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Recommendations for a Department of Energy Nuclear Energy R&D Agenda

Volume 2
Appendices

Prepared by
U.S. Department of Energy
National Laboratory Directors

December 1997

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**U.S. Department of Energy
National Laboratory Directors**

December 1997

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Contents

VOLUME 1

	<i>Page</i>
Executive Summary	ES-1
Summary Report	1
Introduction	1
Perspectives	6
Nuclear Energy Policies	14
Current Nuclear Energy R&D	16
Benefits and Risks of Nuclear Power	18
Key Issues for Nuclear Energy R&D	20
Challenges for Nuclear Energy Policy and R&D	25
Recommendations	27

VOLUME 2

Appendix 1: Objectives of the Federal Government Nuclear Energy Related Policies and Research and Development Programs	A1-1
Appendix 2: Nuclear Energy Related R&D in the United States	A2-1
Appendix 3: Summary of Issues That Drive Nuclear Energy Research and Development	A3-1
Appendix 4: Options for Policy and Research & Development	A4-1
Appendix 5: Pros and Cons of Objectives and Options	A5-1
Appendix 6: Recommendations	A6-1

Recommendations for a Department of Energy Nuclear Energy R&D Agenda

Appendix 1

Objectives of the Federal Government Nuclear Energy Related Policies and Research and Development Programs

1.0 INTRODUCTION

The current U. S. nuclear energy policy is primarily formulated as part of the nation's overall energy policy. In addition, nuclear energy policy is impacted by other U.S. policies, such as those for defense and environment, and by international obligations through their effects on nuclear weapons dismantlement and stewardship, continued reliance on space and naval nuclear power sources, defense waste cleanup, and on nuclear non-proliferation.

2.0 NATIONAL ENERGY POLICY

As succinctly stated in the 1995 National Energy Policy Plan¹ (NEPP), the current administration's energy policy focuses on development of sustainable energy supply, generation, and use and has three strategic goals:

- Maximize energy productivity.
- Reduce adverse environmental impacts.
- Reduce vulnerability to the global energy market.

¹*Sustainable Energy Strategy—Clean and Secure Energy for a Competitive Economy*, July 1995, National Energy Policy Plan Pursuant to Section 801 of the Department of Energy Organization Act.

The NEPP identifies five strategic components contributing to the implementation of a sustainable energy policy. These are:

- Increase the energy efficiency.
- Develop a balanced domestic energy resource portfolio.
- Invest in science and technology.
- Reinvent environmental protection.
- Engage the international market.

Nuclear energy is specifically mentioned in the NEPP as one of the elements of a balanced domestic energy portfolio. According to the plan, the Administration's nuclear energy policy is:

“...to maintain the safe operation of existing nuclear plants in the United States and abroad, and to preserve the option to construct the next generation of nuclear energy plants.”

The safety component of the administration's policy is implemented along two major paths:

- Working with industry to enhance safety (both domestically and internationally).
- Continuing to press for safe storage of spent nuclear fuel.

The component focused on preserving the nuclear option is reflected in the Department's commitment to:

- Assist industry in the development of advanced light-water reactor designs.

In addition to the overt statements concerning nuclear energy policy, the NEPP defines policies and objectives that can be directly impacted by nuclear energy. Indeed, nuclear power can effectively contribute to each of the five strategic components of the NEPP.

Nuclear energy can improve the efficiency of primary energy use and reduce overall resource utilization. Use of advanced fuel cycles offers potential very long-term resource lifetimes.

Nuclear power R&D contributes directly and indirectly to a broad range of important science and technology advances. Materials science and control systems are just two examples of significant progress that has been achieved as a result of nuclear power development.

One of the more pressing international issues is that of greenhouse gas emissions and their effect on global climate change. This sensitivity is explicitly recognized in the NEPP:

Clear evidence of significant global climate changes or other energy-related environmental problems could precipitate widespread public demand for more stringent measures to reduce greenhouse gas emissions or other environmental risks from energy production and use. Many scientists believe that stronger evidence could emerge in the next decade or two indicating that human-induced climate changes would result in large adverse impacts. Although it is difficult to forecast how the international community would respond, nations that are less dependent on carbon-intensive fuels or that have developed and begun to deploy the technologies needed to reduce such dependence are likely to have an advantage.

Although not specifically mentioned, nuclear energy is the only currently deployable technology capable of significantly reducing dependence on carbon-containing fuels. Of the competitors, wind, solar and geothermal are unlikely to become major contributors to the nation's electrical grid in the next 10–20 years, and the nation's capacity for increased hydroelectric resources is near its limit and subject to considerable environmental concern.

With projections of significant growth in worldwide energy demand, particularly in the developing countries and in eastern Asia, interest in and potential markets for nuclear technologies are increasing rapidly. Although the U.S. nuclear industry was once the world's sole supplier of nuclear goods and services, that position of leadership has eroded in recent years. Active reengagement in the nuclear marketplace is needed if the U.S. is to avoid missing this lucrative market.

2.1 DOE Implementation

The Department of Energy has outlined its implementation of the administration's energy policy in its current "DOE Strategic Plan"² and identified five strategic goals, including one for each of four "businesses areas" and one for corporate management. These are paraphrased here:

- Energy resources—Assure adequate supplies of clean energy.
- National security—Provide a safe and reliable stockpile and weapons infrastructure, provide technical leadership in nonproliferation and nuclear safety, and support naval nuclear reactor technology.
- Environmental quality—Minimize environmental, health, and safety risks and impacts.

²DOE Strategic Plan, DOE/PO-0053, September 1997.

- Science and technology—Maintain leadership in science and technology.
- Corporate management—Protect the environment, ensure health and safety (both of workers and the public), build communication and trust (including stakeholders and customers), and demonstrate good management practices (including workforce and infrastructure management, cost, and schedule.)

In addition to the above goals, there is one additional overarching consideration that may be considered a strategic goal:

- Industrial competitiveness—Contribute to the nation’s economic and industrial competitiveness in an increasingly global economy.

This latter goal was explicitly included in the 1994 DOE Strategic Plan,³ and although the principle of industrial competitiveness is embedded in much of the current plan, it is not explicitly developed there.

3.0 HISTORICAL PERSPECTIVE

The Atomic Energy Act of 1946, as amended in 1954 and later, provided the nation’s fundamental nuclear policies. It delineated the roles and separation of the peaceful and military uses of atomic energy. The Act declared in Section 1 that it is the policy of the United States that “the development, use, and control of atomic energy shall be directed so as to promote world peace, improve the general welfare, increase the standard of living, and strengthen free competition in private enterprise.” The purpose of the Act, set forth in Section 3, is to effectuate the policy by providing for, in addition to defense related programs, (a) a program of conducting, assisting, and fostering research and development in order to encourage maximum scientific and industrial progress; (b) a program to encourage widespread participation in the development and utilization of atomic energy for peaceful purposes to the maximum extent consistent with the common defense and security and with the health and safety of the public; and (c) a program of international cooperation to promote common defense and security and to make available to cooperating nations the benefits of peaceful applications of atomic energy. The Act created the Atomic Energy Commission to carry out these programs and empowered it with the authority to conduct nuclear R&D and training programs, contract and make grants, and license and regulate reactors and nuclear materials.

³“Fueling a Competitive Economy,” DOE Strategic Plan, DOE/S-0108, April 1994.

President Eisenhower, in his December 1953 “Atoms for Peace” speech, called for greater international cooperation in the development of atomic energy for peaceful purposes. In October 1957 the United Nations created the International Atomic Energy Agency (IAEA) to promote the peaceful use of nuclear energy worldwide and prevent the spread of nuclear weapons.

The official source of direction from Congress to the Department of Energy (DOE) with respect to nuclear energy R&D policy can be found in the Energy Policy Act of 1992 (EPACT). The EPACT was enacted in October 1992 and implemented and built upon strategies put forth by the Bush Administration in its National Energy Strategy (NES) published in February 1991. The NES clearly states that nuclear energy will continue to be important as a key component of a flexible, secure energy mix for the country. It predicted an increase in nuclear energy generation in the U.S. of 10% by 2010 if the measures it recommended are fully implemented. The NES describes four nuclear energy goals and approaches to achieve those goals:

Goal	Approach
Maintain exacting safety and design standards	Accelerate introduction of advanced design nuclear power plants
Reduce economic risk	Accelerate introduction of standard power plant designs
Reduce regulatory risk	Reform the NRC licensing process
Establish an effective high-level nuclear waste program	Site and license a permanent waste repository and a monitored retrievable storage facility

EPACT Title XXI, Energy and Environment, Subtitle C, Advanced Nuclear Reactor, Section 2121, requires DOE to carry out civilian nuclear programs in a way that will lead toward commercial availability of advanced nuclear reactor technologies. The DOE Office of Nuclear Energy, Science and Technology’s (NE) advanced reactor development projects underway at the time EPACT became law included the high temperature gas-cooled reactor (HTGR), the advanced liquid metal reactor (ALMR), the actinide burn technology evaluation (Integral Fast Reactor), and the advanced light water reactor (ALWR). Section 2124 of EPACT directed DOE to complete R&D on HTGR and ALMR designs to support selection of one or both designs for prototype construction by September 30, 1998. Congress canceled the ALMR and IFR projects in FY1995 and the HTGR in FY1996.

EPACT Section 2121 directed DOE to further timely availability of advanced nuclear reactor technologies, including technologies that use standardized

designs or exhibit passive safety features. In Section 2123, DOE was authorized to continue its cost-shared program with industry to complete design certification of the advanced light water reactors (ALWR) and to conduct the first-of-a-kind engineering (FOAKE) program. Two of three ALWR designs were certified by the Nuclear Regulatory Commission in May 1997 (General Electric advanced boiling water reactor and ABB-Combustion Engineering System 80+), and the third (Westinghouse AP600) is projected for final design approval in 1998 and certification in 1999. The FOAKE program developed designs more completely for two plants, the ABWR and the AP600. The program was limited to four years and had a \$100 million funding cap. FOAKE was completed for the ABWR in FY 1996 and for the AP600 in FY 1997.

EPACT also contains provisions regarding cost-sharing of energy R&D programs. For demonstration or commercial application projects, at least 50% of the costs must be provided from non-Federal sources. The Secretary of Energy may reduce or eliminate the cost-share requirement if he/she determines that the reduction is necessary and appropriate considering the technological risks involved in the project.

When the Clinton Administration took office in early 1993, the new President's policy on nuclear energy was made clear in his inaugural address and published in his "Vision of a Change for America", issued via the Office of Management and Budget, in February 1993. His statement was clear in that his energy policy included the elimination of unnecessary nuclear reactor research. The administration supports funding in R&D to maintain operation of the current generation of reactors and licensing actions of reactors that have commercial interest. This argument was used to continue ALWR, FOAKE, and commercial LWR plant life improvement programs. However, it eliminated R&D funding support for reactors which have no near-term commercial or other identified application. This resulted in cancellation of the HTGR, ALMR and IFR programs in 1995-1996.

The Secretary of Energy published the first DOE Strategic Plan in April 1994. As stated above, this document made no definite policy statements regarding use of nuclear energy. It did, however, mention continued operation of safe, economical nuclear power plants as one of several methods available to reduce greenhouse gases. The 1997 DOE Strategic Plan states that "by resolving nuclear waste disposal issues and developing advanced nuclear technology, DOE will remove some concerns and may open the door to renewed consideration of nuclear energy as an additional option for addressing air quality and greenhouse gas emissions."

3.1 Emphasis on Nuclear Safety

The DOE Office of Nuclear Energy, Science and Technology (DOE-NE) developed a draft strategic plan of its own in 1994–1995 to support the DOE strategic plan. Among the goals of DOE-NE were to:

- Cooperate and coordinate with other departmental offices and government agencies in the implementation of U.S. non-proliferation policy. This goal's objectives were to assist in the cessation of weapons-grade plutonium production in Russia; monitor low-enriched uranium purchased from Russia to verify it was blended down from highly-enriched uranium (HEU); maintain U.S. leadership in technical and programmatic aspects of international reprocessing and related reactor programs, and promote alternative technologies; and maximize the use of existing programs to increase the transition of former Soviet Union nuclear and weapons scientists to non-defense activities.
- Foster increase in U.S. exports of nuclear goods and services. This goal had two objectives: to facilitate and increase commercial contracts between U.S. suppliers and potential foreign buyers; and to overcome obstacles to U.S. nuclear supplier participation in foreign markets.
- Support maintenance of the light water reactor (LWR) option for domestic electricity generation. The objectives of this goal were to complete the design certification of advanced evolutionary and passive LWRs ; encourage commercial standardization by completing the FOAKE program for evolutionary and passive ALWR designs, and perform remaining detailed design work to achieve the design stage of commercial standardization; establish and demonstrate the license renewal process, in cooperation with industry and the NRC; develop technology to manage the effects of material degradation on key nuclear plant equipment that impacts safety; support development of technology and methods to improve plant performance and economics, while maintaining safety; and support technology to improve decommissioning and decontamination (D&D) and plant life decisions.

The DOE-NE strategic plan remains a draft document, not yet formally approved by the Office Director.

In July 1995 the Department of Energy issued the Sustainable Energy Strategy document, described earlier, which presented the Clinton Administration's national energy policy as a National Energy Policy Plan. This document contains all of the current policies in effect for the use of nuclear energy in the U.S. The Administration's nuclear energy policies include:

- Maintain the safe operation of existing nuclear plants in the United States and abroad and preserve the option to construct the next generation of nuclear energy plants.
- Increase operational safety at existing nuclear power plants. A top priority is achieving the greatest possible degree of global nuclear safety.
- Promote improving the safety of nuclear energy abroad by actively supporting the U.S. nuclear industry's pursuit of the multi billion-dollar international nuclear energy export market.
- Expedite the characterization of a geological repository as a safe method for high-level waste disposal and, if determined to be safe, build a geological repository to accept commercial nuclear waste. The characterization of Yucca Mountain is scheduled to be completed by the end of 1998, and if acceptable, the repository will be completed by 2010.

The current DOE program status for nuclear energy technology development is as follows:

- The ALWR program completed in FY 1997; no further DOE funds are budgeted for it.
The ABWR and System 80+ evolutionary ALWR designs were certified by NRC in May 1997.
- The AP600 is expected to receive NRC final design approval in mid-1998 and enter the NRC rulemaking process for final design certification, which could take another year. Westinghouse and industry will have to fund the remaining effort needed to achieve certification.
- The FOAKE program was completed for the ABWR in September 1996. The FOAKE program for the AP600 is about 80% complete and will be completed by Westinghouse in conjunction with design certification.
- The advanced reactor severe accident program (ARSAP) was completed for the AP600 design in 1997.

DOE proposed in its FY 1998 budget request a new Nuclear Energy Security Program, which was designed to promote license renewal of existing plants, develop advanced technologies for improved safety and performance of existing and new plants, and minimize the generation of spent nuclear fuel. The details of the Nuclear Energy Security Program are discussed under Objective 2. The FY 1998 Energy and Water Resources appropriations bill provides no funding for this program. Thus, for the first time since the U.S. started its civilian nuclear energy program, there is no current government role in the nuclear energy R&D program.

3.2 High-level Waste

The Nuclear Waste Policy Act (NWPA) of 1982 established a program to site a repository for the disposal of high-level radioactive waste, including spent fuel from commercial nuclear reactors. It also established the Nuclear Waste Fund with a fee structure for nuclear power plant owners and generators of radioactive waste and spent nuclear fuel (SNF) to pay for the program. The NWPA was amended in 1987 to direct DOE to study only one site, Yucca Mountain in Nevada, for the permanent repository. DOE was also directed to begin moving SNF to the permanent repository by January 31, 1998. An interim storage facility, the monitored retrievable storage (MRS) facility, other than the temporary storage facilities at the nuclear power plant sites, was authorized initially but no volunteer host sites were identified before Congress stopped funding the MRS effort in 1995.

The EPACT Title VIII (High-level Radioactive Waste) Section 801 directs the Administrator of the Environmental Protection Agency (EPA) to set public health and safety standards for the Yucca Mountain site, after commissioning the National Academy of Sciences to conduct a study and make recommendations. NRC is directed to modify its rulemaking to incorporate the EPA standards, and DOE is to implement the standards. DOE is also required to report whether its nuclear waste management plan and program is adequate for management of additional nuclear wastes that might be generated by new nuclear power plants.

The current status of the permanent repository is that the Yucca Mountain characterization studies are in progress and are expected to be completed by the end of 1998. If Yucca Mountain is found to be acceptable as a site, DOE plans on building the repository there and being ready to accept SNF shipments from commercial nuclear power plants by 2010.

In 1997, both houses of Congress passed legislation requiring DOE to provide a temporary central storage facility for spent nuclear fuel and defense high-level waste. A joint conference committee to finalize the bill to be sent to the President will meet early in 1998.

3.3 Nonproliferation

The Nuclear Non-proliferation Treaty (NPT) process was begun in 1964 by an Eighteen-Nation Disarmament Committee (ENDC). Several years of negotiations among the world's nuclear weapons states culminated in a treaty that was signed by President Johnson and 61 other national leaders in July 1968. The Senate approved the treaty, and the U.S. ratified the treaty on March 5, 1970. With respect to nuclear energy technology, the treaty provides for (a) assurance, through international safeguards, that the peaceful nuclear

activities of non-nuclear weapons states will not be diverted to making nuclear weapons; and (b) promoting the peaceful uses of atomic energy, to include the potential benefits of any peaceful application of nuclear explosion technology being made available to nonnuclear parties under international observation.

Article VIII of the treaty required a conference every five years to review the treaty. The 1975 conference expressed firm support for IAEA safeguards and recommended that greater efforts be made to make them universal and more effective. It also urged common export requirements designed to extend safeguards to all peaceful nuclear activities, called “comprehensive safeguards.” It also concluded that treaty compliance should facilitate access to peaceful nuclear assistance and credit arrangements.

The 1985 conference endorsed the IAEA and its safeguards system and examined ways to strengthen peaceful nuclear cooperation. Although it was unable to agree that “comprehensive safeguards” should be a precondition for significant nuclear exports to non-NPT, non-nuclear weapons states, the conference agreed not only on the desirability of such safeguards in non-nuclear weapons states but also that effective steps should be taken to achieve them.

The 1990 NPT review conference endorsed full-scope IAEA safeguards as a condition of significant nuclear supply, tighter export controls on nuclear technology transfers, and further cooperation in the peaceful uses of nuclear energy.

To implement export controls requirements of the NPT, the Zangger Committee was organized in the early 1970s. Article III of the NPT requires each member state not to provide source or special fissionable material, nor equipment or material designed for the processing, use or production of special fissionable material, to any non-nuclear weapons state for peaceful purposes, unless the source or special fissionable material shall be subject to IAEA safeguards. The Zangger Committee developed a list of controlled items, called the Trigger List because export of those items triggers IAEA safeguards. The list contains items that if misused could contribute to a nuclear weapons program, including plutonium, highly-enriched uranium (HEU), reactors, reprocessing and enrichment plants, and equipment and components for such facilities. The Zangger Committee meets twice a year and updates the Trigger List.

Another NPT-inspired group, called the Nuclear Suppliers Group (NSG), was organized by the U.S. in 1974 after India exploded a nuclear device. The group is now up to 34 members and has a stated purpose to ensure that nuclear technology suppliers uniformly apply a comprehensive set of guidelines to ensure that nuclear cooperation does not contribute to proliferation. The

guidelines for Trigger List exports require an agreement between IAEA and the recipient state demanding full-scope safeguards on *all* of its nuclear materials, not just the exported items; physical protection against unauthorized use of transferred materials and facilities; and restraints in the transfer of sensitive facilities, technology, and weapons-usable materials, i.e., exports that could contribute to the acquisition of plutonium or HEU. The NSG issued guidelines in 1992 to control “dual-use” goods, i.e., those which could have a nuclear weapons application, to minimize the risk of diversion of those goods.

The Atomic Energy Act of 1954, as amended, requires the NRC to issue an export license prior to the export of a nuclear facility or its components. An approved “Agreement for Cooperation in the Peaceful Uses of Atomic Energy” between the U.S. and the country where the export is bound is required. The Secretary of Energy must also authorize the export of nuclear power plant technology, since nuclear power plants produce plutonium during operation, per 10CFR810. Congress has the ability to block nuclear technology exports if it does not agree with the Executive Branch’s desires, as it has in the case of China in the Foreign Relations Authorization Act of 1990.

The Nuclear Non-Proliferation Act of 1978 contained President Carter’s policy statement against U.S. participation in the reprocessing of spent nuclear fuel. This policy statement continues to provide the basis of U.S. policy.

The current Administration’s policy on nonproliferation and export controls was announced by the President at his United Nations address delivered on September 27, 1993. This policy is enforced through Presidential Decision Directive (PD) 13, also issued on September 27, 1993, which specifically states that it is U.S. policy not to encourage the civil use of plutonium. These documents contain the following key policy elements:

- The U.S. will eliminate where possible stockpiles of HEU and plutonium, and ensure that, where they continue to exist, they are afforded the highest standards of safety, security, and international accountability.
- The U.S. will propose a multinational convention prohibiting the production of HEU or plutonium for nuclear weapons purposes or outside of international safeguards.
- Submit U.S. fissile material no longer needed for our weapons program to IAEA inspection.
- Pursue the purchase of HEU from former Soviet Union countries for its conversion to commercial fuel.
- Explore means to limit the stockpiling of plutonium from civil nuclear programs.
- Seek to minimize the civil use of HEU.

- Initiate a comprehensive review of long-term options for plutonium disposition, taking into account technical, nonproliferation, environmental, budgetary, and economic considerations.
- The U.S. does not encourage the civil use of plutonium, and accordingly does not itself engage in plutonium reprocessing for either nuclear power or nuclear explosive purposes.
- Dual-use technology export controls will be reviewed and eliminated unless required for national security and foreign policy interests.
- Nonproliferation export controls implementation procedures will be streamlined.

Recommendations for a Department of Energy Nuclear Energy R&D Agenda

Appendix 2 Nuclear Energy Related R&D in the United States

EXECUTIVE SUMMARY

Most of the nuclear energy-related research and development (R&D) in the U.S. is done by six organizations: the U.S. Department of Energy (DOE), the Electric Power Research Institute (EPRI), the U.S. Nuclear Regulatory Commission (NRC), the Westinghouse Owner's Group, the Boiling Water Reactor Owner's Group, and the Babcock & Wilcox Owner's Group (there is no Combustion Engineering Owner's Group). Some limited R&D is done by individual utilities and by the reactor fuel vendors. The DOE, EPRI, and NRC budgets have been in the range of \$60–90 million per year in recent years. The Owners' Group budgets are somewhat lower.

The goals and objectives, organization of the work, focus of the R&D, type of contract support, and final products of the DOE, EPRI, and NRC R&D are not the same. The DOE tends to sponsor a few large programs that, if successful, will make a significant impact on the use of nuclear power in the U.S., respond to certain international obligations, or support other Federal responsibilities such as spent fuel disposition. EPRI tends to sponsor a much larger number of smaller, shorter-term R&D projects that are focused on safe, environmentally benign, and cost-effective *plant performance*. The EPRI projects are organized around utility operational areas (for example, technologies to improve fuel reliability, reduce low-level waste, reduce operation and maintenance costs, etc.) and are expected to produce products that will be used by the utilities. The NRC also has many small R&D projects. But the NRC Office of Research projects are organized around certain technical disciplines (for example, thermal-hydraulics, materials aging, reactor structural performance, probabilistic risk assessment, etc.), and much of the exploratory research is concerned with advancing the state-of-the-art of the technology and thereby staying ahead of industry and putting the NRC in a position to make authoritative judgments. The R&D sponsored by the NRC Office of Research also responds to research requests from the Office of Regulation and to questions from the public, the Commissioners, and others. The Owner's Group programs are somewhat similar to the programs

sponsored by EPRI and primarily focus on current material aging issues and operation and maintenance cost savings items. However, the Owners Group programs are somewhat more involved with component aging mitigation and replacement technologies (for example, new bolting or pump shaft materials and designs), improved instrumentation and control, and operational procedures.

1.0 U.S. DEPARTMENT OF ENERGY SPONSORED R&D

The Clinton administration's nuclear energy policies include:

- Maintaining the safe operation of the existing nuclear power plants (NPPs) in the U.S..
- Retaining the option to construct a next generation of NPPs.
- Promoting nuclear safety worldwide.
- Expediting the characterization of the geological repository for high-level waste.
- Concluding an agreement with Russia to dispose of excess nuclear weapons materials by burning the plutonium in commercial reactors.

The most recent Congressional direction is contained in the Energy Policy Act of 1992 and requires the DOE to carry out its civilian nuclear programs in a way that will lead toward commercial availability of advanced nuclear reactor technologies, including technologies that use standardized designs or exhibit passive safety features. In response to these policies and directions, DOE has been sponsoring (or plans to sponsor) the development of three advanced light water reactor designs, technologies to support the implementation of reactor-based plutonium disposition in the U.S. and Russia, technologies to help assure the economic and safe operation of the existing NPPs through current and renewed license terms, and technologies to minimize the generation of spent (used) nuclear fuel.

1.1 Advanced Light Water Reactor Program

The objective of this program was to make available standardized nuclear power plant (NPP) designs with certification by the NRC and do so in a joint cooperative effort with industry. The designs will provide enhanced safety and reliability and will meet the needs of the electric power utilities as reflected in the Utilities Requirements Document developed in conjunction with the utility industry through the EPRI. When employed with advanced plant modularization and prefabrication techniques, pre-certified, commercially standardized ALWR designs will offer the prospect of

significantly improved competitiveness through reductions in life-cycle costs and construction time. The program is a cooperative cost-shared effort with the nuclear industry (foreign and domestic).

Three new standardized ALWR plant designs are currently under development. The two evolutionary plant designs were certified by the NRC in 1996. They are called “evolutionary” designs because they build directly on the experience and lessons learned from the NPPs already operating in the U.S. and around the world. However, the ALWRs will be easier to build, operate, and maintain and they will meet safety goals that are more than ten times more stringent than those of current plants. The two evolutionary designs are the General Electric (GE) Advanced Boiling Water Reactor (ABWR) and the ABB Combustion Engineering (ABB-CE) System 80+, both of which are large (1,350 MWe) plants.

