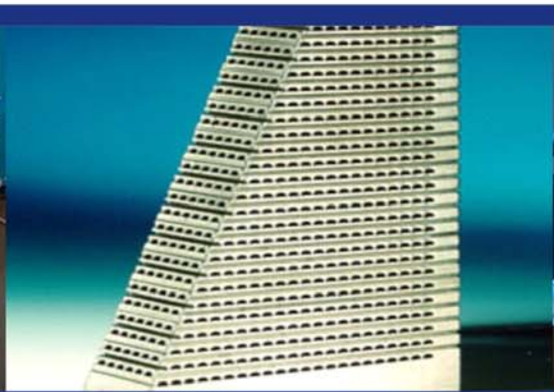
Next Generation Nuclear Plant


A Report to Congress

Prepared by
The U.S. Department of Energy
Office of Nuclear Energy

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NGNP
Next Generation
Nuclear Plant

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EXECUTIVE SUMMARY

The U.S. Department of Energy's (DOE's) Next Generation Nuclear Plant (NGNP) project helps address the President's goals for reducing greenhouse gas emissions and enhancing energy security. The NGNP project was formally established by the Energy Policy Act of 2005 (EPAct 2005), designated as Public Law 109-58, 42 USC 16021, to demonstrate the generation of electricity and/or hydrogen with a high-temperature nuclear energy source. The project is being executed in collaboration with industry, DOE national laboratories, and U.S. universities. The U.S. Nuclear Regulatory Commission (NRC) is responsible for licensing and regulatory oversight of the demonstration nuclear reactor.

The NGNP project includes design, licensing, construction, and research and development (R&D) conducted in two phases as defined in EPAct 2005. Phase 1 consists of pre-conceptual and conceptual design and demonstration activities leading to the selection of a single technology for NGNP. Phase 2 is the preliminary and final design leading to licensing and construction of a demonstration plant. Licensing scope supports the development of a licensing framework for high-temperature gas reactors and includes the preparation and submission of a combined construction and operating license application (COLA) for the NGNP. The scope of R&D falls into the following four major technical areas: (a) fuel development and qualification, (b) graphite qualification, (c) high-temperature materials qualification, and (d) design and safety methods validation. Licensing and R&D activities are included in both Phase 1 and Phase 2 of the project, with appropriate risk-mitigation strategies incorporated to minimize the impact on design from conducting research and development in parallel.

From fiscal year (FY) 2006 through FY 2010, a total of $528.4 million has been appropriated for the NGNP project. Of this amount, $192.8 million will have been spent on NGNP research and development; $177.6 million on NGNP design, engineering, licensing and project management; and $158 million on university R&D programs and other NGNP-related activities.

On September 18, 2009, DOE published a funding opportunity announcement (FOA) for the conceptual design and demonstration activities of the NGNP. Proposals were received by the Department on November 16, 2009 and winning proposals were announced in March. Conceptual design reports are expected to be completed by September 30, 2010. These conceptual design reports are the last major deliverables of Phase 1 of the NGNP project.

DOE plans to have the Nuclear Energy Advisory Committee launch a programmatic review of the NGNP project in September 2010. This review will inform the Secretary of Energy on the readiness of the NGNP project to proceed to Phase 2. It is expected that a Secretarial decision on whether or not to proceed into Phase 2 will be made in January 2011. All planned milestones and activities referenced in this report that occur after that timeframe are dependent on the outcome of the Secretarial decision. Phase 2 includes the competitive selection of a single reactor design for demonstration as the NGNP. The conceptual design reports completed in Phase 1 would inform the competitive selection of a final design for the prototype reactor and plant.

Phase 2 also includes finalizing the design of all safety systems in order to facilitate the preparation and submittal of a COLA to the NRC in accordance with the licensing strategy recommended in the *NGNP Licensing Strategy Report to Congress* (2008). The COLA is presently scheduled for submittal in FY 2013. The COLA schedule will be re-evaluated in conjunction with the conceptual design activities in preparation for the Secretarial decision and revised as necessary. Whether or not the overall schedule for completing the construction of the NGNP in FY 2021 can still be met depends on many factors, including funding availability from both federal and private sectors.

Assuming completion by FY 2021, the current preliminary project cost estimate, based on FY 2007 pre-conceptual design information, is $4 billion. Improved cost estimates will be part of the conceptual design reports due in September 2010. More detailed cost estimates that would meet commercial financing requirements are dependent on the completion of preliminary design activities. The relative share of costs allocated to government and industry will conform to EPAct 2005 requirements. To date, cost share requirements have not been imposed on the national laboratories and universities who have been conducting R&D on enabling gas reactor technologies. After a public-private partnership is formed for Phase 2 activities, any R&D required to support a specific reactor design may be cost shared in accordance with EPAct 2005.

Currently there are two major types of high-temperature gas reactor designs under consideration: the pebble bed and the prismatic designs. Early versions of these reactor designs were demonstrated in the 1970s and 1980s. Test reactors for the pebble bed and prismatic designs are presently operating in China and Japan respectively. Both of these reactor designs are graphite-moderated and helium-cooled, and both use coated particle fuel kernels embedded in a graphitic matrix material. The primary differences between these designs are the shape of the fuel-bearing graphitic matrix and the distribution of fuel in the reactor core.

The pebble bed design uses hundreds of thousands of tennis ball-sized spherical fuel elements called *pebbles*. The pebbles are stacked together in contact with each other like gumballs in a vending machine. The pebbles are added at the top, circulate through the reactor core, and are removed from the bottom. Fuel replacement in a pebble bed design is continuous and allows for online refueling.

The prismatic design uses cylindrical fuel elements that are pressed into channels drilled into graphite blocks. These fuel-bearing blocks are stacked in columns in fixed locations in the reactor core. Refueling is accomplished by shutting down the reactor, removing the fuel-bearing blocks, and replacing the oldest ones with new blocks.

Most of the challenges for these two reactor types are held in common. These consist of licensing and regulatory issues associated with containment and emergency planning, business issues associated with breaking into new markets for nuclear energy in the transportation and industrial sectors, and infrastructure issues associated with first-of-a-kind technology demonstrations. Other challenges are unique to each reactor type. For the pebble-bed, the stochastic nature of the fuel presents a unique design and licensing challenge. For the prismatic design, controlling coolant flow through the narrow channels of the graphite blocks is a unique design and manufacturing challenge.

LIST OF ACRONYMS

AGR	Advanced Gas Reactor
ASME	American Society of Mechanical Engineers
AVR	*Arbeitsgemeinschaft Versuchsreaktor*
CTC	Component Testing Capability
CD	Critical Decision
COL	Combined Construction and Operating License
COLA	Combined Construction and Operating License Application
DDN	Design Data Needs
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
EPAct 2005	Energy Policy Act of 2005
FOA	Funding Opportunity Announcement
FRG	Federal Republic of Germany
FSV	Fort Saint Vrain
FY	Fiscal Year
Gen IV	Generation IV Nuclear Energy Systems
GHG	Greenhouse Gas
GIF	Generation IV International Forum
GT-MHR	Gas Turbine – Modular Helium Reactor
HTGR	High-Temperature Gas Reactor
HTTF	High Temperature Test Facility
HTTR	High-Temperature Test Reactor
INL	Idaho National Laboratory
LFR	Lead-Cooled Fast Reactor
LWR	Light Water Reactor
MSR	Molten Salt Reactor
MWe	Megawatt (electric)
MWt	Megawatt (thermal)
NASA	National Aeronautics and Space Administration
NE	Office of Nuclear Energy
NEAC	Nuclear Energy Advisory Committee
NERI	Nuclear Energy Research Initiative
NGNP	Next Generation Nuclear Plant
NRC	U.S. Nuclear Regulatory Commission
NQA	Nuclear Quality Assurance
OECD	Organization for Economic Co-operation and Development
PICS	Project Information Collection System
PBMR	Pebble Bed Modular Reactor
PIRT	Phenomena Identification and Ranking Tables
QAP	Quality Assurance Program
QAPP	Quality Assurance Program Plan
R&D	Research and Development
RD&D	Research, Development and Demonstration

RFI/EOI	Request for Information/Expression of Interest
SBIR/STTR	Small Business Innovation Research and Technology Transfer Research
SCWR	Supercritical Water Reactor
SFR	Sodium Fast Reactor
SSC	Structures, Systems and Components
TDO	Technology Development Office
THTR	*Thorium Hochtemperatur Reaktor* (Thorium High-Temperature Reactor)
TRISO	Tri-Isotropic
TRL	Technology Readiness Level
UK	United Kingdom
US	United States
VHTR	Very High-Temperature Reactor

1. INTRODUCTION

This report has been prepared by the U.S. Department of Energy, Office of Nuclear Energy (DOE-NE) to give the status of the Next Generation Nuclear Plant (NGNP) project in accordance with Conference Report 111-278 for Public Law 111-85, which states that a program execution plan, detailing the scope and scheduling of activities, milestones, or critical decision points, total cost estimates including anticipated cost share requirements, and any necessary updates to the licensing strategy, should be included in the report as well as a detailed accounting of the funds appropriated to date. The report presents the historical background of the project; details the project's spending; and discusses the principal investments in design, licensing, and research. Finally, the report highlights the technology options for the NGNP and presents the principal challenges.

The primary mission of NE is to advance nuclear power as a resource capable of making major contributions in meeting the Nation's energy supply, environmental, and energy security needs by resolving technical, cost, safety, security and proliferation resistance barriers through research, development, and demonstration (RD&D) as appropriate.

In addition to its primary mission, NE performs several mission-related functions, including providing:

- International engagement in support of the safe, secure, and peaceful use of nuclear energy as well as support to other departmental offices and other federal agencies on issues related to the international use of civilian nuclear energy
- The capability to develop and furnish nuclear power systems for use in national security and space exploration missions
- Stewardship of the DOE Idaho National Laboratory (INL) site

NE is working to develop innovative and transformative technologies to improve the competitiveness, safety and proliferation resistance of nuclear energy to support its continued use in the United States and abroad. NE has established programmatic goals that reflect nuclear power's continuing role in satisfying the demand for clean energy. Those goals include exploring the following through RD&D: technology and other solutions that can improve the reliability, sustain the safety, and extend the life of current reactors; improvements in the affordability of new reactors to enable nuclear energy to help meet the Administration's energy security and climate change goals; understanding of options for nuclear energy to contribute to reduced carbon emissions outside the electricity sector; development of sustainable nuclear fuel cycles; and minimization of risks of nuclear proliferation and terrorism.

