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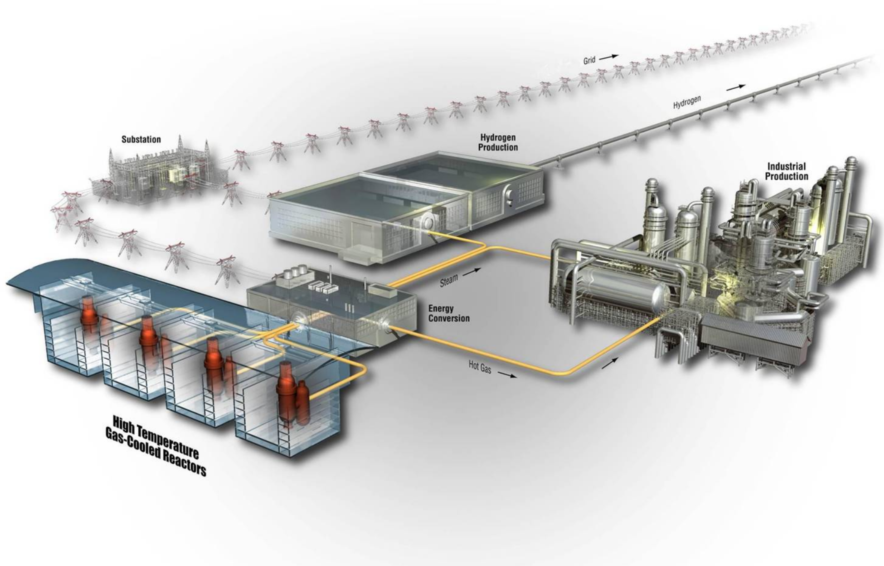
NGNP Project 2011 Status and Path Forward

December 2011



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NGNP Project
2011 Status and Path Forward

December 2011

Idaho National Laboratory
Next Generation Nuclear Plant Project
Idaho Falls, Idaho 83415

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Next Generation Nuclear Plant Project

NGNP Project
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Approved by:

Greg A. Gibbs NGNP Project Director	12/22/11 Date

EXECUTIVE SUMMARY

General

High temperature gas-cooled reactor (HTGR) technology can play an important role in the energy future of the United States by extending the use of nuclear energy for non-electricity energy production missions, as well as continuing to provide a considerable base load electric power generation capability. Extending nuclear energy into the industrial and transportation sectors through the coproduction of process heat and electricity provides safe, reliable energy for these sectors in an environmentally responsible manner. The modular HTGR provides a substantial improvement in nuclear plant safety for the protection of the public and the environment, and supports collocation of the HTGR with major industrial facilities. Under U.S. Department of Energy (DOE) direction since 2006, the Next Generation Nuclear Plant (NGNP) Project at Idaho National Laboratory (INL) has been working toward commercializing the HTGR technology. However, based on a recent decision by the Secretary of Energy to reduce the scope of the NGNP Project to a research and development (R&D) program, considerable realignment is taking place. This report (1) summarizes the accomplishments of the NGNP Project through 2011, (2) lays out the path forward necessary to achieve the ultimate objective of commercializing HTGR technology, and (3) discusses ongoing technical, licensing, and evaluation activities under the realigned NGNP program considered important to preserve the significant investment made by the government to-date and to maintain some progress in meeting this objective.

Project Accomplishments

In December 2002, development of the International Generation IV Technology Roadmap concluded that a very high temperature reactor (VHTR) concept based on gas-cooled reactor technology should be one of several nuclear energy systems pursued. This concept could provide high temperature process heat and produce hydrogen for industrial processes. In the September 2003 *U.S. Generation IV Implementation Strategy* report to Congress, the NGNP based on VHTR gas-cooled reactor technology was designated the first priority for U.S. development.

Via the November 2004 DOE Contract with INL (DEAC07-05ID14517), Battelle Energy Alliance, LLC (BEA) was directed to lead U.S. research, development, and exploration of NGNP technologies and carry out this mission in cooperation with other national laboratories, universities, international partners, and the private sector. BEA was also directed to assist with the establishment and administration of an international public/private consortium to design, build, and operate the NGNP. Subsequently, Congress established the NGNP Project thru the *Energy Policy Act of 2005*. DOE was directed to form this Project to conduct research, development, design, construction and operation of a prototype nuclear reactor plant. The Project was to be conducted in two phases with interim reviews by the Nuclear Energy Advisory Committee.

The NGNP Project at INL was formally initiated in March 2006 with the issuance of the *Preliminary Project Management Plan*. Since that time, the Project has undertaken the following selected activities:

- Consolidated all R&D, design, engineering, licensing, quality assurance, and management activities under a single management team.
- Performed a substantial scope of R&D activities for HTGR applications that have (1) demonstrated proof of the tristructural- isotropic (TRISO) fuel design concept, consistent production quality, and performance under irradiated conditions, (2) characterized and is in the process of qualifying graphite structural materials under irradiated conditions, (3) extended the high temperature material characterization data for achieving consensus design code requirements for metals applications, and (4) initiated the analytical modeling qualification for the fuel, graphite, high temperature materials, and overall reactor and nuclear system behavior.

- Managed and performed pre-conceptual design activities in 2007 for NGNP/HTGR design concepts by three design teams comprised of approximately two dozen companies with interests in development of HTGR technology.[a]
- Performed a broad range of engineering trade studies to evaluate technical areas important to the development and maturation of the NGNP/HTGR concept.
- Developed and initiated the implementation of a technical risk management program that characterized the technology readiness levels of key structures, systems, and components (SSCs) of the HTGR and production of technology development roadmaps for increasing the technical readiness of these SSCs to required levels.
- Developed new and updated American Society for Testing and Materials International material specifications for nuclear graphite and selected high temperature metals.
- Developed and supported approval and publication of a new American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section III, Division 5 providing construction rules for high temperature reactors, including rules for graphite core components.
- Prepared an implementing strategy for licensing HTGR technologies and submitted it to the Nuclear Regulatory Commission (NRC).
- Prepared a series of white papers and responses to Requests for Additional Information for policy and high level technical areas important to developing the regulatory requirements in these areas.
- Evaluated the technical feasibility and economic viability of integrating HTGR technology as an alternative source of energy to the current use of fossil fuels in a broad range of major industrial processes.
- Evaluated several selected proxy sites for technical feasibility and economic viability for integrating HTGR technology with existing industrial processes. The potential licensing of two of the proxy sites by the NRC was evaluated, which included considerations of collocated hazards and other issues important to licensing HTGR technology.
- Upgraded and implemented the quality assurance function to ensure that the information developed within the Project could eventually be used directly in submittals and applications to the NRC.
- Provided planning and budget support to DOE.
- Supported formation of an industry consortium (currently known as the NGNP Industry Alliance, Limited), which is comprised of energy end-users and off-takers, a major nuclear owner/operator, nuclear system suppliers, and fuel and materials suppliers.

This report describes the culmination of Project activities anticipated to occur in early 2012, the effort needed to achieve the Project objective of commercializing the HTGR technology, and the scope of activities in R&D and Licensing under the realigned NGNP Program to be managed by the INL VHTR Technology Development Office (TDO).

Project Status

On October 17, 2011, the Secretary of Energy forwarded to Congress the report and recommendations of a Nuclear Energy Advisory Committee review of the NGNP Project EPAct Phase 1 activities. The Secretary's letter concludes that "…Given current fiscal constraints, competing priorities, projected cost of the prototype, and the inability to reach agreement with industry on cost share, the

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a Plant design work beyond pre-conceptual design was not performed by the INL NGNP Project from April 2009 to the present by direction of the DOE.

Department will not proceed with the Phase 2 design activities[b] at this time. The Project will continue to focus on high temperature reactor research and development activities, interactions with the Nuclear Regulatory Commission to develop a licensing framework, and establishment of a public-private partnership until conditions warrant a change of direction." The scope and schedule of these continuing activities, and the conditions warranting a change of direction have not yet been defined.

The result of the Secretary's letter is that the NGNP Project at INL will be reconfigured as an R&D Program early in CY 2012 and a considerably reduced scope of work will be managed by the VHTR TDO at INL. The reduced scope will include supporting a limited set of ongoing R&D priorities and continuing the pre-application licensing activities built around the series of white papers, associated responses to NRC Requests for Additional Information, and the pending NRC policy issue assessment reports. No design work will be performed, consistent with the direction from DOE in April 2009, although such design work is considered necessary to support these licensing activities and to otherwise further the development and deployment of the HTGR technology.

Although the Secretary's October letter did not provide conditions or a schedule for restarting full NGNP Project activities, for purposes of the structure of this report, the INL-managed NGNP Project has assumed that a resumption of full scope activities for development and deployment of the HTGR technology may occur at some future date. The objective of this report is to provide a baseline from which future development and deployment of the HTGR technology can progress. This baseline is derived from results of the considerable development work completed by the NGNP Project at the time of this writing and insights of the NGNP Project on the work that is needed to complete technology development, design, and licensing to commercialize the technology. In the meantime, the following recommended activities are specifically directed at maximizing the future value gained from the considerable investment in technology development by DOE over the past 6 years and minimizing the startup time to resume a larger scope of development and deployment activities at some future time.

Future Activities to Commercialize HTGR Technology

The capabilities of the HTGR have attracted the attention of an ever-increasing number of industries as an option to address ongoing environmental concerns, large price variability, and unsure availability associated with traditional fossil fuels used for energy and feedstock. However, the HTGR option will exist only if the necessary investment is made to complete its development and commercialize the technology through initial deployment in industry. This investment requires a collaborative commitment between the private sector interests and government. The fundamental risks to investors are those associated with modifying the NRC technical and policy infrastructure to support licensing of HTGRs and ensuring that viable business cases can be built around the economics of HTGR nuclear energy systems.

As a result of the Secretary's decision, alternative strategies will need to be developed if industry wants HTGR technology to be available as an option over the longer term. Suggested alternative strategies to this end include:

- Government could complete development and construct the modular demonstration reactor as a national priority. For example, this national priority could be established to provide power for and production of synthetic transportation fuels for Department of Defense purposes. Based on this demonstration, it is anticipated that industry would commercialize the technology for those applications demonstrating a viable business case.
- Private industry, in partnership and cost sharing with government, could complete development and construction of the NGNP demonstration modular reactor in a first-of-a-kind commercial application

b Phase 2 as defined in section 643, Project Organization, of the EPAct.

as part of a multiple module plant, providing the energy requirements of an industrial energy off-taker. Such an endeavor would be pursued, presuming a viable business case can be demonstrated for this multiple-module plant.

- Private industry, within a private sector consortium with sufficient resources and commitment from national and/or international entities, could complete development and construction of the demonstration modular reactor as part of a first-of-a-kind multiple module plant, providing the energy requirements of an industrial energy off-taker. Such an endeavor would be pursued, presuming that a viable business case can be demonstrated for this multiple-module plant. The consortium may request limited U.S. and foreign government assistance (e.g., tax credits or loan guarantees).

These alternative strategies or variations of them can be enabled by the following U.S. Government actions in the near-term:

- Continue to pursue a common ground for a comprehensive public-private partnership or other collaborative arrangement between DOE and industry to pursue a substantive scope of development activities to enable deployment and commercialization of HTGR technology. Substantive scope refers to deliverable activities for which industry can identify an acceptable return on cost share or other form of investment with an appropriate level of risk. This will require demonstrated planning and commitment for out-year funding by the government that would provide the confidence necessary for the private sector to invest in such a partnership.

- Complete the following activities to protect and maximize the value derived from the over $500 million investment made by the U.S. in HTGR technology over the past 6 years by:
  - Continue the R&D program to the point of qualifying and codifying the TRISO fuel, graphite structural materials, high temperature metals, and applicable analytical methods for reactor outlet temperature applications up to 925°C.
  - Prepare technical reports as part of the R&D program, on the fuel, graphite, high temperature metals, and analytical methods for use by an applicant in developing topical reports for submittal as part of an application for a combined license and/or design certification from the NRC.
  - Support continuing interactions with NRC to ensure the subjects of the extant licensing white papers, responses to the Requests for Additional Information, and NRC assessment reports are brought to conclusion and, where needed, formally acted upon by the Commissioners. This will help ensure that the foundation for regulatory requirements and a review process exist for HTGR technology and are formally recognized via topical reports and changes to regulatory infrastructure, as appropriate. This support may require collaboration with one or more industry applicants for HTGR technology Design Certifications and/or combined licenses.

  Appendix K of this report summarizes a scope of work in the R&D and Licensing areas consistent with these activities. This scope of work is reduced from the original NGNP Project planning to be consistent with the Secretary's letter of October 17, 2011 and is the minimum judged to be required to maintain some progress in meeting the objectives of commercializing the HTGR technology. The reduced scope of work will result in a reconfiguration of the INL organization from a Project to an R&D Program managed by the INL Technology Development Office. Appendix K also discusses this reconfigured organization.

  It should be made clear that this reduced scope of work is not sufficient to meet the objective of commercializing HTGR technology. This is a stopgap measure to maintain some progress and protect prior investment toward that objective until a means to accomplish this objective has been identified and implemented. The main body of this report (Sections 1 through 8) and the supporting Appendices A-J summarize what the Project has accomplished at the time of this writing and what more is needed to meet this objective.

CONTENTS

FIGURES

TABLES

ACRONYMS

AGC	Advanced Graphite Creep
AGR	Advanced Gas Reactor
ANL	Argonne National Laboratory
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATR	Advanced Test Reactor
B&W	Babcox and Wilcox
BEA	Battelle Energy Alliance, LLC
BPV	boiler pressure vessel
CEA	Commissariat à l'Énergie Atomique
CFD	computational fluid dynamics
COL	Combined License
COLA	Combined License Application
CTF	Component Test Facility
DDN	Design Data Need
DOE	Department of Energy
DOE-NE	DOE Office of Nuclear Energy
DOORS	Dynamic Object Oriented Requirements System
dpa	displacements per atom
DPP	Demonstration Power Plant
EPAct	Energy Policy Act of 2005
FIMA	fissions per initial metal atom
FSAR	Final Safety Analysis Report
FSV	Fort St. Vrain
GA	General Atomics
GT-MHR	Gas Turbine Modular Helium Reactor
HFIR	high flux isotope reactor
HPS	hydrogen production system
HTE	high temperature electrolysis

HTGR	high temperature gas-cooled reactor
HTS	heat transport system
HTSE	high temperature steam electrolysis
HTTF	High Temperature Test Facility
HTTR	high temperature test reactor
HTV	HFIR-Target-VHTR
IAEA	International Atomic Energy Agency
ICAMS	Issues and Corrective Actions Management System
IHX	intermediate heat exchanger
ILS	integrated laboratory scale
IMGA	irradiated microsphere gamma analyzer
INL	Idaho National Laboratory
IPyC	inner pyrolytic carbon
IRT	independent review team
ISI	in-service inspection
ITGR	Independent Technical Review Group
JAEA	Japan Atomic Energy Research Agency
LI	laboratory instruction
LST	list
LWP	laboratory wide procedures
LWR	light water reactor
MCP	management control procedures
MHTGR	modular high temperature gas reactor
MISTER	Mixed Stream Test Rig
MOU	memorandum of understanding
NDE	non-destructive examination
NEAC	Nuclear Energy Advisory Committee
NEI	Nuclear Energy Institute
NERAC	Nuclear Energy Research Advisory Committee
NERI	Nuclear Energy Research Initiative
NEUP	Nuclear Energy University Program
NGCC	natural gas combined cycle
NGNP	Next Generation Nuclear Plant
NHI	Nuclear Hydrogen Initiative

NHSS	Nuclear Heat Supply System
NL	normal liters
NPR	New Production Reactor
NQA	National Quality Assurance
NRC	Nuclear Regulatory Commission
NRO	Office of New Reactors
OPyC	outer pyrolytic carbon
ORNL	Oak Ridge National Laboratory
PASSC	plant, area, systems, subsystem or structures, and/or components
PBMR	Pebble Bed Modular Reactor (Pty) Limited
PBR	pebble bed reactor
PRD	program requirements documents
PDRD	plant design requirements document
PIE	post-irradiation examination
PIRT	phenomena identification and ranking table
PRA	probabilistic risk assessment
PSID	preliminary safety information document
PSQ	purchaser and supplier quality
PyC	pyrolytic carbon
QA	quality assurance
QAP	Quality Assurance Program
QAPD	Quality Assurance Program Description
QAPP	Quality Assurance Program Plan
R&D	research and development
RAI	Request for Additional Information
RCCS	reactor cavity cooling system
RGA	Regulatory Gap Analysis
RMP	Risk Management Plan
RMS	Risk Management System
ROT	reactor outlet temperature
SAG	Senior Advisory Group
SAFDL	Specified Acceptable Fuel Design Limits
SAGD	steam assisted gravity drainage
SC-MHR	Steam Cycle Modular Helium Reactor

SECY	commission papers written by NRC
S-I	sulfur-iodine
SiC	silicon carbide
SNL	Sandia National Laboratories
SPECTR	small pressure cycling test rig
SSBD	Safeguards and Security by Design
SSC	structure, system, and component
STD	Standard
TDO	Technology Development Office
TDRM	technology development roadmap
TEV	technical evaluation
TGA	thermal gravimetric analysis
TRISO	tristructural-isotropic
TRL	technology readiness level
TRP	technical procedure
V&V	verification and validation
VHTR	Very High Temperature Reactor
WBS	work breakdown structure

NGNP Project
2011 Status and Path Forward

1. INTRODUCTION

1.1 Purpose

The purpose of this report is to provide a snapshot of the current status of the Next Generation Nuclear Plant (NGNP) Project by describing (1) what has been accomplished by the Project to the time of this writing, and (2) what needs to be accomplished to enable timely future commercialization of high temperature gas-cooled reactor (HTGR) technology.

Following a review by the Nuclear Energy Advisory Committee (NEAC) of NGNP Project Phase 1 activities,[c] the Secretary of Energy informed Congress in his letter of October 17, 2011 to selected members that "… the Department will not proceed with the Phase 2 design activities at this time. The Project will continue to focus on high temperature reactor research and development activities, interactions with the Nuclear Regulatory Commission to develop a licensing framework, and establishment of a public-private partnership until conditions warrant a change in direction." No conditions or schedule for the change in direction were included in this letter.

Because the Secretary's report does not include conditions nor provide a schedule for entering into Phase 2, there is uncertainty about if and when the Project may enter into that phase. Current Idaho National Laboratory (INL) Project management has assumed that there is a reasonable likelihood that even if the Department of Energy (DOE) does not continue the NGNP Project, another entity, either in concert with or independent of DOE, may continue to develop and deploy the HTGR technology. This assumption is based on the benefits of the HTGR technology in addressing energy supply issues and the significant interest that has been expressed in the technology by national and international potential end users of the technology. Accordingly, the objective of this report is to provide a baseline from which future development and deployment of the HTGR technology can progress. This baseline is derived as a result of considerable development work completed by the NGNP Project at the time of this writing and insights of the NGNP Project on the work that is needed to complete technology development, design, and licensing to commercialize the technology.

1.2 Report Scope

Several development and deployment elements must be successfully completed to commercialize the HTGR technology. The following describes these elements in the context of establishing the baseline to support future work and the scope and organization of this report:

- **Section 2.0—Technology Development**

  Confirming the fundamental functional performance and safety characteristics of the HTGR technology.[d] The functionality, performance and safety of the technology are based on thermal, hydraulic, neutronic and structural properties and configurations of the ceramic fuel, the graphite core, the helium coolant, the core internal structures, the plant support systems, and the helium pressure boundary that make up the nuclear heat supply system. The Very High Temperature Reactor (VHTR) Technology Development Office (TDO) is completing the research and development (R&D)

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c See Appendix C for a review of the support the NGNP Project provided to NEAC for this review and a summary of the NEAC conclusions and recommendations of this review

d Appendix A provides a description of the HTGR technology and its safety basis.

necessary to confirm that the fundamental properties of these components and structures are acceptable to support performance of the technology as a viable energy source within its safety basis.

- **Section 3.0—Engineering**

  Developing the NGNP demonstration plant design. The engineering process develops the physical configuration of the plant structures, systems, and components (SSCs), applying industry codes and standards and the fundamental properties confirmed by the TDO to meet specific functional and performance requirements consistent with end user energy needs. In this process, multiple engineering trade studies are performed to optimize the designs of SSCs within performance, reliability, safety, and economic criteria. New and innovative technologies are also developed and proved to support the evolution of this new technology. Finally, the engineering process establishes and manages objectives on Project technical risk, cost, and schedule.

  The NGNP Project has not performed any plant design work since April 2009 by direction of the DOE and none is planned under the continuing work scope defined by the Secretary's letter of October 17, 2011. NGNP Project Engineering has performed many trade studies, application studies and end user evaluations to support development of functional and performance requirements for the plant. This work forms part of the baseline for future completion of the plant design.

- **Section 4.0—Licensing**

  Obtaining a license from the Nuclear Regulatory Commission (NRC) for the construction and operation of the demonstration plant. The HTGR nuclear plant will be licensed for construction and operation by the NRC. The traditional NRC licensing regulations have evolved from the significant experience in U.S. licensing of light water reactor (LWR) technology. Not all elements of the current regulations apply to the HTGR technology and certain policies have been established in licensing the LWRs that need to be realigned for the HTGR technology. A strategy for licensing the HTGR technology was developed in a cooperative effort of the DOE and the NRC. NGNP Regulatory Affairs has developed and is implementing a plan consistent with that strategy to ultimately license the NGNP demonstration plant.

- **Section 5.0—Application of HTGR Technology to Industrial Applications**

  Confirming technical and economic viability of applying and integrating HTGR technology with industrial applications. It is necessary to develop confidence that HTGR technology can be an effective substitute for traditional energy supplies in a wide range of industrial applications. The EPAct focused on using the high temperature capabilities of the HTGR technology to produce hydrogen and generate electricity. However, NGNP Engineering evaluations have determined that this technology has technical and economic benefits by application to a much broader range of industrial processes. This is an important conclusion in identifying and promoting markets for the technology.

  Within this effort the interactions with potential end users and technical evaluations of specific applications has supported development of the functional and performance requirements for the HTGR demonstration plant.

- **Section 6.0—Potential Market and Economics for HTGR Application**

  Assessing potential market size and character. There must be a viable, identified market for the HTGR technology to justify industry investing in commercializing this technology. NGNP Engineering evaluations have concluded that there is a large potential market. The formation and continuing activities of the NGNP Industry Alliance, Ltd., which includes several potential end users of the technology, is also confirmation of this market.

- **Section 7.0—Quality Assurance**

  Assuring quality of work to support design and licensing activities. The INL Quality Assurance Department has developed and implemented necessary quality assurance plans and procedures to meet provisions of National Quality Assurance (NQA)-1. This program will continue to support ongoing activities under the R&D Program.

- **Section 8.0—Development and Deployment of HTGR Technology**

  Developing a viable public-private partnership to support commercialization of the HTGR technology. The history of NGNP Project development, DOE actions, and the formation and activities of the NGNP Industry Alliance, Ltd., collectively provide insights into the elements required to achieve a viable public-private partnership or other entity to continue the development and deployment of the HTGR technology to commercialization.

The following appendices supplement the discussions contained in sections of this report and cover other salient topics:

Appendix A—Summary Description of the HTGR Technology and Safety Basis

Appendix B—Key Provisions of the EPAct and the Status of Meeting these Provisions

Appendix C—Support of the NEAC Review of the NGNP Project

Appendix D—Technology Development Status and Path Forward

Appendix E—Engineering Status and Path Forward

Appendix F—Licensing Status and Path Forward

Appendix G—Quality Assurance Status and Path Forward

Appendix H—Engineering Studies

Appendix I—Integrated Schedule—Level 5

Appendix J—NRC HTGR Technology Training Syllabus

Appendix K—R&D Program Organization and Workscope.

1.3 NGNP Project Documentation and Records

Sections 1 through 8 of this report contain listings of NGNP Project documents that pertain to the discussions in each of these sections; the appendices include references to similar documentation. These documents have been posted to the NGNP Public Web page at https://inlportal.inl.gov/vhtrinformation and/or the DOE Public Web page at www.osti.gov and are accessible to the public without controls.

The NGNP Official records and implementing documents are held in the INL Electronic Document Management System, a NQA-1 approved electronic vault. All records/documents are organized/categorized with a National Archives and Records Administration approved uniform file code and disposition description. NGNP meets NQA-1 20008/9a and NRC requirements by following PLN-2825, "Preliminary Project Execution Plan for Next Generation Nuclear Plant, PLN-1485, "NGNP Records Management Plan," PLN-2021, "Quality Assurance Program Plan for the Next Generation Nuclear Plant Project," and MCP-3055, "NGNP Records Management Procedure."

1.4 Background

The NGNP Project was established as a result of a DOE Generation IV R&D evaluation completed in 2003 to integrate HTGR technology with advanced hydrogen, electricity, and process heat production capabilities. The Project was authorized by the *Energy Policy Act of 2005* (EPAct)[e] and initiated at INL in 2006. The HTGR technology selected for development by the NGNP Project comprises a ceramic fuel design, a graphite based core and helium coolant with a reactor outlet temperature capability up to 950°C. At Project inception, the HTGR was anticipated to fuel the hydrogen economy, giving the United States an advanced energy solution that would reduce its carbon emissions and dependence on foreign fossil fuels. The work accomplished by the Project thus far, coupled with global changes in the energy sector, reveal that the benefits of this technology can be realized over a broader range of industrial applications than just hydrogen production; extending into market sectors not currently served by nuclear power.

The overall objective of the NGNP Project is to enable commercialization of HTGR technology. This technology can broaden the environmental and economic benefits of nuclear energy to the United States and other economies by demonstrating its applicability to the market sectors (e.g., industrial and transportation) not currently served by nuclear energy (the current fleet of LWRs is used almost exclusively for the generation of electricity). The industrial and transportation sectors typically use fossil fuels to fulfill their energy needs. HTGRs can be used in place of fossil fuels, thereby (1) reducing or eliminating the greenhouse gas emissions from these fuels, (2) providing a long term secure and independent energy source, and (3) insulating the end-user from the economic challenges associated with the volatility in the price of fossil fuels. HTGR technology substantially improves the safety of nuclear energy and permits close collocation with industrial processes, providing flexibility and efficiency in its application.

The NGNP Project's scope has included completing the R&D necessary to confirm the performance of key nuclear core constituents (e.g., fuel, graphite, high temperature metals), developing key technologies (e.g., heat transport system, hydrogen generation), and establishing a licensing framework that will support NRC review and approval of the license application. This effort has supported plant engineering studies and pre-application licensing work with the NRC to begin revising regulation that has evolved through licensing of LWRs to be applicable to HTGRs. The ultimate objective of the NGNP Project has been to design, license, construct, and operate a full-scale demonstration HTGR plant and associated technologies, supplying energy to an industrial application. Achieving that objective would establish the technological and licensing basis for expanded commercial applications and develop the infrastructure necessary for the commercialization of this new generation of advanced nuclear plants.

The 2005 EPAct set an objective of having the NGNP demonstration plant operational by 2021. This schedule will not be met now because of delays in achieving the goals of Phase 1 of the program as defined by the EPAct, resulting primarily from failures to adequately fund the Project at a level that could support this schedule, initiate design development in a timely manner, and implement a public-private partnership to manage and share the costs of the Project to completion. It is not possible to estimate a schedule for future deployment of a demonstration plant at the time of this writing because of the action by the Secretary to reduce the ongoing scope of work.

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[e] See Appendix B for a brief summary of key provisions of the EPAct and specific work completed by the NGNP Project to complete certain of these provisions.

2. TECHNOLOGY DEVELOPMENT STATUS AND PATH FORWARD

(Confirming the fundamental functional, performance, and safety characteristics of the technology)

At the inception of the NGNP Project, experts from DOE national laboratories, gas reactor vendors, and universities collaborated to establish technology R&D roadmaps. These roadmaps outlined the testing and computational development activities needed to qualify the materials and validate the modeling and simulation tools to be used in the design of the NGNP HTGR demonstration plant. The technology development roadmaps (TDRMs) draw on world-wide experience gained from the six demonstration and/or prototype HTGRs that have been built and operated over the past 60 years. The roadmaps include detailed descriptions of the required technical activities with associated schedules and budgets for completion of the project and form the baseline for execution of the R&D needed for the NGNP Project. 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 the DOE via the Generation IV International Forum. The R&D activities are organized into five major technical areas: fuel development and qualification, graphite qualification, high temperature materials qualification, design and safety methods validation, and hydrogen production. The objectives of each area, current status, accomplishments to date, and future plans are summarized below.

Appendix D provides more detailed discussions on each of these programs. Appendix K summarizes ongoing R&D work scope, schedule, and cost estimates under the R&D Program managed by the INL VHTR TDO. This work scope is consistent with the Secretary of Energy's October 17, 2011 letter to Congress and is considered the minimum required to preserve the significant investment made in R&D to-date and to continue some progress toward completing this program in support of commercializing the HTGR technology.

2.1 Fuel Development and Qualification

The objective of the Advanced Gas Reactor (AGR) Fuel Development and Qualification Program is to qualify tristructural-isotropic (TRISO)-coated particle fuel for use in the HTGR being designed and licensed by the NGNP project. TRISO-coated particles must be fabricated at industrial scale, as opposed to small batches in a laboratory, for use in qualification testing. The testing consists of a variety of experiments and examinations that will enable an understanding of the behavior of TRISO-coated fuel under the radiation and temperature environment expected in an HTGR. The program also contains experiments to provide an understanding of how the fission products—the elements produced when uranium fissions—are retained by or transported through the coated fuel particles and the graphite matrix that comprise the reactor core (the quantity of fission products released to the environment after passing through all barriers to release is called the *source term*). Another important part of the program is the development of fuel performance and source term modeling and simulation computer tools and the associated physical testing to validate those tools for use in the NGNP design and safety analysis.

At its inception, the AGR Fuel Development and Qualification Program had to reestablish the capability to fabricate and characterize TRISO-coated particle fuel in the United States after about a decade long hiatus. Many of the characterization procedures and associated equipment used in the past were still available but needed to be modernized to take advantage of current measurement technology. New procedures and personnel have to be qualified to meet NQA-1 requirements. In some cases (e.g., pyrolytic carbon layer [PyC] anisotropy) new, more accurate and repeatable measurement methods were developed. The result has been more controlled and reproducible fabrication and much more accurate and precise characterization of this fuel form. The population standard deviations of coating layer thicknesses from the lab and engineering scale coaters (AGR-1 and AGR-2) are smaller than historical U.S., German, and Japanese data. The smaller standard deviation of the AGR fuel demonstrates tighter process control associated with chemical vapor deposition and enhanced characterization techniques that provide greater precision to the measurements. Systematic fabrication studies, combined with improved characterization capabilities, have also enhanced the understanding of how to fabricate high-quality TRISO fuel. The program is now fabricating high quality TRISO-coated fuel particles in an engineering-scale coater that exhibit a historically low rate of about one defect in every 100,000 particles because of flawed coatings (SiC [silicon carbide] or inner pyrolytic carbon [IPyC]) or exposed uranium. Placing a U.S. fuel vendor in position to fabricate high-quality TRISO fuel with an improved fundamental understanding of the relationships between the fuel fabrication process, fuel properties, and fuel performance enhances credibility with the NRC with respect to the safety approach for modular HTGRs.

The first irradiation test, AGR-1, recently ended after approximately 3 years of irradiation. The fuel in AGR-1, composed of a reference fuel and three fuel variants having different IPyC or SiC coating properties, was irradiated to a peak burnup of 19% FIMA (fissions per initial heavy metal atom) a peak fast-neutron fluence of about 4.5×10^{25} n/m^2, and a maximum time-averaged fuel temperature of less than 1,250°C. About 300,000 TRISO fuel particles were irradiated without a single particle failure, as indicated by fission-gas measurements on the purge gas from each of the capsules. This is the best irradiation performance of a large quantity of TRISO fuel ever achieved in the United States, exceeding previous levels of burnup by almost a factor of 2. These results provide a high level of confidence that the AGR fuel program will successfully demonstrate the superior performance capability of TRISO fuel required by the modular HTGR concept. Post-irradiation examination (PIE) of fuel irradiated in AGR-1 is underway and safety testing began in FY 2011.

The second irradiation, AGR-2, is underway. It contains both UCO and UO_2 TRISO produced at lab, engineering and production scale from U.S. and international collaborators (France/AREVA and South Africa/Pebble Bed Modular Reactor [PBMR]). The UCO will be irradiated under prototypical prismatic core conditions while the UO_2 TRISO will experience conditions typical of a pebble-bed HTGR. The third irradiation, AGR 3/4, is being assembled, and the start of irradiation is scheduled for the first quarter of FY 2012.

The AGR program has been extremely successful to date. Three key programmatic goals are: (1) develop and qualify a domestic vendor capable of fabricating HTGR TRISO fuel, (2) qualify the TRISO fuel, and (3) develop and qualify the source term used in HTGR safety analysis.

The key remaining activities that are necessary to meet these programmatic goals are:

- Development of U.S. vendor (90% complete as of this writing):
  - Complete final fuel fabrication activities to develop and qualify a pilot line fuel fabrication capability that can be used (in replicate) to produce the first core of NGNP
  - Complete fabrication of qualification test fuel.
- Qualify TRISO fuel (50% complete as of this writing):
  - Complete AGR-1 safety testing and PIE to confirm robustness of TRISO fuel under accident conditions
  - Complete AGR-2 irradiation of industrially fabricated UCO and UO_2 TRISO fuel
  - Complete AGR-2 safety testing and PIE
  - Complete development of a test furnace to evaluate moisture and air ingress effects on fuel under accident conditions
  - Complete irradiation and accident safety testing in the AGR 5/6/7 campaign (including margin testing in AGR-7).

- Develop and Qualify Source Term (25% complete as of this writing):
  - Complete AGR-3/4 irradiation, safety testing and PIE to demonstrate fission product retentiveness of graphite and fuel matrix materials, and update database on fission product transport rates in HTGRs to support source term evaluations
  - Complete fission product generation and transport model validation irradiation and safety testing in AGR-8
  - Complete plateout and liftoff studies to support fission product transport evaluations in the primary system and reactor building
  - Complete tritium permeation testing for potential intermediate heat exchanger alloy systems.

Beyond the AGR program, once preliminary design activities near completion, there is a need to re-evaluate the fuel acquisition strategy and the specific test conditions being used in the program to ensure they meet the needs of the design and the deployment strategy for meeting the Project objectives.

2.2 Graphite Development and Qualification

The objective of the graphite program is to develop the qualification data set of thermomechanical and thermophysical properties for unirradiated and irradiated candidate grades of graphite for HTGRs. Four major graphite grades, suitable for use within both pebble bed and prismatic HTGR designs, have been selected for further evaluation. These include NBG-18 (SGL in Europe), PCEA (GrafTech Inc. in the U.S.), IG-110 (Toyo Tanso in Japan), and 2114 (Mersen, formerly known as Carbonne Lorraine, in the U.S.). Historical samples and minor grades such as PGX, HLM, PCIB, and NBG-17 have also been incorporated into the program to help further elucidate the impact of fabrication processes and coke sources on the resulting microstructure of the graphite and its performance under irradiation. The planned activities will demonstrate the performance of various graphite types under bounding conditions, including irradiation dose levels, anticipated applied stress levels, and maximum core temperatures.

The program consists of statistical characterization of unirradiated graphite material properties to establish the lot-to-lot, billet-to-billet, and within-billet variability of the material. This characterization will establish a quantitative baseline of material properties from which changes under irradiation can be understood. Significant effort has gone into establishing the analytical measurement laboratories required to perform the extensive characterization of nuclear graphite under consideration for HTGRs being developed by the NGNP project. This task consisted of procuring, setting up, and calibrating state-of-the-art analytical testing equipment and developing protocols and testing methods to make accurate, repeatable measurements on graphite. An extensive characterization effort is currently underway at the Idaho and Oak Ridge National Laboratories to establish the material properties before irradiation on a series of large graphite billets for the four major grades selected.

As of this writing, the baseline statistical characterization of the thermomechanical and thermophysical properties of one large billet of one of the major graphite grades is complete and characterization for a billet of a second grade is underway. Characterization of 425 samples in both Advanced Graphite Creep (AGC) experiments AGC-1 and AGC-2 prior to irradiation is also complete. Irradiation of AGC-1 is complete, and irradiation of AGC-2 has just begun. PIE of the AGC-1 graphite samples has just started. Other important accomplishments were as follows:

- Completed extensive studies on graphite-air oxidation to better understand mechanisms of oxidation as a function of temperature, microstructure, and air concentration. These studies addressed chronic oxidation concerns and supported accident safety evaluations.

- Evaluated advanced failure models for graphite based on measurements of graphite in complex combinations of potential multiaxial stress states.

- Developed and issued a new graphite core component design and construction code that was approved by the American Society of Mechanical Engineers (ASME) on November 1, 2011 as part of the new ASME Boiler and Pressure Vessel (BPV) Code Section III, Division 5.

- Initiated a comprehensive nondestructive examination program to address both the flaws in as-fabricated large graphite components as well as to develop new in situ inspection techniques. These will be important to monitoring of the actual behavior of the core components in the reactor.

- Initiated fundamental studies through the Nuclear Energy University Program (NEUP) and international collaborations such as the International Atomic Energy Agency to better understand the damage mechanisms and behavior of graphite under irradiation. This will yield an improved understanding of the fundamental principles underlying the behavior of graphite, enabling the development of sophisticated analytical models to better predict graphite behavior while in service.

The key remaining activities necessary to qualify graphite for use in NGNP are as follows:

- Complete post-irradiation characterization of low-temperature graphite samples from AGC-1 and 2 capsules
- Complete medium and high temperature irradiations (AGC-3, 4, and 5) and associated post-irradiation characterization
- Complete oxidation and nondestructive examination studies for graphite
- Complete modeling activities to improve fundamental understanding of graphite.

2.3 High Temperature Materials Qualification

The high outlet temperature of an HTGR requires development of high-performance metallic alloys for prolonged use in core and plant components at elevated temperatures. The goal of high temperature materials R&D is to obtain performance data required to support the development of these high temperature components and associated design codes over the broad range of HTGR applications (e.g., cogeneration of steam and electricity at lower temperatures [750 to 800°C] and hydrogen production and hot gas delivery at higher temperatures [850 to 950°C]). A number of solid-solution-strengthened, nickel-based alloys have been considered for application in heat exchangers and core internals for an HTGR. The primary candidates are Alloy 617, Haynes 230, Alloy 800H, and Hastelloy X. Of these alloys, only Alloy 800H is currently approved for high temperature design in the ASME Code and only up to 760°C. At temperatures higher than 750°C, the specific wear and failure mechanisms change and the number of potential alloys decreases.

Based on technical maturity, availability in required product forms, experience base, and mechanical properties at elevated temperatures, all of the NGNP pre-conceptual design studies have specified Alloy 617 as the material of choice for heat exchangers. An ASME code case for Alloy 617 has been drafted but not yet approved. Nonetheless, the draft code case provides a significant head start for achieving material codification. Similarly, Alloy 800H, which is already listed in the nuclear section of the ASME code, is the material of choice for control rod sleeves, albeit with limits on the maximum use temperature and exposure. For steam generation, Alloy 800 H is the preferred alloy because of experience with previous HTGR steam generators and its inclusion in the ASME code. Alloy 800 H and Hastelloy X are potential options for internal core metallics such as the core barrel and core support structure.

Recent accomplishments include:

- Establishment of an acquisition strategy for the large metallic components.

- Assessment of major alloy grades and the availability of large metallic components. It was determined that there will be few issues associated with required product forms of the alloys under study.
- Procurement of production-grade quantities of candidate high temperature alloys. State-of-the-art mechanical and environmental testing of the candidate high temperature metallic alloys is underway to understand the mechanical behavior at high temperatures and ensure that the material does not degrade after long-term exposure to low levels of moisture and other constituents anticipated in the HTGR operating environment.
- Extensive development of traditional testing equipment and associated experimental procedures to achieve the expected conditions and obtain the accuracy and repeatability needed to qualify the alloys. 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. A detailed characterization of each alloy is performed after each test to understand the underlying behavior at the microscopic scale that contributes to the measured mechanical behavior of the metal.
- Development of and testing with a low-velocity flow loop to evaluate the effects of low concentrations of impurities in helium on Ni-based alloys. Results indicate that a slightly oxidizing chemistry results in maximum component life.

Recent testing on the creep behavior of Alloy 617 indicates that the majority of the alloy's life will be spent in the tertiary creep regime, not in primary and secondary creep. ASME design rules written for typical stainless-steel behavior must be modified to account for these behaviors in Alloy 617, or unrealistic lifetime predictions will severely limit design life. Creep-fatigue of base metal and weldments is the degradation mechanism of primary concern. Current mechanical testing experiments focus on determining the effect of tensile hold time on cycles-to-failure and properly summing combined effects of creep and fatigue for lifetime prediction.