The third standard design, referred to as the AP600, is being developed by Westinghouse Electric Corporation and is a smaller 600-MWe pressurized water reactor (PWR) design that uses “passive” safety features. The passive design employs conventional reactor and power generation technology but uses passive features for safety functions that are performed in current and evolutionary plant designs with active systems that use pumps and motors. This design is expected to be certified by the NRC in 1999. Once a design is certified, a utility may acquire the plant without further NRC review of the design, except for any changes from the certified design.

A fourth standard design, General Electric’s Simplified Boiling Water Reactor (SBWR), was also under development as part of the ALWR program. General Electric terminated the SBWR project in March 1996 to pursue a larger, passive BWR design.

The second part of the ALWR Program is the First-Of-a-Kind Engineering (FOAKE) Program. The specific objectives of this program are to perform detailed engineering beyond what is required to make a safety determination of two competitively selected ALWR designs in order to promote design standardization and facilitate firm and reliable cost estimates and construction schedules.

Advanced Boiling Water Reactor

The design for the ABWR differs from today’s BWR in a number of ways:

- (1) Safety improvements resulted in a more compact design; the ABWR’s building volume is only about 70% of that of current operating BWRs. This will reduce construction time and cost. It also makes the design more rugged and more immune to earthquake.

- (2) In the ABWR, the control rods are driven by electro-hydraulic systems as opposed to the simpler hydraulic design in the current BWRs. Having an additional drive mechanism reduces the probability of failure and improves the plant's ability to produce electricity and to meet changes in electricity demand.
- (3) All major equipment and components have been engineered with service and maintenance in mind so as to minimize downtime and reduce worker exposure to radiation.

Two ABWRs, which are very similar to the design certified in the United States, have been under built Japan. The first unit began operation in January 1996, and the second unit began commercial operation in July 1997. The total construction schedule for these plants was about five years.

System 80+

Like the ABWR, the System 80+ PWR is a simpler design and is engineered to achieve improvements in cost and safety with a number of significant features:

- (1) The volume of cooling water is greater than in the current ABB-CE plants, the System 80+ plant operates at lower temperatures, and the power density in the fuel is lower.
- (2) Design margins are increased, reliability of existing systems is increased, and new safety systems are added.
- (3) The control room and information processing systems have been totally revamped in ways that will reduce the burden on the operators and improve comprehension.
- (4) The steam generator design incorporates advances in materials technology and has also been improved for ease of maintenance.
- (5) The reactor is housed in a very large steel dual containment designed to withstand any credible accident.

Two ABB-CE System 80 units under construction in South Korea incorporate many of the advanced design features of the System 80+. Through ABB-CE's simplified design, the construction time can be reduced to only 48 months from first pouring of concrete to fuel load.

AP600 Passive Plant

The AP600 plant design is considered "passive" because the safety systems predominantly depend on the reliable natural forces of gravity, convection, evaporation, and condensation instead of operator actions, AC power supplies, and motor driven components. The AP600 has several large tanks of

emergency cooling water inside the containment structure above the reactor vessel. During an emergency, pressure and gravity assure that the reactor core is fully cooled. The main passive safety systems include:

- (1) Decay heat removal by a natural circulation heat exchanger using water stored inside the containment.
- (2) Passive safety injection systems:
 - Gravity flow core makeup tanks at high pressure.
 - Nitrogen pressurized accumulators.
 - A gravity drain refueling water storage tank at low pressure.
 - Gravity drain from the containment.
- (3) Passive containment cooling by natural circulation of air and gravity flow of water.
- (4) Emergency heating, ventilation, and air conditioning in the control room—compressed air and concrete walls as the heat sink.
- (5) Low power density core.

Because of their simplicity, these smaller plants can be built much faster than recently completed U.S. nuclear plants. Quick construction (3 to 4 years) is possible because many systems and subsystems would be assembled as modules in the factory, not on the plant site. Some of the important design features are:

- (1) A reactor coolant pump design with canned rotor pumps.
- (2) Fifty percent fewer valves, 35% fewer pumps, 80% less pipe, 45% less seismic building volume, and 70% less cable than a comparable conventional 2-loop 600-MWe plant.
- (3) A plant arrangement to enhance construction, operation, maintenance, and safety, and to lower costs.
- (4) Construction with modular systems and structures.

The AP600 design certification program included the initial plant design activities as well as the current activities related to the NRC design certification review process. A major test and analysis program was included to demonstrate the performance of the new passive design features and to provide a basis for the safety analysis of the AP600. Westinghouse used several test facilities in the United States and abroad to conduct extensive tests to prove the operation of the plant's passive safety features. A detailed analysis of the test results showed that the computer codes used for this design are valid and accurately predict plant behavior under normal and accident conditions.

FOAKE Program

In February 1992, DOE and a consortium of electric utilities called the Advanced Reactor Corporation (ARC) entered into a Cooperative Agreement for a five-year, cost-shared program to do detailed “First-Of-A-Kind Engineering” on at least two standardized ALWRs. The FOAKE Program implements requirements of the Energy Policy Act of 1992. This program completes much of the detailed, standardized engineering work that goes beyond what the NRC requires to conduct safety reviews and will provide the level of information needed by potential buyers to estimate construction costs and schedules with a high degree of certainty.

Two designs—GE’s 1,350 MWe ABWR and Westinghouse’s 600 MWe AP600—were selected in January 1993 by ARC to share FOAKE support. ARC manages the FOAKE Program under the overall guidance provided by DOE, assuring in-depth utility technical input and coordination in the management and performance of the program. The FOAKE Program for the ABWR design was completed in 1996. Completion for the AP600 is projected in 1998.

The goal of the FOAKE Program is to develop the engineering design for the site-independent features for the plant to a level of detail sufficient to define credible cost estimates and construction schedules to provide a baseline for achieving commercial standardization. A primary objective of FOAKE is to complete engineering to the point where essentially the only design work remaining is:

- (1) Procurement of equipment and material, and completion of necessary detailed design work that flows from that action.
- (2) Adaptation of the design to the specific site on which the plant will be built.
- (3) Incorporation of as-built information necessary as a result of the normal construction process, subject to strict control procedures that would discourage changes for other than unavoidable reasons.

The FOAKE Program will complete the ABWR and AP600 designs to the point of preparing specific procurement specifications for a predetermined set of major components that have long lead times for fabrication. For the remainder of the plant components, standardized performance requirements and specifications are to be defined on a basis of “form, fit, and function” in order to avoid unduly limiting competitive offers from component vendors at the time of plant acquisition.

1.2 Mixed Oxide Fuel R&D

The goal of the program sponsored by DOE's Office of Fissile Materials Disposition (DOE/MD), is to conduct the R&D necessary to support the implementation of reactor-based plutonium disposition in the U.S. and Russia. Current efforts focus on four generic areas: (1) development and demonstration of mixed oxide (MOX) fuel and cladding technologies; (2) fuel fabrication facility, reactor, and fuel cycle computational methods assessment, development, and applications; (3) fuel packaging and transportation technologies; and (4) economic evaluations of fuel fabrication facility and reactor operations.

Fuel and Cladding Technology Development

The first major activity focuses on the development of an improved understanding of fuel-side clad corrosion mechanisms and fuel reliability and performance issues. The ultimate goal of this effort is to provide guidance necessary for specifying impurity limits in MOX fuels, and to support licensing of these fuels for use in commercial light water reactors. DOE/MD is sponsoring both out-of-pile, and in-pile experimental programs to provide a better understanding of the behavior of chemical impurities in the fuel matrix, the transport of these impurities to the fuel/clad interface, and the potential interactions of these impurities with the fuel cladding material. The major impurity of interest is gallium.

DOE/MD is also sponsoring a joint U.S./Russian project to develop, test, and qualify weapons-grade VVER-1000 MOX fuels for use in Russia. The MOX fuel for these tests will be fabricated at the Bochvar Institute in Moscow and irradiated in the MIR test reactor at the Research Institute of Atomic Reactors (RIAR) in Dimitrovgrad. The U.S. is working with these Russian institutes to design the test, develop the fuel specification, fabricate the test fuel, perform the irradiations, and conduct the required post-irradiation examination.

Computational Methods

A significant computation effort is underway to identify and evaluate fuel and fuel-cycle management strategies to accommodate various disposition mission contingencies. This work includes detailed neutronic evaluations of various mixed low-enriched uranium and MOX core geometries, and the identification of reasonable fuel and core design options to achieve variable plutonium disposition rates through the reactor.

DOE/MD is also sponsoring a detailed evaluation of previous U.S. commercial MOX fuel tests to identify data of potential utility for

benchmarking of U.S. physics, neutronics, and safety codes and to apply the data in benchmarking and validation exercises. Additional new data is being obtained via participation in the international ARIANE Program, in which Belgium, France, Japan, England, and other nations are obtaining detailed data on both PWR and BWR commercial low-enriched uranium and MOX fuel performance at a variety of burnups and thermal conditions.

The Oak Ridge National Laboratory (ORNL) is the U.S. co-chair of the Joint U.S./Russian Working Group on thermal reactor- and fast reactor-based plutonium disposition and has the lead for coordinating the joint U.S./Russian efforts related to benchmarking of the U.S. and Russian computer codes. Researchers at ORNL, Texas A&M University, Kurchatov Institute (near Moscow), and the Institute for Physics and Power Engineering (near Obninsk) are working together to benchmark and validate a suite of U.S. and Russian computer codes required for criticality, physics, safety, and thermal hydraulic analyses of fuel fabrication facilities, reactors, and fresh and spent fuel shipping containers.

Fuel Packaging and Transportation Technology

Approximately 1500 to 3000 MOX fuel assemblies will be required for disposition of the U.S. surplus plutonium inventory. Current fuel shipping containers only accommodate two PWR assemblies. DOE/MD is currently sponsoring the design of an improved, high-capacity, fuel shipping container that would provide major advantages over existing shipping container options. These advantages include higher fuel capacity (two to three times as much fuel per container), and easier handling of the fuel container at the reactor site.

Fuel Fabrication Facility and Reactor Economics

DOE/MD has recently completed an evaluation of the cost and economic implications of construction and operation of a domestic MOX fuel fabrication facility, and conversion and operation of existing light water reactors for the plutonium disposition mission.

1.3 Nuclear Energy Security

The DOE Nuclear Energy Security Initiative focuses on research and development of technologies needed to help assure the economic operation of the existing U.S. NPPs through their current and renewed license terms, while at the same time enhancing safety and minimizing the generation of spent nuclear fuel. This will help maintain the current share of nuclear

power generation in the U.S. and preserve the option to increase its use in the future.

One hundred and nine NPPs now provide about 22% of the electricity generated in the U.S. These plants have proven to be a reliable source of baseload power. However, five NPPs have closed prematurely since 1989 due to age-related problems such as steam generator tube degradation and reactor pressure vessel embrittlement. In addition, the licenses for 48 of the currently operating plants will expire by 2015. Key technological issues and significant regulatory uncertainty threaten the license renewal option for many of these plants, which would otherwise be cost-competitive. Also, the lack of a deep geologic repository, located at an isolated and arid location, has resulted in used fuel piling up at NPPs in 41 states and, at some plants, political pressure for premature shutdown. The potential loss of nuclear baseload electricity generation capacity, compounded by the expected future growth in electricity demand, will have a significant impact on U.S. carbon emissions. This initiative proposes to conduct critical research and development of technology that is needed to address issues of age-related degradation and equipment obsolescence, and to develop ultrahigh-burnup fuel (and thereby minimize the amount of used fuel being discharged from the U.S. NPPs). This initiative also includes funding to support DOE's participation in selected international programs and to maintain certain critical university research capabilities. By achieving its objectives, the Nuclear Energy Security initiative will help the U.S. maintain its strong leadership position in the world to positively influence nonproliferation, global climate change, and reactor safety worldwide.

Maximizing Benefits from the U.S. Investment in Nuclear Power Plants

Technologies will be developed that can help maintain the continued safe, reliable, and economic operation of existing U.S. NPPs throughout their current and renewed license terms. To achieve this goal, the Department will accomplish the following objectives:

- (1) Develop technologies to inspect, characterize, and manage the effects of aging on key nuclear plant systems, structures, and components that impact safety and operation.
- (2) Develop technologies to improve plant operation and control, relieve critical equipment obsolescence issues, and enhance plant performance and economics while maintaining safety.
- (3) Develop technologies to reduce the costs and regulatory uncertainties for license renewal.

The materials used in some NPP components can be damaged by the temperatures, stresses, and radiation that are associated with the normal

operation of the plants. To assure the economic and safe operation of these plants, it is necessary to predict and measure the extent of this material damage and to determine its effect on the ability of the components to perform their design functions. It is also sometimes necessary to take appropriate and cost-effective actions to mitigate the effects of this degradation. Examples of key component-aging degradation include reactor pressure vessels embrittled after decades of operation in intense radiation fields; reactor internals damaged by stress corrosion cracking; instrumentation and electrical cables damaged after long-term exposure to radiation and high temperatures; and steam generator tubes cracked or degraded in harsh chemical or stress environments.

The instrumentation and control (I&C) systems in today's nuclear plants are based on technology developed in the 1960s and have been overtaken by the revolution in digital and computer technology. Spare parts for these old control systems have become increasingly scarce, in some cases nonexistent, increasing the potential for equipment failure or human error. Modern digital and microprocessor-based I&C technologies, while used extensively in the process and petrochemical industries, have not been designed and approved by the NRC for application in NPPs. In much the same way that modern digital controls and ergonomics make today's advanced jet liners safer and easier to fly than the aircraft of 25 years ago, modern advances in I&C technologies, man-machine interface techniques, and advanced information management systems could provide many benefits in the operation of NPPs. The DOE proposes to help the nuclear industry implement those advances.

The DOE technologies to inspect, characterize, and manage the effects of aging on key NPP systems, structures, and components and the DOE technologies to improve plant operation and control, relieve equipment obsolescence issues, and enhance plant economics while maintaining safety will then provide a basis for the nuclear industry to address the uncertainties associated with license renewal.

Spent Fuel Minimization Research and Development

The objective of the program is to minimize the amount of spent fuel discharged from the 109 commercial NPPs now operating in the United States. The specific goals are to (1) reduce the rate of spent fuel generation by 25% in seven years and cut the rate in half in 15 years and (2) improve the reliability and safety margins of LWR fuel. A reduction in the rate of spent fuel generation by one half and use of high burnup cores in the U.S. NPPs will reduce the cost of the DOE Civilian Radioactive Waste Management Program by \$1–8 billion, help improve NPP capacity factors by 5–9% (which is equivalent to adding 5–9 1000 MWe NPPs to the existing fleet), reduce

pressures on temporary fuel storage facilities, and significantly reduce worker exposure and the amount of low-level waste produced by the nuclear power industry.

The LWR fuel is currently limited to (a) 60 GWD/MTU peak rod burnup by the NRC because of concerns about high-burnup fuel integrity, and (b) less than 5% enrichment because of the design and licensing of the fuel fabrication plants and handling and storage equipment. In addition, the control rod worths and other aspects of the core neutronics designs may have to be modified to allow the use of significantly higher burnup fuel. Therefore, the program will address the following issues: high-burnup fuel integrity; high-burnup core design; equipment and procedural changes required to fabricate, ship, store, and handle higher enriched and higher burnup fuel; and the changes in equipment reliability and the surveillance and maintenance intervals required for extended refueling cycles. The most difficult challenge will be to develop a fuel with improved reliability and safety margins that can be operated to very high burnups. Most of the U.S. utilities are somewhat reluctant to extend the burnup of their fuel because the costs of handling failed fuel can be quite high, possibly requiring an unscheduled shutdown of the reactor.

The planned program will include a three-part approach:

- (1) Determine the useful life of the best fuel currently in commercial NPPs.
- (2) Develop a better fundamental understanding of the life-limiting degradation mechanisms at high-burnup.
- (3) Design and test advanced and innovative LWR fuel forms.

The research with the commercial spent fuel will include characterization of the condition of modern fuel that has been burned in commercial NPPs to the current limits, further irradiation of this fuel in a test reactor to ultra-high burnups, and design basis accident testing to assure that the fuel will meet the current NRC licensing criteria. Both loss-of-coolant (LOCA) and reactivity initiated accident (RIA) tests will be conducted. A complete set of results, including appropriate computer models, should be available in about six to seven years.

The development of the advanced fuel will be done in collaboration with the international fuel vendors and fuel experts at the various national laboratories. The various advanced fuel designs will probably first be irradiated in a test reactor (including power ramp tests) and then removed, examined, and subjected to transient testing. Some advanced fuel may also be placed in lead test assemblies (LTAs) in commercial NPPs and then moved into a test reactor for further irradiation and transient testing.

In parallel with the irradiation of the advanced design fuels in the test reactors, laboratory research to study the metallurgical and environmental factors that affect the degradation (corrosion and radiation hardening) of the fuel cladding and analysis to evaluate fuel designs that better retain the fission products within the fuel, have more uniform rod internal pressure, and minimize fuel-cladding mechanical interactions will be conducted. This work will be a collaborative effort involving national laboratories as well as fuel vendors and a number of universities.

The products available for use in the commercial nuclear power industry include:

- (1) A thorough evaluation of the useful life of the best fuel currently being sold by the fuel vendors at the end of 7 years. We expect that a number (maybe all) of the latest product lines can be used at burnups above the current U.S. NRC limit of 60 GWD/MTU.
- (2) Development of initial testing of advanced ultra-high-burnup fuel designs, sufficient for the vendors to start selling lead fuel assemblies at the end of 7 or 8 years.
- (3) A well-documented physical understanding of the metallurgical and environmental factors that affect cladding (and assembly structural material) degradation. Improved fuel and fuel assembly predictive models and a solid technical basis for the sale and licensing of advanced fuels will be developed at the end of 15 years.

International Collaboration

Participation in international programs:

- (1) Helps maintain U.S. leadership and influence in the international application of nuclear technologies.
- (2) Helps open new markets to U.S. industry to create new, high-technology jobs in the U.S..
- (3) Helps provide U.S. access to overseas expertise, technology, and research capabilities to reduce program costs.

Much of this work will be done through two important international organizations: the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD/NEA) and the United Nation's International Atomic Energy Agency (IAEA). Collaboration through OECD/NEA will allow DOE to use certain international facilities and program activities to leverage domestic investments in related activities. Research areas of interest include high-burnup-fuel performance and safety, aging degradation of selected NPP materials, and man-machine systems research. The DOE also plans to continue its leadership and participation in the IAEA

in areas related to enhancing the safety, performance, and reliability of commercial NPPs.

The DOE also has several important international bilateral agreements, including work with Russia to help them improve the safety of their nuclear facilities and an agreement with Japan to develop advanced robotic systems for decontamination and decommissioning projects. The DOE has also been working with a number of countries to help resolve certain severe accident issues so as to complete the development of a suite of advanced severe accident management tools for use in the U.S. and elsewhere.

The U.S. has a very important strategic interest in assuring that the overseas nuclear energy growth takes place with an emphasis on safety and on minimizing proliferation risks. The U.S. has been the world leader in nuclear safety and nonproliferation issues in the past; however, if the U.S. is to continue to have a significant voice in the international arena, the U.S. must maintain an active nuclear industry and remain engaged on a government level. In addition, the worldwide growth of nuclear power provides a broad market for U.S. industry. The U.S. has the safest, most advanced NPP designs in the world, and the sale of these designs could provide significant economic benefit to the country.

Maintaining Critical University Research Capabilities

An effort is proposed under the Nuclear Energy Security program to involve the nuclear engineering departments at the U.S. universities in the individual research areas discussed above. Specifically, the Department proposes to set aside a fixed portion (about 10–15%) of the program funding to sponsor university research that supports the goals and objectives of the Nuclear Energy Security Program. This will:

- (1) Help maintain a valuable part of the nation's science and technology base.
- (2) Apply the creativity and energy available in U.S. universities to solve real-world technology problems at low cost.
- (3) Encourage talented students to study the radiological sciences, which are needed for broad application in today's high-technology economy.

The Department regards universities as integral team players on the program and seeks the involvement of young scientists and engineers who can work with experienced researchers and professionals on these programs. University participation and input will be encouraged in team program reviews, work plan meetings, and technology reviews. Student participation in the conduct of university R&D support work will be required as a condition for eligibility to receive funding.

2.0 ELECTRIC POWER RESEARCH INSTITUTE SPONSORED R&D

EPRI's nuclear energy related research and development is conducted by the Nuclear Power Group. The goal of the Nuclear Power Group is to provide the integrated technology base essential to achieve safe, environmentally benign, and cost-effective plant performance. This should promote the regulatory stabilization and cost competitiveness required for a renewed expansion of nuclear power. The EPRI R&D program is organized around the six *targets* discussed in the remainder of this section and is supportive of the short-range economic interests of EPRI's nuclear members and their stakeholders.

During the past two decades, more than 400 R&D products have been developed and delivered by the Nuclear Power Group. Noteworthy developments include operational guidelines to prevent and control steam generator tubing degradation in PWRs; remedial measures for BWR pipe stress corrosion cracking; radiation reduction technologies; state-of-the-art safety analysis methods; cost-saving maintenance, engineering, and human factors guides; advanced nondestructive examination (NDE) technologies; and requirements for advanced light water reactors ALWRs. The CY-1997 budget for those activities was approximately \$84 million.

2.1 Advanced Nuclear Technology Target

The objectives of this target are to: (1) develop investment-ready nuclear energy options that have the potential for economic implementation around the turn of the century; (2) follow developments related to advanced reactor concepts and perform joint studies with utilities, government, and international organizations; (3) explore innovative ideas that have a high potential for reducing the cost of operating current plants; (4) conduct limited, but effective, exploratory research, in a highly leveraged way, to support the resolution of corrosion issues in NPPs, and, in particular, extend the life of components that are subject to high radiation doses and may be limiting to economical plant life extension; and (5) develop integrated solutions that can simplify the management and reduce the cost of designing, building, operating, maintaining, and decommissioning nuclear plants.

Activities completed include Utility Requirements Documents for Evolutionary ALWRs and for Passive ALWRs, and the NRC Safety Evaluation Reports on these documents. Ongoing projects include (1) designs for investment-ready Westinghouse AP600s; and (2) validated stress corrosion cracking models. Future projects will include (1) the development of tools to simplify management and reduce the cost of designing, building, operating, maintaining, and decommissioning NPPs; and (2) selected studies

on the technical and economic issues surrounding the advanced reactor concepts.

2.2 Fuel Reliability, Storage, and Disposal Target

This target focuses on increasing fuel reliability by identifying the root causes of fuel failures and providing technologies for evaluating vendor-proposed new designs or remedies. Significant resources are directed toward lowering overall fuel-related operations and maintenance (O&M) costs, providing cost-effective and licensable methods for on-site storage of spent fuel, developing and delivering technical bases that support long-term storage, facilitating the transfer of spent nuclear fuel to the DOE, and helping DOE develop a cost-effective and timely high-level waste repository.

Activities completed include guidelines on fuel reliability and ESCORE (a computer program for fuel burnup extension), Boraflex guidelines, and on-site storage technologies such as NUHOMS and metal casks. Future and ongoing products include technical evaluations of postfailure fuel degradation, reactivity insertion accident criteria, fuel performance, burnup extension, and impact of water chemistry on fuel cladding corrosion. Other products include R&D that will enable efficient use of multipurpose canisters by utilities, produce a detailed design of a spent fuel transfer facility, remedial measures to address Boraflex degradation, transportation technology, and improvements in the EPRI-developed performance assessment code (IMARC) that will assist in repository licensing.

2.3 Low-Level Waste, Chemistry, and Radiation Control Target

This target provides technology to reduce low-level waste (LLW) sources, minimize LLW volumes, develop storage options, control water chemistry to minimize corrosion and the input of corrosion products, improve radiation protection procedures, and control out-of-core radiation fields. Recent developments include the LLW characterization guidelines, amines for PWR secondary system pH control, the NOREM cobalt-free hardfacing alloy, the BWR zinc injection passivation process, and improved LOMI and EPRI DFD decontamination processes. Other activities completed include guidelines on LLW interim on-site storage and mixed waste management and updated PWR/BWR water chemistry guidelines. Software products include the LLWWASTECOST modules, chemWORKS simulator for PWR/BWR plants, and DERAD decommissioning economics and risk advisor.

Revisions to the above products will incorporate new plant experience and technical developments. Future products include the EPRI wasteWORKS

software for evaluating dry and liquid waste processing options; the EPRI SMART chemWORKS software for real-time water chemistry control; a technical evaluation of advanced technologies for LLW and mixed waste management including liquid waste management guidelines and demonstrations of the BWR depleted zinc-64 injection, various improved decontamination processes, and a chromium passivation process for replacement components; guidelines on effective dose equivalent implementation and application of water chemistry developments, including improved PWR amines and BWR feedwater iron reduction; and software/guides on evaluating decommissioning technology developments.

2.4 Major Component Reliability Target

The objectives of this target are to reduce and control the cost impact of corrosion-related damage in steam generators, pressure vessel penetrations, piping, reactor vessel internal components, and steel containments; and to develop cost-effective means to manage radiation embrittlement and maintain serviceable reactor pressure vessels. Activities under this target have resulted in technology, information and tools for managing degradation of major components. Previous results have been applied to manage the residual life of steam generators and to improve their reliability and have resulted in avoided costs of >\$5 billion in PWR plants since 1978. Ongoing work on degradation-specific management is expected to delay steam generator replacement or derating by up to five years and to further improve reliability. A series of products related to mitigation and repair of stress corrosion cracking have resulted in avoided costs of >\$2 billion in BWR plants since 1981.

Current projects are producing water chemistry remedies applicable to degradation of steam generator tubing, vessel head penetrations, and BWR vessel internals. Products related to BWR vessel internals will include evaluation, inspection, repair, and mitigation guidance. This guidance will be disseminated as BWR Vessel & Internals Projects (BWRVIP) products. Corrosion-related technology applications will be delivered through the CHECWORKS software workstation. Planned repair-related developments are also applicable to pressure vessels, internals, and steam-generator tubing. Another group of planned products includes evaluation methods, data, and computer codes for managing reactor vessel radiation embrittlement. Thermal annealing for restoration of properties is a related product objective.

