2.4 NUCLEAR FISSION

2.4.1 RESEARCH UNDER THE GENERATION IV NUCLEAR ENERGY SYSTEMS INITIATIVE

Technology Description

Electricity from nuclear power generates no greenhouse gas emissions. To the extent that next-generation nuclear fission energy systems can address prevailing concerns, nuclear power can continue to be an important part of a greenhouse gas emissions-free energy portfolio. Although evolutionary light water reactors of standardized design are now available – and have received Nuclear Regulatory Commission design certification and been constructed on schedule in Japan and South Korea – newer nuclear energy systems in the long term need to offer significant advances in the areas of sustainability, proliferation resistance and physical protection, safety, and economics. These newer nuclear energy systems are required to replace or add to existing light water reactor capacity and can be available starting in 2020.

To develop these next-generation systems, DOE has initiated the Generation IV Nuclear Energy Systems Initiative. Generation IV is an international effort, with participation by Argentina, Brazil, Canada, France, Japan, Republic of Korea, Republic of South Africa, Switzerland, the United Kingdom, and the United States. The *Generation IV Nuclear Energy Systems Technology Roadmap* was completed in December 2002. The completed roadmap has identified the six most promising fission energy systems for potential further development. In FY 2003, DOE and its international partners initiated preconceptual design studies, fuel and materials development, and energy conversion development on promising systems of interest, which will lead to demonstration and eventual deployment (with industry and international participation) of one or more systems.

System Concepts

- Advanced fission reactors and fuel cycles that will reduce the potential for proliferation of nuclear materials, provide economical electricity generation, and contribute to hydrogen generation, with minimal waste products.

Representative Technologies

- Gas-Cooled Fast Reactor (GFR).
- Lead-Cooled Fast Reactor (LFR).
- Molten Salt Reactor (MSR).
- Sodium-Cooled Fast Reactor (SFR).
- Supercritical-Water-Cooled Reactor (SCWR).
- Very-High-Temperature Reactor (VHTR).

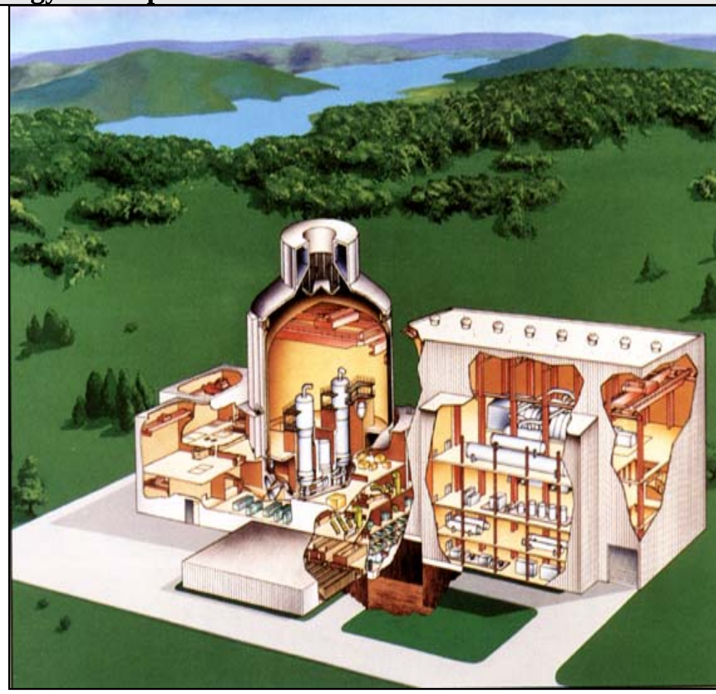
Technology Status/Applications

- Advanced fission reactors and fuel cycles: development is at advanced stage; demonstration is incomplete.
- High-temperature gas-cooled reactor development is focused on high-conversion efficiency through direct use of the high-temperature gaseous reactor coolant to power a gas turbine driving a generator (i.e., direct conversion), also capable of high-efficiency hydrogen production through electrolysis or chemical processes.
- Liquid metal-cooled reactors (both sodium and lead) have been successfully operated worldwide. Safety performance has been demonstrated, but economic performance needs improvement.
- Technologies for advanced fuel recycle and remote fuel refabrication have been developed in the laboratory, and some elements have advanced to pilot scale.
- Nuclear-assisted hydrogen production by means of thermochemical cracking of water is at the preconceptual design stage, requiring extensive development.
- Other advanced fission systems are at a preconceptual stage, requiring extensive development and irradiation testing of new fuel forms and high-temperature materials.
- Direct-cycle turbine technology requires development and demonstration.

