - —Availability of the financial incentives on a first-come, first-served basis.
- Requirements for new base-load capacity by utilities in the Southeast before 2015.
- The probability of some form of carbon constraint (or tax) in the near future.

To support the anticipated number of new nuclear plants, USNRC is updating its regulations, regulatory guides, standard review plans, and other guidance documents governing the licensing and operation of new nuclear power plants (Reyes, 2006), so that these will be in place prior to the receipt of the first COL application, expected in the fall of 2007.

The USNRC is responding to needs for future application reviews by estimating the durations of the reviews and the resources needed (in staff, dollars, and technical assistance) to complete the reviews, ensuring the availability of critical skills within the agency or through contracts; and by developing the regulatory infrastructure to support future licensing reviews. On August 28, 2007, the USNRC published in the Federal Register the revisions to Part 52, effective September 27, 2007, which establish key rules governing new plant licensing activities (USNRC, 2006).

In addition to the large number of ESP, DC, and COL licensing reviews for new plants discussed above, USNRC is also expected to review license extensions for many of the current nuclear plants and to begin the licensing process for the Yucca Mountain repository in the same period. Because of this increased workload, the USNRC is currently understaffed and is planning to add 200 staff every year for the next 3 years. Additional staff members will help to handle the extra work, but they must be trained for this purpose, which will take up to a year depending on the level of expertise required to process the applications.

Organizational changes are being made to better handle this heavy workload. In late 2006, USNRC established an Office of New Reactors to focus on licensing and building new nuclear power plants in the near term. It has also established the Human Capital Council, which is preparing plans to strengthen the workforce by upgrading their knowledge, increasing their numbers, and qualifying their staff to perform specific review tasks. The Government Accountability Office has completed an assessment of the personnel situation, observing that about one-third of USNRC's workforce with mission-critical skills will be eligible to retire through FY 2010 (GAO, 2007).

USNRC is holding periodic public meetings with the industry to provide a common understanding of the emerging licensing framework for new plants. The early meetings indicate that considerable additional material will be required from the applicants. For example, USNRC is proposing that the applicant apply lessons learned in plant design and operational programs to minimize radioactive contamination, reduce radwaste by-products, and facilitate the ultimate decommissioning, through license termination after 60 years of operation.

National Laboratories

The national laboratories, including the Idaho National Laboratory (INL), provide limited support to DOE's NP 2010 program. So far, laboratory technical support in several key areas has been used for soil characterization, spent fuel transportation analysis, and economic analysis. The national laboratories are also contracted by USNRC to provide technical support on USNRC reviews of nuclear plant safety issues.

Standardization

DOE and the industry have placed strong emphasis on standardization of each family of nuclear power plants (EPRI, 1990). The goal is that all plants of a design family will be the same, except for limited site-specific differences. Standardization covers the entire generating plant: nuclear and turbine islands and key supporting facilities such as radioactive waste treatment and includes design, licensing, operations, maintenance, and decommissioning. Form-fit-function specifications provide for standardization of components procured competitively from subsuppliers. Standardization also applies to commonalities in safety and licensing for different families of designs.

Standardization will reduce the licensing burden for duplicate plants and will reduce their construction time and operational costs as the learning curve proceeds. It will also lead to greater efficiencies and simplicity in all aspects of nuclear plant operations, including safety, maintenance, training, and spare parts procurement. Consortia pursuing COLs under NP 2010 have endorsed a USNRC design-centered licensing approach that promotes standardization

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[15] From the September 11, 2007, version of http://www.nrc.gov/reactors/new-licensing/new-licensing-files/expected-new-rx-applications.pdf.

of license applications. A series of letters[16] to the USNRC have clearly laid out team-based approaches for each of the plant designs currently undergoing initial or revised certification. The industry consortia are implementing this approach by outlining the proposed content of the applications and committing to response times on USNRC Requests for Additional Information (RAI) during review of the COL applications. This license standardization will help to reduce the time required for review of COL applications and the time and costs for the subsequent license applications for the same standard design.

Inspections, Tests, Analyses, and Acceptance Criteria

A primary purpose of 10 CFR Part 52 is to eliminate unnecessary construction delays and start-ups of operation caused by preoperational licensing or litigation. This requires resolution of design and siting issues before the start of construction and continued attention to assuring compliance with the COL during construction. To achieve this purpose, the ITAAC process was formulated to verify conformance with the COL as the construction proceeds.

ITAAC consist of license commitments (top-level key design features and performance characteristics) and a list of inspections, tests, and analyses to confirm that the plant was built in accordance with these licensing commitments.[17] A set of design-related ITAAC are prepared and submitted to the USNRC as part of the design certification process. The COL applicant is also required to submit a set of project- and site-related ITAAC and performs the inspections, tests, and analyses during and after construction. Once the acceptance criteria have been confirmed, the licensee informs USNRC that ITAAC have been met. After USNRC determines ITAAC criteria have been successfully met, a notice is published in the Federal Register.

As part of DOE's cooperative agreements with EPRI and NEI focused on resolving generic new plant licensing issues, DOE supported an ITAAC demonstration project. This activity was divided into two main parts: (1) working with USNRC to develop principles on how to meet ITAAC and (2) applying these principles to develop ITAAC determination bases (IDBs) for closing ITAAC. Westinghouse worked collaboratively with USNRC construction inspection personnel to develop guidance for defining IDBs. This process also included stakeholder participation through workshops, identified IDBs, and discussed types of documentation required for verification and various scenarios that could impact ITAAC for AP1000 systems and buildings. Black & Veatch showed that the principles cooperatively developed by Westinghouse/USNRC are valid and could be applied to a larger range of the ITAAC process when determining compliance with ITAAC.

Infrastructure Needs

Infrastructure Assessment

As part of NP 2010, DOE tasked MPR Associates, Inc., with deciding what infrastructure would be necessary to support construction of new ALWR nuclear power plants in the 2010 timeframe (MPR, 2004a, 2004b, 2005). MPR's infrastructure assessment identified several infrastructure weaknesses and recommended for actions to mitigate their potential impacts on new plant construction schedules.

MPR representatives held discussions with Nuclear Steam Supply System (NSSS) vendors; equipment manufacturers; material suppliers; module fabricators; engineering, procurement and construction (EPC) contractors; U.S. Department of Labor; labor unions; trade organizations; and the USNRC to investigate their ability to support the near-term deployment of new plants. These capabilities were then compared with the resource requirements associated with a hypothetical scenario involving the construction of up to eight nuclear units between 2010 and 2017 to identify any resource shortfalls. For this assessment, shortfalls were defined as insufficient infrastructure resources or deficiencies that would require actions more than 5 years before the commercial operation date of the first new units, not including COL application work, site-specific design work, and normal early procurement activities. Where shortfalls were identified, further investigations were conducted to develop recommendations and lead times that would mitigate impacts on the construction schedules.

Availability of Large Forgings and Castings

Forgings for the large-diameter, thick-walled reactor pressure vessels (RPVs) are difficult to procure. They require a long lead time, and orders must be placed several years prior to installation at the plant site. The only facility worldwide that can produce these components is the Japan Steel Works (JSW). It is reported that 20 percent of the facilities at JSW is for nuclear equipment, with the remaining facilities utilized for other heavy equipment. The next slot available for manufacturing a reactor vessel at JSW is in 2009. Some initial steps are being taken to commit and enlarge future capacity:

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[16] Dominion (North Anna), NuStart (Grand Gulf), and Entergy (River Bend) COL application for USNRC Project Nos. 741, 744, 745, Response to RIS 2006-06, New Reactor Standardization Needed to Support the Design-Centered Licensing Review Approach, Letter 06-480 signed by Grecheck (Dominion), Kray (NuStart), and C. Randy Hutchinson (Entergy), July 17, 2006. NuStart (Bellefonte) COL USNRC Project No. 740, Response to RIS 2006-06, New Reactor Standardization Needed to Support the Design-Centered Licensing Review Approach, Letter signed by Kray, July 17, 2006. USNRC Regulatory Issue Summary 2006-06, New Reactor Standardization Needed to Support the Design-Centered Licensing Review Approach, May 31, 2006.

[17] See SECY-02-0067, staff requirements memorandum (SRM), "Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC) for Operational Programs (Programmatic ITAAC)," issued September 11, 2002; "Inspections, Test, Analyses, and Acceptance Criteria for Operational Programs (Programmatic ITAAC)," issued April 15, 2002.

UniStar announced in August 2006 that AREVA had arranged for the procurement of forgings for the EPR. In May 2007, Dominion signed a contract with GE Energy to order heavy forgings and castings and long-lead components for "a possible new reactor," presumably the ESBWR. In connection with the plans to build the AP1000 in China, plans are being developed to provide substantial component manufacturing capacity in China as well as in South Korea, where Doosan Heavy Industries has been selected to fabricate many of the nuclear components for the AP1000s in China.

A significant concern is the limited global capacity to manufacture reactor heads and other large components with worldwide demand for reactor vessels, large components for fossil plants, parts for scrubber upgrades, liquefied natural gas (LNG) facilities, pipelines, and new refineries.

Supply Chain for N-Stamped Components

Construction of fossil power plants, LNG facilities, pipelines, and other infrastructure for the petroleum industry is currently at a very high level. Most suppliers have adopted the ISO 9000 quality programs that are required to compete in the global marketplace. In comparison with the 25-year absence of business associated with new nuclear plants, many companies have not maintained the quality programs required for the N stamp certification of authorization. This certification confirms that the American Society for Mechanical Engineers (ASME) has surveyed the operations of the certificate holder and has authorized it to use the code stamps exhibiting compliance with ASME Codes.[18]

Many manufacturers that want to provide nuclear components such as valves, headers, piping, pumps, pressure vessels, and core supports will be required to adopt the quality assurance program to meet the safety standards set by the ASME. However, it is uncertain that a sufficient number of manufacturers will adapt to the nuclear marketplace in time to meet the demand for components.

Financial considerations have caused many of the traditional manufacturers of nuclear plant electrical and control equipment to eliminate their special quality assurance programs for the nuclear industry. This has opened up a third-party qualification process for off-the-shelf equipment for replacing, refurbishing, and upgrading the existing plants: a process where standard commercial equipment is procured from a manufacturer and then qualified to meet USNRC safety standards. This process has been enabled by continuing improvement in the quality of standard commercial equipment due to processes such as the ISO 9000 international standard; it includes a series of functional, dimensional, and qualification tests to verify critical characteristics of the equipment; assuring that the component is capable of performing its intended safety function. All components are furnished under a Nuclear Procurement Issues Committee (NUPIC)-audited quality assurance program, with the third-party qualifying laboratory accepting 10 CFR Part 21 responsibilities. Documentation includes direct traceability to the original equipment manufacturer. It is probable that this process will be employed in part during the initial deployment while the buildup of N-stamped manufacturers proceeds.

The Personnel Problem

The industry reports that if 15 new nuclear plants are under construction between 2015 and 2020, it is estimated that 247,000 new jobs will be created. The demand for professionals, including engineers, designers, operators, health physicists, and technicians, will far exceed the current supply. Freshman engineering enrollment has actually decreased slightly since 2002 and is not expected to increase in the coming years. During the past two decades college graduates grew by 20 percent; however, in the next two decades that growth is estimated to drop to 7 percent.[19]

A skilled worker shortage of 5.3 million is predicted by the industry in the United States by 2010, and this shortage is expected to increase to 14 million by 2020. As NP 2010 is completed, and especially when the first plant is authorized, confirmation of the demand surge and evidence of new commercial and career opportunities may accelerate the supply, including overseas sources, alleviating some of the shortages.[20]

A large increase in nuclear power production and additional nuclear R&D will necessitate the education of many new engineers and scientists. DOE's current support of university research and educational infrastructure must continue.

The construction of 15 nuclear plants by 2015 is expected to create 29,000 to 32,000 new construction and operating jobs. In addition, increased demand for electricity and other energy-related facilities will place pressure on the construction workforce. A shortage of welders, ironworkers, pipefitters, and maintenance personnel is anticipated in 2007 and beyond. One-third of the construction workforce is expected to retire in the next 5 years, and there are not enough training programs to replace these workers. If a large number of plants are under construction simultaneously, the supply of qualified tradesmen and heavy rigging equipment may not be adequate.

Setting Priorities

DOE reports that the priorities of the NP 2010 program are consistent with U.S. energy policy (Public Law 109-58) and further defined by the NERAC roadmap. In his presenta-

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[18] ASME Code Section III, Division 1, Nuclear Power Plant Components, requiring compliance with ASME QAI-1, Qualifications and Duties for Authorized Nuclear Inspection.

[19] See http://ewc-online.org/degrees-data.asp.

[20] Jim Reinsch, Bechtel, Presentation to the committee on January 8, 2007.

tion to the committee, the assistant secretary for NE, Dennis Spurgeon, stated that NP 2010 has top priority in the NE development portfolio. Within the constraints of funding, the NP 2010 program is following the high-priority roadmap recommendations to demonstrate the 10 CFR Part 52 process.

Oversight Methods and Metrics

DOE reports on the methods and metrics it uses for oversight of its projects to ensure progress and accountability, including semiannual project reviews, periodic progress report and schedule evaluations, invoice review, as well as participation in periodic project meetings and conference calls.

DOE has negotiated individual interface and oversight agreements with NuStart and Dominion to define the practices to be implemented on the COL demonstration projects. These agreements required implementation of the project management principles outlined in DOE Order 413.3 (DOE, 2003). Various project reviews are performed, including 6-month and annual review, participation in periodic project status conference calls, and, in the case of NuStart, participation in the meetings of NuStart's Management Review Committee. In addition, DOE conducts monthly financial reviews using earned value data submitted by NuStart and Dominion and monthly invoices. DOE has also conducted external independent evaluations of the project baselines. The NP 2010 program evaluates the earned value data, which measures cost and schedule to ensure that adequate progress has been made (EIA, 1998). DOE has also had independent program assessments performed periodically by either NERAC members or outside experts.

Cooperative Industry–Government R&D

DOE reports that the goals of the NP 2010 program could not be accomplished effectively unless the program is cooperative, cost-shared, and governed by cooperative agreements. The success of NP 2010 depends on effective melding of the capabilities and responsibilities of industry and government.

Economic Issues

Economic competitiveness is the primary challenge faced in near-term deployment of new nuclear plants. Studies on the economic prospects of new nuclear plants have been completed by the Massachusetts Institute of Technology (MIT, 2003) and the University of Chicago (UC, 2004). The MIT estimate for *n*th-of-a-kind levelized cost of electricity (LCOE) is \$51-\$67/MWh, and the University of Chicago estimate is \$31-\$46/MWh, indicating that coal presently has the competitive edge. Incentives provided in EPAct05, when fully defined, will allow the first plants to meet the challenge, but subsequent deployments must be competitive in the prevailing rate, regulatory, and market environments.

Legislation to constrain the release of carbon dioxide (CO_2) is likely to be implemented within the next 10 years. For example, states in the Northeast have already taken action through the Regional Greenhouse Gas Initiative[21] to establish a mandatory CO_2 cap-and-trade program in the electric power sector. In addition, California has enacted an aggressive greenhouse gas control law (California Senate Bill 1368 and Assembly Bill 32 [Nuñez/Pavley]). Federal legislative proposals to limit CO_2 emissions have been put forth in the U.S. Senate and House [S. 280, The Climate Stewardship and Innovation Act of 2007, July 2007, and H.R. 5049, the Keep America Competitive Global Warming Policy Act, August 2006]. Evaluations of these bills (EIA 2007, EIA 2006) by the Energy Information Administration project substantial increases in the growth of U.S. nuclear power capacity as a result of such CO_2 emissions control legislation.

The increased economic competitiveness of nuclear power if CO_2 limitations are imposed is clear from comparing estimates of the LCOEs with no carbon tax with a \$50/MT carbon tax or its equivalent, assuming that the average natural gas price will settle at \$6 per million Btu (Specker, 2006). The present state of technology is assumed in these comparisons except it is assumed that in 2020 the technology will provide economical carbon sequestration for the Integrated Coal Gasification Combined Cycle (IGCC) and pulverized coal systems. The cost estimates (in 2005 \$/MWh) are for *n*th-of-a-kind units in a series of standard plants. The ALWR would stay constant at \$46/MWh; natural gas combined cycle (NGCC) would move from \$55/MWh to \$75/MWh; pulverized coal without carbon sequestration would go from \$40/MWh to \$81/MWh; IGCC without carbon sequestration would change from \$47/MWh to \$90/MWh; and advanced IGCC with carbon sequestration would remain constant at \$55/MWh.

Independent of the legislative resolution of CO_2 emission controls, NP 2010, as well as the EPAct05 incentives, are needed to establish that the COL process, in the actual practice of licensing and building the first six plants, will permit prudent investments in new nuclear power plants.

Energy Policy Act 2005: Provisions for New Nuclear Plants

Loan Guarantee

Title XVII of EPAct05 conferred broad authority on DOE to provide loan guarantees to projects that reduce, avoid, or sequester emissions of air pollution or greenhouse gases and employ a new or significantly improved technology. Although the first solicitation does not invite preapplications for advanced nuclear and petroleum refinery projects, future

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[21] See http://www.rggi.org/agreement.html.

loan guarantee solicitations under the final loan guarantee program regulation could help utilities interested in nuclear power raise the substantial up-front capital associated with these major energy projects and, combined with delay risk insurance (standby support), reduce uncertainty and reduce the cost of obtaining capital for sponsors of new nuclear plants. The Loan Guarantee Office has yet to announce how it will administer the first loan guarantee, but it has said that additional requests for solicitations are forthcoming.

The Loan Guarantee Office issued a Notice of Proposed Rulemaking (NOPR) in May 2007, which capped the total amount of loans at 80 percent of that allowed in EPAct05 and limited to 90 percent the share of a loan that would be guaranteed. DOE will gather stakeholder input in connection with the NOPR. It values such input and believes that DOE will be best served by a collaborative process for establishing the loan guarantee program. After resolution of the public comments on NOPR, the final rule will become the basis for future solicitations.

Production Tax Credit

Production Tax Credit-Section 1306, Credit for Production from Advanced Nuclear Power Facilities, permits an entity producing electricity at a qualified advanced nuclear power facility that is placed into service before January 1, 2021, to claim a credit equal to $0.018/kWh of electricity produced for 8 years. Among other requirements, the statutory provision specifies a national megawatt capacity limitation of 6,000 (MWe), which will be prorated among new plants that apply for licenses by 2008 and enter construction by 2014.[22] This production tax credit has been granted to renewable sources, and nuclear energy is included in this category. The limitation is subject to an allocation process to be prescribed by the Department of the Treasury. The statutory provision further states that the process governing the approval and allocation of production credits is to be developed in consultation with the Secretary of Energy.

The production tax credit is administered by the Internal Revenue Service. The NP 2010 program will provide technical support for determining the eligibility requirements. Industry has responded favorably to the program to reduce financial and regulatory risk and to the incentives package. NEI reports that utilities and reactor vendors have spent or committed $1 billion to $1.5 billion on their preparations to build additional generating capacity using nuclear reactors.

Risk Insurance

Section 638, Standby Support for Certain Nuclear Plant Delays, of EPAct05 authorizes the Secretary of Energy to enter into six contracts with sponsors of advanced nuclear facilities to ensure against certain delays in attainment of full-power operation and to indemnify 100 percent of covered costs up to $500 million for each of the initial two reactors and 50 percent of covered costs up to $250 million for each of the subsequent four reactors after an initial 180-day delay. In August 2006, DOE issued a final rule on standby support[23] that sets forth three types of events (Congress calls them "inclusions") for coverage: (1) ITAAC-related delays, (2) preoperational hearings, and (3) litigation based on this statutory delineation. DOE's final rule on standby support states that any ITAAC-related event, preoperational hearing, or litigation that delays the commencement of full-power operations is considered a covered event and would therefore be covered under a standby support contract. DOE defines litigation to include only adjudication in state, federal, local, or tribal courts, including appeals of USNRC decisions related to the combined license to such courts and excluding administrative litigation that occurs at the USNRC related to the combined license process.

GOALS, TIMETABLES, AND PROGRESS

Strategy for Accomplishing NP 2010 Goals

Key strategic elements of NP 2010 bode well for its success. A good working relationship has been achieved between DOE and its contractors in accordance with the related cooperative agreements and their statements of goals, milestones, project controls, responsibilities, and accountabilities. The selection of the projects funded is, appropriately, market driven. The cooperative agreement allows industry to convey its request for projects it deems will address the technical, regulatory, and institutional challenges to new nuclear plant deployment. There is a strong focus on demonstrating the regulatory processes, finalizing and standardizing the designs, and implementing the EPAct05 standby support provisions, all of which are essential front-end activities.

Yet, other activities essential to ultimate success do not seem to have achieved that same focus in planning, let alone implementation. Whereas standardization within a family of designs is progressing well, it has not progressed discernibly on common safety, regulatory, power reliability, and operational issues among the families. Construction planning that uses the most practicable and advanced digital simulation software is not discussed in the programmatic material. Standardization protocols, such as form-fit-function do not seem to have been established to permit competitive bidding on the great variety of smaller plant components. Subsequent sections identify in detail the main deployment and infrastructure issues that should be addressed in the NP 2010 strategy to assure ultimate success.

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[22] See http://www.irs.gov/irb/20068_IRB/ar07/html: Notice pertaining to EPAct05, Section 1306.

[23] Final rule on standby support, Section 638(c) of EPAct05, August 13, 2006. Available at http://www.nuclear.gov/.

Progress vs. Goals and Timetables

Overall Progress

Although progress has been made on the licensing demonstration projects, the pace is far slower than that proposed in the near-term roadmap (NERAC, 2001), and there has been further slippage against the original NP 2010 schedules. This slippage does not suggest the high priority DOE has given to NP 2010. The NE budget for FY 2008, submitted to Congress in January 2007, has begun to correct the funding shortfalls with an NP 2010 request of $114 million. Congress has added $26.3 million to NP 2010 under the FY 2007 Continuing Resolution, bringing the FY 2007 total to $80.3 million. Additional funding is needed to accelerate design finalization and to pave the way for an industry decision to build new nuclear plants. Industry has recommended a total of $727 million in spending by DOE to complete the NP 2010 program.

DOE has asked the consortia for preliminary life-cycle baseline (cost, schedule, and scope through project completion) data. A detailed review of this information by an independent review team should assist DOE in putting in establishing baselines, which will improve out-year project planning and lead to more effective monitoring of project performance.

Licensing Demonstration

Solution Objectives Endorsement. The objectives of the licensing demonstration projects come from recommendations in the near-term deployment roadmap that action be taken to "resolve the uncertainties regarding the new plant regulatory approval process through actual use, and secure regulatory approval for several reactor designs and siting applications on a time scale that will support plant deployments in this decade" (NERAC, 2001, p. 44). In discussing the gaps that need to be closed to achieve this goal, the roadmap identified "key dimensions and solution objectives," including three that require essentially complete resolution to achieve near-term deployment and which are strongly endorsed by the committee (NERAC, 2001, pp. 3-4):

> 1. The DC process must be expedited to help resolve the "time to market" obstacle to nuclear plant orders in a deregulated market. In all instances of a design submittal that is complete and high quality, the DC process should take no more than three years, including the rulemaking phase. Experience gained from the first three DC rulemakings during the 1990s should provide a solid basis for achieving this goal. For DC applications that rely significantly on design information from a previously reviewed and/or certified design, the goal should be to complete the process in less than two years.
>
> 2. ESP and COL processes must be demonstrated successfully for new plants to be built. The must be shown to be stable and predictable processes that can be completed efficiently, in no more than 1-2 years each.
>
> 3. Generic guidance needs to be developed to ensure efficient, safety-focused implementation of key Part 52 processes, including ESP, COL, and ITAAC verification.

These key dimensions and solution objectives contribute to an important goal of NP 2010 and are predicated on assuring, through the industry's design effort and USNRC's licensing effort, that the new plants are even safer than the present ones. The central importance of this objective was reiterated by the Secretary of Energy Advisory Board,[24] when they wrote that "the new regulatory process has not been completely tested, and generating companies have understandably been reluctant to be the first in line to exercise the new system."

COL Schedules. The president and CEO of Southern Nuclear Operating Company noted in testimony[25] before Congress that timely and predictable licensing was critical to investor confidence in new nuclear units. A key litmus test for the program would be the ability of DOE and industry, through the NP 2010 program, to demonstrate that ESPs, DCs, and COLs can be obtained through the untested USNRC processes within a reasonable and predictable time frame. This, in turn, would be an important bellwether of the industry's willingness to pursue a new generation of nuclear plants.

Recognizing that substantial effort and funding are currently being devoted to preparation of COL applications for submission to the USNRC in 2007, aggressive attention should be paid by DOE and the consortia to ensuring that the COL applications are complete and of high quality and that they will be evaluated in an efficient and timely manner. USNRC currently estimates that the review of COL applications will take about 30 months, with an additional year to complete the public hearings. It is unclear to the committee what the basis is for the 30-month estimate.

Equally important, there appears to be no integrated schedule laying out how the technical and legal reviews, including any contested hearing, will be conducted and providing a detailed schedule for achieving each milestone. Other recent licensing efforts involving substantial intervention suggest that detailed milestones and schedules need to be established at the outset of the proceeding and reflected in a binding order issued by the USNRC at the time the application is formally docketed. This will require substantial effort by the industry, DOE, and USNRC in advance of the formal submission of the application. With the applications of two NP 2010 consortia slated for submission in the fourth quarter of 2007, this issue requires aggressive attention. In the absence of an effort to clearly define and establish sched-

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[24] Secretary of Energy Advisory Board, Moving Forward with Nuclear Power: Issues and Key Factors, January 2005, pp. 2-3.

[25] J. Barnie Beasely, Jr., President and CEO of Southern Nuclear Operating Company, Testimony before the Committee on Environment and Public Works of the United States Senate, June 22, 2006.

ules and milestones, there is a possibility that the conduct of these reviews, including the formal legal review required to be undertaken by USNRC's Atomic Safety and Licensing Board, will suffer from inefficiency and unpredictability. USNRC has not yet finalized Regulatory Guide (RG) 1.206 on COLs, which is needed to clarify the finality of environmental reviews, the change process for new plant designs that have already been certified, and the requirements related to construction and inspection.

Further attention should be paid to streamlining the COL schedule considering the ongoing efforts to standardize the COL application. The number of person-years required to process the COL application is not known at this time. It will depend on the successful resolution of all the issues arising in the development of the standardized COL application. Processing information, including time, cost, and level of effort, for the standardized COL is not available; however, processing the information USNRC required to certify the design of the AP600 required 6 years and 3 months. The USNRC review effort required 110 person-years. Westinghouse submitted a 6,500-page safety analysis report and a 4,500-page probabilistic risk assessment report. Westinghouse responded to 7,400 formal written questions and attended 380 USNRC meetings. The USNRC safety evaluation report (NUREG 1512 of September 1998) was 2,700 pages long. To obtain a DC for the power-upgraded version, AP1000, an additional 31 person-years of USNRC effort was required over 2.5 calendar years, and its SER (NUREG 1793 of September 2004) was 2,400 pages. Additional reviews of amendments to AP1000 are scheduled to take more than 2 years.[26]

Despite their efforts to prepare, it is probable that USNRC's Office of New Reactors will be overloaded in the first several years.[25] Similar circumstances existed in the late 1960s, when a sudden spate of new nuclear plant orders caused a large backlog of construction license applications, which led to significant schedule delays and cost increases. The present plan is to deal with everyone on a first-come, first-served basis, which may seem fair but might lead to long and indeterminate delays.[27] The USNRC has already established criteria, set forth in a November 16, 2006, staff requirements memorandum, for prioritizing its reviews in the event that budgetary resources are constrained. These criteria should be adapted to provide a COL queuing process to avoid conflicts between applicants, to ease the USNRC workload, to maintain standardization, and to assure satisfactory USNRC reviews. Such an adaptation should give priority to companies that have made major financial commitments to deployment and have fully defined plans to build plants immediately upon receipt of a COL. In addition, the USNRC could establish priority based on the shortages of electricity projected by the utility commissions and independent service organizations in the affected area.

Vendors of nuclear steam supply systems (NSSSs) have specified the function but not the specific design of digital plant control systems and plant simulators in their DCs. Current USNRC guidance endorses older versions of Institute of Electronics and Electrical Engineers (IEEE) standards, and the software safety analysis is too general to support efficient design and USNRC review of control system software. USNRC needs to be given adequate lead time to develop new guidance. This action would need to begin now to meet the start of construction assumed in the NP 2010 program. DOE should consider cost-sharing efforts with the IEEE and the nuclear industry to revise standards and provide advice on revision of applicable regulatory guides by the USNRC.

Standardization

DOE and the consortia have all emphasized the importance of standardization. While standardization of the COL application is stressed for each reactor design, it is not clear that the COLs would be standardized with respect to common safety and licensing issues from one family of reactor design to another. This seeming lack of focus on standardization among different families of reactors is a concern.

It is encouraging that USNRC has adopted the design-centered review approach. It is also helpful that agreements are being reached on the length of time it takes the USNRC and the applicants to respond to questions and answers. Success in this approach requires high-quality design and license application preparation, supported by a thorough effort in code scaling, applicability, and uncertainty analysis.

Design Finalization

With completion of the new plant regulatory framework and standardization processes discussed above, more attention has to be given to completing a standardized, first-of-a-kind design of the AP1000 and ESBWR, because prudence requires that full construction should not begin without it.

Design completion should be accelerated. The new Five Year NP 2010 Program Plan schedules completion of the design for mid-FY 2011, but scheduling the start of construction for late FY 2010 violates the notion of completing a design before construction starts (DOE, 2006). Further, one of the most important outputs of NP 2010, a dependable cost and construction schedule estimate, is scheduled for the end of FY 2008, some 2.5 years before design completion.

The time squeeze between first-of-a-kind engineering design completion and meeting the deployment schedules will require ordering some components a long time before full attainment of the COL. Means of avoiding the long lead time should be planned for more explicitly. Standardization protocols are also needed to permit competitive bidding on plant components such as form-fit-function. Standardiza-

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[26] George Davis, Westinghouse, Information provided to the committee, November 8, 2006.

[27] USNRC, Regulatory Issue Summary on COL Prioritization, April 16, 2007.

tion can be maintained when ordering components on a competitive basis by establishing the space within which the component must fit, the type and location of its connection to the overall system, and the function that it must provide. The details of design within that envelope can be determined by the supplier in conformance with industrial standards and safety regulations.

Greater attention to efficiencies of construction, operation, and maintenance in the design finalization effort will lead to more efficient construction. Although focus on the COL design issues is appropriate, parallel effort on the first-of-a-kind design issues outside the COL can speed up design completion.

ITAAC

Demonstration of ITAAC is not assured. The effort to fully define the ITAAC process has been dormant for almost a year but is now being reactivated through a NEI supplier committee. It is of crucial importance to economic deployment that these definitions be completed promptly. With the construction of 15 reactors from four or possibly five manufacturers by 2015, the demands on the USNRC to support the ITAAC process will be significant, particularly considering ASME's requirements[28] for authorized nuclear inspectors.

The ITAAC process may be particularly difficult to implement because of the large number of modules involved. The AP1000 involves 342 different modules (including structural, piping, and equipment modules). If the other four reactor plants have about the same number of modules, the USNRC will have to inspect more than 1,700 different modules. Moreover, these modules will be provided by a supply chain with plants in many countries. Clearly, inspection, testing, and analysis of this many different modules manufactured by a large number of N-stamped companies in several foreign countries will be a serious challenge.