2.5 O&M Cost Control Technology Target

This target involves development and delivery of technology that contributes to successful utility cost-control programs. Activities completed include a comprehensive set of tools to implement least-cost, reliability-centered maintenance; validated models to predict the performance of motor-operated valves; a handbook to assist plants in avoiding fatigue-related failures; the development of technology centers and programs such as the Nuclear Maintenance Applications Center, the Nondestructive Evaluation Center, and the Plant Support Engineering program; I&C guidelines on licensing digital upgrades and electromagnetic interference and software verification and validation; and the technical basis for an improved license renewal rule and life-cycle management (LCM) evaluations of key systems and structures.

Future and ongoing activities include integration of preventive maintenance technologies with predictive maintenance techniques; evaluation of in-situ piping rehabilitation; demonstration of LAMB wave ultrasonic inspection of heat exchanger tubing; application of risk-based inspection; the timely development of maintenance and engineering guides, periodicals, and databases; further development of the test bank for use in assessing maintenance personnel proficiency; I&C LCM guidance and results from host plant demonstrations of I&C modernization; and application of LCM products to specific nuclear unit issues.

2.6 Safety and Reliability Assessment Target

The objectives of this target are (1) to deliver risk and reliability technology aimed at reducing O&M costs without compromising safety, (2) to develop and deliver analysis methodologies needed to resolve regulatory issues and to perform independent reload and plant operational safety analyses, and (3) to ensure a stable regulatory environment linked to quantitative safety criteria that permits industry resource allocations proportional to risk. Results and products completed in the target include outage risk assessment and management software; Seismic Qualification Users Group methodologies; a motor-operated valve ranking methodology; Individual Plant Examination (IPE) and Individual Plant Examination of External Events (IPEEE) software products; and the widely used safety codes RETRAN, VIPRE, GOTHIC, and MAAP. Application of EPRI's risk assessment technology has supported reduced containment leak testing under the revised 10 CFR Appendix J. EPRI's PSA Applications Guide is being utilized by industry analysts in conjunction with risk-based in-service testing and other applications.

Ongoing and future efforts include more outage management technology, seismic equipment qualification databases and guidelines, Appendix B (Q/A)

cost reduction, on-line maintenance support software, performance-based fire protection, the risk and reliability workstation to integrate and improve the efficiency of using PSA software, integration and in-plant application of the safety codes, application of the revised source term to reduce equipment qualification costs, and timely solutions to severe accident management implementation issues.

3.0 U.S. NUCLEAR REGULATORY COMMISSION SPONSORED R&D

3.1 Office of Nuclear Regulatory Research

The Energy Reorganization Act of 1974 mandated the formation of the Office of Nuclear Regulatory Research to ensure that the Commission would have “an independent capability for developing and analyzing technical information related to reactor safety, safeguards, and environmental protection in support of the licensing and regulatory process.” The current NRC research program includes both confirmatory and anticipatory research and focuses on areas with high safety and regulatory significance. It is organized into the six major program areas discussed below and is funded at about \$60 million per year (FY96). The NRC research funding has been sharply declining in recent years. Activities that stimulate collaborative international research, cooperation with DOE and industry, and support the university nuclear engineering departments are being encouraged.

Reactor Aging Program

The goal of the reactor aging program is to provide data and analysis tools necessary to identify (anticipate), quantify (inspect, validate), manage, and regulate the effects of aging in NPPs for the current license periods and license renewal. The subjects of interest include reactor pressure vessel (RPV) embrittlement and thermal annealing; fracture analysis methods; environmentally assisted cracking of safety-critical systems and components; nondestructive evaluation techniques; steam generator tube and electric cable degradation; and inspection, surveillance, testing, and maintenance technologies for various mechanical components. Current and near-term deliverables include data to validate the RPV annealing rule and regulatory guide, a revised PTS regulatory guide, implementation of improved fracture mechanics methods into the ASME Code, validated models for steam generator tube severe accident analysis, revised guidelines and supporting data for electric cable qualification, and revised criteria for evaluating licensee in-service testing (IST) programs for pumps and valves.

Reactor Structural Performance Program

The goals of the Reactor Structural Performance Program are to (a) provide information needed to develop regulatory acceptance criteria for judging NPP site suitability; (b) assess and validate analytical methods for structural performance; and (c) determine the adequacy of margins of existing facilities. This program addresses the seismological, geological, and geotechnical factors associated with plant siting. Subjects of interest include inspection of aged/degraded NPP structures and components; assessment of the design and operational capacities of NPP structures, systems, and components; earth sciences investigations; and siting and structural aspects of non-reactor facilities such as gaseous diffusion plants and independent fuel storage facilities. Current and near-term deliverables include a trial implementation of the NRC, DOE, and EPRI guidance on conducting probabilistic seismic analyses; revised Regulatory Guides 1.60, 1.61, and 1.92; seismic data from large-scale main steam and feedwater piping systems; data from large-scale concrete containment pressure tests; an assessment of the effects of grease leakage from prestressing tendons on concrete containment strength; and data from seismic proving tests of concrete containments.

Probabilistic Risk Assessment Program

The goals of the Probabilistic Risk Assessment (PRA) Program are to (a) support risk-informed regulation by developing guidance and methods for PRA and (b) develop insights on the application of PRA through reviews of the IPEs and IPEEEs. The current and near-term products include Regulatory Guides in the area of overall PRA, inservice inspection (ISI), IST, quality assurance (QA), and Plant Technical Specifications. Other products include PRA methods for human reliability analysis, organizational performance evaluations, fire risk, plant aging, digital I&C, and consequence uncertainty. In addition to these R&D activities, this program also performs IPE and IPEEE reviews and issues appropriate regulatory documentation and insight reports.

Thermal Hydraulics Program

The goals of the Thermal Hydraulics Program are to (a) develop and maintain thermal-hydraulics experimental capabilities and analytical tools for the independent assessment of NRC licensee submittals and (b) analyze and evaluate NPP operating events and safety issues to assure an appropriate basis for regulation. Subjects of interest include plant transient analysis, plant transient code improvements, thermal hydraulic testing, fuel behavior, and reactor physics analysis. Current and near-term deliverables include correction of currently identified deficiencies in the existing thermal-

hydraulics codes, completion of the AP600 related experiments, and completion of the FRAPCON and FRAP-T6 codes with high-burnup-fuel properties. Longer-term deliverables include a new state-of-the-art thermal-hydraulics code to replace the existing thermal-hydraulics codes, data to support the future code, and high-burnup-fuel cladding ballooning and quench data from simulated loss-of-coolant accident (LOCA) tests.

Control, Instrumentation, and Human Factors Program

The goals of this program are to (a) develop a credible basis of understanding of the performance characteristics of digital I&C systems, including software reliability and man-machine interface issues, and (b) develop methods for assessing human and organizational performance for use in regulatory applications. Subjects of interest include hybrid control rooms, root cause investigations, human performance evaluations, environmental qualification of digital I&C hardware, programming languages and CASE tools, adequacy of industry standards, guidelines for evaluation of the human-system interface, and total system reliability and acceptability. Current and near-term deliverables include development of a technical basis (reports) for hybrid and advanced control rooms and for staffing levels at operating plants, a revised Regulatory Guide 1.8, a new Regulatory Guide 1.1.64 (time response criteria for safety-related operator actions), a complete revision to the HPIP, a new Regulatory Guide on EMI/RFI, and data on the effects of smoke on digital I&C equipment.

Severe Accidents Program

The goals of the Severe Accidents Program are to (a) develop and maintain tools for analysis of severe accidents and (b) expand the experimental base (through international collaboration) to understand and quantify severe accident phenomena. The technical issues of concern include fuel-coolant interactions, hydrogen combustion, lower head integrity, debris coolability, and radioactive source terms. The work includes the further development of various severe accident computer models. Current and near-term deliverables include completion of (a) the fuel-coolant interaction experiments designed to evaluate the chemical augmentation of the energetics, (b) the high-temperature hydrogen combustion experiments, (c) the RASPLAV program, (d) the in-vessel cooling experiments, and (e) the lower head failure experiments. Other near-term deliverables include updated releases of the MELCOR, SCDAP, and CONTAIN codes; complete peer reviews of the VICTORIA and the fuel-coolant interaction codes; and analyses in support of the AP600 review.

3.2 Office for Analysis and Evaluation of Operational Data

The Office for Analysis and Evaluation of Operational Data provides the NRC with independent analysis of operational data and serves as the focal point for the assessment of operational experience through the review, analysis, and evaluation of the safety performance of both reactor and nuclear material facilities. The office collects, analyzes, and disseminates operational data; assesses trends in performance; evaluates operating experience to provide insights into, and to improve the understanding of, the risk-significance of events; conducts reliability studies of risk-important systems; analyzes human performance in operating events; and produces periodic Performance Indicator, Abnormal Occurrence, and Accident Sequence Precursor Reports. The office is also responsible for the NRC's Diagnostic Evaluation Program, Technical Training, and Incident Investigation and Response Programs. The Office spent about \$13 million for contractor support in FY96, of which, about half went for R&D-related activities to support its mission. Examples of these R&D activities are listed below.

- Development of enhanced algorithms that utilize increased types of operational data (e.g., allegation data, regulatory fines, O&M costs, etc.) to predict poor or declining performance of operating commercial NPPs. This will primarily be used to support the semiannual review of the commercial NPP performance by the NRC senior managers.
- Development of risk-based performance indicators for the commercial power plants. This process has been underway for a long time, and the Office of Analysis and Evaluation of Operational Data (AEOD) has planned on incorporating the results of several operating event analysis programs into the development of the risk-based performance indicators.

3.3 Office of Nuclear Material Safety and Safeguards

The Office of Nuclear Material Safety and Safeguards develops and implements NRC policies for non-reactor nuclear and radioactive material activities such as uranium recovery activities; fuel fabrication and fuel development; medical, industrial, academic, and commercial uses of radioactive isotopes; safeguards activities; transportation of nuclear materials; away-from-reactor spent fuel storage; low-level and high-level radioactive waste disposal; and nuclear facility decommissioning. The Office of Nuclear Material Safety and Safeguards sponsors some R&D in support of their mission.

4.0 INDUSTRY SPONSORED R&D

4.1 Babcock & Wilcox Owner's Group

4.2 Boiling Water Reactor Owner's Group

4.3 Westinghouse Owner's Group

The Westinghouse Owners Group (WOG) historically has conducted R&D programs on a very limited basis, relying on other industry organizations to provide the needed R&D effort, most notably the EPRI. However, the WOG does conduct some programs to address issues that other industry organizations are unable to address when the need is identified to support the continued safe operation of its members plants, or when the benefit of such an effort could provide a significant O&M cost savings to the membership. The WOG has conducted or is conducting programs, some in conjunction with other organizations, which address material aging issues and O&M cost-saving items.

For material aging issues, the programs are:

- (1) Reactor Vessel Closure Head Penetration Alloy 600 Program: Determine the effect of penetration microstructure and material type on PWSCC susceptibility, and assess the mitigative techniques for PWSCC initiation and growth rates. Program deliverables will include a methodology for the members to assess their unit(s) susceptibility, inspection guidelines, repair techniques, and possible mitigative options.
- (2) Reactor Vessel Internals Bolting Program: Develop and qualify a new material for reactor vessel internals bolting that will extend the life of this component. Program deliverables will include an assessment of the current bolting material, testing of bolts removed from service, operational safety assessment, and tooling requirements for bolt inspection and replacement.
- (3) Charging Pump Shaft Failure Program: Identify and demonstrate a new replacement pump shaft material for achieving improvement in service life for this component. Program deliverable will be a report on the various materials tested.

- (4) Reactor Vessel Annealing Program: Verify that the reactor vessel and appurtenances' dimensional stability is maintained during and after an in-situ annealing process, which included heating curves, homogeneity of temperatures, temperature gradients, temperatures experienced by primary concrete structure, and validation of computation models for these parameters. Program deliverables will be the reports documenting the tests performed, pre-test predictions and post-test results, validation of the computation model, and procedures developed and used for the annealing demonstration.
- (5) Reactor Vessel Fracture Toughness Testing Program: Determine applicability and demonstrate the new transition region fracture toughness techniques and work with the industry to have these techniques incorporated into the ASME codes. Program deliverable consist of technical reports detailing the results of the testing performed to support the development of the appropriate ASME code cases.
- (6) Guide Tube Support Pin Replacement Material Program: Develop and qualify a new pin material and design that will alleviate SCC concerns and significantly extend the operational life of these components. Program deliverable will be reports on the design of a new guide tube support pin and qualification of the new material.

For O&M cost-saving items, the programs are:

- (1) Application Specific Integrated Circuit (ASIC) Replacement Cards Development program: Develop a new I&C process protection system hardware platform that offers the advantages of state-of-the-art digital technology in a software-less form. The new hardware platform will be an ASIC mounted on new printed circuit boards designed to interface directly with the existing analog system hardware. Effort includes design, qualification, and licensing of the ASIC-based replacement boards for use in NPPs. Program deliverable will be the reports with the manufacturing design information, documentation of the qualification process, and licensing information.
- (2) GOTHIC Shutdown Assessment Model program: Develop models for the Westinghouse 2, 3, and 4 loop plants using the GOTHIC computer code for use in assessing the plant conditions during shutdown operations that would provide plant capabilities and responses to both operational cases and postulated accident cases. Program deliverable will be the generic 2, 3, and 4 loop model shutdown codes.
- (3) Reactor Coolant Chemistry Initiatives: Based on current plant operations and chemistry data, assess and determine the optimum chemistry management that will lead to reduced shutdown radiation fields,

optimize practices in regard to production and release of fission products to improve outage schedules, and assess chemistry management to minimize the production of corrosion products affecting fuel performance. Program deliverable will be a report that discuss the findings and recommendations for the control, production and transport of corrosion products, optimization of shutdown chemistry operations, and reduction in the rate of fuel clad crud deposition.

4.4 Fuel Vendor-sponsored Nuclear Energy R&D

Nuclear fuel vendors conduct R&D programs that are targeted at technology improvements to enhance market share. Currently U.S. fuel vendor R&D focuses on two areas: fuel reliability and fuel burnup extension. The two areas are closely related, because measures developed to extend the burnup capability must not impact reliability.

Although the overall fuel reliability has continued to improve over the past decade, three modes dominate the remaining failures: debris fretting, fretting from assembly hardware, and manufacturing defects. All of the vendors are addressing debris fretting through advanced filters incorporated into their assemblies. Westinghouse has developed and is supplying a debris filter bottom nozzle, a protective bottom grid, elongated bottom end plugs, and fuel rods coated with zirconia near the bottom to mitigate debris fretting. Framatome and Framatome Cogema Fuels have also developed an advanced anti-debris plate that includes electrochemically machined flow holes to achieve a lower overall pressure drop than current designs. GE has developed a debris filter lower tie plate and is assisting utilities with development of more effective foreign material exclusion programs. Siemens has developed the FUELGUARD lower tie plate, which utilize parallel curved blades to reduce debris fretting. ABB-CE has developed the GUARDIAN bottom grid for debris filtering. These companies continue to research additional modifications to further reduce the size of debris potentially entering the fuel assemblies.

The second type of failure is fretting from assembly hardware, usually grid spacers. Westinghouse has developed low-pressure drop grids and is investigating alternative placement of these grids to reduce flow-induced vibration. Siemens has developed new spacer and intermediate flow mixer designs that utilize a larger spring-to-rod contact area to reduce fretting. ABB-CE has developed an advanced grid that incorporates an “I” spring to increase the contact area and reduce fretting.

The final failure mode impacting reliability is undetected manufacturing defects. GE has implemented a laser welding procedure on all end caps to eliminate the potential for undetected, interconnected porosity in the Zircaloy

bar stock. GE has also introduced a new upper end cap welding procedure that utilizes a single step rather than the girth weld/seal weld two-step procedure utilized previously. GE continues to develop “soft-handling” fabrication procedures to eliminate pellet chips and missing surface area. ABB-CE has adopted automated laser welding and 100% non-contact inspection of all grids to improve their performance. The other vendors continue to implement similar improvements.

The vendors are also investing substantial R&D budgets into burnup extension. Burnup is currently limited by fission gas release (and the associated fuel rod internal pressure and fuel swelling) and by cladding degradation. Fission gas release is being addressed through the incorporation of additives in the fuel matrix and through advanced fabrication processes that increase the average grain size of the fuel while maintaining an acceptable fuel creep rate to limit the potential for pellet clad interaction. Advanced fuel designs are also under development that provide additional room for rod axial growth during irradiation and provide additional plenum volume for additional fission gas release.

Cladding degradation is the subject of much of the current vendor-sponsored R&D. Westinghouse has developed ZIRLO, a proprietary zirconium-based alloy that contains niobium to minimize water-side corrosion. ABB-CE has developed OPTIN, a process-optimized low-tin Zircaloy-4, and is currently testing Anikuloy, an advanced zirconium-based alloy that includes niobium. GE is investigating process modifications to control the secondary phase particle sizes to optimize the cladding mechanical properties. Siemens is testing an advanced duplex liner cladding for BWRs that utilizes an iron-enhanced liner to reduce the severity of secondary hydriding of the zirconium liner following a primary cladding breach.

Recommendations for a Department of Energy Nuclear Energy R&D Agenda

Appendix 3 Summary of Issues That Drive Nuclear Energy Research and Development

EXECUTIVE SUMMARY

Nuclear energy is a fundamental element of the United States' policies on national security, environmental quality, waste management, economic competitiveness, and institutional infrastructure; without this component, all would be weakened. For example, the policy of the United States to prevent proliferation of nuclear materials is not possible without the essential foundation of a nuclear energy program. At the same time, nuclear energy is a key component of the nation's energy security and diversity, providing nearly 22% of electrical generation in the country today. The environmental benefits of nuclear power are well known; and the use of nuclear energy has a smaller environmental impact than fossil fuel technologies, impacting the public well-being throughout the entire world. However, nuclear energy must maintain its competitive edge in the face of uncertainties such as utility deregulation, spent fuel disposal, and large decommissioning and decontamination costs.

Nonproliferation is a significant issue with nuclear power because the fissile materials used and generated in power production can be subverted for use in nuclear weapons. If the United States loses its leadership role in nuclear power generation, then the U.S. has a much more difficult task of exporting a culture of control of nuclear materials, which is essential to nonproliferation. Effective nonproliferation policies require the protection of enabling and supporting technologies. In addition, a nonproliferation approach could be built into exports to the world—if the United States has a position of world leadership. On the other hand, other countries that develop a commercial nuclear power industry will gain expertise in areas necessary for a nuclear weapons program. Any state or group investing the effort can acquire the experts and technology for nuclear technology; and this is why control of essential materials and technology is mandatory. With the decline of its nuclear industry, the United States is no longer the sole source of nuclear

expertise or the major supplier of parts to the international nuclear market, and its attitude of nonproliferation consequently has less influence worldwide.

Internationally, nuclear plants in the former Soviet Union continue to operate in areas of economic uncertainty. Several of these plants are crucial to maintain a secure supply of electricity to the local region but suffer from the economics woes that often accompany a time of political change. The security of the energy supply is dependent on the continued safe and secure operation of these plants.

Nuclear energy is a key component to the stability of the energy infrastructure in the United States. A diverse fuel mix, including nuclear, is essential to the United States; it ensures that electrical power will be readily available at all times. Approximately 22% of the current U.S. electrical generation is provided by nuclear power. An infrastructure of nuclear technology is needed to preserve the reliability and stability in these 109 operating plants and to maintain the option of building advanced reactors.

As part of the essential energy supply of the United States, nuclear energy helps limit the production of carbon dioxide, nitrogen oxides, sulfur dioxide, and particulate emissions associated with fossil fuels. The environmental consequences, as the worldwide demand for energy burgeons, are a concern of increasing importance. Nuclear energy is an integral part of the energy mix in the United States at the moment, and must be for the foreseeable future if supplies of electricity are to remain adequate without an appreciable increase in the use of fossil fuels and an inevitable accompanying increase in carbon dioxide emissions. Because nuclear power plants do not use fossil fuels, they do not emit air pollutants.

Internationally, the demand for electricity is growing and is projected to nearly double between now and 2015. This is particularly true in Asia where the demand for electricity is growing at a phenomenal rate and there is a need to ensure that the global supply of energy is met without environmental degradation. The rapid growth in global demand for fossil fuel-driven new generation capacity, particularly coal-generated capacity in China and India, will be accompanied by proportional increases in air pollutant emissions. The environmental costs of these plants will affect the whole world, and alternative power generation technologies to these countries are necessary to prevent excessive environmental damage.

Safe, reliable, and cost-effective nuclear waste disposal is needed; this area presents a host of issues that are crucial to nuclear power in the United States. It includes not only high- and low-level waste disposal but also transportation of spent fuel and decontamination and decommissioning of nuclear facilities. Missing now is a national solution for waste disposition.

Nuclear power faces a number of challenges to survive in the impending era of utility deregulation. Thus, issues connected with economic

competitiveness are high on the list of concerns. The amount of spent fuel generated by a utility directly contributes to the size of spent fuel storage pools and waste disposal costs. The economic competitiveness of the utility is greatly dependent on the minimization of spent fuel. Also, today's consolidation and compaction methods will no longer be viable when large numbers of facilities must be decontaminated and decommissioned. While utilities have accumulated large decommissioning funds, these funds will not be adequate if utilities must use current decontamination and decommissioning (D&D) techniques.

The nation has more than a \$200 billion investment in nuclear power plants and has the infrastructure for maintaining "American know-how" in nuclear technology. The major issues connected with the future of nuclear power must be resolved to ensure the future energy supply and environmental well-being of the country. The decline in the nuclear industry is resulting in an erosion of the technical knowledge base.

At present, funding is inadequate to maintain a meaningful nuclear program in the United States. Without continued research and development, the United States will no longer have the personnel to actively engage the international community and encourage a safety culture in other countries. If this trend continues, the United States, former leader in nuclear power, will be only an observer.

Finally, the successful application of nuclear energy in support of national security requires gaining public acceptance of the technology. While nuclear energy is accepted and being pursued enthusiastically in other countries, the U.S. public has not accepted it as anything more than an option for the future. The tide of negative information provided to the public must change to a new climate of open communication in order to obtain public trust and acceptance.

1.0 NATIONAL SECURITY ISSUES

The U.S. nuclear energy program is an important component of national security. U.S. policy to prevent the proliferation of nuclear materials is not possible without the essential foundation of a nuclear energy program. With an in-depth knowledge of the technologies of the nuclear fuel cycle and with a leadership position in the area of nuclear technology, the U.S. is positioned to provide credible leadership in the control and disposal of special nuclear materials and nuclear technology. U.S. involvement provides not only the basis for leadership but also for access to international relationships that allow us to directly monitor the nuclear activities of other countries. Without involvement, the U.S. does not have access to a dedicated professional community and must seek other means to gather this information.

1.1 Nonproliferation

An important issue with nuclear power is that the fissile materials used and generated in power production can also be used in nuclear weapons. The ability of a nation or group to develop a nuclear weapon is a function of the following:

- Material availability.
- Ability to obtain material from either spent fuel, reprocessing plant, or fuel fabrication facility.
- Enabling technology.
- Ability to separate and enrich the material into the needed type.
- Ability to produce the isotopes needed.
- Political “will” to develop weapons of mass destruction.
- Ability to proceed in isolation.

To work towards nonproliferation, the risks of all these must be reduced.

Materials Control

In protecting materials from subversion into weapons, both uranium and plutonium must be considered. Uranium is present in fresh fuel and spent fuel. Plutonium is present in spent fuel as well as that which has already been processed for weapon usage.

Large quantities of plutonium are accumulating as weapons are dismantled. Likewise, large quantities of plutonium are accumulating in the form of spent nuclear fuel. Technology is available for reprocessing spent fuel. While reprocessing technology is expensive, with the cost providing a proliferation barrier, restrictions on the export of this technology are essential to prevent diversion for weapons purposes. France extensively reprocesses its fuel, and Japan is currently developing a reprocessing program. The U.S. discontinued civilian reprocessing during the Carter administration to reduce the amount of plutonium that could be subverted for weapons use.

The primary issue surrounding materials controls supporting nonproliferation is to account for the material so that other nations have reasonable assurances that no materials are being subverted for weapon usage.

In addition, if the U.S. loses its leadership role in nuclear power generation, then the U.S. has a much more difficult, if not impossible, task of exporting a material control culture. Several regional and worldwide agencies have been developed such as EURATOM. These agencies provide materials controls for a region, ensuring each other a margin of transparency; however, such

agencies do not cover all countries that have nuclear capabilities at this time, and they are subject to the cooperation of such governments.

Adding to the difficulty of encouraging material control is the change in the type of threat for subversion. Traditional materials control looked at the country-level of activity. Since the breakup of the Soviet Union, the possibility of subversion of materials by terrorist groups has become increasingly important.

A consideration in materials control is the diversion of hot cells and other supporting hardware and technology into weapons development.

Technology Dissemination

Nonproliferation also requires the protection of enabling and supporting technologies. By developing a commercial nuclear power industry, areas of expertise are developed. The U.S. has developed many nuclear engineering programs for the purpose of educating engineers and creating a technical infrastructure to support the nuclear power industry. The U.S. is still educating many of the world's nuclear engineers. While commercial nuclear technology cannot be used directly to build a weapon, the technology can be the basis for beginning and sustaining a weapons development program.

The vitality of the commercial nuclear industry and the U.S. government philosophy of openness have resulted in an abundance of information in the open literature. If a potential proliferant state or group desires to invest in the effort, and has or can acquire the knowledgeable people and technology for nuclear technology, then it is difficult to stop them. Under Eisenhower's Atoms for Peace Program, the IAEA was chartered to assist member states in developing nuclear industries. The idea was to have all such industries under safeguards, but the knowledge and experience gained thereby cannot be safeguarded. In addition, countries other than the U.S. have had rather low requirements for safeguards when exporting nuclear technology in the past, especially France. With the U.S. losing its leadership role in the nuclear industry, it is difficult to export a safeguards culture to prevent further dissemination of technology by other countries.