Current Research, Development, and Demonstration
RD&D Goals • Goals for next-generation fission energy systems (Generation IV) research are focused on the design of reactors and fuel cycles that are safer, more economically competitive, more resistant to proliferation, produce less waste, and make better use of the energy content in uranium. **RD&D Challenges** • Demonstrate technology for advanced concepts. • Develop proliferation-resistant fuel-cycle concepts. • Develop safety, waste, and proliferation aspects of advanced fission reactors. • Conduct comprehensive R&D on advanced fission reactor concepts, relying heavily on international collaboration. **RD&D Activities** • Federally funded development of advanced reactors and fuel cycles has been resumed in the United States, through the Nuclear Energy Research Initiative, the Generation IV Nuclear Energy Systems Initiative, and the Advanced Fuel Cycle Initiative. • Advanced used fuel treatment technologies are under development through the Advanced Fuel Cycle Initiative.
Recent Progress
• Advanced light water reactors have received design certification from the Nuclear Regulatory Commission. • An advanced boiling water reactor, which was built in less than five years, is operating in Japan.
Commercialization and Deployment Activities
• Generation IV Nuclear Energy Systems are projected to be ready for commercial deployment in the timeframe of 2020 to 2030. **Market Context** • Indeterminate at this time. Potentially large international and domestic markets.

2.4.2 RESEARCH ON NUCLEAR POWER PLANT TECHNOLOGIES FOR NEAR-TERM DEPLOYMENT

Technology Description



Electricity from nuclear power generates no greenhouse gas emissions. To the extent that deployment of near-term nuclear power plants can address prevailing concerns, nuclear power can continue to be an important part of a greenhouse gas emissions-free energy portfolio. In order to enable the deployment of new, advanced nuclear power plants in the United States in the relatively near-term – within a decade – it is essential to demonstrate the untested federal regulatory and licensing processes for the siting, construction, and operation of new nuclear plants. In addition, other major obstacles (including the initial high capital costs of the first few plants and the business risks resulting from this and the regulatory uncertainty) must be addressed. Technology development on near-term advanced reactor concepts that offer enhancements to safety and economics is needed to enable these new technologies to be competitive in the deregulated electricity market, and support energy supply diversity and security.

The *Near-Term Deployment Roadmap* was issued in October 2001 and advises DOE on actions and resource requirements needed to support deployment of new nuclear power plants. The primary focus of the roadmap is to identify the generic and design-specific gaps to near-term deployment, to identify those designs that best promise to meet the needs of the marketplace, and to propose recommended actions that would close gaps and otherwise support deployment. This includes, but is not limited to, actions to achieve economic competitiveness and timely regulatory approvals.

System Concepts

- Advanced fission reactor designs that are currently available or could be made available with limited additional work to complete design development and deployment in the 2010 timeframe.

Representative Technologies

- Certified Advanced Light Water Reactor designs: ABWR, AP600, System 80+.
- Enhancements to certified designs with some engineering work already completed: AP1000, ESBWR. (An NRC design certification rulemaking is scheduled for the AP-1000 in December 2005.)
- Proposed light water reactor designs from overseas with potential for near-term deployment in the United States: ACR-700, EPR.

Technology Status/Applications

- All near-term deployment designs are well-defined concepts in varying stages of development. Most still need significant detailed engineering development and/or regulatory approval.

Current Research, Development, and Demonstration

RD&D Goals

- Research goals are focused on successfully demonstrating the untested regulatory processes for Early Site Permit (ESP) and combined Construction and Operating License (COL) processes and on the regulatory acceptance (certification) and completion of first-of-a-kind engineering and design.
- Specific goals include an industry decision to order a new nuclear power plant by 2008 and deployment of one or more new nuclear power plants in the 2010 time frame.