The activities represented in this report are designed to support the development of advanced reactor designs and technologies that could be capable of meeting electricity generation, co-generation of process heat, and performance demands beyond current base load nuclear power plants.

2. BACKGROUND

2.1 GAS-COOLED REACTOR HISTORY

As shown in Figure 1, gas-cooled reactors have a rich history and a promising future. The earliest commercial gas-cooled reactors, using carbon dioxide (CO_2) as a coolant, were primarily developed and used in the United Kingdom (UK) and France. Eighteen of these CO_2 gas-cooled reactors are still in operation in the UK. Because of its capacity to produce higher outlet temperatures, helium is the coolant of choice for future gas reactors. Peach Bottom Unit 1 and Fort Saint Vrain (FSV) were two helium-cooled demonstration plants built and operated in the United States using a graphite block fuel configuration. Peach Bottom Unit 1 was a 110 MWt reactor with an outlet temperature of 794°C and was operational from 1967–1974. FSV was an 842 MWt reactor with an outlet temperature of 778°C and was operational from 1976–1989. There were numerous successes and problems with FSV and Peach Bottom Unit 1 that provided valuable insight into the design, construction and operation of gas-cooled reactors. The Germans developed pebble bed gas reactors and demonstrated them with the Arbeitsgemeinschaft Versuch Reaktor (AVR) and the Thorium High-Temperature Reactor (THTR). The People's Republic of China high-temperature gas reactor (HTGR) program is based on the German pebble bed design. The centerpiece of the Chinese program is the 10 MWt test reactor called HTR-10. The Chinese are also pursuing a modular design called HTR-PM, which builds upon their operational test reactor experience. In Japan, the High-Temperature Test Reactor (HTTR) is the centerpiece of their HTGR program. The 30 MWt HTTR is a prismatic block design with outlet temperatures as high as 950°C. The Republic of South Africa has a gas reactor program that is structured to support the deployment of the Pebble Bed Modular Reactor (PBMR). South Africa is presently evaluating the configuration and size of a PBMR best suited to their national needs with a potential co-generation cycle for electricity production that will also support near-term process heat applications in the 200 MWt size for use in their coal-to-liquids industry, which supplies over 40 percent of their liquid petroleum needs.

While not all of the gas reactor demonstrations and deployments satisfied every expectation, the operation of the early reactors and the current test reactors have demonstrated the practicality of the pebble bed and prismatic gas-cooled reactor designs. The NGNP project is aimed at demonstrating improvements to the gas-cooled reactor technology and supporting its commercial viability in the United States.

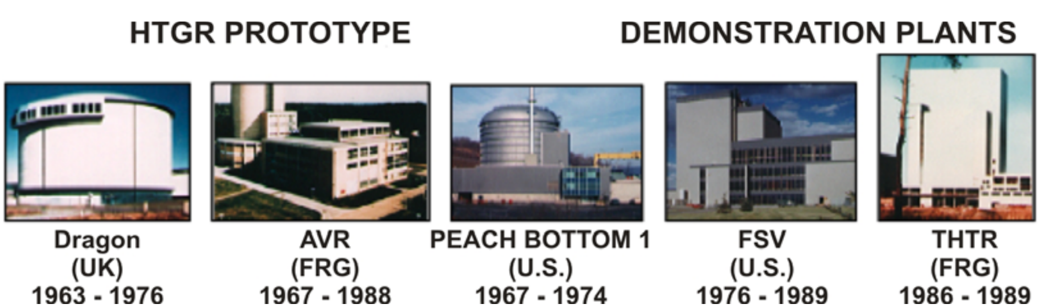

Figure 1. Historical High-Temperature Gas Reactor Demonstration Plants

2.2 NGNP Project History

The Next Generation Nuclear Plant project found its origins in *A Technology Roadmap for Generation IV Nuclear Energy Systems*, published in December 2002 by the Department's Nuclear Energy Research Advisory Committee in cooperation with the Generation IV International Forum (GIF). The roadmap identified the Very High-Temperature Reactor (VHTR) as a system with potential for economical near-term development that is compatible with advanced electricity and hydrogen production, and high-temperature process-heat applications. VHTRs extend the operating temperature range of HTGRs upwards of 950°C. It should be noted that although the operating temperatures envisioned under the NGNP are less than those of the GIF VHTR concept, many research and development (R&D) activities are mutually supportive and, therefore, the NGNP project benefits from this international collaboration.

In fiscal year (FY) 2003 and FY 2004, the Department invested in early program planning and limited R&D activities for VHTR concepts. These investments included an independent assessment of the near-term commercialization potential for VHTR technology options that included prismatic and pebble bed designs as well as a design using salt as a coolant. These development efforts were the beginnings of the NGNP project.

In 2005, the Energy Policy Act of 2005 (EPAct 2005), designated as Public Law 109-58, 42 USC 16021, formally authorized the NGNP project. The provisions of EPAct 2005 established two distinct phases for the project. Phase 1 covers selecting and validating the appropriate technology, carrying out enabling RD&D activities, including conceptual design work, development of design methods, and safety analytical methods and studies. Phase 2 covers development of a final design for the prototype through a competitive process, application of licenses to construct and operate the nuclear reactor from the U.S. Nuclear Regulatory Commission (NRC), and construction and start-up operations. Both phases include R&D and licensing activities with full consideration to risk mitigation from parallel R&D and design in order to avoid technical complications, cost overruns, and schedule disruptions.

2.3 Benefits of the NGNP

To meet our national goals for greenhouse gas (GHG) emission reductions while maintaining a reliable and secure domestic energy supply, the United States must develop and deploy safe, clean, and affordable energy sources as quickly as possible. Nuclear energy has been and will continue to be a key component of our domestic energy portfolio. Nuclear power plants presently provide 20 percent of our nation's electricity and constitute 70 percent of our low-emissions energy supply.

DOE's NGNP project supports the application of nuclear energy to help address the President's goals for reducing GHG emissions and enhancing energy security. The NGNP's HTGR technology is uniquely able to provide economical electricity and high-temperature process heat with low lifecycle GHG emissions.

The NGNP project has supported the evaluation of this technology in a wide range of industrial applications. For example, the HTGR technology could be a technically viable low-carbon substitute for the burning of natural gas and other fossil fuels to supply steam, electricity and high-temperature heat to industrial applications. Every 750 MWt of installed HTGR capacity could avoid one million metric tons of CO_2 emissions per year when compared to a similarly sized natural gas plant. The NGNP project has performed technical and economic analyses of specific co-generation applications that show the HTGR technology can be competitive with natural gas as an energy source in certain non-utility electricity and co-generation applications. The price of energy from the HTGR will be stable and secure, insulating the industries from the volatility in natural gas pricing. The use of HTGR technology in place of natural gas may also free up more of this domestic resource for more productive uses in home heating and as feedstock for plastics and chemical manufacturing.

The NGNP project has also performed studies integrating the HTGR technology with petro-chemical processes (e.g., production of ammonium and ammonium products, extraction of non-conventional crude, production of hydrogen). These studies show that the HTGR technology could help reduce GHG emissions when compared with conventional processing.

The NGNP is being developed for economical production of electricity and other desirable products derived from high-quality heat. The capabilities of the HTGR may help meet both greenhouse gas reduction goals and our need for energy security.

2.4 Key Accomplishments

Pre-conceptual design activities conducted thus far have been carried out to determine R&D needs, inform licensing process development, and establish the basic parameters for the reactor system. The pre-conceptual design work has included an assessment of the maturity and availability of equipment to operate at the design conditions for the HTGR, and R&D needed to support the design and licensing processes. Project cost and schedule estimates based on pre-conceptual design were also developed as a part of these pre-conceptual design activities.

In developing the strategy for partnering with industry, the Department issued a Request for Information/Expression of Interest (RFI/EOI) in April 2008 to obtain input on the scope, cost, schedule, licensing development strategy, financing, and cost-share provisions needed to support the complete scope of the NGNP project. Responses were received in June 2008 from several companies including General Atomics, AREVA NP, Westinghouse/Pebble Bed Modular Reactor Pty Ltd, and a group of companies referred to as the *Consortium*. Meetings and correspondence with these potential partners indicated that industry would like to deviate from the EPAct 2005 framework for the project by accelerating the development schedule, minimizing industry up-front cost sharing while maintaining an overall equal cost share requirement, and building the demonstration at a commercial/industrial site rather than at the INL.

On September 18, 2009, the Department of Energy issued a funding opportunity announcement (FOA) for the conceptual design of the NGNP. In accordance with EPAct 2005, Section 988, the FOA established a 50–50 cost-share requirement for conceptual design and demonstration activities and allowed the Secretary of Energy to grant a reduction to the cost-share requirement if he determines it to be necessary and appropriate. On November 16, 2009, the Department received several applications that were evaluated by an independent review team of nuclear reactor professionals and by a federally staffed review panel that advised the selection official. The resulting selections were announced in March 2010. DOE will award approximately $40 million in total to two teams led by Pittsburgh-based Westinghouse Electric Company and San Diego-based General Atomics. DOE anticipates completed conceptual designs will be available by September 30, 2010. Approximately $38 million of the $40 million obligation for these awards is from FY 2009 funds held for this specific purpose.