Other technologies are needed by proliferant states and groups, such as isotope production (with the theft of fresh fuel) and enrichment technologies, and much of this information is available in the open literature.

1.2 Physical Security of Nuclear Power Plants Worldwide

With the break up of the Soviet Union, several nuclear power plants have had a disruption in operations. New governments have formed within the new countries, and the responsibilities for oversight of the nuclear power plants have changed. These regions rely on the nuclear plants to supply large percentages of their electricity and residential heating, and the continued

operation of these plants is essential to maintain the economic infrastructure. Many of these reactors are of the same type as Chernobyl and lack containment structures. The combination of the change in government and the lack of adequate safety systems makes these reactors particularly vulnerable to failures or accidents, leading to increased hardship in these regions.

When the U.S. began the Atoms for Peace Program, the IAEA was chartered with assisting member states with development of the nuclear industry including the safeguards and physical security of the nuclear plants. Countries other than the U.S. have a far more lax approach to the physical security of their nuclear power plants. With the U.S. nuclear industry declining and its share of the international market in jeopardy, the U.S. is in a poor position to export its own safeguards and security culture.

1.3 U.S. Leadership in Nuclear Energy Technology

The U.S. has always taken a strong stance in pursuing a nonproliferation policy of preventing commercial nuclear materials and technology diversion into weapons uses. However, with the U.S. nuclear industry on the decline and no longer the source of nuclear expertise or a supplier of parts to the international nuclear market, it can no longer have the same influence to encourage similar nonproliferating attitudes.

The U.S. needs to ensure that the option to use nuclear energy is available to meet the nation's future energy needs. Internationally, competition for scarce fossil energy resources is likely to increase, and the demand for these fuels is reduced through nuclear energy. Numerous conflicts have been fought over energy resources and the ability to improve a nation's standard of living using these resources. Current projections suggest that electrical energy consumption is growing at a rate of ~2%/year. Ideally, future demand growth will be met by a combination of renewable and nuclear energy, thus conserving fossil fuels for future generations and uses other than electrical energy generation. Nuclear energy has the potential to reduce international tension/conflict in that it can help meet the energy needs of developing nations. Major economic expansion in China, India, etc. will strain existing fossil fuel production capabilities and consume reserves at increasing rates.

1.4 Energy Security

Nuclear energy is a key component of the U.S. energy infrastructure, which would be weakened without this component. Approximately 22% of the current U.S. electrical generation is provided by nuclear power. An infrastructure of nuclear technology is needed to preserve the investment in these 109 operating plants and to support their continued operation in a safe, reliable, and environmentally friendly manner. Supporting R&D and technology transfer from government laboratories and universities is needed

to reduce uncertainties in the license renewal option. This will maximize the economic benefit from the ~\$200B investment in operating nuclear power plants. Internationally, the availability of nuclear energy technology provides options for other nations to improve their energy infrastructure, without aggression, and to obtain needed energy resources.

A diverse fuel mix, including nuclear fission, helps ensure that power is readily available to run the economy and ensure economic competitiveness. A tangible benefit of a diverse energy supply was clearly displayed on the East Coast during winter 1995. Coal piles were frozen, oil barges were stranded, and natural gas supplies were used primarily to heat homes and businesses. If they had been available, photovoltaics and wind power would have been incapacitated, too. Commercial nuclear power plants and power-wheeling prevented blackouts and reduced the number of brownouts. Whether the challenge is inclement weather or a political crisis (e.g., in the Persian Gulf), nuclear power is a secure domestic source of electrical energy.

2.0 ENVIRONMENTAL QUALITY ISSUES

2.1 CO₂ Emissions

Public well-being is supported by a U.S. program in nuclear energy because using nuclear energy instead of fossil fuels reduces CO₂ emissions. Promoting nuclear energy use, both domestically and internationally, will reduce CO₂ emissions without reducing power produced. Over 1.9 billion metric tons of carbon emissions have been avoided in the U.S. alone through the use of nuclear energy.

The ability to substantially curtail the production of CO₂ will strengthen the U.S. position in negotiations and demonstrates our commitment to the control of CO₂ emissions.

2.2 Air Pollution

Nuclear energy is more environmentally friendly than fossil fuel electrical generation. Electric power plants that burn fossil fuels emit air pollutants linked to the environmental problems of acid rain and urban ozone. These pollutants include volatile organic compounds (VOCs), nitrogen oxides (NOx); carbon monoxide (CO), particulate matter less than 10 microns in diameter (PM10), and sulfur dioxide (SO₂). At present, 72%, 35%, and 33% of the total U.S. emissions of SO₂, CO₂, and NOx, respectively, come from fossil fuel combustion at U.S. utilities.

A 1996 study by the Energy Information Administration (EIA) and the Federal Energy Regulatory Commission (FERC) examined the anticipated impacts of projected fuel prices, electricity demand, and proposed utility deregulation on

the production of these air pollutants from electricity generation. In all of the scenarios evaluated in this study, air pollutant emissions were projected to steadily increase in the U.S. between 1996 and 2015, due primarily to increased fossil fuel consumption resulting from rising demand for cheaper electricity, the expected retirement of existing nuclear generation capacity, and the replacement of retired nuclear generation capacity by fossil fuel-based generation options. Moreover, world demand for electricity is projected to nearly double between now and 2015, with about half the increase coming from the developing world, which will rely on fossil fuels for over three-quarters of its electricity generation. This rapid growth in global demand for generation capacity, particularly coal-generated capacity in China and India, will be accompanied by proportional increases in air pollutant emissions.

Because nuclear power plants do not use fossil fuels, they do not emit air pollutants. By displacing the need to burn fossil fuels, nuclear energy has been a major contributor to reduced air pollution in the U.S. and the world. In the U.S., recognizing the problems caused by acid rain and urban smog, the Clean Air Act Amendments of 1990 mandated sharp emission reductions and placed annual limits on utility emissions of both SO₂ and NO_x. In total, U.S. utilities must achieve annual reductions of 10 million tons of SO₂ and 2 million tons of NO_x by the year 2000. In comparison, the nuclear industry notes that U.S. nuclear plants in 1994 already offset approximately 4.9 million tons of SO₂ and 2.3 million tons of NO_x on an annual basis. And worldwide, in 1994, the 430 nuclear power plants in the world prevented the discharge to the atmosphere of 455 million tons of carbon, 15 million tons of sulfur dioxide, and 7 million tons of nitrogen oxide.

3.0 WASTE MANAGEMENT ISSUES

3.1 High-level Waste Disposal

Safe, reliable, and cost-effective nuclear waste disposal is needed. The scope of the effort must include spent fuel storage, transportation, and handling; high-level and low-level waste disposal; and decontamination and decommissioning of nuclear facilities.

Policy-based issues, including the decision to permanently dispose of spent fuel in geologic repositories, are perceived by the public as having negative health effects and environmental impacts. Having a national solution for high-level waste (HLW) disposition is currently missing. The issues facing waste disposal come from multiple, separate agencies. This issue can be addressed by establishing a uniform policy addressing radioactive, chemical, and mixed-waste issues.

High-level waste (HLW) disposal issues must be resolved soon. The government is developing a geologic repository and has obligated itself to take HLW from the nuclear industry. The plan for putting the waste into a geological repository represents a political and public acceptance challenge. However, the “political will” to implement the policy must be strengthened so we can proceed with the proposed disposal methods.

3.2 Depleted Uranium

The ongoing operation of the U.S. nuclear fuel cycle requires the operation of the U.S. uranium enrichment plants, which produce depleted uranium as a byproduct or waste material. Over 500,000 tonnes of depleted uranium exist as uranium hexafluoride, UF_6 , and no decision or path forward exists on its disposition or disposal. This depleted uranium inventory has been stored for over 50 years against the scenario of its use as fertile material in fast breeder reactors. With the termination of the U.S. breeder reactor program the largest beneficial use for depleted uranium has disappeared, and questions exist concerning its disposal or beneficial use. Currently there are neither established commercial uses for depleted uranium nor is there any regulatory path forward for its disposal as waste (the NRC has indicated that it may not be disposed as low-level waste).

Although depleted uranium is not radiologically hazardous, the UF_6 form is chemically hazardous, and corrosion of UF_6 storage cylinders is a concern. Experience in the nuclear and chemical industries has been that the continued production of hazardous waste streams such as depleted uranium that have no disposal endpoint are eventually declared to be unacceptable by state authorities and public interest groups. As such, the lack of established beneficial uses or disposal pathways for depleted uranium represents a vulnerability for the U.S. nuclear energy option and thus requires attention.

3.3 Urbanization and Environmental Degradation in Developing Nations

As nations develop, their use of electricity will increase. This results in a need to quickly build power plants to meet the demand for electricity. Usually, a coal-burning plant is built without pollution controls or an accounting for the amount of carbon dioxide generated. The environmental costs of these plants will affect the whole world.

This is particularly true in Asia where the demand for electricity is growing at a phenomenal rate, and there is a need to ensure that the global supply of energy is met without degradation of the environment.

3.4 Safety Issues

It is the opinion of those knowledgeable about the nuclear industry, both from the regulating side and the industrial side, that U.S. nuclear plants are very safe. However, the low-probability, high-risk accident must be considered from both the prevention standpoint and the management standpoint.

Accident Prevention and Management

Accident prevention, in many ways, is the process of retrofitting existing plants and modifying new designs to incorporate lessons learned as the industry has matured. This process has continued throughout the history of the nuclear power plant industry and continues today. However, complete prevention requires a two-prong approach: not only must the design and the hardware of a plant be designed with safety as a driver, the operational personnel must also continually perform their jobs with safety as an integral part of the task at hand.

Reactor Safety Assurance Worldwide

Although we have reasonable assurances that the reactors in the U.S. are safe, the question remains as to how we assure ourselves that the rest of the world builds and operates plants as safely as possible. The IAEA and EURATOM were both established with this objective as part of their missions. The issue is that, while each of these organizations does inspect and monitor plants, neither of these organizations has the breadth to cover all nuclear plants.

Internationally, there needs to be a continued effort to retrofit plants in the former Soviet Union to make them safer and to instill a safety culture into the operations of these plants. With the demise of the USSR and the time it will take for the new countries to establish themselves, this effort is essential to maintain a secure supply of electricity to many of these regions.

4.0 ECONOMIC COMPETITIVENESS ISSUES

4.1 Decontamination and Decommissioning

Today's consolidation and compaction methods will no longer be viable when large numbers of facilities must be decontaminated and decommissioned. While utilities have accumulated large decommissioning funds, these funds will not be adequate if utilities must use current decontamination and decommissioning (D&D) techniques. These costs may impact decisions regarding continued operation of the plant.

4.2 Impact of Utility Deregulation

Until today's "deregulatory" environment evolved for the electric utility industry, it was always assumed that a compact existed between regulators (such as state Public Utility Commissions) and regulated utilities. If a plant (such as a nuclear unit) were needed and the PUC allowed construction of such, then the utility was allowed to fully recover all of the costs, including capital amortization, associated with the facility as part of their rate structure. The agreement was made independent of the power generation mix and power prices in other utility's service areas or regions outside the plant's service area. When the electric power industry is deregulated, "captive" utility customers formerly committed to buy power from their regional utility will be allowed to shop for lower prices and drop their current utility. Such deregulation will introduce marketplace efficiencies into the electricity market; however, it will have the effect of leaving those utilities with higher-cost, unamortized generation investments, such as nuclear plants brought on line in the late 1970s through the early 1990s, with unrecovered capital costs. This part of the total power generation cost unrecoverable by revenues is called "stranded investment." Many nuclear utilities may face stranded investments in the billions of dollars if new legislation does not allow some form of recovery from former customers, such as "exit fees" from the utility system. Those nuclear plants with high production cost (O&M plus fuel) will also have a difficult time competing in a deregulated environment where large blocks of wholesale power will be sold for rates in the 1.5–2.5 ¢/kWh range. It is likely that older plants (those facing large investments such as new steam generators) and small plants (where costs are distributed over a smaller number of kilowatt-hours) will be the plants most likely to have production costs that are above the competitive range. These plants are very likely candidates for early shutdown, and a few such closures have already been announced in the past two years.

Historically, a regulated utility had a straightforward path for the raising of capital for new nuclear plant construction. Since the rate of return to investors was guaranteed by a compact with economic regulators (PUCs) and the revenues within a service region were guaranteed, the utilities normally had no difficulty borrowing money at reasonable rates (utility bonds) or issuing stock. The rates of return to investors were lower than for other industrial ventures, but the risk was also lower. In the new deregulated environment the above will no longer be true. The market will not be guaranteed; a nuclear plant will have to compete with other generation sources on the wholesale baseload market. The risk to both bondholders and stockholders will be significantly higher, hence higher rates of return on debt and equity will be required, perhaps by several points above typical utility returns. Small utilities are unlikely to be able to raise such financing, therefore consortia (such as independent power producers [IPPs] or teams of utilities, reactor vendors, fuel manufacturers, Architect/Engineers, etc.) may be required to finance and build such plants. Because of the licensing, siting,

and public relations risk associated with nuclear projects, there may be additional premium on the return to investors.

The near term market for reactors, however, is not in the U.S. or Europe but rather in the developing world, mainly Asia. The problem in much of Asia, such as China, Indonesia, Thailand, and Vietnam, is the lack of indigenous capital needed for plant construction. It is likely that foreign investment on a massive scale will be needed to finance nuclear programs in these nations. There is also an institutional risk with such investments related to the stability of their governments and the lack of experience with capitalism and Western business practices. It is very likely that future nuclear plants will be financed in ways never foreseen when the last domestic reactor order was placed in the 1970s. The U.S. nuclear industry would greatly benefit from a study of how large, risky international projects, such as mining and petroleum projects, are financed. It is very likely that similar paths will be needed for the nuclear industry.

In addition to the cost effects of deregulation, there are other significant infrastructure and institutional issues, both positive and negative, that may arise. Four of these are:

- Economic pressure on utilities might force the utilities to cut costs in areas related to plant safety.
- Mergers and buyouts of utilities and plants will cause most nuclear plants to be owned and/or operated by very large, multi-regional utilities, each having several plants. Greater cost efficiencies may result from such an arrangement.
- Reactor equipment vendors and architect engineers may find themselves in the role of financing in addition to equipment manufacturing and construction for future nuclear plants built for the domestic U.S. market.
- Nuclear facilities may find themselves being used in a load-following or non-baseload mode. Since these plants were designed to provide baseload, operational efficiency may be impaired.

4.3 License Renewal and Plant Aging Management

Many nuclear plants will be reaching the end of their original operating license in the next 20 years. Renewing the operating license of safe, economically-competitive plants will allow a utility to recover its capital costs over a longer period, ultimately reducing the price of electricity and making the plant more economically competitive.

The regulatory process to renew an operating license for a period exceeding 40 years, as defined in 10CFR54 and known as license renewal, has not been demonstrated. To date, no utility has submitted a license renewal application. The first license renewal application will be submitted in late 1997 or early

1998. The NRC has suggested that it will take approximately three years to review the first application, obtain additional information, conduct hearings, and, if the application is judged acceptable, grant an amended license. The uncertainty associated with an unproven regulatory process can be reduced by accelerating efforts to resolve technical concerns (e.g., time-limited aging analyses such as fatigue) and the review and approval process.

Regardless of a utility's decision for plant license renewal, understanding the safety issues associated with plant aging will become critical in the next 20 years. Advanced techniques that can identify aging phenomena and mitigate problems will be needed. Stress corrosion cracking will become a significant issue. Plant infrastructure, like electrical cables, will need close examination to determine the impact of aging on safety.

4.4 Construction of New Plants

Capitalization

In the U.S., the competitiveness of existing nuclear power plants is very much determined by the extent to which the large capital costs have been amortized and by the electrical production cost (annual O&M costs plus fuel). Existing nuclear plants for which the capital costs have been amortized can produce electricity for 1.5–3.0 ¢/kilowatt-hour. Even in a deregulated market, these prices are competitive with the most economic of fossil fuels. New U.S. nuclear plants of evolutionary design are expected to have power generation (busbar) costs of 3.6–5.0 ¢/kilowatt-hour, which is not expected to be competitive with natural gas or coal-fired plants.

Constructibility

A long construction period leads to uncertainty in the total cost of construction, both as a function of time and materials escalation and changes in interest rate. Advanced construction techniques are required to minimize the construction period. While new Japanese and Korean nuclear power plants are built in less than five years, the U.S. has yet to demonstrate the ability to achieve similar results. There has been significant technology improvement in foreign infrastructure to construct nuclear power plants. A similar infrastructure has not been tested in the U.S. Two major DOE/industry efforts help reduce construction uncertainty. The Design for Constructability Program was completed in 1989, and the Construction Project of the Technology Program in Support of Advanced Light Waters was completed in 1991. While uncertainties have been reduced, closure is dependent on a program to build a new plant in the U.S. in less than five years.

The licensing process for new plants is defined in 10CFR52. Per the new process, a utility can obtain a construction permit and “provisional” operating

license (i.e., all essential NRC approvals) prior to starting construction. The process depends on both an Early Site Permit (ESP) for a qualified site and construction of a “Certified Design.” The scope of public hearings that could delay plant startup are then limited to safety issues that have not been addressed during the design certification process; and the intervenor must demonstrate that a substantial safety concern has not been addressed in previous hearings. Two standard, evolutionary designs have been certified by the NRC: General Electric’s Advanced Boiling Water Reactor (ABWR) and ABB-Combustion Engineering’s System 80+ pressurized water reactor (PWR). A third design certification review, of the Westinghouse AP600 advanced PWR design, is in progress. The first two phases of the ESP process have been demonstrated; the third phase will be completed when a utility proposes a candidate site. Hence, an issue remains that can only be overcome when a utility decides to build a new reactor. Ideally, improved economics of existing plants will motivate utilities to order new plants; however, incentives may be required to stimulate interest and begin construction before the necessary infrastructure withers away.

5.0 INFRASTRUCTURE AND INSTITUTIONAL ISSUES

5.1 Regulatory Framework and Certainty

Regulatory oversight is necessary; however, there is a consensus among both the NRC and the utilities that the current regulations need to be changed to reflect a risk-informed performance-based policy. Recent decisions by the NRC to abandon risk-informed policy in favor of defense in-depth (i.e., AP600 containment spray system) demonstrates the need for continued research. Regulatory changes and utility implementation are occurring slowly. This current atmosphere breeds an amount of uncertainty among participants.

Regulation of radiation exposure is inconsistent with data and is causing unnecessary public concern. Health physicists are beginning to realize that the linear, no-threshold model of radiation exposure is inaccurate and are beginning to move toward a baseline dose model. The consequences of a conservative model have caused unnecessary abortions in the wake of the Chernobyl accident by families who feared radiation damage based on the linear no-threshold model.

It is the opinion of most knowledgeable people that U.S. nuclear power plants are very safe. However, while there is a need to be inside the circle of safety, there is an increasing belief that that circle is too small and that the utilities are spending far too many resources in excessive safety measures.

Also in the regulatory framework is the issue of interagency cooperation. The EPA and the NRC are currently debating the residual limit of radioactivity in a cleaned-up site, with the EPA holding to a lower limit (15 mrem/year)

ground and 5 mrem/yr for water) than the NRC (25 mrem/year, all sources). Regardless of the merits of the debate, without clear lines between which agency has jurisdiction over certain areas of regulation and subsequent enforcement, the utilities may find themselves unable to accommodate both sides at the same time.

5.2 Availability of Qualified Vendors

The nuclear industry is in a state of decline in the U.S. with no new plants having been started since the late 1970s. Until recently, the U.S. had dominated the nuclear power industry and exported all of the hardware used in the western world's nuclear reactors. As other countries have picked up manufacturing expertise and are advancing the design of their reactors, the U.S. no longer provides hardware or parts to the international market. Consequently, the vendors that had produced nuclear power plant hardware in the past have significantly dropped their capacity for manufacturing parts to maintain the currently operating plants.

5.3 Nuclear Energy Needs of U.S. Government Agencies

Nuclear technology developments should not be made in isolation. Particularly in the face of a shrinking industry, there is a need to share research, insights and lessons learned between the commercial nuclear industry and other areas that the government is working on such as stockpile stewardship, naval propulsion, and risk-assessment technology. There is a need to provide interesting research opportunities to attract intelligent people to the field to maintain the core of technology in the commercial industry.

5.4 Resources for R&D Infrastructures

Currently, funding resources are inadequate to maintain a meaningful U.S. nuclear program. Increased funding is essential to restoring the U.S. as a world leader in the nuclear power industry. Without the ability to attract intelligent people to the field through providing research funds, the industry will lack a sufficient pool of personnel to provide an infrastructure for the nuclear industry.

Without the R&D activities, the U.S. is at a disadvantage for participating in international conferences and will have a decreasing opportunity to encourage a safety culture with other countries. The U.S. will no longer have the personnel to actively engage with the international community on an exchange basis. It will only be as an observer, decreasing credibility of the U.S. to encourage a safety culture in foreign reactor operations.

6.0 OTHER CONSIDERATIONS

6.1 Public Acceptance Issues

The successful application of nuclear energy in support of national security requires gaining public acceptance of the technology. Although nuclear energy is accepted and being pursued enthusiastically in other countries, the U.S. public has not accepted nuclear power; they are only interested in preserving the option to use nuclear energy in the future. Public acceptance will likely never be gained without a serious crisis to force a change in public perception (e.g., the U.S. had no interest in small, high-mileage vehicles until the Arab Oil Embargo).

In general, the support for nuclear power is highest in communities closest to nuclear power plants, while support declines rapidly with distance from the facilities. Recent de-facto changes in nuclear policy, however, involving the construction of semipermanent dry storage facilities for spent nuclear fuel on site at generating facilities have begun to erode community support.

Attitude surveys show a declining proportion of the public in favor of more nuclear power plants (less than 30%) and only a tiny fraction willing to have nuclear or hazardous waste facilities within 100 miles. The decline in public acceptance over the past 20 years is broadly spread among all stakeholder groups except the pro-nuclear support core of about 15–20%. There is an anti-nuclear opponent core of similar size (about 20%), but the remaining 60% is a vast undeclared, uncommitted, and nonattentive middle group. Besides community support, the only other bright spot is a growing proportion of the general public (more than 40%) that grudgingly admit that nuclear power may have an important role to play in the U.S. energy future.

A recent *Nuclear News* article claims that journalists are aware that nuclear energy is the safest form of power production yet also know that articles in favor of nuclear power will not sell newspapers, magazines, or air time.¹ The tide of negative information provided to the public must change; a new climate of open communication is needed to obtain public trust and acceptance.

The declining support for nuclear power has several components that must be understood and acknowledged before steps can be taken in an attempt to reverse this slide. Some of these components include:

¹“Turning the Tide of Public Opinion on Nuclear Power,” *Nuclear News*, April 1997, pp. 26–30.

- Past history and record of secretive, arrogant, closed decision-making about nuclear matters and pollution at Cold War defense sites.
- Nuclear fears and radiation phobia based on the dread and fear conjured up by mushroom-cloud images and white-suited workers in gas masks.
- The nuclear enterprise has mostly chosen a passive-reactive approach to public acceptance, with little effort to counter antinuclear rhetoric or inaccurate information about radioactivity, etc.
- The size of the pronuclear constituency has declined. With the demise of many U.S. nuclear vendors and support infrastructure, this group is largely silent in the face of antinuclear rhetoric.
- Nuclear opponent groups mostly define and frame nuclear energy issues in the absence of a proactive stance by either the government or the nuclear industry.
- Little effort is expended on defining or interacting with the various sets of stakeholders at the local, state, and national levels.

Despite scientific studies showing that atomic bomb survivors and radiation workers experience minimal long-term health effects, the fantasy effects portrayed in certain entertainment products continue to dominate public perception. Traditional technical and logical arguments comparing nuclear power to radon in basements or medical/dental diagnostic x rays are ineffective because the public perceives risk differently depending on who is “in control.” People feel safe in their homes and trust their health care providers; they don’t trust the government and power companies. Just as most people feel safer in their own car than flying because the FAA, air traffic control, and pilots are responsible for air travel, power plants controlled by utilities and the NRC are not perceived to be safe (and statistical evidence will never convince them otherwise). Public acceptance of nuclear power must be linked to energy security, reduction of CO₂ emissions, and the need to provide world leadership. Without public acceptance of nuclear energy, revitalization of the industry will not happen because the industry will be too reluctant to invest the capital needed to build new plants.

The U.S. situation is in direct contrast to the situation in France. In general, the French have embraced nuclear energy. In fact, multiple towns/regions vie against one another to be selected for the next plant construction project. This attitude extends beyond plant construction and operation to the entire fuel cycle. The French government initially proposed a geologic repository, which was unacceptable to its population. Public debate and further study altered the proposed approach to a storage facility that is monitored by an independent agency responsible for verifying that the waste remains in a safe form and that the people and environment are protected.

A recent PBS Frontline special, “Nuclear Reaction,” that aired on April 20, 1997,² is an excellent source of information containing both anti- and pro-nuclear views of commercial nuclear power.

The following list summarizes issues in public acceptance of nuclear technology implementation. Further work and analysis is required to develop options, tailored strategies, and possible solutions.

- Local public acceptance for relicensing existing nuclear power plants is not assured.
- Local public acceptance of continued storage of spent nuclear fuel (dry or wet) at some of the 70 nuclear power plant sites appears to be problematic.
- The Low Level Radioactive Waste Policy Act of 1980 may need further revision to define acceptable levels of radiation.
- The socio-political gap between the technical and nontechnical worlds continues to widen, making productive dialog increasing difficult.
- Local and national public acceptance of new nuclear power or nuclear waste management facilities must be developed.

²A videotape of the show is available from WGBH, Boston. Another alternative for obtaining additional information is on the Web at [\[http://www.pbs.org/wgbh/pages/frontline/shows/reaction\]](http://www.pbs.org/wgbh/pages/frontline/shows/reaction).