RD&D Challenges

- Support resolution of the technical, institutional, and regulatory barriers to the deployment of new nuclear power plants in the 2010 time frame, consistent with recommendations in *Near-Term Deployment Roadmap.*
- In cooperation with the nuclear industry, demonstrate the untested regulatory processes for Early Site Permit and combined Construction and Operating Licenses to reduce licensing uncertainties and attendant financial risk to the licensees.
- Provide for technology development to enable finalization and NRC certification of those advanced nuclear power plant designs that the U.S. power generation companies are willing to build.
- Provide for development and demonstration of advanced technologies to reduce construction time for new nuclear power plants and to minimize schedule uncertainties and associated costs for construction.

RD&D Activities

- Demonstration of regulatory processes for Early Site Permit and combined Construction and Operating Licenses.
- Development and NRC certification of advanced nuclear plant designs.

Recent Progress

- Three near-term deployment designs have been certified by the Nuclear Regulatory Commission.
- Reactor vendors are exploring NRC certification of advanced reactor concepts.
- The three cost-shared Early Site Permit (ESP) demonstration projects initiated with industry in FY 2002; power companies submitted ESP applications to the NRC for review and approval. Issuance of NRC approved ESPs is anticipated in calendar year 2006.
- Two cost-shared Construction and Operating License (COL) demonstrations projects were initiated with power companies in FY2005, with activities leading to a decision to submit a COL application to the NRC in 2007.
- A nuclear power plant cost and construction assessment to independently evaluate the cost, schedule, and construction methods of the Advanced Boiling Water Reactor design by GE, as well as identify promising improvements to the construction methods and techniques to support new nuclear power plant deployment in the 2010 timeframe will complete in FY 2005.
- The Advanced Boiling Water Reactor has been deployed successfully in Japan; Advanced Boiling Water Reactors are under construction in Taiwan.

Commercialization and Deployment Activities

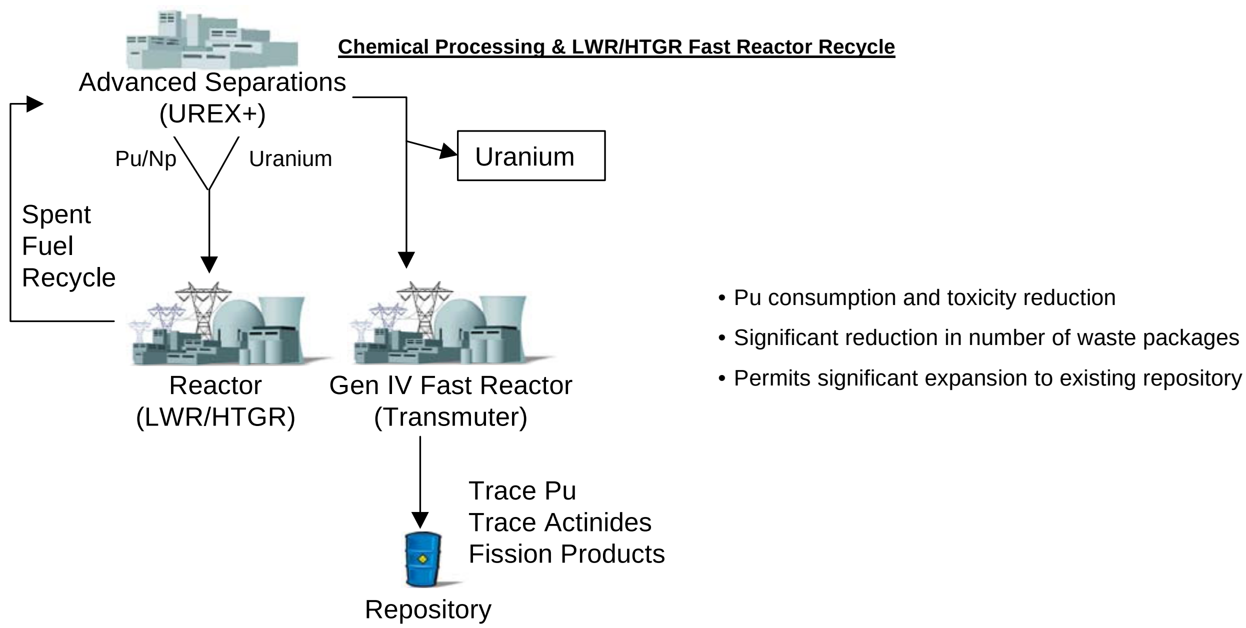
- At least two designs and perhaps more can be commercialized in the United States within the next decade. Achieving this goal will require a major effort by industry and DOE to work together to resolve open issues and to share the one-time costs of closing both generic and design-specific gaps.