Key accomplishments since the beginning of the project are listed below:

- Established a comprehensive R&D program that is integrated by the INL
  - Demonstrated U.S. capability to manufacture gas reactor fuel with very few defects (2007)
  - Began irradiation of over 400 graphite specimens to test mechanical properties under irradiation (2009)
  - Completed record-breaking irradiation of NGNP test fuel with no fuel failures (2009)
- Collaborated with the NRC to develop a joint NGNP licensing strategy (2008)
- Established a licensing implementation plan for near-term interactions with the NRC to address NGNP licensing issues (2009)
- Completed engineering studies and pre-conceptual design to establish industrial end-user requirements and focus R&D activities (2007–2009)
- Established a systematic approach to managing technology-related risk and uncertainty, based on models used by the National Aeronautics and Space Administration (NASA) and the U.S. Department of Defense (DoD) (2008–2009)
- Announced selection of design teams for conducting conceptual design studies (2010)
- Supported the continuing development of industry codes to qualify high-temperature materials and analytical methods (2006–2010)
- Supported the continuing development of models related to specific HTGR systems and structure behaviors of interest for analyses and design method validation (2008–2010)
- Supported the continuing development of models and scaling analyses to support ongoing testing at multiple U.S. and international facilities related to HTGR development (2008–2010)
- Conducted cost-shared research and benchmark activities in collaboration with the GIF VHTR System Arrangement (2007–2010)
- Established collaborations with international entities on NGNP-related R&D, design, and licensing activities (2006–2010)

An expanded description of the supporting RD&D for these accomplishments is given in Section 4.5 of this report.

2.5 Next Steps

The Department is presently working toward the completion of Phase 1 activities. In September 2010, DOE plans to provide information derived from Phase 1 R&D licensing activities and conceptual design(s), including the associated cost and schedule estimates and program execution plans to the Nuclear Energy Advisory Committee (NEAC) for review. It is expected that in December 2010, NEAC will make a recommendation to the Secretary of Energy on the project's readiness to move into Phase 2. This recommendation will be an input in the Secretary's decision on whether to take the project into Phase 2. A Secretarial decision on Phase 2 readiness is planned for January 2011.

3. BUDGET HISTORY AND DATA FOR FY 2006–FY 2010

This section of the report provides figures that illustrate the cumulative distribution of funding for all years following the EPAct 2005 authorization of the NGNP project. Also provided are figures that give year-by-year as-spent distributions of appropriated funds. In total, approximately $528 million will have been spent on the NGNP project by the end of FY 2010. In broad terms, $192.8 million will have been spent on NGNP R&D in the areas of reactor fuel development, high-temperature metals and graphite development, and analytical codes and methods development. $177.6 million will have been spent on NGNP design, engineering, licensing and project management to inform the R&D process, the development of public-private partnerships, and advancing the design and licensing of NGNP. $158 million will have been spent on university supportive and competitive R&D grants and contracts and other NGNP-related activities, including domestic and international partners in accelerating the development of gas reactor technology. Key accomplishments from the application of this funding are listed in section 2.5 of this report.

Table 1 defines the terms and categories found in the budget figures below:

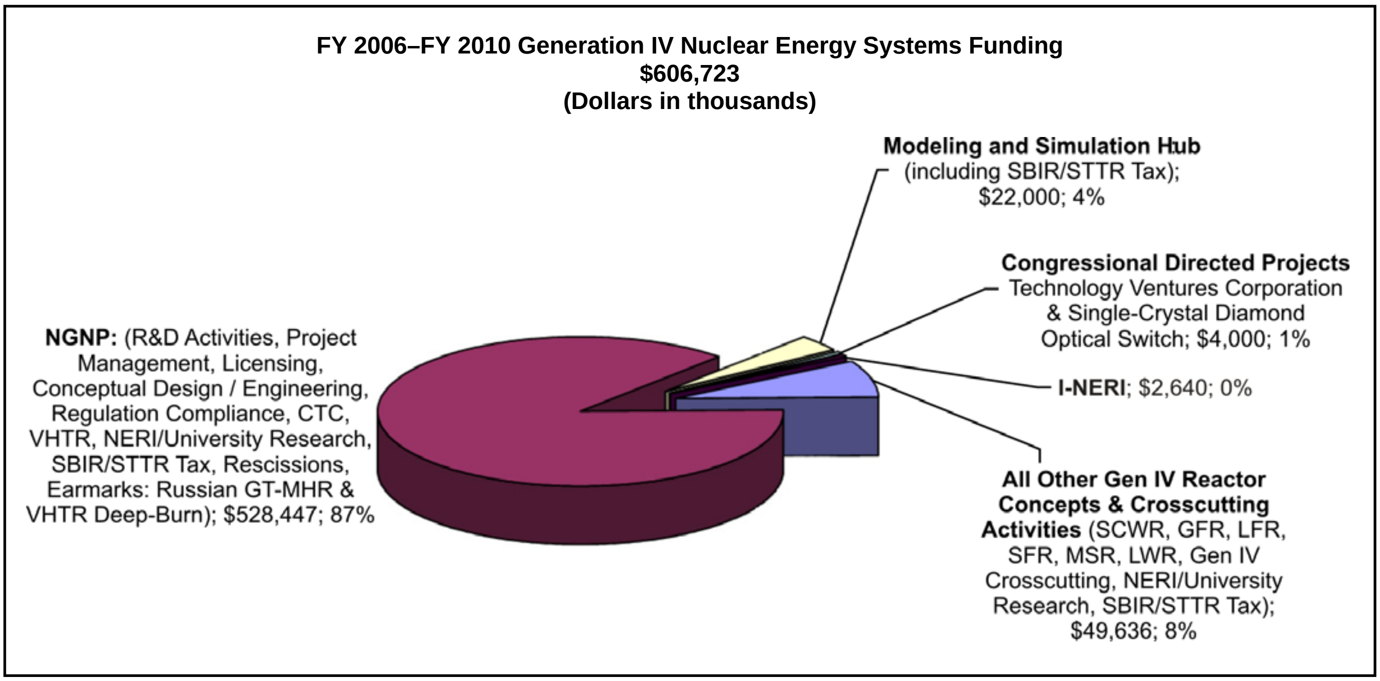

Figure 2. FY 2006–FY 2010 Gen IV Funding

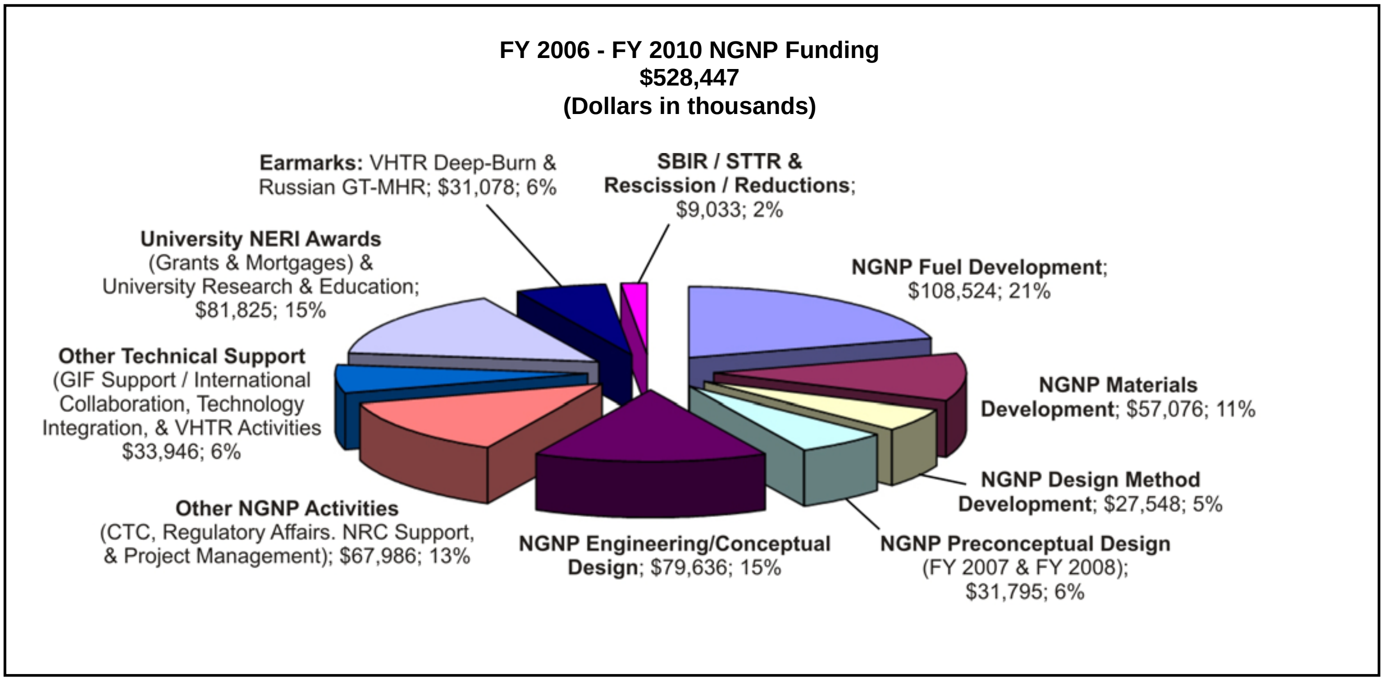

Figure 3. FY 2006–FY 2010 NGNP Funding

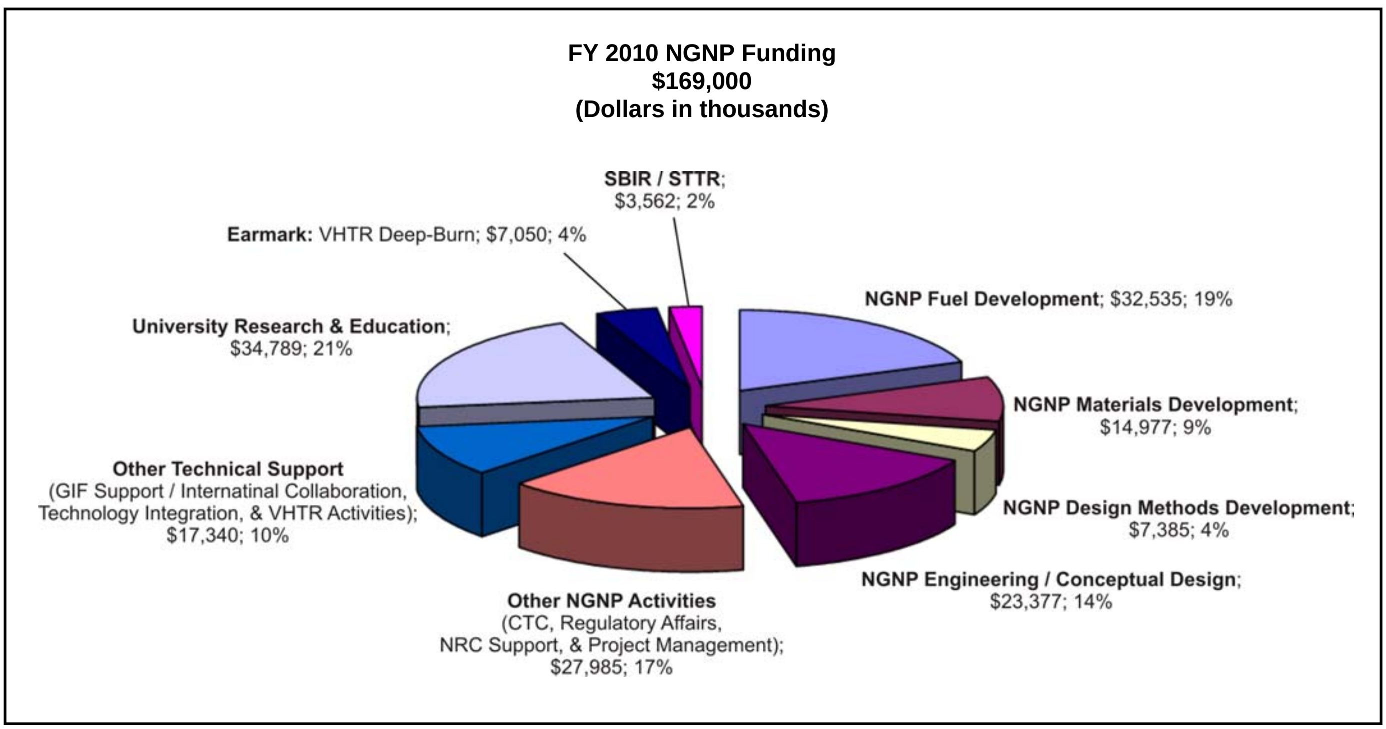

Figure 4. FY 2010 NGNP Funding

Table 1. Definition of Budget Terms

Term	Definition
NGNP Regulatory Affairs	INL-staffed activity to work with the NRC on the licensing implementation plan
NGNP Component Test Capability (CTC) Investigation	INL-staffed activity to investigate the need for large-scale component testing capability
Other NGNP Activities	Compilation of a number of small contracted activities in support of NGNP
VHTR Activities	R&D aimed at extended temperature operation of gas-cooled reactors and multi-physics modeling
GIF Support/International Collaboration	Support to attend meetings and develop materials for GIF collaborations including the Generation IV Materials Handbook
Technical Integration	Multi-laboratory coordination and management of NGNP R&D
University Nuclear Energy Research Initiative (NERI) Awards	R&D awards that highlight collaborations between U.S. universities and laboratories
University Research & Education	Competitive grants provided to U.S. universities for work related to Gen IV and NGNP
Small Business Innovation Research and Technology Transfer Research (SBIR/STTR)	Legally mandated set asides for small business
Rescission/Reductions	Programmatic reductions mandated by law
NGNP Project Management	INL Project Office funding to manage the NGNP project, includes quality assurance, safety, project management, procurement, etc.
NGNP Fuel Development:	R&D to develop the advanced coated particle fuel for the NGNP
NGNP Materials Development	R&D to qualify high-temperature metals, ceramics and graphite for the NGNP
NGNP Design Methods Development	R&D to benchmark improved methods for calculating reactor system phenomena
NRC Support for the NGNP	Funding provided directly to the NRC for regulatory work on the NGNP
NGNP Pre-Conceptual Designs	Vendor pre-conceptual design studies for the NGNP
NGNP Engineering/ Conceptual Design	NGNP engineering activities and vendor conceptual designs for the NGNP
Earmark: Russian Gas Turbine – Modular Helium Reactor (GT-MHR)	Congressional earmark to continue Russian GT-MHR work
Earmark: VHTR Deep-Burn	Congressional earmark to look at extended fuel utilization and actinide burning in the NGNP
Modeling and Simulation Hub	Secretarial Initiative to advance modeling and simulation capability of U.S. designers

4. Project Execution Plan

The NGNP project includes R&D, design, licensing, construction, and initial operations of a first-of-a-kind demonstration facility to be conducted in two phases as defined in EPAct 2005. The project is managed by DOE-NE using the Idaho National Laboratory as a project integrator. Private industry may take on the role of systems integration of the project in Phase 2 after a suitable public-private partnership is formed. High-level NGNP project objectives are to:

- Develop prototype NGNP design and licensing basis through a public/private partnership resulting from a competitive selection process
- Establish regulatory licensing basis and design certification process for HTGRs by the NRC
- Demonstrate basis for commercialization through construction and reliable operations of the NGNP and associated technologies

The following sections describe the scope and execution of the various programmatic elements of the NGNP project. In addition to the principal elements of design, licensing, R&D, and construction, project execution also involves risk management, quality assurance, and program controls to track budget and schedule performance. An updated project execution plan, following a process comparable to that required by DOE Order 413.3A, *Program and Project Management for the Acquisition of Capital Assets*, will be developed by the Department to support the January 2011 Secretarial Decision on whether to proceed into Phase 2.

4.1 Project Management

Fundamental project management principles provide a framework for successful project execution. This section describes the project management systems that have been put in place to successfully manage the NGNP project, comparable to processes identified in DOE O 413.3A.

4.1.1 Project Organizational Framework and Relationships

The NGNP project is sponsored by NE and is managed under the Office of Gas Reactor Deployment (NE-33). The NGNP Program Manager (sometimes referred to as the DOE Federal Project Director) is a senior staff position in NE-33 responsible for the project's mission, goals, objectives and budget, and provides those elements to the INL NGNP Project Director, who executes the project via implementation of the INL Project Management System Document (PLN-7305, Rev. 1).

The INL's Technology Development Office (TDO) is responsible for planning and executing the R&D work scope required to design and ultimately license the NGNP, identify and meet R&D milestones and deliverables, report on monthly status, develop schedules, and provide earned value management on the budget assigned to the TDO for the NGNP.

4.1.2 Project Risk Management Process

The project risk management process ensures that project risks and uncertainties are identified, analyzed, managed, or determined to have been mitigated or eliminated. The process also provides a structured, formal, and disciplined approach to determine and control risks and general uncertainties at an acceptable level through the lifecycle of the project. Under this approach, risks are first identified and used to populate the project risk register. These are analyzed and categorized as very low, moderate, high, or very high based on probability of occurrence and consequence. A risk mitigation strategy is then developed for each risk and becomes part of the risk response plan for high and very high risks.

NGNP risks are technical and programmatic, and both types have the ability to manifest themselves in cost and schedule impacts. NGNP pre-conceptual design work has highlighted several known technical risks that must be resolved to ensure successful completion of the NGNP project. Additionally, DOE expects that, throughout the design process, other risks will be identified. To ensure that decisions are made and risks (both known and unknown) are addressed on a consistent and objective basis, the NGNP project has tailored a systematic approach to managing technology-related risk and uncertainty. This approach combines similar technology maturity measurement methodologies as those used by NASA and DoD in their programs, with unique approaches and tools developed at the INL for using uncertainty measurement to both make decisions and manage project execution. This systematic approach correlates technical risk areas identified through design data needs (DDNs) to the maturity of any one technology using technology readiness levels (TRLs), as depicted in Figure 5 below. Given the historical experience with the HTGR concept, most of the components are at a modest level of maturity. This indicates that the technology may require some enhancement in performance or some greater level of engineering demonstration to meet the mission and goals of the NGNP project. At the same time, the components are not at the lowest level of maturity where the fundamental, scientific or proof-of-principle experiments would have been needed to establish concept feasibility. These readiness measures, when coupled with other technical information, not only allow management of the complex set of R&D activities but also provide simple metrics to monitor progress, mitigate risks, and prioritize activities relative to funding to ensure that the higher-risk activities with little schedule contingency receive the greatest attention.

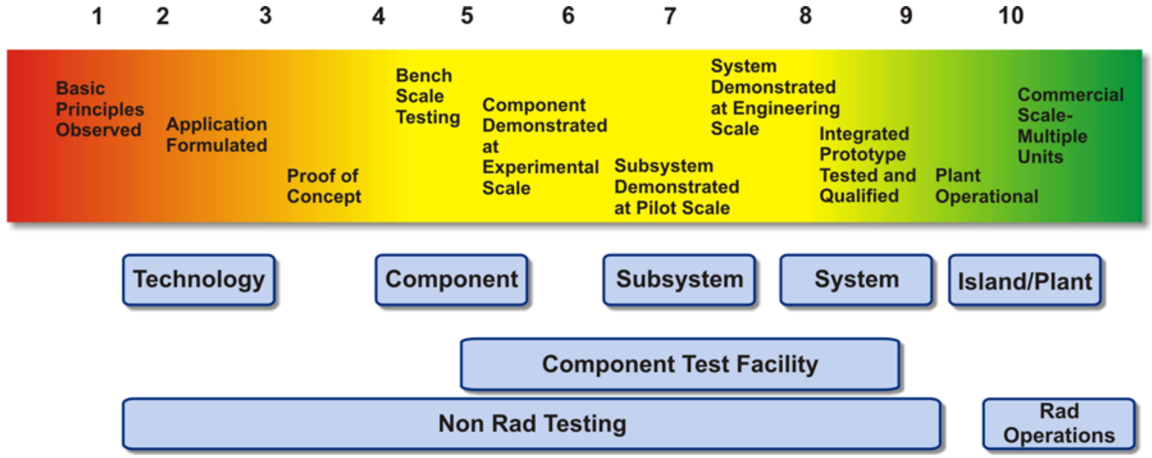

Figure 5. Technology Readiness Levels

4.1.3 Long-Lead Procurement Items and Their Procurement Strategy

DOE is conducting R&D to reduce the technical risk associated with key components and systems in order to facilitate long-lead procurements by the future Phase 2 private industry partners. The plan is to select the most promising technologies and mature them through R&D and testing. Long-lead procurement items will be identified as early as possible. Procurement will be scheduled and consistent with the overall project schedule. Some items anticipated to be long-lead procurement include fuel, graphite, high-temperature material, the intermediate heat exchanger, the reactor pressure vessel, and the power conversion system.