The key remaining activities that are required to complete the high temperature materials program include:

- Creep testing is needed to continue to support codification of Inconel 617 and extension of alloy 800H in the ASME design code.
- Creep-fatigue testing at 850ºC is required for codification of Inconel 617. Continuing investigation of the influence of a VHTR helium environment on the creep-fatigue behavior of Inconel 617 is also necessary.
- Theoretical work on the development of the proper type of constitutive relations and design rules to capture the behavior that is being measured in the laboratory must be completed.
- Mechanical testing including fracture toughness and tensile testing of thermally aged Inconel 617 and welded Inconel 617 material is needed for the development of a unified constitutive model and to determine strength reduction factors for ASME codification.
- Mechanical property testing of a second heat of Inconel 617 is necessary for selected properties, particularly to address the impact of thermal aging.
- Fracture toughness, tensile, creep, charpy impact, and cyclic testing of A508/A533 RPV is in the process of being completed to support code case N499 (extension to higher temperatures).
- Inspection techniques and technologies need to be established as the design configuration is developed for the NGNP demonstration plant.

By the end of FY 2012, all of the testing needed to allow design using SA508/533 for normal operation of a HTGR for 60 years will be completed. In addition, all of the data needed to extend the code case for Alloy 800H will be available in FY 2012. For Alloy 617, testing will need to continue until 2015 before all of the data necessary for codification are available.

2.4 Design and Safety Methods

The design and safety methods program focuses on the development and validation of tools to assess the neutronic and thermal fluid behavior of the plant. An important activity in designing and licensing an HTGR is to confirm that the intended analysis tools are validated and cover the anticipated operating envelope such that they can be used with confidence to ensure that all reactor systems are safe and will meet performance objectives.

Thermal, neutronic, and fluid analysis codes have not been validated for HTGR safety analysis and may not capture the range of safety significant neutronic and thermal fluid phenomena characteristic of the HTGR technology. The Methods program is therefore executing a series of fluid and heat transfer experiments designed to investigate these phenomena and to provide data for the validation of analysis tools. The program is also engaged in the development of new physics analysis methods that account for the heterogeneous core and fuel designs and the nature of radiation transport in graphite-moderated reactors.

Accomplishments to date include:

- Completion of a series of benchmarks of core simulation tools for the pebble-bed reactor and initiation of a comparable benchmark series for prismatic reactors. The benchmarks will enable the testing and evaluation of analysis tools under development by NRC, DOE, and vendors.
- Simulation of pebble bed reactor fuel cycles using the INL's PEBBED code. This simulation involves a complex coupling of neutronics, fuel shuffling and burnup, spectrum analysis, and thermal fluid modules that yield steady-state core profiles (power, temperature, isotopics) for a recirculating pebble bed reactor.
- Simulation of transients in pebble bed reactors with the plant thermal-hydraulic simulator RELAP and the neutron kinetics code CYNOD. This provides the ability to couple process heat plant dynamics (using established codes such as ASPEN and HYSIS) to a pebble bed core simulation.
- Development and demonstration of a new nodal neutron diffusion solver for prismatic VHTRs.
- Development of a high fidelity simulation tool (PRONGHORN) to investigate complex, safety-significant phenomena (e.g., heat transfer at the core-reflector boundary in a pebble bed) not captured adequately by existing tools.
- Design and execution of large-scale integral experiments to provide safety-related data that will be used independently to validate performance and evaluations models used by vendors and the NRC. This is a joint development effort with the NRC that prevents the duplication of costly experiments by DOE and the regulator. The two major experiments being constructed today are (1) the High Temperature Test Facility (HTTF), an integral in-vessel experiment at Oregon State University to study various loss of core cooling scenarios, and (2), the Natural Circulation Shutdown test Facility at Argonne National Laboratory, designed to investigate ex-core heat removal phenomena and performance. Scaling studies are underway to properly define the experiments to be used in these facilities.
- Application of uncertainty software (SUSA) to systematically evaluate the uncertainties in predictions of peak fuel temperature under depressurized loss of forced cooling transients in a pebble bed VHTR using the PEBBED-THERMIX codes.

- Completion of the first series of experiments investigating lower plenum coolant flow and the two-component exchange flow that simulates replacement of helium in the pressure vessel with air after a breach in the primary coolant system. The flow of helium around prismatic reactor fuel blocks (so called "bypass flow") has also been investigated experimentally in Korea through collaboration with Seoul National University.
- Initiation of a joint collaboration with the Japanese gas reactor team to obtain unique operational data from their operating high temperature test reactor (the HTTR) to further validate core and plant simulation tools. Assessments are currently underway to technically evaluate other international technical capabilities that can be used to provide relevant safety data (e.g., at the HTR-10—the 10-MW pebble bed reactor in China and the SANA heat transfer and NACOK air ingress integral facilities in Germany).

The key activities necessary to complete and qualify the Evaluation Models for use in NGNP include:

- Complete the design and execution of the small separate effects tests performed largely at universities under the DOE NEUP to validate the computer codes used to simulate the HTGR.
- Complete the design and execution of the two large integral experiments (the HTTR and the RCCS simulation at Argonne National Laboratory needed to validate the computer codes used to simulate the HTGR.
- Complete bypass flow experiments and associated computational fluid dynamics modeling.
- Complete model to evaluate air and/or water ingress in HTGRs
- Obtain unique operational data from HTTR and HTR-10 to support validation of HTGR code and plant simulation tools.
- Develop higher order high fidelity simulations (e.g. using PRONGHORN) running on supercomputers to investigate complex behavior and confirm the results of low order simulations.
- Test the low order core simulation tools used for design (e.g., PEBBED-THERMIX, TINTE, GASNET, RELAP), system response (e.g. MELCOR) and sensitivity studies (e.g., SUSA) against benchmarks and higher order simulations.
- Characterize the uncertainty in all of these simulations.

2.5 Hydrogen Production

Carbon emissions-free production of hydrogen can potentially play a key role in decreasing future petroleum imports, relieving the pressure on U.S. natural gas supplies, and reducing emissions from transportation fuels. Beyond the need for process heat, hydrogen is a vital feedstock in the production of ammonia, upgrading low-grade petroleum and the production of synthetic transportation fuels.

High Temperature Electrolysis (HTE) is an efficient and modular method for producing hydrogen. HTE was recently selected by DOE as the hydrogen generation technology of choice after it was recommended by an independent review team for use with the HTGR plant based on its maturity. The review team also recommended that HTE R&D (1) Refine the understanding of cell/stack degradation modes and mechanisms, and (2) Demonstrate pressurized cell/stack operation at a laboratory scale." The report also recommended evaluation of other alternative cell and stack designs. The NGNP Project will complete laboratory testing through FY 2012 with the objective of identifying the mechanisms of cell degradation and the work required to obtain acceptable cell life. It is judged that the HTE technology will then be at a sufficient technology readiness level to transfer to the private sector for commercialization.

2.6 Pertinent Documentation

The following identifies Project documentation pertinent to the status and path forward requirements of NGNP Project Technology Development.

1. Jack Simonds, *Technical Program Plan for the Advanced Gas Reactor Fuel Development and Qualification Program*, PLN-3636, September 2010.
2. C. M. Barnes and J. D. Hunn, "Fabrication and Comparison of Fuels for Advanced Gas Reactor Tests," 5th International Topical Meeting on High Temperature Reactor Technology (HTR-2010), Prague, Czech Republic, October 18–20, 2010.
3. S. B. Grover, D. A. Petti, and J. T. Maki, "Mission and Status of the First Two Next Generation Nuclear Plant Fuel Irradiation Experiments in the Advanced Test Reactor," Proceedings of the 18th International Conference on Nuclear Engineering, Xi an China, May 17–21, 2010.
4. G. K. Miller, J. T. Maki, D. L. Knudson, and D. A. Petti, "Current Capabilities of the Fuel Performance Modeling Code PARFUME," Proceedings of the Conference on High Temperature Reactors, HTR-2004, Beijing, China, September 22–24, 2004.
5. D. Petti, T. Abram, B. Franklin, R. Hobbins, and J. Kendall, "Assessment of Next Generation Nuclear Plant (NGNP) Fuel Acquisition Strategies," INL/EXT-07-12441, Rev 1, October 2007.
6. T. Burchell, R. Bratton, W. Windes, "NGNP Graphite Selection and Acquisition Strategy, ORNL/TM-2007/153, September 2007.
7. PLN-2497, "Graphite Technology Development Plan," Rev 0, W. Windes, T. Burchell, R. Bratton, October 2007.
8. PLN-2804, "Next Generation Nuclear Plant Intermediate Heat Exchanger Materials Research and Development Plan," Idaho National Laboratory, April 2008.
9. PLN-2803, "Next Generation Nuclear Plant Reactor Pressure Vessel Materials Research and Development Plan," Rev. 1, Idaho National Laboratory, R. N. Wright, and J. K. Wright, 07/14/10.
10. R. E. Mizia, *Next Generation Nuclear Plant Intermediate Heat Exchanger Acquisition Strategy*, INL/EXT-08-14054, April 2008.
11. R. E. Mizia, *Next Generation Nuclear Plant Reactor Pressure Vessel Acquisition Strategy*, INL/EXT-08-13951, April 2008.
12. PLN-2498, "Next Generation Nuclear Plant Methods Technical Program Plan," Idaho National Laboratory, Rev 1, Schultz, R., et al., 9/24/08.
13. Varrin, R., et al., 2009, *NGNP Hydrogen Technology Down-Selection Results of the Independent Review Team (IRT) Evaluation*, R-6917-00-01, Rev. 0, July 31, 2009.

3. ENGINEERING STATUS AND PATH FORWARD

(Developing the NGNP demonstration plant design)

3.1 Engineering Activities and Responsibilities

NGNP Project Engineering activities were initiated in 2006 with preparation for initiating pre-conceptual design work in FY 2007 (e.g., preparation of a specification and RFP for that work). In FY 2007, engineering studies were completed to develop pre-conceptual designs of HTGR plants that generate electricity and hydrogen in accordance with provisions of the EPAct. This work was completed by three reactor supplier teams, led by AREVA, General Atomics (GA), and Westinghouse/PBMR Pty (Ltd). Designs were developed for both prismatic block reactors (AREVA, GA) and pebble bed reactors (Westinghouse). Separate engineering studies focused on defining functional and performance requirements, evaluating the pros and cons of alternatives, such as reactor type, rating, operating temperature and nuclear heat supply system configurations were also completed by these teams. The HTGR plant designs developed by the three teams covered thermal ratings over the range of 500 to 600 MW(t) and reactor outlet temperatures in the range of 900 to 950°C. Designs for hydrogen production using high temperature steam electrolysis, sulfur iodine, and hybrid sulfur processes were included. The teams also provided pre-conceptual estimates of the cost and schedule to complete the Project through the initial operating period of the demonstration plant and recommended additional studies to support technology selection and design development. These studies were prioritized and a number of them were completed by the reactor supplier teams in FY 2008 and 2009.

Interactions with a Senior Advisory Group, a subset of the NGNP Industry Alliance, and potential end users of the HTGR technology redirected the focus of the engineering effort to include a broader base of industrial applications than just electricity and hydrogen generation. These interactions also justified lowering the maximum outlet temperature objective for the first phase of HTGR plant development from 950 to 850°C. This was judged to be adequate to meet the needs of the majority of near term industrial applications and to have the beneficial result of significantly reducing technical risks associated with development of materials for operation at higher temperatures.

A comprehensive risk management plan was developed and implemented in FY 2008. Implementation of this plan was coordinated with the three supplier teams to identify the technical readiness of critical SSCs of the plant and develop TDRMs that define the effort needed to progress the technology readiness levels (TRLs) of these SSCs to the level appropriate for installation in the demonstration plant. Under this plan, the system requirements for the plant, design data needs, and the TDRMs have been collected and stored in a relational database to facilitate their use in future design and licensing work.

Support efforts were initiated to revise national codes and standards provisions for applicability to the HTGR technology. Two key milestones of this effort were publication of the new ASME BPV Code Section III, "Rules for Construction of Nuclear Facility Components," Division 5, "High Temperature Reactors" on November 1, 2011, and the approval in December 2011 of the new joint American National Standards Institute (ANSI) and American Nuclear Society (ANS) standard ANSI/ANS-53.1, "Nuclear Safety Design Process for Modular Helium-Cooled Reactor Plants."

Initial planning was completed for conceptual design of the NGNP demonstration plant, including development of the Work Breakdown Structure (WBS), cost, and schedule. This effort was completed by the three supplier teams early in FY 2009.

In April 2009, the NGNP Project was instructed by DOE to stop design-related work and commence closure of design-related subcontracts. DOE stated that this action was taken "to ensure that design work and other tasks related to deployment of a specific reactor technology are cost shared as required by the EPAct 2005." Nontechnology-specific studies, efforts related to R&D, and work on licensing related issues that addressed generic gas reactor regulatory issues were allowed to proceed.

As a result of this DOE action, NGNP Project Engineering work has been focused on completing engineering studies that support the development of functional and performance requirements of the NGNP demonstration plant, developing and refining the risk management program, supporting revisions of industrial codes and standards for application to the HTGR technology, evaluating technical and economic viability of applying the HTGR technology to multiple industrial applications, assisting in project planning, cost estimating, and scheduling, developing an integrated Project schedule, assessing the nature and size of the markets for the HTGR technology, and supporting development of high temperature heat transport system technologies (e.g., intermediate heat exchanger).

In summary, to the time of this writing NGNP Project Engineering has been responsible for:

- Managing and completing design activities and engineering trade studies that support the design process for the NGNP Demonstration plant, evaluation of industrial applications for HTGR technology and assessment of the potential market for HTGR energy
- Developing, documenting, and controlling plant system requirements, including overall plant functional and performance requirements
- Developing and controlling the Project WBS, integrated schedule, and estimates of costs to complete the Project
- Interfacing with potential end users to support development of the plant functional and performance requirements
- Developing technical risk management programs and systems including the identification and control of design data needs, characterization of the TRL of critical plant components, and developing TDRMs to advance the TRL of these components.

As cited previously, in October 2011, DOE decided not to proceed with Phase 2 design activities but to focus on high temperature reactor research and development activities, interactions with NRC to develop a licensing framework, and establishment of a public-private partnership. Accordingly, the NGNP Project is being reconfigured to an R&D Program with reduced scope. The reconfigured program does not include an Engineering organization and no design work is expected to be performed under this program. At the time of this writing, when design work will resume on the NGNP Demonstration plant is unknown.

3.2 Engineering Path Forward

Based on DOE direction, the Project has not done any plant design work since the end of FY 2007. Accordingly, an engineering path forward for a specific design cannot be provided. If design work for the demonstration plant is resumed, either under a public/private partnership or other entity, the design of that plant and its functional and performance requirements will be established by the owner and the energy needs of the specific application identified for the plant, thus establishing a path forward for engineering design work. However, the work completed by NGNP Project Engineering can provide a baseline and insights from which this design work can proceed.

The following specific areas have been addressed in this context (detailed discussions of these areas and references to supporting documentation are provided in Appendix E):

- *Comparison of the technical attributes of the high temperature gas-cooled reactor pebble bed and prismatic reactor concepts*. This comparison concludes that there are no technical differences in the two concepts that favor selection of one over the other. Further, it is the judgment of the NGNP Project that, throughout the design and licensing process, no differentiating technical factors will be identified that justify selection of one reactor design (pebble bed or prismatic) over the other. It is anticipated that selection of the reactor design will be made by the future owner of the plant based on the specifics of the application, the licensing basis requirements, and the business case.

- *Functional and Performance requirements meeting end user needs*. These were developed through comprehensive reviews, technical and economic evaluations of multiple industrial applications, and discussions with multiple potential end users and energy off-takers. These support a reduced maximum reactor operating temperature from 950 to 850°C and development of heat transport system configurations capable of supplying steam, electricity, and high-temperature gas to collocated industrial facilities.
- *Conceptual Design work plan development.* These are detailed works scopes developed by the three Supplier teams. They include detailed cost and schedules within the NGNP Project WBS (see following item). The actual conceptual design work was not initiated because of the decision by DOE to stop all design work in April 2009.
- *Work Breakdown Structure.* During pre-conceptual design scope, a WBS was developed for the NGNP Project that subdivided the HTGR plant into five major areas: (1) nuclear island, consisting primarily of the reactor and ancillary service systems; (2) heat transport system, consisting of both the primary and secondary heat transfer loops and intermediate heat exchanger (IHX) or steam generator; (3) power conversion system, consisting of the turbine generator system and associated steam, condensate, and feed systems; (4) balance-of-plant consisting of a number of plant-wide supply, distribution, waste, and auxiliary systems; and (5) hydrogen production system, consisting of the equipment directly associated with hydrogen production and storage. This WBS has been retained by the Project and used for detailed scheduling and for organizing systems requirements and design data needs.
- *System Requirements Manual and Database, including Design Data Needs.* The information contained in these documents has evolved over the life of the Project starting with the pre-conceptual design work in FY 2007. The information has been placed into a relational database (DOORS) that facilitates its use and updates as design work is initiated.
- *Risk Management Program.* This program has provided quantitative assessments of the schedule and cost risks for variations in plant operating conditions and configurations (e.g., reactor operating temperature, reactor rating, heat transport system configurations applying steam generator and/or IHX). Assessments of technology readiness and the development of TDRMs have covered multiple critical SSCs.
- *National Codes and Standards updates for HTGR technology.* The licensing and operation of the NGNP Project HTGR will require the advancement and completion of a number of National Standards and Consensus Codes. The ASME, ANS, and American Society for Testing and Materials International (ASTM) have all been supportive of the NGNP Project, and have been engaged by NGNP Engineering for the standards and codes advancement activities.
- *Large scale component test facility requirements and design.* The need for a capability to test NGNP reactor and heat transport system components at representative temperatures and pressures and in a relevant environment was identified during pre-conceptual design. Conceptual Designs for a testing facility and a draft of the Justification of Mission Need were developed during FY 2008 and FY 2009. The NGNP Project was notified by the DOE in March of 2010 that the Mission Need would not be submitted to the DOE Acquisition Executive and all related activity ceased. When HTGR deployment activities are re-initiated, the design and deployment of a large scale component test facility should be addressed with high priority to ensure its availability to meet schedule objectives.

- *Transport of radionuclides to end-user products* **.** The integration of nuclear power to industrial applications generates a concern regarding fission product transport to conventional processes and products during normal operations. A primary radionuclide of concern is tritium. A number of reviews and assessments of bounding requirements, contamination limits, and preventive measures have been documented, and a validated model of tritium transport throughout an HTGR plant has been developed (tritium permeation analyses code).
- *Nuclear island boundaries and scope of design certification.* The licensing of the HTGR by the NRC will require a distinct definition of boundaries among the HTGR nuclear facility, industrial facility, and related interface requirements. Ultimately, selected HTGR nuclear facility systems and interface requirements will be defined as part of a design certification process that will support deployment of follow-on HTGR plants under the 10 CFR Part 52 licensing process. A number of assessments and studies regarding HTGR plant configuration have resulted in the definition of an initial set of SSCs, interface requirements, and design information that will be included within the scope of an HTGR design certification.
- *Infrastructure development needs.* The deployment of the HTGR technology may be limited by weaknesses of the nuclear power industry to provide timely support. A detailed assessment of the nuclear industry's current infrastructure capabilities was performed to identify development needs and recommend improvements to support the deployment of the first reactor module for the NGNP Project.

The NGNP Project has managed a large number of engineering studies addressing key design issues that can inform future design activities. The study topics of primary interest include:

- Nuclear heat supply system boundaries, interfaces, and functional and operational requirements
- IHX and secondary heat transport loop alternatives
- Reactor pressure vessel and vessel system alternatives
- Power conversion system alternatives
- Steam cycle concept evaluation
- Reactor containment and building functions and embedment depth
- Contamination control and fission product transport
- High temperature materials
- Hydrogen plant alternatives
- Helium purification.

The NGNP Project has managed investigations into the technical and economic viability of applying the HTGR technology to multiple industrial processes. These include:

- Electricity generation
- Ammonia and ammonia derivatives production
- Hydrogen production
- Conversion of coal and natural gas to transportation fuels
- Recovery and upgrading of bitumen from oil sands
- Recovery and upgrading of oil from oil shale using in-situ and ex-situ processes
- Seawater desalination
- Coke and steel manufacturing.

Concepts have been developed for applying the HTGR technology to three specific sites providing energy to support collocated industrial plants and processes. This effort also included the development of detailed discounted cash flow models used to investigate the economic viability of these applications. The results of these efforts can be applied in the future when identifying and assessing potential applications for the demonstration plant.

Advancement of process heat transport technology has been accomplished through collaborative agreements with universities to engineer and test advanced compact heat exchanger designs. These designs would be applied in gas-to-gas or gas-to-other-fluids (e.g., liquid metals) for high temperature process heat applications (e.g., hydrogen production). Assessments of the potential markets for the HTGR technology show that the high temperature process heat market is substantial. The development of these advanced heat transport technologies should be continued to provide the means for early penetration of this market.

If the HTGR technology is to be designed and applied for higher temperatures and higher power ratings than currently planned for the NGNP Demonstration Plant, several areas must be addressed:

- *Materials.* At higher reactor outlet temperatures, ceramics or composite materials may be required for some of the core internals. There has been little work done on developing the necessary data for ASME and ASTM code case development or code revision for these materials. The materials selection for the vessel system material may need to be upgraded to a higher temperature alloy than SA508/533, which will require significant development of weld techniques, materials testing, and ASME code cases or code revisions. One alternative to using a higher temperature material is to redesign the reactor vessel configuration for active cooling sufficient to maintain the SA508/533 material in its design range. Higher temperatures will also require reassessing the viability of the heat transfer surface materials in the steam generator and the IHX. The ASME BPV Code allowables will need to be revised as required to include new materials at the appropriate operating conditions.
- *Circulators.* As required circulator capacity ratings increase, which may be necessary for higher power ratings of the HTGR, the circulators change from being essentially off-the-shelf equipment to items requiring substantial development. The alternative is to use parallel circulator configurations that will also require increased design effort.
- *Heat exchange equipment.* In addition to materials considerations, new configurations and materials joining methods may be required at higher operating temperatures.
- *Instrumentation and controls.* Higher temperatures may require development of new instrumentation rated for those temperatures.

3.3 Project Plan, Schedule, and Costs

3.3.1 Project Plan Status

Several project plans, schedules, and cost estimates have been developed to complete the NGNP Project since the initial one developed during pre-conceptual design work in FY 2007. Variations in the plans have reflected changes in the objectives of the Project (e.g., expanding the market for the HTGR technology beyond hydrogen and electricity generation), improved assessments of risks to technology development and Project completion, updates to cost estimates, and shifts in the direction of the Project because of DOE actions (e.g., stop design work in April 2009). The latest update of the program planning bases document was prepared in the first quarter of FY 2011 following a Project review of the progress in R&D and licensing and assessment of outstanding risks to Project completion. Table 1 and Figure 1 show the current estimated costs for completing the Project from FY 2012 if the Project were to continue as projected in this plan. Note that these cost estimates are what is required by the Project to complete work and does not include amounts set aside from appropriations for DOE Nuclear Energy University Programs, Small Business Innovation Research, etc. Figure 2 shows a schedule to complete the Project that was judged viable at this last update of the program plan. The dates have been removed from this schedule because of uncertainty in the future of the Project. The schedule does depict the relative relationships and durations of the Project activities judged to be necessary to complete development of the HTGR technology through operation of the demonstration plant.

Table 1. Current best estimate of cost to complete the NGNP Project.

Project Element (2011$ Costs to Complete Project 2012–2026)	Subtotals	Total Costs ($Millions)
Research and Development		550
Fuel Development and Qualification	200	
Graphite Development and Qualification	80	
High Temperature Materials Testing	95	
Methods Qualification	65	
Heat Transport Component Development	110	
Plant Design		580
Conceptual Design	100	
Preliminary Design	180	
Final Design	300	
Licensing		230
Pre-Application	30	
COL, Early Site Permit (ESP) and Permit Application Preparation	70	
COL, ESP and Permit Application Review	110	
Construction, Testing and Startup	20	
Procurement		1,080
Construction Labor		620
Startup and Testing		55
Initial Operations		415
Income During Initial Operations		-265
Partnership Management		90
Project Cost to Complete		3,355

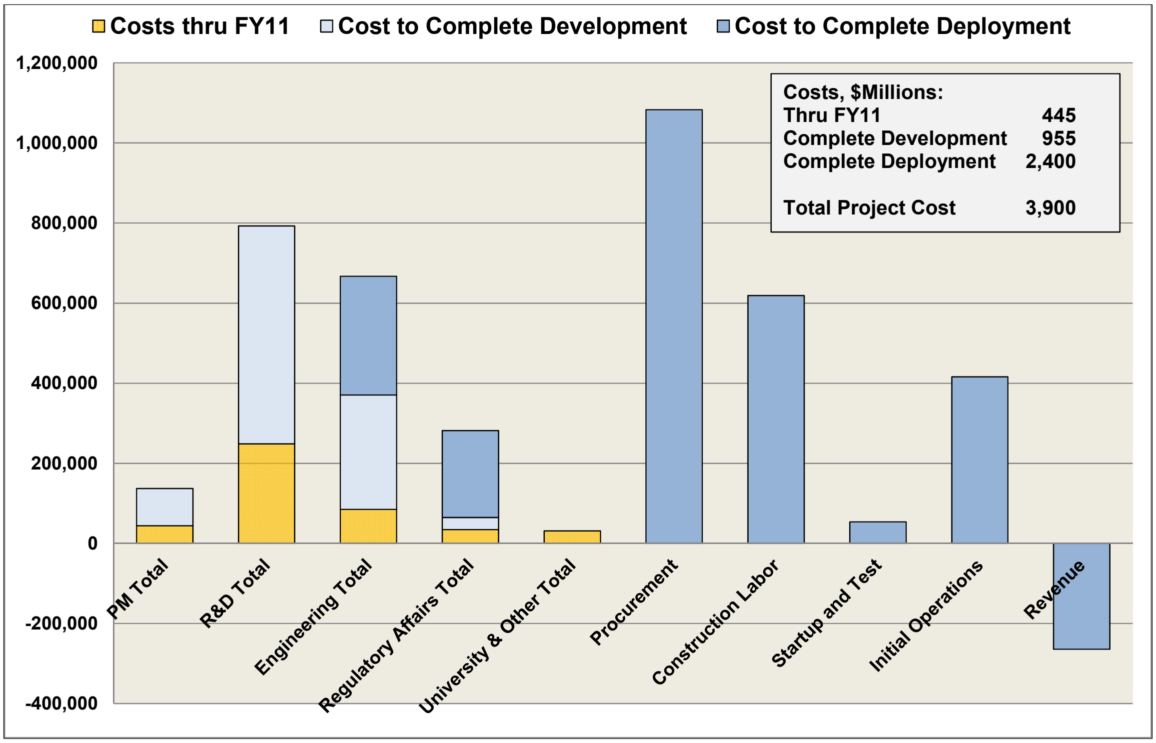

Figure 1. Summary of NGNP Project actual and projected costs through FY 2011.

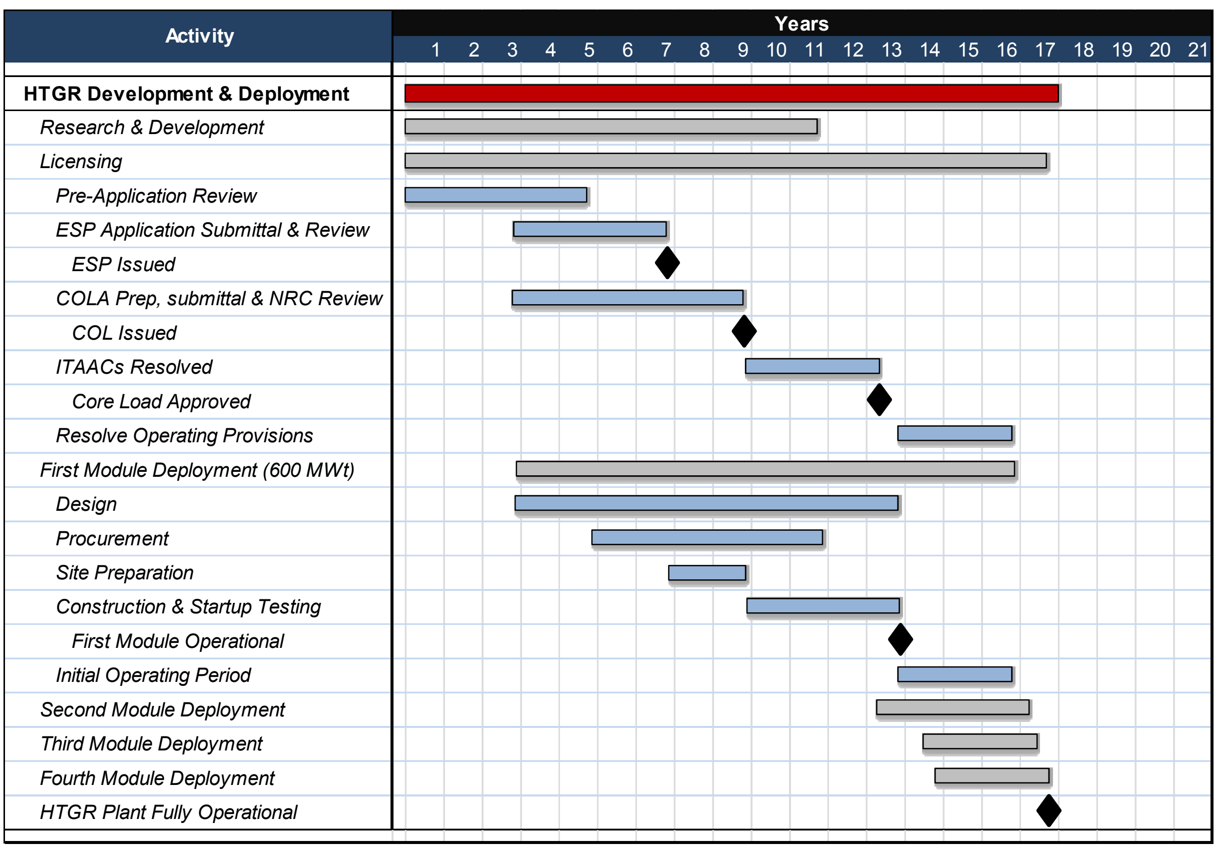

Figure 2. NGNP Project strategy schedule.

Figure 1 (above) shows the total Project costs summarized in three segments; costs expended through FY 2011, projected costs to complete development and projected costs to complete deployment. As shown, the development segment includes costs projected to complete R&D, Engineering through Preliminary Design and Licensing through the pre-application reviews with NRC. The deployment segment is that effort required to complete the initial operating period of the demonstration plant. This includes final design, licensing, procurement of equipment and materials, construction, startup and test, and initial operation. It is assumed that there will be a 3 year period of operation of the demonstration plant during which all open items with the NRC will be closed and the performance and reliability of the plant will be confirmed. This is assumed to entail special tests and inspections of key components of the plant. This adds cost to the operation of the plant and reduces its capacity factor over the initial operating period. However, since the plant will be commercially operated, revenue will be generated offsetting costs.

3.4 Development of Integrated Schedule

The development of an integrated planning schedule commenced in 2007 as part of the pre-conceptual design effort. In addition to developing an overall project schedule that supported a reactor deployment meeting 2005 EPAct requirements and other project goals, this integrated schedule combined planning schedules developed independently by each of the NGNP Project functional areas into a single schedule with appropriate logic ties that identify conflicts and interdependencies not previously recognized.

The integrated schedule was developed up to Level 8 using the NGNP Project's WBS and the Primavera scheduling tool, starting with version P3 and later updates in P6. A schedule snapshot representing the level of information available from the pre-conceptual design and early conceptual design studies, R&D and the licensing path forward was captured and issued in September of 2008, along with an initial set of assumptions used for schedule development.

Additional refinement of schedule information continued throughout FY 2009 and part of FY 2010. The schedule included activities for developing both the prismatic block and pebble bed reactors through the completion of final design. Although no additional versions of this integrated schedule were formally issued, an update reflecting information as of April 2010 was submitted as a record in the INL's Electronic Document Management System database. The current schedule is shown at Level 5 in Appendix I.

3.5 Pertinent Documentation

The following summarizes key documentation pertinent to the progress and planning of NGNP Engineering. The status and path forward of Engineering to achieve the objective of HTGR technology commercialization are discussed in Appendix E, along with a more complete listing of NGNP Engineering references.

1. INL, *Engineering Status*, INL/EXT-10-19261, August 2010.

2. INL, *Next Generation Nuclear Plant Pre-Conceptual Design Report*, INL/EXT-07-12967, Rev. 1, November 2007.

3. PLN-3247, "Risk Management Plan for the Next Generation Nuclear Plant Project," Rev. 0, Idaho National Laboratory, September 2009.

4. INL, *Next Generation Nuclear Plant Project Technology Development Roadmaps: The Technical Path Forward*, INL/EXT-08-15148, Rev. 0, January, 2009.

5. INL, *Next Generation Nuclear Plant Project Technology Development Roadmaps: The Technical Path Forward for 750—800°C Reactor Outlet Temperature*, INL/EXT-09-16598, Rev. 0, August 2009.

6. INL, *Research and Development Technology Roadmaps for the Next Generation Nuclear Plant Project*, INL/EXT-11-22512, Rev. 0, July 2011.

7. Letter (AS-CMD-INL-09-169), Michael L. Adams to Lisa A. Sehlke, Subject: Contract No. DEAC07-05IDI4517 Next Generation Nuclear Plant Subcontracts, dated April 7,2009.

8. Letter (CCN 217051), Lisa A. Sehlke to Suzette M. Olson, Subject: Contract No. DEAC07-05IDI4517 Response to Request for Recommendations for Next Generation Nuclear Plant Subcontracts Closures, dated April 15, 2009.

9. Suzette M. Olson letter to Lisa Sehlke, CCN 217107, "Contract No. DEAC07-05ID14517—Next Generation Nuclear Plant Subcontracts Closures (AS-CMD-INL-09-177)" April 21, 2009.

10. INL, *Integration of High Temperature Gas-Cooled Reactors into Industrial Process Applications*, INL/EXT-09-16942, Rev. 2, May 2010.

11. INL, *Integration of High Temperature Gas-Cooled Reactors into Selected Industrial Process Applications*, INL/EXT-11-23008, Rev. 0, August 2011.

12. INL and Petroleum Technology Alliance Canada, *NGNP Integration of High Temperature Gas-cooled Reactor Technology with Oil Sands Processes,* INL/EXT-11-23239, October 2011.

13. INL, *NGNP Project Evaluation of Siting a HTGR Cogeneration Plant on an Operating Commercial Nuclear Power Plant*, INL/EXT-11-23282, Rev. 1, October 2011.

14. PLN-2970, "NGNP Program Planning Bases for the Schedule and Cost Estimates," Rev. 1, dated Idaho National Laboratory, December 2010.

15. PLN-224, "Next Generation Nuclear Plant (NGNP) Integrated Schedule Development Plan," Idaho National Laboratory, September 2008.

4. Licensing Status and Path Forward

(Obtaining a combined license from the NRC for the construction and operation of the demonstration plant)

The EPAct provisions required the Secretary of Energy and the Chairman of the NRC to jointly submit a licensing strategy for the NGNP to Congress within 3 years of enactment. This requirement resulted in DOE and NRC jointly developing the *Next Generation Nuclear Plant Licensing Strategy—A Report to Congress.* This strategy report included a summary description of a recommended risk-informed and performance-based approach for adapting existing light water reactor (LWR)-based NRC requirements when establishing the licensing framework and safety basis for the NGNP Project. This adaptation strategy, as opposed to creating a set of new and different regulatory requirements for HTGRs, is a key to the overall licensing process being implemented for NGNP. This strategy is being implemented by the Project through the completion of pre-application activities identified in the NGNP Project Licensing Plan. These activities are focused on the project's development and NRC's approval of a Combined License (COL) application in accordance with 10 CFR 52 requirements for the HTGR demonstration plant.

The NGNP Project addresses the most significant policy and technical issues through a series of pre-application licensing white paper submittals to the NRC that contain a set of outcome objectives specific to the resolution of the associated HTGR licensing issue. These white papers address four key policy issues for resolution (as defined in the *DOE/NRC 2008 Licensing Strategy – Report to Congress*):

1. *Source Terms*. Source terms are used for the assessment of dose to workers and the public and comparison against regulatory dose criteria. The NRC will need to establish such source terms for an HTGR and the conditions under which their use can be justified in licensing, based on the information being provided by the NGNP Project.
2. *Containment Functional Performance*. NRC will need to identify the types of fission product barriers in an HTGR design and the role these barriers play in confining radiological release, based on the information being provided by the NGNP Project. This will involve consideration of factors such as fuel quality and performance, plant transient behavior, defense-in-depth, and security.
3. *Defense-in-Depth*. It will be necessary to determine defense-in-depth measures and to develop appropriate requirements and guidance for licensing.
4. *Use of Probabilistic Risk Assessment in the Licensing Process*. Use of a risk-informed and performance-based licensing approach in licensing an HTGR will likely require NRC decisions in some areas and is in general alignment with the NRC move to a more risk-informed approach to plant licensing (e.g., the basis for and use of selected risk metrics and criteria and the quality and scope of the NGNP PRA).

To date, all of the planned white papers (a total of 11) have been submitted to the NRC, and NGNP has provided written responses to all of the NRC's follow-up requests for additional information (RAIs; a total of over 500 requests). The NRC is currently in the process of documenting the results of their review of these policy issue white papers in a series of assessment reports.

The project has also completed a detailed review and analysis of all of the specific regulations and regulatory guidance that applies to nuclear plant licensing to identify areas that require either modification or new HTGR-related requirements. This regulatory gap analysis work has been completed and has been provided to the NRC in a summary report that indicates that the bulk of existing regulation can be applied to HTGRs either as written or with minor adaptation. Areas where new regulatory requirements must be developed have, for the most part, been previously addressed by the licensing white papers.

The licensing path forward, through submittal of the COL application to the NRC for review and approval to construct and operate the demonstration plant includes the following four major activities:

1. Review and address identified open issues or areas for further development as described in the pending NRC policy issue assessment reports of the submitted NGNP white papers and associated RAI responses.
2. Continue to closely coordinate NGNP and NRC research activities to assure that the identified work being funded and implemented supports the disposition of identified policy and technical issues as required to support NGNP design, licensing, and demonstration plant deployment.
3. Using results of the HTGR regulatory gap analysis and any related insights from the pending NRC policy issue assessment reports, the NGNP project team and the NRC will work together to develop a COL Application Content Guide for HTGRs.
4. A plant site, plant design, and license applicant must be selected for the demonstration plant. Once these selections have been made and sufficient design detail has been developed, a COL application will be developed as described in the COLA Content Guide. (Design maturity required for the COL application will generally be at the Final Safety Analysis Report level of detail, which is commensurate with the preliminary design efforts envisioned by the NGNP Project.)

4.1 Pertinent Documentation

The following are documents that pertain to the progress and planning for activities supporting the licensing of the NGNP demonstration plant. Appendix K of this report summarizes the near term work scope, schedule, and cost of licensing activities consistent with the Secretary of Energy's guidance letter of October 17, 2011. Appendix F provides more detailed discussion of the NGNP Project Regulatory Affairs progress and planning for licensing of the demonstration plant.

4.1.1 Fuel Qualification and Mechanistic Source Terms:

1. "Next Generation Nuclear Plant—Fuel Qualification White Paper," July 21, 2010, CCN 221270.
2. "Next Generation Nuclear Plant—Mechanistic Source Terms White Paper," July 21, 2010, CCN 221271.
3. Idaho National Laboratory, Next Generation Nuclear Plant Project Submittal, "Supplemental Information to Next Generation Nuclear Plant Project Fuel Qualification and Mechanistic Source Terms White Papers," May 3, 2011, CCN 223977.
4. NRC RAI Letter Number 002 (Request for Additional Information No's. 5771 and 5772, Rev. 0), June 7, 2011.
5. NRC RAI Letter Number 003 (Request for Additional Information No. 5895, Rev. 0), July 25, 2011.
6. Next Generation Nuclear Plant Project Submittal—Response to Nuclear Regulatory Commission Request for Additional Information Letter No. 002 Regarding Next Generation Nuclear Project Fuel Qualification and Mechanistic Source Terms, August 10, 2011, CCN 224915.
7. Next Generation Nuclear Plant Project Submittal—Response to Nuclear Regulatory Commission Request for Additional Information Letter No. 003 Regarding Next Generation Nuclear Plant Project Fuel Qualification and Mechanistic Source Terms—NRC Project # 0748, September 21, 2011, CCN 225363.