Market Context

- The focus of the market is in the United States. Due to the uncertainty regarding the impacts of deregulation, designs in the 100-300 MW_e range and the 1,000 MW_e-plus range are both required.

2.4.3 ADVANCED FUEL CYCLE INITIATIVE

Technology Description



The Advanced Fuel Cycle Initiative (AFCI), under the leadership of DOE, is focused on developing advanced fuel cycle technologies, which include spent fuel treatment, advanced fuels, and transmutation technologies, for application to current operating commercial reactors and next-generation reactors and to inform a recommendation by the Secretary of Energy in the 2007-2010 time frame on the need for a second geologic repository. The AFCI program will develop technologies to address intermediate and long-term issues associated with spent nuclear fuel. The intermediate-term issues are the reduction of the volume and heat generation of material requiring geologic disposal. The program will develop proliferation-resistant processes and fuels for application to current light water reactor systems and Generation IV reactor systems to enable the energy value of these materials to be recovered, while destroying significant quantities of plutonium. This work provides the opportunity to optimize use of the nation's first repository and reduce the technical need for an additional repository. The longer-term issues to be addressed by the AFCI program are the development of fuel cycle technologies to destroy minor actinides, greatly reducing the long-term radiotoxicity and heat load of high-level waste sent to a geologic repository. This will be accomplished through the development of Gen IV fast reactor fuel cycle technologies and possibly accelerator-driven systems

System Concepts

- Advanced nuclear systems (fission reactors and accelerator-driven systems) that aim to reduce the lifetime of the waste from current-generation fission reactors to short times.
- Advanced nuclear systems that aim to extract the full energy potential of the spent nuclear fuel from current fission reactors, while reducing or eliminating the potential for proliferation of nuclear materials and technologies, and reducing the amount of waste produced.

Representative Technologies

- Spent-fuel treatment technologies that are proliferation resistant.
- Advanced fuel types for waste transmutation.
- Advanced fuel types for sustained nuclear energy.
- Accelerator-driven systems for rapid waste transmutation.
- Advanced reactors for sustained nuclear energy.

Technology Status/Applications

- Advanced fuel-cycle development has reached the laboratory scale-demonstration stage in some cases.
- Transmutation fuels are in early R&D stages.
- Development of accelerator-driven systems is at the early R&D stage.

Current Research, Development, and Demonstration

RD&D Goals

- Proving design principles of spent-fuel treatment and transmutation technologies.
- Demonstrating the fuel and separation technologies for waste transmutation.
- Deploying Generation IV advanced fast spectrum reactors that can transmute nuclear waste.

RD&D Challenges

- Demonstrate performance of advanced fuel cycles.
- Demonstrate performance of advanced transmutation fuels.
- Demonstrate technology for advanced fission reactor concepts.
- Demonstrate feasibility and technology for accelerator-driven systems.

RD&D Activities

- Continued development and demonstration of aqueous and electrometallurgical spent-fuel treatment technologies.
- Development of transmutation fuels for Generation IV reactor systems.
- Development of technologies for accelerator-driven systems.

Recent Progress

- Hot demonstration of several parts of the UREX+ (Uranium Extraction Plus) aqueous spent fuel-treatment process, including separation of high-purity uranium, cesium/strontium, plutonium/neptunium, and americium/curium products.
- Irradiation tests of several transmutation fuels containing transuranic elements

Commercialization and Deployment Activities

- Disposal of spent nuclear fuel is a government activity in the United States. Similar spent-fuel treatment and transmutation technology development programs exist in France, Japan, and the United States. Development of treatment and transmutation technologies for use with advanced Generation IV fuel cycles will increase the acceptability of nuclear energy.
- Advanced Fuel Cycle Initiative has the potential to decrease the quantity and toxicity of nuclear waste, possibly eliminating the need for a second geologic repository.

Market Context

- Technologies to improve spent-fuel disposition increase the value of keeping existing nuclear power plants online as well as increase the likelihood for expanded new nuclear power capacity.