Critical Deployment Issues

Other than a generally stated commitment to using modern construction processes, DOE and the consortia have not devoted sufficient effort to critical deployment issues such as preoperational testing, advanced construction technology or processes, and operational training. Examples are the use of advanced multidimensional CAD-CAM methodologies for planning and monitoring construction and component installation, application of advanced digital information systems to monitor and assess construction quality assurance and plant status, provision of a complete, construction-interactive database to assist the ITAAC process, planning for the preoperational testing necessary for a smooth transition from construction completion to preoperational systems testing, and preparation of operating instructions and employment of simulators for operator training.

NSSS vendors and EPC contractors should complete the plant design (including the routing of small bore piping, tubing, and conduit to the maximum amount practical) prior to starting construction, prepare a detailed critical path construction schedule, and plan for sufficient staffing for rapid response teams at the point of work for problem resolution. Not having this level of design completion and project preparation in the past often doubled labor requirements and construction schedule durations.

Nuclear utilities, NSSS vendors, component suppliers, material suppliers, and EPC contractors should ensure that appropriate quality assurance (QA) and quality control (QC) programs are in place and properly implemented for the design, fabrication, construction, and inspection of new plants. Experience detailed in NUREG-1055 shows that QA and QC problems caused major difficulties in earlier nuclear plant construction projects. These steps ensure that the work gets done right the first time so that additional labor and construction time are not needed to correct deficiencies.

In sum, notwithstanding the high priority that must be maintained on first-of-a-kind design completion, plans and processes for the actual steps in deployment need to be established now to provide a complete basis for investment assessment, to assure timely initiation of construction with a sufficiently supportive infrastructure, and to provide guidance to the designers on construction, operation, quality assurance, and maintenance issues. DOE's present Five-Year NP 2010 Program Plan does not address these issues. The plan terminates NP 2010 when the COL is issued, when many of these deployment actions should be ongoing. Industry and DOE should seriously consider increasing the scope and funding of NP 2010 to address these deployment issues.

Infrastructure Needs

The de facto 25-year moratorium on new plant construction in the United States, along with a prolonged period of reduced government and industry funding of nuclear energy R&D, has badly weakened the infrastructure needed to support a major expansion of nuclear electric generation capacity. To date, NP 2010 has devoted little effort to this issue. The plan seems to be to wait until plant design and USNRC reviews are completed. A parallel rather than a series approach to infrastructure revitalization should be pursued to assure that NP 2010 provides the basis for construction for which it is intended. NP 2010 should include work to develop construction plans in parallel with design finalization. These plans should include the transition from construction to preoperational systems testing, operational procedures, and operator training. Such planning is needed to ensure that the

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[28] ASME Code Section III, Division 1, Nuclear Power Plant Components, requiring compliance with ASME QAI-1, Qualifications and Duties for Authorized Nuclear Inspection.

consortia's construction time goal of 4 years or less will be met.

The construction infrastructure assessment provided by MPR Associates, Inc., for NP 2010 (MPR, 2005) contains important recommendations bearing on this issue:

1. The NSSS vendors should

> monitor the availability of large ring forgings and adjust their procurement schedules to ensure that they will be available for RPV fabrication. If necessary and with financial support from their customers, NSSS vendors should purchase the large ring forgings early and arrange deliveries to support normal RPV fabrication schedules. If the demand for new nuclear units is sufficient, NSSS vendors should develop additional capacity for the supply of nuclear-grade large ring forgings. (MPR, 2005, p. iv)

Perhaps the demand for very heavy forgings could be alleviated by considering fabricating the cylinders and reactor vessel heads from weldments. The use of weldments would reduce the size of the forging equipment required and expand the supply chain. Advance ordering of these key components should be given serious consideration.

2. Reestablishment of the N-stamps by ASME should take into consideration upgrades in ISO 9000 formulated in recent years. It should be noted that the passive plants—AP1000 and ESBWR—have significantly reduced the amount of equipment requiring such qualification capabilities.

> 3. Hiring highly-skilled construction workers needed to build nuclear units is expected to be a challenge. Qualified boilermakers, pipe fitters, electricians, and ironworkers are expected to be in short supply in local labor markets…. All other construction trades (i.e., laborers, insulators, equipment operators, teamsters, etc.) should be available in sufficient numbers to support the new plant construction projects…. EPC contractors as a group should negotiate and sign a national labor agreement with major labor unions to provide flexibility in staffing nuclear construction projects (e.g., allowing union members from different areas to work at any nuclear plant construction site). This step helps ensure the needed construction workers will be available. (MPR, 2005, p. v)
>
> 4. Nuclear power plant operators should recruit and train health physicists, operators, and maintenance technicians at their existing nuclear plants to serve as replacements at their existing plants and to staff the new GEN III+ plants. This ensures that the plant operator's staff is available for training and for supporting the start-up, commissioning, and testing of new GEN III+ units. (MPR, 2005, p. v)

5. Interactions are needed among the stakeholders, reactor manufacturers, utilities, architect engineers, construction firms, NEI, the Institute for Nuclear Power Operators (INPO), DOE, USNRC, and universities to expand their efforts to increase the number of professional staff and skilled craftspeople and construction personnel as well as the manufacturing capacity needed to achieve the ultimate goal of NP 2010.

In view of the importance of these recommendations, DOE should follow up on them as part of the NP 2010 program.

Evaluation of Priorities

The priorities are appropriate and are derived from U.S. energy policy, the DOE and NERAC assessments, and management guidance for top-level utility executives. It is important to monitor progress in light of those priorities and devise recovery actions in the event of program delays. Close follow-up and guidance are needed from DOE top management, the industry's top-level Nuclear Power Oversight Committee, and the NEI New Plant Task Force and should be a focal point for the independent reviews that are planned.

Evaluation of Oversight and Metrics

A good system has been established to ensure progress and accountability, although limited funding has had a negative impact on progress. Consideration was given to updating the NERAC roadmap, but it was concluded that the goals for NP 2010 for the next 3 years are clear and no update is needed.

Role of Joint Industry–Government R&D

The DOE–industry cost-sharing using cooperative agreements is an effective way of performing R&D for nuclear plant development and preparing for their deployment. Past experience with that approach gained in the DOE-industry ALWR program proved cost effective and valuable for producing an R&D foundation for the near-term deployment of new nuclear plants.

The Most Meritorious Elements of NP 2010

The beneficial elements of NP 2010 are as follows:

- The focus on licensing demonstrations, including joint planning with USNRC,
- Commitment to standardization,
- DOE–industry partnership through cooperative agreements, which offer
  - —DOE program management and authority,
  - —Industry experience in design, operations, costing, and the marketplace,
  - —Provisions for completing plant design so that realistic plant cost and construction time estimates can be made.

As important and necessary as these elements are, they are not sufficient to assure success without increased effort on planning for, and initial implementation of, subsequent deployment needs.

EPAct05 Incentives

EPAct05 provisions for the first six new nuclear plants are essential to paving the way for the multi-billion-dollar private investment needed to construct and operate these first plants. The definitions of the incentives have not yet been fully spelled out, nor have the qualifications for recipients or the administration of the incentives themselves been completed and should be expedited. DOE needs to take all necessary steps to ensure that the guidance for the incentives authorized by EPAct05 is finalized.

Although the direct responsibility of NE for managing NP 2010 is limited to standby support, all of the EPAct05 incentives for which DOE shares major responsibility are key to the success of NP 2010. The loan guarantee program, critical to new plant construction, has not yet been finalized. The reason cited is that industry has not yet committed itself to building a new plant. Yet, the incremental funds expended by industry to date exceed $1.5 billion. Recent progress has been made by issuance of the loan guarantee NOPR, but the proposed caps are lower than had been anticipated and allowed by EPAct05, raising concern about their adequacy to assure deployment of the first plants.

Effective application of the EPAct05 nuclear standby support provisions will contribute significantly to lowering the busbar costs of the first six plants, and it is essential that NP 2010 develop the contract terms for insurance against the potential risk of delays with these plants.

Commercial Implications of NP 2010 Portfolio

The commercial implications of NP 2010 and the EPAct05 nuclear incentives are immense. Successful demonstration of the new regulatory process will remove much uncertainty from estimates of construction cost and the time-to-market for building nuclear generating stations. Loan guarantees and production tax credits are essential for increasing the availability of capital at a much reduced cost for the first six new plants. Risk insurance protects companies from the financial losses caused by unexpected regulatory or litigation delays. The incentives may lead to the building of several privately funded nuclear plants every year from 2015 to 2020.

Commercial deployment of the new plants would entail sizeable private investment. NEI estimates that a $727 million total government investment in NP 2010, matched by equal industry funding, will stimulate over $40 billion of investment commitments to new nuclear projects by 2015, assuming that a substantial fraction of the plants scheduled for COLs are constructed in that time frame.

Balance of R&D Within Scope of Resources Considering NP 2010 Objectives

Although there is a substantial amount of development work needed to assure that new safety issues are addressed and that timely and cost-effective deployment is brought about, little research is being performed under the NP 2010 program. As discussed, the essential research has been completed. In the 1990s, DOE cost-shared the R&D that defined, tested, and obtained licensing acceptance for advanced LWR designs. The total cost of that R&D was ~$800 million, including in-kind contributions from the U.S. vendors, and DOE funding of ~$200 million.

The mission of NP 2010 is to complete the licensing and final design of new plants and prepare for their deployment; no further research is needed to accomplish this purpose. Additional research on these new designs could impede deployment.

Identifying Promising New R&D Not Currently Included in NP 2010

No research is proposed by DOE or the industry for NP 2010. NE has been sponsoring a small amount of additional R&D, cost-shared with industry, to improve the performance, operating cost, and long-term operational reliability of existing nuclear plants under DOE's Nuclear Energy Plant Optimization (NEPO) program. But no funding has been provided for relevant new projects for FY 2008. A small NP 2010 research effort on high burn-up fuels was cost-shared with industry in the FY 2005 budget, but none is planned for the next 3 years.

Substantial R&D on safety, aging of materials, component reliability, coolant chemical controls, inspection/monitoring, and the man-machine interface is currently being funded by the utilities in support of the current operating plants. The results from this R&D can also be applied to the new plants when they are deployed. A DOE-industry cost-shared R&D effort expanding this program and including R&D on high-burn-up LWR fuel would be of significant value. Recently, EPAct05 authorized a new cost-shared R&D program, the Nuclear Energy Systems Support Program (NESSP), with the same purpose as the LWR R&D program described above, but no action has been taken on it by DOE. The R&D needed to improve operational plants was defined in the joint DOE/industry LWR Strategic Plan (DOE, 2004). If the goal of high-burn-up fuel is achieved, not only will fuel economy improve, but capacity needs for the spent fuel repository will also be reduced (EPRI, 2006).

This R&D should be pursued by NE outside NP 2010 through NEPO or NESSP to help assure the safety and reliability of U.S. nuclear plants. This R&D should be given a relatively high priority in the overall DOE nuclear energy R&D portfolio. But, adequate funding of design finalization in NP 2010 should have higher priority than cost-shared

LWR R&D if funding conflicts arise. The value of such R&D would come from enhancing the effectiveness of a growing U.S. nuclear fleet by

- Assuring continuing and improved safety and reliability, a sine qua non for sustaining the nuclear role in the nation's electric energy portfolio;
- Increasing the investment value of the fleet by extending its productive life; and
- Reducing capacity requirements for the spent fuel repository.

Relationship of R&D Program to the Idaho Facilities Program and NERAC

The Operations Office of the Idaho National Laboratory (INL) provides technical and administrative support to the NP 2010 program. This support includes solicitation and procurement activities, contract administrative activities, and headquarters project management and technical activities. INL has provided technical support to NP 2010 in soil characterization, spent fuel transportation analysis, and economic analysis. NP 2010 also cost-shared fuel research in 2005, when DOE transferred funds to INL to pay for facility usage. Currently, however, no technical support is being provided to NP 2010 by INL.

FINDINGS AND RECOMMENDATIONS

Strategy for Accomplishing Goals

Finding 2-1. Unless the commercial fleet of LWRs grows, nuclear power will be a diminishing energy resource for the United States and there will be little need for all of NE's longer-term research programs.

To foster growth of the commercial fleet of LWRs, the committee recommends the following:

Recommendation 2-1. NE should make the successful completion of the NP 2010 program its highest priority. It should take all necessary steps to ensure that guidance for the loan guarantee program authorized by the EPAct05 is finalized. NE should immediately initiate a cooperative project with industry to identify problems that arise in the construction and start-up of new plants and define best practices for use by the industry.

Licensing Demonstration

USNRC and industry need to improve the presently planned pace of COL reviews, avoiding review of already-settled issues and setting a more challenging schedule that assumes the applicants will submit high-quality design and license applications and meet schedule commitments for response to questions. In spite of the substantial effort that USNRC and the industry are devoting to preparing for the COL reviews, the planned schedules are still too long. Detailed milestones and schedules need to be established at the outset of the COL hearings and reflected in a binding order issued by the USNRC at the time the application is formally docketed. The ITAAC process needs to be defined fully and demonstrated to ensure against construction delays caused by questions about licensing compliance or by litigation.

The recent surge of interest in new plant construction, with 15 companies planning to apply for COLs for as many as 33 plants in the 2007 to 2009 time frame, will greatly increase USNRC's workload. To address this crunch, priority should be given to applicants that have made major financial commitments to deployment and have fully defined plans to build the plant immediately upon receipt of the COL.

Recommendation 2-2. DOE should propose and support a joint DOE/industry/USNRC high-level working group to ensure that the following transpire:

- High-quality, complete applications are submitted and response times to requests for additional information (RAIs) are met as stipulated in USNRC's design-centered licensing review approach.
- Schedules for review of DC, ESP, and COL applications, including the legal review by the Atomic Safety and Licensing Board, are clearly established, complete, contain mechanisms for monitoring progress, show 3 years or less for review and approval of the initial COL applications, and show shorter durations for subsequent same-design applications.
- ITAAC is being developed so that its implementation will minimize interruptions in construction and preoperational litigation delays.
- Common safety and licensing issues among the families of reactor designs are fully standardized.

Standardized Design Completion

The present schedules for completion of the full designs need to be accelerated to be consistent with the goal of determining cost and construction time estimates scheduled for mid-FY 2008 and completing first-of-a-kind design before the start of construction. In addition to standardization across the families of reactor designs, as recommended above, design standardization efforts also need to be expanded to cover:

- Construction, operational, and maintenance efficiencies,
- Protocols such as form-fit-function to permit competitive bidding on the great variety of smaller components for plants, and

- Change processes and operational standards for the plant life.

Recommendation 2-3. DOE should work with the industry consortia to increase efforts to standardize safety and licensing issues across all families of reactor designs. DOE should also provide additional cost-shared funds to accelerate the schedules in the NP 2010 Five-Year Plan.

Deployment and Infrastructure Issues

The 25-year-long suspension of new plant construction in the United States has badly weakened the infrastructure needed to support a robust and growing nuclear power industry. A vigorous and comprehensive program to strengthen it should be carried out to assure that NP 2010 provides the basis for construction for which it was intended.

More intensive construction planning and the application of advanced construction technologies are needed to assure that construction time will be no more than 4 years. The scope of this planning should cover the transition from construction to preoperational systems testing, operational procedures, the man–machine interface, and operator training. The impact of these issues on the success of the NP 2010 program calls for reconsideration by both DOE and industry of the decision conveyed in the present DOE Five-Year Plan to terminate NP 2010 when the COL is issued.

Recommendation 2-4. NE should immediately initiate a cooperative project with industry to identify problems that have arisen in the construction and start-up of new plants and define best practices for use by the industry.

Recommendation 2-5. DOE should include within the NP 2010 program a DOE/industry workshop to identify activities that would revitalize infrastructure for the construction of new nuclear plants, including the nuclear qualification of vendors and constructors; manufacturing capacity; and the availability of professional staff and skilled craftspeople and construction personnel. Additional tasks that merit further DOE support should be identified at this workshop.

Recommendation 2-6. DOE should fund a taskforce to work with industry groups on construction technology and planning to ensure that consortia construction time goals of 4 years or less will be met.

R&D Relevant to the NP 2010 Program

R&D needed to improve operational plants has been carried out primarily by industry and supplemented by joint cost-shared efforts with DOE under the NEPO Program. The work includes advanced materials, high-burn-up LWR fuel, coolant chemical controls, equipment reliability, and life extension beyond 60 years. If the goal of high-burn-up fuel is achieved, not only will fuel economy improve, but also the capacity requirements for the spent fuel repository will be substantially reduced. The R&D can be applied to new plants when deployed. Although Congress has authorized funding for this kind of R&D (NESSP), DOE has not submitted budget requests for that purpose.

Recommendation 2-7. DOE should evaluate the need for a reinvigorated R&D program to improve the performance of existing nuclear plants in a DOE-industry cost-shared effort separate from NP 2010. The estimated benefits to society should substantially exceed the government investment. In the event of funding constraints, NP 2010 funding for new plant deployment should have priority over this R&D for LWRs.

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3

The Generation IV and Nuclear Hydrogen Initiative Programs

BACKGROUND

As of mid-2007, there were 439 operating nuclear power plants totaling 371.7 GWe of capacity in 31 countries and generating nearly 16 percent of the world's electricity. In addition there are five units in long-term shutdown with a total capacity 2.8 GWe. Thirty reactor units with a total capacity 23.4 GWe are under construction in 12 countries. Nuclear power had improved its performance and achieved an excellent operating record by the end of the twentieth century. In the United States, where no new plants have been ordered since the 1970s, improved operation and power upgrades to 104 nuclear power plants have enabled nuclear energy to maintain a 20 percent share of electricity generation since 1985.

Concerns over energy resource availability, climate change, air quality, and energy security suggest an important role for nuclear power in the future energy supply. Current nuclear power plants (Generation II models in the United States or the more recent Generation III models deployed internationally) supply reliable and economic baseload electricity in many markets. With a total of over 12,000 reactor-years of worldwide experience, the performance of these reactors today is far more satisfactory than it was two decades ago. Also, the NP 2010 program, as noted in Chapter 2, is assisting with the licensing and deployment of some new reactors with improved features (Generation III+) that are ready for the market. However, longer term advances in nuclear energy system design could broaden the desirability and future uses of nuclear energy. The U.S. Department of Energy (DOE) has engaged other governments, the international and domestic industry, and the research community in a wide-ranging effort to develop advanced next-generation nuclear energy systems (Generation IV). The goals are to widen the applications and enhance the economics, safety, and physical protection of the reactors, to improve the management of fuel cycle waste, and to advance proliferation resistance in the coming decades—that is, 2020 and beyond.

OVERALL PROGRAM DESCRIPTION

Six nuclear reactor technology concepts were identified in the DOE-initiated international Generation IV Technology Roadmap (DOE, 2002). Each of these six technologies, as well as several areas of crosscutting research, is now being pursued by a consortium of countries as part of the Generation IV International Forum (GIF), with varying levels of effort being expended by the various members of GIF based on the technology that is of interest to them and its status and potential to meet national goals. Three of the concepts are thermal neutron spectrum systems—very-high-temperature reactors (VHTRs), molten salt reactors (MSRs), and supercritical-water-cooled reactors (SCWRs)—with coolants and temperatures that enable hydrogen or electricity production with high efficiency. The remaining three concepts are fast neutron spectrum systems—gas-cooled fast reactors (GFRs), lead-cooled fast reactors (LFRs), and sodium-cooled fast reactors (SFRs)—that will enable better fuel use and more effective management of actinides by recycling most components in the discharged fuel. DOE has selected the VHTR as the highest priority concept but has given some support for the other concepts (except for the MSR, where DOE has only funded an effort to monitor international activities and university-based programs). The priority ranking of the other concepts has varied over the years, with the SFR recently taking second place. Crosscutting fuel cycle research has been performed under the Advanced Fuel Cycle Initiative (AFCI), which is a national program but could become an international one under the recent Global Nuclear Energy Partnership (GNEP), started in 2006 (see Chapter 4).

There are three major strategic goals on the Generation IV Technology Roadmap:

- Electricity generation at competitive cost in large and small reactors,
- Use of process heat to produce alternative energy products (e.g., hydrogen), and

- Used-fuel recycle and actinide burning to reduce waste and enable the sustainable use of fuel resources.

Other Generation IV goals include enhancing reliability and safety and increasing proliferation resistance and physical security.

Focus Areas of the Generation IV Program

From 2002 to 2005, since the publication of the Generation IV Technology Roadmap (DOE, 2002), the Generation IV program was reviewed by the DOE Nuclear Energy Research Advisory Committee (NERAC) on an ongoing basis. In those years, the primary goal of the program was the use of high-temperature (850ºC to 1000ºC) process heat and innovative approaches to yield energy products, such as hydrogen, that might benefit the transportation and chemical industries. To that end, DOE published an Expression of Interest (DOE, 2004) in the development of industrial and international partnerships for the Next-Generation Nuclear Plant (NGNP), with the VHTR reactor concept as its key focus. This initiative resulted in reviews of the VHTR concept by the Independent Technology Review Group (ITRG, 2004) as well as by NERAC.[1] These reviews recommended a faster schedule for the NGNP but a technologically less aggressive approach for the VHTR concept—for example, lower gas outlet temperature, more traditional materials, and proven UO_2 particle fuel. These recommendations have largely been adopted as the NGNP program reaches performance-phase R&D. The DOE VHTR effort was reinforced by the passage of the Energy Policy Act of 2005 (EPAct05),[2] which authorized $1.25 billion in funding for the NGNP and identified the VHTR as its lead concept. Since FY 2003, over 90 percent of the line item program funds for the Generation IV systems were used for NGNP (see Table 1-1).

In that same time period (2002 to 2005), the secondary goals of the Generation IV program were to examine innovative reactor concepts for managing spent fuel inventories to minimize waste products as well as improve the power conversion efficiency and minimize the cost of advanced reactor systems. These goals were implemented by much smaller efforts in the other four reactor nuclear energy systems. Each reactor concept research program was focused on its main viability issues:

- SCWR: advanced materials, chemistry, and heat transfer ($T > 500$ºC),
- GFR: alternative fuel types and innovative safety concepts,
- LFR: lead corrosion and materials studies, modular reactor design, and
- SFR: development of actinide transmutation fuels, and reduction of capital costs through improved design features and power conversion technologies.

At the end of 2005, DOE shifted the fundamental emphasis of the overall AFCI and the Generation IV program, making spent fuel management using a closed fuel cycle the main goal of the NE program by introducing GNEP in early 2006 as part of the budget request for FY 2007. This new priority had a number of effects on the projected funding for the other programs starting in FY 2007:

- Reduced funding for the NP 2010 and NGNP programs;
- Phasing out of the SCWR, GFR, and LFR R&D programs;
- Refocusing the SFR effort on near-term demonstration (Chang et al., 2006; DOE, 2006).

With these changes, NGNP's VHTR remains the only major reactor concept that is not integrated into the GNEP program. In the sections that follow, the NGNP concept is reviewed first, and the current status of its program plan and its R&D results are assessed. Subsequently, the Nuclear Hydrogen Initiative (NHI) is addressed. Finally, the progress made on the other Generation IV reactor concepts and their current status are examined. The SFR concept, as applied to near-term demonstration, is discussed in greater detail in Chapter 4 because responsibility for its development has been shifted to the GNEP program.

Reactor Development Evaluation Criteria from the Generation IV Roadmap

During the development of the Generation IV Technology Roadmap (DOE, 2002), three different R&D phases were defined, going from conceptual design to commercialization:

- *Viability assessment phase R&D.* Viability phase R&D examines the feasibility of key technologies. Its objective is to prove out, on a laboratory scale, the basic concepts, technologies, and processes under relevant conditions and to identify and resolve all potential technical show-stoppers.
- *Performance assessment phase R&D.* Performance phase R&D undertakes the development of performance data and optimization of the system on an engineering scale. The objective is to verify and optimize engineering-scale processes, phenomena, and materials capabilities under prototypical conditions.
- *Demonstration phase R&D.* Demonstration phase activities undertake the licensing, construction, and operation of a prototype or demonstration system in partnership with industry or, perhaps, other countries. The detailed design and licensing of the system are performed during this phase. Its objective is to create a new product that is then selected by industry for wide-scale commercial deployment.

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[1] U.S. Department of Energy, Generation IV presentations to the NERAC Generation IV subcommittee on July 19, 2004; October 25, 2004; May 2, 2005; and November 15, 2005.

[2] See Subtitle C: Next Generation Nuclear Plant Project.

Each of these three R&D phases involves increasingly expensive efforts and facilities. For this reason, the Generation IV Technology Roadmap identified nine criteria that a technology would be required to meet before it would be allowed to advance to the next R&D phase. These nine criteria, listed in Table 3-1, set expectations for nuclear energy R&D that had national and international agreement. Each of the six reactor concepts identified on the roadmap had several viability topics that needed resolution through viability R&D before the concept could transition to the performance assessment phase. When these criteria were finalized (mid-2002), it was assumed that there would be a viability downselect in 2007 to choose among the six technologies.

Because these Generation IV R&D end points establish reasonable criteria for evaluating nuclear technologies, the committee has used them as a basis for evaluating the technology readiness of the NGNP. Further, the committee finds these R&D end points useful as criteria to evaluate the major GNEP technologies (UREX+ and pyro-reprocessing, transmutation fuel fabrication, and the SFR).

NEXT-GENERATION NUCLEAR PLANT

Program Description

The NGNP program represents DOE's focused effort under the Generation IV program on the VHTR. NGNP is envisioned to be a commercial-scale modular gas-cooled thermal reactor with a power output of ~600 megawatts of thermal energy (MWth). The NGNP will use high-temperature helium coolant with an exit temperature of ~850ºC to 950ºC to produce electricity and/or hydrogen. (While conceptual design studies totaling $2.9 million were performed in FY 2005 and FY 2006 on a liquid-salt-cooled variant operating at higher power with the same high-temperature fuel design, that design is no longer being considered for the NGNP. However, concept evaluation of salt-cooled reactors continues at universities.) The NGNP will be designed to meet as many as possible of the Generation IV objectives of high reliability, enhanced safety, proliferation resistance, sustainability (low waste generation), and improved economics compared to existing commercial nuclear power plants.

There are two basic candidates for the reactor core: one based on pebble fuel and the other based on prismatic/block fuel. The fundamental element of both fuel types is tristructural isotropic (TRISO)-coated particles that have high fuel integrity characteristics even at high fuel burn-up and excellent fission product retention under steady state and postulated adverse transient and accident conditions. The program benefits from significant past experience with helium cooled reactors in the United States and Germany, but it couples the reactor to a gas-turbine power cycle instead of a steam turbine cycle for power conversion. The program also benefits from the experience in operating small (10- to 30-MWth) test reactors in China and Japan and the design studies for a 400-MWth power plant that is planned to enter construction in 2008 in South Africa. The Generation IV Technology Roadmap identified six R&D areas for the VHTR, which was assumed to have a coolant outlet temperature above 1000ºC (DOE, 2002, p. 81):

TABLE 3-1 End Points for Viability Phase and Performance Phase R&D, as Defined in the Generation IV Technology Roadmap

Viability Phase End Points	Performance Phase End Points
1. Preconceptual design of the entire system, with nominal interface requirements between subsystems, and established pathways for disposal of all waste streams	1. Conceptual design of the entire system, sufficient for procurement specifications for construction of a demonstration plant and with validated acceptability of disposal of all waste streams
2. Basic fuel cycle and energy conversion (if applicable) process flowsheets established through testing at appropriate scale	2. Processes validated at scale sufficient for demonstration plant
3. Cost analysis based on preconceptual design	3. Detailed cost evaluation for the system
4. Simplified probabilistic risk assessment for the system	4. Probabilistic risk assessment for the system
5. Definition of analytical tools	5. Validation of analytical tools
6. Preconceptual design and analysis of safety features	6. Demonstration of safety features through testing, analysis, or relevant experience
7. Simplified preliminary environmental impact statement for the system	7. Environmental impact statement for the system
8. Preliminary safeguards and physical protection strategy	8. Safeguards and physical protection strategy for system, including cost estimate for extrinsic features
9. Consultation(s) with regulatory agency on safety approach and framework issues	9. Preapplication meeting(s) with regulatory agency

SOURCE: DOE, 2002, p. 80.

- High-temperature helium turbine,
- Reactor/hydrogen production process coupling approach,
- Identification of targeted operating temperature,
- Fuel coating material and design concept,
- Adequacy of fuel performance potential, and
- Reactor structural material selection.

Subsequently, the desirable maximum temperature of the coolant was reduced to 900ºC, with a longer-term target of 950ºC, which reduced the challenge to materials and fuel integrity in the construction of NGNP.

The NGNP program is authorized under EPAct05 at total funding of $1.25 billion for Phase I, which extends to 2011. During this phase, fundamental R&D would be carried out for the associated technologies and components. This includes the reactor and its fuel, the energy conversion system, materials, and hydrogen generation technologies. In addition, certain fundamental decisions are to be made, including selection of the mission of the NGNP (efficient electricity production, process heat, hydrogen generation, or a combination of these) and the specific hydrogen generation technology. EPAct05 also discusses Phase II, which extends from 2012 to 2021 and wherein a detailed design should be competitively developed, a license should be obtained from the U.S. Nuclear Regulatory Commission (USNRC), and the plant should be constructed and commissioned.

According to EPAct05, the program will be based on the R&D activities of the Generation IV program, the Idaho National Laboratory (INL) will be the lead national laboratory, and the NGNP demonstration will be sited at INL. INL is charged to organize a consortium of industrial partners to cost-share the project. The NGNP project is to maximize technical exchange and transfer from other relevant sources, including other industries and international Generation IV partners.

The overall program has been estimated to cost approximately $2.3 billion, which means that significant cost share (roughly 50 percent) will be needed from collaborative private sector partners, in the form of actual funding or work in kind and transfer of already developed intellectual property.

INL has formed program plans for the basic NGNP program, and a complementary private sector initiative has been started to form a public/private partnership for bringing end users, industrial suppliers, technology developers, and national laboratories together with DOE for the development and demonstration of NGNP on a commercial scale. Potential end users might include the petroleum industry, industrial gas producers, the transportation industry, the coal industry and their associates who are interested in gasification and liquefaction applications, and traditional electric power companies.

The potential end users represent the broad range of applications for high-temperature process heat; some of them will also need economic bulk hydrogen in the future. This partnership is being formed to show Congress that there is genuine interest in this technology for the intended purposes and to attract the needed cost-share funding to accomplish the goals of the program without asking for more public sector funding, which might be difficult to obtain. This approach is consistent with the R&D model recommended by Electric Power Research Institute (EPRI) and INL, which proposed substantial industry contributions for nearer-term R&D, with the government maintaining primary but not sole responsibility for funding longer-term R&D (Modeen, 2006).

This NGNP public/private partnership initiative has formulated a four-phase program that starts with a currently contracted 1-year NGNP preconceptual engineering effort, scheduled for completion in August 2007, and ends in FY 2017 with full commissioning and start-up of a plant at the INL site. This is a more aggressive schedule than that of EPAct05, which called for 2020. The earlier target date was motivated by congressional supporters, INL management, and the engaged industrial participants as a way to drive the technology to commercialization during a period of strong interest in a nuclear energy renaissance and growing industrial demand for the capabilities of the NGNP.