4.1.2 Risk Informed Performance Based Approach

1. Next Generation Nuclear Plant Project Licensing White Paper—Next Generation Nuclear Plant Project Defense-in-Depth Approach - NRC Project #0748 (ML 093480191), December 9, 2009.
2. USNRC, Next Generation Nuclear Plant (NGNP)—Request for Additional Information Letter No. 001 Regarding Defense in Depth, NRC Project #0748 (ML102020580), July 26, 2010.
3. Next Generation Nuclear Plant Project Defense-in-Depth Approach—Response to Nuclear Regulatory Commission Request for Additional Information Letter No. 001—NRC Project #0748, September 15, 2010, CCN 222027.
4. Next Generation Nuclear Plant Project Licensing White Paper—Next Generation Nuclear Plant Project Licensing Basis Event Selection - NRC Project #0748, September 16, 2010, CCN 222013.
5. Next Generation Nuclear Plant Project Licensing White Paper—Next Generation Nuclear Plant Project Structure, Systems, and Components Safety Classification - NRC Project #0748, September 21, 2010, CCN 221997.
6. NRC RAI Letter Number 005 (Request for Additional Information No's, 5903, 5904, and 5911), dated August 3, 2011
7. "Next Generation Nuclear Plant Probabilistic Risk Assessment White Paper"– NRC Project #0748, September 20, 2011, CCN 224329.
8. Next Generation Nuclear Plant Project Submittal—Response to Nuclear Regulatory Commission Request for Additional Information Letter No. 005 Regarding the Risk-Informed, Performance Based Licensing Approach—NRC Project #0748, October 14, 2011, CCN 225601.

4.1.3 Emergency Planning

1. Next Generation Nuclear Plant Project White Paper, "Determining the Appropriate Emergency Planning Zone Size and Emergency Planning Attributes for a High Temperature Gas Reactor"—NRC Project 0748—October 28, 2010, CCN 222327.

4.1.4 Nuclear-Industrial Facility Boundaries

1. Next Generation Nuclear Plant Project Nuclear Industrial Facility and Design Certification Boundaries—NRC Project #0748, July 22, 2011, CCN 224753.

4.1.5 License Structure for Multi-Module Facilities

1. Next Generation Nuclear Plant Project Licensing White Paper - License Structure for Multi-Module Facilities—NRC Project #0748, August 10, 2010, CCN 221425.
2. NRC SECY-11-0079, "Subject: License Structure for Multi-Module Facilities Related to Small Modular Nuclear Power Reactors, June 12, 2011.

4.1.6 High Temperature Materials

1. "Next Generation Nuclear Plant—High Temperature Materials White Paper," June 25, 2010, CCN 221269.
2. NRC RAI Letter Number 004 (Request for Additional Information No's. 5901, 5898, 5800, 5899, and 5900), dated July 25, 2011.

3. Response to Nuclear Regulatory Commission Request for Additional Information Letter No. 004 Regarding Next Generation Nuclear Plant Project High Temperature Materials White Paper — NRC Project #0748, September 27, 2011, CCN 225396.

4.1.7 Safety Basis and Approach

1. Next Generation Nuclear Plant Project Nuclear—Modular High Temperature Gas-cooled Reactor Safety Basis and Approach—NRC Project #0748, September 6, 2011, CCN 225061.
2. Next Generation Nuclear Plant Licensing Strategy—A Report to Congress (August 2008).

4.1.8 Summary of Key HTGR Licensing Issues

1. NGNP Licensing Plan, PLN-3202 (June 2009).
2. Potential Policy, Licensing, and Key Technical Issues for Small Modular Nuclear Reactor Designs, NRC SECY-10-0034 (March, 2010).
3. Memorandum of Understanding Between the US-NRC and the US-DOE for US-NRC Participation in the Next Generation Nuclear Plant Project (executed August 2008).

4.1.9 Regulatory Gap Analysis

1. NGNP Project Regulatory Gap Analysis for Modular HTGRs, INL/EXT-11-23216 (September 2011).
2. "Procedure for Performing the Regulatory Gap Analysis," NGNP-LIC-ETR-PROC-0001.

5. APPLICATION OF HTGR TECHNOLOGY TO INDUSTRIAL APPLICATIONS

(Confirming technical and economic viability of applying and integrating HTGR technology with industrial applications)

5.1 Process Models and Economic Analyses

Process models of a number of industrial applications for the HTGR technology were developed to evaluate their technical viability. Models of the processes using a conventional energy supply (e.g., natural gas) and the HTGR energy supply were developed and used in these evaluations. A common set of assumptions regarding thermodynamic and thermal-hydraulic performance and capacity of the processes were used so that the output of these models can be compared on an equitable basis. The industrial processes that were evaluated included:

- Electricity generation applying alternative power conversion systems including Rankine and Brayton cycles
- Hydrogen production using steam methane reforming and when applying the HTGR high temperature electrolysis process
- Conversion of coal and natural gas to transportation fuels and other products to include:
    - Gasoline using the methanol to gasoline process
    - Diesel, naphtha, and liquefied petroleum gas using the Fischer-Tropsch process
- Ammonia and ammonia derivatives production
- Conversion of coal to synthetic natural gas
- Steam assisted gravity drainage for extraction of Bitumen from oil sands
- Upgrade Bitumen extracted from oil sands to premium synthetic crude oil
- Oil recovery from oil shale using the in-situ and the ex-situ processes
- Cogeneration supply of steam and electricity to industrial applications for a range of reactor operating temperatures
- Seawater desalination
- Coke and steel production.

The thermal and hydraulic functions of the conventional and HTGR integrated processes were modeled using Excel spreadsheets, ASPEN and HYSYS. The conventional models were used to establish the energy requirements for the process. The HTGR plant was then conceptualized to provide those requirements and used to evaluate the technical viability of the application.

Detailed discounted cashflow evaluations were conducted for the conventional and HTGR integrated processes to compare the costs of energy and/or process products to establish if the use of an HTGR for each application was economically viable. These evaluations also examined the effects of potential costs of carbon emissions on the conventional case economics.

The results of these analyses are summarized in two INL reports (documents 1 and 2 in Section 5.4). These reports reference INL Technology Evaluation (TEVs) reports that provide detailed descriptions of the methods, results, and conclusions of these process heat application evaluations. The conclusion of these evaluations is that the HTGR application is technically viable in all cases. The conclusions on economics varied considerably; the costs for some of the HTGR processes were much higher than current commodity prices or prices projected for the conventional processes (e.g., oil shale extraction using the ex-situ process), or were very competitive with conventional processes, even at the current low price of natural gas (e.g., cogeneration applications). The effect of potential costs associated with carbon emissions was significant in many cases and would affect the conclusion on economic viability (e.g., conversion of coal to transportation fuels and feedstocks).

5.2 Industrial Applications

The Project has assessed the feasibility of siting the HTGR under different conditions to support specific applications in actual industrial facilities. An objective of this effort was to perform these evaluations for as many varying site conditions as achievable. These include a brownfield site closely collocated with petrochemical, refining or other industry with high and varied energy usage, a brown or greenfield site on an existing nuclear site in close proximity to one or more potential energy off-takers, a brown or greenfield site in a remote location, and a greenfield site for electricity generation and distribution only. The Project has completed detailed evaluations for the first three site conditions.

5.2.1 Petrochemical Facility

This evaluation involved siting an HTGR plant to provide steam and electricity to a closely located petrochemical facility with a potential future expansion of the HTGR plant to supply high temperature gas to specific processes within the facility. The evaluation assessed the technical and economic viability of the application and potential site hazards from a licensing perspective.

The objectives of the Project site hazard assessment are to identify and initially screen potential challenges and constraints that exist at representative industrial sites to be addressed in the design and licensing processes; provide assurance that the HTGR technology can be deployed at a variety of sites for a range of applications; describe some of the actions necessary to mitigate impacts of hazards; and provide key insights that can inform the plant design process. The hazards report summarizes potential impacts from significant hazards typical of a class of candidate sites for potential deployment of HTGR reactor technology. These assessments considered certain health, safety, and other important siting characteristics to determine the potential impact of identified hazards and potential challenges presented by the location for this technology. Such hazards include the storage of explosive and/or toxic chemicals, the location of railways, roads or waterways that may transport explosive and/or toxic chemicals or materials, commercial airways, and major industrial facilities located within 5 miles of the potential site. Other considerations include seismicity, area geology, hurricane, tornado, rain, snow, and other environmental characteristics of the site.

The technical and site hazard assessment of the petrochemical application concluded that the site was acceptable for locating the HTGR plant. The initial HTGR plant incorporated four 600-MW(t) nuclear heat supply systems with steam generators supplying 2,500 psig 1000°F superheated steam. The power conversion system included two subcritical Rankine extracting steam turbine generators providing process steam and electricity to the industrial facility. Two more 350 MW(t) nuclear heat supply systems with IHX would be needed to supply the high temperature gas for the potential expansion of the HTGR plant. The HTGR plant prices of energy (e.g., steam and electricity) were projected to be comparable with a conventional natural gas combined cycle (NGCC) based plant at a natural gas price in the $8/MMBtu range with no cost of carbon. Sensitivity analyses show that a $10/ton of CO_2 carbon cost is equivalent to ~$0.5/MMBtu increase in natural gas price for the NGCC. At $20/ton, the cost of carbon would therefore be equivalent to reducing the natural gas price to $7/MMBtu, at which point the HTGR and NGCC plant energy prices are the same.

5.2.2 Recovery and Upgrade of Bitumen from the Alberta, Canada Oil Sands

The second application that was studied involved the use of the HTGR plant to supply energy for the recovery of bitumen from the Alberta oil sands, and the upgrading of that bitumen to premium synthetic crude oil for further refining in Canada or the United States.

The Project developed a concept wherein energy would be supplied from an HTGR Central Energy facility that would supply steam, electricity, and high temperature gas to multiple oil sands production facilities using the steam assisted gravity drainage (SAGD) process and an upgrading facility, Figure 3. For the purposes of this evaluation, a central 3,000 MW(t) HTGR facility was envisioned that can supply sufficient energy for recovery of ~150,000 barrels per day of bitumen using the SAGD process and for upgrading of the bitumen to produce ~145,000 barrels per day of premium synthetic crude.

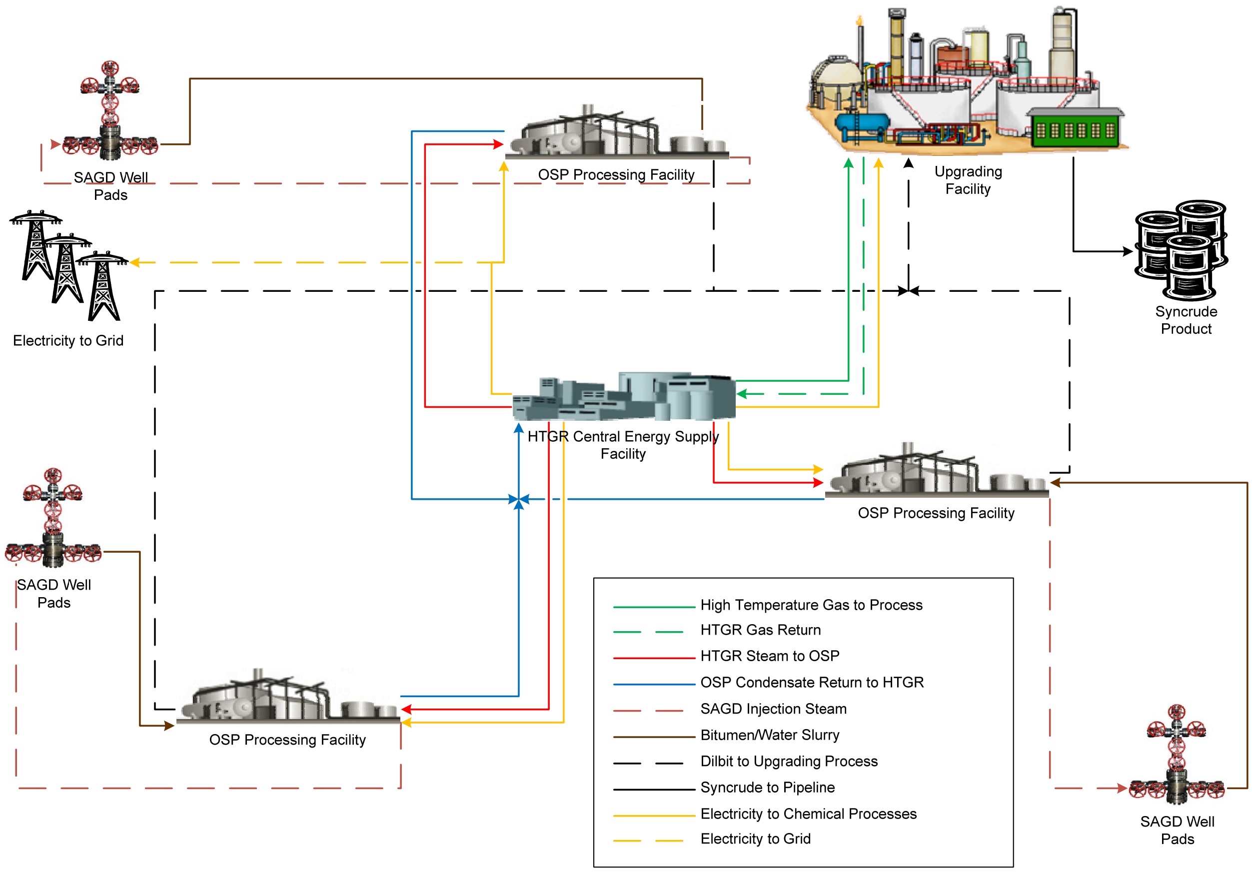

Figure 3. HTGR Central Energy Facility for bitumen recovery and upgrading in Alberta, Canada oil sands.

The application of an HTGR based central energy facility in the Alberta oil sands can address potential long term issues associated with recovering and upgrading bitumen; principally greenhouse gas emissions and price instability associated with the large quantities of natural gas used currently as the energy supply.

A hazards analysis was not performed for this site because of its location outside the United States.

The results of the technical and economic evaluation of this application are reported in document 5, in Section 5.4.

5.2.3 Cogeneration Plant at an Existing Nuclear Plant Site

The third application involved locating an HTGR cogeneration plant on an existing nuclear plant site in an area with closely located major industrial facilities. The nuclear plant site used for this evaluation was the Entergy Waterford 3 site in St. Charles Parish, LA. Entergy, a member of the NGNP Industry Alliance, offered the site for this evaluation.

Waterford 3 is located in a highly industrialized area on the south bank of the Mississippi river. The feasibility study for locating the HTGR plant on the Waterford site considered the size of the HTGR plant boundaries, expected exclusion area boundary of the plant, ability to construct the plant on the site with emphasis on the nature and depth of required excavations and site preparation, use of water extracted from the Mississippi for turbine generator condenser and other auxiliary cooling needs, availability of water for other plant needs, and ability to receive and transport large vessels and other major components (e.g., turbine generator shells and rotors) to the HTGR plant site.

The location and energy needs of industrial plants (potential off-takers) close by the selected site were identified and assessed for supply by an HTGR plant. This effort included determining the annual energy consumption of these industrial plants through review of data collected and published by the DOE Energy Information Agency. Meetings were also held with The Dow Chemical Company to elicit their interest in considering the HTGR as a long term energy supply for their Union Carbide plant near the Waterford site and the types and amounts of energy that they require.

A conceptual HTGR plant design was developed with the capability to meet the energy needs of the potential end users, which included forms of energy, reliability, and availability. Scoping analyses were performed for this plant design to evaluate the economic viability of this application.

In support of this evaluation, a separate site assessment was performed that considered siting characteristics such as health and safety, environment impact, sociological impact, and others to determine the potential impact of identified hazards and potential challenges presented by the typical industrial location for licensing this technology with NRC.

For the purposes of this evaluation, it was assumed that this plant would supply steam and electricity to the plants located within 1-1/2 miles of the selected HTGR plant site and sell excess electricity to regional utilities. The plant design selected had a thermal rating of 3,600 MW(t) comprised of six 600-MW(t) HTGR nuclear heat supply systems. The plant could supply up to ~3 million lb/hour of steam and 500-MW(e) to industrial facilities and 750-MW(e) of electricity to the regional grid or other local facilities. The HTGR plant energy price was projected to be equivalent to that of a comparable NGCC plant at natural gas prices between $6 and $8/MMBtu with no cost of carbon. The technical, hazards and economic evaluations summarized in this report do not identify any conditions that would prevent locating an HTGR cogeneration plant on the Waterford site.

5.3 Industrial Applications Path Forward

Additional feasibility studies similar to those described above should be completed with industrial partners for application of HTGR technology to other specific industrial processes such as:

- Carbon Conversion
  - Methanol to gasoline
  - Coal to liquids
- Hydrogen production
- Oil shale recovery

- Electricity generation
- Other high temperature applications.

5.4 Pertinent Documentation

1. INL, Integration of High Temperature Gas-Cooled Reactors into Industrial Process Applications, INL/EXT-09-16942, Idaho National Laboratory, Rev. 2, May 2010.
2. INL, Integration of High Temperature Gas-Cooled Reactors into Selected Industrial Process Applications, INL/EXT-11-112308, Idaho National Laboratory, August 2011.
3. INL, Evaluating Use of HTGR Technology as an Energy Supply in Petro-Chemical Facilities, INL/LTD-09-17394, September 2009 [Restricted Distribution].
4. NGNP, NGNP Site 1 Hazards Assessment, NGNP-LIC-ETR-RPT-004, March 2011 [Restricted Distribution].
5. INL and Petroleum Technology Alliance Canada, Integration of High Temperature Gas-cooled Reactor with Oil Sands Processes, INL/EXT-11-23239, Idaho National Laboratory, October 2011.
6. INL, NGNP Project Evaluation of Siting a HTGR Cogeneration Plant on an Operating Commercial Nuclear Power Plant, Idaho National Laboratory, INL/EXT-11-23282, Rev. 1, October 2011.
7. INL, NGNP Site 2 Hazards Assessment, INL/EXT-23178, Idaho National Laboratory, September 2011.

6. POTENTIAL MARKET AND PRELIMINARY ECONOMICS

(Assessing the potential size of the market, its character and economics)

6.1 Potential Market

The objective of the NGNP Project is to commercialize HTGR technology as a substitute for the combustion of fossil fuels in industrial applications. The high temperature operating conditions of the HTGR make it applicable to a wide range of industrial processes as shown in Figure 4. To this end the Project has explored applications to which the HTGR technology could be applied and made preliminary evaluations of the technical and economic viability of these applications and the potential market for its deployment. This effort has taken several forms:

- The energy needs of industrial applications were broadly identified for the Project in a 2008 report by MPR Associates, Inc. This report estimates the amount of energy consumed by each application (e.g., petrochemical processes, hydrogen production) and identifies those for which the HTGR technology appeared applicable.
- Meetings were held with petrochemical firms, crude oil refiners, oils sands producers, ammonia and fertilizer producers, and coal companies (potential end users of the HTGR technology) to understand their use of energy, the amount consumed, and concerns regarding its supply.
- Reviews were conducted to determine the historical and projected energy consumption of prospective markets that utilize industrial processes applicable to HTGR technologies. These markets include the cogeneration of electricity, steam, and process heat for use in industrial plants, to recover and upgrade unconventional oil, generate hydrogen for petrochemical and refining processes, supply steam, heat, hydrogen, and oxygen for converting coal and biomass to transportation fuels, and generate electricity for sale on the electrical grid. Assessments were performed to determine how these markets could be penetrated and a schedule was developed for deploying HTGR based plants in these markets.

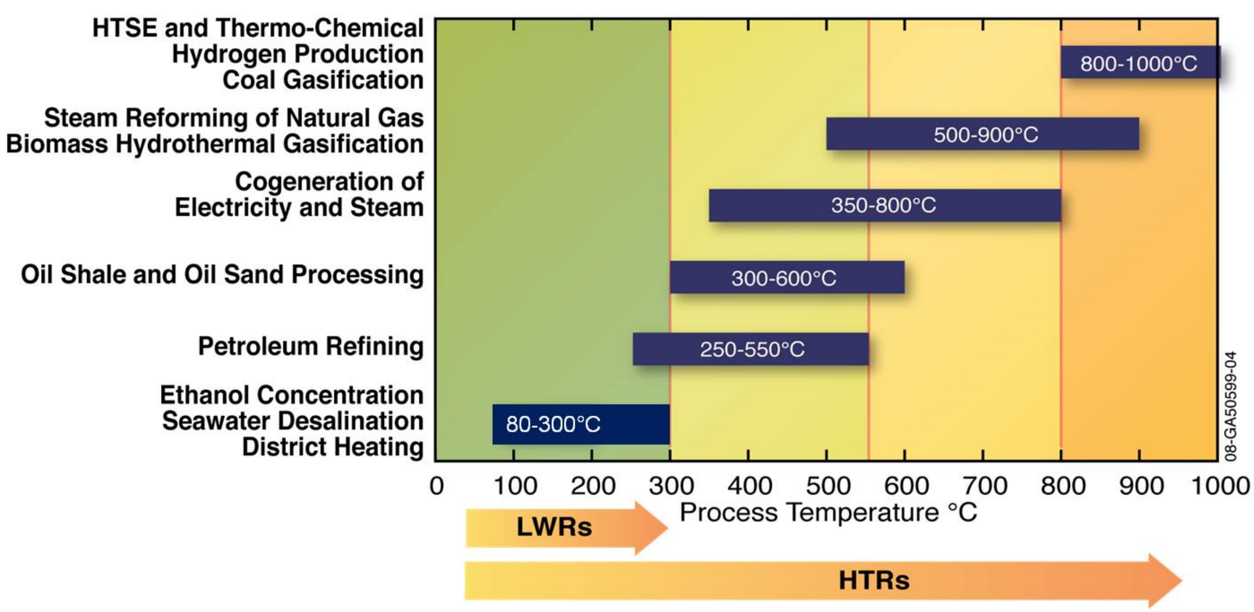

Figure 4. Temperature requirements of potential applications compared with LWR and HTGR operating temperatures.

The objectives of this effort included:

- Developing appropriate functional and performance requirements for the HTGR based plants to meet the energy needs of the end users.
- Identifying the specific energy needs, consumption methods of energy usage, and concerns with traditional forms of energy (e.g., availability and price volatility of natural gas and coal and potential governmental actions to limit carbon emissions) to develop strategies for deploying the HTGR technology to meet these needs and address these concerns. This formed the basis for the market assessments cited above.
- Developing an end user constituency to support the completion of the Project objective of commercializing the HTGR technology. This constituency is formally represented by the NGNP Industrial Alliance.

The current assessment of the potential market for the HTGR technology is summarized in INL report, *High Temperature Gas-Cooled Reactor Projected Markets and Preliminary Economics*. This assessment concluded that there is a large and viable market for the HTGR technology in industrial applications, including cogenerated steam and electricity for: collocated industrial facilities, producing hydrogen, extracting and upgrading bitumen from Alberta, Canada oil sands, converting coal to transportation fuel, producing petrochemical feedstock, and generating electricity. Full realization of the NGNP Project estimate in penetrating these targeted markets for the HTGR technology over the time frame of mid-2020 to 2050 would result in:

- Deployment of ~488,400 MW(t) of HTGR technology (~800 reactor modules rated at 600-MW(t))
- Providing steam, electricity, and high-temperature gas to the process heat market; providing steam, electricity, and hydrogen for bitumen recovery, water treatment, and the upgrading from oil sands; producing hydrogen for the merchant market; and producing synthetic fuels and feedstock from coal and biomass
- Providing a significant fraction of non-greenhouse-emitting electricity generation on the national electrical grid
- Reducing the importation of ~2.4 million barrels of imported crude oil per day (~25% of the imported oil in 2009); replacing the equivalent in crude oil based gasoline and diesel fuels with synthetic transportation fuels produced from coal
- Implementing a beneficial and efficient use of coal without generating greenhouse gas emissions
- Reducing ~6.5 trillion scf in natural gas consumption in the United States, per annum
- Reducing CO_2 emissions of ~380 million metric tons per annum (reducing by ~7% the total CO_2 emissions in the United States in 2009).

A broader based study of strategies for transforming the U.S. energy infrastructure show that the HTGR technology can be an even more significant asset in improving the energy security in the United States (reduce reliance on imported oil), stabilizing energy prices (insulating the price of energy and feedstock from the large variations seen in natural gas prices over the last decade), and reducing CO_2 emissions.

6.2 Market Assessment Path Forward

Work should continue with industrial partners to mature the technical and economic understanding of the application of the HTGR technology to all of these markets in a manner similar to that performed for co-generation and oil sands bitumen recovery and upgrading described in Section 5. Such applications include carbon conversion and electricity generation.

Efforts to identify and evaluate other markets for the HTGR technology need to continue. For example:

- Although several applications have been identified and evaluated for hydrogen usage, discussions with major suppliers of hydrogen on the merchant market have not taken place. This is judged to be a potential significant market that needs to be explored more fully.
- The evaluation of using HTGR technology to recover and upgrade nonconventional oil from oil shale has been initiated but the potential market has not been assessed.
- The evaluations to-date have focused on clearly viable processes and markets. There are other applications, such as requiring lower and higher temperatures, identified in prior studies as having marginal applicability that should be explored in more detail, for example: calcining processes used in cement production and potash mining, pharmaceutical processes, paper mills, and glass production.

6.3 Preliminary Economics

The NGNP Project developed a detailed economic modeling code to support evaluating the economic viability of specific applications of the HTGR technology. The model performs a discounted cash flow analysis from project initiation through decommissioning of the plant. The analysis considers the cost of designing, licensing, constructing, and commissioning the plant; debt and interest on debt during construction; revenues from the sale of commodities produced by the plant; and operating costs, including continuing capital expenditures, depreciation of assets, tax, and decommissioning costs. Inflation and escalation factors can be applied to each cost and revenue element, providing complete flexibility in accounting for the relative effects of inflation and escalation for each element. Inputs can vary for the financial parameters, including debt-to-equity ratio, interest during construction and on debt, debt financing term, required internal rate of return, depreciation method, and effective tax rate. The model assumes a stand-alone project and, therefore, does not take into account credits or other tax conditions that may apply to an associated corporate entity. Net present value, internal rate of return on equity, net income, and simple pay-back period are calculated for the Project.

Business models were also formulated and economic evaluations of these business models were conducted to establish the economic viability of these applications. These business models address:

- The fundamental differences in the economics of a nuclear plant, which are sensitive to capital recovery, with a fossil fired plant (e.g., natural gas) whose economics are driven primarily by fuel costs.
- The potential differences in the economic criteria and financial parameters that apply to ownership of a nuclear plant versus that of a conventional industrial plant to which the HTGR plant may supply energy.
- Potential variations in nuclear plant and industrial process ownership and operation. For example, a likely condition is that the nuclear plant will be operated by an entity with prior experience in operation of a nuclear plant rather than by the industrial plant owner. The industrial plant owner could own all, part, or none of the nuclear plant.

The economic and business models were used to evaluate the economic viability of the specific applications of HTGR technology and to develop product pricing used to assess the market potential of these applications. Because of the pre-conceptual phase of the NGNP HTGR plant design, there is considerable uncertainty in the costs and financial parameters used in the evaluations. As a result, means are provided in the economic model to perform sensitivity analyses to generate Tornado charts depicting the effect of varying the values of key components on the results. Monte Carlo analyses can also be performed to establish the combined effect of these variations.

6.4 Economic Evaluation Path Forward

The following areas need to be addressed as economic evaluations of HTGR applications continue:

- The economic model should be formally audited to validate the implementation of key algorithms in the calculation, improving confidence in its performance. The results of the model calculations have been compared favorably with those of another similar model, but neither of the models has been through a formal audit.
- A standard set of assumptions should be developed and applied to all economic evaluations, including establishing uncertainties in key parameters that can be applied in performing sensitivity analyses.
- More complicated business models and/or financing structures may be needed to address specific applications. These will need to be developed on a case basis.
- Additional economic models may be required to examine the viability of applications from different perspectives. As cited above, the current model considers the application as a standalone enterprise. It may be necessary to incorporate the application into a broader based enterprise. Other perspectives from the suppliers of major components and systems for the plant, potential investors, and end users may need to be considered during the initial phases of HTGR development and deployment.
- As the Project progresses, uncertainties in the costs for the applications and the financial parameters to be used in the economic evaluations will be improved. Existing economic evaluations should be updated to determine if the updates in these values change the conclusions of these evaluations.
- The economic model will need to be maintained and updated as new applications and new features of the model are identified. An entity should be identified and procedures developed to maintain control of both configuration and formal application (those that affect Project decision making) of the model.

6.5 Pertinent Documentation

1. MPR Associates, Inc., "Survey of HTGR Process Energy Applications," MPR-3181, May 2008.
2. MPR Associates Inc., "Number of High Temperature Gas-cooled Reactors that Could Hypothetically be Applied to U.S. Hydrogen Production and to Canadian Oil Sands Recovery," MPR Letter Report, August 8, 2008.
3. Idaho National Laboratory, *End User Functional and Performance Requirements for HTGR Energy Supply to Industrial Processes*, INL/EXT-10-19808, September 2010.
4. Idaho National Laboratory, *Key Design Requirements for the High Temperature Gas-cooled Reactor Nuclear Heat Supply System*, INL/EXT-10-19887, September 2010.
5. Idaho National Laboratory, *High Temperature Gas-Cooled Reactor Projected Markets and Preliminary Economics*, INL/EXT-10-19037, Rev. 1, August 2011.
6. Idaho National Laboratory, *Transforming the U.S. Energy Infrastructure*, INL/EXT-09-17436, Idaho National Laboratory, July 2010.
7. Idaho National Laboratory, *HTGR Economic Model User's Manual,* INL/EXT-11-24143, December 2011.
8. Idaho National Laboratory *Integration of High Temperature Gas-Cooled Reactors into Industrial Process Applications*, INL/EXT-09-16942, Idaho National Laboratory, Rev. 2, May 2010.
9. Idaho National Laboratory, *Integration of High Temperature Gas-Cooled Reactors into Selected Industrial Process Applications*, INL/EXT-11-23008, Idaho National Laboratory, August 2011.

7. Quality Assurance

(Assuring the quality of work to support design and licensing activities)

The NGNP Project is established under the INL Management and Operations contract between DOE and Batelle Energy Alliance (BEA). The BEA contract requires compliance with 10 CFR 830, Subpart A, “Quality Assurance Requirements,” and DOE Order 414.1C, “Quality Assurance,” and uses consensus standard NQA-1-2000 as the baseline.

The NGNP Quality Assurance Program Description (QAPD) (PDD-172) was developed to implement ASME NQA-1-2008, 1a-2009 through a phased approach as identified in PLN-3635, “NGNP Quality Assurance Program Description Implementation Plan.” The QAPD was developed using the Nuclear Energy Institute (NEI) 11-04 Draft, “Nuclear Generation Quality Assurance Program Description (NG-QAPD)” as a template, which is based on ASME NQA-1-2008, 1a-2009. The Project’s quality assurance (QA) requirements are based on Regulatory Guide 1.28, Rev. 4, “Quality Assurance Requirements (Design and Construction), and on Regulatory Guide 1.33, Rev. 2, “Quality Assurance Program Requirements (Operation).” Regulatory Guide 1.28, Revision 4 states that Part I and Part II requirements of NQA-1-2008, 1a-2009, “Quality Assurance Requirements for Nuclear Facility Applications” provide an adequate basis for complying with the requirements of 10 CFR Part 50, Appendix B, subject to additions and modifications, with specific reference to selected sections of Parts III and IV as identified in the document.

In many instances, INL procedures are used to implement NGNP QA requirements. When INL procedures lacked specific requirements and rigor to implement NGNP QA requirements, NGNP project-specific procedures were established. PLN-2021 “Quality Assurance Program Plan for the Next Generation Nuclear Plant Project” and PLN-2690 “VHTR TDO Quality Assurance Program Plan” were developed to address additional requirements, serving to identify: unique NGNP Project QA requirements, a set of management controls for NGNP Project SSCs and related quality-affecting activities, and which procedures are used to implement the INL Quality Assurance Program (QAP) requirements through the use of Laboratory Wide Procedures (LWP) and which requirements are implemented using NGNP specific procedures.

The INL NGNP QAP is described and implemented through a tiered document structure. At the highest level (Tier 1), the QAPD establishes the NGNP Project QA requirements, providing an overall description of the QAP and how it is implemented to facilitate understanding of the program scope and structure. The next level (Tier 2) consists of Program Requirements Documents that identify the requirements by program elements contained in standards NQA-1-2008, 1a-2009, ASNT-SNT-TC-1A, and ANSI/NCSL Z540-1, and DOE Guides 414.1-1A, 414.1-2A, 414.1-3, and 414.1-4. The third level (Tier 3) consists of Management Control Procedures (MCPs), Standards (STDs), Guides (GDEs), Lists (LSTs), Laboratory Instructions (LIs), Technical Procedures (TPRs), and other site-specific procedures that implement the QAP at the organizational, functional support area, or facility levels.

The objective of the NGNP Project is to sufficiently develop the technology necessary to obtain a NRC license to build and operate the NGNP. INL submitted the NGNP QAPD to the NRC for initial feedback. The NRC provided its feedback, resulting in the submittal of NGNP QAPD Rev. 3, which addressed the two items of interest from the NRC letter that required clarification. On October 25, 2011, NGNP received notification that the NRC will need additional information to complete their assessment of Rev 3. A number of those RAIs are associated with the paper’s commitment to certain aspects of the draft version of NEI 11-04. The project is currently drafting responses to those RAIs and is scheduled to formally submit responses during first quarter FY 2012.

The NGNP project scope could be transitioned to another entity (license applicant). In that case, a quality assurance program implemented and maintained by that entity will be required. Selected portions of the remaining INL quality affecting work scope (presumably R&D activity) would be subject to review and acceptance by that entity.

A more detailed description of the Quality Assurance Program supporting the NGNP Project is provided in Appendix G.

8. DEVELOPMENT AND DEPLOYMENT OF HIGH TEMPERATURE GAS-COOLED REACTOR TECHNOLOGY

(Developing a viable public-private partnership to support commercialization of the HTGR technology)

HTGR technology can play an important role in the future of U.S. energy by extending the use of nuclear energy for non-electricity energy production missions as well as continuing to provide a considerable base load electric power generation capability. Extending nuclear energy into the industrial and transportation sectors through the coproduction of process heat and electricity provides the opportunity to provide safe and reliable energy for these sectors in an environmentally responsible manner. The safety case for the modular HTGR provides a substantial improvement in the extent of protection for the public and the environment, and supports collocation of the HTGR with major industrial facilities.

8.1 NGNP Program Overview

Based on the Generation IV Technology Roadmap completed in December 2002, a VHTR concept based on gas-cooled reactor technology is one of several nuclear energy systems that should be pursued. This concept could provide high temperature process heat and produce hydrogen for industrial processes. In the September 2003 U.S. Generation IV Implementation Strategy Report to Congress, the Next Generation Nuclear Plant based on VHTR gas-cooled reactor technology was designated the first priority for U.S. development. Figure 5 summarizes selected programmatic activities showing these actions.

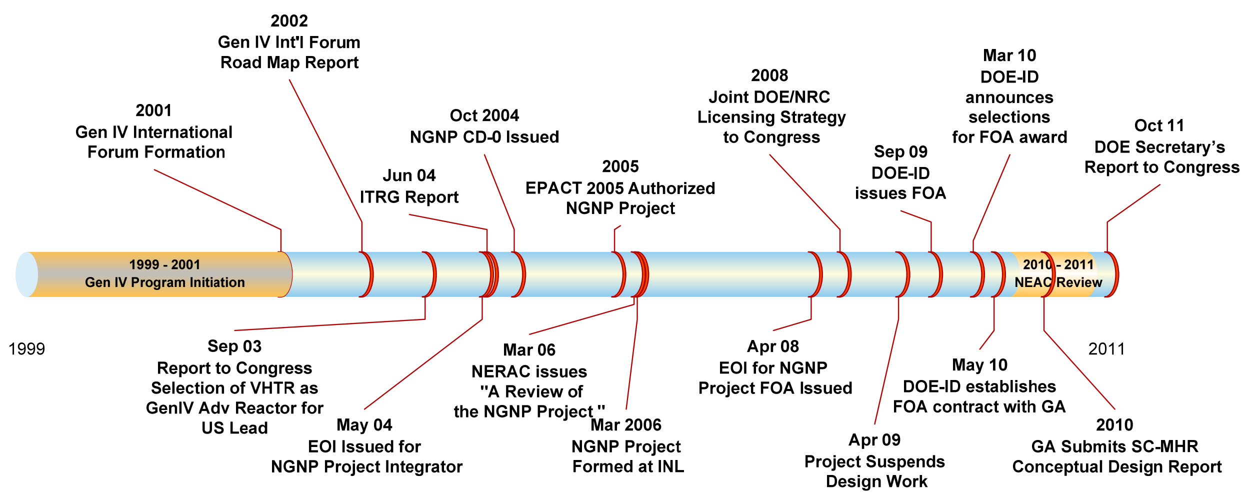

Figure 5. Summary of NGNP programmatic activities.

Follow-on NGNP Project programmatic activities to the present are as follows:

- An Expression of Interest for the NGNP project was issued in May 2004 built around the concept of a Project Integrator under a cooperative agreement between the DOE and a private sector industry entity. Responses from industry indicated interest in pursuing this concept. No subsequent solicitation for a cooperative agreement was issued by DOE.
- In November 2004, BEA, via DOE Contract DEAC07-05ID14517 of November 2004, was directed to have INL lead the U.S. research, development, and exploration of NGNP technologies and carry out this mission in cooperation with other national laboratories, universities, international partners,

and the private sector. BEA was also directed to assist with the establishment and administration of an international public/private consortium to design, build, and operate the NGNP.

- The NGNP Project was subsequently established by the U.S. Congress in the EPAct (Public Law 109-58, August 8, 2005). The Secretary of Energy was directed to form this project to conduct the research, development, design, construction, and operation of a demonstration nuclear reactor plant. The Project was to be conducted in two phases with interim reviews by the NEAC.
- In accordance with contract direction to BEA, and consistent with the authorization of 2005 EPAct, the Next Generation Nuclear Plant Project was formally formed at INL in March 2006 with the issuance of the Preliminary Project Management Plan, which continues to the present.
- In April 2008, DOE issued a request for Expression of Interest/Request for Information regarding a potential future funding opportunity announcement for the formation of a comprehensive public-private partnership. Several affirmative private industry responses were received and follow-up meetings with selected industry entities were conducted by DOE. No subsequent solicitation for a cooperative agreement for a public-private partnership was issued by DOE.
- In August 2008, a jointly developed DOE/NRC overall licensing strategy was summarized in a report to Congress. This overall strategy has formed the underpinning for the development of the HTGR licensing framework, including the pre-application white papers submitted to NRC.
- In September 2009, DOE issued a funding opportunity announcement for development of the conceptual design for the NGNP. A cooperative agreement was placed with GA in May 2010, which then submitted the steam cycle modular helium reactor conceptual design report in December 2010.
- On January 13, 2011, DOE issued a market research request to industry regarding the NGNP. Industry's position was requested on designing, licensing, constructing, and starting up a prototype nuclear reactor and plant. The purpose of requesting this information was to improve the government's understanding of industry's positions on government requirements and to understand industry's capabilities in meeting these requirements. Industry responses were provided in early February 2011.
- On October 17, 2011, the Secretary of Energy forwarded the report and recommendations of the NEACs review of the NGNP Project. The Secretary's letter concludes that "…given current fiscal constraints, competing priorities, projected cost of the prototype, and the inability to reach agreement with industry on cost share, the Department will not proceed with the Phase 2 design activities at this time. The Project will continue to focus on high temperature reactor research and development activities, interactions with the Nuclear Regulatory Commission to develop a licensing framework, and establishment of a public-private partnership until conditions warrant a change of direction." The scope and schedule for these continuing activities, and the conditions warranting a change of direction have not yet been defined.

8.2 Development of the Public-Private Consortium

Via the November 2004 DOE Contract (DEAC07-05ID14517), BEA was directed to assist with the establishment and administration of an international public/private consortium to design, build, and operate the NGNP demonstration reactor plant. These activities are summarized below.