4.1.4 Quality Assurance

The American Society of Mechanical Engineers (ASME) standard *Quality Assurance Requirements for Nuclear Facility Applications* (NQA-1) is the baseline for the NGNP quality assurance program (QAP). Currently, the NGNP project is relying on the INL's QAP, which implements the requirements of NQA-1-2000 and meets the requirements of 10 CFR 830 Subpart A, *Quality Assurance Requirements*, and DOE Order 414.1C, *Quality Assurance*. An NGNP project-specific quality assurance program plan (QAPP) was developed to identify deviations from the INL QAP and to addresses NGNP project-specific implementation approaches. Personnel performing quality-affecting activities are required to abide by the NGNP QAPP.

The NGNP project is sponsored by NE and will be subject to the licensing and related regulatory authority of the NRC as stated in EPAct 2005. NRC requirements in 10 CFR 50, Appendix B, *Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants*, will be applicable to the fabrication, construction, and testing of the structures, systems and components (SSCs) of the reactor. The NGNP QA program will be updated to meet these NRC requirements on a schedule consistent with the NGNP regulatory strategy and agreements reached during pre-application discussions with the NRC. It is anticipated that the NRC will soon adopt NQA-1-2008 and the NGNP project will complete the transition to NQA-1-2008 in FY 2010.

4.1.5 Project Controls

Project controls describe the project work authorization, project controls processes, and performance measurement commensurate with the framework of the current level of maturity of the project. The non-resource-loaded project schedule is aligned with the work breakdown structure (WBS) to integrate individual schedules from each functional area.

The project will continue to use the current INL financial control reporting processes until such time as the framework of the public-private partnership and a project performance baseline are more fully established. The project is using the INL's earned value management system as the mechanism for reporting project earned value status. At the federal level, the project is monitored and tracked using proprietary custom software known as the Project Information Collection System (PICS). This software suite allows for online posting of project cost and schedule performance, project deliverables, and variance analysis by the many project participants.

4.1.6 Acquisition Strategy

DOE is managing this project consistent with the project management and development philosophy described in DOE Order 413.3A, *Program and Project Management for the Acquisition of Capital Assets*. The mission need statement developed for NGNP was approved by the DOE Deputy Secretary on October 18, 2004, officially completing Critical Decision (CD)-0. Responses to the RFI/EOI issued in April 2008 constitute a collection of alternatives that will provide input into the project's acquisition strategy and cost and schedule projections equivalent to DOE Order 413.3A, CD-1, "Approve Alternative Selection and Cost Range."

The Department anticipates that industry standards and practices under NRC licensing will drive many of the activities necessary in executing the remainder of the project scope. The formal NGNP public-private partnership would have provisions equivalent to hold points corresponding to DOE CDs for launching final design and construction activities. This structured decision process will assure high visibility and appropriate project management controls on CDs for the Department.

4.2 DESIGN

Phase 1 design scope includes pre-conceptual and conceptual design. Design through the conceptual phase is sufficient to make technology selections, develop a project cost and schedule estimate, and initiate pre-application licensing review with the NRC. Phase 2 design scope, expected to commence in FY 2011, includes preliminary and final design. Preliminary design is sufficient to inform long-lead procurements, prepare a COLA for submittal to the NRC, and develop high-confidence cost and schedule estimates. Final design is required to complete NGNP construction.

Pre-conceptual design was completed in September 2007 with the issuing of the pre-conceptual design reports by Westinghouse/Pebble Bed Modular Reactor Pty Ltd, AREVA NP, and General Atomics. The NGNP is currently in the conceptual design and demonstration phase. Conceptual design tasks include supporting technology down-selections, developing key SSCs, and addressing generic concerns such as issues identified in the NRC's Phenomena Identification and Ranking Tables (PIRT).

During the conceptual design and demonstration phase, the INL will work with industry to develop and validate documentation of design technology maturation levels and will subsequently develop and implement the process to perform and track risk-reduction strategies and activities for key SSCs. The design of the NGNP will be developed so as to provide technical and functional requirements, including safety requirements; hazards analysis; project risk evaluation; information needed for a focused R&D effort; and a defined basis for the project's cost range, schedule, and performance requirements. At the end of conceptual design, key piping and instrumentation diagrams, general arrangements, and process flow diagrams for critical systems will be provided. The project baseline (i.e., cost estimates, schedule, design documents, long-lead procurements, etc.) will be developed at a conceptual design level.

Conceptual design is expected to conclude by September 30, 2010, with the submission of the conceptual design reports. DOE plans to request that NEAC commence a programmatic review of the NGNP program as stipulated by EPAct 2005 in September 2010. This review will include an examination of the conceptual designs completed by the awardees under the FOA, along with the associated cost and schedule estimates and program execution plans. The review will also cover the results of pre-conceptual design studies, completed R&D and the status of R&D still in progress, and any NEPA studies and licensing reports that have been developed. At the completion of the programmatic review, NEAC will make a recommendation to the Secretary of Energy or his designate on the readiness of the program to proceed to Phase 2 activities. The NEAC review is expected to be completed in November 2010. Secretarial approval is required to move into Phase 2.

4.3 NGNP Licensing Scope and Strategy

Although gas-cooled reactor technology dates back to the 1960s, the gas reactors built in the United States were licensed through exceptions to regulations established for light-water reactors. In accordance with Section 644 of EPAct 2005, the NRC will need to establish licensing requirements and processes to support the commercialization of gas reactor technology.

4.3.1 Summary of Recommended Licensing Approach Reflected in the *NGNP Licensing Strategy Report to Congress*

The *NGNP Licensing Strategy Report to Congress* concluded that the best alternative for licensing the NGNP demonstration facility will be for the applicant to submit a COLA under Subpart C, “Combined Licenses,” of Title 10, Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants.” This recommended licensing approach is expected to take advantage of the new one-step plant licensing process, which is expected to reduce both licensing risk and attendant financial risk compared to other available licensing options. Risks would be reduced because the NRC will approve the final design, site, verification criteria, and operational and procedural aspects of the application before any significant construction begins. Therefore, this licensing approach is expected to ensure the most effective and efficient use of NRC and applicant resources, with completion occurring within the same timeframe as alternative approaches. This licensing approach is also expected to minimize licensing risk and reduce financial risk to the industry stakeholders who may decide to fund the project.

The following sections describe NGNP actions and progress to date, as well as next steps, as both DOE and the NRC begin executing the licensing strategy described in the *NGNP Licensing Strategy Report to Congress.*

4.3.2 NGNP Project Licensing Activities and Accomplishments to Date

The NGNP project has adopted the 10 CFR 52 COLA process as the foundation for the NGNP licensing strategy. As a first step in executing this licensing strategy, NGNP project team members have conducted a review of gas reactor licensing history and precedents. The team has also performed an initial screening review of applicable light-water reactor regulations and associated regulatory guidance that the project will need to address. The plan is to establish a regulatory framework and project licensing structure that will enable the successful licensing, construction, and operation of the NGNP demonstration facility. For the near term, DOE and the NRC will focus on the most significant policy issues and outline a licensing path for the NGNP that will lead to the approval and issuance of a COL by the NRC. Issuance of the COL will allow the construction and operation of the HTGR plant. Near-term critical licensing activities will proceed in parallel with DOE's planned establishment of a public-private partnership, which is expected to ultimately be responsible for the facility's COL. Establishment and implementation of this licensing structure provides a framework for future commercial HTGR applications.

4.3.3 NGNP Project Interactions With the NRC

As described in the *NGNP Licensing Strategy Report to Congress*, the NRC is participating in the early NGNP project licensing process by gathering information; identifying and developing proposals for resolution of key design, safety, and licensing issues; and preparing papers identifying programmatic, regulatory and key technical issues with recommendations for consideration and approval by the Commission. Frequent, focused and coordinated interactions between the NRC staff and the NGNP project team are being conducted and are critical to the success of the project. In order to support these interactions, the following steps have occurred:

- The NRC has established and staffed an Advanced Reactor Program, with a specific project branch assigned to the NGNP project.
- The NGNP project team has engaged the NRC staff in initial public meetings regarding the resolution of priority licensing issues.

A Memorandum of Understanding was established between the NRC and DOE to collaborate on NGNP-related licensing issues, including R&D, as appropriate. Regulatory-related R&D includes:

- Developing models and scaling analyses to support ongoing testing at multiple facilities related to HTGR development (Note: These models will be at the heart of the licensing process to predict performance under normal and off-normal conditions)
  - Perform reference modeling and analyses in support of Oregon State University's High-Temperature Test Facility (HTTF)
  - Provide technical support for Japan Atomic Energy Agency's HTTR
- Developing models related to specific HTGR systems and structure behaviors of interest for analyses and design method validation
  - Develop pre-conceptual model for reactor cavity-cooling system in NGNP geometry
  - Develop air ingress experiments and analyses
  - Develop bypass flow experiments and analyses

4.3.4 International Collaborations

DOE and the NRC have also established collaborations with international regulators, vendors and academia to further the establishment of HTGR licensing framework. International collaborations include:

- Collaborations through the Organization for Economic Co-operation and Development (OECD)/Nuclear Energy Agency/Committee on the Safety of Nuclear Installations to conduct integrated large-scale tests in Japan's HTTR to examine HTGR safety characteristics in support of regulatory research and licensing activities

- Collaborative efforts among DOE, the NRC, international regulators, international vendors and international universities to discuss the graphite dust safety issues in the context of the NGNP; a comprehensive workshop on this topic is being planned for a future date
- Collaborations with international researchers on HTGR-related research topics through the International Nuclear Energy Research Initiative; one such collaboration is with the Republic of Korea on experimental and analytical studies of the core bypass flow in HTGRs

4.3.5 NGNP Licensing Integration Strategy and Priorities – Next Steps

The priority licensing topics currently being addressed were developed based on an initial review of existing requirements, references, and project materials that were expected to identify many of the most critical regulatory issues for commencement of the licensing process. In order to arrive at a more comprehensive listing of issues to be addressed as a part of the COLA development process, a more detailed regulatory gap analysis will be required. The NGNP project is currently establishing an approach for implementing this process and expects to commence this work in the near term in order to supplement the high-priority licensing work already under way.