A Brief History of High-Temperature Reactor Development

The United Kingdom embraced high-temperature reactor (HTR) technology in the early 1950s with the start of a large fleet of graphite-moderated, metal fueled, and CO_2-cooled MAGNOX reactors for electricity generation and weapons plutonium production. In total, 28 reactors of this type were built, with outputs ranging from 50 to 490 MWe and a total capacity of 4,200 MWe. In 2006, eight of these MAGNOX reactors remained operational, but all will be shut down by 2011. The 20-MWth helium-cooled Dragon reactor**,** a cooperative project of the Organisation for Economic Cooperation and Development (OECD) and Euratom, demonstrated the use of thorium/uranium fuel starting in 1964, with operations continuing to 1975. Also in 1964, while the MAGNOX build program was in full swing, the U.K. government decided to start the next phase of CO_2-cooled reactor development with advanced gas-cooled reactors (AGRs). Eventually, 14 AGRs would be built, with outputs ranging from 550 to 625 MWe and a total capacity of 8,600 MWe. These reactors had coolant, at 4 MPa, traveling downward in the core and exiting at 645°C, coupled to a steam cycle power conversion system, through a steam generator. The steam, at 17 MPa, entered the turbines at 540°C, which provided over 40 percent thermal conversion efficiency.

The performance of the AGR reactors was poor in the early days because of materials problems and lack of standardization of the design. The principal technical issues from the U.K. gas reactor experience are related to graphite corrosion and aging under radiation, as well as carbon deposition on the fuel rods. Graphite corrosion can occur for thermal and radiolytic reasons. With experience, a coolant composition was found to inhibit those tendencies with the right levels of CO, CH_4 and H_2O (Hall and Chaffey, 1982). The CO inhibits corrosion due to radiolysis of CO_2, and CH_4 inhibits corrosion as it forms a deposit on graphite pores. The oxidation of structural steel materials in the presence of CO_2 was also a source of some problems. Subsequently, the United Kingdom turned to light water reactors (LWRs), importing the technology from the United States but building only one large plant, Sizewell B.

France also experimented with CO_2-cooled, graphite-moderated reactors. The initial reactors suffered from unsatisfactory fuel performance and graphite corrosion problems. France turned to LWRs based on the U.S. experience in 1974.

The United States and Germany each explored HTR technology about the same time with two small developmental graphite-moderated, helium-cooled reactors, Peach Bottom 1 (operated from 1967 to 1974) and AVR (operated from 1966 to 1988), respectively. These small reactors demonstrated the prismatic and pebble bed fuel/moderator arrangements and technologies and encouraged their promoters to proceed to the commercial demonstration stage. The United States commissioned the Fort St. Vrain reactor in 1979 and Germany commissioned a thorium high-temperature reactor in 1985, both with outputs in the 300-MWe range. With a coolant maximum temperature of 700°C, all these plants operated using indirect steam Rankine cycles to generate electricity. The Fort St. Vrain plant was beset by technical problems. These problems were mainly in the auxiliary systems, such as the cooling and oil systems. However, there was also a significant problem with flow-induced vibration of the reflector and fuel graphite blocks. This was partially corrected by pinning the blocks together, but the overall coolant flow rate still had to be limited, which prevented the reactor from operating at full power. Technical issues also arose in the German program due to the approach of inserting control rods into the pebbles of the core, introducing the problem of broken pebbles in the fuel handling and storage systems. Furthermore, the German HTR program was caught up in the political aftermath of the Chernobyl (water-cooled but graphite-moderated) reactor accident. Both the Fort St. Vrain reactor in the United States and the HTR reactors in Germany were permanently shut down in 1989, ending the early era of gas reactor demonstration in those two countries.

Subsequent to the shutdown of these commercial demonstration reactors, system design and evaluation studies continued and focused on modular, passively safe concepts, including the German MODUL and the U.S. modular high-temperature gas reactor designs. These design studies shifted from an indirect Rankine steam cycle for power conversion to a direct recuperative Brayton cycle, taking advantage of the improved gas-turbine technology to increase thermal efficiency and improve economics. These changes resulted in designs that had plant capacities of about 300 MWe or less, which is a significant challenge economically compared to large LWRs for electricity generation. On the other hand, the small thermal power enables the reactor to transfer decay heat to the surrounding environment without requiring emergency coolant or reaching intolerable temperatures.

HTR development has undergone a resurgence outside the United States over the past decade. Key national programs are being conducted in China, Japan, and South Africa.

China

In China, the Institute of Nuclear Energy Technology (INET), operated by Tsinghua University, has taken the lead for development of HTR technology. It spearheaded the design and construction of a small HTR-10 test reactor. Construction of the HTR-10 started in 1995, and it achieved criticality in 2000. It is a 10-MWth pebble bed reactor that utilizes UO_2 pebble fuel and a steam generator for heat rejection. Numerous tests have been completed confirming the inherent safety features of the design, including reactor shutdown due to fuel heating when power increases following the withdrawal of control rods. The intention is to couple this test reactor directly to a gas turbine, thereby also demonstrating the Brayton cycle.

A commercial project (HTR-PM) has already been established as a collaborative effort between INET, China Nuclear Engineering and Construction Company, and the China Huaneng Group, a large Chinese electric utility company. The plant design was initially sized at 450 MWth with a 750ºC coolant outlet temperature and a helical steam generator providing steam to a Rankine cycle. Recently, the thermal output has been reduced to 250 MWth to facilitate early deployment. Construction was planned to start about 2008 and criticality to be achieved around 2013, but delays have been experienced that could push the project back by several years.

Japan

Under the direction and sponsorship of the Japan Atomic Energy Agency, an industry collaborative program on HTRs has been in place for nearly two decades. The centerpiece of this program is the high-temperature test reactor (HTTR), which is a 30-MWth reactor using prismatic fuel/moderator arrangement and a coolant outlet temperature of up to 850ºC, although 950ºC was reached for short operating periods. Construction on the HTTR started in 1991, and criticality was achieved in 2000. The purpose of the project is to establish an HTR technology basis, to develop process heat application technology, and to provide a heat source for a hydrogen production plant based on the thermochemical sulfur-iodine water splitting process. Although no commercial demonstration project has been defined, a conceptual design for a commercial cogeneration plant, called the GTH-TR300C, has been developed.

South Africa

Pebble Bed Modular Reactor Pty. Ltd. is developing the pebble bed modular reactor (PBMR) design as a national strategic project in South Africa. The design of the demonstration power plant is for a 400-MWth reactor connected to a direct cycle helium turbine, with pebble fuel/moderator and a coolant outlet temperature of 900ºC. The project has been defined, all major components ordered and construction will start in 2009 with initial criticality planned for 2013. The plant will be built at ESKOM's Koeberg site, where two large LWRs already exist. As part of this overall project, extensive testing facilities are planned and several are already being commissioned. A pilot fuel plant has been designed and should start construction in 2008. Advanced fuel will be manufactured in a full-size production line facility (already constructed) starting in late 2007 for irradiation testing in Russia beginning in early 2008.

With successful demonstration of the technology, it is planned that 24-30 PBMRs will be added to the ESKOM grid starting in about 2015 to distribute power along the coast of South Africa and at certain remote inland sites (Rosenberg, 2007; Bloomberg, 2007). A letter of intent has already been issued by ESKOM for these units. In addition, process heat plant development is ongoing to evaluate the best applications for this HTR technology and to assess the economic competitiveness against the competing fuel, natural gas. Finally, preapplication review for design certification of the basic technology has already started in the United States, and the USNRC activity is timed to be consistent with the development of information, including the licensing documentation, on the South African Demonstration Power Plant.

Benefits of High-Temperature Reactor Deployment

Economic benefits of early commercialization of HTRs and VHTRs based on NGNP technology could be realized in four market segments where HTRs could make products at a lower cost than competing technologies: base-load electricity, combined heat and power, high-temperature process heat, and hydrogen. A long-term goal for the NGNP is to support the production of hydrogen as an energy carrier in a hydrogen economy. However, in each of those four market segments listed above, there are specific applications where HTRs will have near-term advantages. By directing NGNP and NHI R&D toward these specific applications, stronger near-term industry interest and investment is more likely, which in turn will support continued R&D investments for subsequent expansion of HTR technology into additional market segments and, in the longer term, support the transition to a hydrogen economy.

Environmental benefits of HTRs arise from their efficiency at producing carbon-free electricity, carbon-free hydrogen, and/or carbon-free process heat. A 1,000-MW combined cycle natural gas plant produces about 3 million tonnes of CO_2 per year. In the United States, natural gas power plants emit a billion tonnes of CO_2 per year. Replacing combined cycle gas turbine capacity with gas turbine HTRs could significantly reduce carbon emissions. Also, a commercial-scale 3 million cubic meters per day (100 million standard cubic feet) steam methane reforming (SMR) plant producing pipeline hydrogen produces at least 1 million tonnes of CO_2 per year. SMR capacity in the United States was 56.4 million cubic meters per day in 2004, producing 18 million tonnes of CO_2 per year. Hydrogen demand has been growing at 5 percent per year since 2000. HTR technology could significantly reduce carbon emissions in the hydrogen production industry.

Economic and security benefits follow from reducing dependence of the United States on fuel imports. While a small portion (15 percent) of the U.S. needs for natural gas is currently imported, there is a growing demand but limited supply of it from our major supplier, Canada. Thus liquefied natural gas, probably from the Middle East or Russia, will be increasingly important to meet U.S. needs. (Western Europe depends heavily on supplies from Russia and North Africa even today.) Natural gas is used for electricity production, home heating, and as a feedstock for chemicals and plastics. It is the main source of energy for the U.S. production of process heat and hydrogen for use in the preparation of liquid transport fuels from crude oil. In the future, even larger quantities of natural gas may be required to produce liquid fuels from unconventional sources that are abundant in North America, including tar sands, shale oils, coal, and biomass. Liquid fuels can be expected to continue to play a large role in the transportation sector, supplemented in the longer term by hydrogen fuel cells or chargeable batteries for ground transportation. HTRs may play a role in displacing natural gas consumption in all of these market segments.

Base-Load Electricity

For base-load electricity generation, HTRs may initially be competitive with mature LWR technology in niche market segments where HTR's technical characteristics provide specific advantages. For small grids, as exist in developing countries, modular HTRs have a direct advantage due to their smaller unit power outputs and slower transients compared to market ready, large-capacity LWRs. Also, in regions where water is scarce, as in the U.S. Southwest, HTRs that use direct Brayton cycle power conversion hold an advantage over LWRs because they can operate with greater efficiency while rejecting to the surroundings reduced quantities of waste heat at higher temperatures. This enables economical dry cooling for inland locations. By breaking the linkage between cooling water availability and electricity production, HTRs can remove a significant constraint on reactor siting.

If a portion of the heat supplied to the gas entering the turbines in gas-fired plants is derived from HTRs, it will reduce the natural gas consumed, which would reduce carbon emissions associated with gas plants. At high natural gas prices (about $8 per million Btu [MMBtu]), the nuclear heat addition is also more economical (Joeng and Kazimi, 2005).

Combined Heat and Power

Currently, combined heat and power applications are fueled dominantly by natural gas. In many cases combined heat and power facilities run steadily because they are coupled to facilities that create a steady demand for heat. In these situations where combined heat and power systems run with high availability, HTRs with direct Brayton power cycles and bottoming steam production can directly displace the carbon-emitting natural gas usage. Current large-scale applications for low- and intermediate-temperature steam include enhanced oil recovery, oil production from tar sands, and process heat for large petrochemical facilities.

High-Temperature Process Heat

Natural gas is also used to supply high-temperature process heat. HTRs can also provide high-temperature process heat between 600°C and 950°C and can directly displace natural gas in these applications, as discussed earlier.

Nuclear Hydrogen

Hydrogen is being used to upgrade heavier crude oils. Also, as more biomass (e.g., corn) is grown to produce biofuels, more ammonia-based fertilizer will be required, increasing the demand for hydrogen. Natural gas is currently the dominant feedstock for production of hydrogen through steam methane reforming (SMR). Unfortunately, each kilogram of hydrogen produced through SMR releases over 9 kg of CO_2. EPRI studies (EPRI, 2003) have shown that nuclear heat could be an economic application that partly displaces high-priced natural gas in steam reforming. The use of hydrogen is extensive in the petrochemical industry, including large-scale usage in the production of transportation fuels and fertilizers, and it would increase further if lower cost sources became available. Currently, all major refineries in Texas and Louisiana are connected by a hydrogen pipeline that runs within 100 m of Entergy's Waterford nuclear power plant. Thus a nuclear plant can be said to have coexisted in close proximity to hydrogen equipment for a long time, obviating the need to widely separate a nuclear plant and a hydrogen plant. In the future, hydrogen may be used directly as a fuel for ground transport. Options for displacing the production of hydrogen from natural gas with nuclear hydrogen include distributed low-temperature electrolysis with off-peak base-load nuclear electricity and centralized hydrogen production using high-temperature electrolysis or thermochemical water-splitting cycles (Yildiz et al., 2005; NRC/NAE, 2004). Currently, NHI supports R&D for all three of these technologies.

LWR-based electrolysis can be applied for hydrogen production with an energy efficiency of about 26-30 percent, while sulfur-iodine (S-I) high-temperature steam electrolysis has the potential to reach an energy efficiency of 45-50 percent. The use of HTR for hydrogen production is motivated by its enabling thermochemical schemes that are possible only at high temperatures. However, the improvement in efficiency to about 60-80 percent will increase the chances that HTR-produced hydrogen could be more economic than hydrogen produced by LWR-based water electrolysis. Second, while the reactor side costs of an MHR are likely to be higher than those of an LWR, owing to the lower energy density, its associated gas turbine power cycle cost is likely to be lower than the cost of the steam power cycle. Third, the financial terms of a large pressurized water reactor plant may be more demanding than those of the smaller capacity, modular HTR unit. Finally, the HTR technology has far more potential for improvement than the more mature LWR technology (for example, moving to liquid salt cooling could increase the power density and significantly reduce capital costs).

HTR/NGNP Technology Challenges and Development Needs

Because several gas-cooled reactors have already been built and operated, significant insight into the reliable operation of such reactors has been gathered. In addition, better economy and process heat applications call for operating the NGNP and future HTRs at even higher temperatures than those attained in past reactors, which implies a need for R&D on materials and other technology needs. Such needs were reviewed by the Independent Technology Review Group (ITRG, 2004) and by NERAC.[3] These reviews involved discussions with members of the industrial team building a demonstration plant in South Africa that had assessed the need for technology development. Six areas were identified as needing the most R&D.

Materials Development and Improvements

The unique material challenges for the VHTR are based on the need for adequate strength and dimensional stability at high temperatures and for the transport of corrosion products from metals and graphite in the presence of a potentially impure helium coolant. Although a number of materials and alloys for high-temperature applications are in use in the

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[3] U.S. Department of Energy Generation IV, Presentations to NERAC on July 19, 2004, October 25, 2004, May 2, 2005, and November 15, 2005.

petrochemical, metals processing, and aerospace industries, a very limited number of these materials have been tested or qualified for use in nuclear-reactor-related systems. Some primary system components of the VHTR will require use of materials at temperatures above 800°C; at present, there are no such ASME-code-qualified materials. Significant R&D is needed in a number of areas:

1. Understanding of the high-temperature- and irradiation-induced dimensional and material property changes of nuclear graphite and carbon fiber/carbon matrix composites.
2. Development of a basis for professional codes and standards for very high-temperature design methodology.
3. Improved understanding of environmental effects on metallic alloys and thermal aging of the alloys, as well as better models for studying them and mitigating them.
4. Understanding of thermal radiation and emissivity of large pressure vessels and core barrel surfaces in order to optimize passive core cooling.

Fuels Development and Requirements

The basic fuel element in a gas-cooled reactor is the TRISO particle, consisting initially of a UO_2 fuel kernel covered in layers of porous graphite, dense pyrolytic graphite, silicon carbide, and pyrolytic graphite. A number of challenges must be overcome before these fuel forms can be optimized for higher temperature and higher dose operation and before sufficiently high reliability and acceptably low fuel failures can be assured. These challenges include anisotropic shrinkage and swelling of the pyrolytic carbon; adequate mechanical stability at high gas pressure due to fission gas or carbon dioxide; kernel migration due to temperature gradients in the fuel particle; palladium attack on the silicon carbide layer; and selective diffusion and transport of certain fission products, such as silver, through the silicon carbide. Some key research activities for mitigating the current limitations of TRISO particles include using a smaller fuel kernel, using alternative fuel kernels such as UCO, or replacing the silicon carbide with an alternative such as zirconium carbide. Additionally, optimizing the microstructure as a function of the processing conditions under which the particles are produced may improve performance.

Primary to Secondary Heat Transfer

The extraction of process heat from the NGNP requires an intermediate heat transport loop. The two key technology decisions needed are the design of the intermediate heat exchanger (IHX) and the form and composition of the heat transport fluid. The high temperatures and potential induced stresses in the IHX (e.g., as a result of loss of electrical load or shutdown of the process heat plant) place extreme demands on the design. Normal heat exchanger design approaches using conventional materials will most likely not be adequate. The heat transport fluid should (1) be chemically compatible with the surrounding structural materials, (2) have superior fluid-mechanical and heat-transfer properties for an economical design of the process heat exchangers and the heat transport loop, and (3) have acceptable safety characteristics under normal and off-normal conditions. The fluid could be a high-pressure inert gas such as helium or a high-temperature molten salt. A molten salt, if it is properly compatible with the heat exchanger and piping materials, can minimize the temperature drop in the intermediate heat-transport loop and the required pumping power, thereby minimizing the cost of the delivered process heat.

An immediate problem with using molten salts is their corrosive nature at the high temperatures of use. In terms of corrosion mechanisms in materials, the molten fluoride salt environment is quite different from other high-temperature environments. The normally accepted paradigm of developing a protective oxide layer to provide corrosion resistance does not fully apply to this environment, owing to thermodynamically driven dissolution effects. Although the heat transfer characteristics of molten salt are superior to those of inert gas, optimizing heat exchanger design at high temperature and high stresses (due to the pressure differential) is an important area of research.

Plant Operations

The potential need to couple two diverse processes (electric power generation and hydrogen production) complicates the mission of the NGNP. Differing dynamic responses of the reactor to the hydrogen production plant or an electricity-generating plant must be carefully assessed for NGNP's single mission project. Design and analytical studies are needed to investigate possible configurations and control schemes. The results of these studies will provide insights into the reactor design conditions, including provision of direct versus indirect process heat cycles and relying on steam power cycles instead of helium gas turbines at the outset.

Safety and Licensing

There needs to be a discussion with the USNRC on the key aspects of safety and licensing that should be addressed if the NGNP is deployed in the 2017 to 2021 time frame. It is known that USNRC staff has already begun to develop a technology-neutral licensing framework that the NGNP project can use as initial guidance (SECY-05-0130). However, this staff document has not yet been adopted by the USNRC but is still being reviewed by the staff and the Advisory Committee on Reactor Safeguards. EPAct05 requires that DOE and USNRC develop a joint approach to licensing NGNP by August 2008. This activity is currently under way with inputs from the Phase 1 NGNP program. The DOE-USNRC discussions related to NGNP licensing are focused on defining the approach that will be used. It is possible the technology-neutral approach will be used, but it is not clear if that approach would be ready in time for the engineering phase of the NGNP. In addition, the PBMR is currently in pre-application review for design certification by the USNRC. The issues being addressed are generic to HTR licensing, and this effort will provide a tangible forum in which to make progress on a licensing strategy for NGNP.

Fuel Cycle and Waste Technology

The disposition of spent fuel from the proposed NGNP reactor has not yet been addressed. HTR fuel is inherently stable in storage because it remains at low temperatures and because of the graphite matrix's good thermal conductivity and low density of decay heat. However, the fuel volume is relatively large due to the low thermal power density and the fuel being imbedded in the graphite moderator. It has been suggested that the fuel might be consolidated by removing the matrix graphite, leaving only the coated particles, which in pebble bed reactors, reduces volume by more than an order of magnitude. A similar but smaller volume reduction (because of the higher packing density of the fuel particles) is possible with prismatic fuel. After volume reduction, the principal fission barrier is still retained by the TRISO coatings around the fuel kernels. However, the engineering-scale recovery of actinides from TRISO particles in an economic way has never been demonstrated, so that it is uncertain whether the HTR reactor can support a closed fuel cycle.

The treatment of the NGNP as a DOE reactor will allow interim storage of its fuels at DOE sites. However, should this reactor be a demonstration plant for a whole fleet of future reactors, then a broader program to address the disposition of the fuel from a whole fleet of HTRs is needed. In particular, if a closed-fuel cycle is desired for waste management or enhancing the fuel resources in the future, it is important to consider the processing that would be required to achieve a closed cycle for this fuel. This will be a significant challenge since, as already noted, the TRISO coatings that are key to fission product retention could also seriously complicate the reprocessing technologies.

NGNP Evaluation

Is the Program Purpose Clear?

The purpose of the NGNP program is to develop a commercial-scale VHTR that can satisfy the Generation IV VHTR goals, which include the generation of electricity and/or hydrogen, but within somewhat less ambitious parameters—for example, lower-temperature helium coolant outlet. This nuclear system, if successful, would provide a method for producing the bulk hydrogen necessary to move the country away from a carbon-based energy economy and could thereby help provide long-term energy security for the United States.

While nuclear hydrogen will have to be competitive with other methods for hydrogen production, the wide oscillations in the price of natural gas, the main source of hydrogen today, and the possibility of taxing carbon fuels in the future open the way for nuclear energy to provide hydrogen and/or heat needed in a wide sector of the chemical processing business. To the extent the HTR is also applied for electricity alone, this would enlarge the technology base and improve the economics of other HTR energy products, such as process heat and hydrogen.

As articulated in EPAct05, the NGNP program did not explicitly address the broader use of high-temperature process heat, but the complementary public/private partnership initiative clearly hopes to extend the HTR to industrial process heat applications that now primarily use expensive natural gas. The generation of bulk hydrogen for a hydrogen economy is an ambitious endeavor that is likely to be decades away because of the requirement to develop a hydrogen infrastructure, as well as the need to overcome many obstacles posed by a fuel-cell-based transportation industry. However, nearer-term applications could use process heat to displace natural gas, including the combined production of electricity and process steam, the direct application of high-temperature process heat in technologies such as steam-methane reforming, and the generation of hydrogen for existing markets. (Existing hydrogen markets include refineries and ammonia plants, which together use about 7 percent of the natural gas consumed in the United States.)

Does the Program Address a Specific and Existing Problem?

The program is designed to develop an advanced new reactor that can provide process heat and/or electricity. The cogeneration function appears to be a complication since electricity might be generated more economically by advanced LWRs. However, no other nuclear technology can generate the high temperatures needed for the broad range of process heat applications discussed. It has been recommended by NERAC that this dual mission be reconsidered and not be accepted without further analysis. It was felt that the dual mission would drive the design, increase the cost of the program, and extend the schedule. It is important to maintain flexibility in the sizing of the NGNP reactor to facilitate obtaining the needed international collaboration or co-funding by end users. Furthermore, while a dual-purpose mission would not be necessary for future commercial plants, it could serve as an engineering-scale heat exchanger for the NGNP plant to demonstrate the viability of coupling of a nuclear plant with a hydrogen production plant.

Is the Program Design Free of Major Flaws That Would Limit Its Effectiveness or Efficiency?

There is not a single articulated program schedule that is coordinated with all the required elements to successfully commission the NGNP. The current disconnect between the base NGNP program plan and the complementary public/private partnership initiative must be resolved so that all parties are working to achieve a consistent set of milestones. These elements include the reactor design; the heat transport system design, including the IHX; the fuel design and supply; and the hydrogen generation process design. There currently exist both a schedule gap and a funding gap that prevent the hydrogen process plant design and the NGNP reactor design from being available by the time of plant operation (at the end of FY 2017).

Little planning has been done on how the fuel for the NGNP would be supplied. There is a particle fuel R&D program that is focusing on UCO fuel; however, it will take up to two decades to complete the development and testing of this new fuel form before it can be loaded into the NGNP. Further, the source of the fuel for the NGNP has largely been ignored. There is very limited capacity available today for TRISO-coated particle fuel—it exists in Japan, China, and South Africa, but only for UO_2 kernels. There is no industrial UCO fuel fabrication capacity, nor has the manufacturing process been proven.

The reactor design is probably the least problematic aspect, although it must soon be decided whether to base it on pebble or prismatic (sometimes called "block") fuel. The technology area with the most uncertainty and risk is the heat transport system. The intermediate heat exchanger (IHX) is a very demanding component and is critical for most process heat applications, including the generation of hydrogen. University- and industry-based R&D is ongoing for both metallic and ceramic designs, but it is not clear that an acceptable solution will be obtained consistent with the NGNP program schedule given current funding levels.

Are Key Decision Points and Alternative Courses of Action Identified?

The decision points and technical alternatives are well known. The key technical alternatives are the fuel type, the heat transport working fluid and the IHX, and the hydrogen generation process. It is important to evaluate the status of the technology using the Generation IV evaluation criteria given in Table 3-1 to ensure that the demonstration phase begins at the appropriate time.

Another significant decision point is the nuclear licensing approach. The alternatives are the old 10 CFR Part 50 multistep process, the new 10 CFR Part 52 one-step process, or the yet-to-be-developed 10 CFR Part 53 technology-neutral process. To meet the apparently preferred date of FY 2017 for plant operations will require that some of these decisions be made quickly, so that the detailed design, component and system testing, and licensing can be initiated to support this schedule. The approach to licensing the NGNP is critical and should be decided on early.

Is the Program Effectively Targeted So That Resources Will Address the Program's Purpose Directly?

The budget for NGNP currently requested by DOE is not adequate to meet the preferred schedule: To remedy this state of affairs, a significant ramp-up of roughly $100 million per year would be required within 1 or 2 years. The budget for FY 2008 should be at least $60 million if the program is to be launched on a trajectory that will meet the 2017 operations date. DOE's notional budget projection for the next 6 years is only about 20 percent of what is required to meet the stated schedule. The budgets for NHI are also probably not adequate if this preferred schedule is to be maintained. Finally, it is imperative that private sector funding be brought into the program to supplement the required research, development, and demonstration. The technology partners must be selected and end users must be convinced to join the public/private partnership at significant levels.

Does the Program Have a Limited Number of Long-Term Performance Measures That Focus on Outcomes and Meaningfully Reflect the Purpose of the Program?

Program milestones have been established, although there is no consistent set of milestones that is used by all the relevant stakeholders. The Generation IV program has developed evaluation methods and measures for assessing nuclear system design options. However, no specific performance metrics that clearly define the real commercial targets—for example, the cost of energy on a MWth or a MWe basis or the cost per kilogram of hydrogen generated—have been established for NGNP. On the other hand, once process heat end users are engaged, it should be possible to develop specific performance metrics for each fundamental application—for example, the cost of petroleum generated from coal.

Has the Program Demonstrated Adequate Progress in Achieving Its Long-Term Performance Goals?

Since the long-term performance goals are not fully established—for example, the final temperature design for the VHTR is not defined—it is not possible to judge the NGNP's program on this criterion yet. The actual NGNP program remains in an early formative stage. This criterion should be held in abeyance until more progress is made on the program.

NUCLEAR HYDROGEN INITIATIVE

Nuclear Hydrogen Production

NHI is the DOE's research program for technologies to produce hydrogen and oxygen from water feedstock using nuclear energy. The program includes a small effort supporting advanced low-temperature electrolysis, but the primary focus of the R&D is three methods that use high-temperature process heat to achieve higher efficiency: thermochemical cycles, hybrid thermochemical cycles, and high-temperature electrolysis. Because the high-temperature methods could realize 60-80 percent greater efficiency than conventional electrolysis, the NHI program is tightly connected to the NGNP program to develop a reactor capable of providing high-temperature process heat. The mission of the NHI program is to operate a nuclear hydrogen plant to produce hydrogen at a price that is cost competitive with other transportation fuels by 2019. NHI activities are coordinated with the larger DOE hydrogen program led by the Office of Energy Efficiency and Renewable Energy, as well as with the NGNP project.

Most of the hydrogen production in the United States today uses steam reforming of natural gas as the source of both the hydrogen (about 10 million tons per year) and the heat needed to enable the chemical processes in steam reforming to take place. With the uncertain availability of low-cost natural gas in the future, it is prudent to look for alternative ways to produce the hydrogen needed for current and future applications. About 50 percent of current hydrogen production in the United States is used to make ammonia, which is mostly used for manufacturing fertilizers. Almost 40 percent of it is used at oil refineries for lightening and sweetening the heavy oils to produce liquid fuel products for vehicles and aircraft. The lightening process used in refineries will grow as production continues to shift toward heavier conventional oils in the United States and in Central and South America. Additionally, even heavier oils are being produced in greater quantities from tar sands in Canada, and new production of shale oils in the United States is anticipated. Given the size of the unconventional oil resources in North America (about 10,000 exajoules, as compared to 2,500 exajoules of conventional oil reserves in the Middle East), it is plausible that these resources may become a major source of U.S. liquid fuels. In fact, Canada already produces over 1 million barrels a day from tar sands, getting the needed heat and hydrogen from natural gas. The environmental burden of extracting and processing of such unconventional fuels is generally very heavy. If the heat and hydrogen needed to lighten and sweeten the heavy oils could be produced from water using nuclear or renewable energy sources, the importation of liquefied natural gas from sources outside North America and the emisson of carbon to the atmosphere could both be reduced.

Applications for hydrogen can be classified into near, intermediate, and long-term markets. The near-term markets involve existing industrial applications for hydrogen: oil refining, ammonia production for fertilizer, methanol production, and tar sands processing. Mid-term markets involve the expanding production of liquid fuels from unconventional resources, including coal, oil shale, and biomass. Some of these mid-term markets have become economic given the higher price of oil and gas in the last 2 years in comparison to the prices before 2004. For example, liquefied coal is used in South Africa to satisfy nearly half of the petroleum fuel demand. Long-term markets involve the direct use of hydrogen as an energy carrier for ground transportation and energy storage. The growth of these markets will be driven by the evolution of the technology and by economics. To support NHI planning, these markets should be studied with the aid of a systems analysis model. Given the escalating prices of gasoline and the mounting desire to reduce carbon emissions, the need for these products is likely to grow substantially, within years rather than decades.

Hydrogen Production Technology Options and R&D Status

Current R&D on high-temperature steam electrolysis focuses on solid oxide electrolysis cells, a process that was recently demonstrated on the laboratory scale at Idaho National Laboratory (INL). The electrolyzer cell energy efficiency of the process was close to 90 percent at a temperature of 850°C; this is higher than the conventional alkaline electrolyzer cell efficiency of 80 percent. A high-temperature cogeneration reactor—for example, the NGNP reactor—could provide both the process heat and the electricity needed for this higher-efficiency production of hydrogen.

The production of hydrogen from water via nuclear energy is also possible by means of high-temperature chemical reactions using heat alone (the so-called thermochemical water-splitting approach). Current NHI R&D focuses on two options, both of which rely on the thermal decomposition of sulfuric acid into oxygen and SO_2 at 800°C to 1000°C as the fundamental reaction, and two different approaches—S-I and hybrid processes—to use the SO_2 to produce hydrogen, oxygen, and recycled sulfuric acid.