Recommendations for a Department of Energy Nuclear Energy R&D Agenda

Appendix 4 Options for Policy and Research & Development

EXECUTIVE SUMMARY

Safety, security (safeguards, security, and proliferation concerns), environment and waste management (including disposal), cost, and public acceptance are the prime factors affecting the U.S. nuclear energy program. Although these factors have been of concern since the beginning of the peaceful use of the atom, their relative importance has evolved in the decades since the beginning of nuclear power generation. In the 1960s and early 1970s, public perception of nuclear energy was very positive, and public support was generally taken for granted. Permanent waste management was an issue too far in the future to be worried about. Proliferation was just a topic for experts. Electricity was said to be too cheap to meter. The only subject that warranted immediate concern was safety. Today, cost, the environment, and waste management issues have emerged to dominate the domestic nuclear energy scene, and proliferation is the major international issue for the U.S.

Thus, the first generation of nuclear power in the U.S. started in a way that was not based on today's realities or on likely long-term realities. It may be very difficult to restart the U.S. nuclear power program without an overhaul of the entire system. A partial correction will not likely be sufficient.

With this situation in mind, it is appropriate to consider the conditions and scenarios that may unfold as the future of the U.S. nuclear energy program develops. In this paper, three Scenarios or phases that represent possible components of the future development of nuclear power are identified and discussed. The three Scenarios, which are not mutually exclusive but rather can be viewed as sequential phases taken in combination, include: Scenario 1, representing the current situation in the U.S. in which there are no new orders for nuclear power plants; Scenario 2, in which actions are taken to maintain the current (20%) level of the nuclear option; and Scenario 3, in which fission power grows in a less constrained manner as a preferred source of new generation capacity. The identification and discussion of these Scenarios leads directly to consideration of the policy implications and research needs that will be necessary to effectively support the continued viability of the nuclear power option in the U.S.

Scenario 1. Gradual abandonment of the U.S. nuclear option. Although in the current situation, there are no new nuclear power plant orders in the U.S., we cannot stop the world community from pursuing the nuclear power option. As a basic concern, nuclear proliferation is tied to the international issues over which

the U.S. has even less control. We must initiate a U.S. nuclear energy program to secure technology leadership and thereby be more effective in influencing the world community on nuclear matters, including the advancement of our policies on proliferation. Under this Scenario, there are a few activities (including R&D) that we should pursue to achieve our goals:

- Develop a small nuclear reactor system based on integration of the entire fuel cycle, i.e., safety, proliferation, waste management, and cost. The primary driver is proliferation concerns.
- Take effective steps to extend the safe, economic operating life of existing plants to ensure a robust energy supply and minimize increased greenhouse gas emissions.
- Maintain critical underlying educational and research infrastructures through focused research initiatives between the universities and national laboratories.
- Increase international technical dialogue, particularly with the developing nations of East Asia in order to secure and maintain vital U.S. interests.

Scenario 2. Continued reliance on nuclear generation. If fission power is to continue to be depended upon for the generation of roughly 20% of our electricity, we must overhaul the nuclear power system. A partial fix will not do. Only a new system of nuclear power generation that balances safety, proliferation, waste management, technology, and cost will succeed. Many activities (including R&D) are necessary in addition to those of Scenario 1 development:

- Develop initiatives to reduce cost with improved safety.
 - Safety regulations and standards reform.
 - Quality assurance reform.
 - Regulatory philosophy reform.
- Improve public understanding and perception of nuclear energy.
- Integrate nuclear fuel cycle elements into nuclear reactor system development.

Scenario 3. Reemergence of nuclear power as a preferred choice for future base-load electricity generation. If fission reactors are going to play a major role in base-load electricity generation in the U.S., we must develop new technologies and approaches to take full advantage of the developments included in Scenarios 1 and 2. The activities above and beyond Scenarios 1 and 2 include:

- Advanced reactor system development.
- Completion of deployment preparation for selected new technologies.

These three Scenarios comprise the spectrum of future possibilities with regard to the nuclear power option. It is essential to anticipate the R&D needs to support these Scenarios not only to effectively plan for the future but also to maintain a meaningful involvement in the development of the international nuclear power industry. Such involvement is key to the need for the U.S. to remain informed

and to be positioned to influence the development of nuclear power on a worldwide basis.

1.0 INTRODUCTION

The future of nuclear energy, both domestically and internationally, is dominated by major uncertainties. Domestically, nuclear energy appears to be in a declining trend, substantially due to energy demand and market uncertainties, increasing pressure caused by growing deregulation of domestic electricity production, and uncertain public acceptance. All domestic energy-demand projections show growth; some suggest slow growth in total energy requirements, but most indicate significant domestic energy growth. Moreover, uncertainties in how best to address future energy needs and to reduce carbon and greenhouse gas emissions and in the future availability and economic viability of alternatives suggest that nuclear power may be needed in the near future.

Internationally, while similar uncertainties are at work in Western Europe, it is clear that developing countries and East Asia will require increasing amounts of energy, and electricity in particular, over the next 50 years, and nuclear power is emerging as one of their preferred options.

Within this environment of certain energy demand growth, coupled with significant uncertainty with respect to all energy sources, it is vital to maintain and develop all viable options toward ensuring a stable energy supply for the future. At issue here is not a comparative assessment of the prospects of nuclear power relative to the alternatives, rather it is an analysis of the risks and benefits of nuclear power, of the research efforts needed to minimize the risks and realize the benefits, and of the policies and environment within which nuclear power can achieve renewed interest.

This analysis begins with a brief review of the perspectives and issues underlying the nuclear power option. We then define a series of scenarios, or alternative futures, for the role of nuclear power in the nation's and world's energy market as a tool for visualizing implications, risks, and benefits of nuclear power. From this basis, we then develop the requirements for R&D and policy support needed to address the implications, minimize the risks, and realize the benefits of nuclear power in the future.

2.0 PERSPECTIVES

The future of nuclear power generation in this country and abroad is at a critical point. Although a competitive alternative, nuclear power has insufficient political and public acceptability in many countries, including the U.S., to support the substantial economic and social costs of increased reliance on its use. Increasing emphasis on short-term energy economics is undermining the long-term economic advantages of nuclear power. The broad energy picture (i.e., supply and demand, domestic and international) is in a state of conditional stability (i.e., at saddle-point). Energy prices and supplies are reasonably stable, and demand growth is generally under control. However, population pressures and the industrialization of developing countries are leading to significant new energy demands in the coming decades. These pressures, along with the increasing environmental, economic, and geopolitical concerns related to burning fossil fuels,

will contribute to increased demand for new nuclear power technologies and greater generating capacity.

Safety, security (safeguards, security, and proliferation concerns), waste management (including disposal), cost, and public acceptance are the prime factors affecting the U.S. nuclear energy program. Those factors have been of concern since the beginning of the peaceful use of the atom. For the last 40 years, the relative importance of these factors has changed to reflect social, economic, and political changes. To identify what policies and research will be necessary to support a U.S. nuclear energy program, we must define the objectives of such a program and, in addition, we must identify the major concerns of the U.S. government, the utility industry, and the general public that might affect this program.

While there continue to be large uncertainties and differences of opinion about the future role of nuclear energy both in the United States and abroad, it has national security, economic, and environmental dimensions that are of primary concern. The future of nuclear energy hinges on a number of key principles, objectives, and assumptions:

- Nuclear power supplies more than 20% of the nation's electricity, and currently operating reactors will continue to supply a significant amount for decades.
- Meeting U.S. electrical energy demands is key to continued economic growth and security. A diverse set of production alternatives, including nuclear, is vital to the national interest in the mid-to-long term.
- Programs to assure that safety, environmental, and waste management problems are solved with favorable economics are essential to a viable nuclear option; regardless of the future of nuclear power, the benefits from nuclear activities over the past 50 years have left a legacy of materials, wastes, and facilities that will require long-term nuclear expertise.
- Environmental, national security, and economic developments and surprises can have short-term, substantial impacts on the relative advantages of respective energy sources. In particular, the environmental advantages of nuclear reactors, which do not create emissions related to greenhouse gases or acid rain, provide an essential energy resource to address environmental security issues and needs.
- Energy demands in the rest of the world are expected to grow dramatically, and the growth of nuclear power may be much greater in developing countries. Even in the slowest-growth projections, total worldwide nuclear generating capacity is expected to grow over the next 50 years. As has been the case for the first 50 years of the Nuclear Age, it is in our national security and economic interest to maintain international leadership and expertise in nuclear energy, assuring that we have maximum impact on the proliferation, safety, environmental, material control, and waste management aspects of nuclear developments worldwide.
- A vibrant U.S. educational infrastructure and the maintenance of critical skills, technology, and facilities are essential to our ability to meet future national challenges but the existing infrastructure may erode to unacceptable levels without a healthy national nuclear research agenda.

2.1 Time-frame

Many of the issues surrounding nuclear power are long-lived. The average plant lifetime is on the order of 30 years. Nuclear waste has a very long life. Because of these long time-lines, there is a tendency to focus on the longer-term, and to treat nuclear power primarily as an option for the future.

However, if one looks at the current situation, there are a number of features that will become increasingly important earlier on:

- Aging of the current nuclear power fleet, with early retirement of some units, will soon exacerbate the energy supply/demand balance.
- Increased environmental, CO₂, and global warming concerns are increasing the demand for fossil fuel-free energy sources.
- The desire and/or need for nuclear power is increasing among the developing countries, particularly in Asia.
- Civil stocks of plutonium, particularly as separated material but also in spent fuel, are increasing, and with a continued imbalance in mixed oxide (MOX) utilization likely.
- Uranium is inexpensive, a situation exacerbated by excess weapons material supplies.
- There is a near-general consensus that breeders are unnecessary in the next few decades.
- There is a critical decline in nuclear-engineering university programs and enrollment.
- The domestic industrial base for nuclear power is eroding rapidly in the U.S, and even optimistic demands for new nuclear capacity may be insufficient to maintain vital capabilities.

All of these issues presently affect the status of nuclear energy, and pressures from them will increase in the near future. Current trends do not promise solutions within the next two decades.

As an observation, it is interesting to note that the market share for a new generating technology (wood, coal, oil, natural gas, etc.) historically grows at rate of 5% per year. From its beginnings in the 1950s to the late 1960s, U.S. domestic nuclear power shared that same growth rate, but during the 1970s and 1980s, the growth rate of nuclear power greatly exceeded the historic trend. The current installed market share for U.S. nuclear power is, in effect, 20 years ahead of the trend.

2.2 The role of DOE and USGOV in the development of nuclear power

The role of the DOE (and its predecessors) has changed dramatically from that of the early days of the Atomic Energy Commission (AEC). Although now a substantially mature industry, the nuclear industry does not have the resources to meet all the demands that society places on it. There are significant technical challenges having importance to society as a whole, and DOE has responsibilities for meeting many of these challenges. Some of the general issues related to nuclear power that will impact DOE nuclear policy or that can be impacted by DOE nuclear R&D include:

- Energy security.
- Environmental concerns.
- Proliferation concerns.
- Public and workers' health and safety.
- Waste generation and management.
- International trade (jobs for U.S. workers), technology diffusion and cooperation.

2.3 The Future of Nuclear Energy

Current energy trends, if continued, suggest that the U.S. is heading toward a *gradual abandonment* of the nuclear power option. However, growing concern over emissions of carbon dioxide and other greenhouse gases is creating pressure for a *continued reliance* on nuclear power in the U.S., and the *reemergence* of nuclear power as the preferred option for new generating capacity could be possible in the future. These alternative futures, or scenarios, are not entirely mutually exclusive. As the various societal issues and forces change with time, the constraints and incentives affecting the nuclear power option may change, resulting in one scenario's phasing into another over time.

The alternative U.S. nuclear energy futures, and the implications of those futures, are closely tied to the alternative futures for nuclear power internationally. Internationally, nuclear power generation is likely to experience either *growth* or *decline*. It is, of course, possible that globally, nuclear power may maintain its current share of electrical generation. However, the implications of the international nuclear market on U.S. policy and R&D options are sufficiently constrained by these two limiting cases. Thus, we will consider the implications of U.S. options in the face of these two international frameworks.

3.0 KEY ISSUES FOR NUCLEAR ENERGY

The four most visible issues associated with nuclear power (economics, proliferation, safety, and waste management) are only a subset of broader issues of national importance. Vital national issues affecting or affected by nuclear energy R&D can be lumped into three broad categories:

- National security (e.g., nuclear nonproliferation).
- Environment, safety, and health (including nuclear waste management).
- Economic competitiveness (e.g., maintaining the nuclear infrastructure).

Each of these areas encompasses a variety of issues and concerns, although the perspectives from which these issues are viewed vary widely. It is also clear that the various perspectives will change with time, and there are other considerations that affect nuclear energy policy, such as public perception and international obligations.

Each of these issues has implications on both policy and technology, and can be addressed, at least in part, through R&D and technical innovation. DOE policies and R&D objectives must have one common characteristic: They must contribute to, or further, a set of "enduring objectives" for the overall U.S. nuclear policy. These objectives are embodied in the following broad issues.

3.1 National Security

National security encompasses three principal issues: (1) nuclear nonproliferation, (2) energy security, and (3) national defense.

Nuclear nonproliferation is defined here to address proliferation, as well as illicit procurement and use of nuclear materials from the commercial nuclear fuel cycle. Continued development of nuclear power abroad is likely, particularly among the developing nations and throughout Eastern Asia. Such a spread of nuclear power, particularly among less affluent and less stable nations, will increase the need for a strong nonproliferation regime. Development of technologies to improve the proliferation resistance of nuclear power systems can help augment the more traditional safeguards, transparency, and physical security approaches to nonproliferation. Without U.S. leadership in technology development for enhanced security and proliferation resistance, developing countries must choose from the currently available reactor systems, and some may choose reactors having even less desirable proliferation implications.

Energy security, including global sustainability, is here considered an element of national security because of its increasing global importance. The public expects reliable energy supplies at reasonable prices, and our domestic economy and international economic competitiveness demand both. The trend toward energy-market deregulation is reducing the energy sector's resilience and increasing dependence on fossil fuels at a rapid rate, potentially at the expense of long-term sustainability. Development of energy systems less vulnerable to economic and supply disruptions can help reduce one source of international tension and enhance U.S. national security. Nuclear power has and will continue to have an important role in minimizing the U.S. dependence on fossil energy resources and in assuring diversity in the nation's energy supply.

National defense relies heavily on nuclear technology for a variety of needs, from supplying the weapons arsenal to powering naval vessels and spacecraft. The coupling between civilian nuclear R&D and military applications cannot be completely severed, and indeed civilian R&D can contribute effectively to reducing the nation's weapons' legacy, as evidenced in the potential use of civilian power reactors to burn excess weapons plutonium.

Nuclear Nonproliferation

Nuclear proliferation is perceived to be one of the major risks associated with nuclear power. Reducing the risk of proliferation (and/or other diversion of nuclear materials and technologies) is and will remain an important element of U.S. nuclear policy. It is essentially a fact that new nuclear generating capacity will be introduced throughout the world, notably in Asia, and that this new capacity will result in ever-increasing accumulations and shipments of spent fuel. Both Japan and China have commercial reprocessing facilities under construction or planned. Other countries are likely to pursue reprocessing, both as a mechanism for extending energy resources and as a mechanism for waste management. Research into new fuel cycles for reduced spent fuel accumulation and reduced plutonium buildup, as well as research into new processes for proliferation-resistant waste isolation, could have substantial favorable impact on the proliferation resistance of this new generating capacity.

Current national thinking on proliferation appears dominated by a distrust of safeguards in their current form. This leads directly to the U.S. position of (at best) inconsistent "begrudging acceptance" of reprocessing in a few "chosen"

countries. It is possible that improved safeguards technologies, increased transparency, and more enthusiastic global acceptance of the international safeguards regime could result in an improved U.S. trust of international safeguards. This could result in increased acceptability of reprocessing.

Energy Security

Nuclear power's ability to ensure a safe, reliable supply of environmentally clean energy is its greatest benefit. The public expects reliable energy supplies at reasonable prices, and our domestic economy and international economic competitiveness demands both. Even in the current energy glut, pressures are building that will result in increased energy prices and increased competition for energy supplies. Pressures to decrease reliance on fossil fuels continue to build. Accumulation of greenhouse gases and other environmental issues are impacting the desirability of coal and natural gas as energy resources. Eventual supply shortages of oil will ultimately shift transportation toward alternative fuels including electricity and natural gas (possibly displacing natural gas for electrical generation), further increasing our dependency on electricity.

Nuclear power has and will continue to have an important role in minimizing the U.S. dependence on fossil energy resources. Even with the current worldwide energy glut, options must be preserved in order to meet future challenges. The current glut cannot be long-lived. Fossil reserves will eventually become more scarce, and political uncertainties and unrest always have the potential for severely changing the current energy picture. Even the U.S., with ample coal reserves for domestic requirements, may ultimately yield to international pressure for a reduction in emission of greenhouse gases and may have to reduce coal's share of electrical power generating capacity in the U.S.

Over the past decade, there has been a trend towards a more market-driven energy economy. This trend is accelerating with increasing deregulation, resulting in new market pressures emphasizing current economics as the primary figure of merit in energy decision-making. This trend is having several major impacts on the diversity and endurance of energy supplies and infrastructures. Utilities are beginning to shed those plants whose operational and capital costs are considered currently uneconomic or even marginally economic. Capital-intensive, new, long-life generating capacity is being ignored in favor of inexpensive, but short-lived, smaller unit generators. These trends are reducing the energy sector's resilience and increasing dependence on fossil fuels at a rapid rate.

There is a strong imbalance between the world's distribution of energy resources (particularly of fossil fuels) and the consumption of these fuels. This imbalance contributes to international tensions and has a destabilizing influence on international politics. As the world's population and overall energy consumption increases, the need for truly sustainable energy resources will become an increasingly important aspect of world stability, and nuclear power is in an ideal position to make a significant contribution. Even with current trends toward a once-through fuel cycle, nuclear power can contribute significant capacity. With advanced fuel cycles, nuclear power can have significant impacts on energy supply sustainability worldwide for very long times.

Conventional knowledge holds that the U.S., while dependent of foreign resources for much of its oil supplies, is self-reliant on its electrical generating capacity. This is, in fact, no longer true, particularly in the Northeast. Recent announcements by Ontario Hydro concerning the possible shutdown of seven of

their CANDU reactors can have a significant impact on electricity supplies in the Northeast and illustrate the increasing dependence of U.S. energy supplies on foreign sources.

National Security

The Department has responsibilities for defense materials and technologies, and these responsibilities have been largely segregated from those related to civilian applications of nuclear energy. There are, however, developments ensuing that may blur the distinction between civil and military nuclear programs. Proposals for tritium generation using either an LWR or FFTF, and the use of excess-Pu-derived MOX in commercial reactors are the two prime examples of such blurring.

Major elements of our national defense rely on nuclear power supplies, from naval propulsion reactors for ships and submarines, to radioisotope generators for spacecraft power. Loss of domestic nuclear infrastructures threatens these important capabilities.

3.2 Environment, Safety & Health

The environment, safety, and health area includes the nuclear energy issues of major importance to the general public today. Nuclear energy continues to be the only sufficiently mature technology having *environmental benefits* for the reduction of acid rain, greenhouse gases, and global warming in the near future. Continuing public concerns about the potential health impacts of radiation lead to demands for further improvements in *nuclear safety*, both technically and culturally. Visible progress in *waste management*, particularly in spent fuel disposal, is necessary to reinstall public and industrial confidence in federal energy management.

Environmental Benefits

The environmental benefits of nuclear power as a tool in the fight against increasing greenhouse gas emissions are clear, and nuclear power continues to have great promise for reducing society's adverse impact on the environment. Nuclear power plants are currently displacing some 140 million tonnes of carbon (MtC) emissions per year in the U.S., and nearly 500 MtC annually worldwide. Also, nuclear power plants do not emit volatile organic compounds, nitrogen oxides, carbon monoxide, particulate matter, and sulfur dioxide, all of which come from fossil fuel combustion and have significant health impacts on the public. The Clean Air Act Amendments of 1990 mandated sharp reductions in nitrogen oxide and sulfur dioxide emissions and placed annual limits on these emissions. It will be difficult or impossible to meet these limits without a significant nuclear component to the electrical generation mix. It will also be difficult to meet our international commitments on greenhouse gas emission reductions without a significant nuclear component to the U.S. electric power generation mix.

On the other hand, even though nuclear waste issues appear technically solvable, the apparent inability to resolve nuclear waste political issues will continue to slow public acceptance of nuclear power.

Nuclear Safety

Nuclear safety is perceived as one of the most important issues affecting nuclear power today. Although western reactors are actually quite safe, the graphic events at Three Mile Island and Chernobyl have perhaps irreversibly altered public perception of the risks associated with nuclear power, and have made safety an enduring nuclear issue. The consequences of another nuclear accident such as Chernobyl could lead to demands for termination of the world's nuclear generators and potentially eliminate the nuclear option for decades to come.

Waste Management

Waste management, particularly that of spent fuel, is one of the dominant concerns the U.S. public has regarding continued use of nuclear energy. The Federal government is having difficulty meeting its statutory responsibility to manage the spent fuel from the nation's commercial nuclear power plants. Utilities, electricity customers, and state leaders are increasingly frustrated by the Federal inaction on the spent fuel disposal program. The task of nuclear waste disposal has been made much more difficult by nonattainable standards for proving the safety of the repository and by the "set it and forget it" philosophy of repository design. Concrete progress in the management and disposition of all forms of nuclear waste is an essential element for the future of nuclear energy in the U.S. and ultimately in the global community. One subject particularly important to waste management, but common to all nuclear ES&H issues, is the definition of acceptable lower limits of radiation content and exposure, i.e., definition of an acceptable minimus.

3.3 Economic Competitiveness

Economic competitiveness is an increasingly important issue in an increasingly global economy. International power and influence is ever more closely coupled with economic strength and competitive advantage in the marketplace. Both our domestic standard of living and our ability to compete internationally are dependent on favorable energy *economics*. The U.S. ability to impact foreign nuclear policy will depend substantially on U.S. involvement in the nuclear markets, and the economic competitiveness of the domestic U.S. nuclear energy *infrastructure* is synergistically linked to our foreign competitiveness and influence.

Economics

The economics of nuclear power in a changing domestic energy market is an increasingly important issue. The ability of nuclear power to compete domestically with other alternatives is dependent on several important issues. One is nuclear energy's ability to compete fairly with other forms of generation, an issue increasingly uncertain under pending deregulation. The other issue is nuclear's ability to fulfill cost and schedule promises. Whether the economics are a cost or benefit of nuclear power will depend as much on the economics of the alternatives as on the economics of nuclear power.

Deregulation may represent the greatest threat to the economics of many nuclear power plants. Under deregulation, the cost bases for assessing and recovering capital are changing in a way that penalizes capital-intensive installations. Nuclear plants (and similarly, large coal-fired baseload plants) were constructed

at a time when recovery of capital costs over the normal operating life of the plant was essentially assured. Even though operating costs at many plants are low enough that they generate power at very competitive prices, plants with large unde depreciated capital costs will be at a distinct disadvantage in a deregulated environment even in light of lower operating costs. Without some mechanism for equitably dealing with these “stranded costs,” deregulation is likely to lead to a situation where, on paper, it is more profitable to close major power plants even though their operating costs may be less than the competition.

Whether in the current market or in a deregulated market, new domestic nuclear power plants will only be built if it can be shown that they can be constructed and operated cost effectively and on schedule. Industry is working hard to meet this challenge by increasing reliability, improving operations and extending fuel lifetime. New technologies, materials, and processes are needed to make even more progress. Improvements in the regulatory process have helped reduce both cost and schedule uncertainties, but even more is needed to effect real improvements in cost and schedule while simultaneously improving safety in real terms.

Infrastructure

Infrastructure is the basis of the U.S. nuclear capability, and it is in serious jeopardy. Overall economic competitiveness of U.S. nuclear energy depends on the maintenance of this capability and underlying infrastructure. Even in a future with dwindling domestic nuclear power, much of the existing infrastructure will be needed to ensure safe operation of remaining facilities, and to deal with the long-term waste management issues resulting both from nuclear power and defense activities.

Nuclear engineering enrollment is declining nationally, nuclear engineering departments are being dissolved or absorbed into other departments, and faculties are dwindling. Serious efforts to address this decline are necessary.

Major industries, such as medical and energy industries, increasingly rely on a wide variety of nuclear materials, technologies, and products. DOE (as the AEC) was once responsible for essentially all nuclear material supply, from nuclear fuel to medical and industrial isotopes. Most of these responsibilities have long migrated to the private sector. However, changes in the marketplace, coupled with aging facilities and reluctance to invest in new nuclear facilities, has eroded the country’s abilities to supply important materials, especially medical and industrial isotopes.

3.4 Other Considerations

Other considerations impacting nuclear energy include in general the nation’s need to adhere to international agreements, and the public acceptance of nuclear energy.

International obligations and international relations impact the nation’s responsibilities for nuclear energy and nuclear research and development. As one example, disarmament and resulting fissile materials disposition relies on technologies and infrastructures existing and in development to accomplish goals set by international accords. The U.S. is at odds with many others over the nuclear fuel cycle, citing proliferation and economic issues as overriding, while others place higher value on energy security and believe that the U.S. position

contributes to growing plutonium inventories and that plutonium recycling is an effective path to nonproliferation by limiting stockpiles of plutonium. What are the conditions under which these views might change? Under what conditions might the U.S. find itself needing to reopen fuel cycle R&D? What are the likely or potential time-frames, and what do we need to preserve for that eventuality?

Public perception of nuclear energy relies on satisfactory progress in issues already discussed, and on active and overt steps taken to communicate with and involve the public on important nuclear matters. Even more important in today's society, the public must see the DOE and the nuclear industry as being truly responsive to their needs and concerns. An example of this is the public demand for "passively safe" reactors, based on a growing sentiment against reliance on technologies for ultimate safety. The ALWR program addresses this and many of the underlying concerns, but does this program go far enough? Even if nuclear power were to emerge clearly as the technology of choice for future energy needs, implementation of future nuclear technologies will not be possible without public acceptance of nuclear power. Some of the questions underlying this issue include: What is the current level of public confidence in nuclear power, and in DOE? What can DOE do to respond effectively to public concerns and criticisms? What can DOE do to improve public confidence, and what can R&D do to help? Are DOE policies and programs viewed by the public as being reasonable and well thought-out?