4.3.6 Updates to the *NGNP Licensing Strategy Report to Congress*

The following table describes updates to the *NGNP Licensing Strategy Report to Congress* that have occurred since it was first published in August 2008. The licensing approach recommended in the report has not changed, but some schedule adjustments have been made. DOE and the NRC continue to be engaged in review activities that should mitigate any overall schedule delay. Change will be evaluated in conjunction with the conceptual design and demonstration activities, and a revised schedule will be developed as needed. Whether the overall schedule for completing the construction of the NGNP in FY 2021 can still be met depends on many factors, including funding availability from both federal and private sectors.

Table 2. Updates to the *NGNP Licensing Strategy Report to Congress*

Report Section	Report to Congress Text	Update or Revision to Report to Congress
2.1.3	…DOE chooses a single design no later than March 2009 to support the pre-application review.	DOE has decided to fund up to two designs through the Phase 1 conceptual design and demonstration phase.
2.1.3	…DOE identifies the applicant for the NGNP prototype by the start of the pre-application review in FY 2010.	Choosing an applicant is a Phase 2 activity that occurs after a down-select decision is made. The NGNP project team will be engaged with the NRC on high-priority licensing activities until the applicant is identified.
2.1.3	The applicant submits a regulatory gap analysis in FY 2010…	Choosing an applicant is a Phase 2 activity that occurs after a down-select decision is made. The NGNP project team will begin regulatory analysis work in FY 2010.

Report Section	Report to Congress Text	Update or Revision to Report to Congress
2.1.3	Programmatic, regulatory, and key technical issues identified during the pre-application review are resolved at least one year before the licensing application is submitted to ensure the incorporation of any design modifications. To achieve this, preliminary design descriptions of all safety-significant systems must be available at the beginning of the pre-application review (FY 2010), and the applicant must propose reasonable solutions to potential programmatic, regulatory, and key technical issues at that time.	Pre-application is a Phase 2 activity. Conceptual design reports completed by awardees under the FOA will include preliminary design descriptions of all safety-significant systems and anticipated solutions to potential programmatic, regulatory, and key technical issues. Conceptual design reports are expected to be completed in September 2010. The NGNP project efforts to address and resolve priority licensing issues will proceed in parallel with the completion of safety-significant design descriptions. Those descriptions will be available on or after the completion of Phase 1 (January 2011).
Basis Doc	DOE has stated that it will submit the license application, which would include the preliminary design (final design of all safety-significant systems), no later than September 2013 (NGNP project Phase 2)	The COLA submittal schedule will be re-evaluated in conjunction with the conceptual design activities and will be revised as needed, reflecting the 2011 Secretarial decision.

4.4 CONSTRUCTION

The project is not at the level of design and planning maturity necessary to formulate specific plant construction information. However, an initial estimate would have construction beginning in late 2017, depending on the 2011 Secretarial decision. Development of detailed construction schedules is a Phase 2 activity.

4.5 NGNP RESEARCH AND DEVELOPMENT

At the inception of the NGNP project, experts from DOE national laboratories, gas reactor vendors, and universities collaborated to establish technology R&D roadmaps to help guide NGNP R&D. These internal roadmaps outlined the testing and computational development activities needed to qualify the materials and to validate the modeling and simulation tools to be used in the design and operation of the NGNP. The technology development roadmaps drew on worldwide experience gained from the six demonstrations and/or prototype HTGRs that were built and operated over the past 60 years. The roadmaps included detailed descriptions of the required technical activities with associated schedules and budgets for project completion and still formed the baseline for execution of the R&D needed for the NGNP project. The R&D activities are organized into the following four major technical areas: (a) fuel development and qualification, (b) graphite qualification, (c) high-temperature materials qualification, and (d) design and safety methods validation. The objectives of each activity, current status, accomplishments to date, and future plans are discussed in this section. To accomplish these objectives, the R&D program draws upon expertise at DOE national laboratories and a broad array of universities, along with international facilities and expertise accessible to DOE via the GIF. All R&D activities are being conducted in compliance with the QA requirements established by the ASME NQA-1 code. This will ensure that experimental data is useful to designers and regulators of the NGNP.

4.5.1 Fuel Development and Qualification

The NGNP concept is based on coated particle fuels as shown in the upper left corner of Figure 6. Such fuels have been extensively studied over the past four decades. Layers of carbon and silicon carbide surround a uranium kernel to form a tri-isotropic (TRISO)-coated fuel particle of approximately one millimeter in diameter. The NGNP will contain billions of TRISO-coated particles that are pressed into compacts. The compacts are shaped as either chalk-sized, right circular cylinders or tennis-ball-sized spheres called pebbles. Rigorous control is applied at every step of the fabrication process to produce high-quality, very low-defect fuel. Defect levels are typically on the order of one defect per 100,000 particles.

The TRISO layers provide robust protection for the uranium kernels and superb retention of the radioactive material produced during fission. Extensive testing in Germany in the 1970s and 1980s demonstrated the outstanding performance of TRISO-coated particle fuels under both normal operation and accident conditions. It is this fuel performance, combined with passive plant safety features, which could allow an NGNP class reactor to be located in an industrial complex to provide heat and electricity to that complex. Prior to the NGNP project, the German experience was considered the “gold standard” around the world. Today, the NGNP project is also achieving, and in some cases exceeding, the high levels of fuel performance established by the Germans.

Qualification of fuel for use in a licensed reactor involves experiments and examinations that will allow an understanding of the behavior of TRISO-coated fuel under the radiation and temperature environment expected in an HTGR. It also involves experiments to allow for an understanding of how well the fission products (i.e., the elements produced when uranium fissions) stay inside or move outside of the coated fuel particles and through the graphite reactor core. Development of modeling and simulation tools to analyze and predict this behavior is also important to the design and safety analysis for the NGNP.

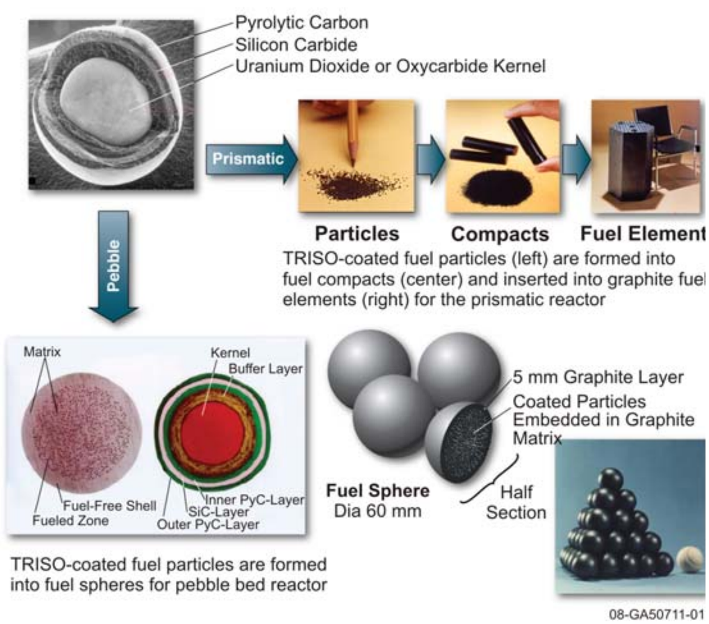

Figure 6. TRISO Coated Particle Fuel

TRISO fuel particles are formed into spheres for a pebble bed HTGR and compacts for a prismatic HTGR.

The NGNP project had to re-establish the capability to fabricate and characterize TRISO-coated particle fuel in the United States. This was a significant effort that required the development of the fabrication processes and characterization approaches used in historical TRISO-coated fuel made in the 1970s and 1980s. Many of the procedures and recipes used in the past were still available but needed to be modernized to take advantage of improvements in measurement science over the past 25 years. The result has been much more accurate and precise characterization of this fuel form. The project is now fabricating TRISO-coated fuel particles on an industrial scale with very low defects (about one defect in every 100,000 particles).

The first fuel experiment, called AGR-1, has recently completed approximately three years of radiation exposure at the high temperatures expected under normal operation in an HTGR. About 300,000 TRISO fuel particles have been tested to a real level of energy utilization, called peak burnup, of 19 percent *without a measureable indication of a single particle failure*. These results are critical in demonstrating the superior performance capability of TRISO fuel and ultimately the HTGR concept. This level of burnup is about three times that of current light-water reactors and double the level achieved by the German gas reactor program in the 1980s. Work has also been under way to establish the capability to perform high-temperature testing of this fuel at accident conditions (i.e., higher temperatures) to confirm robust safety performance of the fuel under highly unlikely but possible conditions. This testing will begin in late 2010 and provide critical qualified data on the safety basis of the fuel for NRC licensing.

The NGNP fuel development program has also spent significant effort developing a state-of-the-art computer modeling and simulation capability to predict the behavior of TRISO fuel under the wide range of conditions anticipated in an HTGR. The model has been extensively compared to similar tools developed by international colleagues as part of an effort under the auspices of the International Atomic Energy Agency.

4.5.2 Graphite Qualification

Graphite has been effectively used in the past as structural material for high-temperature reactor cores. Historical grades of graphite and the supply of raw feed stocks used in gas reactors no longer exist. The objective of the NGNP graphite qualification RD&D is to demonstrate that modern grades of nuclear graphite made with current feedstock materials will perform at least as well as historical grades did. The project is seeking a science-based understanding of the fundamental mechanisms of irradiation behavior of graphite in order to predict how new types and grades will behave in the future. In the longer term, the project plans to evaluate the influence of fabrication processes and different feedstock materials on graphite behavior so that extensive qualification efforts are not needed when feedstocks or improved fabrication methods are used to make graphite for future HTGRs after the NGNP.