8.2.1 Forming the Industry Consortium

An industry consortium was formed through an initial collaborative effort of Entergy and INL. The initial formation was in mid-2006 via combined meetings with nuclear industry nuclear system suppliers, nuclear fuel and equipment suppliers, nuclear owner/operators, architect-engineers, the Electric Power Research Institute, the Nuclear Energy Institute, and the National Hydrogen Association. Over the next

2 years the consortium matured and added energy end-users and off-takers from the petrochemical, petroleum, and nitrogen/fertilizer industries—potential future customers for the energy produced by HTGR technology.

The industry consortium is now incorporated as the NGNP Industry Alliance, Limited (Alliance) and is led by three executives from the petrochemical and petroleum industries and a nuclear owner/operator. The company membership in the Alliance represents:

- International ownership. The U.S. headquartered companies have international business scope.
- All business capabilities necessary to execute a successful project(s) to complete development, design, license, construct, and operate a demonstration plant based on HTGR technology.
- Several major energy end-user/off-takers that are among the largest globally in their respective industries.

The Industry Alliance membership represents a collective investment in advancing HTGR technology over the last decade in excess of $1 billion.

As a result of the action taken by the Secretary of Energy's letter of October 17, 2011, the Alliance is revising its overall business plan and seeking active collaboration with international interests such as the European Industry Alliance[f] and the Oil Sands Producers in Alberta, Canada, and their respective governments. Further, the Alliance is seeking to broaden its energy end-user/off-taker membership through discussion with other interests such as the coal industry. Over the next several months, the Alliance will be describing its revised business plan and approach to members of the U.S. Congress and other officials in the U.S. Government.

The Alliance has also participated in the Senior Advisory Group that provides consultation to the NGNP Project regarding industry perspectives on energy needs, preferred HTGR plant configurations and priorities for development of longer-term capabilities such as increased reactor temperatures, and alternative process heat transport methods.

Figure 6 presents a summary timeline of the consortium/Alliance interactions with DOE. There are several additional formal communications with the DOE and the Congress on issues of interest to the Alliance.

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f The European Industry Alliance was formed in 2011 with the objective of supporting the development and commercialization of high temperature reactor technology. It is a consortium of companies formed as a successor to EUROPAIRS. Membership includes end users, nuclear system suppliers and major equipment vendors.

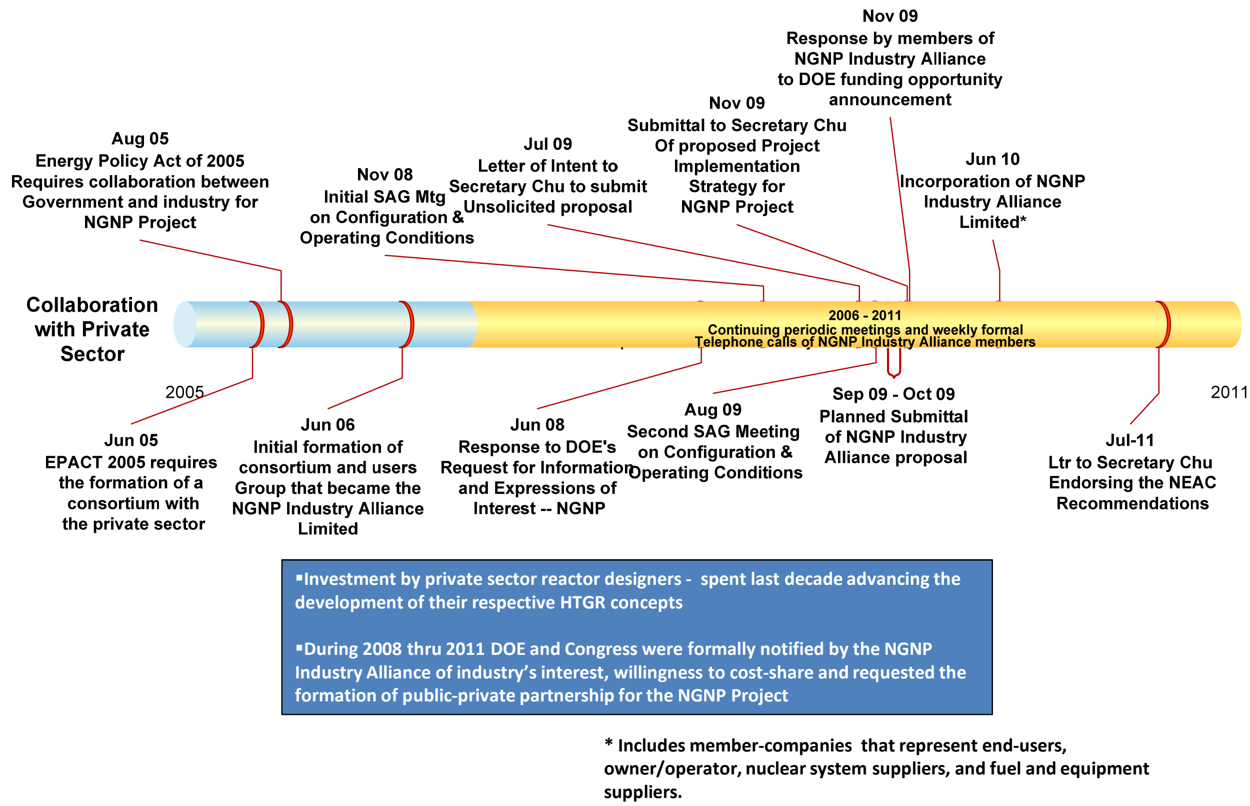

Figure 6. Summary of industrial consortium activities.

8.2.2 Establishing a Viable Public-Private Partnership

Nuclear energy involves a complex and intimate relationship between government and industry. In most countries, nuclear energy is primarily a government-run enterprise. While the U.S. nuclear industry itself is private, it is necessarily intertwined with the government at every stage. Developing, demonstrating, licensing, and deploying new nuclear technologies such as the HTGR is necessary if the U.S. is to realize the broader benefits of nuclear energy beyond solely electric power generation. Given the costs involved, the development of new nuclear energy technology is generally beyond the reach of industry alone and requires government assistance to share risk.

The NGNP Project has provided support to the DOE in developing the foundation for a successful public-private partnership between DOE and private industry. This assistance has taken the form of developing program planning, cost estimates, and summary schedules for the entire project; evaluating alternative cost sharing approaches; and working with industry to gain understanding of its perspectives regarding HTGR technology and the NGNP Project.

DOE issued requests for expression of interest/requests for information on two occasions, in 2004 and 2008, and a market research study in 2011; however, a solicitation for a funding opportunity announcement for a comprehensive public-private partnership has not been forthcoming as of the date of this report. It is noted that DOE issued a limited scope funding opportunity announcement for conceptual design activities for NGNP, which subsequently led to a cooperative agreement with General Atomics in May 2010. This effort involved activities comprising less than 1% of the Project's overall estimated cost for the scope as defined in the 2005 EPAct.

DOE recently issued a presolicitation announcement for a "Request For Proposal Number/Title: DESOL-0003503, *High Temperature Gas Reactor (HTGR) Technology Economic/Business Analyses and Trade Studies*. The Department of Energy-Idaho Operations Office intends to issue a Request for Proposals to provide analyses, data, and information on the long term commercial viability of HTGR technology. The information provided will be used by the DOE to formulate future activities for the NGNP project." This Request for Proposals had not been issued at the time of this writing.

The legal structure for a cooperative agreement or technology investment agreement to form a viable partnership is described in 10 CFR 600. No other legislation or codification appears necessary. Other considerations, such as acceptable cost share and ensuring the government funding stream via appropriations, can be addressed as part of the negotiations with industry in response to a DOE solicitation leading to an agreement for the partnership.

Based on working with industry interests on the NGNP Project, it is concluded that a comprehensive public-private partnership must include a substantive portion of the entire scope of the NGNP Project to successfully interest industry in investing via cost share. Additionally, there must be sufficient demonstrated planning and commitment for out-year funding by the government that would provide the confidence necessary for the private sector to invest in such a partnership. Such a comprehensive partnership would include a detailed decision framework that a priori establishes the criteria for making decisions and the on-ramps and off-ramps that would be mutually agreed to over the life of the entire Project. The industry perspective is that it wishes to have its investment in HTGR technology development and demonstration lead to deployment and commercialization so that a recognizable return on its investment can be anticipated over the long term. The scope of the partnership must be sufficiently comprehensive such that the end-deliverables can be recognized in terms of return on such investment.

Appendix A

High Temperature Gas-cooled Reactor Technology and Safety Basis

Appendix A
High Temperature Gas-cooled Reactor Technology and Safety Basis

A-1. NUCLEAR HEAT SUPPLY SYSTEM

The high temperature gas-cooled reactor (HTGR) is helium cooled, with a graphite moderated reactor core and robust ceramic fuel. The HTGR nuclear heat supply system (NHSS) is comprised of three major components: the helium cooled nuclear reactor, a heat transport system, and a cross vessel that routes the helium between the reactor and the heat transport system. The NHSS supplies energy in the form of steam and/or high-temperature fluid that can be used for the generation of high efficiency electricity and to support a wide range of industrial processes.

The NHSS design is modular with module ratings from 200 to 625 MW(t), reactor outlet temperatures from 700 to 850°C and heat transport systems that provide steam and/or high temperature fluids. The range of power ratings, temperatures and heat transport system configurations provides flexibility in adapting the modules to the specific application.

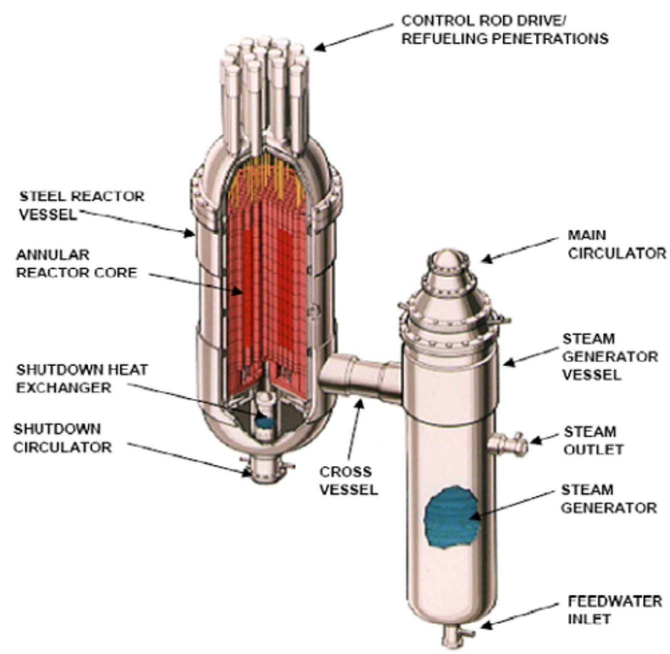

Figure A-1. HTGR Reactor and HTS.

As shown Figure A-1, the three major components are enclosed in metallic pressure vessels that make up the primary helium circuit. Under normal operating conditions helium flow is maintained by the main circulator and heat is transferred from the reactor to the heat transport system (shown as the steam generator in Figure A-1) and then to an energy conversion system (e.g., a steam turbine generator) that interfaces with the industrial process and/or the electrical grid. When the reactor and plant are shut down for maintenance or refueling, reactor temperature is maintained by the shutdown cooling system. In the event the heat transport system or shutdown cooling system are not operational (e.g., on loss of all electrical power), reactor temperature is maintained via a radial conduction path through the reactor pressure vessel to an annular cavity formed between the reactor pressure vessel and the reactor building structure (silo)—the so-called reactor cavity. This cavity can be actively cooled or cooled by natural circulation. In the event neither of these reactor cavity cooling mechanisms is operational, conduction through the reactor building structure to the ground is sufficient to maintain reactor temperatures within acceptable limits.

Several different plant configurations have been developed as part of the Idaho National Laboratory (INL) Next Generation Nuclear Plant (NGNP) Project and in prior work conducted by the Department of Energy (DOE). These are described in References 1 thru 6.[1,2,3,4,5,6]

A-2. HTGR SAFETY BASIS

The principal design objective of the NHSS is to ensure that there is no internal or external event that could lead to substantive release of radioactive material beyond the boundaries of the plant and endanger the safety of the public. This reduces the complexity and extent of emergency planning and response and facilitates use of the HTGR technology in industrial applications.

This objective is met by provision of multiple barriers to the release of radioactive material from the plant that provide retention of those materials, thereby meeting associated regulatory requirements and assuring the protection of public health and safety and the environment under all normal, abnormal, and accident conditions, whether affected by internal (e.g., loss of all electrical power, a leak in a steam generator tube) or external events (e.g., earthquakes, flooding, tornadoes). These barriers include:

- A robust carbon-based fuel structure that forms the principal barrier to release and transport radioactive material. As shown in Figure A-2, the fuel is made up of minute (~1 mm diameter) particles comprised of multiple ceramic layers surrounding the uranium based kernels. These ceramic layers are designed to retain the products of nuclear fission and limit release to the fuel elements and the helium coolant.
- Distribution and containment of the fuel particles in fuel elements (compacts or spheres) of carbon based material.
- Enclosure of the fuel elements in a large graphite core.

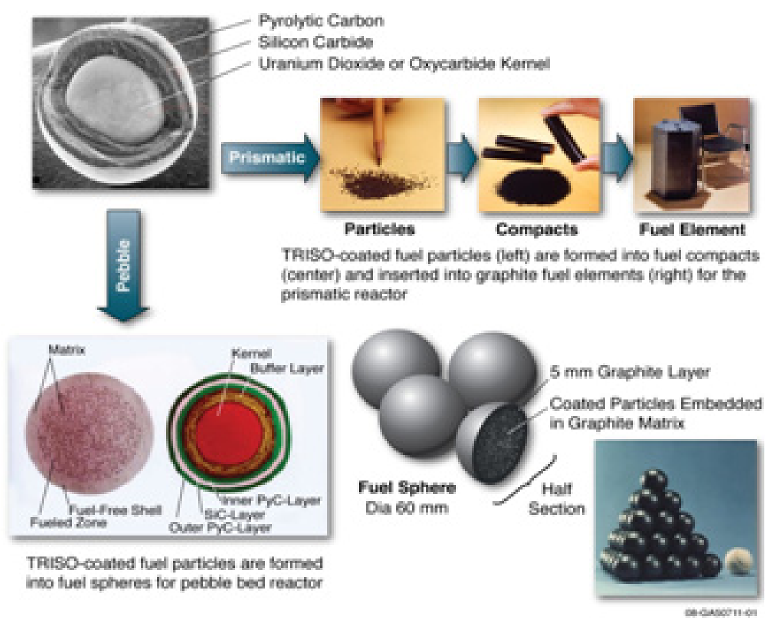

Figure A-2. HTGR TRISO fuel.

- Enclosure of the core structure and the helium coolant system in American Society of Mechanical Engineers (ASME) Nuclear Grade metallic vessels meeting ASME Code requirements for nuclear components.
- Enclosure of the NHSS vessels in a robust underground reactor building.

Additional reactor characteristics that prevent release of radioactive materials include:

- Extreme high temperature capability of the ceramic coated and carbon-based fuel and core structure.
- No metal or water in the fuel and core structure that can, in combination, chemically react to form hydrogen or increase pressure.
- Plant design features limit intrusion of air or water so that the reactor remains shutdown and containment of radioactive materials is maintained.
- Chemically inert helium coolant.
- Inherent nuclear and heat transfer properties of the reactor design that are continuously functional to ensure that the fuel temperatures remain within acceptable limits under all conditions.

- Inherent properties of the reactor core that regulate nuclear power so no electrical power, coolant flow, or any other active systems or operator actions are required to limit nuclear power levels and fuel temperatures under any condition (see Figures A-3 and A-4).[g]

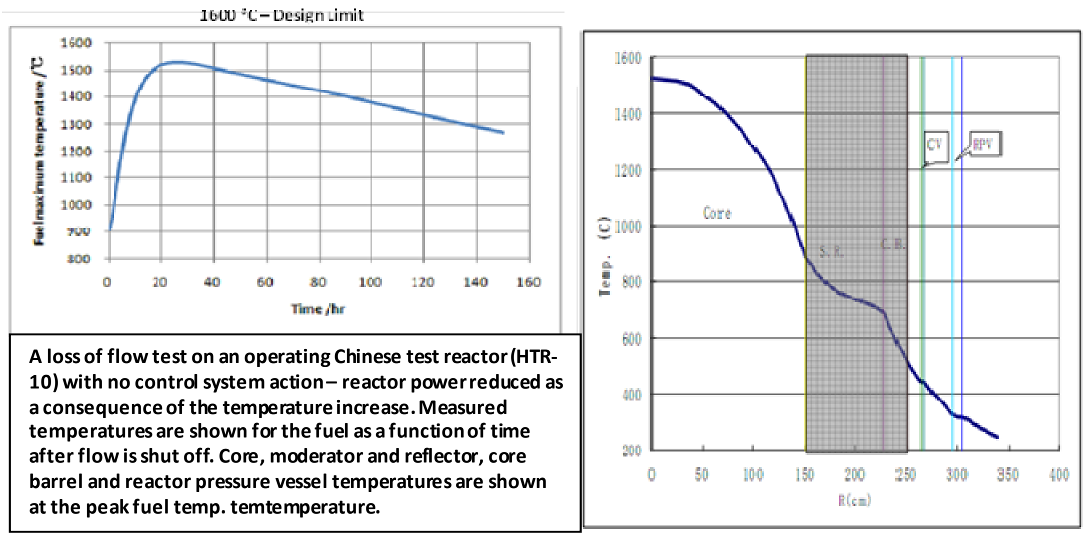

Figure A-3. Demonstration of response to loss of flow accident.

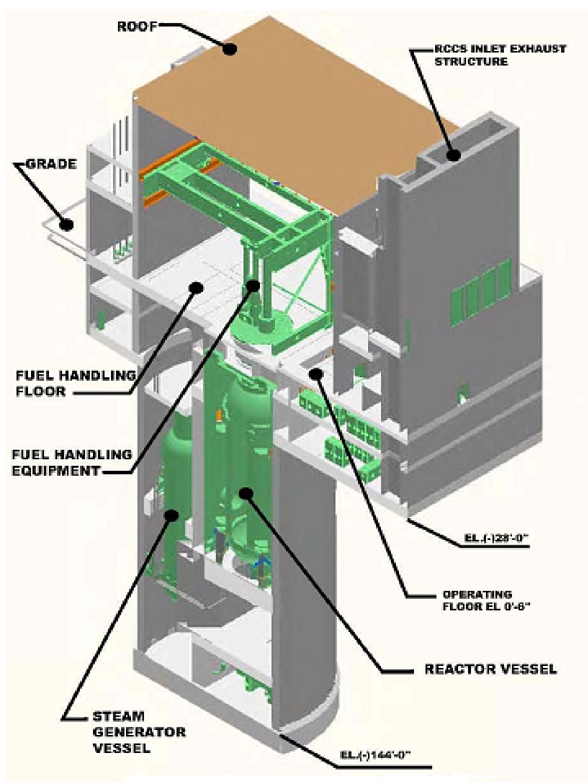

Figure A-4. Typical reactor building.

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[g] Dong, Yujie, *Status of Development and Deployment Scheme of HTR-PM in the People's Republic of China,* INET, Tsinghua University, Beijing, China, presented at the Interregional Workshop on Advanced Nuclear Reactor Technology for Near Term Deployment, Vienna, Austria, July 2011)

- Reactors and heat transport systems are located underground in reinforced concrete silos reducing response to earthquakes and providing a natural heat transfer path from the core, through the reactor pressure vessel, into the silo, and ultimately to the passive reactor cavity cooling system under loss of all forced cooling conditions. If the reactor cavity cooling system is unavailable, heat transfer to the ground is sufficient to maintain fuel temperatures in the acceptable range.
- The graphite core has the ability to absorb large quantities of heat. It takes hours or days to reach peak accident temperatures, independent of whether active cooling systems are working or not.
- The heat transfer path from the core to the reactor cavity cooling system and to the ground is continuously functional, making it available independent of the plant condition.

A-3. SPENT AND USED FUEL STORAGE

- Spent and used fuel is stored in casks or tanks in underground vaults that can be cooled by naturally circulating air as shown in Figure A-5.
- Active systems are not required to maintain acceptable temperatures of stored spent or used (defined as not completely used but removed from the core for maintenance) fuel because of low retained energy and robust carbon based fuel material.
- Carbon based material used for the fuel and fuel elements facilitates long term stable storage

Figure A-5. Spent fuel storage.

A-4. Status and Path Forward

The design of the NGNP HTGR Demonstration Plant has not progressed beyond the pre-conceptual design work completed in FY 2007 and the beginning of conceptual design work performed by General Atomics for the DOE in FY 2010. Design work was halted by the DOE in early 2008 in anticipation of initiation of the public-private partnership. This partnership has not been formed and is not likely to be formed, if at all, until late 2012. Appendix E provides discussions of what engineering studies have been done and what design work remains to be done.

The safety basis of the HTGR has been developed and described in detail in several white papers submitted to the Nuclear Regulatory Commission for review. These white papers cover the elements described above and the mechanisms that are being executed to confirm their performance over all possible normal, abnormal, and accident conditions. The following documents provide design descriptions for HTGR plants and the safety basis of the HTGR technology.

A-5. RELATED DOCUMENTS

1 *Next Generation Nuclear Plant Pre-Conceptual Design Report*, INL/EXT-07-12967, Revision 1, November 2007.

2 General Atomics document NGNP-R00016, "Next Generation Nuclear Plant (NGNP) Prismatic HTGR Conceptual Design Project, Conceptual Design Report – Steam Cycle Modular Helium Reactor (SC-MHR) Demonstration Plant," Revision 1, July 15, 2011.

3 AREVA NP Inc. document 12-914697-000, "Pebble Bed Reactor Plant Design Description," January 31, 2011.

4 AREVA NP Inc. document 12-9151714-000, "Pebble Bed Reactor Technology Readiness Study," January 31, 2011.

5 AREVA NP Inc. document 12-9149863-000, "Pebble Bed Reactor Scoping Safety Study," January 31, 2011SC-MHR Conceptual Design Report.

6 *Basis for NGNP Reactor Design Down-Selection*, INL/EXT-10-19565, August 2010.

Appendix B

Energy Policy Act of 2005

Appendix B—Energy Policy Act of 2005

The Energy Policy Act of 2005[1] (EPAct) established a number of energy management goals for Federal facilities and fleets. Title VI, Subtitle C of the EPAct established the Next Generation Nuclear Plant Project (NGNP), the scope of which included:

> *... the research, development, design, construction, and operation of a prototype plant, including a nuclear reactor that—*
>
> *(1) is based on research and development activities supported by the Generation IV Nuclear Energy Systems Initiative under section 942(d); and*
>
> *(2) shall be used—*
>
> *(A) to generate electricity;*
>
> *(B) to produce hydrogen; or*
>
> *(C) both to generate electricity and to produce hydrogen.*

The EPAct also identified the Idaho National Laboratory (INL) as the lead laboratory for the NGNP project and the site for the NGNP high temperature gas-cooled reactor (HTGR) prototype. INL was charged with organizing a consortium of appropriate industrial partners that would carry out cost-shared research, development, design, and construction activities. INL would also lead the necessary research and development (R&D). The project was to be structured such that technical input and transfer of technologies into the project would be obtained from the nuclear power industry and the chemical processing industry. The nuclear power industry would bring expertise regarding issues associated with nuclear plant design, construction, operation, and safety, while the chemical industry would provide input on use of process energy for hydrogen production and integration of the new technologies into chemical processing environments.

Major program elements identified in the EPAct include:

- High temperature hydrogen production technology development and validation
- Energy conversion technology development and validation
- Nuclear fuel development, characterization, and qualification
- Materials selection, development, testing, and qualification
- Reactor and balance-of-plant design, engineering, safety analysis, and qualification.

The Department of Energy (DOE) charged INL with supporting the development of a public-private consortium that would manage and share the costs of completing the Project. Cost-share provisions are covered in Section 988 of the EPAct. In that regard, DOE has submitted several expressions of interest to industry for participation in design development and in participating in Project completion. Although the industry response to these submittals has been positive, as of this writing, DOE has not taken action to develop such a consortium.

The project is to be accomplished using a phased approach, Phase 1 includes selection and validation of hydrogen production technologies; R&D and demonstration of energy conversion technologies, nuclear fuel, and materials; determination of whether electricity generation and hydrogen production can be combined in a single plant; and initial design activities for a prototype reactor and plant, including development of design methods and safety analytical methods.

Phase 2 is to continue the activities under Phase 1 as necessary, develop a final design for the prototype plant through a competitive process, apply for licenses from the Nuclear Regulatory Commission (NRC) to construct and operate the prototype plant, and construct and start up the prototype reactor and its associated hydrogen or electrical generation facilities.

B-1. STATUS

Although the Project has not yet completed the full scope of Phase 1 (e.g., design not matured; public-private partnership not established), the Secretary of Energy requested the Nuclear Energy Advisory Committee (NEAC) (formerly the Nuclear Energy Research Advisory Committee) to conduct a comprehensive review of the Project and to report to the Secretary the recommendation of the NEAC concerning whether the Project was ready to proceed to the second project phase. This review was initiated by DOE in August 2010. Pursuant to completing this review the NGNP Project provided multiple reference documents to the NEAC Nuclear Reactor Technology Subcommittee and met with them four times to review the results and recommendations of Project work, including planning for completion of the Project. The NEAC submitted conclusions of this review and recommendations on the path forward for the Project to DOE in June 2011.[2] In summary, the NEAC concluded

> *"…that the project is not ready for a decision to proceed to the complete set of Phase II activities. However, …we recommend proceeding with a portion of the Phase II activities suggested in EPACT-2005; i.e., continue with Phase 1 efforts, initiate a partnership and begin the needed design activities required to support NRC licensing."*

October 2011, DOE informed Congress that[3]:

> *"Given current fiscal constraints, competing priorities, projected cost of the prototype, and inability to reach agreement with industry on cost share, the Department will not proceed with the Phase 2 design activities at this time. The Project will continue to focus on high temperature reactor research and development activities, interactions with the Nuclear Regulatory Commission to develop a licensing framework, and establishment of a public- private partnership until conditions warrant a change in direction."*

No schedule has yet been provided for establishing the partnership or review of conditions that may warrant a change in direction. This action combined with the FY 2012 budget request requires reducing the scope and organizational structure of the INL NGNP Project and initiating this report addressing planning for transition of the Project activities. The remaining, limited scope of activities will be managed at INL by the Very High Temperature Reactor Technology Development Office.

B-2. PATH FORWARD FOR EPACT AND RELATED ITEMS

The Project recommends that DOE:

- Ensure that the necessary DOE infrastructure remains current and consistent with the EPAct to facilitate reengagement on the Project when conditions warrant a change in direction consistent with the Secretary's letter of October 17, 2011 (e.g., 10 CFR 600 provisions for cooperative agreements and technology investment agreements, and for cost share provisions consistent with Section 988).
- Ensure that R&D, pre-application licensing, and partnership development activities that derive from the Secretary's letter of October 17, 2011, are consistent with the scope, objectives, and requirements of the EPAct to facilitate restarting the Project under a public-private partnership within the

authorization of EPAct if such partnership is implemented and conditions warrant a change in direction.

- Maintain relationships that have been developed with collaborative international industry entities to facilitate restarting the Project within the authorization of EPAct 2005 when conditions warrant a change in direction.

B-3. MEETING THE EPACT OBJECTIVES

The following summarizes the status and path forward required to achieve key objectives of the NGNP Project cited in the EPAct.

B-1.1 Select and Validate the High-Temperature Hydrogen Production Technology

An assessment [4] was conducted in 2009 by an independent review team (IRT) that considered the three leading hydrogen production technologies: sulfur-iodine process, high temperature electrolysis process (HTE), and hybrid sulfur process. The assessment included an evaluation of background information provided to the IRT followed by a 5-day workshop in June 2009. The workshop included presentations by technical experts for each of the three leading candidate technologies followed by question and answer sessions. The IRT generated an extensive compilation of technical issues identified through the discussions. An evaluation of these technical issues using procedures documented in Reference [5] was completed, which in turn led to each of the technologies receiving a numerical score or ranking. These rankings served as the principal basis for the IRT recommendations. The main recommendation was that DOE continue to develop high temperature electrolysis as the leading candidate for integration with NGNP.

The DOE terminated the Nuclear Hydrogen Initiative as a separate program at the end of FY 2009, however the NGNP project has continued to fund R&D on the HTE process . through FY 2012. Thereafter, further development will likely need to be undertaken by private industry. See discussions of the HTE process development in Section 2.0 and Appendix D.

The DOE Secretary confirmed the selection of HTE as the hydrogen generation process for the NGNP Project in the letter to Congress October 17, 2011.

B-1.2 Enabling Research, Development, and Demonstration

The EPAct requires the Project to:

> *"Carry out enabling research, development, and demonstration activities on technologies and components in the areas of energy conversion technology development and validation, nuclear fuel development, characterization, and qualification, and materials selection, development, testing, and qualification.*

The following summarizes the how the project has addressed these objectives and the status of each initiative.

B-1.2.1 Energy conversion technology

See Appendix E

B-1.2.2 Nuclear fuels

See Appendix D

B-1.2.3 Materials

See Appendix D

B-1.3 Determine Whether it is Appropriate to Combine Electricity Generation and Hydrogen Production in a Single Prototype Nuclear Reactor and Plant

Pre-conceptual design studies performed in FY 2007 by three reactor supplier teams (led by AREVA, General Atomics, and Westinghouse) and evaluations developed by INL identified feasible plant configurations that combined electricity generation and hydrogen production in a single plant.[6] In addition, INL developed an evaluation of the economics of producing hydrogen using an HTSE process with heat supplied by an HTGR.[7] Accordingly, the Project has confirmed that it is feasible to combine electricity and hydrogen generation in a single plant. Additional work by the Project has determined, however, that such a plant may not be appropriate as the Project demonstration (prototype) plant.

Although, several industrial applications have been identified by the Project for which hydrogen generation is a primary need (e.g., ammonia and fertilizer production, conversion of coal to liquid fuels, bitumen upgrading), Project interactions with potential end users of the HTGR technology suggest that the HTGR has broader applications (e.g., providing steam, electricity and process heat in cogeneration, petrochemical and unconventional oil recovery). It has also been concluded that the demonstration plant should be sited to support industrial applications as part of an eventual multi-module plant rather than as a single module at INL. It is uncertain at this time what and where that industrial application will be and, therefore, the energy requirements of the application. Making this determination will be a principal focus of the entity that continues completion of the Project (e.g., a public-private partnership, an industry consortium.)

B-4. REFERENCES

1. *Energy Policy Act of 2005*, Public Law No. 109-58, U.S. Congress, August 8, 2005.
2. Martin, W.F., Ahearne, J. to Chu, S., Secretary of Energy, “Nuclear Energy Advisory Committee,” June 30, 2011.
3. The Secretary of Energy to Members of Congress, October 17, 2011, EXEC-2008-010194.
4. DEIR-6917-00-01, “NGNP Hydrogen Technology Down-Selections, Result of the Independent Review Team Evaluation, Dominion Engineering, 2009.
5. PLN-3131, “*Hydrogen Technology Down-Selection Methodology, Criteria and Weighting”*, Revision0, June 09, 2009.
6. INL/EXT-07-12967, “*Next Generation Nuclear Plant Pre-Conceptual Design Report*,” Revision 1, November 2007.
7. TEV-693, “*Nuclear Assisted Hydrogen Production Analysis*”, Idaho National Laboratory, Revision 1, February 2010.

Appendix C

Nuclear Energy Advisory Committee (NEAC) Review

Appendix C—Nuclear Energy Advisory Committee (NEAC) Review

C-1. PURPOSE

Section 643(c)(3), "Review by Nuclear Energy Research Advisory Committee" of the *Energy Policy Act of 2005* (EPAct) includes the following provisions:

> *(A) IN GENERAL.—The Nuclear Energy Research Advisory Committee of the Department (referred to in this paragraph as the ''NERAC'') shall—*
>
> > *(i) review all program plans for the Project and all progress under the Project on an ongoing basis; and*
> >
> > *(ii) ensure that important scientific, technical, safety, and program management issues receive attention in the Project and by the Secretary.*
>
> *(B) ADDITIONAL EXPERTISE.—The NERAC shall supplement the expertise of the NERAC or appoint subpanels to incorporate into the review by the NERAC the relevant sources of expertise described under paragraph (1).*
>
> *(C) INITIAL REVIEW.—Not later than 180 days after the date of enactment of this Act, the NERAC shall—*
>
> > *(i) review existing program plans for the Project in light of the recommendations of the document entitled ''Design Features and Technology Uncertainties for the Next Generation Nuclear Plant,'' dated June 30, 2004; and*
> >
> > *(ii) address any recommendations of the document not incorporated in program plans for the Project.*
>
> *(D) FIRST PROJECT PHASE REVIEW.—On a determination by the Secretary that the appropriate activities under the first project phase under subsection (b)(1) are nearly complete, the Secretary shall request the NERAC to conduct a comprehensive review of the Project and to report to the Secretary the recommendation of the NERAC concerning whether the Project is ready to proceed to the second project phase under subsection (b)(2).*
>
> *(E) TRANSMITTAL OF REPORTS TO CONGRESS.—Not later than 60 days after receiving any report from the NERAC related to the Project, the Secretary shall submit to the appropriate committees of the Senate and the House of Representatives a copy of the report, along with any additional views of the Secretary that the Secretary may consider appropriate.*

The first review by the Nuclear Energy Research Advisory Committee (NERAC), now called the Nuclear Energy Advisory Committee (NEAC), was performed in March 2006 with the following recommendations:

The full NERAC adopts the report titled *A Review of the NGNP Project: February 22, 2006* and endorsed its recommendations. These include:

- That the dual mission of electricity and hydrogen production be reconsidered and not accepted without further analysis;
- That Department of Energy (DOE) Staff, with the assistance of key industry representatives, should conduct economic and engineering trade studies that should be funded, initiated immediately, and completed as soon as possible;
- That DOE develop the Next Generation Nuclear Plant (NGNP) as a reactor facility that can be upgraded as the technology advances; and
- That DOE Office of Nuclear Energy staff should update its research and development (R&D) plans and develop options that can support a reactor deployment much before the 2017-2021 timeframe.

Section VIII of the report provides more detailed R&D suggestions.

In August 2010, the Assistant Secretary of Nuclear Energy requested the NEAC (so-called at that time) to conduct a review of the first phase of the Project to advise whether the Project was ready to proceed to Phase 2. The Idaho National Laboratory (INL) R&D, Engineering, and Regulatory Affairs groups, along with the reactor supplier teams, assembled a large number of documents and developed summary presentations to describe the status and accomplishments of the NGNP project for the NEAC. As noted in the Engineering discussion, only one reactor supplier team was funded under the Funding Opportunity Announcement and that was a team proposing the prismatic block concept. In order to retain the alternative concept of a pebble bed reactor as an option, a separate study was subcontracted to AREVA to provide an assessment of the pebble bed reactor technology.

The NEAC Nuclear Reactor Technology Subcommittee held four meetings with NGNP Project personnel, suppliers, and members of the NGNP Industry Alliance on September 30 and November 15, 2010, and on February 22 and April 20, 2011, to review the NGNP status.

C-2. CONCLUSIONS AND RECOMMENDATIONS

On June 30, 2011, NEAC provided a summary of the results of the Nuclear Reactor Technology Subcommittee's review with recommendations on the readiness of the Project to enter into Phase 2. The following summarize the conclusions of the review and recommendations:

Conclusions:

> *Based on the review of the NGNP Project, NEAC concludes that the project is not ready for a decision to proceed to the complete set of Phase II activities. However, because of the great potential for the NGNP to reduce the carbon footprint associated with process heat for industrial uses, for electricity production in certain applications, and ultimately, for its potential for hydrogen production, we recommend proceeding with a portion of the Phase II activities suggested in EPACT-2005; i.e., continue with Phase I efforts, initiate a partnership and begin the needed design activities required to support NRC licensing.*
>
> *The NEAC recommends that the federal government continue to support the development of the NGNP at an appropriate level in the next few years to sustain its investment in this technology. However, NEAC does not see a credible path forward within the constraints imposed by EPACT-2005 and the current lack of potential vendors, owner-operators, and customers willing to make substantial up-front funding commitments for the licensing and construction of a first-of-a-kind HTGR design.*

Recommendations of the NEAC:

1. *Accelerate the formation of a public-private partnership as soon as practical to obtain end-user input into the design activities and fund additional design activities to support this effort. …*
2. *Continue to engage the NRC for necessary licensing activities to ensure that the regulatory framework for this new reactor technology is ready to support commercialization. …*
3. *Expedite NGNP deployment efforts by:*
   a) *Revising the NGNP program plan to reflect the current situation and sustain progress through appropriate funding levels for a single design concept (prismatic or pebble bed) to move forward.*
   b) *Completing additional design activities required to support a PSAR level of detail for this single design concept that is selected by the partnership. The partnership would select this concept based on site-specific information and end-user needs. Hence, it is essential that the partnership be established as soon as possible.*
   c) *Focusing current research and design efforts on this single concept that will accelerate initial deployment efforts. While high reactor outlet temperatures are desirable for ultimate NGNP applications, issues associated with licensing and deployment must first be addressed.*
   d) *Removing the EPACT-2005 requirement that the NGNP first-of-a-kind be located at the INL site. Rather, the NGNP should be sited at an appropriate location defined by the industrial partnership that will be formed by the end of FY 2012.*
4. *If the development of the public-private partnership is not substantially under way by the end of FY 2012, then the NGNP program should be repurposed for advanced reactor systems R&D.*

C-3. NGNP PROJECT SUPPORT

The NGNP Project provided documentation and made presentations on pertinent topics to support the NEAC review. This documentation and presentation material has been assembled and is available at https://inlportal.inl.gov/portal/server.pt/community/ngnp_public_documents.

Appendix D

Next Generation Nuclear Plant Technology Development

Appendix D—Next Generation Nuclear Plant Technology Development

At the inception of the Next Generation Nuclear Plant (NGNP) project, experts from Department of Energy (DOE) national laboratories, gas reactor vendors, and universities collaborated to establish technology research and development (R&D) roadmaps. These roadmaps outlined the testing and computational development activities needed to qualify the materials and validate the modeling and simulation tools to be used in the design and safe operation of the NGNP, a high temperature gas-cooled reactor (HTGR). The technology development roadmaps draw on worldwide experience gained from the six demonstration and/or prototype HTGRs that have been built and operated over the past 60 years and their related technology development programs. The roadmaps include detailed descriptions of the required technical activities with associated schedules and budgets for completing the activities, forming the baseline for execution of the R&D needed for the NGNP Project. The R&D activities are organized into five major technical areas: Fuel Development and Qualification, Graphite Development and Qualification, High temperature Materials Qualification, Design and Safety Methods Validation, and Hydrogen Production. The objectives, current status, accomplishments to date, and future plans for each area are discussed in this appendix. To accomplish these objectives, the R&D program draws on the expertise at DOE national laboratories, industry, and a broad array of universities, along with international facilities and expertise accessible to the DOE via the Generation IV International Forum. The R&D program uses technical coordination teams in the major areas of fuels, graphite and materials, and methods to help plan and review the work. A Management Integration Committee consisting of senior managers from each of the national labs (Idaho National Laboratory [INL], Oak Ridge National Laboratory [ORNL], Argonne National Laboratory [ANL]) is used to help raise the visibility of the work at each laboratory and improve understanding of the importance of the work being performed. The results of the R&D are communicated to stakeholders in annual Very High Temperature Reactor (VHTR) R&D meetings held every spring. Participation includes personnel from reactor vendors, universities, the Nuclear Regulatory Commission (NRC), and DOE national labs.

D-1. FUEL DEVELOPMENT AND QUALIFICATION

D-1.1 Background and Objectives

The HTGR concept is based on coated-particle fuels, shown in the upper left of Figure D-1. Such fuels have been extensively studied worldwide over the past four decades. Layers of carbon and silicon carbide (SiC) surround the uranium kernel (the active part of the particle) to form the tristructural-isotropic (TRISO)-coated particle fuel. The HTGR would contain billions of multilayered TRISO-coated particles. Either small cylinders called compacts or tennis-ball-sized spheres called pebbles, as shown in Figure D-1, are made from carbonaceous material with the tiny particles of fuel distributed throughout.

The TRISO layers make this fuel extremely resistant to physical deterioration, thus providing robust protection for the nuclear material and outstanding retention of the radioactive material produced during fission. Extensive testing performed in Germany in the 1970s and 1980s demonstrated that outstanding performance of high-quality low-defect TRISO-coated particle fuels under both normal operation and potential but highly improbable accident conditions can be achieved. It is this performance combined with the passive safety features of modern modular HTGRs that allows these reactors to be located close to industrial complexes where they can provide heat for the high temperature chemical processes and hydrogen for chemical and petrochemical industries, the major objective of the NGNP project.