The key elements of the S-I process have been tested separately at the laboratory scale and shown to work in the United States and Japan. In Japan, the synthesized process was demonstrated at low pressure on a small scale (30 L/hr) in December 2004. A similar demonstration (100 L/hr) was accomplished 20 years earlier by the Westinghouse Electric Company using the hybrid sulfur (HyS) process. In the United States, the construction of the S-I Integrated Laboratory Scale Experiment will be completed in FY 2007 in collaboration with the French CEA and will provide the first pilot-scale integrated demonstration at prototypical pressure and process conditions using electrical heating. In addition, small-scale university-based research in the United States is working on alternative thermochemical cycles that do not use sulfuric acid, along with research in catalysts and membranes to improve process efficiency. An integrated laboratory-scale experiment using modern electrolyzer technology is still needed for the HyS process and should be included in the NHI program.

The current NHI schedule calls for construction of an engineering-scale process demonstration (several tens of megawatts) in 2015, to be coupled to the NGNP reactor. The Japanese are also moving ahead with a project producing

30 m^3/hr, or 1,000 times bigger than the country's current laboratory-scale facility. The project will be coupled to Japan's 30-MW high-temperature nuclear reactor, which started up in 2000.

The NHI program is focused on hydrogen production by nuclear heat or electricity. However, other aspects of the hydrogen technology are being developed by DOE offices other than NE. The research includes technology for the storage, transport, and regeneration of hydrogen, as well as infrastructure and standards for safe use by the public. The NE effort is being coordinated with the efforts of other DOE offices. However, because the use of hydrogen in the near term is likely to be in large chemical plants, much of the practice today for handling hydrogen at large plants can be applied to nuclear hydrogen as well. The only new element might be the potential for generating tritium in some reactors, which then could be of concern if there is a way for it to leak into the hydrogen side of the complex. However, such a possibility appears to be minimal when the reactor coolant is a nonhydrogenous material. In the longer term, when hydrogen might become useful as a distributed energy carrier, new technologies for storage and distribution will be needed.

Nuclear Hydrogen Initiative Evaluation

Is the Program Purpose Clear?

The purpose of the NHI program is to develop technologies that produce hydrogen using nuclear energy. The most efficient methods for producing hydrogen involve the direct use of high-temperature process heat, possibly coupled with some electricity input. The NHI program is closely linked to the NGNP program, which will develop a reactor capable of providing high-temperature process heat. The principal technology issues for the NHI program involve (1) identifying materials and associated fabrication methods for heat exchangers, cell stacks, and other equipment that must operate at high temperatures with very corrosive candidate process fluids such as sulfuric acid and (2) selecting, optimizing, and demonstrating integrated processes capable of producing hydrogen at the laboratory, pilot plant, and, finally, engineering demonstration scales.

Does the Program Address a Specific and Existing Problem?

The successful development of economically efficient methods to generate hydrogen using nuclear energy would address a number of important problems. In the near term, hydrogen produced in this way could replace the large quantities of hydrogen currently produced using natural gas, reducing carbon emissions and reducing the quantities of liquefied natural gas that the United States would need to import. In the longer term, this hydrogen could be used more broadly in other petrochemical applications, including the production of liquid fuels from unconventional sources such as tar sands, shale oils, coal, and biomass, and could be used directly as an energy carrier for transportation vehicles equipped with fuel cells.

Is the Program Design Free of Major Flaws That Would Limit Its Effectiveness or Efficiency?

The program is currently exploring several technology options for hydrogen production using laboratory-scale experiments. For thermochemical processes, integrated laboratory-scale experiments are scheduled to start in 2007, while for high-temperature electrolysis, cell and stack experiments are now under way, and module experiments will start in 2008. This laboratory-scale R&D is intended to inform decisions in 2011 on technologies and materials for two pilot-scale integrated experiments. One or more of these pilot-scale technologies would be selected in 2015 for demonstration at the engineering scale using heat delivered by the NGNP reactor. The current portfolio of research in the program is appropriate for the current phase of the project, and the program is free of major flaws. The committee has concerns, however, that the resources being devoted to the program are insufficient to meet the proposed schedule, and that the schedule is not fully integrated with the NGNP program schedule.

Are Key Decision Points and Alternative Courses of Action Identified?

Two key decision points have been defined by the program, the first in 2011 to select two system designs for pilot-scale experiments and the second to select one or two designs for engineering-scale demonstration in 2015. At each decision point the design options that prove unsuccessful are discarded.

Is the Program Effectively Targeted So That Resources Will Address the Program's Purpose Directly?

Much of the current NHI R&D is university based, which is appropriate for many aspects of the current laboratory-scale R&D. However, as integrated experiments are started, an increasing fraction of the program support will need to be directed to the national laboratories and industrial participants in the program. More attention to industrial-scale implications of the technology is needed, starting with studying the implications of operating conditions for cost, reliability, and safety.

Does the Program Have a Limited Number of Long-Term Performance Measures That Focus on Outcomes and Meaningfully Reflect the Purpose of the Program?

The NHI program is evaluated using the Generation IV program performance measures. For the NHI program, the economics and the safety and reliability criteria are the most important. However, specific metrics for evaluating performance have not been established. The committee recommends that the NHI program select specific economic metrics that can be linked to the cost of hydrogen produced by competing technologies, such as natural gas steam reforming. It is reasonable that until materials and fabrication methods have been identified for all of the major system components, a great deal of uncertainty will surround these evaluations. The design information will become available once decisions have been made before entering the pilot-scale demonstration phase in 2011. These decisions should be based on the potential to meet specific economic criteria.

Has the Program Demonstrated Adequate Progress in Achieving Its Long-Term Performance Goals?

The program is making adequate progress, but some acceleration is required to meet the milestones proposed for the NGNP project.

OTHER GENERATION IV REACTOR NUCLEAR ENERGY SYSTEMS

Other Generation IV System Program Descriptions

Six reactor concepts were recommended in the Generation IV Roadmap as having the most promise for meeting the Generation IV goals. Five concepts were selected for further development by DOE. The remaining concept, the MSR, has not been included in the scope of effort supported in the United States, but the United States monitors international progress on this concept. Of the concepts included in the plans of DOE, two are thermal neutron spectrum systems and three are fast neutron spectrum systems. The total amount of annual R&D funding in the United States for the alternative concepts (excluding NGNP) has been about $3 million per year. Therefore, even with the efforts abroad to address these concepts outside the United States, this level of funding allows only basic concept definition and limits focused research to areas of greatest uncertainty. For each technology a brief discussion of the concepts, the scope of R&D effort selected for the DOE effort, and the time line identified for progress is provided as follows.

Thermal Spectrum Reactors

VHTR. As noted above, this concept has been selected as the most promising concept for nuclear energy to produce process heat and hydrogen. Known as NGNP, DOE efforts (discussed above) for this concept have focused on the adoption of a demonstration plant/prototype. DOE has funded conceptual design efforts for a liquid-salt-cooled VHTR that would allow large power-up rates compared to gas-cooled reactors of the same size with the same fuel, offering the potential for improved economics.

SCWR. Like the VHTR, the supercritical-water-cooled reactor concept is a thermal-spectrum reactor that also holds the potential for improved technology. This reactor concept offers significant advances in economics through plant simplification and increased thermal efficiency, with reactor outlet temperatures of 500°C, well above the 300°C of today's reactors. DOE, through GIF partnerships, has positioned itself to leave the leadership of this reactor concept to its international partners Canada and Japan. The GIF has identified the critical R&D issues that were examined from 2002 to 2005:

- Corrosion of structural materials and cladding,
- Water chemistry and heat transfer related to the materials issues, and
- Demonstration for a base SCWR design of adequate safety and stability during operation and under off-normal conditions.

Fast Spectrum Reactors: the GFR, LFR, and SFR Concepts

Fast spectrum reactors can operate as either burners or breeders of fissile materials. As breeders they can multiply nuclear fuel resources by between 10- and 100-fold, depending on the particular design. As burners of fissile material they have the advantage of burning the minor actinides (neptunium and transplutonium) more efficiently than thermal-spectrum reactors. When operating with a fissile breeding ratio of unity, they are called self-sustaining reactors, although the fuel they breed can be used by thermal as well as fast reactors. The use of thorium in thermal reactors, which results in reduced production of the actinides that affect repository capacity and in improved fuel use, has also been studied as a route to self-sustaining reactors. Widespread deployment of self-sustaining reactors based on some combination of these technologies would extend the fuel resources for nuclear fission for hundreds of years should that be needed. One of the chief issues in the development of a self-sustaining reactor for use in the United States is economic competitiveness, given the requirements for high reliability and safety.

Since the completion of the Generation IV Technology Roadmap, three self-sustaining fast-spectrum reactors concepts—the GFR, LFR, and SFR—have been the subject of R&D efforts. All three systems were to be brought to a state where the best system could be chosen based on economics, safety, reliability, sustainability, proliferation resistance, and physical protection.

Because the SFR was already at a fairly advanced state of basic design, GIF organized a modest effort between 2002 and 2005 in which the Japanese and the French led the development of advanced SFR fuels for actinide transmutation and more economically competitive designs. In contrast, the much less developed LFR effort focused on corrosion issues and advanced modular designs. The GFR has received the most attention over the last few years in France, where fuels, safety systems, and power conversion were the focus of efforts.

DOE worked with its GIF partners to maintain modest R&D programs for all three fast reactor concepts from 2002 to 2005. Originally the performance downselection for these concepts was planned for the same time frame as NGNP—2011. The R&D goal for the fast reactors (GFR, LFR, and SFR) has been to obtain enough reliable information on materials issues and fuel behavior in the event of an accident, while developing an economically competitive design. For all three reactor concepts, these R&D issues must be sufficiently understood by 2010 to allow a decision to be made about the best concept for further development and demonstration between 2011 and 2021.

Crosscutting R&D can benefit more than one reactor concept. Important fundamental information is needed in the following crosscutting areas:

- Data to validate the models for the effects of irradiation on materials characteristics since the expected service time for nuclear power plants has effectively become at least 60 years and could soon be as much as 80 years.
- Data on the behavior of UO_2 and nonfertile (neutronically inert) actinide-bearing fuels operating at high temperatures for long times. For example, ceria, magnesia, and zirconia could be used in the Generation IV reactors to host the actinide fuel.
- Information on advanced energy conversion systems, including equipment that interfaces between the coolant and the turbine working fluids in advanced cycles, such as the supercritical CO_2 power cycle.
- Information on the application of technology-neutral approaches to reactor licensing and advances in the regulatory system to include performance-based criteria for monitoring.

Current Status and Priorities for the Alternative Concepts

As previously noted, a downselect implicitly took place at DOE in late 2005 and early 2006, given the redirection at DOE toward support of GNEP. The DOE R&D focus has recently been shifted to elevate the priority for development and demonstration of the SFR as an advanced burner reactor (ABR) (Chang et al., 2006). Under the new DOE priorities for near-term deployment of a closed fuel cycle, the SCWR design work and any associated R&D are being closed out in the United States and only the international efforts will continue. The remaining work on the GFR and LFR concepts is gradually being moved to international support within GIF.

Evaluation of Other Generation IV Nuclear Energy System Programs

In effect, the United States selected two Generation IV nuclear energy systems in 2006: the VHTR for NGNP and the SFR for GNEP. Furthermore, the priorities of the two main strategic goals of the Generation IV program have been re-ordered, owing to the emergence of GNEP:

- *First priority.* Used-fuel recycle and actinide burning to minimize waste products.
- *Second priority.* Process heat to produce alternative energy products (e.g., hydrogen).

The committee observes that the Generation IV concept evaluation criteria (see Table 3-1) for reactor development adopted by the Generation IV Technology Roadmap were not applied in this selection. The R&D priorities and concept evaluation have been shifting, with minimal discussion of priorities and alternative courses of action. The Generation IV program formerly had well-defined goals and measures against which to gauge its decisions on the development of reactor technology options for sustainable nuclear energy, among them competitive cost, minimal waste streams, and innovative energy products. Since the arrival of GNEP, the new Generation IV program priorities are not well articulated for the portfolio of concepts, and the development of technology elements that are common to different Generation IV reactor designs are no longer well coordinated.

The committee observes that there is one focus on process heat and hydrogen production and another on reducing the high-level waste burden, but there has been no evaluation of the possibility of developing crosscutting technology in support of the VHTR or the SFR in a way that can take advantage of past related work and expand the base technology. For example, there are technology elements that may be common to both missions, such as supercritical fluid power conversion, high-temperature materials development, and innovative technologies for process heat. In fact, NGNP and GNEP appear to be competing for the chance to be demonstrated and commercialized, with both vying for the same limited DOE budget and not taking advantage of synergisms.

There are established program goals for the NGNP, but it is not clear under the new DOE program plans if the old performance measures for Generation IV will be applied to NGNP. Similarly, it is clear that no performance evaluations were carried out prior to the inclusion of a large demonstration plant for the SFR (i.e., the ABR) or for the large fuel separation facility. The SFR program structure seems vague at this time, appearing to involve selected studies of technology issues that are principally beneficial for commercialization rather than being explicitly linked to the long-term technology needs of nuclear energy.

The use of the Generation IV program metrics to compare the high-temperature reactors and fast-reactor systems for dual missions—a process heat mission and a fuel cycle flexibility mission—appears to be absent from the current program. For example, there is little attention to how either the VHTR or the SFR technology will compete with existing LWRs in the electricity market.

The program resources are barely adequate for basic studies related to NGNP and the VHTR design (NGNP construction will begin only after an industry alliance matches DOE funds). Thus the program funding level for these programs is inadequate for developing the SFR, investigating the other Generation IV reactor concepts, and developing crosscutting nuclear energy technologies. Currently there is little in the way of synergies that can come from R&D developments across reactor concepts.

FINDINGS AND RECOMMENDATIONS

Next-Generation Nuclear Plant

Finding 3-1. The NGNP program has well-established goals, decision points, and technical alternatives. The key technical alternatives are the fuel type, the heat transport working fluid and the IHX, and the hydrogen generation process. A key decision point is the nuclear licensing approach for NGNP. To keep to the apparently preferred schedule, which has a FY 2017 plant operations date, some of the technical decisions must be made quickly, so that detailed design, component and system testing, and licensing can be initiated. However, it is unlikely that operation can be achieved by 2017 due to significant funding gaps that developed in FY 2006 and FY 2007. These gaps affected the scope and schedule for the planned testing of fuel and structural materials as well as the heat transport equipment.

Finding 3-2. Little planning has been done on how the fuel for the NGNP would be supplied. There is a particle fuel R&D program, but it will take up to two decades to complete the development and testing of this new fuel.

Finding 3-3. The main risk associated with NGNP is that the total funding under the current business plan calls for the private sector to match the government (DOE) funding. So far, however, not a single program has been articulated that coordinates all the elements required to successfully commission the NGNP. The current disconnect between the base NGNP program plan and the complementary public/private partnership initiative must be resolved.

With regard to the NGNP program, the committee recommends the following:

Recommendation 3-1. A schedule that coordinates the required elements for public-private partnership, design evolution, defined regulatory approach, and R&D results should be articulated to enhance the potential for program success.

Recommendation 3-2. DOE should decide whether to pursue a different demonstration plant (perhaps a smaller one with less total energy output or a plant with fewer hydrogen production options or a more basic technology approach for the VHTR) with a smaller contribution from industry.

Recommendation 3-3. In assessing NGNP conceptual designs, NE should favor design approaches that can achieve a variety of objectives at an acceptable technical risk—for example, hydrogen production, other high-temperature process heat products, enabling deep-burn actinide management, and improving economics.

Recommendation 3-4. NE should size the NGNP reactor system to facilitate technology demonstration for future commercial units, including safety. Consistent with resources available, NE should adopt an appropriate power level to demonstrate components and functionality of practical significance to commercial size.

Recommendation 3-5. Because of the very high temperatures and severe material performance requirements for thermochemical water splitting, NE should maintain the flexibility to first operate the NGNP using high-temperature steam electrolysis.

Recommendation 3-6. DOE should focus on the following NGNP technologies that require significant development and ensure that sufficient funds are available to advance these technologies whether or not industry matching funds are available:

- Advanced materials for in-reactor operation at temperatures above 900ºC.
- Fuel particles that can withstand high burn-up and adverse transients.
- The heat transport system for process heat applications, specifically to improve its efficiency and reliability.
- Waste management technologies related to commercial deployment.

Recommendation 3-7. To ensure good performance of NGNP-based hydrogen production, NE should put more emphasis on the following:

- Conceptual integrated process development and optimizing plan flow sheets, before moving to engineering designs.
- Selecting the interface between the reactor and the hydrogen plant.
- Developing system performance tools to address unsteady conditions, such as plant start-up, plant trip, and maintenance needs.
- Assessment of total system economics.

Nuclear Hydrogen Initiative

The NHI program is aimed at developing new technologies to produce hydrogen and oxygen with high efficiency using nuclear energy. The focus of the program is the use of high-temperature process heat as the main energy input for the production of hydrogen, which promises significantly higher efficiency and lower cost than conventional low-temperature electrolysis. These processes involve challenging high-temperature materials problems, which are being addressed with laboratory-scale research at this time for three primary hydrogen production methods. Major technology downselections to allow testing at the pilot and engineering demonstration scales are scheduled for 2011 and 2015, respectively.

NHI is well formulated to identify and develop workable technologies, but the schedules and budgets need to be adjusted to assure appropriate coupling to the larger NGNP program.

With regard to the NHI program, the committee recommends the following:

Recommendation 3-8. DOE should expand NHI program interactions with industrial and international research organizations experienced in chemical processes and operating temperatures similar to those in thermochemical water splitting. NE should also broaden the hydrogen production system performance metrics beyond economics—for example, it could use the Generation IV performance metrics of economics, safety, and sustainability.

Other Generation IV Nuclear Energy System Programs

Finding 3-4. The second major concept for development in the Generation IV program, the SFR program, seems vague at this time and appears to involve selected studies of technology issues that are principally beneficial for commercialization rather than being explicitly linked to long-term nuclear energy technology needs.

Finding 3-5. The committee is concerned that the Generation IV concept evaluation criteria for reactor development adopted by the Generation IV Technology Roadmap were not applied in the selection of the VHTR and SFR. The Generation IV R&D priorities have been shifting, with minimum discussion of criteria and alternatives.

Finding 3-6. The program resources are barely adequate for basic studies related to NGNP and the VHTR design and entirely inadequate for exploring the SFR at a research level (unless the new GNEP program also includes basic research components), for investigating other reactor concepts, and for developing crosscutting reactor technology systems.

Finding 3-7. The use of the Generation IV program metrics to compare the high-temperature reactors and fast-reactor systems for dual missions—a process heat mission and a fuel cycle flexibility mission—appears to be absent from the current program.

With regard to the other Generation IV nuclear energy system programs, the committee recommends the following:

Recommendation 3-9. Within the Generation IV program, NE should modestly and reasonably support long-term base technology options other than the VHTR and the SFR, particularly for actinide management, using thermal and fast reactors and appropriate fuels.

Recommendation 3-10. Though NE currently focuses on the VHTR for process heat and the SFR for advanced fuel cycles, it should assess the cost-benefit of a single reactor system design to meet both needs.

Recommendation 3-11. Funding for NGNP and NHI should be increased if the schedule is to be accelerated to attract more industrial support.

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The Advanced Fuel Cycle Initiative and Global Nuclear Energy Partnership Programs

BACKGROUND

From the first introduction of nuclear power, the management of spent nuclear fuel, especially the highly radioactive components, has been a concern. Three main issues underlie this concern: the disposal of nuclear wastes, the reduction of opportunities for nuclear weapons proliferation, and the long-term supply of fissionable material for nuclear fuel. A central question in dealing with these issues is whether to close the nuclear fuel cycle by reprocessing the spent fuel and recycling its components or to employ a once-through fuel cycle, treating spent fuel as waste. Various nations have answered this question differently.

In 1976, the United States decided to suspend plans for reprocessing and recycling plutonium due to the potential risk of proliferation. Then in 1979, it changed its policy, deciding to defer reprocessing indefinitely and to pursue the once-through fuel cycle. Some countries, notably France, the United Kingdom, Germany, the Soviet Union, and Japan, continued to reprocess plutonium. In France, the recovered plutonium is now recycled once in the form of uranium-plutonium mixed oxide (MOX*)* fuel to produce power while the rest of the minor actinides, primarily neptunium (Np), americium (Am), and curium (Cu), and the fission products from the spent fuel are stored until a repository is available. Other isotopes such as krypton (Kr) and iodine (I) are released as effluent.

All nuclear fuel cycle options, including closed fuel cycles, require the capacity for permanent disposal of high-level wastes. The National Research Council (NRC) recommended in 1957 that deep geologic isolation would be a suitable approach for disposal (NRC, 1957). Other nations have adopted the same view. However, no nation yet has a fully functioning geologic disposal operation for high-level radioactive waste.

Since 2002, the United States has been conducting a program of spent fuel reprocessing research and development (R&D), in part to consider alternative spent fuel management options. This program is built on earlier work funded by DOE that was evaluated by the 1996 NRC report *Nuclear Wastes: Technologies for Separations and Transmutation*. The Advanced Fuel Cycle Initiative (AFCI) was the program under which DOE was carrying out its long-term direction to recycle nuclear fuel waste. In February 2006, 5 months before the committee's first meeting, the United States announced a change in its nuclear energy programs. The FY 2007 budget request included work on recycling that would be done under a new effort, the Global Nuclear Energy Partnership (GNEP). This new effort would incorporate the AFCI as one of its activities. If the recycling R&D program leads to successful deployment, GNEP would eventually require the United States to be an active participant in the community of nations that recycle fuel, because part of the GNEP program has some nations recycling the nuclear wastes for other user nations. The presumption is that by having only a few supplier nations carry out the enrichment and recycling for many others, nuclear power could be made economically attractive to the user nations and, at the same time, the number of locations where enrichment and recycling are carried out would be minimized, reducing opportunities for diversion of fissionable material and misuse of fuel cycle facilities and technologies.

In this way, the AFCI/GNEP program under review by this committee is being conducted in the face of change and uncertainty in U.S. policies for the disposition of commercial spent fuel and high-level waste. One effect of this uncertainty is to make more difficult the acquisition of clear and complete program documentation. To develop the necessary information for its evaluation, the committee has drawn on interviews with individuals from DOE, the Nuclear Energy Institute (NEI), the Electric Power Research Institute (EPRI), academia, and others, as described in Appendix E, and on a variety of written reports.[1]

The committee also saw copies of slides presented at a GNEP panel session at the U.S. Nuclear Regulatory Commission (USNRC) on March 15, 2007, and GNEP-relevant presentations at the American Chemical Society annual meeting on March 27, 2007. The GNEP Technology Development Plan (TDP) was released on July 25, 2007, after the committee began its peer review stage. Because TDP said that the plans it described did "not necessarily reflect the views and decisions of the Department of Energy," the committee could not accept it as DOE policy and had to use other references (e.g., reports of the Organisation for Economic Co-operation and Development (OECD) in evaluating the technical aspects of fuel recycling.

In the balance of this chapter, the committee first describes the AFCI program as it existed until 2006 and then describes and evaluates its successor, GNEP. The chapter concludes with the committee's findings and recommendations.

Proliferation Concerns and Efficient Use of Nuclear Fuel: The AFCI Context

The United States rejected the idea of recycling spent nuclear fuel during the 1970s because the then-available methods all produced separated plutonium, which can be purified relatively easily into material to make a fission bomb. Similarly, the uranium enrichment process can be misused to generate enough highly enriched uranium to make nuclear weapons. The United States and other countries that are members of the International Atomic Energy Agency (IAEA) have worked to reduce proliferation risks and to rectify the shortcomings identified by the International Nuclear Fuel Cycle Evaluation (IAEA, 1980).

Since the time of that decision not to recycle, other recycling processes have been under development that do not yield separated plutonium. In the United States, processes were worked on, beginning in 2002, under the AFCI, which itself had grown out of the Accelerator Transmutation of Waste program, initiated in 1999. This effort was under the direction of DOE's Office of Nuclear Energy (NE). The AFCI program was created with the following objectives (DOE, 2005; 2006c, p. 3):

> AFCI technology development focuses on reducing the long-term environmental burden of nuclear waste, improving proliferation resistance, and enhancing the use of nuclear fuel resources. The program has one major objective associated with each of these three considerations. The AFCI Program also has a fourth "system management" objective that emphasizes safe and economic nuclear materials management, integrating all of the above considerations.

It is of particular importance to note that the AFCI was to provide an alternative to building the multiple repositories that might be needed for the once-through fuel cycle and to support a growing role for nuclear energy. The published DOE GNEP strategy does not consider the possibility of Yucca Mountain being rejected or of it being accepted and its capacity significantly increased for the storage of more spent fuel. AFCI was to inform the Secretary of Energy about the need for a second repository as early as January 1, 2007, and no later than January 1, 2010, because according to the Nuclear Waste Policy Act, the Secretary is required to report to Congress on that schedule.

To meet its objectives, AFCI examined four fuel cycle strategies (DOE, 2006c, p. 11):

- The current U.S. strategy is once-through—all the components of spent fuel are kept together and sent to a geologic repository for disposal.
- The second strategy is recycling in thermal reactors only. Uranium in spent fuel and depleted uranium would be disposed of as low-level waste. Transuranic elements, such as plutonium and neptunium, would be recycled several times, deferring the need for a second geologic repository. However, eventually transuranic elements would accumulate and would require geologic disposal. Long-lived fission products would also go to geologic disposal. Short-lived fission products would be first stored and ultimately disposed of as low-level waste. This strategy would use existing types of nuclear power plants, which are all thermal reactors.
- The third strategy is sustained recycle with a symbiotic mix of thermal and fast reactors, recycling transuranic elements from spent fuel repeatedly until destroyed. The introduction of fast reactors makes this strategy sustainable from the repository standpoint; the accumulation of transuranic elements during repeated recycle passes is controlled and limited by fast reactors serving as transuranic element burners. Essentially no transuranic elements would go to geologic disposal, only processing losses. Uranium and fission products would be disposed of as with thermal recycling. This strategy requires a significant, but minority, fraction of nuclear power plants to be fast reactors, which are being researched by the Generation IV Nuclear Energy Systems initiative.
- The fourth strategy is sustained recycle with fast reactors, recycling both uranium and transuranic elements repeatedly until all energy is extracted. Phasing out thermal reactors in favor of fast reactors means that all types of uranium ultimately serve as fuel; thus this strategy is sustainable both in terms of repository constraints and in terms of uranium ore resources. Essentially no uranium or transuranic elements would be wasted, only processing losses. As with other recycle strategies, long-lived fission products would tend to

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[1] For AFCI, Comparison Report, FY 2005, May 2005 (DOE, 2005); Comparison Report, FY 2006 Update, July 2006 (DOE, 2006c); and Status Report for FY 2006, February 2006 (DOE, 2006a).

For GNEP, Mission Need for GNEP, approved on March 22, 2006 (DOE, 2006b); GNEP Implementation Strategy, November 2006 (DOE, 2006d); and GNEP Strategic Plan, January 2007 (DOE, 2007).

go to geologic disposal; short-lived fission products would be stored and ultimately disposed of as low-level waste after sufficient decay. This strategy would use Generation IV fast reactors.

AFCI envisioned that for all fuel cycles, long-lived fission products and residual transuranics would go to geologic disposal. For the last three fuel cycles, short-lived fission products would be managed separately to allow decay heat levels to drop before disposal as waste, either into a high-level waste geologic repository after several decades of interim storage or as low-level waste after approximately 300 years' storage. Large inventories of transuranics would reside in the fuel cycle. Depending on the future evolution and use of nuclear energy, particularly if nuclear energy is replaced in the longer term with other energy sources, most of these transuranics could also require geologic disposal when the fast reactors are decommissioned.

The newer recycling processes would, if adopted, impact security in a number of ways. To help protect against the threat of concealed diversion of fissionable material, keeping other materials mixed with plutonium increases the effectiveness of safeguards containment and surveillance measures but may complicate material accounting. Avoiding the separation of pure plutonium is beneficial because it may increase the mass, bulk, and radioactivity of the material and can shift the handling of the material into less accessibe locations, such as hot cells. At the same time, the radioactivity of the plutonium plus actinides is not significantly higher than that of just plutonium itself. Moreover, separation of plutonium plus actinides does not preclude its use in weapons. Although weapons made from the unseparated material may be less powerful than those made from material meant to be put into weapons, the effects would still be devastating.

The programs that would eventually become AFCI received funding of $68.7 million in FY 2001, $77.2 million in FY 2002, and $57.3 million in FY 2003. In FY 2004, AFCI officially came into existence and was funded at $65.8 million in FY 2004, $66.4 million in FY 2005, and $78.4 million in FY 2006 (see Table 1-1). Beginning in FY 2007, DOE requested that the AFCI program be subsumed in a larger program, GNEP, described below, and requested $243 million for the AFCI account.

OVERALL PROGRAM DESCRIPTION

The goals of DOE's GNEP program appear to consist of what DOE terms "objectives" and "criteria." In its GNEP Strategic Plan (DOE, 2007, pp. 1-10 and 2-10), DOE says that in order to

> enable the expansion of nuclear energy for peaceful purposes and make a major contribution to global development into the 21st century, the United States seeks to pursue and accelerate cooperation to:
>
> - Expand nuclear power to help meet growing energy demand in an environmentally sustainable manner.
> - Develop, demonstrate, and deploy advanced technologies for recycling spent nuclear fuel that do not separate plutonium, with the goal over time of ceasing separation of plutonium and eventually eliminating excess stocks of civilian plutonium and drawing down existing stocks of civilian spent fuel. Such advanced fuel cycle technologies would substantially reduce nuclear waste, simplify its disposition, and help to ensure the need for only one geologic repository in the United States through the end of this century.
> - Develop, demonstrate, and deploy advanced reactors that consume transuranic elements from recycled spent fuel.
> - Establish supply arrangements among nations to provide reliable fuel services worldwide for generating nuclear energy, by providing nuclear fuel and taking back spent fuel for recycling, without spreading enrichment and reprocessing technologies.
> - Develop, demonstrate, and deploy advanced, proliferation resistant nuclear power reactors appropriate for the power grids of developing countries and regions.
> - In cooperation with the IAEA, develop enhanced nuclear safeguards to effectively and efficiently monitor nuclear materials and facilities, to ensure commercial nuclear energy systems are used only for peaceful purposes.

The charge to the committee concerns the technical, scientific, economic, and management aspects of the GNEP program. Therefore, it has focused primarily on the second and third objectives. Though the fifth objective is also within the committee's purview, DOE appears to be in only the early stages of formulating a plan for this work, so the committee has not attempted to evaluate it.

Questions of international collaboration lie outside the charge of this study. It is worth noting that the committee learned of efforts to establish discussions with other countries, notably to initiate collaboration with the Russian Global Nuclear Infrastructure (GNI) (WNN, 2007). It is unclear how well the GNI goals fit with those of GNEP. In addition, the committee learned from some of its outside expert consultants about the challenges surrounding the international aspects of bringing GNEP to reality, and there are some aspects of international interactions that do have a direct bearing on the response to the charge. These will be addressed in a later section.