Regulatory environment. The current regulatory environment, even with recent advances, will require additional reform for nuclear power to continue to play a major role in the U.S. energy future. Regulatory uncertainties and delays must be further reduced. Regulations must be sufficiently flexible to adapt to new safety technologies without major disruptions to existing systems and infrastructures. Many current regulations are unnecessary, and others inadvertently serve to reduce real safety. These need to be thoroughly reviewed and modified or dropped as appropriate.

Government role. The role of the U.S. government, and of DOE/NE in particular, in the continued development of nuclear energy and the balance between federal and industry funding of nuclear energy R&D are under serious debate. Perhaps even more basic is the question of what *should* the role of nuclear power be over the next 20 to 50 years, and how can DOE help realize that role? Can nuclear power reemerge as part of a bold energy plan in the next decade(s), or is nuclear to be relegated to an "insurance" role? In either case, what are the policy and R&D requirements?

The issues discussed above each have an effect on public attitudes toward nuclear power, Federal policy, and/or private industry investment decisions. Some tend to drive the country towards gradual abandonment of the nuclear option, others tend to support the maintenance of the current level of nuclear activity or even the reemergence of nuclear power as a preferred option. For example, the Federal inaction on the nuclear waste issue tends to discourage the U.S. utilities from wanting to build more nuclear power plants. The lack of effective public information on nuclear safety also tends to encourage the public to prefer a gradual abandonment of the nuclear option. On the other hand, the environmental impacts of the fossil fuel-fired electric power plants are leading some of the public to reconsider the need for nuclear energy. The relationships between the issues (drivers) and scenarios (alternative futures) are summarized in Table 1 below.

Table 1. Relationships between issues and scenarios.

	Gradual abandonment	Continued reliance	Reemergence
Nuclear nonproliferation	X ¹		
Energy security		X	X
National security		X	
Nuclear safety	X		
Environmental impact			X
Waste management	X		
Economics	X ²		X ²
Infrastructure		X	
X indicates that the issue is currently tending to bring about that option.			
¹	A segment of the public is in favor of gradual abandonment because of proliferation concerns. Gradual abandonment may make the proliferation problem worse.		
²	The current cost of nuclear power is tending toward abandonment of nuclear energy. However, long-term economic competitiveness in light of expected fossil-fuel cost increases may tend toward future reemergence.		

In the face of these drivers, three possible scenarios can be envisioned for the future of nuclear power in the U.S. Nuclear power will continue to be a viable option in most of the rest of the world, driven by increasing demand in the developing countries and by the lack of other alternatives.

4.0 SCENARIOS FOR THE NUCLEAR FUTURES

Three scenarios, or alternate futures, for nuclear power in the U.S. are described within the context of two scenarios for international nuclear power. From these, a number of observations and conclusions regarding the policy implications and R&D requirements for the U.S. are drawn. These U.S. nuclear scenarios are not mutually exclusive, and they can be viewed as representing possible phases in the potential reemergence of nuclear energy as an important element in the country's power spectrum. The three U.S. scenarios are:

- *Gradual abandonment* of the nuclear power option in the U.S..
- *Continued reliance* on the current nuclear generation technologies.
- *Reemergence* of nuclear power as the preferred option for new generating capacity.

These scenarios are discussed in the context of two alternative futures for nuclear power internationally: internationally, nuclear power generation will either grow or wither away. It is, of course, possible that globally, nuclear power may maintain its current share of electrical generation. However, we believe the implications of the international nuclear market on U.S. policy and R&D options are sufficiently bounded by these two limiting cases. Thus, we will consider the implications of U.S. options in the face of two international frameworks:

- *Decline* of nuclear power internationally.
- *Growth* of nuclear power energy generation worldwide.

Essentially all energy projections, including those emphasizing conservation and renewables, predict some growth of nuclear power on a worldwide basis. Rather than discussing in detail all six permutations of the domestic and international scenarios, we will here discuss the U.S. scenarios under the assumption of a growing international nuclear market, then discuss the additional implications a withering international market may have on the U.S. nuclear futures and options.

Each of these scenarios requires certain assumptions and invokes particular implications and challenges. Meeting these challenges will place demands on policy and requirements for R&D. The assumptions and implications are described below. The policy implications and R&D requirements are discussed in section 5.

4.1 Scenario 1: Gradual Abandonment

Under this scenario, there will be no new domestic orders for reactors in the U.S. Most existing reactors will operate through the end of their current licenses. Some (10–15) power reactors may be decommissioned early because of economic pressures caused by deregulation. A few reactors may be operated beyond the end of their current licensed lifetimes.

Assumptions for Scenario 1

Nuclear market: The international market for power reactors will continue to grow, particularly in East Asia, and a new market for small reactors will develop among the developing countries.

Safety: No major nuclear power accidents will occur in the world.

Waste management: Waste management, particularly geological repository development, will make reasonable progress in the U.S., providing an indication to the world nuclear energy community that waste can be managed in the long term.

Cost: In the U.S., deregulation will lead to 10–15 power reactors being decommissioned before the end of their design life. A few reactors could undergo life extension. All other power reactors will continue to perform well and be competitive in cost to other means of power generation. No major change is expected in the world energy cost structure.

Public acceptance: Worldwide public acceptance of nuclear energy will remain in its current state.

Security and proliferation: Security issues (safeguards, security, and proliferation concerns) will continue to increase in the U.S. because of: (1) Expansion of the nuclear option in the developing countries and East Asia; (2) Countries like France aggressively selling nuclear energy technology to those developing countries in order to maintain a viable domestic nuclear energy program; and (3) The U.S. gradually losing influence in nuclear matters, particularly in East Asia.

Light Water Reactor (LWR): The light water reactor (LWR) will continue to serve as the leading technology in the world market. No advanced reactor of any other kind will demonstrate the potential to replace LWR technology within the next 20-plus years.

Domestic Implications of Scenario 1

Since Scenario 1 assumes no new orders will be placed in the U.S., domestic activity will focus on safe operation of existing plants and successful handling of nuclear waste, including completion of the geological repository in what will probably be a deregulated cost structure. The objectives of the resulting U.S. program are therefore as follows:

Safety: The U.S. government's role is to assure that the regulatory process provides additional assurance. Ensuring the safety of aging plants and demonstrating adequate safety for potential life extension will be important goals.

Waste management, particularly the use of a geological repository, is of great importance in the U.S. as well as in the rest of the world: Scientific success is a must. Failure to develop a geological repository in the U.S. would not only be a disaster for U.S. operating plants but also could be a show-stopper in international nuclear deployment. The scientific challenge is enormous, considering the need to maintain public health and safety for not only tens of thousands of years but perhaps as long as many millions of years.

Deregulation will have some impact on the nuclear power industry. Some plants with high operating costs may be forced to shut down before their 40-year design life. Approximately 10–15 plants may be affected.

Security (safeguards, security, and proliferation concerns): The current domestic program is probably adequate. No major new issues are expected.

Infrastructure: With no prospects for a domestic nuclear option, the U.S. nuclear infrastructure will become increasingly reliant on an increasingly competitive foreign market. Already, U.S. industry is forced to license technology rather than to manufacture goods and systems. These forces will continue to erode the domestic U.S. nuclear infrastructure. In particular, loss of U.S. nuclear infrastructure and expertise will seriously jeopardize our ability to deal with the long-term nuclear waste and nuclear legacy issues.

International Implications of Scenario 1

International influence: Under Scenario 1, international proliferation is a major concern to the U.S. Without a major effort, the U.S. will lose its influence in nuclear matters. The loss of U.S. technology leadership (with the result that countries such as France will eventually have more advanced technology and will be able to attract international business); and the two-tier policy on proliferation that introduces friction between the U.S. and some other countries. Moreover, the potential for U.S. self-sufficiency in energy supply makes it politically difficult for the U.S. to implement a policy preventing other countries from exercising the nuclear power option.

To support our policy regarding proliferation, we must continue to have an influence in the international nuclear arena. The most effective way of achieving that goal is to maintain U.S. leadership in nuclear technology. We currently have sufficient resources (natural and financial) to provide for secure domestic energy supplies. However, it will be difficult to convince other countries with fewer resources not to pursue the nuclear energy option.

Our nuclear foreign policy is driven more by proliferation concerns than by potential for increased international business. We thus anticipate that other suppliers will gradually take a bigger share of the international market, and our influence on nuclear matters will experience a world-wide decline. We will therefore have less opportunity to influence international proliferation. In the end, our industry will be forced to pull out of international competition. In addition, we will be less able to address international nuclear safety concerns because we will have progressively less information to verify that the receiving countries have been adequately trained by their suppliers. The bottom line for the U.S. is that, although domestic nuclear energy may be phased out, it is essential to maintain a viable nuclear energy activity with adequate R&D elements in order to support U.S. international interests for the following reasons:

- To monitor and affect proliferation matters.
- To influence other nuclear matters worldwide.
- To be the leader in Light Water Reactor technology for the international market in order to help implement proliferation policy and enhance U.S. influence on nuclear matters.

Foreign markets: U.S. technology, on the other hand, is generally more expensive than that of other world suppliers. As a result, U.S. industry is fighting an uphill battle competing in the international market. Although we may believe that the U.S. has the safest LWR design, other world nuclear technology suppliers also meet western safety standards. Thus our claim of a safer design may not add much when we compete in the international market.

4.2 Scenario 2: Continued Reliance on Current Nuclear Technologies

Under this scenario, nuclear power will continue to be relied on and will likely maintain an approximate 20% share of the country's electrical generating capacity. Although some (10–15) power reactors may be decommissioned early because of economic pressures caused by deregulation, and a few reactors may be operated beyond the end of their current licensed lifetimes, new evolutionary reactor design and construction will proceed to take up the additional demands arising from decommissioning and growth in electricity demand.

Assumptions for Scenario 2

With regard to the nuclear energy situation in U.S., the following assumptions are made:

Nuclear power purchases: The U.S. would like (or is compelled) to strive to maintain a 20% share of its electricity generated by nuclear power. This may be driven by environmental concerns about fossil fuel. New orders would be placed during the next 10–15 years to replace retired reactors or reactors retired earlier due to lack of cost competitiveness.

Price deregulation. Nuclear power must be competitive in cost in order to stimulate the utility industry's interest in placing orders in a continuing environment of deregulation.

Public understanding and acceptance of nuclear energy. Enhanced public acceptance is essential for significant new domestic orders.

New nuclear power systems. New systems that integrate the entire nuclear fuel cycle from fuel to reactor systems to waste management, with attention to cost and proliferation concerns, are a must if the second generation of nuclear power is to begin.

Domestic Implications of Scenario 2

In addition to the implications under Scenario 1, a number of some additional implications arise, and some of the Scenario 1 implications must be expanded.

Safety, including related quality assurance and regulatory practice, will continue to be a dominant concern. However, economic pressures will force a shift in safety, quality assurance, and regulatory philosophies towards achieving demonstrable safety improvements in real terms. This shift in philosophy will, by necessity, lead to evolutionary improvements in reactor design, and may result in significantly new reactor concepts.

Waste management must be demonstrated as an achievable in practice. Integration of waste management within the context of the overall fuel cycle will be an important element of success.

Infrastructure: Continuing to rely on the U.S. nuclear option at roughly its current levels will help maintain our infrastructure to cover future needs. However, the lack of a clear mandate for significant technical innovation will limit the growth and capabilities of that infrastructure. At the current level of nuclear generation, and an anticipated growth rate in U.S. electrical demand of 1.5%, this scenario translates into only one 1500-MWe unit per year. This rate may be too low to maintain industrial capability unless significant export sales help support the industrial infrastructure necessary.

International Implications of Scenario 2

Safeguards and security: Although current safeguards and security practices are likely sufficient for domestic purposes, the intrinsic validation of the nuclear power option under this scenario will likely lead to development of improved safeguards and security measures as a model for the rest of the world.

International influence: Our ability to influence foreign nuclear decisions relies on the U.S. position as a reliable supplier of world-class technology. Continuation of the domestic nuclear option would enhance the U.S. ability to maintain its influence in nuclear matters worldwide.

Foreign markets: Maintenance of the U.S. nuclear option will serve to maintain or increase the presence of the U.S. and its nuclear industries in the world nuclear markets.

4.3 Scenario 3: Reemergence of Nuclear Power as the Preferred Option for New Power

In this scenario, nuclear power's share of the U.S. electrical generation capacity would increase, possibly due to increasing environmental concerns associated with fossil fuels and increasing costs and diminishing supplies of those fuels.

Assumptions for Scenario 3

It is difficult to foresee the distant future. Many elements, such as fossil fuel availability, changes in energy demand, international power shifts, environmental concerns, or new technology breakthroughs, can affect decisions on nuclear energy. Clearly, the further out we project, the higher the uncertainty. Thus benchmarking our projections against social, economic, and political realities from time to time is necessary. In Scenario 3, we assume that:

Technical breakthroughs in energy technology for base-load electricity generation (such as renewables or fusion) do not occur during the next 30–50 years.

Environmental concerns related to fossil fuel consumption, including global warming, acid rain, and others are confirmed to be harmful.

Economics of fossil fuel consumption becomes increasingly unsatisfactory due to increased fuel costs and increased costs of pollution prevention measures.

Domestic Implications of Scenario 3

Reactor technology development must proceed along revolutionary rather than evolutionary lines, with even greater emphasis on inherent safety and overall systems integration.

Fuel cycle development, carefully integrated with reactor systems and supporting infrastructures and focused on resource conservation and waste minimization, will become increasingly important.

Regulatory, siting, and operational philosophies need to shift towards improving overall system efficiencies, emphasizing standardized design, commonality of operations and procedures, and better accounting for social and political realities.

International Implications of Scenario 3

Foreign markets: Reemergence of the U.S. as the leader in nuclear technology and infrastructure can reestablish our role in the international nuclear markets. The international community embraced U.S. reactor and safety designs, and most foreign manufacturers reactor designs are based on U.S. designs. New generations of U.S. designs, featuring enhanced safety and proliferation resistance, will significantly impact the international markets.

International influence: Our ability to back up U.S. goals and interests with demonstrable technologies and systems will advance our ability to influence international nuclear policy and decisions.

5.0 POLICY AND R&D REQUIREMENTS

The demands of each of the three scenarios will require research and development and modifications to policy. Even under Scenario 1, R&D activities are required to meet domestic safety, environmental, and waste management requirements, as well as to maintain sufficient credibility to meet international policy objectives.

Just as the scenarios themselves are not mutually exclusive, the needs of each scenario relies on R&D and policy from the preceding and contributes to the next-higher scenario.

5.1 Policy and R&D Requirements for Scenario 1

As already pointed out, two great challenges face the U.S. if it essentially abandons the nuclear energy option: (1) maintaining sufficient influence in international nuclear energy policy and politics, and (2) ameliorating the impact of nuclear waste and the nuclear legacy.

International Cooperation and Dialog

International collaboration is an important part of the U.S. nuclear research agenda in areas ranging from collaboration in technical projects to support of State Department policy initiatives. Examples include:

- Joint international nuclear technology development projects aimed at improving the long-term safety and performance of nuclear power plants.
- Joint international cooperation on development and application of nonproliferation technologies.
- Participation in research and development programs coordinated or sponsored by international organizations.
- International safety information exchange.
- Agreements with foreign countries or regional organizations furthering U.S. nonproliferation and safety objectives.
- Increased direct dialogue and cooperation, most notably with China and other East Asian countries.
- Establishing a strong U.S. role in regional nuclear energy cooperation frameworks, particularly in East Asia.

The most unpredictable country in terms of nuclear development is China. China often has the same desires as the U.S. but disagrees with our methods. A discussion with China on nuclear matters, dealing as equals, could be much more effective than current approaches in dealing with some of our proliferation concerns. Opening a scientific channel for discussion with China is a good investment for both short-term and long-term goals. Since China is aggressively developing nuclear power, it will be relatively easy to establish dialogue on nuclear energy, particularly about U.S. technology and safety experience.

Only when we have a major role to play in the international arena can we have influence on nuclear matters. Our influence in Europe on nuclear matters is not as great as desired because of the strong role that the French play in that region. We are not even a member of EURATOM, a union of European countries on nuclear matters. Our effort to seek nuclear transparency in that region has had to rely on our allies and on the International Atomic Energy Agency (IAEA). It is obvious that Asian Pacific countries are going to organize nuclear cooperation with or without U.S. participation. We must avoid repeating our European experience. Thus, we must participate in arrangements on East Asian regional cooperation on nuclear energy as a member and hopefully a major player.

Safety

Maintaining safe operation of the 109 operating commercial nuclear power reactors is the primary responsibility of the nuclear power utilities and industry. The U.S. government's role is to assure that the regulatory process provides additional assurance. Research should focus on operational safety enhancements, such as digital instrumentation and control upgrades, control system enhancement, fire prevention and control, operator training and human engineering integration, etc. Most of these R&D activities will be carried out by industry; only those requirements involving advanced technology with significant potential effect on safety and commonality to all plants should be sponsored by the Federal government. Digital I&C is in that category.

Waste Management

Waste management, particularly the use of a geological repository, is of great importance in the U.S. as well as in the rest of the world: Scientific success is a must. Failure to develop a geological repository in the U.S. would not only be a disaster for U.S. operating plants but also could be a show-stopper in international nuclear deployment. The scientific challenge is enormous, considering the need to maintain public health and safety for not only tens of thousands of years but perhaps as long as many millions of years. A strong R&D program must therefore be continued, emphasizing a combination of engineering barriers with a natural barrier system. In a worst-case situation in which the repository development is unsuccessful, we may have to use dry storage either on-site or at a centralized location to temporarily store the spent fuel for up to 50 years or more. The technology and licensing process are mature for dry storage and thus this area requires little R&D.

Spent Fuel Minimization and Advanced Fuels Development

A major priority is to develop and test very-high-burnup nuclear fuels that will significantly reduce the amount and cost of commercial spent fuel disposition by

the government. In addition, some work should be done on the development of more proliferation-resistant fuels that might be used in either current LWR systems or potentially in small, low-cost reactors for export.

Small Reactor System Development

Maintain involvement in the development of a small reactor system (50 MWe~150 MWe) that can be used for electricity generation and/or desalination of water. This system must take the entire nuclear fuel cycle into consideration, using risk-based decision analysis to achieve the proper balance in fuel supply, waste generation handling and disposal, proliferation resistance, safe operation, and cost effectiveness. The system should have the following features:

- *No on-site refueling* in order to reduce proliferation concerns with operation life targeted for 10–15 years. The entire reactor will be shipped back to the factory for refueling and a new reactor installed. During the process, electricity and water desalination could be provided from reactors located on a transport barge.
- *High safety margin.*
- *Automated* operation and easy handling.
- *Minimized waste stream*, acceptable to geological repository.
- *High cost-effectiveness.*

There is a demand for such a system; and the system would address U.S. concerns on proliferation, safety, and U.S. leadership in technology and would enhance U.S. influence on nuclear matters. Without U.S. involvement, the development of such a system may be carried out by some other country for which the “no on-site refueling” criterion may not be honored. This small-reactor exercise, which integrates the entire fuel cycle including safety and cost into system development, is of long-term importance. Work on a small-reactor-system can be partially justified by the fact that it provides good practical experience if we have a need in the future for large-reactor-system fuel cycle integration, as discussed in Scenario 2. The technology required for certain parts of the system already exists. The most important task is the integration of all elements to achieve the most efficient and balanced design. Automation may be an important challenge. Japan, Korea, France, and Canada are working on automated instrumentation and controls in their nuclear power programs. This small-reactor initiative could also bring the U.S. back into the competition in the area of automated I&C applications, which can also benefit other industries.

Integration of the Nuclear Fuel Cycle

Research and analysis to develop and nuclear systems options from a total fuel cycle standpoint including cost, resource conservation, waste minimization and proliferation resistance. Concern about proliferation is the main reason for the U.S. policy on reprocessing. Since the U.S. is no longer the sole source of nuclear power reactors in the world, it will be very hard to further this proliferation policy. We may have to change our practice from trade control, export control and punishment to participation and cooperation. We must demonstrate that we are the technology leader and know the rest of the world’s energy needs. We will use our technology to help, while at the same time addressing our other concerns.

Our policy on reprocessing is derived from the Nonproliferation Alternative Systems Assessment Program (NASAP-1980 - Carter Administration) in 1980. At the same time the international community conducted a similar study, International Nuclear Fuel Cycle Evaluation (INFCE), and reached a totally different conclusion. Both studies reached very similar technical conclusions but led to totally opposite policy results. Today we have a much greater operational experience in reprocessing through experience in the weapons program. France and Russia also have operational experience through both weapons and commercial nuclear programs. It is time to reassess our reasoning in reaching our position on reprocessing, taking into account the total system: the waste generated by reprocessing, the environmental consequences, the cost and the need for infrastructure, and proliferation concerns. A systems study covering all of these elements may still demonstrate that reprocessing is not the best choice. However, it will be much easier to convince other countries not to reprocess on that basis. Most countries do not have reprocessing experience, so they do not have adequate information with which to perform their own assessments.

Global Fuel Cycle Safety, Security, and Accountability

Research into materials, processes and technologies contributing to the enhancement of the safeguards, security, and accountability regimes of both current and future fuel cycles is needed to meet national security objectives and to help resolve public concerns.

5.2 Policy and R&D Requirements for Scenario 2

For Scenario 2 to become reality, nuclear power must be accepted as a safe, clean, and affordable source of power. Improvements in the economics and perceived safety of nuclear energy will require significant changes in nuclear energy policy, particularly with respect to safety, safety philosophy, and public understanding. Safety improvements must be accomplished along several fronts: real improvements in safety and plant operations; improvements in safety philosophy, regulations, and standards; and improvements in the public's understanding of nuclear safety and their perception of nuclear energy in general. In addition, increased attention to better integration of the fuel cycle, including waste minimization and proliferation-resistant fuel cycles, will become increasingly important.

Safety Regulations and Standards Reform

During the rapid growth of nuclear power in the late 1960s, cost was not a primary concern of either the government or industry. Waste generation, handling, and disposal were viewed as issues to be dealt with in the future. Nuclear power was considered a privilege of the big nuclear weapon states. The U.S. may have had enough influence to dictate to the world community concerning proliferation concerns. Public support of nuclear power was taken for granted, because of the general acceptance of the idea of peaceful use of the atom. Knowledge of the differences between boiler and nuclear reactor design, construction, operation, and in particular accident management was not mature. Since cost was not a major concern, the U.S. established many safety regulations or standards that may, at times, have contributed little to safety, and sometimes even had an adverse effect, but increased cost substantially.

As a result, a 1000-MWe nuclear power plant has 40,000 pumps in comparison with the 4,000 pumps in a fossil power plant with the same 1000-MWe capacity. In reality, the essential difference between nuclear power plants and fossil power plants is that a boiler is replaced by a nuclear reactor. Many protection systems were added, often with two to three levels of redundancy. Of course, we now know that more redundancy does not always improve safety, because redundancy may be lost due to common failure modes, such as earthquakes.

The 10-fold increase in components introduced complexity in design, construction, operation, maintenance and repair, and most significantly accident management. The control room became filled with instruments to show component status, which led to an almost-impossible task for an operator attempting to manage an accident. After the Three Mile Island (TMI) accident and following more than 15 years research and development, we now realize that our control room designs need to be modified. The U.S. has a large-scale control room upgrade task under way. Although control room upgrades may be necessary, the real issue is whether nuclear plants require 10 times more components (i.e., whether those components really enhance safety or perhaps have adverse effects). Although there is little to be done for the existing plants, for future plants (even those with standard LWR technology), we must strike a proper balance between various parameters in design.

There are no doubt many other so-called safety requirements that are questionable in real value, but are certainly costly. Thus Scenario 2 requires that we establish a program to review, identify, and conduct R&D to assess safety standards and regulations of this nature and propose changes. Our extensive experience with the many plants built and operated should allow a useful look at nuclear safety from a systems standpoint. The concentration should be on LWR technology since it will be the approach of choice for the foreseeable future. A 20–50% cost reduction might be achieved without jeopardizing safety.

Quality Assurance (QA) Reform

The American Society of Mechanical Engineers (ASME), Section III Code was developed during the last 20 years to replace the Section 8 Code for nuclear construction. Section III Code has reduced safety margins built into the code but increased inspection and assurance requirements to reduce uncertainty. In implementing this philosophy, ASME introduced quality assurance (QA) requirements to assure that quality is confirmed and uncertainty is indeed bounded. Unfortunately, the QA program was heavily influenced by legal thinking and established a very systematic and burdensome paper trail of documentation control to satisfy litigation concerns. In reality, the actual quality enhancement is not in proportion to the burden it creates. Certain portions of the QA program are beneficial and have safety importance. Other portions need to be reviewed for their significance. We may have to separate the quality assurance from legal protection considerations so that our future QA program can enhance safety at a justifiable cost. A rough estimate is that current QA programs add 10–15% in nuclear plant design and construction cost. The real effect on quality is not well understood.

Regulatory Philosophy Reform

The first generation of nuclear power programs taught us an important lesson. The assignment of responsibility and accountability was not very clearly defined

between government and industry. For the future generation of nuclear power programs, we must clearly define responsibility and accountability. The utility, or the owner/operator of a nuclear plant, should be responsible for safety and public protection, and also be accountable for liability. The regulator (i.e., the NRC) should be an oversight organization to assure that industry is fulfilling its responsibilities. Therefore, safety regulations should not be prescribed in too much detail. Instead, industry must be given a certain amount of room to make judgmental decisions that balance liability and cost. The new, one-step licensing process is headed in the right direction. More needs to be done to define the regulator's role and industry's responsibility.