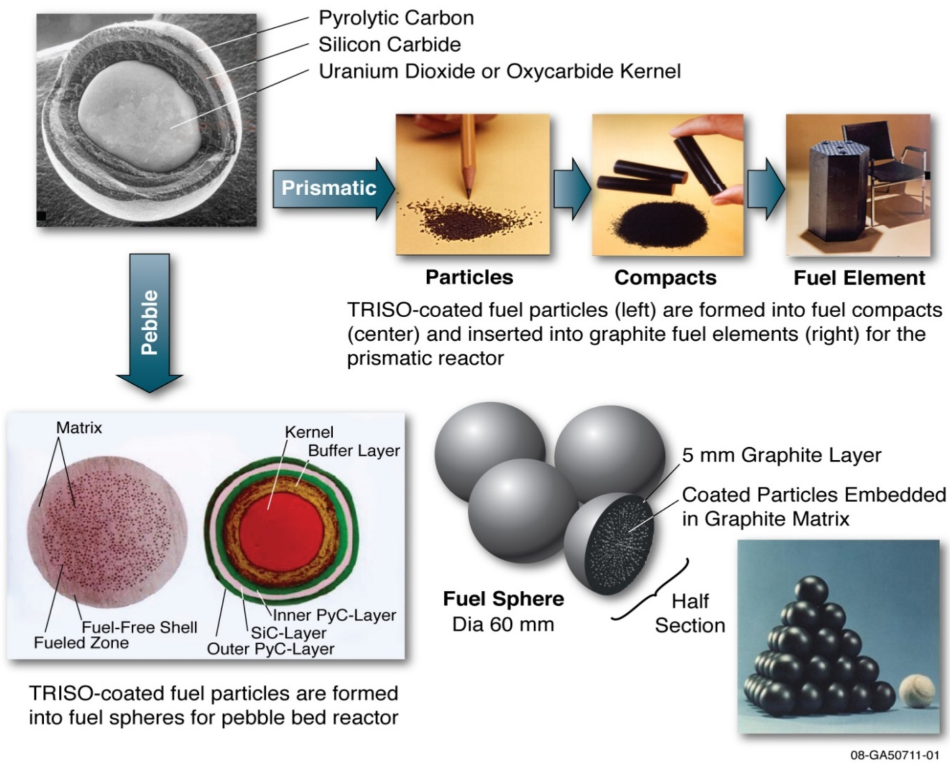

Figure D-1. TRISO fuel and pebble-bed and prismatic-block fuel-element designs.

The objective of the Advanced Gas Reactor (AGR) Fuel Development and Qualification Program is to qualify TRISO-coated particle fuel for use in the HTGR being designed and licensed by the NGNP project.[1] TRISO-coated particles must be fabricated at industrial scale, as opposed to small batches in a laboratory, for use in qualification testing. The testing consists of a variety of 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. The program also contains experiments to provide an understanding of how the fission products—the elements produced when uranium fissions—stay inside or move outside of the coated fuel particles and through the graphite reactor core (this is called the source term). Another important part of the program is the development of fuel performance and source term modeling, and simulation computer tools and the associated physical testing to validate those tools for use in the NGNP design and safety analysis.

The AGR Fuel Development and Qualification Program involves five major program elements:

- Fuel manufacture
- Fuel and materials irradiation
- Safety testing and post-irradiation examination (PIE)
- Fuel performance modeling
- Fission-product transport and source term.

D-1.2 Fuel Manufacture

This element addresses the work necessary to produce coated-particle fuel that meets fuel specifications and performance requirements, and includes process development for kernels, coatings, and compacting; quality control methods development; scale-up analyses; and process documentation needed for technology transfer. This effort will produce fuel and material samples for characterization, irradiation, and accident testing as necessary to meet the overall goals. The plan also identifies work to develop automated fuel fabrication technology suitable for mass production of coated-particle fuel at an acceptable cost.

The uranium-containing kernels are made by a sol-gel process, followed by washing, drying, and calcination to produce UO_2 or UCO kernels. (UCO is a mixture of UO_2, UC, and UC_2.) The coatings are applied in a fluidized-bed coater in a sequential, continuous manner. The coating process for the buffer is based on chemical vapor deposition from a mixture of argon (Ar) and acetylene between 1,250 and 1300°C. The inner and outer pyrolytic carbon (IPyC and OPyC, respectively) layers are deposited from a mixture of acetylene, propylene, and argon between 1200 and 1400°C. The SiC layer is deposited from a mixture of hydrogen or hydrogen and argon, and methyltrichlorosilane between 1500 and 1600°C. Graphite powder and organic binders are used to produce a powder matrix that overcoats the particles. The overcoated particles, and additional matrix for pebble fuel, are then pressed to form the pebble or cylindrical compact. Both fuel forms undergo carbonization and heat treatment at a high temperature to produce the final fuel form.

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. For example, destruct fuel production for German reactors in the 1980s yielded only about 100 defects in 3.3 million particles produced. Specifications are placed on the diameters, thicknesses, and densities of the kernel and layers; the sphericity of the particle; the stoichiometry of the kernel; the isotropy of the carbon; and the acceptable defect levels for each layer. Statistical sampling techniques are used to demonstrate compliance with the specifications, usually at the 95% confidence level.

At its inception, the AGR Fuel Development and Qualification Program had to reestablish the capability to fabricate and characterize TRISO-coated particle fuel in the United States after about a decade long hiatus. Many of the characterization procedures and associated equipment used in the past were still available but needed to be modernized to take advantage of current measurement technology and develop qualified procedures and personnel to meet National Quality Assurance (NQA)-1 requirements. In some cases, such as PyC anisotropy, new more accurate and repeatable methods were developed. The result has been more controlled and reproducible fabrication and much more accurate and precise characterization of this fuel form.

Figure D-2 compares the population standard deviation of coating layer thicknesses from the lab and engineering scale coaters (AGR-1 and AGR-2) with historical U.S., German, and Japanese data. The smaller standard deviation of the AGR fuel demonstrates the tighter process control associated with chemical vapor deposition coating and the enhanced characterization techniques that provide greater precision to the measurements. Systematic fabrication studies, combined with improved characterization capabilities, have also enhanced the understanding of how to fabricate high-quality TRISO fuel. The program is now fabricating high-quality, low-defect (about 1 defect in every 100,000 particles for defective SiC, defective IPyC and exposed uranium) TRISO-coated fuel particles in an engineering-scale coater.2 Placing a U.S. fuel vendor in position to fabricate high-quality TRISO fuel with an improved fundamental understanding of the relationships between the fuel fabrication process, fuel properties, and fuel performance enhances credibility with the NRC with respect to the safety approach for modular HTGRs.

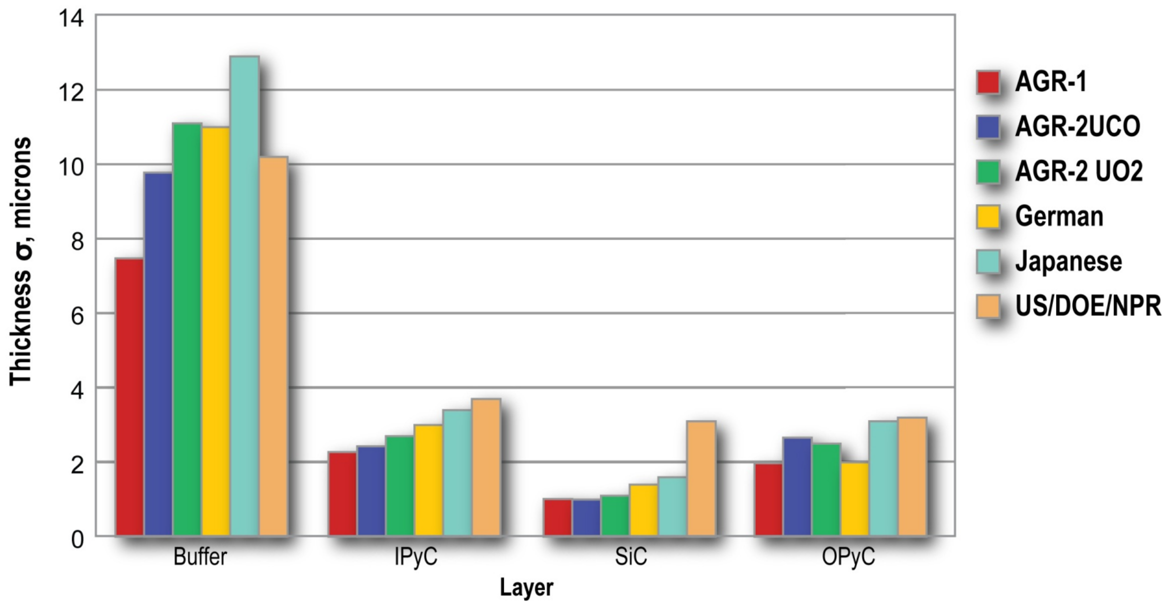

Figure D-2. Comparison of standard deviations of coating layers.

D-1.3 Fuel and Materials Irradiation

Fuel irradiation activities will provide data on TRISO-coated fuel performance under normal operation. The primary objectives include providing data, as necessary, to support fuel-process development, qualify a fuel design and fabrication process for normal operation conditions, support development and validation of fuel performance and fission-product transport models and codes, and provide irradiated fuel and materials as necessary for PIE and safety testing.

Figure D-3 is a radar plot of the important parameters for qualifying fuel performance. The performance envelope for TRISO-coated fuel is shown in terms of five key parameters: fuel temperature, fuel burnup, fuel fast fluence, power density, and particle packing fraction. Envelopes are shown for the successful German and Japanese programs established in the 1980s and 1990s, respectively, along with a prismatic NGNP design.

Because a final core design for NGNP has not yet been established, a bounding envelope has been established in Figure D-3. The irradiations in the AGR program are using this envelope to guide irradiation testing, which is anticipated to bound conditions expected in the NGNP demonstration plant.

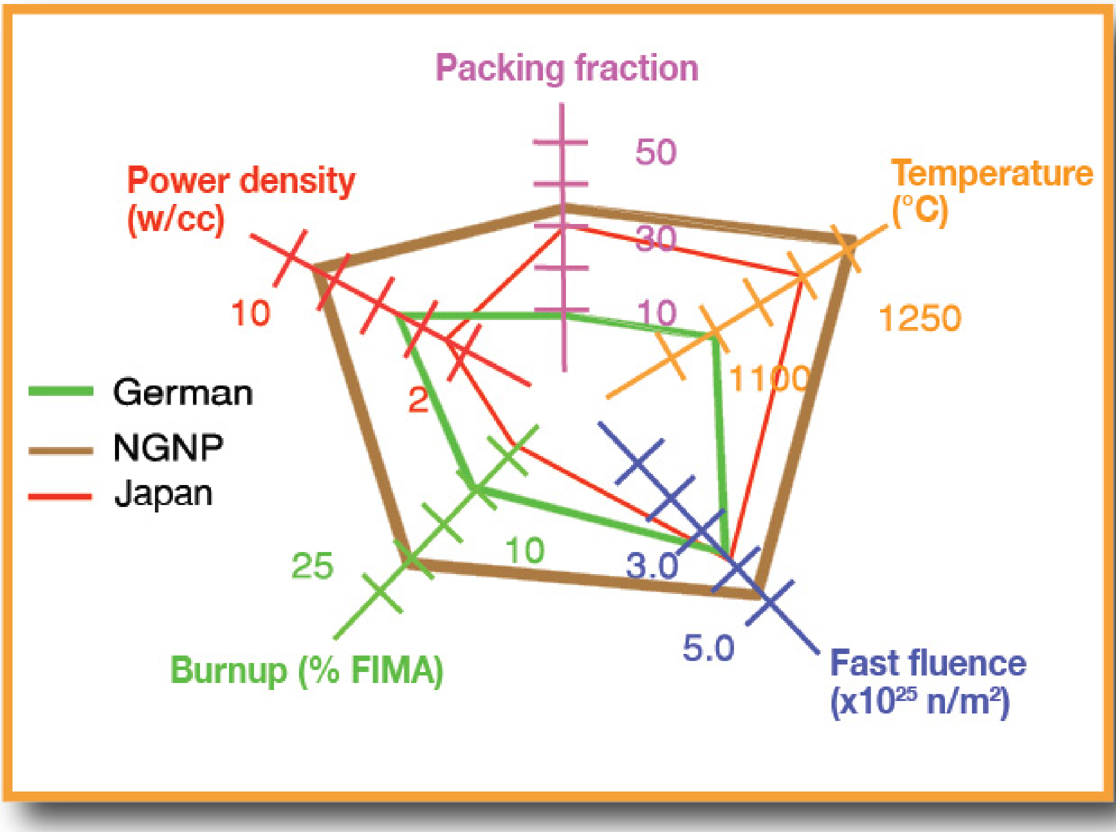

Figure D-3. Radar plot of key parameters for TRISO-coated fuel performance.

Eight irradiation experiments were initially planned for the program. The purpose of the AGR-1 irradiation test, which used laboratory-scale fuel and has been completed, was to shake down the new multicell capsule design, fabrication, and operation to reduce the chances of capsule failures in subsequent irradiation tests and to provide early performance data from laboratory-scale fuel. AGR-2 will be a performance demonstration irradiation of both UO_2 and UCO TRISO with fuel fabricated from an engineering-scale coater and UO_2 TRISO fuel from both laboratory and production scale coaters. Feedback to the fabrication process is expected following both AGR-1 and AGR-2. In AGR-3/4, two separate planned irradiation tests will be combined into one test train to obtain data on the release of fission gases and fission metals from failed particles and their retention in the fuel compact matrix and graphite under a broad range of irradiation conditions (burnup, fluence, temperature) in support of fission product transport model development. Given the statistical nature of coated-particle fuel, a large number of fuel particles are needed to fully qualify the fuel and demonstrate compliance with the fuel-failure fraction limits. AGR-5/6 is one large irradiation that will be used to qualify the fuel for the NGNP. AGR-7 and AGR-8 are irradiations designed to provide data with which to validate fuel performance and fission-product transport models.

The first irradiation test, AGR-1, recently completed approximately 3 years of irradiation. The fuel in AGR-1, composed of a reference fuel and three fuel variants having different IPyC or SiC coating properties, was irradiated to a peak burnup of 19%, a peak fast-neutron fluence of about 4.5×10^{25} n/m^2, and a maximum time-averaged fuel temperature of less than 1250°C. About 300,000 TRISO fuel particles were irradiated without a single particle failure, as indicated by the fission-gas measurements on the purge gas from each of the capsules.[3] Figure D-4 compares the gas release (as measured by the release to birth ratio) for AGR-1 compared with historical U.S. and German data. The gas release is very low, indicative of release from contamination.

This is the best irradiation performance of a large quantity of TRISO fuel ever achieved in the United States, exceeding previous levels of burnup by almost a factor of 2. These results provide a high level of confidence that the AGR fuel program will successfully demonstrate the superior performance capability of TRISO fuel required by the modular HTGR concept. PIE of fuel irradiated in AGR-1 is underway, and safety testing began in FY 2011.

The second irradiation, AGR-2, is underway. It contains both UCO and UO_2 TRISO produced at laboratory, engineering and production scale from U.S. and international collaborators (France/AREVA and South Africa/Pebble Bed Modular Reactor [PBMR]). The UCO will be irradiated at prismatic conditions while the UO2 TRISO will experience conditions typical of a pebble-bed HTGR. The third irradiation, AGR 3/4, is being assembled, and the start of irradiation is scheduled for December 2011.

D-1.4 Safety Testing and PIE

This program element will provide the facilities and processes to measure the performance of TRISO fuel under normal operating and accident conditions. This work will support the fuel manufacture effort by providing feedback on the performance of kernels, coatings, and compacts. Data from PIE and accident testing will supplement the in-reactor measurements as necessary to demonstrate compliance with fuel performance requirements and support the development and validation of computer codes.

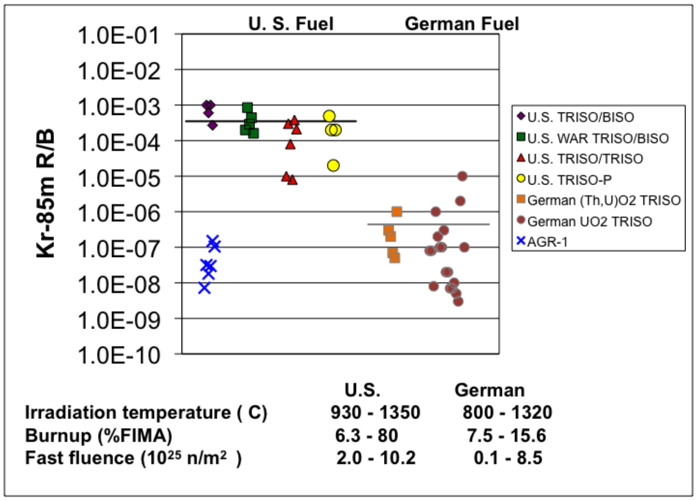

Figure D-4. Comparison of gas release form AGR-1 with historic German and U.S. data.

A variety of nondestructive and destructive techniques will be used during PIE to characterize the state of the fuel after irradiation and after safety testing of irradiated fuel. Techniques include:

- Metrology to characterize shrinkage or swelling of the fuel
- Optical metallography to characterize the state of the kernel and coatings
- Scanning electron microscopy and microprobe to characterize distribution of fission products within the particles, including evidence of chemical attack of SiC
- Gamma scanning of the fuel and other test components to determine fission-product migration, radionuclide inventories and burnup

- Chemical analysis via a leach-burn-leach process[a] to determine fuel-particle failure fraction
- Compact deconsolidation and gamma spectral measurement of key fission products of individual particles using the irradiated microsphere gamma analyzer (IMGA) to establish fission-product retention on a particle-by-particle basis
- Traditional burnup analysis as part of the series of PIEs. Following deconsolidation, a few particles will be sent for destructive radiochemical assay to determine the concentration of transuranics and minor actinides, from which burnup can be assessed.

An important goal of this program is to determine the performance of the fuel under high temperature accident conditions because integrity of the coated particle to high temperature is a crucial part of the safety case for modular HTGRs. In particular, three environments are of interest: helium, air, and steam. The irradiated TRISO fuel will be exposed to these environments for up to 500-hours. Temperatures from 1300 to 1800°C are planned to define the accident response and establish the fuel margin. The experimental facility will consist of a flowing-gas furnace to maintain a fuel specimen at specified temperatures with a cold finger to trap the condensable fission products and a cold trap for trapping fission gases. The cold finger and cold traps are analyzed using traditional gamma spectroscopy, and the cold finger can also be leached for radiochemical analysis. The two furnaces that will be used with flowing helium (one at INL and one at ORNL) are shown in Figure D-5. A new furnace will need to be developed and qualified for testing in air and steam.

The data needed from safety testing are fission-product release, TRISO-coating layer integrity, and fission-product distribution within fuel particles (fission-product attack of the SiC layer) and fuel compacts. Apparatus to perform safety tests in oxidizing atmospheres will be developed later in the program. The anticipated release behavior of the fission products is somewhat different than in other nuclear fuels. For intact particles, silver (Ag-110m) is released first because of its greater mobility through the SiC coating of the TRISO particle fuel. This is followed by Cs-134 and Cs-137, which can diffuse through the pyrolytic carbon (PyC) and SiC layers after long times at these temperatures. Last, because of holdup by PyC layers, the fission gas Kr-85 is released. PIE is also planned following elevated temperature safety tests, similar to those after irradiation is also planned. At the time of this writing, PIE of AGR-1 is underway, and a limited number of accident safety tests have been completed.

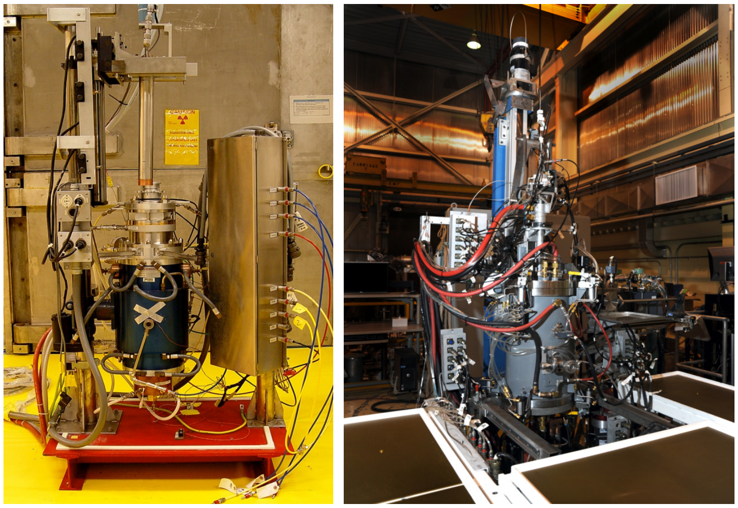

Figure D-5. Furnaces used in accident safety testing of TRISO fuel: (a) ORNL Core Conduction Cooldown Test Facility (b) INL Fuel Accident Condition Simulator.

a. In this technique, the fuel compact or pebble is leached with acid to remove any fission metals (e.g., cesium) released from defective fuel particles and heavy-metal contamination. The fuel element is then burned in air to remove all carbon matrix material, the OPyC layers, and also the IPyC/buffer layers of any particles with failed SiC. Particles that remain are then leached with an acid solution to remove any exposed uranium that had been enclosed by an intact pyrocarbon layer. The measurement of the free uranium is then converted to a SiC defect fraction.

D-1.5 Fuel Performance Modeling

Fuel-performance modeling addresses the structural, thermal, and chemical processes that can lead to coated-particle failures. It also addresses the release and transport of fission products from the fuel kernel, through the coatings and matrix to the reactor coolant system. Physical models and computer programs have been developed and will be validated as necessary to support fuel fabrication process development and plant design and licensing.

New models are currently being developed in the United States that represent a first-principles-based mechanistic, integrated, thermal-mechanical-physio-chemical-irradiation performance model for particle fuel, which has the proper dimensionality yet captures the statistical nature and loading of the fuel. The mechanistic model for coated-particle fuel considers both structural and physio-chemical behavior of a particle-coated fuel system during irradiation. The INL model, called PARFUME,[4] 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 (IAEA). Successful benchmarking of the fuel-performance model has resulted in NRC's desire to use the model as part of their activities in confirming the results from other simulations. Irradiations of the specific coatings are also planned to better characterize the key material properties necessary to calculate fuel performance, including irradiation-induced creep of PyC, strength of SiC and PyC, and other thermomechanical properties.

D-1.6 Fission Product Transport and Source Term

This element will address the transport of fission products to the exclusion area boundary that are produced within the coated particles to provide a technical basis for radiological source terms for HTGRs under normal and accident conditions. The fission-product behavior task will provide primary source-term data needed for licensing. The technical basis will be codified in design methods (computer models) validated by experimental data as necessary to support plant design and licensing. Currently, testing is underway to evaluate the permeation of tritium through potential high-temperature metallic alloys anticipated at the high outlet temperatures in HTGRs.

D-1.7 Fuel Acquisition and Qualification Strategy

A fuel acquisition strategy was established in 2007.[5] That report, detailed a technical assessment of potential fuel vendors for the first core of NGNP. It was conducted by an independent group of international experts based on input from the three major reactor vendor teams. Part of the assessment included an evaluation of the credibility of each option, along with a cost and schedule to implement each strategy compared with the schedule and throughput needs of the NGNP project. This report was updated in response to PBMR's decision to discontinue their pebble bed reactor project. The report outlined the cost and schedule to qualify fuel for both pebble prismatic options using UCO TRISO fuel particles. While credible options were identified, since that time, many changes in the assumptions underlying the strategy and in externalities that have happened in the interim require that the options be reevaluated once the preliminary design activities commence.

D-1.8 Fuel Path Forward

The AGR program has been extremely successful to date. The three key programmatic goals of the program are to (a) stand up a domestic vendor capable of fabricating HTGR TRISO fuel, (b) qualify the TRISO fuel, and (c) qualify the source term used in HTGR safety analysis. The key remaining activities necessary to meet these programmatic goals are:

- Develop a U.S. vendor (90% complete as of this writing)
- Complete final fuel fabrication activities to stand up a pilot line fuel fabrication capability that can be used (in replicate) to produce the first NGNP core
- Complete fabrication of qualification test fuel
- Qualify TRISO fuel (50% complete as of this writing)
- Complete AGR-1 safety testing and PIE to confirm robustness of TRISO fuel under accident conditions
- Complete AGR-2 irradiation of industrially fabricated UCO and UO2 TRISO fuel
- Complete AGR-2 safety testing and PIE
- Complete development of a furnace to evaluate moisture and air ingress effects of fuel under accident conditions
- Complete irradiation and accident safety testing in the AGR 5/6/7 campaign (including margin testing in AGR-7)
- Qualify Source Term (25% complete as of this writing)
- Complete AGR-3/4 irradiation, safety testing and PIE to demonstrate fission product retentiveness of graphite and fuel matrix materials and update database on fission product transport rates in HTGRs to support source term evaluations
- Complete fission product validation irradiation and safety testing in AGR-8
- Complete fission product plateout and liftoff studies to support source term evaluations in the primary system and reactor building
- Complete tritium permeation testing for potential intermediate heat exchanger alloy systems.

Beyond the AGR program, once the preliminary design activities are nearing completion, there is a need to re-evaluate the fuel acquisition strategy and the specific test conditions being used in the program to ensure they meet the needs of the design and the deployment strategy for the project.

D-2. GRAPHITE DEVELOPMENT AND QUALIFICATION

D-2.1 Background and Objectives

In HTGRs, graphite physically contains the fuel and comprises the majority of the core volume. It also forms the inner and outer reflector (nonfueled) regions of the core. Graphite has been used effectively in the past as a structural and moderator material in both research and commercial HTGRs as shown in Figure D-6, thereby establishing graphite as a viable structural material for high temperature reactor cores.

Figure D-6. Graphite core components.

However, while the general characteristics necessary for fabricating available graphite are understood, the specific performance of currently available nuclear-grade graphite at the anticipated operating conditions is unknown. Previous nuclear-grade graphite, such as H327 and H451 used in Fort St. Vrain (FSV), required an extensive development program that covered both fabrication processes and actual performance data to determine if they were suitable for reactor applications. Unfortunately, historical nuclear grades are no longer produced, and the raw feedstock material (e.g., petroleum and pitch coke) used to fabricate the graphite is no longer available from the sources historically used. Thus, the new graphite grades and associated fabrication processes must be qualified. The approach to qualification outlined here is consistent with historical assessments of graphite qualification needs identified by gas reactor vendors, the NRC, and the American Society of Mechanical Engineers (ASME). The approach also factors in international experience, particularly in the United Kingdom, where the current incomplete understanding of in-pile graphite behavior in British gas cooled reactors is causing the British utility to gather such data to respond to regulatory inquiries about the safety of those reactors in light of unexplained cracks found in graphite during reactor operation.

The new graphite grades will use new sources of unique petroleum and pitch coke in previously established fabrication processes. There is no irradiation experience with these new graphite types, so there is currently no way to quantitatively predict how they will actually perform within a reactor environment. While the graphite will be structurally stable for some period of time, the lifetime (as a function of dose and temperature) of the current grades of graphite is unknown. This is an important safety issue in that the stability of the graphite must be understood to determine the structural safety of the internal core. Therefore, the new graphite grades need to be characterized to demonstrate that they exhibit acceptable nonirradiated and irradiated thermomechanical and thermophysical performance. Fortunately, the technology for fabricating nuclear-grade graphite has been established, and a number of graphite types are commercially available for testing and qualification.

D-2.2 Graphite Development and Qualification Program

As part of the acquisition strategy for graphite,[6] four major graphite grades from four vendors around the world (GrafTech and Mersen in the United States, SGL in Europe, and Toyo Tanso in Japan) suitable for use within both a pebble bed and prismatic HTGR design have been selected for further evaluation. Minor grades and historical samples have also been incorporated into the program to help further elucidate the impact of fabrication processes and coke sources on the resulting microstructure of the graphite and its performance under irradiation. Major grades include NBG-18 (SGL), PCEA (GrafTech Inc.), IG-110 (Toyo Tanso), and 2114 (Mersen, formerly known as Carbonne Lorraine) while minor grades include PGX, HLM, PCIB, NBG-17, IG-430, and others. The vendors for the major graphite grades are capable of producing the core for the first NGNP.

Thus, the objective of the graphite program is to develop the qualification data set of thermomechanical and thermophysical properties for unirradiated and irradiated candidate grades of graphite for HTGRs.[7] Where practical, other grades of graphite may be tested and characterized to provide a baseline for comparison or to help understand material property changes for the graphite grades. These activities will demonstrate the performance of various graphite types, including irradiation dose levels, anticipated applied stress levels, and maximum core temperatures.

The program consists of statistical characterization of unirradiated graphite material properties to establish the lot-to-lot, billet-to-billet, and within-billet variability of the material. This characterization will establish a quantitative baseline of material properties from which changes under irradiation can be understood. Significant effort has gone into establishing the analytical measurement laboratories (see Figure D-7) required to perform extensive characterization of nuclear graphite under consideration for HTGRs being developed by the NGNP project. This task consisted of procuring, setting up, and calibrating state-of-the-art analytical testing equipment and developing protocols and testing methods to make accurate, repeatable measurements on graphite. An extensive characterization effort is currently underway at INL and ORNL (Figure D-7) to establish the material properties before irradiation on a series of large graphite chunks or blocks, called billets, from the four major grades selected.

Figure D-7.Graphite characterization laboratories, showing thermal and physical characterization equipment such as Laser Flash Diffusivity, thermal dilatometer (coefficient of thermal expansion measurements), Thermal Gravimetric Analysis (TGA), and ultrasonic physical measurement equipment.

Variability of key nonirradiated material properties can be as low as 3% and as high as a factor of 4 depending on graphite grade and the specific material property. Irradiation will further degrade some of the key properties such as thermal conductivity and density. The large variability must be accounted for in the associated design rules and material property data sets used for graphite mechanical design and safety analysis.

The historic thermomechanical and thermophysical irradiation performance database of graphite focused largely on moderate doses (5 to 7 dpa [displacements per atom]) and modest temperatures (400 to 850°C), which are typical of the design service conditions of FSV and older German pebble bed reactors. There are much less data at the higher temperatures and doses anticipated for the higher temperature designs. For prismatic designs, peak graphite temperatures could be as high as 1,000 to 1,250°C and the expected peak graphite doses in the reflectors could be 5 to 6 dpa with operation service lifetimes of about 6 to 10 years. A series of eight irradiations are planned to establish the thermomechanical and thermophysical response of the major grades of graphite as a function of temperature and radiation dose as shown in Figure D-8. Advanced Graphite Capsule (AGC) experiments AGC-1 through AGC-6 will be conducted at INL's Advanced Test Reactor (ATR) to establish the behavior of graphite in the temperature/dose envelope for NGNP. HTV-1 and HTV-2 will be conducted in the High Flux Isotope Reactor (HFIR) at ORNL to establish graphite behavior under accelerated temperature and damage conditions so that AGC-6 can be designed properly, accounting for shrinkage/swelling and creep anticipated at the high temperature and high dose. These irradiations will contain specimens of sufficient size, number, and type to support statistical assessments necessary to capture the inherent variability in graphite; to support traditional American Society for Testing and Materials (ASTM) International requirements for sample analysis; and to more completely characterize the physical, thermal, and mechanical properties of the irradiated graphite. A schematic of the test train is shown in Figure D-9. Over 400 samples of graphite can be irradiated in this test train. The temperature-fluence envelope is anticipated to bound that expected in a prismatic NGNP.

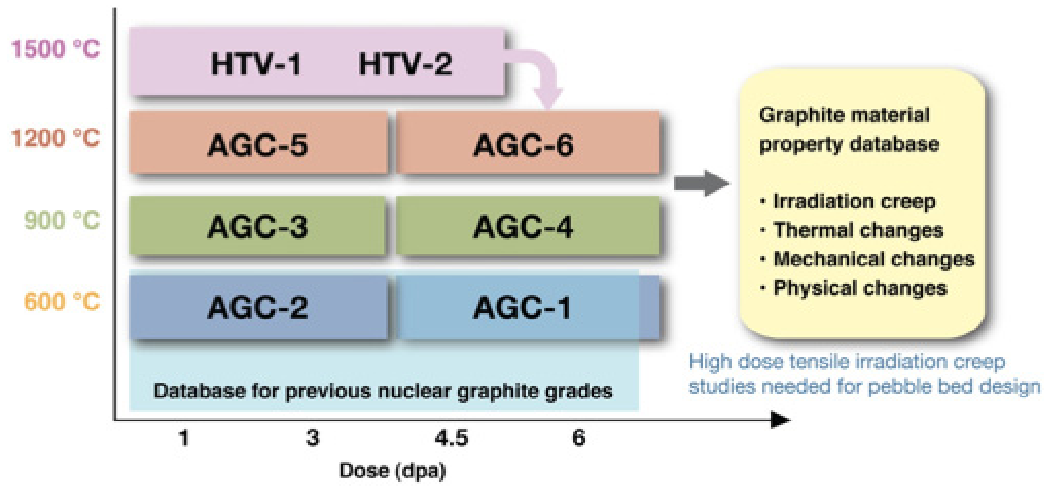

Figure D-8. Irradiations planned to establish the thermomechanical and thermophysical response of the major grades of graphite as a function of temperature and radiation dose.

The graphite technology needed to satisfy requirements for the pebble bed are anticipated to be somewhat more substantial. While lower peak graphite temperatures of 1000 to 1100°C are expected, much higher doses are anticipated (20–25 dpa) because of the vendor's desire to make the reflector a facility lifetime or near-lifetime (changed once during the life) component. Thus, the new graphite grades need to be fabricated and characterized at these conditions to demonstrate acceptable performance within the more demanding environment. Additional irradiations would be needed for a pebble bed HTGR to address the behavior of the graphite at higher dose, which could be accommodated (at additional cost) in the current graphite irradiation program.

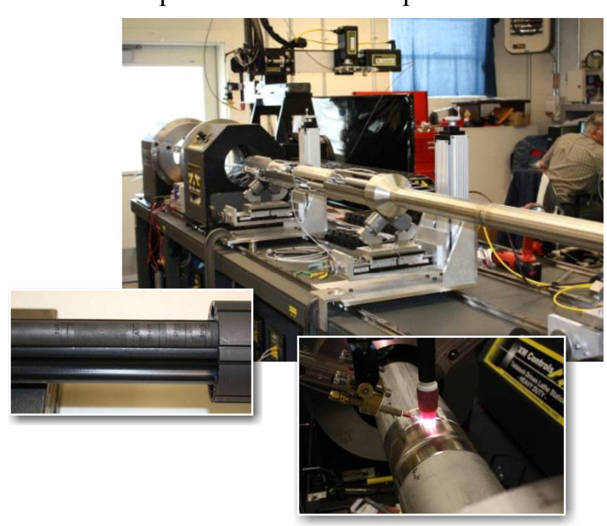

Figure D-9. Photographs of AGC-1 test train during assembly.

Extensive post-irradiation characterizations are planned to establish the change in relevant material properties as a function of temperature and neutron dose. A complete properties database for these new grades of graphite is required to describe the graphite's physical, mechanical, and oxidation properties. Of particular interest is the graphite's irradiation-induced creep, which is critical to determining the lifetime of the graphite under irradiation. From these data sets, constitutive relations will be established for use in a detailed predictive thermomechanical finite element model. Moreover, the data must be statistically sound and take account of in-billet, between billets, and lot-to-lot variations of properties. These data are needed to support the ongoing update and improvement of the new risk-derived graphite code rules recently issued in the ASME Boiler Pressure Vessel Code, Section III, Division 5. ASME codification of graphite design and construction rules will support the NRC in its evaluation and acceptance of this material for use by the NRC and reduce the risk to the reactor designer by establishing a safe operating envelope for graphite.

Beyond the near-term graphite qualification program, a more complete evaluation of the fabrication parameters and raw material constituents' influence on graphite behavior will be required for full commercialization of the nuclear-grade graphite technology in the long term. Appropriate graphite recycling and disposal options must also be considered to reduce the waste volume and the attendant costs of disposal. Recycle is considered a long-term strategy, and would only be pursued by vendors when large numbers of gas reactors are deployed. The magnitude of the R&D program necessary to establish a standard nuclear-grade graphite, whether from a new coke source and/or from recycled material for use within any HTGR design, cannot be firmly estimated today given (a) the insufficient knowledge of the linkage between graphite fabrication, material properties, and in-reactor performance, (b) the more aggressive anticipated operating conditions for the high temperature process heat applications, and (c) issues related to long-term source availability and variability. It is anticipated that the work proposed to qualify graphite for the initial HTGR cores will provide the strong technical basis needed to establish a long-term graphite development and qualification program that meets these more ambitious commercialization goals.

As of this writing, the baseline statistical characterization of the thermomechanical and thermophysical properties of one large billet of one of the major graphite grades is complete, and characterization for a billet of a second grade is underway. Characterization of the 425 samples in both AGC-1 and AGC-2 prior to irradiation is also complete. The first capsule, AGC-1, is complete, and irradiation of the second capsule, AGC-2, is nearing completion. PIE of the AGC-1 graphite samples has just started. Extensive studies on graphite-air oxidation have been completed to better understand mechanisms of oxidation as a function of temperature, microstructure, and air concentration to support both chronic oxidation concerns and accident safety evaluations. Advanced failure models for graphite have been evaluated based on measurements of graphite in complex combinations of potential multiaxial stress states. A comprehensive non-destructive examination (NDE) program has been initiated to address both the flaws in as-fabricated large graphite components as well as to develop new in situ inspection (ISI) techniques, which will be important to monitoring the actual behavior of the core components in the reactor. Finally, multiple fundamental studies (through the Nuclear Energy University Program and international collaborations such as IAEA) have been initiated to better understand the damage mechanisms and behavior of graphite under irradiation. This improved understanding of the fundamental principles underlying the behavior of graphite is being used to assist in the formation of sophisticated analytical models to better predict the graphite behavior while in a reactor. These models and increased understanding were helpful in the development of the ASME code for use of graphite in nuclear applications. ASME has recently approved this new code.

D-2.3 Graphite Path Forward

The key activities necessary to qualify graphite for use in NGNP include:

- Complete post-irradiation characterization of low temperature graphite samples from AGC-1 and 2 capsules
- Complete medium and high temperature irradiations (AGC-3, 4, 5, 6) and associated post-irradiation characterization
- Complete oxidation and NDE studies for graphite
- Complete modeling activities to improve fundamental understanding of graphite

D-3. HIGH TEMPERATURE MATERIALS QUALIFICATION

D-3.1 Background and Objectives

HTGR outlet temperatures above 750°C, depending on the application need, 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 this piping and the equipment through which the helium flows, called the pressure boundary, will maintain its integrity. Design of the pressure boundary and the materials used in these applications must meet the requirements of the nuclear section of the ASME Code. Currently, high temperature alloys and associated ASME codes for reactor applications are approved only up to 760°C. Thus, the goal of high temperature materials R&D is to obtain the performance data required to support the development of these high temperature components and associated design codes over the broader range of envisioned outlet temperatures for HTGRs to support co-generation of steam and electricity at lower temperatures (750 to 800°C) and hydrogen production and hot gas delivery at higher temperatures (850 to 950°C) for a variety of end user applications.[8,9]

D-3.2 Metallic Options

A number of solid-solution-strengthened, nickel-based alloys have been considered for application in heat exchangers and core internals for an HTGR. The primary candidates are Inconel 617, Haynes 230, Incoloy 800H, and Hastelloy X. Of these alloys, only Incoloy 800H is currently approved for high temperature design in the ASME Code and only up to 760°C. As the outlet temperature increases from 750 to 950°C, the number of potential alloys decreases and the specific material issues change. Based on the technical maturity, availability in required product forms, experience base, and mechanical properties at elevated temperatures, all of the NGNP pre-conceptual design studies have specified Alloy 617 as the material of choice for heat exchangers. A draft ASME code case for Alloy 617 was also developed in the past. Although action was suspended before ASME accepted the code case, this draft code case provides a significant head start for achieving material codification. Similarly, Alloy 800H, which is already listed in the nuclear section of the ASME code, is the material of choice for control rod sleeves, although the maximum use temperature and time need to be increased. For steam generations, Alloy 800H is the preferred alloy because of experience with previous HTGR steam generators and because of its Code status. Alloy 800 H and Hastelloy X are potential options for internal core metallics such as core barrel and core support structure.