DOE's strategic plan for GNEP contains the following criteria:

- *Proliferation/safeguards risk*. "The risk of non-peaceful use of the civilian nuclear fuel cycle comes from two principal sources: (1) a nation wanting to advance toward the capability to build nuclear weapons in a shorter period of time and (2) a terrorist group wanting to divert nuclear materials to quickly fabricate and explode an improvised nuclear device or a dirty bomb. GNEP aims to address both of these issues by providing incentives to forego enrichment and reprocessing facilities, and by eliminating over time excess stockpiles of civil plutonium." (DOE, 2007, p. 2-10)

- *Proliferation prevention*. "Preventing the spread of commercial nuclear technology does not by itself prevent the spread of weapons capability. . . . The plutonium contained in spent fuel discharged from a light water reactor is not considered 'weapons grade.' However, plutonium separated from spent nuclear fuel could be fashioned into a weapon and achieve a nuclear yield of some magnitude. . . . While safeguarding bulk-handling facilities will continue to pose significant technical challenges, advances have been made in developing processes that are easier to safeguard, allow improved materials accountability, are more resistant to terrorist threat, and offer the possibility of placing a much reduced burden on our waste disposal facilities. However, *there is no technology 'silver bullet' that can be built into an enrichment plant or reprocessing plant that can prevent a country from diverting these commercial fuel cycle facilities to non-peaceful use*. . . . GNEP seeks to develop advanced fuel cycle technology for civil purposes, centered in existing fuel cycle states that would allow them to provide fuel services more cheaply and reliably than the other states could provide indigenously." (DOE, 2007, p. 3-10)
- *Terrorist threat reduction*. "In the most general terms, GNEP seeks to eliminate over time excess stocks of separated plutonium and reduce stocks of spent fuel worldwide, thereby strengthening nuclear security worldwide. In more specific terms, a key objective with respect to any GNEP recycling facility is to deny access to fissile nuclear materials of critical mass that could be readily made into a nuclear device. Supportive policies can be implemented in this regard: (1) minimize transportation; keep fissile materials inside one integrated facility from the time used fuel enters until recycled material leaves; (2) maintain a mixture of fissile material with non-fissile material in a ratio that is not easily useable as a weapon; (3) use advanced safeguards and security techniques; and (4) maintain a goal of minimizing the buildup of, and eventually eliminating, stockpiles of separated civilian plutonium or its near equivalent." (DOE, 2007, p 3-10)
- *Reduced repository burden*. "Commercial spent nuclear fuel can either be disposed of directly into a repository (e.g., Yucca Mountain in the U.S.) or reprocessed/recycled and the byproduct high level waste sent to a repository. . . . The full benefit envisioned for the separations process in GNEP anticipates substantial repository benefits (by separating out all the actinides) and a reduction in liquid process waste. The most significant repository benefits can be achieved by removing the very long-lived minor actinides and recycling them as part of the fuel for fast reactors. To obtain a repository capacity increase ranging from one to two orders of magnitude and allow Yucca Mountain to satisfy our repository needs for the remainder of the 21st century it will be necessary to remove and fission through recycle the very long-lived minor actinides. Further repository benefit can be achieved by removing the fission products cesium and strontium from the high level waste stream and allowing them to decay separately. These elements have a relatively short half life and after decay could be disposed of as low level waste. Additionally, removing the technetium and fixing it in a matrix with the cladding hulls could reduce the possibility of this fission product migrating away from the repository area. DOE has been conducting work on processes to achieve all of these additional advanced partitioning objectives as well as work on how to recycle and consume these materials in a fast spectrum reactor. To date these efforts have been carried out as part of the Advanced Fuel Cycle Initiative, and it is proposed to continue this work as part of the broader GNEP initiative. Similar work is being carried out in Japan, France, and Russia with promising results." (DOE, 2007, p. 4-10)
- *Assured fuel supply*. "The U.S. seeks to encourage the world's leading nuclear exporters to create a safe, orderly system that spreads nuclear energy without proliferation. States that refrain from enrichment and reprocessing would have reliable access at reasonable cost to fuel for civil nuclear power reactors. . . . The implication for the U.S. is that if we are going to participate in assuring access to nuclear fuel and, in the longer term, spent fuel services to these countries as they enter the nuclear arena, the U.S. must have the capability to provide the needed fuel cycle services—capability that we do not currently possess. Our fuel cycle technology should also build our ability, and those of our partners, to establish and sustain 'cradle to grave' fuel service or leasing arrangements over time and at a scale commensurate with the anticipated expansion of nuclear energy by helping in a major way to solve the nuclear waste challenge. (DOE, 2007, pp. 4-10 and 5-10)
- *Capability and leverage*. "The GNEP vision has been well received by the international nuclear community, particularly among the leading fuel cycle states. Sustaining and building on that enthusiasm depends on the U.S. ability to get back in the commercial nuclear business and assume an active role. Participating fully in that business is essential in order to shape the rules that apply to it. . . . We have a vision of a future world that can universally enjoy the benefits of safe, economical, emission-free energy; and we have programs and plans to put the U.S. back in the nuclear energy game in a leadership role. Access to our market is itself a form of leverage." (DOE, 2007, p. 5-10)

Three facilities are key components of the GNEP program as currently planned: (1) a nuclear fuel recycling center or centralized fuel treatment center (CFTC), (2) an advanced sodium-cooled burner reactor (ABR), which is a fast-neutron reactor, and (3) an advanced fuel cycle facility (AFCF). At the CFTC, spent fuel would be separated into specific waste streams, some of which would go to the ABR (the CFTC is sized to fuel many ABRs, as discussed later in this report) as transmutation fuel and others of which would go to a repository or long-term storage or be disposed of as low-level waste. Initially the transuranics and much of the uranium would go to the AFCF, which would turn those streams into transmutation fuel in the form of lead test assemblies, send its waste to a repository, and accept spent fuel from LWRs as well as partially transmuted fuel from the ABR. Subsequently, once the lead fuel designs were qualified, fuel fabrication would be located at the CFTC to minimize the transport of materials. The ABR would need, in addition to the fuel from the CFTC and the AFCF, some start-up fuel, whether uranium or plutonium. A principal function of the ABR would be to fission transuranic elements, while a secondary function would be to produce electricity.

The DOE has proposed that the CFTC be able to handle 2,000 to 3,000 metric tonnes (MT) per year of spent fuel. (Note that the current U.S. fleet of 104 operating reactors produces only 2,000 MT/yr of spent fuel, and 56,000 MT is already in storage.) At the time of the writing of this report, the latest information the committee had was that the baseline process was UREX+1a, although some other comparable separation technology, most notably pyroprocessing, may be adopted at a later stage. The ABR thermal power is planned to be 500 to 2,000 MWth. Both facilities should be capable of being licensed by the USNRC, although it is not clear if licensing is part of the GNEP plan. The locations of GNEP facilities have not been determined, although various expressions of interest and environmental impacts are being assessed.

GNEP as currently proposed has DOE as the leader for the AFCF and private companies as leaders for the CFTC and ABR. The strategic plan states that “a GNEP goal is to develop and implement fuel cycle facilities in a way that will not require a large amount of government construction and operating funding to sustain it” (DOE, 2007, p. 6-10). According to DOE, industry has filed expressions of interest (EOIs) that show a potential willingness to invest large sums of private funds to build and operate GNEP fuel cycle facilities. Because the EOI responses include proprietary information, the committee was not allowed to review them. The plan does recognize, however, that federal support for R&D and incentives is needed to ensure that the long-term goals are met. The strategic plan does not elaborate on the character or scale of the federal incentives, nor does it say how reprocessing and recycling costs, including potential subsidies for fast reactors, would (presumably) be passed on to nuclear electricity consumers in the form of fees or other charges to recover private investors’ initial investments.

Since the federal government is funded in FY 2007 through a Continuing Resolution (CR), the complete redirection of AFCI into GNEP is proceeding at a slower pace than had been planned. The FY 2007 CR appropriation agreement funds AFCI/GNEP at the level of $167.5 million, including the authority to redirect other programmatic funds to this initiative. The administration has requested $395 million for FY 2008. A decision by the Secretary of Energy on the future of GNEP—whether to conduct more R&D or proceed to commercial scale—is scheduled for June 2008.

ANALYSIS AND EVALUATION OF THE PROPOSED GNEP PROGRAM

The results of the committee’s evaluation of the technical, scientific, economic, and management aspects of the GNEP program are presented in this section. The evaluation looked at the technical and scientific options available for accomplishing some of the GNEP goals, particularly minimizing the burden on domestic nuclear waste repositories.

Reducing the Nuclear Waste Repository Burden

Under the Nuclear Waste Policy Act of 1982 (NWPA), Congress mandated that high-level nuclear waste be put into a geologic repository to be managed by DOE. The 1987 Nuclear Waste Policy Amendments Act directed DOE to evaluate only the Yucca Mountain site in Nevada for its suitability as a geologic repository. Disposal was to begin in 1998 but was delayed for several reasons, including strong opposition by the state of Nevada, technical issues associated with the site, the rewriting of EPA standards as the result of lawsuits and congressional action, insufficient appropriations from the Nuclear Waste Fund, and differences of opinion between the two political parties. The site was approved by the President and Congress in July 2002, though final approval rests with the USNRC, which grants construction and waste acceptance licenses. Program delays have continued for several reasons, including design changes, inadequate quality assurance, and management problems relating to the Yucca Mountain site. DOE is now scheduled to submit a license application in June 2008. If DOE keeps to that schedule, the USNRC’s review of the license application should be completed by 2012 if the USNRC meets certain reporting requirements. Spent fuel could then be accepted starting in 2017, but even DOE has little expectation of meeting that schedule. Meanwhile, spent fuel waste continues to be stored at reactor sites.

The total volume of nuclear waste from conventional LWRs is large enough to require serious attention. The thermal and radiation characteristics of the waste are the main concerns in designing the repository and determining its capacity. The NWPA established a capacity limit of 70,000 MT of waste for Yucca Mountain, 63,000 MT of which is designated for commercial spent fuel and the remainder for defense wastes. By the end of 2006, about 56,000 MT of spent fuel had been generated by U.S. nuclear power plants, and that inventory is growing at approximately 2,000 MT/yr. If all operating reactors receive 20-year license extensions, the total amount of waste from the current U.S. fleet could exceed 120,000 MT.

Although a statutory limit has been placed on the repository capacity, there is a wide range of opinion about the technical limits on the capacity. The technical limits of Yucca Mountain capacity are determined by the total area available with suitable geologic characteristics and by two criteria related to the management of heat from the decay of spent fuel. Significant uncertainty surrounds both the area available that is suitable for repository use and the maximum achievable areal loading. The draft Environmental Impact Statement identified 4,200 acres that possess four characteristics required for use as repository space: 200 meters of overburden, consistency of elevation and dip with the upper block, distance from the saturated zone, and favorable excavation characteristics (CRWMS, 1999). At the current design loading of 60 MT per acre, 4,200 acres would be large enough to store 252,000 MT of spent fuel. Larger areal loading might be possible for fuel with greater burn-up (the extent depending on radiation dose calculations), a trend already under way in the nuclear industry. A study by EPRI likewise suggested that with revised repository design, areal loading could increase by a factor of 2 or 3 (Kessler, 2006), although the study did not take into account limits imposed by geologic considerations.

Areal loading could increase much more if advanced fuel cycle technology, such as that envisioned by GNEP, is used. According to Wigeland and others (2006) the repository's capacity could be increased by reducing the amounts of short-lived cesium (Cs) and strontium (Sr) fission products as well as by lowering the amount of transuranics (TRUs) (Pu, Np, Am, and Cm) in the wastes reaching the repository. For example, the repository's areal capacity could be increased by a factor of 4.4 if the fractions of Pu, Np, Am, and Cm in the waste were decreased to 10 percent of their original values and by a factor of 10 if the fractions of Cs and Sr were also decreased 10-fold. Decay heat from Cs and Sr can be reduced 10-fold by a combination of interim storage and repository ventilation for 100 years; with approximately 300 years of storage, radiation levels drop sufficiently that disposal as low-level waste might be possible. It must be noted that removing Cs and Sr brings up a new siting issue: where and how to store such wastes for several decades to hundreds of years.

Considerations other than areal loading may dominate the Yucca Mountain decision, however. Detailed characterization would be required to determine what fraction of its space also meets other geological constraints (including spacing from fault and fracture zones) required for repository use. The USNRC must also consider other criteria, including public health and safety, in deciding whether to grant a license for the Yucca Mountain repository. It is difficult to predict when, if ever, any of these options for the use of Yucca Mountain might become reality. Significant uncertainty surrounds the maximum technical capacity of the Yucca Mountain site. Geologic studies may limit this capacity significantly. These and other issues will be considered by the USNRC at an uncertain date in the future, and it may or may not ever grant a license for the repository. If it does, the available evidence suggests that the capacity of Yucca Mountain exceeds the current statutory limit of 70,000 MT. If its opening is delayed, spent fuel can be stored using dry-cask storage. Spent nuclear fuel that has spent 5 years cooling in on-site water pools can be put into passively cooled casks, each holding approximately 10 MT of waste. There is general agreement and approval by the USNRC that such a scheme would provide safe, secure storage for at least 100 years.

As noted earlier, one goal of the GNEP program is to reduce the burden on the repository by reducing the volume of waste it must handle. Given the uncertainties discussed above, however, it is difficult to judge precisely when the technical need for additional repository capacity will arise. Therefore, the committee concludes that the need for an accelerated program to deploy commercial-scale reprocessing and fast reactors to reduce the nuclear waste repository burden has not been established. In particular, the near-term need for deployment of advanced fuel cycle infrastructure to avoid a second repository is far from clear.

But even if a second repository were to be required in the near term, the committee does not believe that GNEP would provide short-term answers. As the later discussion will show, however, the committee considers the DOE-preferred option—the GNEP program—also to be a very long-term effort, measured in decades, and very expensive, measured in tens of billions of dollars (or more). Its approval and survival will depend heavily on its broad technical and societal support, steady and continued funding, and effective management. GNEP will need positive actions from several successive presidential administrations and Congresses. With respect to management, GNEP needs a partnership and a business plan agreed on by industry, DOE, and participating foreign countries. To sustain such support, there needs to be more clear evidence that GNEP is preferable to the other options for expanding deep geologic disposal capabilities.

GNEP Technology

In the committee's view, the GNEP concept rests on a set of technologies that present very challenging development and engineering issues. Moreover, it is not clear that all of the relevant options had been evaluated before arriving at the program's preferred choices. Below, the committee discusses these issues, which relate to recycling methods, advanced fuel development, and fast neutron reactors.

Recycling Methods

DOE is currently examining two methods for recycling nuclear fuel that do not isolate plutonium: UREX+ (in effect, a collection of methods) and pyroprocessing. The various separation steps of the UREX+la process were demonstrated at Argonne National Laboratory and reportedly achieved better than 99.999 percent extraction efficiency for U. This test used irradiated fuel from the Cooper nuclear station power plant in Nebraska. The committee understands that a full, integrated project using all the steps has not yet been carried out. A preconceptual design for an AFCF has been completed. In addition, the AFCI has been developing pyrochemical (or pyroprocessing) methods for the treatment of both legacy LWRs and future advanced reactor fuels. While the UREX+ processes work with oxide fuels, pyroprocessing deals with metallic fuels or oxide fuels, with an additional processing step to reduce the oxide to metal. With oxides, "the pyrochemical reduction (PYROX) process is being developed for treatment of Generation IV oxide fuels. High-capacity reduction experiments and improvements in cell design have been completed." (DOE, 2006c, p. 39)

Significant technical problems remain to be solved before either process can be considered to have been successfully demonstrated. One of GNEP's most important goals is showing that TRUs can be consumed, a satisfactory alternative to requiring a means to store them. Special attention must be given to the radiation level of recycled fast reactor fuel and the constraints it will impose during shipment and handling by plant operators. As noted elsewhere, however, it is very unclear whether UREX+ will be able to deal with the high decay heat of fast reactor fuel. Pyroprocessing may better satisfy those needs because it is more suited for remote handling and it can be carried out in much smaller facilities, which could be co-located with fast reactors. It might be best to accelerate the development of pyroprocessing so that it can deal with both water reactor and fast reactor spent fuel.

Beyond these two processes, however, an OECD report (OECD, 2006, p. 11) explains that "given the wide range and flexibility of advanced fuel cycles under development . . . strategic choices will be based on the priorities of policy makers which reflect continuing specific criteria such as characteristics of available waste repositories, access to uranium resources, size of the nuclear power program, and social and economic considerations." The committee has seen no evidence that GNEP has explored those options. Indeed, potential GNEP partners are considering other fuel cycles; these cycles need to be assessed for various projected scenarios of growth in nuclear power production. If the *G* in GNEP is to be taken seriously, the selection of technologies and their allocation among the partners must surely be the result of common agreement.

Advanced Fuels Development

TRU fuels are central and problematic in GNEP technology because "no [reactor] concept can be considered seriously if the appropriate fuels are not defined and proven, i.e., characterized, fabricated, irradiated, and reprocessed" (OECD, 2002, p. 298). A presentation by Frank Goldner[2] and a report by the Nuclear Energy Agency (OECD, 2002) both provide an excellent accounting of how difficult TRU fuel development will be. Goldner pointed out that for oxide fuels, the effect of group TRU on the fabrication process is unknown, as is the effect of lanthanides, and a large-scale fabrication amenable to hot-cell operations must be developed. For metal fuel, he noted that large-scale fabrication without loss of Am must be demonstrated, that fuel-clad interactions at high burn-up must be investigated, and that the effect of lanthanides on fuel cladding chemical interactions must be addressed.

These technical challenges are compounded by the need to repeatedly refabricate the fuel. Although GNEP documents do not specify the number of expected fuel recycles, other sources illustrate the scope of the issue. For example, one report (OECD, 2002, p. 41) says that an

> actinide (or TRU) burner requires a fuel cycle which allows the fuel to be recycled many times. . . . For a maximum burn-up of 25% and recycle intervals of 6 years, it takes 96 years . . . to achieve a hundred fold waste mass reduction.

On page 21 of the same report, it is noted that

> [because] transmutation systems involve unusual fuels with high decay heat and neutron emission . . . a significant effort is required to demonstrate the manufacturability, burn-up behavior, and ability of reprocessing of these fuels. In order to reprocess via pyrochemical methods they would have to tolerate from ten to more than twenty times higher decay heat than those encountered in the pyrochemical reprocessing of fast reactor fuels.

In their presentations to the committee, DOE personnel confirm that no TRU fuel fabrication has been achieved with prototypic materials obtained from actual separation processes and using prototypic fabrication processes suitable for remote operations. DOE reports that it has fabricated mixed actinide fuel successfully and that test fuel pins have been manufactured to permit placement in test reactors. In-reactor testing is in progress at the Phenix fast reactor in France. LWR mixed-oxide fuel pellets containing Np and Pu have been irradiated in the advanced test reactor (ATR). DOE has fabricated and tested inert mixed fuels using magnesium and zirconium oxides, $MgO\text{-}ZrO_2$, as well as microdispersion pellets of $MgO\text{-}ZrO_2\text{-}PuO_2$.[3] DOE is also working on advanced fuels: tristructural isotropic (TRISO), a multilayer micropellet form, for gas-cooled reactors; nitride; sphere-pac; and dispersion fuels. DOE fabricated a variety of test samples of candidate matrix materials and shipped them to the Phenix reactor for irradiation.

For these reasons, the committee regards the development and qualification of advanced reactor fuels as a major technical challenge. Because of the time required to test the fuel

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[2] Frank Goldner, DOE, "GNEP transmutation fuel development," Presentation to the 2007 Regulatory Information Conference on March 15, 2007.

[3] Three members of the committee feel very strongly that the thermal recycling of inert matrix fuel should have priority over GNEP multirecycling in sodium fast reactors; their rationale is summarized in Appendix B. The other committee members believe the concept deserves consideration but are not willing to sponsor it because it may be premature.

through repeated refabrication cycles, achieving a qualified fuel will take many years.

Fast-Neutron Reactors

For its GNEP program, DOE has selected for first consideration the sodium-cooled fast reactor (SFR). Other reactor concepts identified by the Generation IV Technology Roadmap (Chapter 3) and possible GNEP candidates are (1) the lead-cooled fast reactor (LFR), which would also encompass reactors using alloys of lead with other elements; (2) the gas-cooled fast reactor (GFR); (3) the supercritical water-cooled reactor (SCWR); (4) the very-high-temperature reactor (VHTR); and (5) the molten salt reactor (MSR). In its analysis, DOE notes that the SFR and VHTR are the most extensively studied reactors. Because the SFR can perform transmutation effectively and is relatively mature, the GNEP plan has proposed it as the baseline case and presumably the first fast reactor to be built for the overall GNEP program.

SFRs have some important characteristics that make them attractive for development and deployment, including flexibility with respect to mission (e.g., electricity production, breeding of fissile material, or transmutation), high efficiency, and some safety advantages over LWRs, even as they have their own vulnerabilities. Of course reactor safety is a complex issue, and other safety advantages belong to LWRs. The choice of the SFR over other fast reactor options and thermal recycle options (inert matrix fuels for LWRs and deep-burn fuels for VHTRs) should be considered in light of the history of SFRs. There is indeed a several-decade-long history of experience with these reactors dating to the experimental breeder reactor (EBR I), although fewer than 20 have supplied electricity. Accidents involving sodium can be serious, even disastrous, and there have been notable accidents with sodium-cooled reactors. A year after the MONJU reactor went on line in 1994 in Japan, it suffered a sodium leak and has remained closed ever since. The French Superphenix, a 1,200-MWe fast sodium reactor, the largest ever built, had many sodium leaks; it was closed for 2 years in the 1990s and finally shut down altogether in 1998. This plant operated at full capacity for only 174 days. There is no definite announced date for its restart. The outlook for the sodium-cooled fast reactor Fast Flux Test Facility in Hanford, Washington, and the integral fast reactor (IFR) at Idaho Falls is much better. In particular, the IFR demonstrated very high metallic fuel burn-up, is inherently safe, and introduced the important step of electrorefining to pyroprocessing (Hannum, 1997).

Other fast reactors have their own vulnerabilities. Lead-cooled reactors have been used to power Russian submarines, but lead-cooled reactors, especially those using lead-bismuth alloy because of its very low melting point, have suffered from corrosion. Whether some other noncorrosive alloy could be developed is a particularly interesting challenge for research in nuclear science and engineering and illustrates the kind of open problems that the GNEP program faces. Thermal reactor recycle options have lower risk in their reactor technologies but still face substantial transmutation fuel development issues.

The capital costs of sodium-cooled fast reactors have been estimated to be 10 to 50 percent greater than those for LWRs (Bunn et al., 2003). Fast reactors have never been deployed on a commercial scale in the United States, and research has been funded at a low level for a decade or more. This of course must be seen in light of the complicated (and discouraging) history of MONJU and Superphenix, discussed previously. Very little is said in published GNEP documents about the status of safeguards and security, management, and resources. The diffuseness of what brief discussions there are implies that much work lies ahead. The overall portrayal of the state of development of fast reactors, even of the somewhat-more-studied SFRs, suggests that the judicious course of action now would be to study and develop the prototype designs, at most at the engineering scale and presumably with as many options as possible for reactor types and designs kept open at this stage. This suggested direction is inconsistent with the GNEP Strategic Plan (DOE, 2007).

The Generation IV program developed criteria for evaluating reactor technologies (Table 3-1), but to the committee's knowledge, these evaluation criteria were not applied in selecting the SFR. The lack of analogous selection criteria for GNEP represents an important program deficiency because it means the program lacks a basis for choosing among technology options.

GNEP Program Design and Scheduling

The GNEP program emphasizes accelerated schedules. Specifically, the Strategic Plan proposes to proceed to build commercial-scale facilities and "to define a technology roadmap . . . that obviates the need to build engineering scale facilities" (DOE, 2007, p. 7-10). The reasoning behind the accelerated schedule was not clear from the material available to the committee. Indeed, several factors militate against a schedule-driven program design.

Most important is the long-term nature of GNEP and the current state of knowledge about its component parts. For example, the CFTC is expected to be very large—2,000 to 3,000 MT/yr of spent fuel—larger even than the brand-new Japanese reprocessing facility in Rokkashomora, an 800-MT/yr facility. The Strategic Plan indicates that the first construction would be at this large commercial scale, skipping the engineering-scale facility step. However, the Mission Need Statement suggests that the demonstration objectives for the transmutation fuels and separation technologies will require an engineering-scale facility. Moreover, other considerations—technology readiness, fuel cycle plant costs, waste volume and radiotoxicity, vulnerability to diversion or theft, and degree of support by industry, Congress, the U.S. public, and other nations—are at least as important as schedule. They should be assessed and, wherever possible, quantified. If the proposed commitment to UREX+ at a commercial scale turns out to be the course taken by GNEP, then its technology roadmap and business plan (called for in the Strategic Plan) would have to make clear how a facility at that scale, designed for production with one technology, can also serve as a modular test bed for other commercial-scale separation technologies.

The second issue is whether commercial fast reactors would be available to consume the TRUs separated from the spent fuel of LWRs. That is very doubtful, because with present procedures, it will take a very long time to have fast reactors licensed, operating competitively, and accepted commercially as power producers. To make the GNEP closed fuel cycle a reality, fast reactors would have to account for a significant fraction of new construction in the coming decades, a scenario the committee views as completely implausible. These timing, cost, and deployment rate issues need to be addressed.

Third, the Strategic Plan does not discuss whether the demonstration facilities are to be reviewed and approved by the USNRC, although this is implied in the request for EOIs. A position on this issue, reviewed by the USNRC, would be needed before any decisions can be made about GNEP at the Secretarial level.

DOE claims that GNEP is being implemented to save the United States nearly a decade in time and a substantial amount of money. In view of the technical challenges involved, the committee believes that the opposite will likely be true. For example, going ahead with smaller engineering facilities such as a 100- to 200-MT/yr separation facility and a 50- to 100-MWe advanced burner test reactor (ABTR) could save time and money in the long run, for a number of reasons:

1. The engineering facilities might not require USNRC licensing and public hearings. This could save about 3 years for the CFTC and 3-5 years for the ABTR because the commercial fast reactor is anticipated to run into increased opposition.
2. The engineering facilities construction schedule could be shortened by 1 or 2 years because they are smaller.
3. The engineering facilities could cost only about one tenth as much as the full-scale facilities, and the possibility of structuring an acceptable government–industry partnership could be enhanced considerably owing to the smaller cash flow.
4. Engineering facilities can be modified much faster and much more cheaply than large-scale facilities. Also, they would be more appropriate for evaluating other recycling options, while large facilities would have to be more dedicated to production. Separation of spent fuel from LWRs, with appropriate treatment and storage of fission products and high-level wastes as well as recycling of fast reactor fuel, can be demonstrated much sooner.
5. The timing issue between CFTC and ABTR can be resolved by sizing the engineering separation facilities at AFCF so that they can handle the needs of ABTR.
6. The handling, storage, and packaging of fission products will be a much smaller effort for engineering facilities, and the resolution of any remaining problems will not be as difficult at a slower production rate.
7. The time by which commercial-scale reprocessing will be needed depends on variables that cannot now be predicted with any reasonable accuracy. In particular, the actual future deployment rate of nuclear reactors and the actual capacity of the repository would be key variables. Engineering-scale facilities allow sufficient time to pass to reduce some of the uncertainties.

The committee concludes that the case presented by the promoters of GNEP for an accelerated schedule for commercial construction is unwise. In general, it believes that the schedule should be guided by technical progress in the R&D program. If and when technical progress justifies construction of a major facility, it is the very strong view of this committee that an engineering-scale facility would be by far the safest, most effective, least risky course. And, as discussed in Chapter 6, the committee believes that DOE should commit to the construction of a major demonstration or facility only when there is a clear economic, national security, or environmental policy reason for doing so.

Costs

DOE has not yet completed a cost analysis of the alternative pathways of research, development, and deployment (RD&D) that could be pursued to achieve the goals of GNEP. Documents reviewed by the committee indicate that the only costs that have been estimated so far are those for a single path and a single scale, with no allowance for contingencies or uncertainties. While there are large uncertainties in any such effort, it appears to the committee that the costs of alternative pathways must be projected to enable regular updating and revision as more is learned and to evolve an RD&D strategy and the tactics for carrying it out. At what stage, for example, do the next-phase costs justify a decision to continue or to drop work on a process that has just emerged, apparently successful as gauged by scientific criteria, from the first laboratory level? Even at the outset, the full complement of alternative methods should be examined for several projected scenarios of growth in nuclear power production. The amounts of spent fuel, uranium needs, and the shipments of spent fuel or high-level waste to repositories should be determined as well as their volumes, radiotoxicity, and vulnerability to diversion or theft. Costs, benefits, and cash flow, including the fees that would be charged to nuclear electricity consumers, should be estimated as a function of the dates for initial deployment of commercial fast reactors, their capital costs, and their growth rate. The GNEP Strategic

Plan implies that these analyses will be part of a business plan to be provided to the Secretary of Energy in June 2008. The committee does not find it credible that such analyses, with uncertainties, can be accomplished by that time. Even implementing an effort to develop such a plan, which would imply that a credible decision can be made by June 2008, is a matter of concern to the committee.

Furthermore, it seems likely that the GNEP fuel cycle will be more costly to operate than some other options. GNEP objectives are satisfied only with transitional or sustained recycles that require partial or full participation by fast reactors. Fast reactors complicate the selection of advanced fuel cycles since their estimated capital costs are currently expected to be 10-50 percent higher than those of LWRs, according to a Harvard study (Bunn et al., 2003, p. 68). Similarly, a preliminary predecisional economic evaluation (Crozat, 2007, p. 8) shows that the cost of nuclear electricity for an SFR would be $71/MWh compared to $56/MWh for an LWR. If that difference is reasonably accurate, producers of nuclear electricity will balk at adopting fast reactors or subsidizing them through an increase in the Nuclear Waste Fund fee, which is only $1/MWh, for thermal reactors.

Finally, a thorough economic analysis should consider several questions not apparent in the work made available to the committee. For example, closed fuel cycle cost analyses seem to have been carried out without considering temporal coordination of the components of GNEP. DOE apparently fails to recognize the crucial importance of the timing of the required separation and fast reactor facilities as well as of the time required to develop qualified fuel and its recycling in fast reactors. For a number of reasons, fuel cycle costs would rise if the separation facilities are ready but the fast reactor requires many more years to be deployed. One reason is that the TRUs separated from spent fuel would have to be stored in the interim. Moreover, the GNEP program would suffer long delays from time spent qualifying new fuels with each successive recycle. The committee is concerned that the plan to move rapidly to recycling and fast reactors has no economic basis.

International Aspects

One international aspect of the GNEP plan falls within the purview of this study. Because the United States has far less experience with fast reactors and recycling than other nations that are potential partners in the program, it is very important to make the program a truly cooperative one, to allow American scientists and engineers to learn from the previous work of their counterparts, and to shape the research and engineering program to be as efficient a win-win program as possible for all the participating nations. For this reason it would be very desirable as GNEP goes forward to enhance the international collaboration that was initiated with the Generation IV Technology Roadmap. One example is the area of waste separation and fuel preparation. While the proposed GNEP plan names UREX+1A as the most favored and presumably first method it wishes to pursue, other nations appear to favor other methods with which they have more experience. If GNEP is to really be an international collaboration, it is crucial that all the participating nations share the knowledge and experience each accumulates as new technologies evolve.

FINDINGS AND RECOMMENDATIONS

The committee concludes that the rationale for the GNEP program, as expressed through the stated goals, objectives, and criteria, has been unpersuasive. The program is premised on an accelerated deployment strategy that will create significant technical and financial risks by prematurely narrowing the technical options. Moreover, there has been insufficient external input, including independent, thorough peer review of GNEP.