Figure 7. Graphite Core Components

At the start of the graphite qualification research, significant effort went into establishing analytical measurement laboratories. These laboratories were required in order to perform the extensive characterization of nuclear graphite under consideration for HTGRs. This task consisted of procuring, preparing, and calibrating state-of-the-art analytical testing equipment. It also included developing protocols and testing methods to make accurate, repeatable measurements on graphite—abilities that are well-established for metals. An extensive characterization effort is currently under way to establish the material properties before irradiation on a series of large graphite chunks or blocks, called billets, which have been procured from two major graphite vendors (one in the U.S. and one in Europe). The first of six planned tests to evaluate the irradiation behavior of graphite under radiation exposure and high temperatures expected in an HTGR is also underway. This test, the largest of its kind ever performed on nuclear graphite, will produce a large number of well-characterized irradiated samples. Tests are planned at specified temperatures and a level of radiation dosage that envelop the anticipated irradiation conditions for the HTGRs being developed by the NGNP project. Extensive post-test examinations are also planned to understand the key material property changes caused by the irradiation exposure. Our current understanding in this area is incomplete. Of particular interest is the need to understand the ability of graphite to relax the stresses induced by neutron bombardment (termed "creep"). If significant relaxation occurs, then the neutron-induced stresses will not cause failure of the graphite components (e.g., cracking), and graphite will have a longer lifetime in HTGRs than currently anticipated. Extending the life of graphite in the reactor would reduce the quantity of graphite used in each HTGR, which would yield important economic and waste disposal benefits. These irradiation data and the as-fabricated material properties will be used to improve the detailed modeling and simulation tools currently being used to predict the structural response of graphite both inside a large block as well as throughout the whole core. The data from all characterization and modeling activities will be required by the ASME to certify the structural adequacy of graphite during the HTGR licensing process.

4.5.3 High-Temperature Materials Qualification

The high HTGR outlet temperature (750°C or higher depending on the application) requires the development of high-performance metallic alloys to transfer heat from the reactor to the process application. Because these alloys will contain the high-pressure helium used to cool the reactor, stringent requirements are imposed to ensure that the piping and equipment through which the helium flows, called the pressure boundary, will maintain its integrity. Thus, the goal of high-temperature materials qualification for the NGNP is to obtain the performance data required to support the development of these high-temperature components over the range of envisioned outlet temperatures.

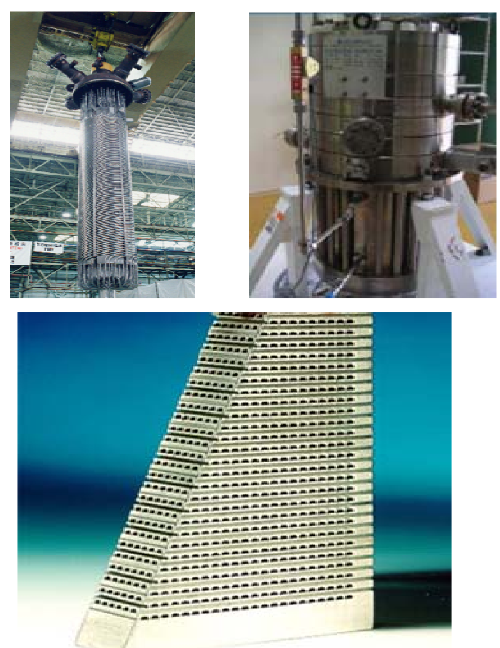

Figure 8. Examples of High Temperature Heat Exchangers and Circulators

Production-grade quantities of candidate high-temperature alloys have been procured. State-of-the-art mechanical and environmental testing of the candidate high temperature metallic alloys is underway to understand their mechanical behavior at high temperatures and ensure that they do not degrade after long term exposure to low levels of moisture or other impurities present in the helium coolant environment at the high temperatures expected in an HTGR. Extensive development of the testing equipment and its associated experimental procedures was required, modifying traditional material test systems to accommodate the high temperatures necessary to obtain the accuracy and repeatability needed to qualify the alloys for use in a nuclear system like those found in HTGRs. The testing will cover a broad range of anticipated physical dimensions and structures to be used for the high temperature components, including both thick and thin sections of the alloy, flat plate and tubes, as well as welded sections and other joints to ensure adequate structural performance and safety margins for use in the HTGRs. A detailed characterization of each alloy will be performed after each test to understand the underlying behavior at the microscopic scale that contributes to the measured mechanical behavior of the metal.

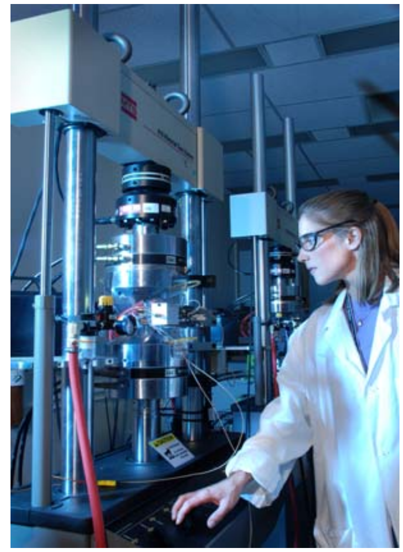

Figure 9. High Temperature Material Testing

All of the high temperature performance data generated in the testing will be needed for ASME to certify the structural adequacy of the high temperature metals via an established process, a part of the NGNP licensing process. As the design of the high temperature components in NGNP matures, R&D is envisioned to establish techniques to inspect the metals that form the pressure boundary during reactor operation. Integrated testing of key high-temperature components (i.e., testing them with the connections and in the environment experienced as part of an HTGR) will be needed to characterize the integrated behavior and validate the inspection techniques for use in the NGNP. It should be noted that the establishment of ASME codes and standards for both graphite and high-temperature metals provides a strong foundation to support licensing by the NRC and broad commercialization of gas reactor technology.

4.5.4 Design and Safety Methods Validation

The goal of the NGNP design and safety methods validation is to develop the experiments and data needed to validate the modeling and simulation tools used to establish the design and safety of the NGNP. DOE researchers have participated with colleagues at the NRC using a well-established expert input process to establish a ranking of important events that might occur during an accident. A best allocation of resources for safety-related R&D activities was developed based on the importance of the specific accident-related event relative to the overall safety of the HTGRs and the associated level of technical knowledge. Areas where the importance is high and the knowledge is low receive the greatest attention.

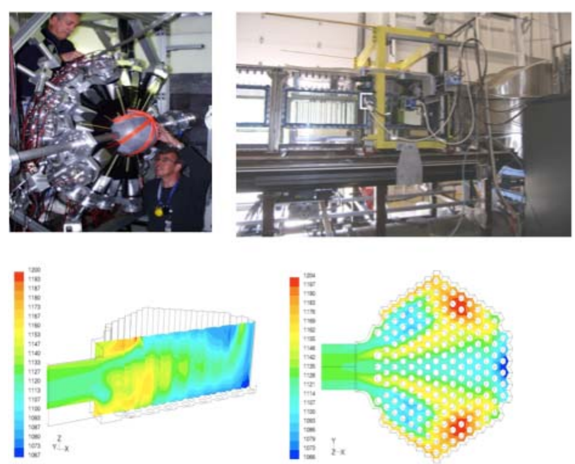

Figure 10. Experiments and Computer Simulations Used in HTGR Design and Safety

Based on this exercise, the NGNP project is interacting with the NRC to jointly develop a set of large-scale experiments to provide the necessary safety-related data to validate the modeling and simulation tools used to design and assess the safety of the HTGR design. This joint development effort avoids duplicative costly experiments by the licensing applicant and the regulator. DOE and the NRC have also initiated a joint collaboration with the Japanese gas reactor team to obtain unique operational data from their operating high temperature gas test reactor to validate modeling and simulation tools that predict the behavior of the integrated reactor system. Assessments are currently under way by DOE, the NRC, and laboratory personnel to technically evaluate other international capabilities that can be used to provide relevant safety data.

In addition, experiments and computer models are being developed to reduce uncertainties and improve design and safety margins.

4.5.5 Future Plans

Given the need for specialized facilities (e.g., nuclear test reactors, hot cells for examining radioactive fuels, specialized high-temperature/high-pressure testing facilities), acquiring the R&D data needed to qualify NGNP fuels, materials, and modeling and simulation tools for licensing will be a protracted effort. Near-term R&D is, therefore, focused on continuing qualification activities in the aforementioned technical areas—fuel development, graphite qualification, high temperature materials qualification and design, and safety methods validation—to reduce risks and develop the data needed for plant design and licensing. Management of the NGNP R&D program will remain at the INL subsequent to the formation of a public-private partnership.

4.6 Schedule of Activities, Milestones and Critical Decision Points

Whether the overall schedule for completing the construction of the NGNP in FY 2021 can still be met depends on many factors, including funding availability from both federal and private sectors. Milestones for Phase 1 of the NGNP schedule are listed in the following table. Detailed timelines for Phase 2 activities will be available after the 2011 Secretarial decision, but, for the sake of completion, current rough estimates are included here.

Table 3. NGNP Schedule

Date	Activity	Type
2005–01/10/2011	Phase 1	Activity
08/2009	Select and validate appropriate hydrogen production technology (high-temperature electrolysis was selected)	Critical Decision Point
2005–2021	Carry out enabling R&D and demonstration activities	Activity
2005–2009	Carry out initial design activities for a prototype reactor and plant	Activity
9/18/2009	Issue FOA for competition to complete conceptual designs	Milestone
11/16/2009	Receive responses to FOA	Milestone
04/30/2010	Issue awards under the FOA	Milestone
04/30/2010–9/30/2010	Complete conceptual designs	Activity
09/30/2010	Detailed conceptual design reports due to DOE	Milestone
09/30/2010–12/15/2010	Conduct NEAC review	Activity
12/15/2010	NEAC recommendation to the Secretary on proceeding to Phase 2	Milestone
12/30/2010	Submit NEAC report to Congress	Milestone
01/11/2011	Secretary of Energy's announcement on path forward to Phase 2	Critical Decision Point
01/11/2011–2021	Phase 2*	Activity
01/15/2011–09/30/2011	Competition process for Phase 2 Award*	Activity
09/30/2011	Award cost-shared, cooperative agreement for final design and licensing*	Milestone
09/30/2011–09/30/2013	Prepare COLA*	Activity
09/30/2013	Submit COLA*	Milestone
10/01/2013–10/01/2017	The NRC to review COLA*	Activity
10/01/2017	The NRC to issue COL*	Milestone
2017	Start of construction*	Milestone
2020–2021	NRC inspections, tests, analysis, acceptance criteria*	Activity
2021	NGNP operational*	Milestone

* The schedule for these milestones and activities is dependent on the outcome of the Secretarial decision currently scheduled for January 2011.