Improvement of Public Understanding and Perception of Nuclear Energy

During the past 30 years, the general public had been misinformed on nuclear energy. It had been told that nuclear power was so safe (with all the many safety protection systems in place) and that the nuclear power safety performance record was so good, that there was no need for concern. The public's lack of knowledge is such that it panics when any incident occurs in a nuclear power plant, whether it is a nuclear or a non-nuclear incident, or whether it is an incident within design limits or a real accident requiring great concern. When many small incidents accumulate, the public wonders if nuclear plants are as safe as they have been assured (after all, things seem to go wrong even though there are so many safety systems). The public must be provided with a correct picture in which nuclear power is described as any other high-technology product, (e.g., that incidents within design limits are expected and that the plant is designed for them). An aggressive public information (or re-education) program is needed involving a very clear description of accident types and risk consequence. This program should be part of the school program, perhaps starting at the junior high level. A period of 20 years passed while public perceptions on nuclear energy changed from totally supportive to negative. It will take at least 20 years to reverse the process. Without public support, nuclear power in this country has little future.

Safety

Along with changes in safety philosophy, regulations, and standards, new methods of safety design and analysis must be developed to support those reforms.

Integration of the Nuclear Fuel Cycle in Large Systems (1000 MWe+)

We should not fund any reactor technology development (even on the Light Water Reactor system) until we have taken the totally integrated nuclear fuel cycle into consideration (including cost, proliferation concern, and waste management). In Scenario 1, we recommended the development of a small reactor system to start the process of integrating the nuclear fuel cycle. Starting with a small reactor system instead of a large reactor system was due to the reality that large reactor systems will not be ordered soon, because we have 109 reactors in operation, and to the fact that a small reactor system is urgently needed by developing countries where the U.S. may have great concerns about proliferation. If it is believed that more orders for nuclear power reactors will be placed in the U.S. during the next 10–15 years, then we must start to assess which reactor

system can produce less waste and waste acceptable to a repository, has the least proliferation potential if exported to foreign countries, has high safety margins, and is very cost-effective. If Scenario 1 activities are pursued and progress successfully, the development of a large-size nuclear power reactor system should be started to prepare for the future needs. If, in addition, regulatory reforms, cost reductions, and safety improvements are pursued successfully, and a totally integrated nuclear fuel cycle is identified, then in-depth R&D for further development and deployment of that system must be supported.

5.3 Policy and R&D Requirements for Scenario 3

Under these assumptions, we must think seriously as to which fission reactor technology should be developed for future generations (i.e., for 30 years from now and beyond). Following our experience gained during Scenarios 1 and 2 on integrating the nuclear fuel cycle, it is necessary to identify and further develop new fission reactor technologies. Can we predict which fission technology will be the choice for the future? Certainly not. Even for today, LWR technology may not be optimal, but it is the best current choice considering present social, economic, and political realities. For us to introduce a new technology to replace one commonly used, we must consider the total system. That total system includes not only reactor technology, fuel cycle considerations, and cost but also infrastructure needs, public understanding, regulatory framework, etc. It is clear that the U.S. cannot afford to introduce many new technologies at the same time. Research and development should thus be focused on a few technologies. A choice will then have to be made of the one technology, for further intensive R&D, and the required development of the entire system carried out. Only when the entire system is in operation and has been demonstrated will society be ready to accept it. This is the lesson learned from the first generation of nuclear power. It should be remembered in order to avoid the same mistake during the second generation.

6.0 IMPLICATIONS OF ALTERNATIVE INTERNATIONAL NUCLEAR POWER FUTURES

The state of nuclear power generation internationally has and will continue to have significant impact on U.S. nuclear policy, the U.S. nuclear marketplace, and on our research and development agenda. While the U.S. has some influence in international nuclear issues, history has demonstrated that the U.S. can only influence, not directly change, the international nuclear marketplace. It is also clear that historically the U.S. ability to influence the international nuclear community has been tied to the relative technological strength of U.S. nuclear technologies, expertise, and supply.

If the current growth of nuclear power internationally were to stop, and international nuclear power were to decline, what would be the implications to the U.S.?

First, a decline in nuclear power would reduce the ultimate generation and accumulation of spent fuel and potential separation and accumulation of plutonium through reprocessing. This would contribute to a reduction of

proliferation risk worldwide, particularly if the decline progressed slowly. In the event of a “catastrophic” decline in nuclear power (for example, in the event of a major reactor accident), the significant quantities of commercially separated plutonium (most notably owned by the French and Japanese and now slated for consumption as MOX) would require disposition similar to today’s stocks of excess weapons plutonium. There would be an even greater need for new forms of long-term international safeguards and security to protect this material.

Second, U.S. influence in international nuclear issues is strongly dependent on the relative strength of U.S. technology and U.S. nuclear position relative to the rest of the world. A decline in worldwide nuclear power would, by default, improve the influence of the U.S.

Third, a worldwide decline of nuclear power would place the same stresses on, and endanger the maintenance of, the world’s nuclear infrastructure that abandonment of nuclear power would place on U.S. infrastructures. Just as in the U.S., the worldwide nuclear legacy (waste, spent fuel, plutonium, and decommissioning) will not disappear, and there will be a critical need for expertise and infrastructures to deal with these legacy issues well beyond the decline of nuclear power generation.

Fourthly, even without nuclear power, the world’s consumption of primary energy is certain to increase, with the most rapid increases occurring in the developing countries and in East Asia. Without nuclear power, much of this increase must be taken up by coal and other fossil fuels. This will increase global release of carbon dioxide and other environmentally sensitive emissions, and increase the demand and competition for oil and gas.

6.1 Policy Implications of a Declining International Nuclear Role

Nonproliferation would continue as a major policy issue for the U.S. and the international community. With no clear use for remaining stockpiles of commercially separated spent fuel, international safeguards and international spent fuel and plutonium disposition will gain importance.

U.S. influence would potentially improve under an international nuclear decline, but simultaneously so pressure would grow for the U.S. to accept increased responsibility for assistance in dealing with the remaining legacy.

International nuclear safety could be threatened by dwindling nuclear expertise and infrastructures. The U.S. would become increasingly relied on to support safety programs for the remaining nuclear programs.

6.2 R&D Implications of a Declining International Nuclear Role

Without a need for new forms of nuclear generating capacity, R&D in related technologies would decrease in importance. However, with the changing nature of nonproliferation concerns, the need to invest in new safeguards technologies for potentially long-term monitoring of spent fuel and commercially separated plutonium would take on new importance. Similarly, many foreign nations may have to modify plans for spent fuel disposal, and new technologies for spent fuel and fissile materials disposition would be needed to meet the differing needs of diverse countries and programs. Renewed interest in internationally monitored disposition regimes may take on new importance.

Recommendations for a Department of Energy Nuclear Energy R&D Agenda

Appendix 5 Pros and Cons of Objectives and Options

1.0 INTRODUCTION AND SUMMARY

Nuclear power plays a significant role in the U.S. economy, and (barring unforeseen circumstances) will continue to play one at least until the end of the licensed lifetimes of the majority of the currently operating reactors. Major issues are facing the nation that may well result in a reemergence of nuclear power as a potential contributor to the nation's environmentally sound energy security goals. Moreover, the need to confront major issues associated with nuclear power will endure far beyond the lifetime of the current generation of reactors.

With these realities in mind, the underlying issue is not whether to continue nuclear power or nuclear power research, rather it is to what extent is nuclear power and nuclear research necessary to ensure vital national interests?

Review of the issues, scenarios, and implications for policy and R&D clearly indicates three major themes, or challenges, for the U.S. common to any nuclear future, even one in which nuclear energy declines both worldwide and domestically:

- *Influence:* How does the U.S. best influence the rest of the world in critical nuclear issues such as nuclear safety, nonproliferation, and waste management?
- *Infrastructure:* How do we maintain sufficient expertise and infrastructure to deal with the enduring nuclear legacy, both domestically and internationally?
- *Future options:* Can the U.S. truly afford to preclude the use of nuclear energy in a future with unclear environmental and energy security issues?

These challenges are at the root of the U.S. government's role in nuclear power and nuclear power research. In addition, government has responsibility for promoting the nation's economic competitiveness. From an energy perspective, this means ensuring that the nation's energy needs, considering all constraints and including nuclear, are met as productively and economically as possible.

Before assessing the pros and cons of the policy and R&D options discussed in previous sections of this study, it is useful to recall some of the benefits and risks associated with nuclear power. Some of the major benefits of nuclear power are:

- It is a significant, dependable, and independent U.S. domestic energy resource.
 - Nuclear power provides over 20% of the domestic electrical energy supply.
 - It is a domestically "independent" energy source, reliable in face of international tensions and market uncertainties.

- It is safe and environmentally sound.
 - Nuclear energy has no direct emissions of CO₂, acid rain, or other environmentally sensitive effluents.
 - It is a safe energy source, notwithstanding continuing concerns and issues.
- Maintains U.S. positions of technical leadership and influence in important international policy areas such as nonproliferation, safety, and waste management.

There are, of course, risks associated with nuclear power:

- There are proliferation implications and risks with nuclear power internationally.
- Spent fuel and waste management, even though technically resolvable, are significant socio-political issues.
- Because of the magnitude of the consequences of a nuclear accident (even more so, the magnitude of the uncertainties surrounding the consequences), nuclear safety remains a significant issue.
- The cost of nuclear power is currently unacceptably high relative to most alternatives.

Just as there are risks associated with nuclear power, there are risks associated with *not* exploiting nuclear power:

- Loss of international influence and technical leadership:
 - With no viable domestic nuclear energy program, U.S. ability to influence international nuclear policy decisions, including major international issues of nonproliferation, safety, and waste management, will deteriorate even further.
 - With no U.S. leadership in proliferation-resistant technologies and no viable U.S. reactor industry, developing countries must opt for indigenous reactor systems or choose other available systems, potentially resulting in even less proliferation resistance than current U.S. designs.
- Erosion of critical infrastructures — the infrastructure necessary to effectively deal with significant nuclear issues, including D&D, waste management, and nuclear facility safety will erode.
- Impairment of energy options and flexibility:
 - The U.S. will become more dependent on fossil fuels in the short term, and perhaps in the long term, further increasing both demand and prices.
 - Our ability to stabilize carbon and greenhouse gas emissions will be impaired.
 - Flexibility of our electrical energy supply sector will be decreased, potentially postponing trends away from fossil fuel dependence, such as electric transportation.

In a very real sense, the analysis of the pros and cons of the alternative objectives, policies, and R&D programs for nuclear power must be developed from the perspective of how best to exploit the benefits of nuclear power and minimize the risks as they relate to nationally important goals.

If the U.S. is going to seriously meet its international environmental commitments, support a growing economy, and ensure its own as well as others' energy security, it must find ways to enhance and support nuclear energy as a part of the U.S. energy portfolio. No other energy source available today offers the demonstrated benefits of nuclear energy. Continued reliance on nuclear power in the U.S. and the significant energy security and environmental benefits of nuclear power will only be realized if the undesirable risks

associated with nuclear power are reduced. These risks can be reduced by well-focused research and development.

In light of major and continuing uncertainties in the world's energy outlook and markets, clear needs for facilities and expertise to deal with existing and future security, safety, and environmental issues and continuing international tensions in much of the world, the U.S. simply cannot afford to allow its nuclear influence, infrastructures, or options to erode further.

Even if the current generation of domestic nuclear power is allowed to decline as a national resource, the U.S. is faced with the task of mitigating a clear set of unacceptable risks and addressing the related major challenges. These challenges will also require specific research and development efforts to reduce these unacceptable risks.

2.0 RELATIVE SIGNIFICANCE OF THE ISSUES IMPACTING NUCLEAR POWER

Rigorous implementation of decision theory requires assigning metrics to the various objectives (issues) and options. Rather than attempting to assign a quantitative ranking to the various issues impacting nuclear power, nuclear R&D, and the government's role, we will briefly discuss, in a nonrigorous relative way, the significance of these issues and the perspectives for their resolution.

Internationally there are three issues impacting nuclear power: two from the U.S. perspective and one from the perspective of foreign countries.

Proliferation is the dominant international issue from the U.S. perspective. "Business-as-usual" will likely only increase sensitivity to this issue. Major efforts in new technologies (fuels, reactor systems, spent fuel management, and international safeguards and safeguards technologies) are needed to address this issue.

Safety is a significant issue, both from the U.S. and foreign perspective. However, from the U.S. perspective (and notwithstanding legitimate altruistic motives) it is primarily an issue due to the potential impact of foreign reactor accidents on the U.S. program and economy. Resolution of the safety issue internationally requires two major elements. One is real technological change. The other is one of public perception.

Energy security is the major nuclear issue for most countries having or embarking on nuclear programs today. Although significant, energy security is not the major domestic issue in the U.S. today.

Domestic issues focus on the environment, economics and safety of nuclear power.

Safety of nuclear power has been the major domestic issue for the past two decades. As in the international safety issue, both technological change and modification of public perception are needed, but changes in safety philosophy and regulation are also needed to resolve this issue.

Environmental issues associated with, or avoided by, nuclear power are becoming increasingly important.

Carbon emissions and its avoidance by the use of nuclear power is the issue most rapidly growing in importance today.

Waste management and spent fuel disposition are, today, on par with the safety issue for nuclear power. Since most technical difficulties associated with this issue appear solvable, the issue is today primarily a social and political one, but resolution is difficult.

Infrastructure issues, particularly ensuring sufficient infrastructure and expertise to deal with the nuclear legacy independent of alternative nuclear futures, is a very important but often (and publicly) overlooked issue.

3.0 IMPLICATIONS OF ALTERNATE FUTURES

The U.S. can influence the future of domestic and international nuclear power by its definition and implementation of nuclear power policies, but it cannot control the nuclear future. Appropriate roles of government are to respond to current realities, to prepare the country to respond to reasonably expected futures, and to guard against unexpected futures. In Section 5, three scenarios for U.S. domestic and two for international nuclear energy futures were identified and are paraphrased below:

Domestic scenarios:

- *Gradual abandonment* of the nuclear power option in the U.S..
- *Continued reliance* on current nuclear generation technologies.
- *Reemergence* of nuclear power as the preferred option for new generating capacity.

International scenarios:

- *Decline* of worldwide nuclear power.
- *Growth* of nuclear power internationally.

Of the six possible combinations of these scenarios, Section 5 discussed the three domestic scenarios assuming international growth and briefly outlined the implications of a decline of worldwide nuclear power.

Currently, the domestic situation in the U.S. is one of gradual abandonment. No new reactors have been ordered for decades, a number of plants under construction have been abandoned, and existing plants are beginning to be shut down prematurely. Internationally, the rest of the world is generally seeing a growth of nuclear power.

The following table outlines the expected severity of the major challenges for government policy and R&D under the scenarios discussed above.

Relative severity of the major nuclear challenges under various scenarios			
Scenario	Challenge		
	Influence	Infrastructure	Future Options
<i>International Decline of Nuclear Power</i>			
Domestic abandonment	Difficult	Very difficult	Very difficult
Continued reliance	Positive	Positive	Positive
Reemergence	Positive	Positive	Positive
<i>International Growth of Nuclear Power</i>			
Domestic abandonment	Very difficult	Very difficult	Very difficult
Continued reliance	Minor	Minor	Positive
Reemergence	Positive	Positive	Positive

The following sections will look at the implications of these scenarios (both domestic and international) with respect to the major challenges described above.

3.1 Implications on U.S. Nuclear Influence

One of the major challenges to the U.S. in any nuclear future is maintaining the nonproliferation and nuclear safety regimes, especially in the face of declining nuclear programs. This challenge is particularly difficult in future scenarios where the U.S. share of the nuclear market continues to decrease.

In the past, some foreign countries pursued nuclear power partially as an affirmation of national technical achievement and pride. This goal, while still part of some country's nuclear agenda, has substantially subsided in the face of the technical and economic difficulties continuing to plague nuclear power worldwide. Today, one of the prime reasons for embracing nuclear power is the lack of affordable energy alternatives in the face of increasing demand.

As past events have shown, the U.S. has little ability to effectively alter worldwide energy issues and markets. Without reasonable optional energy sources, many countries will likely opt for whatever nuclear power systems are commercially available in the future. The U.S. international goals of nonproliferation, safeguards, and nuclear safety can be furthered only if affordable energy systems conducive to those goals are available, and that can be assured only if the U.S. provides and supports those alternatives.

Policies under which the U.S. removes itself from participation in domestic and/or international nuclear power development cannot provide those alternatives.

A decline and abandonment of nuclear energy in the U.S. would significantly reduce U.S. influence on nuclear energy issues worldwide without overt efforts to provide support essential to the international safeguards, nonproliferation, and safety regimes. The U.S. has sufficient coal and natural gas reserves to enable the U.S. to abandon nuclear power as "an example" for others. Nations lacking the energy reserves of the U.S. recognize this as a luxury they cannot afford. Without acceptable alternatives (whether new proliferation-resistant reactors and fuel cycles, or economically and environmentally acceptable alternatives), many such nations will rely on non-U.S. nuclear suppliers. Lack of a U.S. nuclear program would make some arms reduction efforts, notably those aimed at reducing former Soviet HEU and plutonium stockpiles, very difficult.

Even under a worldwide decline in nuclear power, disposition of spent fuel and separated plutonium, waste management, safety of aging plants, and decommissioning present significant issues of vital interest to the U.S. Influence in many of these areas will require both technical leadership as well as political leadership. Current U.S. inability to resolve waste, spent fuel, and excess weapons materials disposition is seriously undermining our ability to influence similar issues worldwide.

Either continued reliance on U.S. nuclear power generation or reemergence of the nuclear option in the U.S. presents similar challenges to U.S. influence internationally. While the U.S. position and influence would increase internationally relative to those under an abandonment of the nuclear power in the U.S., such a scenario demands effective improvements in safety, waste management, and proliferation resistance beyond those of current systems and operations, both for the real benefits gained and for the international examples provided.

3.2 Implications on Nuclear Infrastructures

Under any of the domestic and international scenarios for nuclear energy, there is and will be a continuing need to maintain a robust nuclear infrastructure to manage the nuclear legacy. The only questions raised by the various scenarios are the extent of that infrastructure and the difficulty in maintaining the infrastructure.

Scenarios pessimistic to the future of nuclear energy present the major challenge to preserving and maintaining infrastructure. Without a robust nuclear economy and continuing nuclear R&D, it is difficult to entice and train needed specialists and industrial capabilities and to maintain the necessary technical expertise. Even today, with the world's largest installed nuclear capability, the uncertain future of the domestic U.S. nuclear industry has resulted in ever-declining enrollment of nuclear science students at U.S. universities.

Pessimistic futures for nuclear power do not significantly change the kinds of infrastructures required, they only change the size of the individual components. For example, were there to be no new reactors operated, we would likely continue reactor operations through the end of most reactors' lifetimes and would need safety systems, plant safeguards, and operations for another 40 years or so. We would continue to require spent fuel management for at least another 50 years and would require continued operations of repositories and other waste management facilities for some time later yet.

Internationally, the potential for a worldwide decline in nuclear power appears less likely than in the U.S., but some of the challenges in that event are substantial. Commercial reprocessing and separation of plutonium has outstripped the rate of utilization of plutonium as fuel in reactors. Current projections suggest over 200 metric tonnes of plutonium will have been commercially separated by the year 2000. A premature decline in worldwide nuclear power could result in much or nearly all of these inventories having no clear disposition path.

Relying on the current level of nuclear power generation and potential expansion of the role of nuclear power, either domestically or worldwide, would both serve to maintain the current nuclear infrastructure. However, such scenarios would require improvements in the ability of the nuclear programs to meet increasingly stringent demands on nuclear safety, waste management, safeguards, and nonproliferation.

Reliance or growth of nuclear power would be viewed, particularly by the developing countries, as reinforcing the desirability of nuclear power. This would place additional incentives for the development of proliferation-resistant reactor systems and fuel cycles, as well as on developments aimed at improving the current LWR fuel cycle and proliferation resistance.

3.3 Future Use of Nuclear Power

The current domestic decline of nuclear power is due primarily to economics and increasing public concern regarding nuclear safety and waste management. The relative economics of nuclear power depend strongly on the economics of alternative choices, currently mostly coal. Increasing concern over the environmental impacts of fossil fuel combustion is likely to increase the cost of these fuels, and the potential for alternative sources appears limited. It is not unlikely that future use of nuclear power may be considered both economically and environmentally.

Maintaining the option for nuclear power, even in the face of domestic decline and the (small) possibility for international decline is current U.S. policy, and one that helps protect vital U.S. environmental, economic, and energy security issues. Continued

maintenance of nuclear power as a viable option for future use relies on meeting several significant challenges:

- Solutions for or significant progress in the management and disposition of nuclear waste and spent fuel.
- Improvements in safety, operations, and management of nuclear systems.
- Development of alternative approaches to proliferation-resistant systems and fuel cycles.
- Development of improved nonproliferation and safeguards technologies and regimes.

4.0 PROS AND CONS OF ALTERNATIVES AND REQUIRED RESPONSES

Both Tasks 4 and 5 concluded that three general alternatives appear possible for the future of nuclear energy and nuclear energy policy in the U.S. The three alternatives are, in effect, policy descriptions:

- *Gradual abandonment.* The U.S. Government essentially divorces itself from the nuclear option, and concentrates on safety, environmental cleanup, and decommissioning domestically and aggressively pursues its international nonproliferation agenda.
- *Continued reliance.* The U.S. Government continues to support the current role of domestic nuclear power primarily to preserve the domestic nuclear option for future use and tolerates foreign nuclear developments under effective international safeguards.
- *Reemergence.* The U.S. Government endorses nuclear power and supports active development of new and improved reactor systems both domestically and internationally.

Task 4 identified four alternative paths for U.S. government involvement for both domestic and international nuclear energy. These alternatives range from essentially no government support for nuclear energy to a more aggressive, future-oriented role in nuclear R&D. These alternatives represent policy options, with the foreign and domestic options serving as dimensions in a 4-by-4 matrix. In the conclusions, Task 4 noted that three of the possible 16 combinations appeared the more reasonable subset for discussion. These three map well onto the three suggested above.

The three scenarios presented in Task 5 were predicated on the assumption that nuclear energy would continue to grow internationally, and discussed the alternative scenarios from the perspective of how each would impact the U.S. ability to participate and to influence the international nuclear decision process.

The following matrices summarize the implications of these three scenarios, assuming at least moderate growth in nuclear energy on an international scale. We also briefly identify the impact both slower and more aggressive international nuclear energy growth might have on these implications.

4.1 Implications of Gradual Abandonment

Implications of a gradual abandonment of nuclear power			
Objective	Pros	Cons	Response
National security			
Nuclear non-proliferation	Serve as an example for others Reduce ultimate accumulation of spent fuel and fissile materials	Loss of influence in international nuclear issues	Maintain leadership in technology through developing proliferation-resistant fuels, reactors and systems Increase international cooperation and dialogue
Energy security	None	Loss of significant domestic energy resource Increased reliance on fossil sources	Maintain underlying technology and infrastructure as a future option
National security	None	Erosion of underlying nuclear infrastructure	Maintain infrastructure
ES&H			
Safety	Reduced in risk of nuclear accident	Increased real overall risk to workers and public from alternative energy generating technologies Loss of technical expertise to maintain nuclear safety during phase-out, and cleanup of the legacy	Maintain nuclear option for the future Emphasize research in safety, decommissioning, and waste management
Environment	None	Increased greenhouse and sulfur emissions	Maintain nuclear option for the future
Waste management	Reduction in ultimate waste generated	Reduced incentive for effective, long-term waste management Loss of supporting technical expertise	Emphasize research in waste management
Economic competitiveness			
Economics	Possible-short term improvement in overall energy costs	Increased reliance on foreign expertise, goods and services Likely long-term increase in overall energy costs Loss of international markets	Maintain nuclear option for the future
Infrastructure	None	Significant loss of scientific and technical expertise and industrial capabilities	Maintain nuclear option for the future
Nuclear supply	None	Loss of capabilities	Maintain nuclear option for the future

4.2 Implications of Continued Reliance on Nuclear Power

Implications of continued reliance on nuclear power			
Objective	Pros	Cons	Response
<i>National security</i>			
Nuclear nonproliferation	Maintains U.S. influence	Increased pressure on importance of safeguards Increased accumulation of spent fuel	Increased development of new safeguards technologies
Energy security	Maintains balanced energy supply mix	None	
National security	Maintains supporting infrastructures	None	
<i>ES&H</i>			
Safety	Real improvements in safety via both technical advances and regulatory reform	Requires real improvements in nuclear safety Requires overt efforts to improve public perception of nuclear safety	Increased R&D for nuclear safety
Environment	Reduces potential future increases in greenhouse gases and SO ₂	Requires overt efforts to improve public perception of nuclear environmental impact	
Waste management	Improvements due to better integration of nuclear fuel cycle	Increased volumes of spent fuel accumulation	Improved spent fuel management and disposition methods and technologies
<i>Economic Competitiveness</i>			
Economics	Reduced overall long-term U.S. energy costs	Requires increased government funding of nuclear R&D	
Infrastructure	Maintains current domestic infrastructure		
Nuclear supply	Maintains current capabilities	None	

4.3 Implications of a Reemergence of Nuclear Power

Implications of a reemergence of nuclear power			
Objective	Pros	Cons	Response
<i>National security</i>			
Nuclear non-proliferation	Potential reduction in proliferation risk via new technologies, processes and designs	Increased worldwide inventories and trade of fissile materials	Improved safeguards practices and technologies
	Enhancement of U.S. influence in international nuclear issues	Increased reliance on international safeguards	Improved spent fuel management and technologies
Energy security	Significant improvements in both domestic and international energy resources and security	None	
National security	Improved nuclear infrastructure supports related national security needs	None	
<i>ES&H</i>			
Safety	Reduced worker and public risk through improved safety and avoiding health and safety impacts of alternative technologies	Increased sensitivity to and importance of nuclear safety issues	Safety R&D
Environment	Significant reductions in emissions of environmentally sensitive effluents		
Waste management	Improvements in waste management technologies	Effective waste management continues as an important issue	Improved waste management technology and practices
<i>Economic competitiveness</i>			
Economics	Reduced energy costs by avoiding impact of escalating fossil energy costs		
	Improved U.S. position in international markets		
Infrastructure	Improved technical, scientific and industrial capabilities		
Nuclear supply	Improved nuclear supply capabilities		

4.4 Implications of a Worldwide Decline in Nuclear Power

Implications of a worldwide decline in nuclear power			
Objective	Pros	Cons	Response
National security			
Nuclear non-proliferation	Reduce ultimate accumulation of spent fuel and fissile materials	Orphaned separated plutonium spent fuel and waste management legacy Loss of nuclear infrastructure	Maintain leadership in technology through development of proliferation-resistant fuels, reactors and systems. Increase international cooperation and dialogue
Energy security	None	Loss of significant energy resources Increased reliance on fossil sources	Maintain underlying technology and infrastructure as a future option
National security	None	Erosion of underlying nuclear infrastructure	Maintain infrastructure
ES&H			
Safety	Reduction in risk of nuclear accident	Increased real overall risk to workers and public from alternative energy generating technologies Loss of technical expertise to maintain nuclear safety during phase-out, and cleanup of the legacy	Maintain nuclear option for the future Emphasize research in safety, decommissioning and waste management.
Environment	None	Increased greenhouse and sulfur emissions.	Maintain nuclear option for the future
Waste management	Reduction in ultimate waste generated	Reduced incentive for effective, long-term waste management Loss of supporting technical expertise	Emphasize research in waste management.
Economic competitiveness			
Economics	Possible short term improvement in overall energy costs	Likely long term increase in overall energy costs Loss of international markets	Maintain nuclear option for the future
Infrastructure	None	Significant loss of scientific and technical expertise and industrial capabilities	Maintain nuclear option for the future
Nuclear supply	None	Loss of capabilities	Maintain nuclear option for the future

5.0 SUMMARY R&D REQUIREMENTS

The previous chapter identified a number of R&D efforts required to respond to hypothesized future nuclear scenarios. These are summarized in the following 11 activities.