D-3.3 High Temperature Materials R&D

The objective of the high temperature materials R&D program is to establish the relevant thermomechanical performance data to support development of the high-temperature components operating between 750 to 900°C. Creep, creep-fatigue, aging, and environmental degradation testing is planned using the candidate high-temperature alloys such as Incoloy 800H and Inconel 617 (Figure D-10). Constitutive models are also needed to describe the behavior of the alloy in tensile loading at elevated temperatures. Thick and thin sections of base material, weldments, and other joints such as diffusion bonding will be evaluated given the different design options under consideration for the intermediate heat exchanger (IHX). Depending on the outlet temperature, additional high temperature data may be needed to support relevant ASME code cases or code revisions for the material.

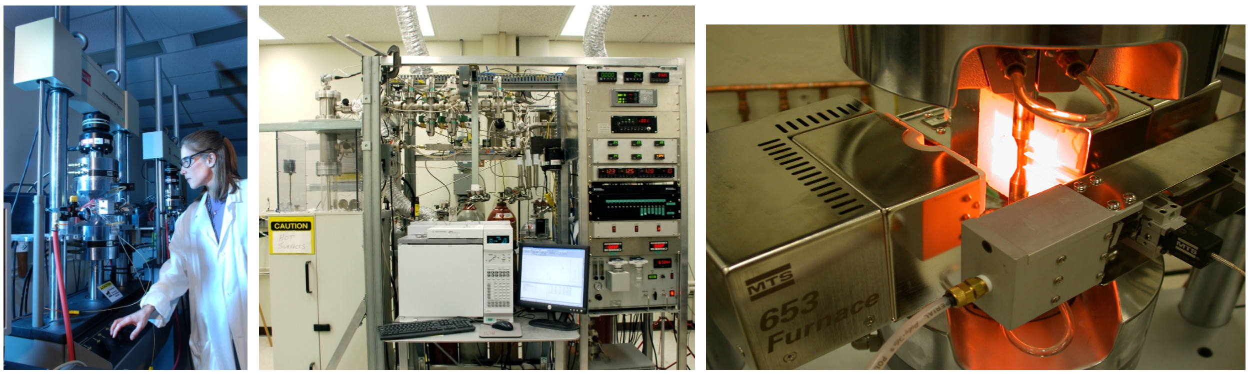

Figure D-10. Examples of high temperature material testing: creep fatigue testing (left), controlled helium impurity test loop (center), creep-fatigue specimen at 1000°C (right).

Additional scoping studies of potential degradation of the properties of material candidates are required to characterize the high temperature interaction with the anticipated HTGR helium environment. Phenomenological models for environmental degradation and greater understanding of the kinetics of degradation are needed to help bound the requirements for controlling impurities in primary and secondary helium during HTGR operation. Tests are specified to determine environmental effects on microstructure and properties.

The availability of large components, ease of fabrication, and nuclear service experience with the A508/533 steels strongly favor their use in the reactor pressure vessel for the NGNP, a near-term application of an HTGR. This material selection reduces the amount of R&D needed. The majority of additional required information is related to long-term aging behavior at HTGR vessel temperatures, which are higher than those commonly encountered in the existing database from light water reactor experience in the anticipated HTGR environment.

As key components are designed, the R&D required to establish the requisite ISI techniques will be developed. Prototype testing of key components is envisioned in a high temperature flow loop to characterize overall behavior under prototypic HTGR flow conditions and to validate ISI techniques.

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 alloy is underway to understand its mechanical behavior at high temperatures and ensure that it does not degrade after long-term exposure to low levels of moisture and other impurities 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 to modify 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 is performed after each test to understand the underlying behavior at the microscopic scale that contributes to the measured mechanical behavior of the metal. All of the high temperature performance data generated thru testing will be needed to meet ASME code requirements to ensure structural adequacy of the high temperature metals via an established process, a part of the NGNP licensing process. As 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 operation of the reactor. Integrated testing of key high temperature components, or testing them with the connections and in the environment experienced as part of HTGR, will be needed to characterize the integrated behavior and validate the inspection techniques for use in NGNP. An acquisition strategy for the large components was established.[10,11] An assessment of major alloy grades and available large components determined that there will be few issues associated with required product forms of the alloys under study.

Recent testing on the creep behavior of Alloy 617 indicates that the majority of the alloy's life will be spent in tertiary creep regime as shown in Figure D-11, not in primary and secondary creep. ASME design rules written for typical stainless-steel behavior must be modified to account for the behaviors in Alloy 617, or unrealistic lifetime predictions will severely limit design life. Creep-fatigue of base metal and weldments is the degradation mechanism of primary concern. Current mechanical testing experiments focus on determining the effect of tensile hold time on cycles to failure and properly summing combined effects of creep and fatigue for lifetime prediction.

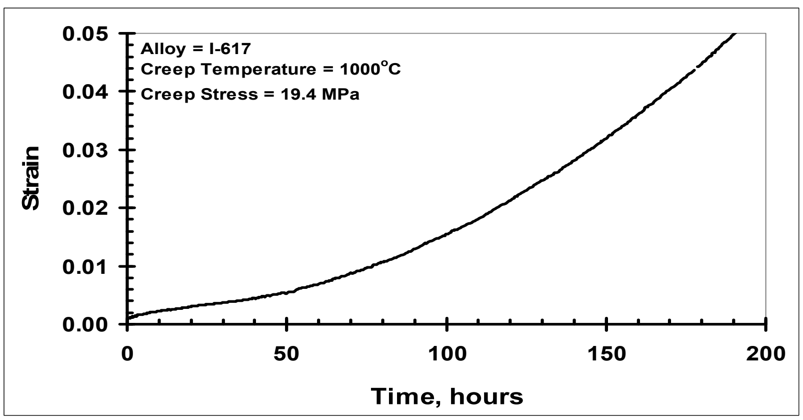

Figure D-11. Mechanical response of Alloy 617 indicating tertiary creep.

A low-velocity flow loop has been developed to evaluate the effects of the low level of impurities in helium on nickel-based alloys. As expected, NGNP helium chemistry is not inert with respect to nickel-based alloys. Testing is focused on determining an acceptable range of operating chemistry for the primary helium coolant. The results indicated that a slightly oxidizing chemistry results in maximum component life.

D-3.4 High Temperature Materials Path Forward

Creep and creep-fatigue testing need to continue to support codification of Inconel 617 and extension of Alloy 800H in the ASME code. Theoretical work on the development of the proper type of constitutive relations and design rules to capture the behavior being measured in the laboratory is also necessary. Inspection techniques and technology need to be established at the same time as preliminary design configuration is established for the NGNP.

By the end of FY 2012, all of the testing needed to allow design using SA508/533 for normal operation of a HTGR for 60 years will be completed. In addition, all of the data needed to extend the code case for Alloy 800H will be available in FY 2012. For Alloy 617, testing will need to continue until 2015 before all of the data necessary for codification are available.

D-4. DESIGN AND SAFETY METHODS DEVELOPMENT AND VALIDATION

D-4.1 Background and Objectives

The methods R&D area focuses on developing and validating tools to assess the neutronic and thermal fluid behavior of an HTGR plant. An important activity in designing and licensing an HTGR is to confirm that the intended HTGR analysis tools can be used confidently to make technical decisions, ensure that all reactor systems are safe, and meet the design performance objectives. The R&D activities defined in the design methods development and validation program[12] will ensure that tools used to perform the required calculations and analyses are validated and can be trusted. The methods R&D tasks are designed to ensure that the calculational envelope of the tools used to analyze HTGR reactor systems fully encompasses the operational and transient envelope of the HTGR. Thus the primary objectives of the Design and Safety Methods Development and Validation R&D are to:

1. Define the calculational envelope required to analyze candidate HTGR reactor systems.
2. Define and develop an NGNP Evaluation Model capable of performing all the required calculations encompassed by the calculational envelope developed in primary objective 1. This Evaluation Model will provide reference results against which licensee and regulator simulation results can be compared.
3. Design and execute a matrix of experiments that will produce a comprehensive data set used to enable a comprehensive verification and validation (V&V) of the NGNP Evaluation Models developed by DOE, NRC, and the vendors.
4. Support near-term deployment of the NGNP for process heat and electricity production in the United States (2021) by reducing market entry risks posed by technical uncertainties associated with thermal, fluid, and neutronic phenomena
5. Develop an uncertainty and sensitivity analysis capability that can be used to identify and prioritize gaps in the ability of an Evaluation Model to compute safety and performance parameters within confidence intervals.
6. Utilize international collaboration mechanisms to extend the value of DOE resources (e.g., GIF VHTR activities).

To date, since the NGNP design has not formally been selected, the R&D effort to design and validate design and safety methods has focused on primary objectives 1, 2, and 3. However, all work performed to date will have to be evaluated, upon selection of the NGNP design, to confirm the degree to which it is applicable to the design of choice.

As a starting point, DOE researchers have participated with colleagues at NRC using a well established expert solicitation process to establish a ranking of important events that might occur during accidents in HTGRs. An optimal allocation of resources for safety-related R&D activities was developed based on the importance of the specific accident-related event to the overall safety of HTGRs and the associated level of technical knowledge. Areas where the importance is high and the knowledge is low receive the greatest attention. Areas of focus include: (a) assessing, benchmarking, and improving reactor physics and kinetic methods and data for prismatic and pebble-bed HTGRs; (b) evaluating important phenomena that influence thermal-fluid behavior in HTGRs, and establishing relevant separate effects and scaled integral experiments for verification and validation; (c) developing experiments to validate reactor cavity cooling system behavior; and (d) evaluating and establishing system-level codes appropriate for HTGR safety. The normal and off-normal scenarios and the associated physical phenomena that the reactor simulation programs can calculate with confidence define the calculational envelope of software and data used for HTGR designs. Software tools can only be used confidently once the results they produce have been shown to be in reasonable agreement with first-principle results, analytic solutions, and data. The NRC expects that the scope of these results, solutions, and data describe completely the highly ranked phenomena inherent in all operational conditions and important accident scenarios for the HTGR.

Because actual operating experience is limited, a series of computational benchmarks of core simulation tools is underway for both pebble bed and prismatic reactors as shown in Table D-1. Based upon smaller experimental facilities and proposed designs, the benchmarks consist of tools under development by NRC, those under development for DOE as part of the NGNP project, and vendor tools. Together, these benchmarks will provide data necessary to validate the computer programs and models (the *Evaluation Model*) used to validate NGNP.

Table D-1. Benchmarks and facilities suitable for NGNP code validation and verification.

Type of Benchmark	Physics Captured	Examples
Critical Facility	Flux profiles, global reaction rates, k_{eff}, rod worth, isothermal temperature coefficients	ASTRA, PROTEUS, VHTR-C
Engineering/Test Reactor	Flux profiles, global reaction rates, k_{eff}, rod worth, reactivity coefficients, power profiles, coarse temperature maps, global transient behavior, passive and active system dynamics, fission-product transport	High Temperature Reactor (HTR)-10 High Temperature Test Reactor (HTTR) International Reactor Physics Experiment Evaluation Project (IRPhEP)
Pin/Pebble or Block/Pebble Box Standard Problems	Neutron scattering and absorption (heterogeneity, resonance effects, self-shielding), depletion	Simplified HTTR Block Model CRP-5 Pebble Box, HTGR Depletion Benchmark (ORNL)
2D Isothermal Subcore Standard Problem	Spectral coupling (R-q), flux profiles, local absorbers	HTTR 1/12th, or 1/6th core axial planes
3D Partial or Full Core Steady State Standard Problem	Spectral coupling (axial and radial), flux profiles, rod worth, and isothermal temperature coefficient predictions	HTTR and HTR-10 initial criticality (CRP-5), General Atomics–Modular High Temperature Gas cooled Reactor (GA-MHTGR) Neutronics Benchmark
R-Z or 3D Core with Specified Boundary Conditions - Fixed temperature map - Fixed power map - Fixed inlet coolant conditions	Core transient response predictions: - Predicted power and flux profiles - Thermal fluid maps (pressure, flow, temperature) - Predicted criticality condition, hot steady-state - Wide range transient response	PBMR400 Coupled Core Transient Benchmark, Proposed Block CCTB, HTTR and HTR-10 start-up core (CRP-5)
Integral Core Thermal Fluid Test Facility	Core Thermal Fluid behavior during and after a pipe break: - Steady state core heat transfer characteristics - Temperature profiles during a loss of forced cooling - Air ingress rates and characteristics - Natural Circulation behavior under loss of forced cooling	High Temperature Test Facility and associated separate effects experiments High Temperature Test Facility (South Africa) High Pressure Test Facility (South Africa) Helium Test Facility (South Africa)

Type of Benchmark	Physics Captured	Examples
Ex-core Heat Transfer (RCCS) Facility	Vessel Heat rejection rates and dependencies: - Natural circulation flow patterns between the vessel and RCCS risers - Effect of dust on heat rejection - Water and air-cooled RCCS performance parameters	Natural Circulation Shutdown test Facility and associated separate effects experiments
CFD Benchmarks	Fundamental fluid behavior in simple geometries and conditions: - Flow patterns and temperature profiles around core structures - Flow patterns, temperature profiles, and sensitivities between blocks - Natural circulation profiles inside the core	ASME standard problems

The NGNP core simulation team made considerable progress in construction of this Evaluation Model for both pebble bed and prismatic core simulation. Well-established computer codes used in commercial light water reactor analysis are not adequate for these reactor concepts so the team has assembled a set of modified commercial, university, and national laboratory tools, supplementing them with new codes when the existing ones would require too much modification. The result is a combination of fast low fidelity simulation tools for rapid design and sensitivity studies and complex high-performance computer models for confirming the faster codes or for detailed investigations of complex phenomena such as heat transfer near the walls of pebble bed reactors as shown in Figure D-12.

All of the codes (developmental or commercial) used for NGNP design and analysis must be subjected to a rigorous qualification process before they can be used for a license application. NGNP Methods R&D staff are working with the NRC to jointly develop and execute a set of large-scale experiments to provide safety-related data that will be used independently by reactor designers and the NRC to validate modeling and simulation tools used to design a reactor or assess the safety of the design. This joint development effort avoids duplication of costly experiments by DOE and the regulator. As shown in Table D-1, the two major experiments being constructed today are (1) an integral in-vessel experiment in the High Temperature Test Facility (HTTF) at Oregon State University, and (2) a simulation of the reactor cavity cooling system, the heat sink for the HTGR, at ANL as shown in Figure D-13.

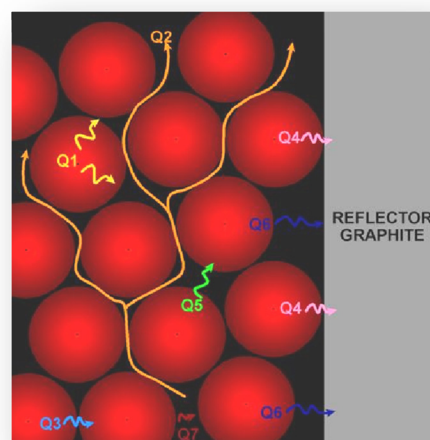

Figure D-12. Coupled heat transfer and fluid flow near the wall of a pebble bed reactor.

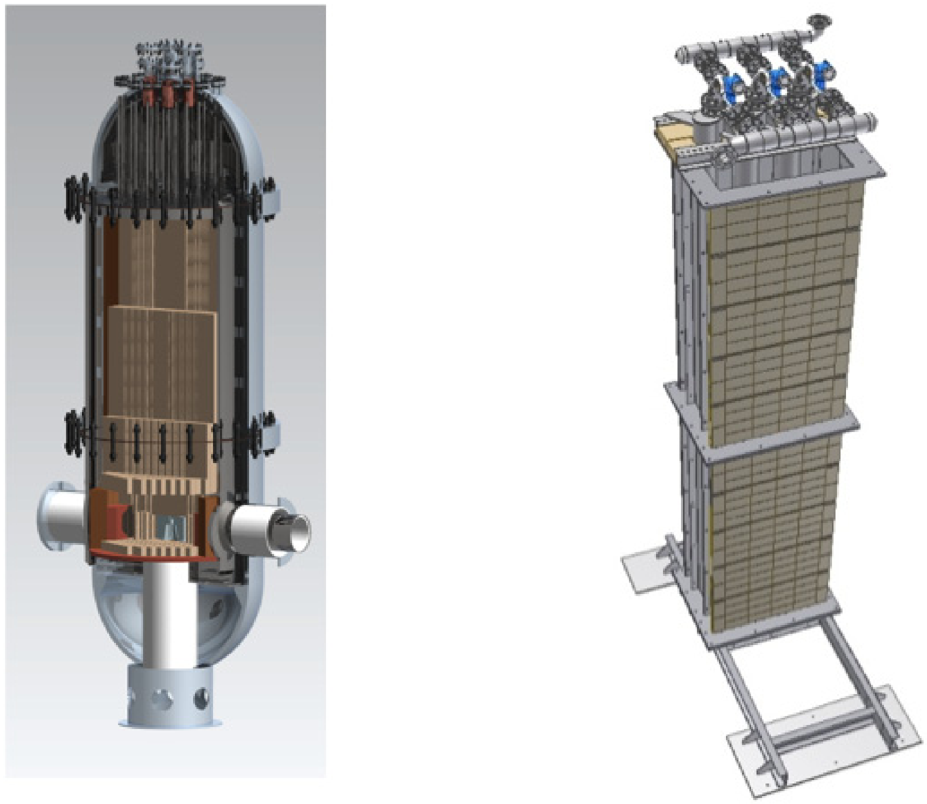

Figure D-13. Schematics of the HTTF at Oregon State University and the reactor cavity cooling system (RCCS) simulation at ANL.

Scaling studies are underway to properly define the experiments to be used in these facilities. A larger number of separate effects tests are also planned or underway in universities to support these larger integral test facilities. For example, experiments have been performed to study two-component exchange flow that simulates the replacement of helium in the pressure vessel with air after a pipe break. The flow of helium around prismatic reactor fuel blocks (bypass flow) is also being investigated experimentally.

DOE and NRC initiated a joint collaboration with Japan 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 underway by DOE, NRC, and laboratory personnel to technically evaluate international capabilities that can be used to provide relevant safety data (e.g., HTR-10, the 10-MW pebble bed in China, the SANA heat transfer and NACOK, integral air ingress facilities in Germany).

D-4.2 Methods Path Forward

Key activities necessary to complete and qualify the Evaluation Model for use in NGNP include:

- Completing the design and execution of separate effects and integral experiments needed to validate the computer codes used to simulate the HTGR.
- Testing the low order core simulation tools used for design and sensitivity studies against benchmarks and higher order simulations.
- Developing high fidelity simulations running on supercomputers to investigate complex behavior and confirm the results of low order simulations.

- Characterizing the uncertainty in all of these simulations so that the real plant behavior falls within the bounds of the simulation results despite the uncertainty.

D-5. HYDROGEN PRODUCTION

D-5.1 Background and Objectives

Carbon-free production of hydrogen can potentially play a key role in decreasing future petroleum imports, relieving the pressure on U.S. natural gas supplies and reducing emissions from transportation fuels. Beyond the need for process heat, hydrogen is a vital feedstock in the production of ammonia, upgrading of low-grade petroleum, and the production of synthetic transportation fuels, all potential end uses for HTGR energy.

The Nuclear Hydrogen Initiative (NHI) in the DOE Office of Nuclear Energy began in FY 2004 to explore and develop methods for using the heat and/or electricity of high temperature reactors for the production of hydrogen from water. The specific objective of the NHI program was to support the national objectives of emission free, domestically based hydrogen, using efficient, large-scale hydrogen production methods suitable for use with advanced nuclear reactors. Based on these objectives, two research priorities were established to develop (1) thermochemical and high-temperature electrolytic hydrogen production processes that match the thermal output characteristics of the HTGR technology to achieve economically competitive hydrogen production by 2017, and (2) advanced or alternative processes to the baseline cycles to assess the potential for higher efficiency or lower cost options for application using the HTGR technology by 2017.

This interest followed an earlier period of research in nuclear hydrogen production in the early 1980s during which the fundamental thermochemical processes were investigated by General Atomics (GA) in San Diego, CA the Europeans (primarily at the Joint Research Center in Ispra, Italy) and the Japanese, primarily at the Japan Atomic Energy Research Agency (JAERI). The NHI closely followed a 3-year Nuclear Energy Research Initiative (NERI) project that began in 1999 involving researchers at GA, Sandia National Laboratories (SNL) and the University of Kentucky. NERI investigated 115 potential thermochemical hydrogen production processes against criteria including the number of chemical reactions needed by the process, whether the process requires the handling of solids, the maximum temperatures required, the corrosive nature of the intermediate compounds and the efficiency of the overall process.

At the conclusion of the GA-UK NERI study, the researchers ranked the sulfur iodine process as the method most promising and potentially most efficient, which was supported by continuing experiments that were conducted by JAERI at Oarai on the sulfur-iodine process. The Japanese experiments reached a significant milestone in 2004, when a laboratory-scale experiment measuring about 2 m wide, 3.5 m long and 3 m high and using laboratory glassware succeeded in producing an average of 35 normal liters of hydrogen gas per hour for approximately 170 hours. The primary difficulties in the JAERI experiments were corrosion in the sulfuric acid decomposition section and incomplete separations of sulfuric acid, hydroiodic acid, and liquid iodine in the Bunsen reaction.

One of the initial decisions in organizing the NHI was to develop processes that were completely free of carbon, in order to avoid any need for ultimate sequestration of the CO_2. Therefore, no experiments were performed on nuclear-assisted steam methane reforming under the NHI, despite the earlier recommendations of a 2003 Electric Power Research Institute study.

INL researchers submitted a NERI proposal in 2002 for the development of high-temperature electrolysis as an alternate method for hydrogen production. A series of tests over the next 8 years, starting at very small scale and proceeding to a large integrated demonstration, were conducted to demonstrate hydrogen production from high temperature electrolysis. INL contracted with Ceramatec of Salt Lake City to produce button cells and short stacks and shortly thereafter reported the initial successful production of hydrogen at commercially relevant temperatures and current densities. The INL High Temperature Electrolysis project and Ceramatec conducted button-cell experiments and an early six-cell stack that produced an average of 28 normal liters (NL) of hydrogen per hour for 1,100 hours. Using a slightly larger 10-cell stack and a test stand designed specifically for electrolytic testing, INL achieved a hydrogen production rate of 60 to 90 NL/hr. Using a 25-cell stack, a production rate greater than 100 NL/hr was sustained for more than 1,000 hours. Ceramatec also tested a half-module consisting of two 60-cell stacks in a configuration planned for the High Temperature Electrolysis (HTE) integrated laboratory scale (ILS) experiment shown in Figure D-14. The half-module experiment ran for 2,040 hours, initially producing 1,200 NL/hr and averaging about 900 NL/hr. For more than 800 hours of the test, the half-module operated in the co-electrolysis mode, converting a mixture of CO_2 and steam into synthesis gas ($CO + 2\ H_2$). During the test, the half-module produced sufficient syngas for about 110 gallons of diesel fuel. The HTE ILS tested three modules, which incorporated 720 cells, producing a maximum of 5,650 NL/hr after a total of 1,080 hours of operation. However, degradation in the cell production was observed. Based on an experts' workshop, changes in both configurations and materials sets were recommended. Some of these recommendations were incorporated in a subsequent test of a 10-cell stack that was tested for 2,500 hours during May–September 2009. This 10-cell stack had a degradation rate of 8.2% per 1,000 hours, much better than the best previous test's degradation of 21% per 1,000 hours.

Figure D-14. HTE integrated lab-scale experiment (left) and three electrolytic modules (right).

In parallel with the experimental program, the HTE project performed computational fluid dynamics (CFD) and flowsheet analyses to model both planned experiments and possible commercial hydrogen production plants. The models were compared with the results of experiments for validation and insight into cell and stack performance. Based on this R&D, HTE was demonstrated to be an efficient and modular method for producing hydrogen using nuclear energy.

The development of the sulfur-iodine (S-I) process under the NHI also progressed from bench scale experiments to the construction of an ILS experiment. The S-I ILS experiment was a collaboration among GA, which built the hydroiodic acid decomposition section, SNL, which built the sulfuric acid decomposition section, and the Commissariat à l'Énergie Atomique (CEA) in France, which built the Bunsen reaction section, in which the acids are produced from I2, SO2 and water. The three sections were tested together at the GA facilities in San Diego.

Because of difficulties in obtaining components of the required sizes, the three sections were not scaled for the same hydrogen production rate. The SNL sulfuric acid decomposition section operated several times at 100–300 NL/hr rates, while the redesigned GA hydroiodic acid decomposition section operated at 10–75 NL/hr rates.

D-5.2 Future Plans

HTE was recently selected by DOE as the hydrogen generation technology of choice after it was recommended by an independent review team[13] for use with the planned NGNP based on its maturity and ease of integration with nuclear systems. The review team also recommended that HTE R&D "(1) refine the understanding of cell/stack degradation modes and mechanisms, and (2) demonstrate pressurized cell/stack operation at a laboratory scale." The report also recommended evaluation of other alternative cell and stack designs.

The NHI program was terminated shortly after HTE was selected for coupling with the HTGR technology as the preferred method for hydrogen generation. Continuing development of the HTE process was then funded under the INL NGNP Project. With the reduction in the scope and realignment of the NGNP Project into an R&D Program as a consequence of the Secretary of Energy's letter to Congress of October 17, 2011, the development of the HTE process will not be continued as part of the NGNP program at the end of FY 2012. It is expected that at that time it will be possible for a private sector entity to take over the development program and bring this technology to commercialization. The following work is expected to be completed by the end of FY 2012 to support this turnover to the private sector.

D-5.2.1 Improvements in Cell Performance

The performance of solid-oxide cells in the electrolytic mode must improve before this technology will be ready for commercial application. The strategy will be to focus on development of cells and stacks optimized for the electrolysis application. Based upon previous testing experience, the emphasis will shift from electrolyte-supported cell designs to advanced electrode or metal-substrate-supported cell designs. The key variables in the cell designs will include cell architecture and the composition and fabrication methodology for all cell layers. In this context, an expansion of industrial collaboration is planned with a range of cell manufacturers and research institutions.

D-5.2.2 Larger Format Cells

Larger cells will be required in the large-scale nuclear production of hydrogen. The manufacture of larger format cells (up to 1 m × 1 m) will require innovative cell designs and fabrication methods. Electrode-supported and porous-metal-supported cells show great potential for large-format designs. The current state of the art for large-format cells is about 25 × 25 cm, with electrode-supported cells. Several large companies and research centers are developing porous-metal-supported cell designs for the fuel-cell application, with the electrode and electrolyte layers deposited by thermal spray techniques. These cells can achieve very large sizes, up to 1 × 1 m. Work is planned with all potential cell providers in exploring the development of large-format cells for electrolysis, based on their respective technologies.

D-5.2.3 Pressurized Operation

Commercial HTE units will have to operate at elevated pressure in order to reduce manifold sizes and pumping power for insertion of the hydrogen into a pipeline or fuel synthesis/refining plant. Analyses and a design for a pressurized test stand will be developed. Elevated-pressure tests of a multi-cell stack will be conducted after the previous two issues are successfully addressed. This work is required to validate the technology at the component level in a relevant operating environment.

D-5.2.4 Scientific Understanding of Electrolytic Operation

A deeper understanding of the implications of various cell and stack designs on details of cell, stack, and overall system performance is needed to complement the basic CFD and system analysis capability. These insights will be gained using advanced post-test examination methods for evaluating degradation mechanisms. The combined physical and numerical analysis will lead to optimized multi-cell and multi-stack manifolding and electrical interconnections.

D-5.2.5 Needs for Engineering Data for HTGR Design

HTE analyses and experiments must be coordinated with the needs for HTE-specific design data by the HTGR engineering teams. These design data needs for HTE have been identified and are being incorporated into a database. The specific parameters and their identified uncertainties will guide the design and operation of HTE experiments and the associated analyses. These data needs may need modification in the future to address the results of the ongoing engineering designs.

D-5.3 Hydrogen Generation Path Forward

As noted HTE development will no longer be funded under the NGNP Project after the end of FY 2012. The approach to the development of HTE will need to be undertaken by a private sector entity. That development should continue the INL emphasis on modularity and progressively larger sizes and operating durations. The next step in that development should be the operation of a pressurized high temperature electrolyser, first as a 10-cell stack and then progressing to a 200 kWe multi-module experiment operating at 3 to 5 MPa.

Based on INL planning the next phase of development is an Engineering Demo, with a rating of 1 to 5 ME(e). The Demo would operate at 3-5 MPa and 800° C, with heat recuperation to allow lower steam input temperatures. The Demo units would have progressively more cells and multiple stacks, concluding with a unit having two stacks of 1250 cells each, a total power of 5 ME(e), a terminal voltage of 1600 VDC and a working pressure of 5 MPa. The planned commercial module would have four stacks and a rating of 9.6 ME(e). The commercial plant would contain 32 of the 9.6 ME(e) modules for a total output of 160 tons of hydrogen per day, The commercial units would thus be truck-transportable and capable of stack repair while the other units remain operating.

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Appendix E

Engineering

Appendix E—Engineering

E-1. Plant Design Development and Supporting Engineering Activities

E-1.1 Status

The following summarizes the Next Generation Nuclear Plant (NGNP) design and engineering efforts through FY 2011. Reference 1 provides a similar but more detailed summary of NGNP Project Engineering efforts through FY 2010.

E-1.1.1 FY 2007 Pre-Conceptual Design

A pre-conceptual design effort was completed in FY 2007 by three design supplier teams led by AREVA, General Atomics (GA), and Westinghouse. The AREVA team prepared a design employing a prismatic block reactor concept based on the “AREVA New Technology based on Advanced gas cooled Reactor for Energy Supply” design. General Atomics also employed a prismatic block reactor concept based on the GA designs for the Modular High Temperature Gas-cooled Reactor (MHTGR) and the Gas Turbine Modular Helium Reactor (GT-MHR). Westinghouse, which was partnered with Pebble Bed Modular Reactor (Pty), Ltd of South Africa (PBMR) prepared a pebble bed reactor design based on the Demonstration Power Plant (DPP). The DPP was being designed at that time in South Africa and had begun initial licensing pre-application activities with the U.S. Nuclear Regulatory Commission (NRC). All of the pre-conceptual design concepts were for single reactor modules designed for electricity and hydrogen generation. These designs incorporated thermal ratings over the range of 500 to 600 MW(t) and reactor outlet temperatures in the range of 900 to 950°C. They also included hydrogen generation processes employing High Temperature Steam Electrolysis, Sulfur Iodine and Hybrid Sulfur processes.

Each team prepared detailed pre-conceptual design reports.[2,3,4] The NGNP Project prepared a summary report.[5] This latter report included a schedule and best estimate cost to complete the NGNP Project based on a reconciliation of schedules and costs prepared by each team. At that time it was estimated that the Project could be completed in 2018 with an accelerated scope and, on a normal schedule, by 2021 as required by the EPAct. The cost to complete the Project as defined at that time was estimated between $3.8B and $4.3B (2007$).

As part of the pre-conceptual design scope, a Work Breakdown Structure (WBS) was developed for the NGNP Project that subdivided the high temperature gas-cooled reactor (HTGR) plant into five major areas: the nuclear island, consisting primarily of the reactor and ancillary service systems; the heat transport system (HTS), consisting of both the primary and secondary heat transfer loops and intermediate heat exchanger (IHX or steam generator); the power conversion system, consisting of the turbine generator system and associated steam, condensate, and feed systems; the balance of plant consisting of a number of plant-wide supply, distribution, waste, and auxiliary systems; and the hydrogen production system (HPS), consisting of the equipment directly associated with hydrogen production and storage. This WBS was originally included as Appendix G of the Idaho National Laboratory (INL) summary report,[5] and has been retained by the Project, refined, and used for detailed scheduling and for organizing systems requirements and design data needs. Note that for convenience in subsequent evaluations the nuclear island and HTS were designated in combination as the Nuclear Heat Supply System (NHSS).

E-1.1.2 FY 2008 Engineering Studies

In FY 2008, the three supplier teams remained mostly intact. They were tasked by the Project with completing a selected number of engineering studies identified during pre-conceptual design and developing plans to complete conceptual design. The engineering studies are discussed in Section E-3. In these studies, several material and configuration alternatives for the NHSS were explored, resulting in reassessments of technology and design selections for fundamental concepts such as reactor design, power rating, reactor outlet temperature, and fundamental primary loop and HTS configuration. Concurrent with these studies, an assessment of potential industrial applications of the HTGR technology was performed.[6] Two key conclusions were drawn from these series of studies. First, there are significant material challenges and potential core design issues in designing the plant for a reactor outlet temperature (ROT) in the range of 850 to 950°C. There is less risk by limiting the ROT to 850°C or less. Secondly, there are a significant number of industrial processes for which the HTGR could be applied at the lower ROT. Accordingly, Engineering began to focus on applications that required lower reactor operating temperatures (e.g., co generation supply of steam and electricity to collocated industrial plants).

A Senior Advisory Group (SAG) comprised of senior personnel from the HTGR suppliers and a nuclear plant owner-operator was formed to advise the NGNP Project on application of the HTGR technology in commercial applications. In September and October 2008, the SAG was convened to provide its perspective on the priorities for the 2009 NGNP Project work scope.[7,8] The SAG recommended that:

- The NGNP Project pursue two reference configurations for conceptual design
- One reference configuration would incorporate a pebble bed reactor with an intermediate gas to gas heat exchanger in the primary helium loop that would supply high temperature gas for steam generation and other industrial process uses. The steam would be used for electricity generation and to support industrial processes.
- The other reference configuration would incorporate a prismatic block reactor with a steam generator in the primary loop. The steam generator would supply a Rankine steam turbine generator and supply steam for industrial process use.
- The plant being developed by the Project should be a demonstration of the HTGR technology, supplying process steam and electricity in a commercial co-generation application, rather than as a prototype plant sited at INL.

A number of high level technical and functional requirements that impact HTGR configuration were defined by the SAG. These requirements were based on the SAG's collective view of the fundamental requirements that the NGNP must meet in order to support development of a viable commercial HTGR offering. These requirements are summarized in Section 3.2.2 of Reference 9.

In June 2008 a Statement of Work was issued to the three design supplier teams to develop detailed conceptual design work plans[10] addressing all major facilities and systems in their reference designs. The conceptual design work plans identified all remaining activities that were needed to complete a conceptual design as identified in Department of Energy (DOE) M 413.3-1,[11,] and the schedule and costs for completing those activities. Detailed conceptual design work plans were issued by all three design supplier teams in October 2008. [12,13,14]

E-1.1.3 FY 2009

In early April 2009 the NGNP Project was instructed by DOE to stop design related work and commence closure of design related subcontracts,[15] DOE stated that this action was taken "to ensure that design work and other tasks related to deployment of a specific reactor technology are cost shared as required by the Energy Policy Act of 2005." Non-technology specific studies, efforts related to R&D, and work on licensing related issues that addressed generic gas reactor regulatory issues were allowed to proceed. At the time of this writing, the order by DOE to stop design work in 2009 is still in place and the NGNP Project has not initiated any design work on the NGNP Project demonstration plant.

The SAG met once again in July 2009[16] to reconsider the reference configurations that would be the basis for conceptual design work by the design supplier teams upon DOE approval to re-engage in design activities. There were several outcomes of this meeting:

- The Westinghouse/PBMR Team presented a revised pebble bed reactor design with a cylindrical core, a reduced rating of 250 MW(t) and an ROT of 750°C. This design is similar to the German HTR-Modul plant and the Chinese HTR-PM. It includes a steam generator in the primary loop supplying steam to a subcritical Rankine steam turbine generator. Main steam or extraction steam can be supplied for industrial use. See Figure E-1.
- The SAG concluded that this configuration and ROT should be the reference for the NGNP demonstration plant whether the reactor is pebble bed or prismatic block. The rating of the plant would be determined by the application. The prismatic block reactor has ratings in the 350 MW(t) to 625 MW(t) range at this lower ROT.

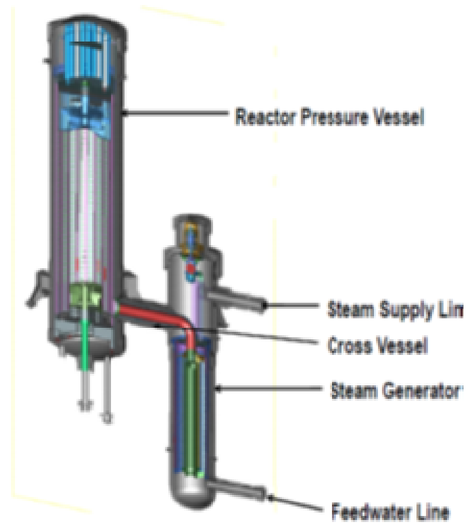

Figure E-1. Pebble Bed Reactor Nuclear Heat Supply System for Steam Generation

- The SAG recommended a reduction in the highest reactor outlet temperature to be considered for the early deployments of the HTGR technology to 850°C.
- The SAG recommended that IHX development be included in a second phase of HTGR technology deployment because of an understanding that most of the near term applications could be satisfied with a steam plant.

E-1.1.4 FY 2010

In September 2009, DOE Idaho Operations Office issued a Funding Opportunity Announcement [17] seeking applications for conceptual design activities for the NGNP. Proposals were received by DOE in November 2009. Two teams led by GA and Westinghouse were selected by DOE in March 2010 for negotiation of the terms and conditions for this work. However, DOE was not able to establish a contract with Westinghouse and in May 2010 only one contract was awarded to GA for a conceptual design based on a prismatic block reactor steam cycle concept.[18]

The GA design concept is referred to as the Steam Cycle Modular Helium Reactor (SC-MHR) plant providing steam and electricity from a 350 MW(t) prismatic block reactor based NHSS in a cogeneration application as shown in Figure E-2. The SC-MHR is a redaction of the GA MHTGR

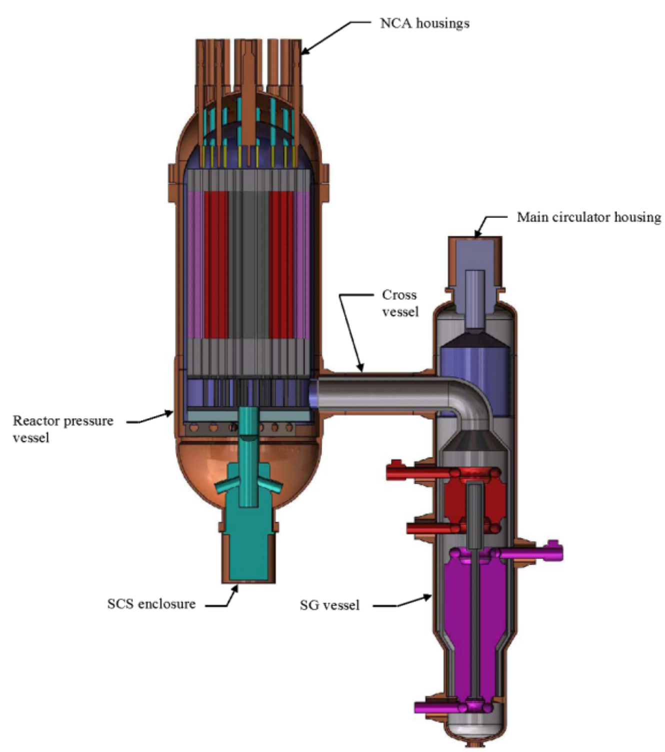

Figure E-2. GA SC-MHR Nuclear Heat Supply System for Steam Generation.

developed for the DOE in the late 1980s. Both plants incorporate a steam generator in the primary loop. There are three primary differences in the designs: (1) the MHTGR was designed for electricity production whereas the SC-MHR is to produce both electricity and process steam; (2) the reactor outlet temperature for the SC-MHR is 725°C compared with 687°C for the MHTGR; and (3) current materials, technologies, and modular construction approaches were applied in conceptualizing the SC-MHR design. GA submitted the initial documents for their conceptual design to DOE in December 2010, and continued to provide associated documents through July 2011. A listing of all documents developed as part of the SC-MHR conceptual design is provided in reference.[19] Two key documents are the conceptual design report [20] and a report assessing upgrading the SC-MHR design to address higher temperature process heat applications. This latter design incorporates an IHX in the primary loop and a higher reactor outlet temperature of 850°C.[21] GA presented the results of this conceptual design effort to the Nuclear Energy Advisory Committee (NEAC) in February 2010.