4.7 Cost Estimate and Anticipated Cost-Share Requirements

Based on FY 2007 pre-conceptual design data, the INL has worked with the reactor vendors to arrive at a total project cost estimate of just under $4 billion for a 350–600 MWt plant through FY 2021. The uncertainty of this estimate is very high and does not include escalation. A better estimate will be available as a product of the conceptual design; however, a completed preliminary design is needed to obtain a high-quality estimate with low uncertainty. This $4 billion estimate assumes that two designs are funded through conceptual design with one design subsequently selected as the NGNP. This is the entire cost of the project and will include industry cost share. In accordance with EPAct 2005, Section 988, the FOA established a 50–50 cost share requirement for conceptual design and demonstration activities and allows the Secretary of Energy to grant a reduction to the cost share requirement if he determines it to be necessary and appropriate. Negotiations are now in progress with the selected industry teams which, if successful, will result in cost shared awards of approximately $40 million of Department funds. DOE anticipates use of a 50–50 cost share for Phase 2 of the NGNP project with the exception of applied R&D, which will be cost shared at 80–20 as required in EPAct 2005. R&D that is fundamental in nature will be funded without a cost share requirement.

The major areas of cost uncertainty are related to project risk regarding the timeliness of the following activities: 1) completion of necessary R&D activities in order to support design development, 2) development of licensing requirements for HTGRs upon which the NGNP can be designed, 3) submittal of the NRC license application with appropriate final design details, and 4) completion of the NRC's regulatory review and hearing process and approval of the license application to permit the start of construction and operations. Delays in any of these areas will increase total project costs.

Table 4. Current Preliminary Estimated Total Project Scope Costs (Federal and Non-Federal Costs)

Cost Category	Cost ($ in millions)
Project Management	279
Research and Development	517
Design*	687
Licensing	276
Procurement	1,099
Construction/Startup/Initial Operation	842
Process Heat Application	210
Total	**$3,911****

* This estimate was prepared in FY 2007 and reflects the support of two designs through the conceptual design phase followed by competitive selection of a single, final design.

** The uncertainty of this estimate is very high and does not include escalation. A better estimate will be available as a product from the conceptual design.

5. Examination of Technology Options

The NGNP will be a graphite-moderated nuclear reactor cooled by helium. The reactor design will be capable of heating its helium coolant to temperatures ranging from 750°C to 950°C, enabling such potential applications as highly efficient electricity generation or co-generation of process heat for use in the chemical industry. Key characteristics of this reactor concept are the use of helium as a coolant, graphite as the neutron moderator, and ceramic-coated particles as the fuel. As helium is chemically inert, it will not react under any conditions. The graphite core slows down the neutrons and provides high-temperature strength and structural stability for the core. The ceramic-coated particle fuel is extremely robust and retains the radioactive byproducts of the fission reaction under both normal and off-normal conditions.

There are two major design concepts for the NGNP under consideration today: a prismatic and pebble bed reactor. In the prismatic configuration, hexagonal graphite blocks are stacked to fit in a cylindrical pressure vessel. Within each block are cooling passages for helium and positions in which to place right circular graphite cylinders, about the size of a piece of chalk, that contain the coated particle fuel. Graphite reflectors surround the core to shape the neutron flux. The reactor is refueled every 12 to 18 months with blocks containing new fuel enriched to 15 percent uranium-235 content. In pebble bed designs, the fuel particles are formed into pebbles the size of a tennis ball . Graphite reflectors surround the pebbles to provide structural support of the core and reflect neutrons back into the core. Pebbles are enriched to about 10 percent uranium-235 and continuously circulate through the core. On average, a pebble is re-circulated six to ten times during its three-year life before it is permanently discharged from the reactor.

Both reactor concepts are based on coated particle fuels, which have been extensively studied around the world over the past four decades. Layers of carbon and silicon carbide surround the uranium core, or kernel (i.e., the active part of the particle), thus forming TRISO-coated particle fuel. HTGRs would contain billions of these multilayered TRISO-coated particles in the form of cylindrical compacts or pebbles.

The TRISO layers provide this fuel with extremely robust protection for the nuclear material and outstanding retention of the radioactive byproducts produced during fission. Extensive testing in Germany in the 1970s and 1980s demonstrated that outstanding performance of high-quality, low-defect TRISO-coated particle fuels can be achieved under both normal operation and potential but highly improbable accident conditions. Recently completed experiments at the INL set the world record for particle fuel performance by consuming a maximum of 19 percent burnup of the initial low-enriched uranium content, with an average burnup of 16 percent for all of the fuel tested. The maximum 19 percent burnup achieved is more than double the previous record set by similar particle fuel experiments run by German scientists, and more than three times that achieved by current light-water reactor fuel. None of the fuel particles experienced failure during the entire three-year irradiation.

This performance, combined with the large graphite reflectors that act as a large heat sink, contribute to the passive safety of the concept, potentially allowing these reactors to be located in close proximity to industrial complexes. At these locations, the reactors can provide heat for the high-temperature chemical processes and hydrogen for chemical and petrochemical industries, which is the major objective of the NGNP project. Schematics of the two design options are shown below.

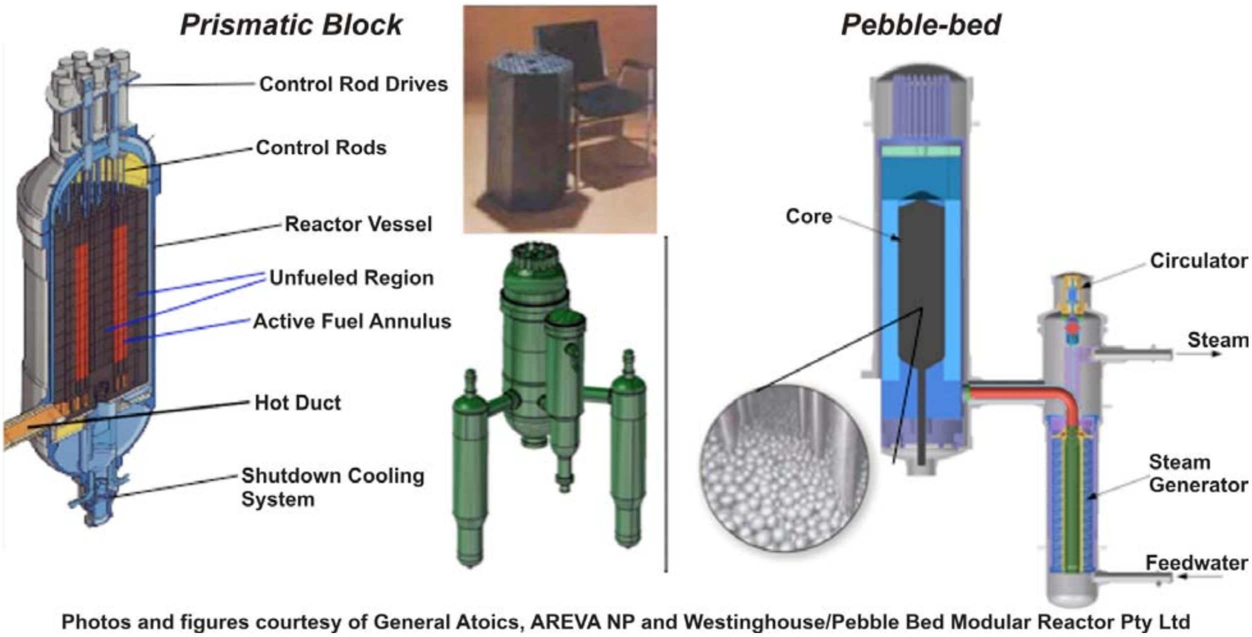

Figure 11. Schematics of the Pebble Bed and Prismatic Designs

Most of the challenges for these two reactor types are held in common. These challenges consist of licensing and regulatory issues associated with containment and emergency planning, business issues associated with breaking into new markets for nuclear energy in the industrial sector, and infrastructure issues associated with first-of-a-kind technology demonstrations. Some challenges, however, are unique to each reactor type. For the pebble bed, the stochastic nature of the fuel presents a unique design and licensing challenge. For the prismatic design, controlling cooling flow through the narrow channels of the graphite blocks is a challenging design and manufacturing issue.

6. CONCLUSIONS

This report presents a detailed account of the funds appropriated to the NGNP project from FY 2006 through FY 2010. Of the $528.4 million, $192.8 million will be spent on NGNP research and development; $177.6 million on NGNP design, engineering, licensing and project management; and $158 million on university programs conducting R&D and other NGNP-related activities. This report also includes a program execution plan that details the scope and schedule of activities, milestones and critical decision points, and total project cost estimates, including anticipated cost-share requirements. The scope of the NGNP project includes R&D, design, licensing, and construction activities leading to the operation of the NGNP in FY 2021. Major near-term milestones include the completion of conceptual design in September 2010, and the Secretarial decision to move into Phase 2, planned for January 2011. The NGNP project, as defined in EPAct 2005, is anticipated to cost $4 billion to execute. This project scope will be conducted on a cost-shared basis with the private sector. The exact details of the cost-share arrangement will not be known until a final public-private partnership is formed. This report also presents the licensing implementation strategy, which details how DOE plans to execute the *NGNP Licensing Strategy Report to Congress*. The licensing approach advocated in the report has not changed, but some schedule adjustments have been made. Finally, the report describes the two major technology options under consideration—the pebble bed modular reactor and the prismatic designs—and the technical and commercial challenges facing each option.