1. GLOBAL FUEL CYCLE SAFETY, SAFEGUARDS and SECURITY, and ACCOUNTABILITY RESEARCH—Research to enhance the safety, security, and accountability of existing and evolutionary fuel cycles will be critical in all foreseeable nuclear futures, including worldwide decline.
2. INTEGRATION OF THE NUCLEAR FUEL CYCLE—Research and analysis to develop and assess reactor *systems* for the future that integrate all aspects of the fuel cycle into systems that have the least proliferation potential, produce less waste and waste acceptable to a repository, have very high safety margins, and are highly cost-effective will be needed to support a continuing nuclear power generation capacity either domestic or foreign.
3. PROLIFERATION-RESISTANT REACTOR SYSTEMS—In all scenarios except worldwide decline, research must be conducted to develop concepts, strategies, and technologies to reduce or eliminate the potential for proliferation of nuclear materials and technology from nuclear energy systems. The objective is reactor systems, large and small, which if exported have little or no on-site refueling for the life of the reactor, and that have high safety margins, ease of operation, minimized waste production, and favorable economics.
4. UNDERSTANDING GLOBAL IMPLICATIONS AND APPROACHES TO NUCLEAR ENERGY—Develop and apply advanced energy/environmental/economics models to examine probable scenarios for nuclear energy development and impacts, nationally and internationally, on future energy demand, the environment, and nuclear materials management and control issues.
5. ADVANCED FUELS FOR EXTENDED BURNUP AND WASTE MINIMIZATION—The development of advanced fuels is needed to support even the most marginal maintenance of current and future nuclear energy options. The very real challenges posed by spent fuel accumulation and waste disposal issues makes development of cost-effective solutions for waste management, including waste minimization through extended burnup and other technical features, a necessity.
6. WASTE MANAGEMENT—Independent of whatever scenarios develop, the need for dramatic improvements on current spent fuel and waste management technologies and practices cannot be overstated.
7. COMPUTATIONAL SCIENCE—Develop advanced, multidimensional computational tools and artificial intelligence technology using the national laboratories' state-of-the-art supercomputers to support development of advanced concepts, and assess the safety and security of current and proposed systems, while providing a user facility for academic research.
8. SAFETY, COST, AND QUALITY ASSURANCE—Appropriate cost, safety and regulatory considerations together form a major component of the potential for nuclear energy contributions. This initiative would analyze the connections among these features, and suggest regulatory and safety philosophy reforms that would enhance performance and safety while minimizing unnecessary schedule and cost impacts.

9. INSTITUTE FOR NUCLEAR ENERGY, SCIENCE, AND TECHNOLOGY—Provide opportunities for students and faculty from core universities to conduct collaborative research with national laboratory programs and mentors.

10. INTERNATIONAL DIALOGUE AND REGIONAL COOPERATION—In cooperation with the State Department and private U.S. industry, explore the interactions of technology with the development of regional frameworks to maximize U.S. involvement and interests, while serving as precedents for development of arrangements that allow for adequate energy production.

11. TECHNICAL AND INSTITUTIONAL INTERFACE—Many key challenges to nuclear activities lie at the interface of science and technology with institutional considerations. This initiative is intended to pursue scientifically meaningful methods for strengthening the ties between the technical and institutional features such as facility siting, transportation, and safety systems.

These 11 research areas contribute in various ways to the major challenges facing nuclear power. The following table summarizes the relationships between the research agendas and challenges.

Relationships between various research agendas and national nuclear challenges			
Research agenda	Challenge		
	Influence	Infrastructure	Nuclear options
Global fuel cycle	√	√	√
Fuel cycle integration	√	√	√
Proliferation-resistant reactors	√	√	√
Global implications	√		
Advanced fuels	√	√	√
Waste management	√	√	√
Computational sciences	√	√	√
Safety	√	√	√
Institute for nuclear S&T	√		
International dialogue	√	√	
Institutional interfaces	√		

Relationships between various research agendas and major issues								
	Issue							
Research agenda	Non-proliferation	Energy security	National defense	Nuclear safety	Environmental impact	Waste management	Economics	Infrastructure
Global fuel cycle	√	√		√	√	√	√	√
Fuel cycle integration	√	√		√	√	√	√	√
Proliferation-resistant reactors	√	√	√	√	√	√	√	√
Global implications	√	√	√	√	√	√	√	√
Advanced fuels	√	√	√	√	√	√	√	√
Waste management	√		√	√	√	√	√	√
Computational sciences	√		√	√	√	√	√	√
Safety		√		√			√	√
Institute for nuclear S&T	√			√	√	√		√
International dialogue	√	√		√	√	√		√
Institutional interfaces	√			√		√	√	√

Recommendations for a Department of Energy Nuclear Energy R&D Agenda

Appendix 6 Recommendations

EXECUTIVE SUMMARY

The U.S. must have a portfolio of energy policies and supporting R&D to:

- Respond effectively to the significant issues and challenges confronting the nation and nuclear power today.
- Prepare the nation for likely futures.
- Protect the nation against unexpected developments.

The current trends suggest that the U.S. is heading toward a *gradual abandonment* of nuclear power. However, a number of pressures and issues exist today, including environmental quality and energy security, that may result in a national need for *continued reliance* on nuclear power as a major contributor towards mitigating these issues. Although a *reemergence* of nuclear power as the preferred option for new energy generation in the U.S. currently appears to be only a long-term prospect, uncertain prospects for alternative energy sources, coupled with certain global population and energy growth, make the maintenance of the nuclear option a necessary objective.

These three domestic nuclear futures, or scenarios, will exist within a global nuclear future in which nuclear power either *grows* or *declines*. The current trend of nuclear power strongly suggests global growth, particularly in the developing countries and East Asia. While some local or regional declines are likely, and some short-term declines in global nuclear energy generation may occur, barring another major nuclear accident or other unforeseen circumstances, a long-term global decline nuclear energy generation appears unlikely.

Of the six possible combinations of domestic and international nuclear futures, the current trend — domestic *abandonment* of nuclear power in the face of global *growth*—and domestic *continued reliance* on nuclear power coupled with global *growth* appear to be the most likely futures and represent the major challenges to U.S. policy and R&D requirements.

Abandonment of nuclear power in the face of global *growth* presents the most difficult challenges for the U.S. internationally, and places critical nuclear infrastructures and expertise in serious jeopardy. In this current trend, the U.S. is faced with three very difficult challenges:

- *Global influence*: How does the U.S. best influence the rest of the world in critical nuclear issues such as nonproliferation and nuclear safety?

- *Technology leadership*: How does the U.S. maintain sufficient long-term expertise, capabilities, and vital infrastructures as well as leading-edge R&D in nuclear safety, waste management, fuels, and advanced proliferation-resistant technologies to deal with the enduring nuclear legacy and to meet statutory requirements, both domestically and globally?
- *Competitive energy options*: Can the U.S. afford to preclude the use of nuclear energy in a future with unclear environmental and energy security issues?

These challenges are at the root of the U.S. government's role in nuclear power and nuclear power research and will persist far beyond the eventual closure of the last U.S. nuclear plant under this pessimistic scenario. Meeting these challenges will require both domestically and internationally focused efforts. Domestically, significant continuing research is needed on safety, waste management, and spent fuel minimization, and real efforts are needed focused on infrastructure maintenance. Internationally, focus on proliferation-resistant reactor development, integration of entire nuclear fuel cycle, fuel cycle safety and security will be critical to maintaining U.S. influence in these enduring issues.

These requirements can best be met through a multipronged program outlined here:

- Nuclear energy research initiative.
 - University and laboratory cooperative research.
 - Peer-reviewed.
 - Proliferation-resistant reactor fuels and systems.
- High-efficiency nuclear fuel.
 - Improved fuels for moderate burnup extension and waste minimization.
 - Spent fuel and waste management.
- U.S. nuclear energy R&D to address global warming.
 - Life extension.
 - New and novel nuclear power approaches for long-term potential applications.
 - Proliferation risk reduction and cost minimization.
- International nuclear dialogue.
 - International nuclear safety.
 - Collaborative approaches to safeguards and security.

We believe a nuclear future in which the nation needs and continues to rely on nuclear power's contribution to the electrical generating capacity in the U.S. is possible, desirable, and reasonably achievable. We also believe that nuclear power capacity will generally grow internationally.

In addition to the steps required to respond to current trends, efforts to improve the proliferation, safety, and waste management regimes are absolutely necessary to ensure the ability to continue domestic reliance on nuclear energy. This will require enhancing the core R&D program to include several additional goals:

- Increased concentration on proliferation-resistant fuels and reactor technologies for implementation in developed countries, and on better integration and proliferation resistance of the fuel cycle for large-scale reactor systems domestically and in the developed countries.
- Improved waste minimization and waste management technologies.

- Continuation of safety enhancements of existing reactor designs and operations and continued regulatory reform.

Several elements of an R&D program responsive to these goals have been discussed. Some of these are essential to meeting the challenges presented by the present situation in a most minimalistic way, and include:

- Nuclear energy research initiative.
 - University and laboratory cooperative research.
 - Peer-reviewed.
 - Proliferation-resistant reactor fuels and systems.
- High-efficiency nuclear fuel.
 - Advanced fuels for greater burnup extension and waste minimization.
 - Long-term waste management perspective.
- International nuclear dialogue.
 - International dialogue and regional cooperation.
 - International safeguards and security technologies.
 - Understanding global implications of and approaches to nuclear energy.
 - Global fuel cycle safety.
- U.S. nuclear energy R&D to address global warming.
 - Continuous safety improvement.
 - Possible life extensions of existing reactors.
 - Investigation of new concepts for higher efficiency, improved safety, and reduced cost.

These research agenda are necessary to respond to the current national and global trends, and to prepare for the reasonably possible futures. They also represent the minimum efforts critically necessary to enable the country to reestablish nuclear power as a preferred option should environmental concerns and energy security issues demand better options than those available today. These agenda also help guard against the less likely future of a global decline in nuclear energy. Just as is seen for an abandonment of nuclear energy domestically, a global decline of nuclear power does not alleviate the enduring concerns of waste and spent fuel management, continuing safety of existing plants and facilities, decontamination and decommissioning of those facilities, or the international imperative to effectively manage stocks of fissile materials and avoid nuclear proliferation. Thus, even in this unlikely scenario, both R&D and policy efforts described above will be necessary to maintain vital infrastructures and meet these global challenges.

1.0 INTRODUCTION

In the final analysis, the U.S. must have a portfolio of energy policies and supporting R&D that responds effectively to the significant challenges confronting the nation and nuclear power today, contributes to the resolution of the significant issues, prepares the nation for likely futures, and protects the nation against unexpected developments.

As was presented in Section 5, there are three scenarios for the future of nuclear power in the U.S.: *gradual abandonment* (the current trend), *continued reliance* (an achievable near-term future), and a *reemergence* of the nuclear option (a long-term prospect). These scenarios can exist within a global environment in which nuclear

power either *grows* or *declines*. As previous sections discussed, a growth of nuclear power internationally, particularly with an abandonment of nuclear power domestically, presents the most difficult challenges for the U.S.

Furthermore, the three scenarios envisioned for domestic nuclear power must be temporally linked. The current trend is toward gradual abandonment, and it is near-certain that some nuclear generating capacity will be lost before the nation will again move toward a continued reliance on nuclear generation. Similarly, before a reemergence of nuclear power can happen, the DOE and industry must demonstrate that nuclear power can be relied on for safe and cost-effective operations.

Thus, the challenges, issues, requirements, and recommendations for each of these scenarios clearly build on each other. Those efforts necessary to deal with a gradual abandonment of nuclear power provide part of the necessary foundation for the continued reliance on the nuclear power option, and those needed for reliance are required for a true reemergence of nuclear power in the longer term.

Currently, the U.S. is tending toward an abandonment of nuclear power. This trend has significant domestic and international implications adversely impacting our energy and national securities, and our ability to resolve globally important issues such as environmental quality and nonproliferation. This trend also has unacceptable effects on our ability to meet long-term safety, economic competitiveness, and waste management issues and on our flexibility to adapt to uncertain energy futures. These implications present a number of challenges to our national interests that must be addressed even if the U.S. abandons the nuclear energy option.

The need to maintain viable options to meet an uncertain energy future, particularly in light of growing concern for the environmental impacts of fossil-fuel combustion and the growing demands of the developing countries make continued reliance on nuclear power's contribution to the domestic energy market a real possibility. Effective efforts are required to ensure that the country is prepared to address this eventuality in a safe, responsible, and economically competitive manner.

Although a reemergence of nuclear power as the preferred option for new electrical generating capacity is unlikely in the near-term, the uncertainties associated with the future importance of environmental and energy security issues are so great that to preclude the nuclear option would be folly. Even the possibility of a reemergence of nuclear power presents an opportunity for a valuable reassessment of current nuclear technologies, and such a reemergence may well require new technologies and approaches to nuclear power.

2.0 GRADUAL ABANDONMENT — THE CURRENT SITUATION

The most likely future for nuclear power in the near term, barring unforeseen circumstances or overt changes in direction and leadership, appears to be the gradual abandonment of the domestic nuclear power generating capacity coupled with growth of nuclear power internationally.

2.1 Challenges

This scenario presents the most difficult challenges for the U.S. internationally and places critical nuclear infrastructures and expertise in serious jeopardy.

Under this scenario, the U.S. is faced with the very difficult challenges of influence, leadership, and options. Reiterating:

- *Continuing global influence*, in such critical areas as nuclear nonproliferation, nuclear safety, and waste management.
- *Maintaining technology leadership*, by providing expertise, long-term capabilities, and vital infrastructures as well as leading-edge R&D in nuclear safety, waste management, fuels, and advanced proliferation-resistant technologies.
- *Providing competitive energy options*, such as retaining commercial nuclear power as a viable, economic alternative to address environmental (i.e., global warming) and energy security issues.

2.2 Major Issues

Under this scenario, the two principal issues are nonproliferation and maintaining necessary infrastructure. Issues of nuclear safety and waste management will become increasingly important as the infrastructures and core competencies erode, and overt steps must be taken to avoid this erosion. Without a viable nuclear option, less reliable, more expensive, undeveloped alternative forms of energy generation will become more important, adversely affecting energy security, economics, and environmental issues.

2.3 Major Uncertainties

The principal uncertainty associated with this scenario is the impact of global sensitivity to emissions of carbon and other environmentally important effluents. This may be the dominant near-term influence capable of spurring renewed interest in maintaining the domestic nuclear generating capacity in the near term, or even increasing it over the longer term. For this influence to be effective, however, significant progress must be demonstrated on the issues of nuclear safety and waste management. In addition, nuclear power must be made more affordable.

2.4 Recommendations

Under this scenario, the two most difficult challenges, influence and infrastructure, must be met head-on, both to further vital U.S. interests and to ensure the continued well-being of the citizenry. This will require a core R&D program focused on three major goals:

- To improve the proliferation-resistance of current and future reactor technologies, particularly for export to developing countries.
- To reduce the spent fuel and waste management burden on future generations.
- To reengage the university, industrial, and international communities.

Several elements of an R&D program responsive to these goals have been discussed. Some of these are essential to meeting the challenges presented by the present situation in a most minimalistic way, and include:

Enhanced Proliferation-Resistant Technologies

Proliferation-resistant reactor systems—In all scenarios except worldwide decline, research must be conducted to develop concepts, strategies, and technologies to

reduce or eliminate the potential for proliferation of nuclear materials and technology from nuclear energy systems. Although the ultimate objective is for both large and small reactor systems, initial concentration should be on small reactors, primarily for export, that need little or no on-site refueling for the life of the reactor and that have high safety margins, ease of operation, minimized waste production and favorable economics.

Global fuel cycle safety, safeguards and security, and accountability research—Research to enhance the safety, security, and accountability of existing and evolutionary fuel cycles will be critical in all foreseeable nuclear futures, including worldwide decline.

Spent Fuel Minimization and Waste Management

Advanced fuels for extended burnup and waste minimization—The development of advanced fuels is needed to support more proliferation-resistant small reactors and will be useful in minimizing the impact of current systems even in a declining domestic nuclear energy program.

Waste management—Independent of whatever scenarios develop, the need for dramatic improvements on current spent fuel and waste management technologies and practices cannot be overstated.

Institutional Revitalization

Institute for nuclear energy, science, and technology—Provide opportunities for students and faculty from core universities to conduct collaborative research with national laboratory programs and mentors on issues of programmatic importance to the Department.

Technical and institutional interface—Many key challenges to nuclear activities lie at the interface of science and technology with institutional considerations. This initiative is intended to pursue scientifically meaningful methods for strengthening the ties between the technical and institutional features such as facility siting, transportation, and safety systems.

International Nuclear Dialogue

International dialogue and regional cooperation—In cooperation with the State Department and private U.S. industry, explore the interactions of technology with the development of regional frameworks to maximize U.S. involvement and interests, while serving as precedents for development of arrangements that allow for adequate energy production.

Understanding global implications and approaches to nuclear energy—Develop and apply advanced energy, environmental, economic, and socio-political models to examine probable scenarios for nuclear energy development and impacts, nationally and internationally, on future energy demand, the environment, and nuclear materials management and control issues.

3.0 CONTINUED RELIANCE — A POTENTIAL NEAR-TERM FUTURE

We believe a nuclear future in which the nation continues to rely on nuclear power's contribution to the electrical generating capacity in the U.S. is possible, desirable, and reasonably achievable. We also believe that nuclear power capacity will generally grow internationally.

Because of the time-frame imposed by the licensed operating lives of current U.S. reactors, continued reliance on the domestic energy market share that nuclear power holds today, by necessity, must rely on technologies substantially in use today.

3.1 Forcing Functions

Two related forces have the potential to lead to a continuation of nuclear power in the U.S. The environmental impacts of burning fossil fuels is the dominant force currently supporting a continued reliance on nuclear power. The current dearth of reliable, cost-effective alternative generating sources to fossil and nuclear generation leads to the second force supporting nuclear power: energy security.

3.2 Challenges

Continued reliance on current nuclear generation helps meet the current major challenges of maintaining influence, infrastructure, and future options. However, two significant challenges may be anticipated.

The first is demonstrating to the American public that the choice of nuclear generation is the right choice for the country and for the global environment. Meeting this challenge requires attacking the major domestic issues of nuclear safety and waste management (including spent fuel) head on.

The second challenge will be the management of nuclear nonproliferation in the face of U.S. validation of the nuclear power option. Fortunately, the increased international influence on nuclear power issues afforded the U.S. under this scenario will help promote this cause, and the major challenge will likely become the technology development of proliferation-resistant alternatives and improvements to the safeguards and security regimes.

3.3 Major Issues

Domestically, two issues emerge that must be effectively addressed to enable maintaining the nuclear power market share in the U.S.: safety and waste management. In contrast to the current trends (where the issues surrounding both safety and waste management might be termed "keeping things from getting worse"), continuing improvements to the current technologies and practices of nuclear safety and waste management are critically important.

Internationally, management of nonproliferation will continue as the major issue. Secondly, enhancement of international nuclear safety will be important for two reasons. First, the continued safe operation of nuclear plants globally is essential for continued support of nuclear power, both internationally and domestically. Second, reaffirmation of the nuclear power option by the U.S. places on the U.S. a leadership responsibility to assist other nations that may choose to follow our lead.

The issue of nuclear power costs and economics will gain in importance as new plant construction and plant relicensing gains momentum. While much of the burden to resolve this issue lies with industry, the federal government (both DOE and NRC) will have significant roles to play to help improve the economics of nuclear power.

3.4 Major Uncertainties

The ability and desirability of relying on today's nuclear power as part of the nation's energy market depend on a number of uncertain factors. Certainly the strength behind the driving forces contributing to the attractiveness of nuclear power (resolve of the global community to reduce carbon buildup, technical and cost uncertainties of alternative energy sources), and the cost uncertainties of nuclear power represent major uncertainties.

The time-frame over which these forces and uncertainties operate represents a significant source of uncertainty for the nation's nuclear future. With current trends adversely impacting the serious challenges of maintaining the needed infrastructures, delays in reinforcing these foundations of our nuclear capabilities continue to undermine our ability to do so in the future.

3.5 Recommendations

In addition to the steps required to respond to current trends, efforts to improve the proliferation, safety, and waste management regimes are absolutely necessary to maintain nuclear energy. This will require enhancing the core R&D program to include several additional goals:

- Increased concentration on proliferation-resistant fuels and reactor technologies for large-scale implementation in the U.S. as well as in developed countries.
- Improved waste minimization and waste management technologies.
- Continuation of safety enhancements of existing reactor designs and operations and continued regulatory reform.

Several elements of an R&D program responsive to these goals have been discussed. Some of these are essential to meeting the challenges presented by the present situation in a most minimalistic way, and include:

Enhanced Proliferation-Resistant Technologies

Proliferation-resistant reactor systems—Under this scenario, this program must be enhanced to include development of larger systems, both the next generation of LWR-based technologies and the development of new follow-on systems.

Global fuel cycle safety, safeguards and security, and accountability research—Research to enhance the safety, security, and accountability of existing and evolutionary fuel cycles will be critical in all foreseeable nuclear futures, including worldwide decline.

Spent Fuel Minimization and Waste Management

Advanced fuels for extended burnup and waste minimization—The development of advanced fuels is needed to support even the most marginal reliance on current and future nuclear energy options. Reduction of spent fuel accumulation will be a critical element of demonstrating that the waste problem is being effectively

attacked from all directions. The very real challenges posed by spent fuel accumulation and waste disposal issues makes development of cost-effective solutions for waste management, including waste minimization through extended burnup and other technical features, a necessity.

Waste management—Continued reliance on nuclear generation invokes an active long-term commitment to waste management that requires technical resolution coupled with broad social and political support.

Enhanced Reactor Operations

Enhanced safety designs—Notwithstanding the excellent safety technology and culture of existing U.S. reactor systems, sufficient variability within the industry and sufficient public concern about nuclear safety exist that continuing to improve nuclear safety is of paramount importance. Ultimately, long-term viability of nuclear power may even require that revolutionary new systems will need to be investigated.

Advanced fuels systems—In addition to fuel development necessary to enhance proliferation resistance and minimize spent fuel accumulation, long-term viability of nuclear power will require major new approaches to dealing with the entire nuclear fuel cycle, including looking at alternative fissile materials (such as the thorium-U233 cycle).

International Dialogue

Understanding global implications and approaches to nuclear energy—The flavor of these efforts will change as the U.S. again assumes a position of global leadership in nuclear power technology and development.

4.0 REEMERGENCE OF NUCLEAR POWER—A LONG-TERM PROSPECT

Reemergence of nuclear power as preferred for new electrical power generating systems, requires not only solution to the issues and challenges presented by the other scenarios, but (barring unforeseen forces or difficulties) will likely require very novel solutions to long-standing issues:

- Major, revolutionary improvements in the technical and political solutions to nuclear nonproliferation.
- Radical improvements in perceived nuclear safety supported by significant progress in real safety technology.
- Publicly accepted resolution of spent fuel and nuclear waste disposal issues.
- Demonstrated, major environmental and economic benefits of nuclear power.

Although significant improvements to the technologies underlying today's nuclear reactor systems can be made (and are expected), the kinds of radical improvements needed to support a true reemergence of nuclear power demand fresh, new approaches to these significant issues.

5.0 GLOBAL DECLINE—AN UNLIKELY FUTURE

Ignoring the current domestic U.S. trends, a general decline in the global use of nuclear power is unlikely, given the general trends of nuclear development worldwide, particularly in the developing countries and energy-hungry countries of East Asia. While some local or regional declines are likely (for example, in Sweden), and some temporal declines may be experienced (because some older reactors may be decommissioned before replacement nuclear generators come on-line), we anticipate a general increase in the use of nuclear power globally.

The challenges, issues, uncertainties, and required responses for the various domestic scenarios under an international decline in nuclear energy would be little different from those expected with growth of nuclear power internationally. The only significant variance is seen in the combination of domestic abandonment and international decline. Under this combination, the challenge of maintaining sufficient nuclear infrastructure to deal with the enduring nuclear legacy becomes a truly global problem.

Other issues and challenges may appear essentially unchanged, although some features of them may change. The issue of nuclear proliferation is one that may exhibit differences. Decline of nuclear power globally may leave significant quantities of commercially separated plutonium with no end use, leading to potential long-term safeguards and security issues.

The major challenge under this unlikely scenario would be the maintenance of sufficient infrastructure and expertise to ensure:

- Continued safe operation of existing reactors.
- Effective waste and spent fuel management.
- Nonproliferation and plutonium disposition.
- Decommissioning and decontamination.
- Accident response and mitigation.