In light of the foregoing, the committee finds as follows:

Finding 4-1. Domestic waste management, security, and fuel supply needs are not adequate to justify early deployment of commercial-scale reprocessing and fast reactor facilities.

Finding 4-2. The state of knowledge surrounding the technologies required for achieving the goals of GNEP is still at an early stage, at best a stage where one can justify beginning to work at an engineering scale. However it seems to the committee that DOE has given more weight to schedule than to conservative economics and technology. To carry out or even initiate efforts on a scale larger than the engineering scale in the next decade would be inconsistent with safe economic and technical practice.

Finding 4-3. The cost of the GNEP program is acknowledged by DOE not to be commercially competitive under present circumstances. There is no economic justification for proceeding with this program at anything approaching commercial scale. Continued research and development are the appropriate level of activity, given the current state of knowledge.

Finding 4-4. Several fuel cycles could potentially form the basis for a recycling system. However none of the cycles proposed, including UREX+ and the sodium fast reactor, is sufficiently reliable and well understood to justify commercial-scale construction at this time.

Finding 4-5. The qualification of multiply-recycled transuranic fuel is far from reaching a stage of demonstrated reliability.

In short, all committee members agree that the GNEP program should not go forward as is and that it should be replaced by a less aggressive research program. Nonetheless, the committee believes that a research program similar to the original AFCI is worth pursuing,[4] for three reasons: to extend uranium resources (when and if this need arises), to greatly reduce the long-lived, high-level actinides in nuclear waste, and to improve the waste forms for disposal of high-level nuclear waste. It may be that the international aspects of GNEP will provide technical benefits to all the participants, and there may even be some benefit in regard to inhibiting proliferation and improving physical protection as well. Such a program should be paced by national needs, taking into account economics, technological readiness, national security, energy security, and other considerations. The committee envisions such a program in the following way:

Recommendation 4-1. DOE should develop and publish detailed technical and economic analyses to explain and describe UREX+1a and fast reactor recycle as well as a range of alternatives. An independent peer review group, as recommended in Chapter 6, should review these analyses. DOE should pursue the development of other separation processes until a fully fact-based comparison can be made and a decision taken on which process or processes could be carried to engineering scale.

Recommendation 4-2. DOE should devote more effort to the qualification of recycled fuel, as it poses a major technical challenge. A fast neutron test facility is needed for fast-spectrum fuel qualification; the committee recommends carrying this out using existing facilities in collaboration with international partners. Parallel development of nonfertile LWR fuel and deep-burn TRISO fuel should be pursued to reduce program risk.

Recommendation 4-3. DOE should compare the technical and financial risks with the potential benefits. Such an analysis should undergo an independent, intensive peer review, as recommended in Chapter 6. Moreover, DOE should identify program benchmarks and report regularly on its attempts to meet them.

Recommendation 4-4. DOE should bring together other appropriate divisions of DOE and other appropriate federal agencies, representatives from industry, and representatives from other nations well before any decisions are made on the technology, in order to create and exploit shared perceptions of the roles of the participants, of the states of the various technologies, and of the commitments and schedules of each of those participants. A research, development, and deployment program can succeed only if all of those participants see themselves as its co-owners and creators.

Recommendation 4-5. DOE should defer the Secretarial decision, now scheduled for 2008, which the committee believes is not credible. Moreover, if it makes this decision in the future, DOE should target construction of new technologies at most at an engineering scale. DOE should commission an independent peer review of the state of knowledge as a prerequisite to any Secretarial decision on future research programs.

In summary, the committee concludes that without first demonstrating relevant technologies at an engineering scale, there are unacceptably high financial and technical risks to commercial-scale construction of a separations facility and a fast burner reactor.

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[4] The dissenting view of two members of the committee is presented in Appendix A.

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Idaho National Laboratory

The U.S. Department of Energy's (DOE's) Office of Nuclear Energy (NE) is the lead program secretarial office (PSO) for the Idaho National Laboratory (INL), and as such, a significant part of DOE's management responsibility and budget is devoted to INL. In FY 2006, for example, the Idaho Facilities Management budget of $99 million accounted for about 19 percent of the total NE budget. The PSO responsibility will continue to be a major one for NE, since to achieve the mission assigned to it by DOE, INL, as a large and aging facility, requires repair and maintenance as well as investment in new capabilities to support the NE program. INL and NE have developed the Ten-Year Site Plan (DOE, 2006a) to guide management of the site facilities to deal with these issues. This chapter presents the committee's conclusions and recommendations regarding the site plan and NE's management of this important asset. The chapter begins with a brief background on the INL and the site and a more detailed discussion of the issues facing the laboratory.

BACKGROUND

The Idaho site was established as a center of nuclear energy research in 1950, when the U.S. Atomic Energy Commission, the predecessor of DOE, obtained land from the U.S. Navy to establish the National Reactor Testing Station. Later, lands were added for use in developing and testing nuclear reactors and related facilities. The site became the first location at which nuclear reactors were built to test the concept of nuclear power as a source of energy for peaceful commercial applications. In 1951, the INL achieved one of the most significant scientific accomplishments of the century—the first use of nuclear fission to produce a usable quantity of electricity at the Experimental Breeder No. 1 (EBR-1). The EBR-1 is now a registered national historical landmark open to the public. In its 57-year history, scientists and engineers at the site designed, constructed, and operated 52 nuclear reactors.

During the 1970s, the site began a succession of changes in mission and program. In 1974 its name changed from the National Reactor Testing Station to the Idaho National Engineering Laboratory (INEL) to reflect its broadened mission into areas like biotechnology, energy and materials research, and conservation and renewable energy. The site name changed again in the spring of 1997 to the Idaho National Engineering and Environmental Laboratory (INEEL), reflecting a major refocusing of the laboratory's work over the long term to engineering applications and environmental solutions for the United States. Thereafter, the site experienced declining support, and much of the activity was directed toward decontamination and disposal of its aging facilities. In July 2002, however, sponsorship of the site was formally transferred to DOE's Office of Nuclear Energy, Science and Technology, which became today's NE. The move to NE supports the nation's expanding nuclear energy initiatives, placing INL at the center of work to develop advanced Generation IV nuclear energy systems; nuclear energy/hydrogen coproduction technology; advanced nuclear energy fuel cycle technologies; and solutions to the Department of Homeland Security's need for a secure national infrastructure. Finally, on February 1, 2005, the site became INL. This change reflects a move back to the laboratory's historic roots in nuclear energy and national security. The vision for INL is to transform its assets and capabilities to become the world's preeminent laboratory for nuclear energy research, development, and demonstration (RD&D) within 10 years.

INL is operated by the Battelle Energy Alliance, LLC (BEA), which consists of Battelle; BWX Technologies, Inc.; Washington Group International; the Electric Power Research Institute; and an alliance of university collaborators, led by the Massachusetts Institute of Technology.

FACILITY ISSUES AT INL

The INL site presents two challenges in the management of its physical facilities: (1) new or rejuvenated facilities are required to support the new mission and vision for the laboratory and (2) NE/INL is the landlord for a large, multitenant site in deteriorating condition. Each of these challenges is described briefly below.

Building Scientific and Engineering Capability

INL's Strategic Plan (DOE, 2006b, p. 3) states its assigned mission as "ensur[ing] the nation's energy security with safe, competitive, and sustainable energy systems and unique homeland security capabilities." The laboratory's vision is that, "within ten years, INL will be the preeminent national and international nuclear energy center with synergistic, world-class, multi-program capabilities and partnerships." To achieve its ambitious goals, INL must attract and retain world-class scientists and engineers in a multiplicity of engineering and scientific disciplines. INL must have a budget to acquire and maintain state-of-the-art facilities and equipment that will be used by researchers of the highest technical competence to lead the development of and sustain nuclear power as a valued energy option nationally and internationally.[1]

To specify the facilities and other capabilities required to realize its vision, INL has prepared three plans, all of which the committee has carefully studied and discussed with NE and INL management.

- The INL Strategic Plan sets out 18 specific objectives that support the vision. Figure 5-1 reproduces the strategy map from the plan that specifies these objectives and the relationship among them. The Strategic Plan has been approved by NE and, according to the Idaho Operations Office (ID), is entirely consistent with the statement of work contained in the operating contract with BEA.
- The Ten-Year Site Plan presents the building-by-building, year-by-year actions recommended to acquire the facilities that INL requires for its mission. Appendix B of the plan lists all of the facilities the laboratory believes it needs for its mission and programs. The Ten-Year Site Plan available to the committee was prepared in June 2006 and is currently being updated to ensure consistency with the INL Business Plan. As a result, the documented track from strategy to business plan to detailed facilities plan is not as tight as it might be. Based on its site visit and discussions with laboratory and ID management, however, the committee concludes that there are no major inconsistencies. Indeed, as a matter of process, the logical progression of plans that INL has developed and is developing present a clear picture of what laboratory management believes is necessary to become "the preeminent, internationally recognized nuclear energy research, development, and demonstration laboratory."
- The INL Business Plan disaggregates the broad objectives into business lines and the laboratory capabilities that distinguish it. While the Business Plan has not yet been made public, the committee discussed it extensively with INL and DOE staff and found it to be consistent with the Ten-Year Site Plan and the Strategic Plan.

It is important to note that the formal INL plan documents were all prepared by INL staff. The committee recognizes and emphasizes the need for NE and ID to fully participate in the planning activity and to eventually agree on what activities are to be carried out and the schedule.

To summarize this sequence of plans, it is useful to distinguish between facilities needed to support the capabilities envisioned for the laboratory and those that would be constructed by programs that might locate at the site, in part because of those capabilities. The latter, for example, might be the reactor or reprocessing demonstration facilities for the Global Nuclear Energy Partnership (GNEP) or the prototype of a Generation IV reactor for process heat applications. Site tenants other than NE might also build facilities there–for example, the Department of Homeland Security or the U.S. Navy. INL will compete with other laboratories for these program facilities.

Given the relatively large fraction of a PSO's budget that must be devoted to landlord-related activities at a site,[2] it is most important to closely couple the project-related facilities and those needed to achieve world-class status for the laboratory and attract capable personnel. Advanced computing capabilities, or highly technical facilities such as test reactors or postirradiation examination laboratories and hot shops are examples. These facilities are very expensive to obtain and keep operational and up to date, so there is a continuing burden on the PSO—first, for a large initial investment and then for the expense of long-term support. Thus the PSO needs to utilize a strategy of making sure facilities to establish world-class capabilities closely overlap with those needed for specific projects. This suggests that investments in those types of capabilities and facilities need to be paced and scheduled so they match project needs, and the capabilities provided should be developed based on specifications that satisfy specific project needs.

As an example, NE has indicated a potential need for major computation and simulation capabilities. This is analogous to the need for similar capability in DOE's National Nuclear Security Administration (NNSA) Weapons Stockpile Stewardship Program. The needs of the specific weapons simulation and modeling projects were first established to define the minimum capability needed for those projects.

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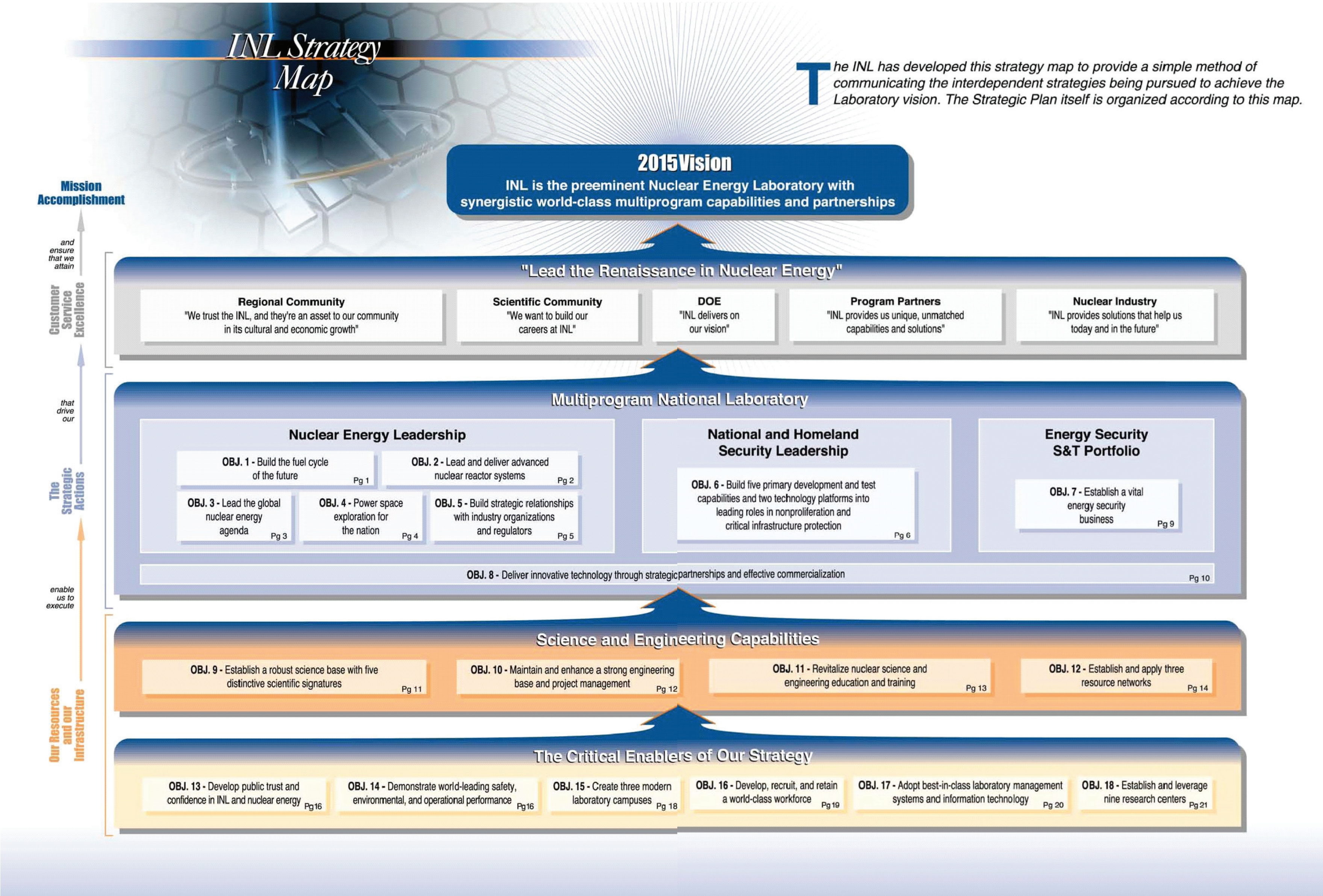
[1] INL also intends to build capability to support the Department of Homeland Security. According to materials supplied to the committee by DOE on November 28, 2006, National and Homeland Security funding in FY 2006 was 15 percent ($104 million) of the total INL business volume, $686 million. However, this report focuses on the DOE program at the laboratory.

[2] Informal discussions with DOE's National Nuclear Security Administration (NNSA) personnel associated with managing their laboratories indicated this could range up to 50 percent. In general, the NNSA laboratories are in a more stable state than INL and require less "landlord" funding. This is because of the very high proportion of aging and obsolete facilities at INL to be eliminated and the many new facilities to be added.



INL Strategy Map

The INL has developed this strategy map to provide a simple method of communicating the interdependent strategies being pursued to achieve the Laboratory vision. The Strategic Plan itself is organized according to this map.

2015Vision

INL is the preeminent Nuclear Energy Laboratory with synergistic world-class multiprogram capabilities and partnerships

"Lead the Renaissance in Nuclear Energy"

Regional Community "We trust the INL, and they're an asset to our community in its cultural and economic growth"

Scientific Community "We want to build our careers at INL"

DOE "INL delivers on our vision"

Program Partners "INL provides us unique, unmatched capabilities and solutions"

Nuclear Industry "INL provides solutions that help us today and in the future"

Multiprogram National Laboratory

Nuclear Energy Leadership

OBJ. 1 - Build the fuel cycle of the future Pg 1

OBJ. 2 - Lead and deliver advanced nuclear reactor systems Pg 2

OBJ. 3 - Lead the global nuclear energy agenda Pg 3

OBJ. 4 - Power space exploration for the nation Pg 4

OBJ. 5 - Build strategic relationships with industry organizations and regulators Pg 5

National and Homeland Security Leadership

OBJ. 6 - Build five primary development and test capabilities and two technology platforms into leading roles in nonproliferation and critical infrastructure protection Pg 6

Energy Security S&T Portfolio

OBJ. 7 - Establish a vital energy security business Pg 9

OBJ. 8 - Deliver innovative technology through strategic partnerships and effective commercialization Pg 10

Science and Engineering Capabilities

OBJ. 9 - Establish a robust science base with five distinctive scientific signatures Pg 11

OBJ. 10 - Maintain and enhance a strong engineering base and project management Pg 12

OBJ. 11 - Revitalize nuclear science and engineering education and training Pg 13

OBJ. 12 - Establish and apply three resource networks Pg 14

The Critical Enablers of Our Strategy

OBJ. 13 - Develop public trust and confidence in INL and nuclear energy Pg16

OBJ. 14 - Demonstrate world-leading safety, environmental, and operational performance Pg16

OBJ. 15 - Create three modern laboratory campuses Pg 18

OBJ. 16 - Develop, recruit, and retain a world-class workforce Pg 19

OBJ. 17 - Adopt best-in-class laboratory management systems and information technology Pg 20

OBJ. 18 - Establish and leverage nine research centers Pg 21

FIGURE 5-1 INL strategy map provides a simple method of communicating the interdependent strategies being pursued to achieve its vision. The Strategic Plan is organized according to this map. SOURCE: DOE (2006b).

This then became the target for the computing facilities and capability to be provided, and funding was sought on this basis. In addition, as the technical programs were further developed and refined, the additional computational capability was defined and used to create a funding profile over several years. This approach provides a credible metric for infrastructure investments, for projecting future needs, and for replanning or adjustments as time passes and actual budgets and technology needs change (DOE, 2007a).

Whether or not the site becomes home to any of these program facilities, however, the INL facilities should be configured to efficiently support the laboratory's ongoing mission. The laboratory plan would group these facilities into three campuses:

- The Science and Technology Campus would consolidate a wide variety of scientists and research facilities into a single area in Idaho Falls. Presently, much of the INL scientific and engineering staff is scattered among 36 buildings in Idaho Falls or work at the site itself. Most of INL's scientific and engineering staff would be located at the new campus, and their research would cover all of INL's lines of business. The new campus would house administrative offices as well as research laboratories.
- The Reactor Technology Complex would focus on testing of advanced and proliferation-resistant fuels for NE, the U.S. Navy, and other users. Nearly half of the buildings at this site were built before 1967. The new Reactor Technology Complex would be built around the existing Advanced Test Reactor (ATR), which would have an upgraded mission capability to support an extended life.
- The Material and Fuels Complex would be the center of research on new reactor fuels, the nuclear fuel cycle, and related materials. It would incorporate and modernize a number of existing facilities for this purpose. Over half of the existing buildings at this site are more than 30 years old.

BEA, the operating contractor, expects to build or upgrade 400,000 ft^2 of space in implementing these plans over the next 10 years.

Managing Site Infrastructure

BEA is also responsible for management of the overall site and its infrastructure. As noted earlier, the site infrastructure is old and deteriorating. About 45 percent of it is under the jurisdiction of DOE's Office of Environmental Management, which is responsible for decontamination, decommissioning, and disposal of assets no longer required for INL's present mission. NE is responsible for maintaining or closing the balance. As a first goal, INL/BEA is committed to eliminating 1.1 million ft^2 of existing space during the 10-year horizon of the site plan. The result would be to reduce the space under NE active stewardship at the site by about one-third from the present 3.2 million ft^2.

A second goal is to maintain the remaining infrastructure in good condition. DOE employs several metrics to assess the condition of infrastructure. At INL, these metrics rank the overall condition of the facilities as adequate and the overall utilization as good. However, the deferred maintenance backlog is high in relation to the value of the assets involved. In FY 2004 the ratio stood at 11.8 percent for INL's nonprogrammatic assets; the DOE target for this ratio is 2 to 4 percent (see Table 5-1). NNSA also maintains a target ratio of roughly 2 to 4 percent for its laboratories but has struggled to achieve this.

ASSESSMENT OF THE TEN-YEAR PLAN

The Ten-Year Site Plan recommends a series of investments to bring the site into compliance with the INL vision and DOE's goals for infrastructure management. While the committee has not attempted to analyze the Ten-Year Plan in detail, it has been able to test it for reasonableness in reaching both objectives.

Building Scientific and Engineering Capability

INL's plans for building the scientific and engineering capability needed to realize its vision are logically constructed and link broad visions with clear and consistent objectives. The Business Plan and the Ten-Year Site Plan, while still in flux, appear systematically to translate the strategy into specific capabilities and facilities plans. The committee has also

TABLE 5-1 Comparison of Multipurpose Laboratory Infrastructure Conditions and Uses

Laboratory	Asset Utilization Index	Asset Condition Index	Deferred Maintenance Ratio (%)
Idaho National Laboratory	0.95	0.92	11.8
Argonne National Laboratory	0.96	0.96	2.0
Brookhaven National Laboratory	0.97	0.83	1.9
Lawrence Berkeley National Laboratory	0.97	0.92	2.0
Oak Ridge National Laboratory	0.98	0.92	2.0

SOURCE: DOE (2006c).

reviewed the work statement for the operating contractor, BEA, and finds that the planning is consistent with the work statement. Its interviews with laboratory personnel, ID, and NE have not revealed any disagreement with this hierarchy of plans, at least conceptually.

The committee has also examined these plans for consistency with the research program the committee recommends elsewhere in this report. The Business Plan lists "distinguishing capabilities" and "distinguishing performance" for INL. The committee reviewed these capabilities and performances for consistency with the specific programmatic plans. Overall, it concludes that the high-level objectives stated in the Ten-Year Site Plan are generally consistent with the program objectives. However, the committee emphasizes the importance of directly attaching facilities' capabilities to specific programs. Tighter coupling is needed for two reasons. First, particularly in view of tight budgets for the foreseeable future, NE needs to ensure facilities at INL do not duplicate those at other laboratories. Second, close attention is needed to ensure facility dollars at INL are closely coupled to specific programs and projects and the requirements are derived from the needs of the program/project, in terms of both capability and timing.

Managing the Infrastructure

As noted above, DOE measures several aspects of infrastructure condition and use. The committee has compared the metrics for INL with those of other multipurpose laboratories, as shown in Table 5-1.

It appears from these data that the metrics for the utilization and condition of INL's assets are within a range comparable to that of other national laboratories. However, deferred maintenance is clearly out of line. The Ten-Year Site Plan estimates that an investment in maintenance of $150 million to $175 million per year would bring deferred maintenance within the high end of the target range by 2014. While the committee has not made an independent estimate, the high level of deferred maintenance at INL would seem to require significant investments to achieve parity with other DOE assets.

It appears the ratio is high at INL because the facility tends to be underfunded: There are many projects seeking funding, and maintenance work has been deferred to support more pressing issues. Other PSOs—for example, NNSA—have had similar difficulties and have evolved approaches to reduce the balance, including limited periods of specific investment in facilities to obtain or reestablish needed levels of performance. In addition, activities at other national laboratories have been graded so that maintenance in direct support of facilities critical to particular programs is ensured; maintenance of needed, but not program-critical, facilities is funded next (an example is fire protection), and other facilities receive the lowest priority.

Resources Available to Implement the Plan

The Idaho Facilities Management Account requested $95.3 million in FY 2007 for support of the INL site (DOE, 2007b). The FY 2008 request is $104.7 million. This account appears to be the chief source of funding for infrastructure support, although another $129 million is requested in FY 2008 for safety, security, and the management of radiological facilities. The FY 2007 request is shown in Table 5-2.

This account contains funds for building capacity and for infrastructure management. In FY 2007, it contains no new capital expenditures or general plant projects funding.

Other funds come through the indirect charge INL makes on program funding. The FY 2007 budget for INL is shown in Table 5-3.

Of these, only the space cost looks much like a facility charge. INL's laboratory-directed research and development (LDRD) is in the mid-range of the national labs, with the NNSA labs leading the pack (see Table 5-4). However, the committee considers that INL is a lead technology laboratory, more like the NNSA lead technology laboratories (Los Alamos National Laboratory, Sandia National Laboratories, Lawrence Livermore National Laboratory) than the more general-purpose DOE laboratories such as Oak Ridge National Laboratory or Argonne National Laboratory. The percentage of total funding spent on LDRD at the NNSA laboratories is about twice that at INL, and the total funding allocated to LDRD at these laboratories is 4.5 to 6 times more. The committee also notes that INL is just starting a steep climb to establish its prominence and capability as the

TABLE 5-2 FY 2007 Request for the Idaho Facilities Management Account (millions of dollars)

Account	MFC	RTC	Sitewide	ATR Life Extension
Infrastructure	29.7	11.6	15.9	18.5
Capital projects	0.6	5.0	2.3	
Operating projects	0.2	0	0.4	0
Capital equipment[a]	0.3	0.2	2.4	1.4

NOTE: ATR, Advanced Test Reactor; MFC, Material Fuels Complex; RTC, Reactor Technology Center.
[a] Except for the ATR life extension, all capital equipment funding in FY 2007 is carryover from FY 2006.
SOURCE: Materials supplied to the committee by DOE on November 28, 2006.

TABLE 5-3 FY 2007 Budget for the Idaho National Laboratory (millions of dollars)

Account	Funding	Description
General and administrative	131.9	Primarily management systems costs and fixed costs like fees, taxes, and insurance
Laboratory-directed research and development	21.1	Long-term research initiatives
Program development	9.2	Business line development
Organization management	49.7	Management overhead
Space	44.5	Common use facilities and space management
Common support	23.8	Infrastructure services line buses, cafeteria, fire, and landfill

SOURCE: Materials supplied to the committee by DOE on November 28, 2006

TABLE 5-4 Reported FY 2006 Overall Laboratory Costs and LDRD Costs at Participating DOE Laboratories (millions of dollars)

Laboratory	LDRD Costs	Total Laboratory Costs	LDRD Fraction (%)	Laboratory WFO Costs
Argonne National Laboratory	22.9	495.9	4.62	126.5
Brookhaven National Laboratory	11.1	420.0	2.64	75.8
Idaho National Laboratory	21.1	685.7	3.08	305.9
Los Alamos National Laboratory	125.4	2,022.0	6.20	254.1
Lawrence Berkeley National Laboratory	18.6	485.6	3.84	119.8
Lawrence Livermore National Laboratory	93.9	1,418.9	6.61	329.7
Oak Ridge National Laboratory	24.2	879.3	2.75	228.2
Pacific Northwest National Laboratory	27.6	660.2	4.17	243.7
Sandia National Laboratories	131.7	2,077.2	6.34	764.9

NOTE: LDRD, laboratory-directed research and development; WFO, work for others.
SOURCE: DOE (2006d).

lead laboratory for nuclear technology in the DOE complex, while the NNSA laboratories are already established. Since LDRD funds are so important for attracting and motivating the kind of people needed to achieve a strong capability, NE should consider expanding the availability of LDRD funds at INL.

INL is attempting to set up ATR as a user facility. This would produce some revenue, but only at an incremental cost level.

FINDINGS AND RECOMMENDATIONS

The committee finds as follows:

Finding 5-1. Overall the committee considers that INL is an important facility and provides important capabilities to support NE's mission, which is to use nuclear technology to provide the United States with safe, secure, environmentally responsible, and affordable energy. INL has developed a strategic vision and a long-term (10 years) plan for this purpose.

Finding 5-2. The funding being provided to INL by NE is substantially less than what is needed to be consistent with INL's current vision. INL has been further short-changed in that it has not received sufficient funding to stay even with the other national laboratories in terms of maintenance and funding of known efforts, which include commitments to the state of Idaho for the cleanup of certain state facilities. NE should consider expanding the availability of LDRD funding at INL; the target range should be competitive with or greater than that of the NNSA lead technology laboratories, 6-8 percent.

Finding 5-3. The NE/INL budgeting system and the budget documents themselves are opaque and hard to understand. It is difficult to trace budget amounts to particular projects and programs and to specific activities within the INL subbudget. The committee observes that the de facto budget process seems to be that INL and the direct overseers at ID and NE come up with a list of tasks they consider to be desirable or needed in a given year, and then NE senior management allocates some fraction of the overall NE budget that remains after allocations are made to other high-priority programs. The sum assigned to the INL facilities budget is then distributed over the original task list so that the highest priority tasks are funded and the others are postponed.

Finding 5-4. A much more transparent, structured, and jointly supported (by NE, ID, and INL-BEA) planning and budgeting process is needed. This will ensure that all parties are in full agreement about the long-term plan and that budget decisions are made more carefully and on a more balanced basis. It will also enhance the credibility of the budget and its bases to reviewers in Congress and the Office of Management and Budget and will, in the long term, provide more stable and effective funding for the agreed-on plan.

Finding 5-5. NE has limited experience of being the PSO for a national laboratory. As such, its procedures for this responsibility are not yet well defined. NE could benefit from discussions with other organizations at DOE (e.g., the Office of Science and NNSA) with longer-standing, more mature PSO efforts.

The committee's recommendations fall into three broad categories: improve the NE organization to better discharge its responsibility as the lead PSO for INL; establish a joint baseline vision and plan for INL; and modify the form of the INL facilities budget documentation to improve credibility and usefulness.

NE as the Lead Program Secretarial Office for INL

Recommendation 5-1. NE should set up and document a process for evaluating alternative approaches for accomplishing NE-sponsored activities, assigning the tasks appropriately, and avoiding duplication. For example, although INL is identified as the lead laboratory for nuclear-energy-related tasks, this does not mean that all such work is to be assigned to INL. Rather, NE should take into account the existing skills and facilities and make best use of available and new resources. The basis for the decision should be clear to INL and the other laboratories and facilities.

Recommendation 5-2. NE should set up a formal, high-level working group jointly with ID and INL (BEA). Consideration should be given to also having one or more knowledgeable outsiders participate on an ongoing basis to provide a wider perspective. This joint group would review the long-term project plan recommended below and serve as a forum for discussion and resolution of issues, such as changes to the plan and the best way to make the inevitable adjustments that will be needed. It will also be a ready source of informal, expert advice to NE senior management on INL facilities management.

Recommendation 5-3. NE should meet with DOE and NNSA organizations that are PSOs for other laboratories to review and discuss their practices and processes. Based on the lessons they learned, it should develop and document its own internal processes and procedures for discharging its responsibilities as the PSO for INL.

INL Facilities Baseline, Vision and Plan

Recommendation 5-4. NE, ID, and INL (BEA) should establish an agreed-on multiyear, resource-loaded, high-level schedule and plan for the INL facilities, such as the Primavera Project Planner (P3). This plan should establish the level of funding needed from NE, recognizing the contributions expected from other agencies that use the site and funding from projects located at INL. It should be based on funding levels that are practical for the foreseeable future, not a wish list. It should be used for developing an annual budget for the INL facilities and should be updated annually as part of the budget cycle. This will support directly assessing the effect of annual budget changes and answering questions on the impact of additional money or the effect of shortfalls.