E-1.1.5 FY 2011

When the DOE was unable to come to agreement in FY 2010 with Westinghouse for pursuing conceptual design work on a pebble bed reactor based plant the Westinghouse team dissolved. The PBMR was also defunded by the South African government. This left the pebble bed reactor concept without an entity to support its continued consideration in the NGNP Project. Prior work by the NGNP Project compared in detail the design, operating and safety bases of the prismatic block and pebble bed reactor concepts and concluded that there is no technical basis for selecting one concept over the other.[22] This was a conclusion that the NGNP Project judged important to be made clear in the NEAC reviews and that a presentation to the NEAC of the pebble bed reactor concept similar to that made by GA on the prismatic block reactor concept was necessary. Accordingly, the NGNP Project tasked AREVA to prepare a report summarizing the status of the pebble bed reactor technology. This assessment was based on prior conceptual design work completed for the German HTR-MODUL reactor. This reference plant design was selected to be consistent with the configurations proposed by the Westinghouse/PBMR team prior to its dissolution. The HTR-MODUL design is for a 200 MW(t) pebble bed reactor with a steam generator in the primary loop and a reactor outlet temperature of 700°C. The plant was designed for electricity generation only. AREVA completed the assessment [23,24,25,26] concluding that the pebble bed reactor concept is a viable concept, that the status of the HTR-MODUL design should be considered to be in the late conceptual design stage, that the pebble bed technology was judged to be capable of achieving a reactor outlet temperature in the range of 750 to 800°C, and that a reconciliation of the design against U.S. regulatory requirements and NGNP Project requirements would need to be performed. This information was presented to the NEAC by AREVA in February 2010.

With no currently active deployment project for the pebble bed reactor, the intellectual property is currently archived in different places. The technical information for the HTR-MODUL reactor is jointly owned by AREVA and Westinghouse. The technical information for the PBMR DPP is controlled by the Republic of South Africa's Ministry of Public Enterprises, via the Nuclear Energy Corporation of South Africa. Additional pebble bed reactor information is being developed in China by that government's nuclear R&D organization called INET, regarding the demonstration plants HTR-10 (10 MW(t)), currently operating, and HTR-PM (2 × 250 MW(t)), currently in-construction.

E-1.1.5.1 Plant Design for Pre-Application Discussions with the NRC

The GA 1980s MHTGR design is being used to support NGNP Project Regulatory Affairs discussion with the NRC as part of the Pre-application phase of the licensing process. This is necessary because no design work has been completed for the NGNP HTGR plant. The MHTGR information used in these discussions is derived from the probabilistic risk assessment (PRA),[27] a preliminary safety information document,[28] and drafts of NRC pre-application safety evaluation reports[29,30] developed in the late 1980s and early 1990s for this design.

E-1.1.5.2 High Level Functional and Performance Requirements

Although no specific design work has been completed by the NGNP Project, the engineering studies, the SAG recommendations and interactions with potential end user have resulted in the development of high level functional and performance requirements for the NGNP HTGR Demonstration Plant.[31]

1. The NGNP Demonstration plant will be a single module of what will ultimately be a multiple module plant in an industrial application.
2. The reactor outlet temperature will be in the range of 725–850°C.
3. The reactor rating will be between 200 and 625 MW(t).
4. The primary operating pressures will be in the range of 6 to 9 MPa.
5. The primary heat exchanger will be a steam generator.
6. The design rules for the vessel system are in Reference 32.
7. The material for the vessel system will be SA 508/SA 533.
8. The crossover vessel will contain both the hot and cold leg of the helium circulating system in an annular configuration. See Figures E-1 and E-2.
9. The power conversion system will be a Rankine steam turbine generator using standard equipment wherever possible.
10. The steam supply temperature will be in the range of 540 to 630°C.
11. The steam system operating pressures will be in the range of 15 to 25 MPa.

E-1.2 Path Forward

It is anticipated that design work for the demonstration plant will be resumed either under a public-private partnership or other entity—future development and deployment is discussed in Section 8 of the main report. The design will be dictated by the specific application identified for the plant. The work completed by NGNP Project Engineering can provide a baseline and insights from which this design work can proceed.

1. Specific key references summarizing the results of this work include:
   - Comparison of the technical attributes of the pebble bed and prismatic reactors[23]
   - Lessons learned in prior HTGR developments and operations [33]
   - Transport of radionuclides to end-user products [34,35]
   - Nuclear island boundaries and scope of design certification [36]
   - Infrastructure development needs [37]
   - Functional and Performance requirements meeting end user needs[44]

- System Requirements Manual[41] and Database [Section E-2.1[i]] including Design Data Needs [Section E-2.2]
- Conceptual Design work plan development[10,12,13,14]
- Work Breakdown Structure[5]
- Risk Management Program [Section E-2.2]
- Market Evaluation and Preliminary Economics [Section 6]
- National Codes and Standards updates for HTGR technology [Section E-5.1]
- Large scale component test facility requirements and design [Section E-6].

2. NGNP Project Engineering has managed a large number of engineering studies addressing key design issues that can inform future design activities. These are discussed in Section E-3 and listed in Appendix H.
3. NGNP Project Engineering has managed investigations into the technical and economic viability of applying the HTGR technology to multiple industrial processes. This work included development of concepts for applying the HTGR technology to three specific sites providing energy to support collocated industrial plants and processes. This effort also included the development of detailed discounted cash flow models used to investigate the economic viability of these applications. The results of these efforts can be applied in the future when identifying and assessing potential applications for the demonstration plant. This effort is discussed in Section 5.
4. NGNP Project Engineering has supported the advancement of process heat transport technology through collaborative agreements with universities to engineer and test advanced compact heat exchanger designs. These designs would be applied in gas to gas or gas to other fluids (e.g., liquid metals) for high temperature process heat applications (e.g., hydrogen production). Assessments of the potential markets for the HTGR technology [Section 6] show that the high temperature process heat market is substantial. The development of these advanced heat transport technologies needs to be continued to provide the means for early penetration of this market. The effort completed in this area is discussed in Section E-4.3.
5. If the HTGR technology is to be designed and applied for higher temperatures and higher power ratings than currently planned for the NGNP Demonstration Plant , there are several areas that will need to be addressed:
   a. *Materials* – At higher reactor outlet temperatures, ceramics or composites may be required for some of the core internals. There has been little work done on developing the data necessary for ASME and American Society for Testing and Materials (ASTM) International code case or code revision development for these materials. The materials selection for the vessel system material may need to be upgraded to a higher temperature alloy than SA 508 / SA 533, which will require significant development of weld techniques, materials testing, and American Society of Mechanical Engineers (ASME) code cases or code revisions. An alternative to use of a higher temperature material is to redesign the reactor vessel configuration for active cooling sufficient to maintain the SA508/533 material in its design range. Higher temperatures will also require re-assessing the viability of the heat transfer surface materials in the steam generator and the IHX. The ASME Boiler Pressure Vessel (BPV) Code allowables will need to be revised as required to include new materials at the appropriate operating conditions.
   b. *Circulators* – As required circulator capacity ratings increase, which would be necessary for higher power ratings of the HTGR, the circulators change from being essentially “off-the-shelf”

[i] The section numbers with multiple levels refer to sections within this appendix; the single level section numbers refer to sections in the main body of the report.

equipment to items requiring substantial development. The alternative is to use parallel circulator configurations, which will also require increased design effort.

c. Heat exchange equipment – In addition to materials considerations new configurations and materials joining methods will be required at higher operating temperatures.

d. Instrumentation and controls – Higher temperatures will require development of new instrumentation rated for those temperatures.

Details regarding development of plant equipment at higher temperatures are addressed in the Technical Development Roadmaps discussed in Section E-2.3.

When full scope NGNP HTGR development and commercialization activities are resumed, a topic that should be addressed in conjunction with design work to establish plant configuration is the performance of plant level assessments and transients analyses. This should include evaluations of radionuclide mass balances for circulating activity and an assessment of Tritium released in the steam plant during normal operations due to small steam leaks. This will ultimately support the performance of probabilistic risk assessments and nuclear safety analysis.

E-2. SYSTEMS ENGINEERING

NGNP Project Systems Engineering activities include:

- Requirements Development
- Risk Identification and Management
- Roadmapping and Decision Making.

This section summarizes the status and path forward for each of these activities.

E-2.1 Requirements Development

E-2.1.1 Status

During the initial phases of the Next Generation Nuclear Plant Project, high-level performance requirements and definitions were established for the project by the Gen IV International Forum and documented by the INL.[38] Subsequently, an independent technical review group (ITRG) assessed the risks associated with development and demonstration of the high temperature gas reactor technology.[39] The ITRG assessment summarizes technical issues that must be resolved for successful implementation of the HTGR technology. The pre-conceptual design work confirmed, in general, the conclusions on the technical risks described by the ITRG report. These requirements documents, EPAct 2005,[40] and requirements contained in the General Atomics Pre-conceptual Design Studies Report[3] formed the initial NGNP requirements basis and were captured in an NGNP System Requirements Manual,[41] as shown in Figure E-3. The SRM includes the programmatic requirements (Regulatory, Legislative, End-User, Stakeholder) and Functional, Operational, and Technical Requirements from each plant area (Nuclear Heat Supply, Heat Transport, Hydrogen Production, Power Conversion, Balance of Plant).

The SRM also captures the requirements documented in the GA Conceptual Design Plant Design Requirements Document (PDRD)[42] and the Summary Bounding Conditions document[43] that establish detailed technical requirements which satisfy the high-level requirements and drive the design. The requirements found in the SRM include attributes that help to sort and categorize the requirements. Some requirements are unique to the reactor design (pebble bed or prismatic block) and can be sorted by their attributes. Other requirements apply to either reactor type.

Figure E-3. NGNP Requirements Evolution.

Industrial involvement is essential to the success of the project as suppliers of the HTGR technology, designers, engineering and construction firms, and the eventual owner/operators of HTGR Plants. Industrial involvement has been a central part in developing the functional and performance requirements of the HTGR.

The NGNP project has engaged industry experts and potential end-users to obtain feedback from the industry regarding the commercial application of the HTGR to a broad range of industrial applications. This has led to the development of an extended list of potential end-users and an end user requirements document.[44]

E-2.1.2 Path Forward

The latest versions of the NGNP SRM and key design requirements documents[41,31] are a snap shot in time of the project requirements. The Project established a relational database using the Dynamic Object Oriented Requirements System (DOORS) requirements management tool as the controlled repository for the NGNP requirements. This is judged to be an efficient way to control, make generally available, and update the Project requirements.

Read-only access to the DOORS database and interaction through comment fields are available through the web at URL: http://sysarchxt:8080/dwa/welcome/welcome.jsp

The DOORS database, designed in accordance with the NGNP System Requirements Database Description,[45] will be controlled following the NGNP SRM database control plan.[46]

Safeguards and Security by Design (SSBD), with emphasis on meeting International Atomic Energy Agency (IAEA) guidelines will need to be a factor in further development of the HTGR requirements set. Some efforts have been expended[47,48,49] but to date only an initial set of SSBD related requirements have been included in the DOORS database.

E-2.2 Risk management

E-2.2.1 Status

The NGNP Risk Management Plan (RMP)[50] and its predecessor report[51] define the scope and methodology for identifying, analyzing, responding, determining impact, reporting, tracking, and closing risks that could prevent the NGNP project from achieving its objectives. The embodiment of this plan is a formal decision-making and risk management process developed for NGNP based on systems engineering principles that have guided aerospace and military applications.[52]

The NGNP project risk management process draws from the principles of INL,[53] DOE orders, guides, and manuals,[54,55,56] and industry standards.[57] This process includes the identification, impact assessment, and prioritization of technical and programmatic risks followed by a coordinated application of resources to mitigate or eliminate risks that may impact the successful outcome of the project. This requires that (1) technical and programmatic risks be identified, quantified, and mitigated (as appropriate) and (2) risk mitigation strategies be developed, documented, and implemented. Risk methodology developed and applied for the NGNP project includes systems for reporting and tracking risks, risk status and risk resolution.

To assure comprehensive risk reduction, the risk handling strategy includes addressing Design Data Needs (DDNs) [24,58,59,60,61] developed during the design process and Phenomena Identification and Ranking Tables (PIRTs) that have been developed in coordination with the NRC.[62,63] Design tasks require detailed technical input on fuels, materials and components used in the construction of the reactor and heat transfer system. The DDNs process is a formal vehicle used to integrate Engineering information with R&D activities. DDNs identify the research and development (R&D) needs for the development of Structures, Systems, and Components (SSCs) to satisfy the technical information needed for design activities. PIRTs are a process used by the NRC to identify and rank issues associated with development of reactor systems and nuclear fuel. Both DDNs and PIRTs need to be aligned to ensure that risks identified in PIRTs are addressed by one DDN or more and, ultimately, by research activities. Those issues identified through the PIRTs that will require additional research are scored as high risks and currently drive much of the research and development activities and analyses. Individual risk items are mapped to associated DDNs and risk reduction tasks are mapped to the PIRTs.[62,63]

One method of risk identification used by the NGNP Project was to evaluate the pertinent lessons learned from past and present HTGRs that apply to the NGNP Project and capture those lessons learned.[64] A subsequent effort was undertaken to evaluate the current and planned NGNP Project activities that address those lessons learned. These project activities are documented in INL R&D plans, the conceptual design report from GA, the pebble bed reactor (PBR) technology readiness study from AREVA, and other NGNP Project design studies and assessments.[33]

The highest risks found from past reactor lessons learned include moisture ingress, helium leakage, dust, fission product transport and cleanup, and plant instrumentation needs.

The NGNP Risk Management System (RMS)[65] performs risk management and tracking functions. The RMS is used to establish and maintain the Project Risk Register, which includes the list of project risks, the risk reduction plan, and the current risk reduction status. The register is organized by critical plant, area, systems, subsystem or structures, and/or components (PASSCs). The RMS allows rollup/drilldown analysis that summarizes quantitative risk scores using various levels of data and information details.

The tool's hierarchy tree also allows the user to view risks by critical system affected. Risk may be scored differently for different reactor outlet temperatures or reactor configurations. Research and design activities are assigned to each risk and projected risk reduction through completion of these activities is assessed. By linking the DDNs to the research and design activities and the PIRTs to the risk, the user is able to visualize and analyze the complex relationships between various NGNP project entities e.g., PASSCs, risks, risk mitigation tasks, DDNs, and PIRTs. Additional RMS functionality includes the ability to analyze and track relational mapping between project risks and PIRTs, risk reduction tasks, and DDNs, thus facilitating gap identification in planning research and development activities. The status of the risk handling strategy is primarily based on the percent completion of risk reduction tasks and may be displayed graphically by plotting the actual/current risk reduction versus the planned risk reduction over time.

E-2.2.2 Path Forward

The RMP and the risk register need to be documented in a system design description and the database needs to be archived.

Continued R&D and design work are needed to advance the technology readiness of critical SSCs sufficiently to have adequate confidence in their performance for installation in the HTGR plant. Figure E-4 shows that the objective of the risk management program is to achieve a Technology Readiness Level (TRL) of at least TRL-8 to achieve the necessary level of confidence that the technology can be deployed without significant risk. The next section discusses the implementation of the TRL assessment and improvement process.

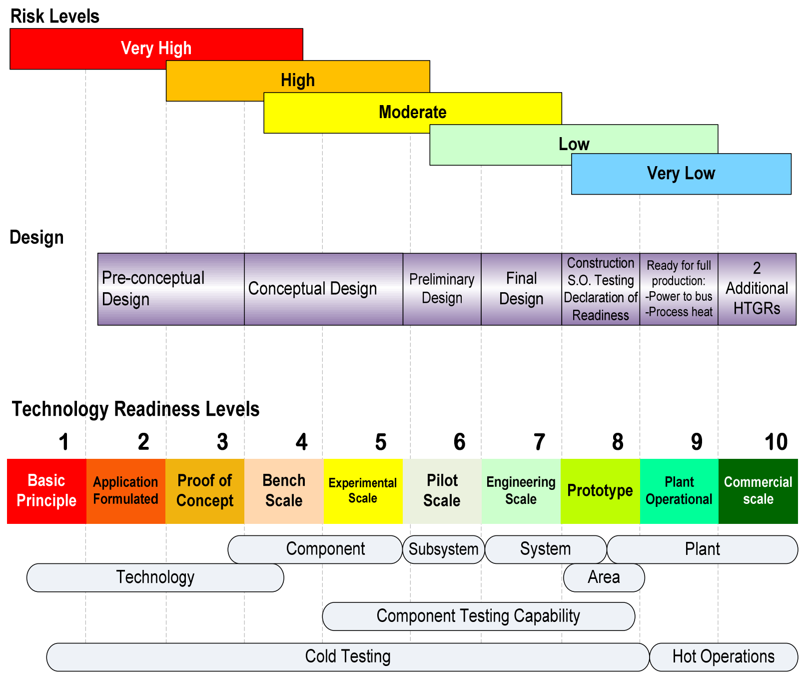

Figure E-4. Design and technical readiness levels advanced in parallel best reduce risk.

E-2.3 Technology Development

E-2.3.1 Status

Industry experience repeatedly demonstrates the consequences of proceeding with projects using technologies that are not sufficiently mature. The U.S. General Accounting Office noted that these consequences manifest themselves as cost overruns and schedule delays late in the project life cycle.[52] To avoid these undesirable consequences, the NGNP Project initiated efforts to assess technology readiness of critical SSCs and identify the steps required to ensure sufficient maturity prior to inclusion into the NGNP design. In this sense, "critical" means that the SSC is on the schedule's critical path for deployment. This effort was completed by the HTGR suppliers and documented in appendices of INL reports.[66,67]

Each critical SSC was evaluated through a Technology Readiness Assessment and assigned a TRL based on the technical maturity of the SSC. The assessment determined that there were 18 SSCs at a Reactor outlet temperature of 950°C as shown in Figure E-5, and 15 for an ROT of 750°C. The list of critical SSCs may continue to change as the HTGR design progresses.

With the baseline critical SSCs and their associated TRLs defined, experts from DOE national laboratories and gas reactor vendors established technology development "roadmaps" and identified the licensing, engineering design, and research and development activities required to guide the technology maturation process. Roadmaps set the project course for technology selection, qualification, and the integration of developing components into mature and operable systems. The roadmaps identify: 1) key selection discriminators; 2) key technology decision points and the scientific and technical information necessary to make informed technology selections; 3) current TRL assessments; 4) development tasks needed to mature technologies; and 5) test plans, including scaled demonstrations, models, and prototypes, many of which were originally intended for testing and development in the Component Test Facility (CTF) (see Section E-6), Roadmaps facilitate successfully meeting scheduling and budgeting demands.

NGNP Area System	Min TRL	Avg TRL
NGNP	3	3.8
Nuclear Heat Supply System (NHSS)	4	4.0
Reactor Pressure Vessel System	4	
Reactor Vessel Internals	4	
Reactor Core and Core Structure	4	
Fuel Elements	4	
Reserve Shutdown System	4	
Reactivity Control System	4	
Core Conditioning System	4	
Reactor Cavity Cooling System	4	
Heat Transfer System (HTS)	3	3.8
Circulators	4	
Intermediate Heat Exchangers	3	
Hot Duct - Cross Vessel	4	
High Temperature Valves	3	
Mixing Chamber	5	
Hydrogen Production System (HPS)	3	3.3
Power Conversion System (PCS)	4	4.0
Steam Generator	4	
Power Conversion Turbomachinery	4	
Balance of Plant (BOP)	3	3.5
Fuel Handling System	4	
Instrumentation & Control	3	

Figure E-5. Assessed TRLs for the NGNP Critical PASSCs

The NGNP project issued a report[65] that documents the Technology Readiness Assessment, critical SSCs, and Technology Development Roadmaps (TDRM) to mature the technologies needed for a high-temperature gas reactor with an outlet temperature of 950°C, as well as other requirements consistent with those found in the NGNP requirement documents[31,41,42] This report reconciled the assessment of TRL levels and the technology development roadmaps developed by the gas reactor vendors. An update to the TDRM report[6768] was issued later in August 2009 to chart a path forward for a 750°C reactor outlet temperature (ROT). An assessment of reactor user interface TDRMs was performed early in FY 2011 to evaluate the technology readiness of the interface components that are required to transfer high temperature heat from an HTGR to selected industrial applications.[68] Prior to demobilizing the Project Engineering group, several TDRMs were updated to package the information not by critical SSC but by research and development (R&D) program. These TDRMs[69] aligned with the risk priorities by the fuel qualification, graphite, high temperature materials, and methods programs currently being pursued by R&D, i.e., the VHTR TDO.

E-2.3.2 Path Forward – TDRMs

The TDRMs can be useful tools in support of the design process once the transition phase is ended and full activities in design development are initiated. As the TDRM tasks are executed and the performance criteria required for advancing technology readiness are met, the uncertainty associated with the successful implementation of that technology is reduced. In this fashion, risk is reduced as technology readiness levels increase, as shown in Figure E-6.

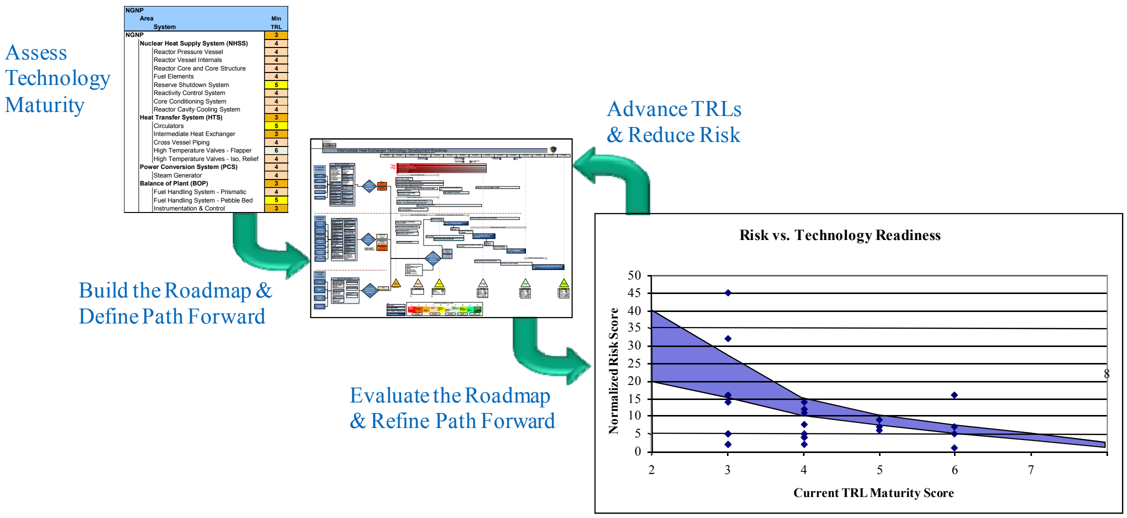

Figure E-6. Executing the TDRM reduces Risk and Uncertainty.

E-3. Engineering studies

E-3.1 Status

In the initial stages of the NGNP Project and as part of the pre-conceptual design work performed in FY 2007 special engineering studies were completed to:

- Support selection of key parameters and technologies
- Define requirements for the plant designs
- Inform R&D
- Inform the licensing effort
- Explore the economic viability of the HTGR in hydrogen production.

Specific special engineering studies conducted by the three HTGR supplier teams (AREVA, GA, and Westinghouse) during the pre-conceptual design effort included:

- Reactor type comparison
- Reactor power level
- High temperature process heat transfer and transport study
- Power conversion system alternatives
- End-products study (addressing potential uses for the NGNP, e.g., generation of electricity, production of hydrogen, and process heat for industrial applications)
- Licensing and permitting issues.

Additional studies were identified by the reactor supplier teams and the Project Engineering group during the pre-conceptual design efforts and were documented in the pre-conceptual design report.[5] These studies were grouped into two categories:

1. Technical Selection Studies that would support the final selection of NGNP operational and physical characteristics.

2. Design Development Studies that would support design development of the NGNP.

Tables 1 and 2 summarize the ones that are the more relevant to the development of the demonstration plant. Note that some were completed in 2008. The references for those that were completed are listed in Appendix H, with “A” designating AREVA, “GA” designating General Atomics, “W” designating Westinghouse, and “I” designating the INL.

Those design development studies that weren’t supportive of technology or site selection neutral assessments were ultimately delayed pending actual design start. As the project evolved and moved into the beginning of a conceptual design phase, additional studies were identified that would inform R&D or Licensing on generic issues applicable to both the prismatic block and pebble bed designs. These included support for fuel design (fuel and core performance and fission product transport), plant level studies and analyses such as a moisture ingress assessment, and availability of the manufacturing and transportation infrastructure.

A listing of all the Engineering-related studies and reports in the NGNP records is provided in Appendix H.

Table E-1. Technical selection studies and status.

No.	Subject	Scope	Completed?	References
1	Nuclear heat supply system functional and operational requirements	Assess design operating conditions for the NGNP including maximum reactor power level, reactor inlet and outlet temperatures, and primary pressure.	Yes	A-11, GA-13, GA-49, W-21, W-24, I-9, I-46, and I-47
2	IHX and secondary heat transport loop alternatives	Determine optimum configuration for IHX and secondary heat transport loop	Yes	A-8, A-14, GA-2, GA-10, GA-11, GA-15, W-17, W-18, W-26, I-18
3	Reactor pressure vessel (RPV) and intermediate heat exchanger pressure vessel alternatives	Evaluate options for the RPV and IHX pressure vessel materials considering required and achievable metallurgical and physical properties, acquisition, fabricability, and reliability	Yes	A-7, GA-8, I-11
4	Reactor containment and building functions	Define initial operating strategies to preclude the need for containment, recognizing the state of qualification of NGNP at the time of initial operation	Yes	A-12, GA-14, W-22
5	Contamination control	Determine expected generation and transport rates and allowable limits on expected contamination of the gas and other heat transport loops	Yes	GA-7, W-23, I-42. See also fission product transport related studies GA-33, W-29
6	Helium circulator limitations and design issues	Evaluate the current state-of-the-art for circulator design	Yes	INL-60
7	Instrumentation and control for nuclear heat supply and plant control	Identify discriminating characteristics in the I&C and plant control requirements of the nuclear heat supply types and configurations that would affect a design decision.	No	(See I-19 and I-45)

No.	Subject	Scope	Completed?	References
8	High temperature gas-cooled reactor applications	Develop the requirements and perform economic assessments for applications of HTGR technology for a broad range of industry needs	Yes	I-25, I-32
9	Hydrogen plant alternatives	Develop life-cycle comparisons of potential hydrogen production processes.	Yes	W-16, I-66
10	Helium supply economics	Assess concerns regarding a potential shortage of Helium supply for both the demonstration and the commercial plant	No	

Table E-2. Design development studies and status.

No.	Subject	Scope	Completed?	References
1	Plant design requirements to support initial operations	Establish specific design features of the plant that will be required to support the proof-of-principle initial operating period of the NGNP	No	
2	Reactor Building Embedment Depth	Develop the requirements and criteria for embedment of the reactor building considering cost, design basis threats, seismic effects and hazards resistance,	Yes	A-12, GA-14, W-22
3	High Temperature Gas Reactor Component Test Facility F&OR and Pre-conceptual Design Requirements	Develop functional and operational requirements for the test facility to support initiation of design work.	Yes	I-10, I-14, I-24
4	Construction techniques	Identify and evaluate advantages and disadvantages of potential innovative construction techniques, e.g., modularization	Yes	A-23, W-30
5	In-service inspection strategy and impact	Prepare an ISI strategy and impact analysis for the NHSS, HTS, and HPS.	No	

E-3.2 Path Forward

When design effort is resumed on the demonstration plant, review of the design data needs and the design development requirements documented in the technology development roadmaps should be used to inform the need for additional engineering studies.

E-4. PROCESS HEAT APPLICATIONS

E-4.1 Process Models and Economic Analyses

Process models of a number of industrial applications for the HTGR technology were developed to evaluate the technical viability of this technology for these applications. These are discussed in Section 5 of this report

E-4.2 Power Conversion Technology Development

E-4.2.1 Status

The Project has focused on HTGR plant configurations that include an HTS with either a steam generator or an IHX and Rankine steam turbine generators for electricity generation. However, other configurations have been developed by HTGR Suppliers, several of which were proposed or investigated during FY 2007 pre-conceptual design work. Two configurations were proposed that position a Brayton cycle turbine generator in the primary loop. The Brayton cycle compressor provides the primary helium circulation function and the turbine generator produces electricity. In this case there is no secondary loop; however, some low temperature heat can be recovered for industrial processes from the heat exchanger downstream of the turbine.

Another configuration was proposed that included an IHX HTS and a Brayton combined cycle turbine generator in the secondary loop. This configuration also generated electricity. In this case a helium/nitrogen mixture was used in the secondary loop to improve the efficiency of the Brayton cycle. It was concluded, however, that the use of the nitrogen in the secondary fluid is not advised because of degradation in the piping material properties caused by nitriding at the high operating temperatures of this cycle (e.g., >900°C).

Two comprehensive studies were performed by Rolls Royce and Pratt-Whitney of several potential power conversion alternatives applying the high temperature capabilities of the HTGR NHSS.[70,71]

The Rolls Royce study performed a detailed evaluation of the GA vertical Brayton cycle turbine generator and provided recommendations on addressing key issues.

The Pratt-Whitney study investigated the application of Steam Rankine, Brayton and Super-critical CO_2 cycles. This study evaluated several different configurations of these cycles, estimated the footprint and relative cost of each cycle. The baseline plant rating was 565 MW(t). Table E-3 summarizes the results of that study.

Table E-3. Comparison of power conversion system cycles.

Parameter	Cycle						
	Direct Brayton	Indirect Brayton	Supercritical CO2	Cascaded Supercritical CO2	CCGT	Subcritical Steam	Supercritical Steam
Hot Temperature (°C)	900	850	642	850	850	565.6	601.7
Cold Temperature (°C)	25	25	32	32	32	32	32
Net Cycle Power (MWe)	268.9	251.6	267.8	281.6	270.9	241.7	264.8
Net Cycle Efficiency (%)	47.6%	44.5%	47.4%	49.8%	47.6%	42.8%	46.9%
Sizes							
Required Heat Transfer Area (m^2)	54,921	63,988	60,976	68,073	49,336	17,957	18,704
Heat Exchangers (m^3)	80	220	144	184	796	285	297
Turbomachinery (m^3)	564	580	5	7	916	676	710
Total Volume (m^3)	645	801	149	191	1,712	961	1,007
Heat Exchangers Floor Space (m^2)	143	160	137	143	108	63	67
Turbomachinery Floor Space (m^2)	131	134	4	9	170	107	111
Total Required Floor Space (m^2)	273	294	141	152	277	170	177
Costs							
Heat Exchanger Costs (Rel.)	21.4	27.1	30.7	29.6	45.9	28.7	29.8
Turbomachinery Costs (Rel.)	57.3	58.9	0.5	0.7	51.7	25.3	26.8
Building Costs (Rel.)	2.3	2.5	1.2	1.3	2.4	1.4	1.5
Total Costs (Rel.)	81.0	88.5	32.4	31.7	100.0	55.4	58.1
O&M	-	+	+	+	0	0	0
TRL (Development Costs)	4	4	3	3	6	9	8

Those plant configurations with a steam generator in the primary HTS, i.e., that will utilize the steam Rankine cycle, have higher technology readiness levels than the Brayton or other cycles, since they utilize standardized steam plant components. Accordingly, they may be more suitable for deployment of early

HTGR modules. Locating the steam generator in the primary loop, however, creates issues regarding moisture ingress to the reactor core that will need to be addressed during design and plant transient analysis. Some early studies[72,73,74] have been performed that include evaluations of moisture ingress and possible impacts to the Reactor Protection System, but additional studies will be needed.

E-4.2.2 Path Forward

The Project decided in FY 2007 to only consider subcritical Rankine steam power conversion cycles for follow-on evaluations. Accordingly, none of the alternative configurations have been pursued by the Project since FY 2007. However, because they offer improvements over Rankine cycle efficiencies, they should be retained for potential application in the future as the Project investigates additional potential applications with a high electricity demand component. This is particularly true for applications that require only electricity or a significant fraction of the HTGR energy is used to generate electricity. For example, over 90% of the energy required to generate hydrogen using high temperature steam electrolysis is electrical. The higher net efficiencies of the supercritical steam, Brayton and super-critical CO_2 cycles warrant further evaluation for these applications.

E-4.3 HTS Technology Development

E-4.3.1 Status

E-4.3.1.1 Program Objective

The HTGR HTS is that part of the NHSS that converts the heat generated in the reactor into a form (e.g., steam, high temperature fluid) compatible with the energy conversion system and the needs of the application. (see Figure E-6) During the FY 2007 pre-conceptual design work, the HTS was identified as a critical area for development. The components of the HTS include:

- Cross-vessel / hot duct; the annular helium flow path between the reactor and the heat transport system
- Primary helium circulator
- Heat Transfer Element; currently, either a steam generator and/or an intermediate heat exchanger (IHX) housed within an HTS Pressure Vessel. Future applications may identify as need for gas to high temperature fluid heat transfer, such as molten salt and liquid metals. Two IHX designs have been considered to-date; a spiral tube design and a more developmental compact heat exchanger design. There is operating experience with the spiral tube design, e.g., it is used in the Japanese high temperature test reactor (HTTR). The focus of the NGNP Project has been on development of the compact heat exchanger.
- Valves used for back flow prevention (through the circulator), isolation on the secondary side and relief of primary over pressure.
- Secondary loop fluid; steam, helium, helium/nitrogen, air, CO_2 have been considered in investigations performed to-date.

The objective of the heat transport and technology development effort is to perform the analysis and testing necessary to advance the technology readiness levels of these components to the level necessary for use in the HTGR plant (a TRL-8). This includes qualifying the properties of the materials used in these components, development and qualification of fabrication methods, particularly for the compact IHX, and characterizing the performance of the components in operation under normal, abnormal and accident conditions. This development effort includes test planning, equipment and test article design and fabrication, and testing of subassemblies and components.

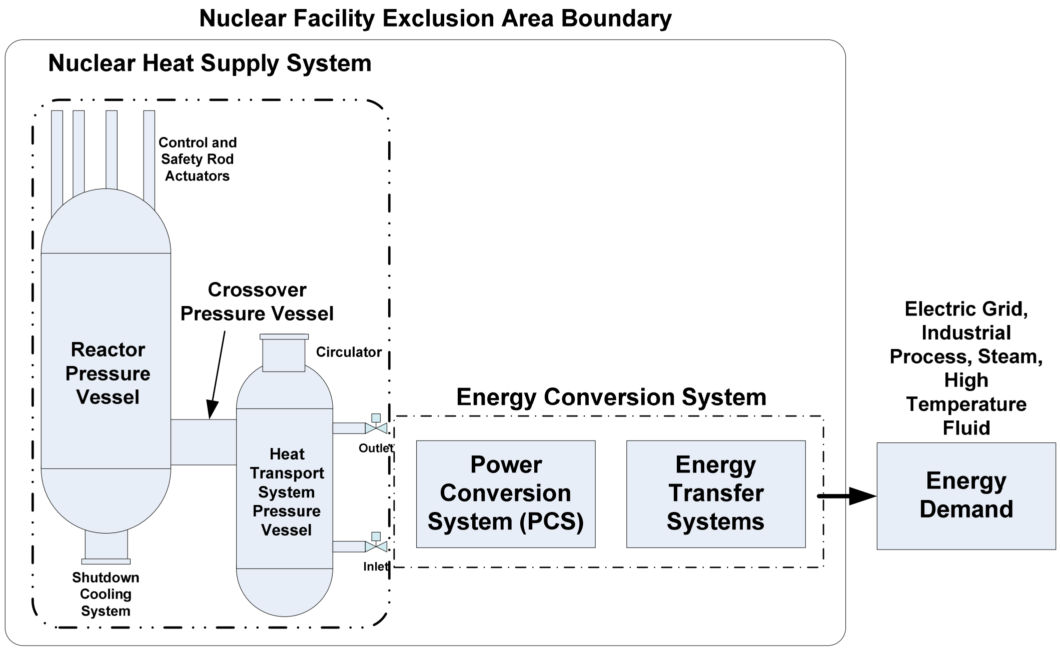

Figure E-6. HTGR plant components.

E-4.3.1.2 Pre-conceptual Design

The NGNP Project pre-conceptual design work in FY 2007 was focused on a plant design to generate electricity and hydrogen. As cited elsewhere in this report pre-conceptual designs for this HTGR plant were prepared by three teams run by Westinghouse/PBMR, AREVA and GA. Each of these teams performed High Temperature Process Heat Transfer and Transport studies as part of the design effort. These studies were limited to a heat transport system configuration that included an IHX. Steam was generated by a steam generator positioned in the secondary gas circuit. High temperature gas was also transferred from the IHX to a hydrogen generation process. The scope of these studies varied from focusing on the selection of the secondary heat transfer fluid [75] to a more comprehensive study of the IHX design, primary and secondary loop configurations, and materials of construction.[76] In this configuration, all three of the reactor suppliers recommended use of helium as the secondary heat transport fluid. Both compact and shell and tube heat exchangers were recommended.

E-4.3.1.3 Technology Readiness Levels

In FY 2008 the HTGR Suppliers performed evaluations of the risks to Project Completion and developed Technology Development Roadmaps that included establishing theTRL of key components and plans to progress the TRLs of each of these components sufficiently to install the component in the HTGR; typically TRL-8. Table E-4 provides the current estimate of the TRL levels for the components of the HTS (see Sections E-2.2.2 and E-2.3.1 for a discussion of TRLs).

A test plan[77] was developed that identified the testing needs for all of these components, however, the efforts from 2007 through 2011 focused on advancing the technology readiness level of the IHX. It has not been practical to develop detailed testing needs for the other components with more advanced TRLs without a better definition of the plant design. Accordingly, the following discussion focuses on the work performed to advance the technology readiness of the compact heat exchanger.

Table E-4. HTS Component TRLs.

Component	TRL
Circulator	4 to 6
Cross Vessel	4
Valves:	
Circulator non-return	5
Primary relief	3
Secondary isolation	3
Compact heat exchanger	3
Shell and tube heat exchanger	3
Steam generator	4

E-4.3.1.4 Compact Heat Exchanger

Design

Several studies by reactor suppliers and INL[78,79,80,81] (also see Table E-1 Item 2), concluded that the compact heat exchanger has advantages for the IHX because of its smaller size and potentially lower cost than the shell and tubular design heat exchanger. It was also concluded that for larger NHSS ratings (e.g., 600 MW(t)) it would be possible to use a single compact IHX in a single primary loop whereas at least two loops would be required for the shell and tubular design. The compact heat exchanger is typically comprised of several small flow passages of alternating primary and secondary flow in a counter-current or cross-flow configuration. The flow passages are formed by thin stamped metal plates or by ceramic plates. The latter is the so-called printed circuit heat exchanger provided by Heatric as shown in Figure E-7. The thin plates and the flow configuration leads to improved heat transfer and lower volume and weight compared to a tubular heat exchanger. However, the high operating temperatures required for the HTGR application and the potential for relatively high primary to secondary pressure differentials during off-normal conditions are serious design challenges for these heat exchangers. There are also challenges related to fabrication and qualification effort required to obtain ASME code rules applicable to these designs.

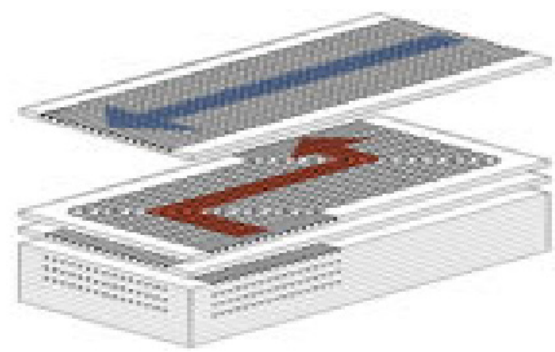

Figure E-7. Heatric printed circuit heat exchanger.

The activities required to address these challenges and advance the compact heat exchanger design from TRL-3 (Proof of Concept) to TRL-5 (Experimental Scale) fall into four broad categories:

- Materials testing
- Fabrication development
- Static (or low flow) single effects tests to investigate specific issues under controlled conditions, such as fatigue or creep testing
- Flowing loops that provide experiment scale demonstrations in a relevant environment.

Materials Testing

Testing and qualification of two promising materials for the compact heat exchanger, Inconel 617 and Alloy 800H is being conducted as part of the NGNP Technology Development effort.

Fabrication

The development of fabrication technologies for the compact heat exchangers has been the subject of several engineering studies, including:

- Investigations of brazing techniques in conjunction with researchers at Sandia National Laboratory[82]
- Development of diffusion welding techniques at the INL
- Investigations of high temperature diffusion welding and demonstration and testing by INL.[83]

These development efforts involved using a servo-hydraulic, thermomechanical testing device (Gleeble ™ device) to subject specimens made of specially prepared small disks to high temperatures and axial pressures to induce grain growth across the disk interfaces (Figure E-8). These efforts produced excellent specimens that had over 90% of the strength of the parent material. Diffusion welding efforts during FY 2011 were focused on Alloy 800H and are reported in Reference 84.