Recommendation 5-5. The initial version of this plan should be based on the current BEA baseline assessment, vision, and supporting Ten-Year Site Plan. This does not mean that the committee gives the BEA plan and documents across-the-board endorsement. Rather, these documents appear to contain the most complete and up-to-date information available, and their structure is such that there is reasonably good traceability from objective to needed funding. They should pay attention to the connections between major programs and facilities. In particular, the capability and timing of facilities should be tightly tied to the program needs.

Recommendation 5-6. For INL to accomplish its expected mission, a number of large, sophisticated, and unique facilities will be needed. These could include large hot cells and associated laboratories for postirradiation examination of materials and test reactors such as the ATR. The intent is for INL to have magnet facilities attracting researchers and industrial users. For these facilities to attract users, the full costs cannot be charged, and the user would pay only the justified incremental costs associated with use. This arrangement is typical of user facilities in the Office of Science laboratories. The result is that the user facilities must also receive dedicated funding from the PSO. NE and INL have begun work to make the ATR at INL into such a user facility. The committee endorses this approach for ATR and recommends as follows:

- NE should promptly address the inclusion of needed funding to support the base costs of the ATR in the INL facilities funding and develop an equitable basis for allocating justified user costs over the longer term.
- As they develop a long-term plan for INL facilities, NE and INL should consider hosting other key capabilities—say, hot cells—as user facilities. Any such user facilities should be separately identified.
- NE and INL should include LRDR tasks associated with establishing and strengthening INL personnel capability in the INL baseline, vision and plan.

Form and Content of the INL Facilities Budget Documentation

Recommendation 5-7. NE, ID, and INL (BEA) should improve the form and content of the INL facilities budget documentation. Currently, a wide variety of documents need to be reviewed to understand the budget and its basis, and even then discussions with the main participants are necessary. NE, ID, and INL (BEA) need to decide on the final form for the budget documentation, and both the Office of Science and NNSA documentation would be worthy of emulation. The improved budget documentation should have the following attributes:

- Budget items should be readily traceable to specific items in the overall plan and schedule.
- Big-ticket items that affect the budgets—for example, the resolution of cleanup commitments with fixed future end dates—should be explicitly identified and accounted for in funding plans.
- The impact of budget amounts on maintenance items should be documented. For example, it appears maintenance is chronically underfunded, the maintenance backlog is rising, and the backlog appears to be out of line with that of other comparable national laboratories. Data that allow discerning trends and drawing comparisons need to be provided or clearly referenced in the budget. Traceability to a living, readily updated overall plan and schedule will also help in this regard.
- The amount and sources of indirect funding at INL used to support facilities-related expenditures should be clarified.
- Work funded by government agencies other than NE should be explicitly accounted for, along with the attendant impacts on resources needed to maintain and enhance INL facilities. The costs of managing for multiple users should also be shown.

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6

Program Priorities, Balance, and Oversight

The committee's statement of task requires it to evaluate the process for establishing program priorities and oversight for DOE's nuclear energy programs, including the method for determining the relative distribution of budgetary resources. Managing budget priorities is a challenging task for DOE's Office of Nuclear Energy (NE), particularly because of the disconnect between the annual federal budget process and the long-term nature of NE's research programs. The committee's evaluation of NE's programs stresses the need for managing programs consistently over time. For example, the committee has recommended approaches for the Generation IV reactor development program, the Advanced Fuel Cycle Initiative (AFCI), and the fast reactor fuels qualification program that aim at creating solid information for decisions on technology selection that may be taken 5 to 10 years from now. NE is the program secretarial office (PSO) for the Idaho National Laboratory (INL) site, and that responsibility requires a steady effort over a similar period of time.

As noted in Chapter 1, however, the NE budget has experienced wide swings in both size and content over the past 10 years. The nature of the federal budget process is at least partly the cause of this problem. The committee reviewed the current NE budget process for annually allocating limited resources among programs. Like the federal budget process in general, the NE process tends to subordinate long-term commitments to more immediate needs. The committee is under no illusion that the pressures created by this annual process will abate. For that very reason, however, it is convinced that NE should set up an internal system to allocate resources consistently over time and among programs. Such a system should have the following characteristics:

- Be robust with respect to policy and technological variables—that is, offer timely science and technology options that will be useful across a range of possible futures and research outcomes.
- Possess a rigorous and independent evaluation process that reexamines the program as policy and technological variables change and focuses available resources on the most promising options.
- Maintain continuity of programs to achieve the desired goals, thereby supporting the bases on which the nuclear industry plans its direction.
- Commit to the construction of a major demonstration or facility only when there is a clear economic, national security, or environmental policy reason for doing so.
- Limit the NE role to activities that the private sector cannot reasonably be expected to undertake.
- Plan to live within a reasonable federal budget constraint, recognizing that some fluctuation is inevitable but that major facility construction should not crowd out ongoing research activities.
- Maintain a balance among programs with near-term and longer-term research objectives.
- Take into account the risks and opportunities created by technological developments in other countries.

In this chapter the committee proposes the major priorities among NE's programs, suggests how they might be applied in a constrained budget environment, and describes the elements of a system to provide independent oversight of the NE research portfolio.

PROGRAM PRIORITIES

To assess the overall priorities among NE programs, the committee examined their relevance to NE's mission goals in light of the committee's recommendations for each program. The mission goals, as developed in Chapter 1, are these:

- Assist the nuclear industry in providing for the safe, secure, and effective operation of nuclear power plants already in service, the anticipated growth in the next generation of light water reactors, and associated fuel cycle facilities.
- Provide for nuclear power at a cost that will be competitive with other energy sources over time.

- Support a safe and publicly acceptable domestic waste management system, including options for long-term disposal of the related waste forms. (The principal DOE responsibility for this function lies with its Office of Civilian Radioactive Waste Management.)
- Provide for effective proliferation resistance and physical protection of nuclear energy systems, both at home and in support of international nonproliferation and nuclear security regimes.
- Create economical and environmentally acceptable nuclear power options for assuring long-term nonelectric energy supplies while displacing insecure and polluting energy sources; such options include electricity production, hydrogen production, process heat, and water desalinization.

Each chapter in this report contains findings on program design and budget implications. In summary, the committee's programmatic recommendations that have budget consequences are these:

- *Nuclear Power 2010.* DOE should augment this program to ensure the timely and cost effective deployment of the first new reactor plants. Of particular importance is the need to address industrial and human resource infrastructure issues. The NP 2010 program will end upon completion of U.S. Nuclear Regulatory Commission (USNRC) certification and finalization of the AP1000 and ESBWR designs, issuance of the first combined construction and operating licenses (COLs) to the lead companies in the Nustart and Dominion consortia, and implementation of the standby support and loan guarantee financial incentives of the Energy Policy Act of 2005 (EPAct05).
- *Research in support of the commercial fleet.* The committee does not suggest a large federal research program, because most of this research should be industry-supported. However, some specific projects have sufficient public benefit to warrant federal funding.
- *University infrastructure support.* A major buildup in nuclear energy production, research, and development requires expanding university capabilities to educate a growing number of young professionals and scientists in the relevant areas. DOE should maintain programs specifically designed to support university research reactors and educational infrastructure. The American Nuclear Society has recommended that NE should retain a separate funding line for university programs in the Energy and Water Appropriations Bill for FY 2007 and future years. The committee agrees with that conclusion and urges that NE fund a separate program as outlined in EPAct05.
- *Generation IV.* This is principally the Next Generation Nuclear Power (NGNP) program aimed at electricity and process heat applications, such as hydrogen production (as in the Nuclear Hydrogen Initiative program) and desalinization. It is designed so that by 2012 NGNP can be evaluated against other technologies directed toward similar outcomes. As a second priority, a focus on fast reactors is appropriate. The committee would like to see NE sustain a balanced R&D portfolio in these advanced reactor development areas.
- *AFCI.* This is the AFCI program with some modifications as called for by the committee in Chapter 4 but not including construction of large demonstration facilities or commercial-scale facilities.
- *Major fuel cycle facilities.* The committee recognizes that major engineering and/or commercial-scale facilities will ultimately be required to test and deploy fuel cycle technology. However, it concludes that the Global Nuclear Energy Partnership (GNEP) has not made a persuasive case for the early deployment of such facilities.
- *Idaho National Laboratory.* NE has PSO responsibility for INL, and this responsibility has a large impact on the NE budget.

Based on its understanding of NE's mission and the criteria for management of NE research programs, the committee views the relative priority of these programs as presented in Table 6-1.

PROGRAM BALANCE

The committee has evaluated the overall balance among these programs within the scope of available resources. The committee cannot, of course, predict what budgetary resources will be available in future years. However, the budgets for NP 2010, Generation IV, NHI, and Idaho Facilities Management totaled between \$220 million and \$240 million from FY 2005 to FY 2007. The GNEP/AFCI budget has been rising, and the university infrastructure budget—while not in the FY 2008 NE budget request—received appropriations of \$16 million to \$26 million (Box 6-1). If these trends persist, they suggest an overall NE research budget of about \$700 million annually. The committee has used these parameters as a basis for evaluating program balance in a constrained budget environment. The committee's judgments are presented in Table 6-2.

PROGRAM OVERSIGHT

Recommendation 6.1. As a counterbalance to the short-term nature of the federal budget process, NE should adopt an oversight process for evaluating the adequacy of program plans, assessing progress against these plans, and adjusting resource allocations as planned decision points are reached.

The oversight process should have the following attributes:

- *Strategic.* The focus of the process should be overall program progress in the light of NE's overarching goals and balancing resources across programs. It does not take the place of detailed technical and peer review, nor should it.

TABLE 6-1 Relative Priorities of NE R&D Programs and INL

Priority	Program	Comments
High	NP 2010 and research in support of the commercial fleet	Unless the commercial fleet of LWRs grows, nuclear power will be a diminishing energy resource for the United States and there will be little need for all of NE's longer term research programs. NP 2010 and selected commercial research projects should be fully funded as a matter of highest priority.
High	University infrastructure support	University support is largely a government responsibility in the committee's view.
Medium	Generation IV, NGNP, NHI, and AFCI	These are all longer term research programs with defined downselect decision points that could change the course of research as more is learned. These programs will perform best if research budgets are consistent with steady progress toward these decision points.
Medium	INL programs to reduce deferred maintenance and to build a capacity that will sustain a useful scientific capability	These activities require steady progress but can evolve over a reasonable time. Construction of user facilities and/or program facilities should be carefully evaluated on a case-by-case basis to validate the need and to avoid duplication with facilities at other national laboratories.
Low	Major facility deployment (large demonstration plants or initial commercial plants) in GNEP	U.S. industry does not urgently require the construction of such facilities.

NOTE: LWR, light water reactor.

BOX 6-1 University Programs[1]

The DOE-NE university program has been in existence for almost 10 years in support of university reactor basic research, undergraduate scholarships, graduate fellowships as well as university research reactor fuel assistance and instrumentation and infrastructure. In August 2005, EPAct05 authorized its continuance and expansion; however, DOE discontinued the program. The Congress appropriated funds over this DOE elimination in FY 2006 and FY 2007. The American Nuclear Society (ANS) appointed a special committee of individuals from industry, the national laboratories, and universities and carried out an in-depth review of the program in the fall of 2006.

One of the major conclusions of the ANS review and report is that a clear national interest exists for the federal government, primarily DOE, to continue and expand its stewardship of the U.S. nuclear science and engineering (NSE) education enterprise. Simply put, university-based NSE programs can continue to be leaders in the field only if there is an active, identifiable university program at DOE. The ANS report recommended that NE retain a separate funding line for university programs in the Energy and Water Appropriations Bill for FY 2007 as well as future years. The committee agrees with that conclusion and urges that NE should fund a separate program, as outlined in EPAct05.

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[1] Information based on American Nuclear Society, Nuclear's Human Element: A Report of the ANS Special Committee on Federal Investment in Nuclear Education, 2006.

For this reason, the process should be in the hands of individuals with high-level research, government, and industry experience.

- *Independent.* Because it is strategic, the oversight process should be designed to serve not just NE but also DOE management. Ideally, the Office of Management and Budget and the Congress would be willing to give considerable weight to the information produced by the process. Therefore, the composition and organizational position of the oversight body should reflect a substantial degree of independence. A clear policy for handling conflicts of interest and ensuring balance among the members will be essential.
- *Transparent.* The topics studied by the oversight body and the reports it issues should be made public.

TABLE 6-2 Budget Recommendations for NE R&D Programs and INL

Program	Budget Issue	Recommended Action
NP 2010	Current funding is as much as a third less than needed to maintain program momentum, and funding is likely to be needed for longer than the current program plan estimates.	Although increases in the NP 2010 budget are likely, they do not make up a large fraction of the total NE funding. The NP 2010 requirements should be fully supported.
Research in support of the commercial fleet	Not presently funded, although some DOE support of continued research on existing and new reactors in the commercial fleet is appropriate.	DOE should provide cost sharing in the 20 percent range and support user facilities at incremental cost. These elements of the program should be fully funded when the NP 2010 licensing and design completion efforts come to an end.
University infrastructure support	Funding at (recent) FY 2006 appropriated levels is appropriate.	DOE should include this program explicitly in its budget at the levels authorized by EPAct05 (see Box 6-1).
Generation IV and NHI	Current funding is considerably less than that required to meet stated goals, especially for NGNP. Full funding would mean ~$50 million to 60 million more annually.	The program requires predictable and steady funding, but its goals can be more modest and its timetables stretched. A revised program can be conducted within levels recently appropriated for Generation IV and for SFR-related R&D under GNEP.
AFCI and fast reactor fuel qualification	Recent proposals for GNEP have substantially increased the NE budget.	The committee recommends a more modest and longer-term program of applied research and engineering, including new research-scale experimental capabilities as envisioned for the Advanced Fuel Cycle Facility, although the design of the program would differ somewhat from the AFCI program before GNEP.
INL programs to reduce deferred maintenance and to build a capacity that will sustain a useful scientific capability	Current budgets for INL deferred maintenance and other landlord demands are substantially below optimal levels. Using the Ten-Year Site Plan as a basis, the shortfall could be on the order of $50 million per year. The capacity-building strategy at INL has not yet been agreed on or costed out.	It is essential to provide reasonable and predictable funding to support the PSO responsibility for site condition and capacity building. However, the funding required for managing the site infrastructure can be reduced by giving priority to mission-critical facilities. Both infrastructure support and capacity-building measures can be supplemented by indirect cost and contributions from non-NE programs (such as the large U.S. Department of Homeland Security program at INL). Finally, care should be taken to avoid duplication of capabilities at other national laboratories. A strategic plan based on these concepts is needed to establish the target funding level for the Idaho Facilities Management account.
Major facility deployment	The current GNEP concept envisions major demonstration or precommercial facilities. The Generation IV program, if successful, could require an NGNP demonstration plant.	These facilities should be funded only when clearly needed, and then as increases to the NE base budget.

The senior advisory body for NE has been the Nuclear Energy Research Advisory Committee (NERAC). This review committee was formed about 10 years ago when the nuclear energy research budget began to grow beyond facilities and infrastructure support. From 1998 through 2005, NERAC gave NE advice on a range of matters, among them:

- Infrastructure for nuclear energy research,
- The education of future nuclear engineers,
- The Generation IV Technology Roadmap,
- Assessment of technology for advanced nuclear processes,
- Review of the Next-Generation Nuclear Plant (NGNP), and
- A roadmap for deploying new nuclear power plants in the United States.

In recent years, however, NERAC has not been effective, for reasons that are not entirely clear. It was largely inactive during the year or so when the director of NE left, the directorship of the Office was elevated to the assistant secretary level, and the new assistant secretary was in place. The upshot was that neither NERAC nor any other external body was much consulted for strategic oversight or advice during a time when the NE program was undergoing major change.

NERAC seems the obvious starting point for reestablishing oversight of the NE programs. In the committee's opinion, the key will be to ensure NERAC's independence and transparency, and allow it to focus on important strategic issues. The committee has not attempted to recommend for NERAC a specific oversight capability, but the oversight body has in mind that it would:

- Encourage objectivity by recognizing that knowledgeable persons have different points of view and that balance is therefore best achieved by diversifying the membership of the oversight body.
- Avoid conflicts of interest by requiring public disclosure of members' connections with study sponsors or organizations likely to be affected by study results. Persons directly funded by sponsors are rarely appointed to such bodies.
- Ensure transparency by requiring that both the statement of task and the final report for each project are routinely made public in a timely fashion.

APPENDIXES

A

Minority Opinion: Dissenting Statement of Gilinsky and Macfarlane

These remarks concentrate on the Global Nuclear Energy Partnership (GNEP), the most prominent U.S. Department of Energy (DOE) R&D program addressed in the committee's report. The committee report criticizes DOE's excessive eagerness to start building commercial-scale facilities when the technologies it relies on are still unproven.

However, the committee does not question the desirability of a substantial "closed" fuel cycle R&D program; moreover, it recommends a reprocessing and fast reactor R&D program along the lines of GNEP's predecessor, the Advanced Fuel Cycle Initiative (AFCI). Nor does the committee question whether DOE and its laboratories should have a key role in developing the new fuel cycle technologies, despite DOE's poor track record in developing commercial technologies.

Our own views on these issues may be summarized as follows: (1) commercial reprocessing and recycle will not help solve resource or waste or proliferation problems and are not sensible technical goals for the United States for the foreseeable future—we would close down GNEP and hold DOE R&D spending in this area to pre-2003 levels, before AFCI; and (2) DOE is the wrong agent for developing commercial technologies beyond the early laboratory stage—it has been unsuccessful in the past and its overall record of managing sizeable projects is very poor. Our thinking is explained below.

It is important to clear up one point at the outset. No one appearing before the committee argued that conserving uranium was a reason for pursuing reprocessing and recycle. The resource argument does not appear in the GNEP Strategic Plan. Instead, the Strategic Plan argues that reprocessing and fast reactors would solve the waste disposal and proliferation problems that bar expanded use of nuclear energy.

WASTE DISPOSAL: DEALING WITH SPENT FUEL

GNEP proposes to operate the nuclear fuel cycle so as to eliminate the need for more than one U.S. waste repository for the rest of the 21st century, even if the number of power reactors—now at about 100—increased by many hundreds. This goal drives the design of both GNEP reprocessing and fast reactor technologies. (By comparison, the "proliferation" constraint—no pure plutonium—is only a wrinkle on the basic pattern.)

GNEP's waste logic runs as follows. A much larger U.S. nuclear program operated on the current once-through basis—with direct disposal of spent fuel—would require many repositories—say, one for every 100 reactors. But the struggle over DOE's proposed Yucca Mountain nuclear waste repository proves, the argument goes, there will never be any additional repositories. We therefore need a closed fuel cycle that could accommodate a large expansion in nuclear power and still use only one repository.

GNEP plans to finesse Yucca Mountain's design capacity—limited by temperature constraints on the repository rock—by leaving the heat-generating waste out of the repository. In particular, it would leave the hottest fission products (shown in red in Figure A-1) in surface storage. This does not expand repository capacity; it just puts less of each reactor's waste inside. Of course, you could do that without GNEP by putting spent fuel in dry cask surface storage, which is essentially unlimited. But GNEP excludes this option. If Yucca Mountain fails to get a license and long-term surface storage is acceptable, the GNEP story collapses; and the same is true if people accept other repositories in the future.

Note that GNEP would leave the radioactive cesium-137 and strontium-90 on the surface. The half-lives of these isotopes are about 30 years, so they would have to remain in such storage for at least 300 years. There is no word on where DOE would store this material. As this would involve roughly as much storage capacity as would the original spent fuel, it is difficult to see any gain over the current once-through fuel cycle, especially considering that reprocessing would produce other waste streams as well.

The proposed technology is complex and would inevitably be very expensive. The design requirements for GNEP's form of light water reactor (LWR) spent fuel reprocessing

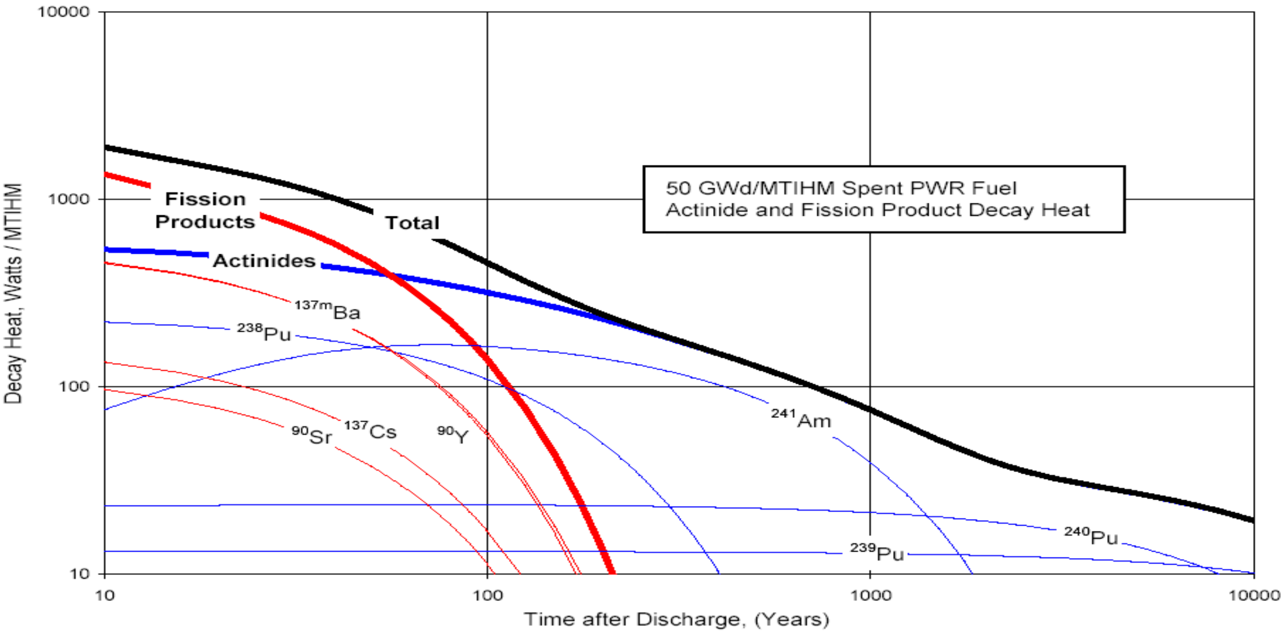

FIGURE A-1 50 GWd/MTIHM spent PWR fuel actinide and fission product decay heat. GWd, gigawatt days of thermal energy production; MTIHM, metric tonnes initial heavy metal; PWR, pressurized water reactor. SOURCE: R.A. Wigeland, T.H. Bauer, T.H. Fanning, and E.E. Morris. 2004. Spent Nuclear Fuel Separations and Transmutation Criteria for Benefit to a Geologic Repository. Paper presented at Waste Management 2004 Conference, February 29-March 4, 2004, Tucson, Ariz.

are driven by the need to separate the various radioactive spent fuel constituents into separate streams to allow different solutions for each. Aside from the radioactive cesium and strontium, the main ones are the plutonium and minor actinides neptunium, americium, and curium (shown in blue in Figure A-1), which are destined for transuranic fast reactor fuel. The longer-lived fission products, technetium-99 and iodine-129, are to be sent to a geologic repository. There are also assorted other radioactive products, including gases such as tritium and krypton; uranium, which DOE wants to send to a low-level waste repository; the cladding hulls, which are destined for a geologic repository; and other wastes from the reprocessing process.

Even if GNEP worked as planned it would likely exacerbate the nuclear waste problem, at least for a long time. The most important thing to remember is that the hottest fission products would accumulate on the surface for hundreds of years. These fission products are the reason that the NRC, the last time it looked at separation and closed fuel cycles, in 1996, recommended the need for geologic repositories. Putting less of the waste into a repository is a choice we could make now without GNEP—we could leave the spent fuel in surface dry storage and put nothing in a repository. Or we may be able to site other repositories. GNEP's notion that siting reprocessing plants and fast reactors and surface storage for radioactive cesium and strontium would be easier is fanciful.

The need for specialized fast reactors comes from GNEP's decision to burn the plutonium and minor actinides to further reduce the repository heat load and long-lived radioactive isotopes. The main heat source after cesium and strontium's radioactivity subsides is americium-241. A new type of fast reactor would have to be designed to burn actinide fuel (and, secondarily, to produce electricity). To make the scheme work would take about one fast reactor for every four ordinary LWRs, so about 100 fast reactors out of a total of, say, 500 nuclear units. DOE acknowledges fast reactors would be more expensive than LWRs; but in our opinion DOE still underestimates the difference in capital and fuel costs.

Further, as pointed out in Chapter 4, it would take many cycles through the fast reactors to burn up a large fraction of the actinides. That means, in effect, the spent actinide fuel from the fast reactors would be reprocessed many times (each time separating the hot fission products for surface storage). The fast reactors' spent fuel would need an entirely new and different reprocessing technology. Each cycle—residence in the fast reactor, cooling, reprocessing, and fuel fabrication—would take a good many years. So in the best of circumstances, many cycles would take the better part of a century. But no one has yet fabricated such an actinide fuel, or designed a reactor to burn it, or developed a reprocessing scheme that could handle it. It is premature to be thinking of going beyond the laboratory with reprocessing and fast reactor technologies.

Finally, the GNEP concept applies only if there is a multifold expansion of nuclear capacity. However, even today's optimistic projections involve a relatively small number of reactors (as of July 2007 no new reactors had been ordered);

it would take hundreds more to get into the GNEP ballpark. Nor is it plausible that GNEP would facilitate such an expansion.

PROLIFERATION: INTERNATIONAL ASPECTS OF GNEP

The other main GNEP goal is antiproliferation, keeping additional countries from getting bombs. There is a lot of confusion about this goal. GNEP's fuel cycle is said to be "proliferation-resistant" because it would keep plutonium mixed with other radioactive elements—the current choice is neptunium—to provide some self-protection.

A committee member pointed out that mixing plutonium with mildly radioactive neptunium is about as effective protection as mixing it with highly enriched uranium, because neptunium-237 and uranium-235 have similar properties. Therefore, the proposed addition of actinides to plutonium does not significantly increase the radiological barriers to theft or make it significantly more difficult to use the material as an explosive. This feature of the reprocessing scheme is really intended to protect against theft and terrorism in the supplier countries that have reprocessing plants and has nothing to do with antiproliferation.

The more important point—GNEP Strategic Plan (Section 2.1.2)—is that the GNEP Strategic Plan is based on there being no technological fix that would make reprocessing safe enough to spread to all countries. The GNEP Strategic Plan argues that antiproliferation dictates finding a way to keep most countries from engaging in reprocessing. Thus GNEP would rely on fuel supply assurances to dissuade most countries—call them *B* countries—from developing their own enrichment or reprocessing facilities.

These countries would in effect lease fuel from a small number of *A* countries and return the spent fuel containing plutonium. In this scheme, only the *A* countries would reprocess and burn the plutonium-actinide mixture in their own fast reactors, so the *B* countries would never have access to this nuclear explosive. GNEP assumes the *B* countries would voluntarily forgo reprocessing to get assured access to fresh fuel.

But if this decision were based on economics, there would not be any reprocessing and recycle today (MOX, plutonium-based fuel, is several times as expensive as low-enriched uranium fuel). And there is no problem today for any country adhering to the Non-Proliferation Treaty (NPT) in buying uranium fuel, so what advantage would GNEP assurances have over current fuel contracts? DOE's Office of Nuclear Energy (NE) said the extra assurances would make it even more difficult than it now is for a country like Iran to justify its own enrichment or reprocessing. That is not a serious reason to spend tens of billions of dollars.

It is also unclear why, as GNEP argues, the United States has to reprocess in order to provide fuel assurances. Since the GNEP idea is that the *B* countries would just lease fresh fuel and send back spent fuel, why would they care whether the spent fuel is reprocessed or not?

There is also the problem of creating, beyond the NPT, another division of nuclear countries, the *A*s and the *B*s—or haves and have-nots. One indicator of the likely reaction is that there are lots of volunteers to be "A" countries but, apparently, none to be a "B" country.

There is another problem: consistency. It is evident from the presentations to the committee that the administration does not intend to take back foreign spent fuel—for one thing because doing so would jeopardize congressional approval of the initial parts of the GNEP program. So the nonproliferation part of GNEP is really about other "supplier" countries—for example, France—taking back foreign spent fuel. It is naïve to expect that the existing reprocessing countries would adopt the more complicated and expensive GNEP technology.

The ultimate nonproliferation argument for GNEP is that only if the United States engages in large-scale reprocessing can it gain a seat at the table in international discussions about the rules for nuclear energy use. The only thing to say about this is that the United States is always going to have a seat at the table.

To sum up, the main point of our discussion is that GNEP's antiproliferation goal does not provide a rationale for DOE-NE R&D on reprocessing and fast reactors, whether in the context of GNEP or of the original AFCI.

We do want to acknowledge that while we disagree with its planned execution, we agree with some of GNEP's underlying assumptions about the dangers of easy access to plutonium: (1) that all grades of plutonium, regardless of the source, could be used to make nuclear explosives and must be controlled; (2) that widespread access to reprocessing, no matter what the technology, is equivalent to access to plutonium and poses an international security problem; (3) that widespread use of MOX fuel by both weapons states and nonweapons states is similarly risky, because the contained plutonium can be extracted relatively easily; and (4) that even in the weapons states, the plutonium must be in a self-protecting form.

MANAGEMENT

DOE-NE has no track record of successful project management. We are unaware of any successful historical DOE model for bringing technology to a commercial scale, as the agency intended to do under GNEP; nor was NE able to provide an example.

In fact, DOE has suffered chronic project management problems, as recorded in numerous GAO reports, the latest of which[1] states as follows:

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[1] Government Accountability Office, Department of Energy Consistent Application of Requirements Needed to Improve Project Management, GAO-07-518, May 2007.

> For years, GAO has reported on DOE's inadequate management and oversight of its contracts and projects and on its failure to hold contractors accountable for results. The poor performance of DOE's contractors has led to schedule delays and cost increases for many of the department's major projects. Such problems led us to designate DOE's contract management—defined broadly to include both contract administration and project management—as a high-risk area for fraud, waste, abuse, and mismanagement in 1990. . . . Ultimately, in January of this year, we concluded that despite DOE's efforts to address contract and project management weaknesses, performance problems continued to occur on DOE's major projects, and DOE contract management remained at high risk for fraud, waste, abuse, and mismanagement.

Congress has taken note of this in reviewing the FY 2008 budget.

The presentations to the committee by NE were also disappointing in how they reflected on NE management capability. The briefing points on GNEP were all pluses and no minuses, and the DOE managers were defensive about any possible deficiencies in their arguments and planning. Perhaps it is natural that they underplayed the technological uncertainties and difficulties, but they also showed a lack of the intellectual flexibility and depth that managers need to address a complicated new subject. Nor did cost enter importantly into their thinking. We had a similar impression of the Idaho National Laboratory presentations and reports.

We also doubt that the DOE laboratories are able to develop technology to full scale in a form that is attractive to the commercial world. The problem is that the laboratory R&D environment is not sufficiently cost-conscious. The laboratories have a lot of strengths, but developing commercial technology is not one of them.

B

Minority Opinion: An Alternative to Technology Proposed for GNEP, Offered by Levy, Kazimi, and Dally

Inert fuel is made of transuranics and an inert material such as zirconium oxide. By not including a fertile material such as uranium, the transuranics are reduced by irradiation in a power reactor. The transuranic inert matrix fuel (IMF) occupies only part of the nuclear core of a light water reactor (LWR). Matrix fuel has been studied extensively in the rest of the world and we are particularly interested in once-through IMF, an idea considered in many other countries, which could be much more economical than the GNEP plan to use sodium fast burner reactors.

The thermal recycling of transuranics from LWR spent fuel IMF should be given priority over multiple recycling in sodium fast reactors, for several reasons:

- Considerable work, including irradiation, has been carried out in many countries, as summarized in IAEA-TEC-DOC-1516, issued in August 2006. This gives the United States the opportunity to join a significant ongoing effort.
- The United States has the necessary development facility—the Advanced Test Reactor—to confirm the development of IMF and the operating LWR to validate IMF performance through lead fuel assemblies. There is no need to wait for an Advanced Burner Reactor, its licensing, costs, and long-term availability.
- Work at the Massachusetts Institute of Technology has shown that the use of IMF in LWR with 20 percent of the fuel assembly pins replaced with IMF pins leads to important reductions in the accumulation of transuranics (TRUs) and confirms early waste benefits encouraged in AFCI 2006.
- GNEP has emphasized the need to avoid TRUs from reaching the U.S. repository, but it failed to recognize the plan to store defense wastes in that same repository, which will set a performance floor in dose reduction at the repository. A risk-informed approach (which is badly needed) would suggest that the GNEP plans to pursue extreme recycling are unnecessary.
- From an economic viewpoint, the capital cost and the fuel cycle costs are higher for fast reactors than for LWRs.
- It is recognized that IMF still requires much development, but the effort required is considerably less than that for the selected GNEP strategy.

C

Biographical Sketches for Committee Members

Robert W. Fri, *Chair*, is a visiting scholar and senior fellow emeritus at Resources for the Future, where he served as president from 1986 to 1995. From 1996 to 2001 he served as director of the National Museum of Natural History at the Smithsonian Institution. Before joining the Smithsonian, Mr. Fri served in both the public and private sectors, specializing in energy and environmental issues. In 1971 he became the first deputy administrator of the U.S. Environmental Protection Agency (EPA). In 1975, President Ford appointed him as the deputy administrator of the Energy Research and Development Administration. He served as acting administrator of both agencies for extended periods. From 1978 to 1986, Mr. Fri headed his own company, Energy Transition Corporation. He began his career with McKinsey & Company, where he was elected a principal. Mr. Fri is a senior advisor to private, public, and nonprofit organizations. He is a director of the American Electric Power Company and of the Electric Power Research Institute (EPRI), and a trustee of Science Service, Inc. (publisher of *Science News* and organizer of the Intel Science Talent Search and International Science and Engineering Fair). He serves as vice-chair of the boards of EPRI and of Science Service. He is a member of the National Petroleum Council, the Advisory Council of the Marian E. Koshland Science Museum, and the steering committee of the Energy Future Coalition. In past years, he has been a member of the President's Commission on Environmental Quality, the Secretary of Energy Advisory Board, and the University of Chicago board of governors for Argonne National Laboratory. He has chaired advisory committees of the National Research Council (NRC), the Carnegie Commission on Science, Technology and Government, EPRI, and the Office of Technology Assessment (OTA). From 1978 to 1995 he was a director of Transco Energy Company, where he served as chair of the audit, compensation, and chief executive search committees. He is a member of Phi Beta Kappa and Sigma Xi and a national associate of the National Academy of Sciences. He received a B.A. in physics from Rice University and an M.B.A. (with distinction) from Harvard University.

R. Stephen Berry (NAS) is the James Franck Distinguished Service Professor Emeritus of Chemistry at the University of Chicago and holds appointments in the College, the James Franck Institute, and the Department of Chemistry. He was special advisor to the director of Argonne National Laboratory for National Security. Dr. Berry has also held an appointment in the School of Public Policy Studies at the university and has worked on a variety of subjects ranging from strictly scientific matters to a variety of topics in policy. He has held a number of positions including visiting professor at the University of Copenhagen (1967 and 1979), the Université de Paris-Sud (1979-1980), and Oxford University (1973-1974, 1980), where he was the Newton-Abraham Professor in 1986-1987. He spent 1994 at the Freie Universität Berlin as an awardee of the Humboldt Prize. He has continued to have close associations with the Aspen Center for Physics (board of directors, 1978-1984) and with the Telluride Summer Research Center (now Telluride Science Research Center) (board of directors, 1984-present; president, 1989-1993). In 1983 Dr. Berry was awarded a MacArthur Fellowship. He is a member of the National Academy of Sciences. In 1997, he received the Heyrovsky Medal of the Czech Academy of Sciences. He has also worked since the mid-1970s with issues of science and the law, and with the management of scientific data, activities that have brought him into the arena of electronic media for scientific information and issues of intellectual property in that context. He has also worked on matters of scientific ethics and on some aspects of national security. Dr. Berry's current scientific interests include the dynamics of atomic and molecular clusters, the basis of guided protein folding and other structure-seeking processes, and the thermodynamics of time-constrained processes and the efficient use of energy. He attended Harvard University, where he received A.B., A.M., and Ph.D. degrees.

Douglas M. Chapin (NAE) is principal officer and director, MPR Associates, Inc., Alexandria, Virginia. He has extensive experience in electrical, chemical, and nuclear engineering, with particular application to nuclear and conventional power plant problems and functions, including numerous aspects of power plant systems and their associated components. He has worked in instrumentation and control systems, nuclear fuels, fluid mechanics, heat transfer, pumps, advanced analysis methods, test facility design, and electrical systems and components. Dr. Chapin has been involved in a number of efforts, including the Japan/Germany/United States research program on loss of coolant accidents (LOCAs), served as project leader for the design, construction, and testing of the loss of fluid test (LOFT) facility, was a member of EPRI's Utility Review Committee on Advanced Reactor Designs, and worked with the Utility/EPRI Advanced Light Water Reactor Program, which defined utility requirements for future nuclear power plants. He was chairman of the NRC's Committee on Application of Digital Instrumentation and Control Technology to Nuclear Power Plant Operations and Safety, and is chair of its Board on Energy and Environmental Systems. Dr. Chapin is a member of the National Academy of Engineering (NAE), has served as a member of its Electric Power/Energy Systems Engineering Peer Committee, and is currently a member of its Committee on Membership. He is a fellow of the American Nuclear Society (ANS). He has a B.S. in electrical engineering, Duke University, an M.S. in applied science, George Washington University, and a Ph.D., nuclear studies in chemical engineering, Princeton University.

Gregory R. Choppin is currently the Robert O. Lawton Distinguished Professor of Chemistry at Florida State University. His research interests involve the chemistry and separation of the f-elements and the physical chemistry of concentrated electrolyte solutions. During a postdoctoral period at the Lawrence Radiation Laboratory, University of California, Berkeley, he participated in the discovery of mendelevium, element 101. His research and educational activities have been recognized by the American Chemical Society's Award in Nuclear Chemistry, the Southern Chemist Award of the American Chemical Society, the Manufacturing Chemist Award in Chemical Education, the Chemical Pioneer Award of the American Institute of Chemistry, a Presidential Citation Award of the ANS, the Becquerel Medal of the Royal Society of Chemistry, the Hevesy Award in Radiochemistry (Hungary), and honorary D.Sc. degrees from Loyola University and the Chalmers University of Technology (Sweden). He has served on numerous advisory groups and NRC committees on separations chemistry, nuclear fuel, and nuclear waste. He has served on over a dozen NRC committees and boards, including the Panel on Separations Technology and Transmutation Systems, the Committee on Electrometallurgical Techniques for DOE Spent Fuel, the Board on Radioactive Waste Management, and the Board on Chemical Sciences and Technology. He holds a Ph.D. in inorganic chemistry from the University of Texas, Austin.

Michael Corradini (NAE) is chairperson and professor in the Department of Engineering Physics at the University of Wisconsin, Madison. Dr. Corradini's research focus is nuclear engineering and multiphase flow with specific interests that include light water reactor safety, fusion reactor design and safety, waste management and disposal, vapor explosions research and molten core concrete interaction research, and energy policy analysis. He is a member of the American Institute of Chemical Engineers, the American Society of Engineering Education, the American Society of Mechanical Engineers, and a fellow of the ANS. Dr. Corradini has received numerous awards, including the National Science Foundation's Presidential Young Investigators Award, the ANS reactor safety best paper award, and the University of Wisconsin-Madison campus teaching award. He is the author of over 100 technical papers and has served on various technical review committees, including the research review panel of the U.S. Nuclear Regulatory Commission (USNRC) and the direct heating review group. He is currently a member of the NRC's Electric Power/Energy Systems Engineering Peer Committee and chair of the Frontiers of Engineering organizing committee. He has served on several NRC committees, including the Committee on Alternatives for Controlling the Release of Solid Materials from NuRC-Licensed Facilities. Dr. Corradini was elected to the NAE in 1998. He received a B.S. in mechanical engineering from Marquette University and M.S. and Ph.D. degrees in nuclear engineering from the Massachusetts Institute of Technology (MIT).

James R. Curtiss is a partner in the Winston & Strawn, Washington, D.C., office and chairs the firm's energy practice. He was a commissioner of the USNRC (1988-1993); counsel to the Subcommittee on Nuclear Regulation of the Senate Committee on Environment and Public Works, working for the committee's Republicans; and a lawyer in the office of the executive legal director of the USNRC and a legal assistant for then-Commissioner Richard T. Kennedy. He concentrates his practice in energy policy and nuclear regulatory law and focuses on strategic advice and counsel for utilities, nuclear fuel cycle companies, government contractors, and trade associations on regulatory and legislative matters, including corporate governance, industry restructuring, and legislative and regulatory energy policy issues. He has extensive experience in regulatory and licensing policy as well as in the drafting and enactment of many key pieces of legislation, having been involved in establishing regulatory policy for all civilian uses of nuclear materials, including commercial nuclear power plants, industrial users, universities, and hospitals, as well as the formulation of the Part 52 framework for certification of nuclear plant designs, early site permits, combined licenses, and nuclear waste policy. He serves as a member of the boards of directors of Constellation Energy Group, where he chairs the board's Nuclear Committee, and Cameco Corporation, where he chairs the board's Human Resources and Compensation Committee and is a member of the Safety, Health, and Environment Committee. In addition, Mr. Curtiss is on the Nuclear Oversight Board for Southern California Edison's San Onofre Nuclear Generation Station. Mr. Curtiss received a B.A. and a J.D., with distinction, from the University of Nebraska, where he served on the Law Review. Mr. Curtiss is a member of the bar of the District of Columbia Court of Appeals and the United States Supreme Court.

James W. Dally (NAE) is professor emeritus, University of Maryland, College Park. Dr. Dally has had a distinguished career in industry, government, and academia and is the former dean of the College of Engineering at the University of Rhode Island. Dr. Dally is Glenn L. Martin Institute Professor of Engineering (emeritus) at the University of Maryland at College Park. His former positions include senior research engineer, Armour Research Foundation; assistant director research, Illinois Institute of Technology Research Institute; and senior engineer, International Business Machines Corporation. Currently, he is also an independent consultant. Dr. Dally is a mechanical engineer and the author or coauthor of six books, including engineering textbooks on experimental stress analysis, engineering design, instrumentation, and the packaging of electronic systems, and has published approximately 200 research papers. He has served on a number of NRC committees, such as the Committee on Alternatives for Controlling the Release of Solid Materials from USNRC-Licensed Facilities, the Panel on Prospective Benefits of DOE's Distributed Energy Resources R&D Program, and the Panel on Air and Ground Vehicle Technology for the Army Research Laboratory Technical Assessment Board. He has a B.S. and an M.S., Carnegie Institute of Technology, and a Ph.D., Illinois Institute of Technology.

Victor Gilinsky is an independent consultant, primarily on domestic and international issues involving nuclear electric generation and associated fuel cycle systems. He has held a number of positions including commissioner, USNRC; head, Physical Sciences Department, and director, Applied Science and Technology Program, The Rand Corporation; assistant director for policy and program review, Office of Planning and Analysis, U.S. Atomic Energy Commission; and physicist, The Rand Corporation. He received the Distinguished Alumni Award, California Institute of Technology, and is a member of the American Physical Society (APS), the Institute of Electrical and Electronics Engineers, the International Council on Large Electric Systems, and the International Institute of Strategic Studies. He has a bachelor's degree in engineering physics, Cornell University, and a Ph.D. in physics, California Institute of Technology.

Mujid S. Kazimi is director, Center for Advanced Nuclear Energy Systems, and professor of nuclear engineering and of mechanical engineering, MIT. He has been on the faculty at MIT since 1976 and previously served as head of the Department of Nuclear Science and Engineering. He also held positions at Brookhaven National Laboratory and the Westinghouse Electric Corporation prior to joining the MIT faculty. He has extensive expertise in advanced nuclear energy systems, in reactor design and safety analysis, the nuclear fuel cycle, and nuclear research. He has served on numerous review committees and panels and currently serves as a member of the board of managers of Battelle Energy Alliance, which manages the Idaho National Laboratory. He is coauthor of *Nuclear Systems*, a two-volume book on the thermal analysis and design of nuclear fission reactors. He served on the NRC Panel on Separations Technology and Transmutation Systems and on the NRC Committee on Alternatives and Strategies for Future Hydrogen Production and Use. He is a fellow of the ANS. He has a B.Eng. (Alexandria University), an M.S. (MIT), and a Ph.D. (MIT) in nuclear engineering.

Salomon Levy (NAE) is sole owner, Levy & Associates, which was formed in 1994 to provide consulting services to the power industry. He has consulted for many electric utilities and several power equipment manufacturers and EPRI. He also held a number of positions at General Electric, including manager, Heat Transfer and Fluid Flow Development; manager, Systems Engineering; manager, Design Engineering; general manager, Nuclear Fuel Department; general manager, Boiling Water Reactor System Department, and general manager, Boiling Water Reactor Operations, where he was responsible for the engineering and manufacturing of all the GE nuclear power business. He has served on a number of nuclear power plant and safety review committees, including the Nuclear Regulatory Safety Research Review Committee, the PSE&G Salem and Hope Creek Nuclear Oversight Committee, the Duane Arnold Safety Review Committee, the Offsite Safety Review Committee of the Palo Verde plants, and the Nuclear Oversight Committee for Ontario Hydro Nuclear, among others. He served on the Advisory Council for the Institute of Nuclear Power Operations and was the U.S. representative on the International Safety Advisory group of the IAEA. He has extensive experience in the development of nuclear systems for high-performance boiling water reactors, regulation and licensing of power plants, nuclear power plant and systems design, and safety control and systems. He has a B.S., M.S., and Ph.D. in mechanical engineering from the University of California, Berkeley.

Allison Macfarlane is currently an associate professor of environmental science and policy at George Mason University in Fairfax, Virginia. She is also an affiliate of the Program in Science, Technology and Society at MIT and the Belfer Center for Science and International Affairs at Harvard University. She has also held a faculty position at Georgia Tech in Atlanta, Georgia. She has held fellowships at the Bunting Institute at Radcliffe College, the Center for International Security and Arms Control at Stanford University, and the Belfer Center for Science and International Affairs at Harvard University. From 1998 to 2000 she was a Social Science Research Council-MacArthur Foundation fellow in international peace and security. She currently serves on the board of the *Bulletin of the Atomic Scientists*. Her research focuses on international security and environmental policy issues associated with nuclear weapons and nuclear energy. MIT Press has just published her book *Uncertainty Underground: Yucca Mountain and the Nation's High-Level Nuclear Waste,* which explores unresolved technical issues for nuclear waste disposal at Yucca Mountain, Nevada. She received her Ph.D. in geology from MIT in 1992.

Regis A. Matzie is senior vice president and chief technology officer, Westinghouse Electric Company. He is responsible for all Westinghouse research and development undertakings and advanced nuclear plant development. Previously, Dr. Matzie was responsible for the development, licensing, detailed engineering, project management, and component manufacturing of new Westinghouse light water reactors. He was also the executive in charge of Westinghouse replacement steam generator projects and dry spent-fuel-canister fabrication projects. He became a senior vice president in 2000, when Westinghouse Electric purchased the nuclear businesses of ABB. Earlier, Dr. Matzie was vice president of nuclear systems for ABB Combustion Engineering (ABB CE) Nuclear Power in Windsor, Connecticut. During his 25 years with ABB CE, he held technical and management positions, including vice president of nuclear engineering; vice president of nuclear systems development; director of advanced water reactor projects; manager of reactor engineering; and manager of analog plants. Dr. Matzie's career has been devoted primarily to the development of advanced nuclear systems and advanced fuel cycles, and he is the author of more than 120 technical papers and reports on these subjects. He completed 30 years of active and reserve service in the U.S. Navy in 1995, retiring with the rank of captain. Dr. Matzie graduated from the U.S. Naval Academy, where he obtained a B.S. in physics, and served in the U.S. nuclear submarine program for 5 years. He then attended Stanford University, where he earned an M.S. and a Ph.D. in nuclear engineering.

Warren F. Miller, Jr. (NAE) was recently appointed associate director of the Nuclear Security Science and Policy Institute, Texas A&M University System. From 1974 to 2001, he held a number of positions at Los Alamos National Laboratory, including group leader, reactor and transport theory; deputy associate director for nuclear programs; associate laboratory director for energy programs; and deputy laboratory director for science and technology. He has held positions at the University of New Mexico, the University of Michigan, Howard University, the University of California, Berkeley, and Northwestern University. He is a fellow of the ANS, a State of New Mexico Eminent Scholar (1989), a member of the NAE, and the 2004 Distinguished Engineer of the National Society of Black Engineers. He has served on a variety of advisory groups and committees and was vice chair of the NRC Committee of the Division on Earth and Life Sciences and was a member of the NRC Committee on Long Term Environmental Quality Research and Development. He served on the DOE Nuclear Energy Research Advisory Council from 1997 to 2006. He has expertise in nuclear reactor design, transport and reactor analysis and theory, radioactive waste management, transmutation of materials, and management of R&D programs. He has a B.S. in engineering sciences, U.S. Military Academy, West Point, and an M.S. and a Ph.D. in engineering sciences, Northwestern University.

David L. Morrison is retired director of the Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission. His previous positions include technical director of the Energy, Resource and Environmental Systems Division, MITRE Corporation; president of the IIT Research Institute; and director of program development and management, Battelle Memorial Institute. He has been a member of the NRC's Energy Engineering Board and the National Materials Advisory Board, chaired the NRC Committee on Alternative Energy R&D Strategies, chaired the NRC Committee on Industrial Energy Conservation, and has served on a number of NRC committees, including the Committee on Fuel Economy of Automobiles and Light Trucks, the Committee on Impact and Effectiveness of Corporate Average Fuel Economy Standards, and the Committee to Review the United States Advanced Battery Consortium's Electric Vehicle R&D Project Selection Process. He also served as chair of the Committee to Review the R&D Strategy for Biomass-Derived Ethanol and Biodiesel Transportation Fuels. Dr. Morrison was designated a lifetime national associate of the National Academy of Sciences in 2001. His areas of expertise include research management, energy and environmental research, materials, nuclear technology, and physical chemistry, and he has extensive experience in the assessment of energy technologies. Dr. Morrison received a B.S. degree from Grove City College and a Ph.D. in chemistry from the Carnegie Institute of Technology.

Per F. Peterson is a professor and former chair of nuclear engineering at the University of California, Berkeley (UCB). Before that he was a fellow of the Japan Society for the Promotion of Science, Tokyo Institute of Technology, and engineer at Bechtel National. Honors and awards include the Excellence in Fusion Engineering Award (1999) of Fusion Power Associates, visiting scholar at Los Alamos National

Laboratory (1997-1998), NSF Presidential Young Investigator (1990-1995), and fellow, ANS. Dr. Peterson's research and teaching focus on problems in energy and environmental systems, including inertial confinement fusion, advanced reactors, high level nuclear waste processing, and nuclear materials management, as well as on heat and mass transfer, fluid dynamics, and reactor thermal hydraulics as they pertain to nuclear applications. Ongoing research includes molten salt applications in nuclear hydrogen and electricity production, advanced high-temperature Brayton cycles, high-temperature ceramic composite heat exchangers, and fission and fusion applications. Recent publications include an assessment methodology for proliferation resistance and physical protection of Generation IV nuclear power systems. Dr. Peterson manages the UCB Thermal Hydraulics Research Laboratory. He has a B.S. in mechanical engineering, University of Nevada, Reno, and M.S. and Ph.D. degrees in mechanical engineering, UCB.

Geoffrey S. Rothwell is a senior lecturer, Department of Economics, and associate director, Public Policy Program, Stanford University (1986-present). His research focuses on all aspects of nuclear power economics, including the application of options theory to investment in new nuclear plants (NP 2010) and the economics of advanced nuclear electricity and hydrogen technology selection (Gen IV). He has been on many advisory groups, including these: (1) Generation IV Roadmap committee (member, Evaluation Methodology Group, 2001-2003, and co-chair, Economics Cross-cut Group, 2002-2003) and, currently, Economic Modeling Working Group, Generation IV International Forum (2003-2007), (2) chair, International Atomic Energy Agency's Committee on Methodology for Nuclear Power Plant Performance and Statistical Analysis (1995-1997), and (3) member, NRC's Committee on Decontamination and Decommissioning of the Uranium Enrichment Facilities (1993-1996). He was a postdoctoral fellow at the California Institute of Technology (1985-1986). He received a Ph.D. in economics from UCB (1985); an M.A. in jurisprudence and social policy, Boalt Hall Law School, UCB (1984); an M.A. in economics, UCB (1982); a B.A. from Evergreen State College (1975); and a baccalauréat (A4) from the Lycée François Premier, Le Havre, France (1972).

John J. Taylor (NAE) is a nuclear energy consultant. As vice president for nuclear power at EPRI (retired), he was responsible for nuclear power R&D in support utilities worldwide. As vice president, now retired, of Westinghouse Electric's water reactors business unit, he was responsible for the company's worldwide commercial nuclear power business. He played key roles in the development of the first U.S. nuclear-powered submarines, aircraft carriers, and cruisers, and the first U.S. nuclear electric generating station. Mr. Taylor has served on many advisory committees on nuclear power R&D, reactor design, the safety and reliability of nuclear power plants, and nuclear weapon proliferation both here and abroad, giving advice to nuclear energy industry associations, the National Academies, DOE, the USNRC, national laboratories, the IAEA, and the OECD Nuclear Energy Agency. He has testified on nuclear energy issues to the U.S. Senate, the U.S. House of Representatives, and the U.K. House of Commons. Mr. Taylor is a member of the NAE, a member and fellow of the ANS, the APS, and the American Association for the Advancement of Science. He has authored or coauthored many papers and articles and several books on various aspects of nuclear energy. He has A.B. and D.Sc.(Hon.) degrees from St. John's University and an M.S. degree from the University of Notre Dame.

D

Acronyms

ABR	advanced burner reactor
ABTR	advanced burner test reactor
ABWR	GE advanced boiling water reactor
AFCF	Advanced Fuel Cycle Facility
AFCI	Advanced Fuel Cycle Initiative
ALWR	advanced light water reactor
AP600	Westinghouse passive 600-MWe advanced light water reactor
AP1000	Westinghouse passive 1,100-MWe advanced light water reactor
ASLB	Atomic Safety and Licensing Board
ASME	American Society of Mechanical Engineering
ATR	Advanced test reactor
BEA	Battelle Energy Alliance
BWR	boiling water reactor
CFR	Code of Federal Regulation
CFTC	Centralized Fuel Treatment Center
COL	combined construction and operating license
CR	Continuing Resolution
DC	USNRC design certification
DOE	U.S. Department of Energy
EIA	Energy Information Agency
EOI	expression of interest
EPAct05	Energy Policy Act of 2005
EPC	engineering, procurement, and construction
EPR	French 1,600-MWe pressurized water reactor
EPRI	Electric Power Research Institute
ESBWR	GE economic simplified boiling water reactor
ESP	early site permit
GFR	gas-cooled fast reactor
GIF	Generation IV International Forum
GNEP	Global Nuclear Energy Partnership
HTR	high-temperature reactor
ID	Idaho Operations Office
IDB	ITAAC determination base
IEEE	Institute of Electrical and Electronics Engineers
IHX	intermediate heat exchanger
INL	Idaho National Laboratory
INPO	Institute for Nuclear Plant Operations
IGCC	integrated gasification combined cycle
ITAAC	inspection, testing, analyses, and acceptance criteria
JSW	Japan Steel Works
LCOE	levelized cost of electricity
LDRD	laboratory-directed research and development
LFR	lead-cooled fast reactor
LNG	liquefied natural gas
LWR	light water reactor
MOX	mixed oxide
MSR	molten salt reactor
NE	Office of Nuclear Energy (DOE)
NEI	Nuclear Energy Institute
NEPDG	National Energy Policy Development Group
NEPO	nuclear energy plant optimization
NERAC	Nuclear Energy Research Advisory Committee
NERI	Nuclear Energy Research Initiative
NESSP	Nuclear Energy Systems Support Program
NGNP	Next-Generation Nuclear Plant
NHI	Nuclear Hydrogen Initiative
NOPR	Notice of Proposed Rulemaking
NP 2010	Nuclear Power 2010
NPOC	New Plant Oversight Committee
NSSS	Nuclear Steam Supply System

NuStart	industry consortium preparing to build new nuclear plants
OMB	Office of Management and Budget
PSO	program secretarial office
PWR	pressurized water reactor
QA	quality assurance
QC	quality control
RAI	request for additional information
RD&D	research, development, and deployment
RPV	reactor pressure vessel
S-I	sulfur-iodine
SBWR	GE simplified boiling water reactor
SCWR	supercritical-water-cooled reactor
SER	safety evaluation report
SFR	sodium-cooled fast reactor
TRU	transuranic
TVA	Tennessee Valley Authority
UCO	uranium oxycarbide
USNRC	U.S. Nuclear Regulatory Commission
VHTR	very-high-temperature reactor

E

Presentations and Committee Meetings

COMMITTEE MEETING
WASHINGTON, D.C.
AUGUST 24-25, 2006

Remarks About Committee's Study
Richard Chandler, Office of Management and Budget

Office of Nuclear Energy Overview
R. Shane Johnson, U.S. Department of Energy

Benefits Analysis Activities
John Stamos, U.S. Department of Energy

Nuclear Power 2010
Rebecca Smith-Kevern, U.S. Department of Energy

Generation IV Nuclear Power Systems
Rebecca Smith-Kevern, U.S. Department of Energy

Nuclear Hydrogen Initiative
Rebecca Smith-Kevern, U.S. Department of Energy

Global Nuclear Energy Partnership
Timothy A. Frazier, U.S. Department of Energy

Idaho Facilities Management
Owen Lowe, U.S. Department of Energy

DOE's Nuclear R&D Program: An Industry Perspective
Dave Modeen, Electric Power Research Institute

Technology Development Considerations
Albert Machiels, Electric Power Research Institute

COMMITTEE SUBGROUP MEETING
WASHINGTON, D.C.
OCTOBER 17, 2006

Q&A
Tom Miller, U.S. Department of Energy

Dominion Energy
Eugene Grecheck, Dominion Energy, Inc.

Drivers and Challenges for New Nuclear Development: One Perspective
Joe Turnage, Constellation Energy/UniStar

NuStart Energy
Marilyn Kray, Exelon/NuStart

Q&A
Dale Klein (by phone), U.S. Nuclear Regulatory Commission

DOE's Light Water Reactor R&D Program: An Industry Perspective
Gary Vine, Electric Power Research Institute

Q&A
Marvin Fertel, Nuclear Energy Institute

COMMITTEE MEETING
WASHINGTON, D.C.
NOVEMBER 8-9, 2006

The Global Nuclear Energy Partnership Update
Paul Lisowski, U.S. Department of Energy

Idaho National Laboratory Nuclear Energy Research
Dave Hill, Deputy Laboratory Director of Science & Technology

Basic Energy Sciences Research Relevant to Advanced Nuclear Energy Systems
John C. Miller, U.S. Department of Energy

New Units: ESBWR and ABWR
Rick Kingston, GE

Q&A
Ray Ganthner, AREVA

Q&A
George Davis, Westinghouse

Q&A
Jim Reinsch, Bechtel

The Global Nuclear Energy Partnership Technology Demonstration Program
Kathryn McCarthy, Idaho National Laboratory

SITE VISIT TO IDAHO NATIONAL LABORATORY
NOVEMBER 28-29, 2006

COMMITTEE MEETING
WASHINGTON, D.C.
JANUARY 9, 2007

Alternatives to GNEP
John Deutch, Massachusetts Institute of Technology

Q&A
Marvin Fertel, Nuclear Energy Institute

Trip Report on INL Site Visit, November 2006
Dave Morrison (committee member)

Q&A on DOE/NE Program
Dennis Spurgeon, U.S. Department of Energy

COMMITTEE MEETING
WASHINGTON, D.C.
MARCH 8-9, 2007

Office of Nuclear Energy, Budget and Planning Overview
Susan L. Harlow, U.S. Department of Energy

Prospective Benefits Methodology
Bob Fri, Committee Chair

Separations Technology
Jim Bresee, U.S. Department of Energy

NP 2010
Rebecca Smith-Kevern (by telephone), U.S. Department of Energy

GNEP
Jim Bresee, U.S. Department of Energy

CLOSED COMMITTEE MEETING
WASHINGTON, D.C.
MAY 30-31, 2007

F

Statement of Task

The committee will undertake a comprehensive, independent evaluation of DOE's nuclear energy (NE) program's goals and plans, and validate the process of establishing program priorities and oversight (including the method for determining the relative distribution of budgetary resources). The evaluation will result in a comprehensive and detailed set of policy and research recommendations and associated priorities (including performance targets and metrics) for an integrated agenda of research activities that can best advance NE's fundamental mission of securing nuclear energy as a viable, long-term commercial energy option to provide diversity in energy supply. The review will also include the relationship of the research program to the Idaho Facilities Management program. In conducting the evaluation of the R&D program, the committee will:

1. Review the technical goals and timetables for government and industry R&D efforts in the various technical areas (e.g., Nuclear Power 2010; Generation IV; Hydrogen Initiative; Advanced Fuel Cycle Initiative);
2. Review the R&D directions and progress in various parts of the program and their relevance to meeting the goals of the R&D program;
3. Review the overall balance and adequacy of the R&D program in light of the objectives and schedules in the major technology areas, and whether efforts in various technical areas are at an appropriate level, should be expanded, reduced, or eliminated;
4. Identify, if appropriate, new and promising technologies not included in the DOE portfolio that the DOE could meaningfully advance to meet the goals of the program;
5. Examine and comment, as necessary, on the appropriate federal role in the various technical areas;
6. Examine and comment on the commercial implications of each major part of the R&D portfolio and what each element needs to contribute to the commercial adoption of the technology;
7. Examine and comment on NE's strategy for accomplishing its goals, which would include such issues as:
    —Program management and organization;
    —The process of setting milestones, research directions and making Go/No Go decisions;
    —Collaborative activities with other parts of the government or private sector;
    —The integration of major activities in each program into a plan and associated schedule;
    —Integration and associated schedule and milestones of the various major programs across DOE-NE;
    —Consistency of the budget, schedule and scope for selected major activities;
    —Risk identification and assessment and mitigation activities; and
    —Other topics that the committee finds important to comment on related to the success of the program to meet its technical goals.
8. Comment on the relationship of the R&D program to the Idaho Facilities Management program.

The committee will write a report documenting its findings and recommendations.