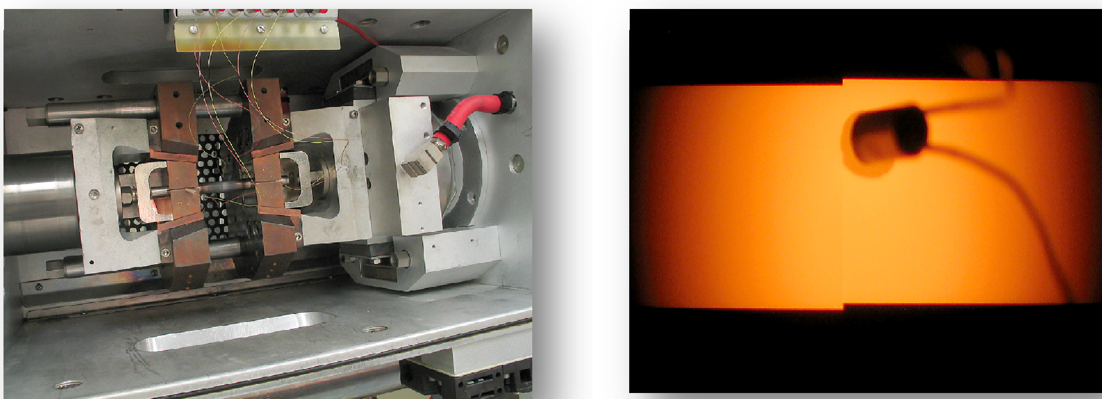

Figure E-8. Gleeble device and close-up of sample being welded.

Planning was underway in FY 2011 to expand the development of material preparations and welding parameters for larger scale coupons when the engineering efforts on NGNP were terminated. Also, a number of recommendations to consider for future work are documented in Reference 85. When full scope NGNP HTGR development and commercialization activities are resumed, development of diffusion welding will need to address Inconel 617 as a likely material for construction of the IHX.

Small Pressure Cycling Test Rig

The thin sections of the compact heat exchanger will be subjected to high temperatures and alternating pressure differentials over their lifetime. The small pressure cycling test rig (SPECTR) was designed and fabricated and commissioned to test these sections under projected operating conditions. SPECTR was intended to perform single effects testing of thin section subassemblies at typical HTGR temperatures and alternating pressures to obtain fatigue and creep-fatigue data on a more geometrically representative sample than the typical materials testing coupon. This approach isolated the fatigue loading to pressure only, which is a less complex loading condition than combined pressure and thermal loading (the thermal loading comes from the differential temperature between the hot and cold streams in the IHX). SPECTR is designed to test diffusion bonded subassemblies of up to 8 inch cubes at temperatures up to 1000°C and pressures up 7 MPa inside the test article. The SPECTR system was installed and operated on simulated test articles in late FY 2011.[86]

Plans for future testing using SPECTR are included in Reference 86.

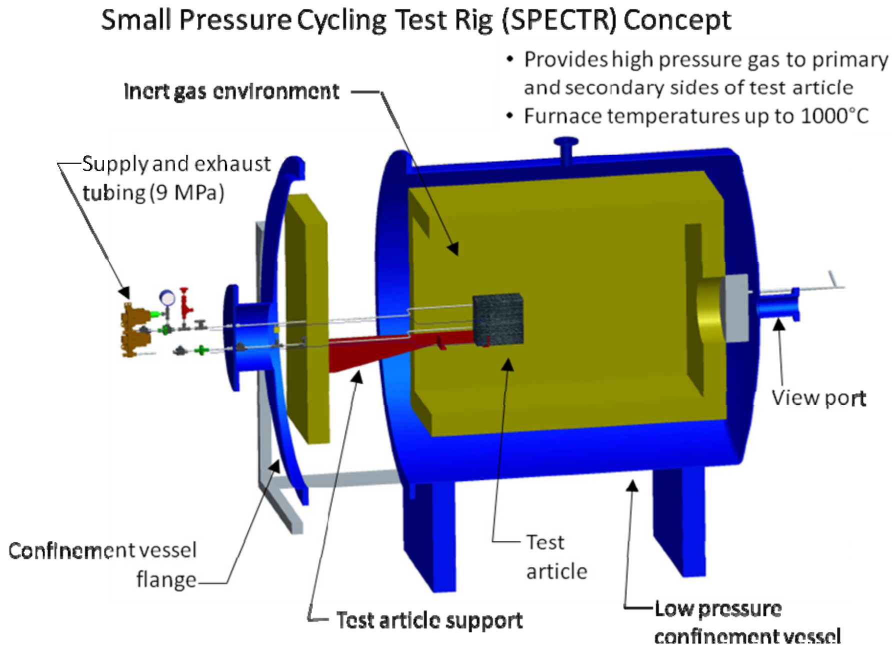

Figure E-9. The SPECTR test system at the INL.

Ohio State High Temperature Test Loop

A small flowing test system was developed in collaboration with the University of Ohio. The Ohio State High Temperature Test Loop (Sun) performs testing of compact heat exchangers under flowing conditions. It is designed for operation at temperatures up to 800°C and pressures up to 3 MPa and has a heat input of about 23 kW. This system can support thermal-hydraulic testing to verify heat transfer coefficients as well as subjecting heat exchangers and other critical components of HTGRs, such as valves, instruments, gaskets, insulation, and piping, to elevated pressures and temperatures to verify mechanical and structural performance.

Documentation of tests performed to-date in the Ohio State loop and plans for future testing are included in Reference 87.

Mixed Stream Test Rig (MISTER)

The Mixed Stream Test Rig (MISTER) was designed and assembled in FY 2010 to test high temperature materials within environments of gas compositions that are expected in the high temperature steam electrolysis (HTSE) hydrogen production process.[88] These include steam, He, O_2, CO, and CO_2.

Results and conclusions of tests performed to-date and plans for future testing are included in Reference 89.

Steam Generator Dissimilar Welds

In the current helical coil steam generator design the water/steam is on the tube side and the helium is on the shell side. Water inlet temperatures are in the range of 230°C and steam outlet temperatures are in the range of 540°C. The helium temperatures at the steam outlet will be in the range of 750 and 350°C at the feedwater inlet. Accordingly, the tubes will be subjected to significant temperature differentials at the feedwater inlet and the superheated steam outlet.

The operating conditions of the tubes can be divided into three zones, an inlet (subcooled) section, an intermediate (evaporator section), and a final superheat section. For economic reasons the steam generator tube bundle uses Alloy 800H for the superheat section and a less expensive 2-¼ Cr–1 Mo steel for the subcooled and evaporator sections. The NGNP project has collaborated with Lehigh University on the development of welding techniques for the dissimilar metal weld at this junction. The results of this collaboration and future work required in this area are included in Reference 90.

Figure E-10 shows the integration of these activities in the advancement of the technical readiness levels of the IHX that was planned prior to the termination of NGNP Engineering activities.

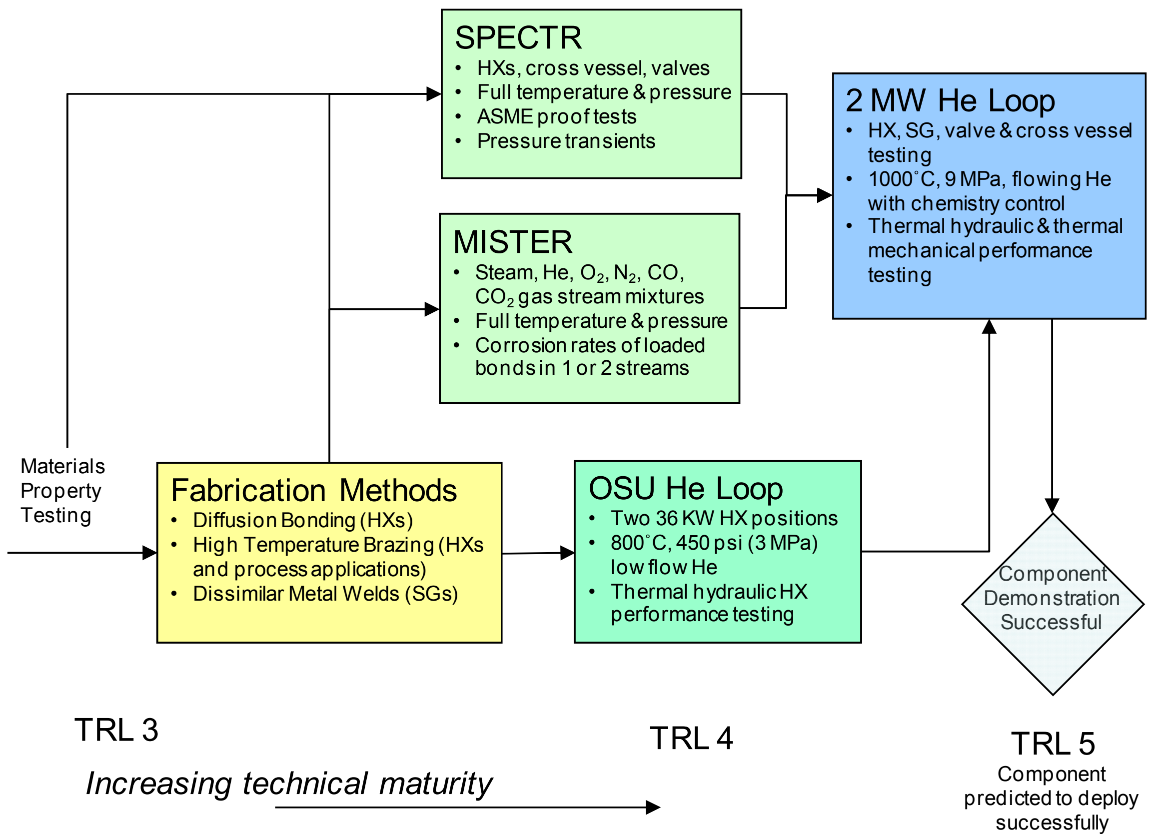

Figure E-10. Heat Transport Component Test Capability required to achieve TRL-5.

E-4.3.2 Path Forward

To ensure their availability for future use, SPECTR and MISTER have been laid up or maintained to facilitate a resumption of testing. The Ohio State High Temperature Test Loop should also be laid up or maintained for future use.

Once design efforts are resumed for the HTGR plant, test plans for achieving the required technical readiness level for each HTS component will need to be reviewed to ensure they encompass the functional and performance requirements of that design. New development and test plans will be required for the cross-ducts, circulators, and valves for the specific design.

Any advances in the design and materials for the HTS components or that occur in other industries during the transition period or relevant testing or operating experience (e.g., with the Japanese HTTR and the Chinese HTR-10) should be evaluated for applicability to the HTGR HTS and/or modification for further testing.

E-5. National Codes and Standards

E-5.1 Status

The licensing and operation of the HTGR will require the advancement and completion of a number of National Standards and Consensus Codes. The ASME, ANS, and ASTM International have all been supportive of the NGNP Project and have been involved with the standards and codes advancement activities. The ASME has developed a path forward for many of the code related issues in their "Roadmap to Develop ASME Code Rules for the Construction of High Temperature Gas Cooled Reactors (HTGRs)" currently available on the ASME Website.[91] This roadmap is being used by ASME management to track the various identified ASME activities needed for codification of materials and material joining techniques at HTGR elevated temperatures. An update to this roadmap should be issued in early 2012.

Development of new ASME Standards or revising existing ASME Codes or Standards will require substantial research and technology development and the development of ASTM specifications. The general approach taken by the NGNP Project to support these efforts depends on the type of information needed. The NGNP Project team has positioned personnel in several key committee positions to advance codes and standards development in collaboration with national standard and consensus code organizations. However, after the realignment of the Project to an R&D program in FY 2012, planned funding appears to be unavailable in following years to continue to provide the necessary BPV Code committee support so that adequate construction rules will exist for the NGNP HTGR. Reference 92 contains additional information on development efforts for ASME Codes and Standards related to HTGRs.

A particular area of concern is that the process to accept graphite data into the proposed ASME BPV Section II Part E will not be in place in FY 2012. Without continued funding, there will be no support to gain acceptance and inclusion of non-irradiated graphite material property data used for design into Section II. This improvement would eliminate the current requirements in Section III, Division 5 for the designer to provide material test data on each grade of graphite. An update to Reference 92 will be issued at the end of FY 2012.

ASME Standards Technology, LLC has partnered with DOE (who provided funding) via the Generation IV Reactor Materials Project to perform research on various technical issues pertinent to the development of construction rules for high temperature reactors. To date, 14 tasks have been addressed and revisions to code rules have been developed and approved as a result of this work. However, more work is necessary to improve the existing ASME Code rules affecting the design of an HTGR. Continued funding from the Department of Energy or other sources to complete new proposed ASME ST, LLC tasks would be extremely helpful for future HTGR design efforts. Reference 92 contains additional information on the completed tasks and proposed future tasks.

E-5.2 Path Forward

When full scope NGNP HTGR development and commercialization activities are resumed, the status of the codes and standards highlighted in Table E-5 will need to be assessed and related efforts picked up as a high priority focus in order to ensure that sufficient code rules are in place to support HTGR design and licensing. Also, the reactor design agent should ensure application of rules applicable to the HTGR technology, such as the ASME BPV Section III, Division 5 as opposed to Section III, Division 1.

Table E-5. Advancement of codes, standards, and rules for the construction and operation of HTGRs.

Code/Standard	Status and Relevance	Project Involvement
ANSI/ANS – 53.1, *Nuclear Safety Design Process for Modular Helium-Cooled Reactor Plants.*	This draft standard has achieved consensus by the Nuclear Facilities Standards Committee and is expected to be certified by the American Nuclear Society (ANS) Standards Board. Following the American National Standards Institute (ANSI) review and approval process, which is expected in December 2011, the ANS editors will complete final editing. The anticipated publishing date is approximately April 2012. This Standard is needed for development of other code rules.	The NGNP Project and commercial design suppliers have been heavily engaged with the development of this standard. An NGNP Project member was formally accepted in 2009 onto the ANS-28 Subcommittee of the American Nuclear Society as a member of the ANS-53.1 Working Group engaged in issuing the draft standard.
ASME PRA Standard, *Technology Neutral Probabilistic Risk Assessment Standard for Advanced Non-LWR Nuclear Power Plants*.	This draft standard is still in development and has been balloted at the Subcommittee on Standards Development. Continued efforts are necessary before it achieves final approval at the Standards Committee on Nuclear Risk Management. Timeframes for publication are unknown at this time. This Standard is needed for development of other code rules.	The NGNP Project has subcontracted with the ASME's Committee for Nuclear Risk Management Non-Light Water Reactor Plants Working Group chair to ensure this standard is completed after progress was halted during FY 2009. The INL lead for Risk, Reliability and NRC Program is also a member of the Working Group that is developing this new PRA standard.
ASME's *Roadmap to Develop ASME Code Rules for the Construction of High Temperature Gas Cooled Reactors (HTGRs).*	This is not actually a standard, but is a roadmap/plan of code rule activities needed to support HTGR development. Many roadmap tasks are included within the various ASME BPV Code updates listed below as well as for other standards. Other tasks are being addressed by ASME Standards Technology, LLC, which is currently managing 14 tasks related to the NGNP Project, of which 12 are complete. Additional new tasks are being considered but funding is needed before they can begin. The ASME ST, LLC uploaded the roadmap document (STP-NU-045) in 2010 as an ASME publication. The Roadmap is currently being updated using NRC carryover funding to reflect recent achievements and to better address available material data and technology capabilities.	The NGNP Project is represented by two Technical Representatives on the ASME ST-LLC Steering Committee. The representatives' function is to ensure that the work sponsored through the ASME ST-LLC gives highest priority to NGNP Project needs. The two representatives of the NGNP Project and other project staff supporting the ASME BPV Code, Section III working groups will also provide review and comment regarding the completion of the ASME ST-LLC tasks. Note also that the NGNP Project will directly perform or lead much of the R&D and other efforts to develop associated ASTM Specifications for materials and joining methods of interest.

Code/Standard	Status and Relevance	Project Involvement
ASME BPV Code	Various updates applicable to both 750 and 950°C reactor outlet temperatures have been initiated. These are needed to qualify material and design rules for nuclear construction. Section II – Update needed to account for new materials. Order and priority is dependent on reactor outlet temperature and design configuration and material selections. Future release of Section II Part E will contain non-irradiated graphite properties Section III – Updates needed for existing Division 5. The order and priority of work is highly dependent on the selection of reactor outlet temperature and design configuration and material selections. Efforts for all of the following materials have been discussed: 308, 316, 617, 800H, Gr 91 (9Cr-1Mo-1V), 2¼Cr-1Mo, Hastelloy X, Hastelloy XR. Section III, Subsection NH – need to extend and simplify Code rules to anticipated higher temperatures. Section III, Division 5 – consolidated near-term needs for HTGRs from Division 1 Subsections (as appropriate, including Subsection NH) and existing elevated temperature Code Cases. Long-term needs involve new analysis methods. Section III, Graphite Rules (general requirements and design / construction rules) Section V – address new non-destructive examination techniques applicable to VHTRs. Section XI, Division 2 – new revision for rules addressing inservice inspection, maintenance, and repair of HTGRs. A draft has been written and is proceeding through the ASME approval process.	The NGNP Project was represented by staff members from the INL and/or Oak Ridge National Laboratory on the following committees and groups during FY 2011: • Subgroup on High Temperature Reactors (Section III) • Working Group on Nuclear High Temperature Gas-Cooled Reactors (Section III) • A Project representative on the Working Group on Nuclear High Temperature Gas-Cooled Reactors (Section III) is the current Chair of the Working Group • An INL staff member was named the Code Committee Project Manager for the development of Division 5, *High Temperature Reactors* and prepared the draft of this new Code • Subgroup on Graphite Core Components (Section III). Note that this Subgroup has interacted with Section II, and that substantial continued interaction is needed • Subgroup on Elevated Temperature Design (Section III) • Subgroup on Elevated Temperature Construction (Section III) • BPV III Standards Committee • Special Working Group on HTGRs (Section XI)

E-6. COMPONENT TEST FACILITY

E-6.1 Status

Figure E-33. Artist's Rendering of the Component Test Facility.

The need for a capability to test NGNP reactor and heat transport system components at representative temperatures and pressures and in a relevant environment was identified during pre-conceptual design work performed in FY 2007. A temperature-controlled, flowing helium loop was judged to be necessary to advance the technology readiness of critical [j] components, such as large helium circulators and heat transport system components (e.g., steam generator, intermediate heat exchanger), and also to support steady state and transient computer code verification and validation.

In March of 2006, a Preliminary Program Management Plan[93] identified the need for the design and construction of a reasonably large-scale (on the order of 1 MW[t]), high-temperature gas test facility for component and materials testing. In August of 2006, a conceptual design was completed[94] for a high temperature gas loop test facility.

The need for a test capability was emphasized by the AREVA design team during the pre-conceptual design effort and documented in their report.2 Helium testing loops also featured prominently in the Westinghouse/PBMR planning for the Demonstration Power Plant in South Africa. During the pre-conceptual design time frame, the NGNP project completed a study of applicable existing testing capabilities world-wide and established preliminary requirements for a high temperature fluid test flow facility sized to support full-scale testing and qualification of primary loop components and also engineering-scale mockup testing of high temperature applications, such as hydrogen production.[95] The need for this test facility was documented in the final NGNP pre-conceptual design report.[5]

It was assumed that the test facility, referred to as the CTF, would be sited as part of the DOE complex infrastructure at INL, and should, therefore, be pursued as a DOE O 413.3 project in parallel with the NGNP Project. Conceptual designs were developed in late 2008 and early 2009 by Westinghouse[96] and AREVA.[97] In August of 2008 a package to support DOE Critical Decision (CD) 0 (Approve Mission Need) for this facility was submitted to DOE.[98] Additional evaluations and requirements definition continued during 2009. In subsequent discussions with DOE, direction was given to cease making reference to a single testing facility and to refer to the need for a "component testing capability." A draft of the Justification of Mission Need was developed and provided to the DOE in April of 2009.[99] Also in 2009, TDRs[66,67] were established which included detailed test plans developed by all three reactor supplier teams to systematically mature technologies for risk-reduced installation into the NGNP. These test plans called for between 87 and 90 tests (depending upon the reactor outlet temperature) to be conducted in a CTF.

j. Critical components are those that are not currently available commercially, have no previous relevant operating experience and, therefore, require development for use in the high temperature gas reactor.

In March of 2010 the NGNP project was notified by DOE that the Mission Need was not approved and all work on the component test capability ceased. The reports and correspondence related to the CTF are stored on the INL Electronic Document Management System.

In lieu of the CTF, additional test apparatus were considered to support the advancement of high temperature components such as the intermediate heat exchanger from TRL-3 to TRL-4. One such apparatus actually designed and built, was the SPECTR, which is described in Section E-4.3.1.4. This apparatus does not have the capacity to advance the technical readiness of this critical component to the level necessary to have confidence in its performance and reliability in the HTGR plant.

The CTF was intended to be used to advance the technical readiness level of critical components from TRL-3 (Proof of Concept) through TRL-7 (Engineering Scale demonstrations). This technical readiness level is judged by the NGNP Project as the level required to develop the necessary confidence in the reliability and performance of a component or system to install it in the demonstration plant. It is anticipated that additional needs for large scale testing will be identified as the design of the demonstration plant advances. In some cases it may be practical to include this large scale testing in the scope of the supplier. Suppliers of helium circulators have test facilities that could be modified appropriately for this purpose. This is not the case for the major heat transport equipment such as intermediate heat exchangers and steam generators. It is also not the case to support integrated testing of heat transport systems, which has been identified as a major need for the CTF.

In preparing the justification for the CTF several alternatives to the CTF were identified and criteria was developed to evaluate each alternative. The conclusion of the diverse and independent panel that conducted the evaluations was that a separate large scale component test facility is required to satisfy the criteria.[100]

Concurrent with this evaluation effort, a simulation was developed to determine the costs of technology development for alternatives including “No action,” “Vendor Provided,” and “Central Development Capability.” The simulation, which was based on the FLEXSIM simulation software coupled with an Excel spreadsheet input file, encompassed the effort associated with technology development from conceptual design through an operational plant and addressed unique items such as dead-end paths during discovery, failures during discovery and development, and issues of rework and resource availability. The simulation was terminated before the design data and reliability estimates were sufficiently advanced to allow final tuning of the model and generation of results. However, the development provided useful experience in development of simulation models to assess the cost and schedule risks for technology development of complex "first-of-a-kind" systems. Some observations noted during model development were:

- Early materials R&D can minimize failure costs at the more advanced technology readiness levels
- Effort spent in the TRL-3 to TRL-5 range can reduce the potential for more severe cost impacts in the more expensive TRL-6 and TRL-7 development efforts.

This work was suspended prior to reaching final conclusions. When more detailed design and reliability data are available, the model should be revisited to identify a preferred option for providing the component test capability.

E-6.2 CTF Path Forward

No subsequent work or evaluations have been performed to change the conclusions of the evaluations cited above or reduce or eliminate the need for this facility. If this facility or capability is not available to the NGNP Project critical components will be installed in the demonstration plant with insufficient technical readiness. The demonstration plant will then be used as the surrogate for the CTF. This is a dubious and very expensive use of the demonstration plant and could result in a major increase in the schedule for initial NRC licensing and full commercialization of the HTGR technology.

When full scope HTGR development and commercialization activities are resumed, design and deployment of the large-scale component test facility should be addressed with high priority to ensure its availability to meet NGNP Project objectives.

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Appendix F

Licensing Status and Path Forward

Appendix F—Licensing

F-1. NGNP PROJECT LICENSING STRATEGY - STATUS

Provisions of Section 644 of the *Energy Policy Act of 2005* (EPAct) required the Secretary of Energy and the Chairman of the Nuclear Regulatory Commission (NRC) to jointly submit to Congress, within 3 years of enactment, a licensing strategy for the Next Generation Nuclear Plant (NGNP). The NGNP licensing strategy report was directed to include the following elements:

- A description of the ways in which NRC needs to adapt its current light water reactor (LWR) licensing requirements to accommodate the types of reactors considered for the project
- A description of the analytical tools that NRC will need to develop to independently verify the NGNP design and its safety performance
- A description of other research or development activities that NRC will need to conduct a review of an NGNP license application
- A budget estimate associated with the licensing strategy.

As a result of the Section 644 provisions, Department of Energy (DOE) and NRC developed the *Next Generation Nuclear Plant Licensing Strategy—A Report to Congress*,[1] that addressed the four elements listed above. The strategy document also concluded that the best approach to establish the licensing and safety basis for the NGNP will be to develop a risk-informed and performance-based technical approach that adapts existing NRC LWR technical licensing requirements in establishing NGNP design-specific technical licensing requirements. This adaptation strategy, as opposed to creating a new and different licensing framework for high temperature gas-cooled reactors (HTGRs), is a key to the overall licensing process being implemented for NGNP.

The NGNP project team then developed a more detailed strategic implementation plan to establish the regulatory licensing bases that will support the issuance of an NRC combined license (COL) in accordance with applicable 10 CFR 52 requirements for the demonstration plant. This NGNP Project Licensing Plan,[2] finalized in June 2009, focuses on three key NRC license application elements, leading to demonstration plant licensing, construction, and deployment:

1. Develop and understanding the radiological source term (based primarily on the particle fuel design, qualification testing results, and analytical methods development).
2. Minimize the source term (including definition of licensing basis events and design/implementation of multiple release barriers, consistent with defense in depth strategies and requirements).
3. Develop an updated emergency planning structure that considers potential radiological releases from the HTGR facility, coupled with various industrial application configurations, in order to assure the protection of public health and safety in the unlikely event of a release.

F-2. PRE-APPLICATION PROCESS - STATUS

The centerpiece of the NGNP licensing approach is development of a COL application submitted to NRC pursuant to 10 CFR 52 of NRC regulations. Development and submittal of the application will require that the:

- NGNP Project and NRC come to a common agreement regarding the COL application development and content requirements, and guidance documents suitable for the NGNP

- NGNP design is developed to the point where sufficient information is available to complete the application, assure NRC acceptance of the COL application for review, and assure timely review by NRC Staff once the application is accepted for review and docketing.

An effective NRC pre-application program is critical to this approach and the overall project plan, because early establishment of the approach to resolution of issues can significantly impact the preparation of acceptable COL applications, the subsequent application review schedule, and ultimate deployment of the demonstration plant. Frequent, focused, and coordinated interactions with NRC Staff are critical to the success of the pre-application period. As described in the DOE-NRC Licensing Strategy (Reference 1 from Section 7.6.1), it is expected that NRC will participate in the project pre-application review 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.

The NGNP Licensing Plan contains a summary listing of licensing issues considered to be of highest priority, and have therefore been a focus of the NGNP Project team in its pre-application interactions with NRC Staff. Issues identified for pre-application discussions with NRC were selected from a number of sources, including modular high temperature gas-cooled reactor (MHTGR) precedent, the Exelon Pebble Bed Modular Reactor (PBMR) licensing program, the PBMR (Pty) Ltd. U.S. Design Certification program, and NGNP program studies. NRC also evaluated a broad set of potential policy issues and licensing topics that may apply to small modular reactors of advanced design, including HTGRs. At the conclusion of this evaluation, NRC developed and issued SECY-10-0034[3] which identifies key areas of focus for both NRC and industry in advanced reactor licensing. The SECY listing of issues aligns very well with the priority topics previously established by NGNP.

The overall COL application development sequence is shown in Figure F-1. The project is currently in the "NGNP Transmittals" portion of this path, with key portions of the process summarized in the subsections below. Transition to the remaining activities is uncertain at this time. It could occur if a public-private partnership is consummated to continue the NGNP Project. Alternatively, another entity could undertake development and licensing of the HTGR technology without a partnership or any U.S. government involvement. In order for the process to proceed, a specific HTGR design must be chosen, a site selected, and NRC license applicant identified.

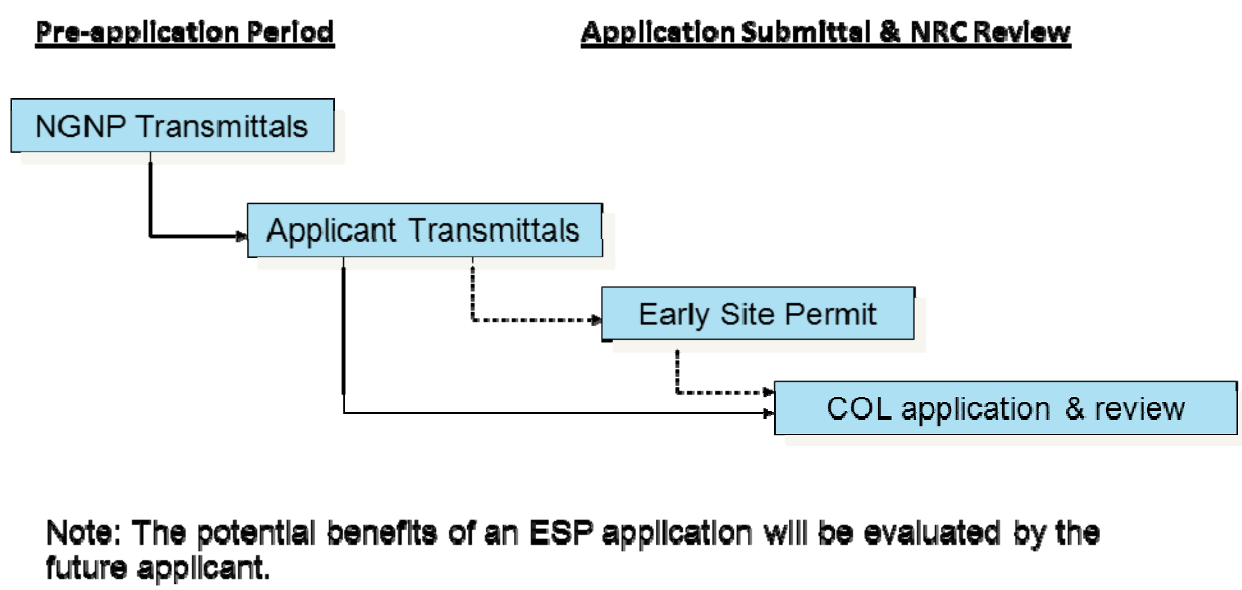

Figure F-1. COL application development sequence.

Fully resolving certain pre-application issues will require more detail regarding plant design and configuration that may not be available until the initial license application is being developed. These additional design details are expected to be developed as the project progresses under whatever organization or entity takes it forward. Therefore, NGNP project licensing activities have focused on priority topics that can be developed and addressed with limited design detail. The ability to continue with this focus is limited, however, such that if more design detail is not available interactions with NRC will be severely curtailed in the mid part of 2012.

F-2.1 NRC Interactions

In the early stages of the project, DOE and NRC entered into a Memorandum of Understanding[4] with a focus on achieving DOE's NGNP project objectives, while maintaining NRC independence as the licensing and regulatory authority. The primary NRC responsibilities outlined in the memorandum of understanding (MOU) include the following:

- Provide feedback to DOE on potential regulatory and licensing issues associated with NGNP design, development, research and assessment plans, analyses, and results
- Provide information and regulatory guidance on existing NRC regulations that are relevant to DOE decisions related to NGNP reactor design and technology development
- Plan and implement safety-related R&D needed for NRC to independently review the NGNP application
- Develop an independent ability to confirm the design and safety performance of the NGNP.

NGNP Project interfaces and pre-application document reviews associated with the above MOU are being coordinated through DOE's Office of Gas Reactors, and through NRC's Division of Advanced Reactors, which is a part of the Office of New Reactors (NRO). The NRO staff also receives support on many key HTGR technical issues from NRC's Office of Research. The primary focus of these interactions is to establish the required HTGR COL application content. This is being accomplished through a series of NGNP document transmittals, and the development of NRC assessment reports covering key policy and technical issues. Interaction with NRC staff under the MOU has also been enhanced through biweekly telephone conferences, in which work status is reviewed, and the calendar of upcoming events is discussed and established.

NRC established Project No. 0748 for NGNP to track all associated activities and to collect related project transmittals and public meeting information. (Note that all NGNP project-related correspondence and NRC public meeting information associated with the project can be retrieved from NRC's Agencywide Documents Access and Management System (**ADAMS** system by entering "PROJ0748" into the "docket number" field of the advanced search screen.)

In the early stages of the pre-application process, DOE sponsored the NGNP Project's development of a training program covering HTGR design and licensing topics to facilitate NRC's review and resolution of the key HTGR policy and technical issues. This comprehensive HTGR training material was then presented in a session that was very well attended by NRC Staff (about 75 attendees over 4 days) in May, 2010. The syllabus from this training session identifying topics that were addressed is provided in Appendix J. The detailed training module material used during the training session can be found at *https://inlportal.inl.gov/portal/server.pt/community/ngnp_public_documents/, NRC Training Presentations.*

F-2.2 Licensing White Papers

The NGNP Project has developed a series of white papers that address each of the most significant pre-application issues as a means of focusing NRC review and establishing requirements for acceptable COL application contents. The priority pre-application items were selected primarily because of potentially significant impact on design configuration of the plant, lead times associated with policy issue resolution, related project activities, licensing, and project completion. It is therefore critical that NRC feedback regarding white papers be developed and documented with as much regulatory certainty as possible (consistent with the maturity of the proposed design and its associated licensing strategy, and the NGNP Project position for the selected topic). This regulatory certainty is critical to the efficient progress of the project.

In this process, white papers are prepared for each priority pre-application issue then submitted to NRC. They are reviewed by NRC, and may be revised following that review and resolution of NRC issues. The following summarizes this process:

1. NGNP prepares and submits the white paper to NRC. The white paper identifies the specific issues to be addressed, summarizes related regulatory history, proposes approaches to resolution of the issues, and delineates expected outcomes from NRC review
2. NRC Staff reviews the paper
3. Workshops are held in NRC public meetings to discuss the elements of the paper and to provide feedback on issues and proposed resolutions of the issues
4. NRC issues Requests for Additional Information (RAIs) as needed
5. NGNP responses to the RAIs are prepared and submitted
6. NRC reviews RAI responses
7. NRC provides final feedback and documentation in a format that can be used as a firm basis for incorporating the resolution of the issue in preparing the license application(s).

The duration of the above process depends on the content of the paper and its significance to NRC safety review. The results of these pre-application activities, and the results of NRC's review, will be used when revising or developing the format and/or content of COL or Early Site Permit applications, so that early and ongoing alignment with NRC is maintained.

A total of 11 NGNP licensing white papers have been developed and submitted to NRC to date, with current status summarized in Table F-1. From this group, NRC staff has completed its review of the white paper addressing the structure of the COL application for a plant facility with multiple modules, and endorsed the proposal. This NRC disposition is contained in SECY-11-0079 (Ref. b for that paper), which states that; "*Consistent with NRC regulations and existing practice, a COL application related to multiple modules at a single facility can undergo a single license review, safety evaluation report (SER), and hearing if a single license application is made for modules of essentially the same design.*" This conclusion is significant for the future commercialization of HTGRs, since it confirms the path for a streamlined licensing process with a single review and reduced hearing risk for multimodule facilities.

NRC is currently developing a series of assessment reports that summarize the results of their review of a portion of the remaining NGNP white papers covering the most significant HTGR policy and technical issues, and expect to issue those reports in the January 2012 timeframe. It is noted that the white paper covering the HTGR Safety Basis and Approach was developed by the Project and provided to NRC for information to aid in overall development of these assessment reports.

The NGNP Project has also submitted its Quality Assurance Program Document (QAPD) to NRC for review and approval. More detail regarding this May 2011 submittal can be found in Section 8 and Appendix G of this report.

Table F-1. White papers.

NGNP Pre-Application Topic	Submittal Date	NRC RAIs Received	NGNP RAI Responses Provided
Defense in Depth	Dec 2009	July 2010	Sept 2010
High Temperature Materials	June 2010	July 2011	Sept 2011
Fuel Qualification	July 2010	June 2011	Aug 2011
Mechanistic Source Terms	July 2010	June 2011	Aug 2011
Licensing Multimodule Facilities	Aug 2010	None	None
Licensing Basis Event Selection	Sept 2010	Aug 2011	Oct 2011
SSC Classification	Sept 2010	Aug 2011	Oct 2011
Emergency Planning	Oct 2010	None	None
Nuclear/Industrial Facility Boundaries	July 2011	TBD	TBD
Use of PRA	Oct 2011	TBD	TBD
HTGR Safety Basis and Approach	Sept 2011	None	None

F-2.3 Regulatory Gap Analysis

In conjunction with the white paper process, a Project Regulatory Gap Analysis (RGA) for HTGRs[5] was conducted to evaluate existing regulatory requirements and guidance against the design characteristics specific to a generic modular HTGR. The information contained in this report is now being used to further efforts in reconciling HTGR-related gaps in NRC licensing structure, which has to date largely focused on light water reactor technology.

The RGA used the MHTGR Preliminary Safety Information Document (PSID) as the reference design basis. The MHTGR-PSID[6] (a prismatic block design) was used because it contains a readily available description of a typical modular HTGR. However, the RGA was executed so that results can be generically applied to both the pebble bed and the prismatic block core modular HTGR designs.

The RGA examined NRC regulatory and guidance positions according to the instructions contained in NGNP-LIC-ETR-PROC-0001, “Procedure for Performing the Regulatory Gap Analysis.”[7] Overall, it was concluded that the majority of existing NRC regulations and guidance documents can be extended and adapted on a case-by-case basis to provide an effective licensing structure for modular HTGRs. However, areas do exist where additional developments in regulation and/or guidance may be warranted. These are key issues concerning regulation and/or guidance that are considered important to establishing a comprehensive HTGR licensing framework and were recommended for further consideration and resolution on that basis. Some examples include the use of high temperature ceramics, and the application of HTGR-compatible probabilistic risk assessment metrics.

F-2.4 INDUSTRY INTERFACES

The NGNP Project maintains and promotes regular interfaces with industry as key HTGR licensing issues are identified, addressed and resolved. Those interfaces occur in two primary forms the NGNP

Licensing Working Group and industry organizations addressing small modular reactor (SMR) licensing topics. These two interface areas are described in more detail below.

1. In 2009, the NGNP Project established a Licensing Working Group that includes the INL project team, the three HTGR suppliers (AREVA, General Atomics, and Westinghouse), Technology Insights (a consulting organization with considerable HTGR design and policy issue experience), and an experienced commercial nuclear plant owner-operator (Entergy). The purpose of the group is to establish inputs on project licensing topics, develop licensing products that support the project's licensing strategies, and directly support project interactions with NRC. It is noted that this is the first domestic HTGR development project where key licensing policy issue resolutions are being developed by the "fleet" rather than a single HTGR design organization, as in past efforts. This assures a consistent and consolidated HTGR licensing framework is developed.
2. In addition, in late 2009, the Nuclear Energy Institute (NEI) and the American Nuclear Society (ANS) initiated individual SMR generic pre-licensing activities to address legal, administrative, and technical regulatory issues common to the SMR community which, in some cases, also relate to NGNP regulatory policy issues. In response to these activities and to coordinate with industry initiatives, in 2010 NRC began conducting periodic public meetings with the NEI's SMR Licensing Task Force at nominally 6-week intervals. NGNP maintain involvement with this process through regular conference calls, by reviewing draft NEI Task Force pre-application documents, and by providing the Task Force with completed NGNP white papers.

F-3. PRE-APPLICATION PROCESS – PATH FORWARD

The path forward, through submittal of the COL application to NRC for their review and approval consists of the following four major activities:

1. Review and address identified open issues or areas for further development as described in the pending NRC assessment reports of the submitted NGNP white papers and associated RAI responses.
2. NGNP and NRC should continue to closely coordinate research activities to assure that the identified work being funded and implemented supports the disposition of identified policy and technical issues, as required for NGNP design, licensing, and deployment.
3. Using the results of the HTGR Regulatory Gap Analysis and any related insights from the pending NRC policy issue assessment reports, the NGNP project team and NRC should work together to develop a combined license application (COLA) Content Guide for HTGRs.
4. Develop the license application, once the applicant is identified and sufficient design detail has been developed, to address the application requirements established within the Content Guide. (Design maturity required will be at the "Final Safety Analysis Report (FSAR)" level of detail, which is commensurate with the preliminary design efforts envisioned by the NGNP Project.)

F-4. REFERENCES FOR NGNP LICENSING WHITE PAPER CORRESPONDENCE WITH NRC

F-4.1 Fuel Qualification and Mechanistic Source Terms

1. "Next Generation Nuclear Plant – Fuel Qualification White Paper," CCN 221270, July 21, 2010.
2. "Next Generation Nuclear Plant - Mechanistic Source Terms White Paper*,"* CCN 221271, July 21, 2010.

3. Idaho National Laboratory, Next Generation Nuclear Plant Project Submittal, "Supplemental Information to Next Generation Nuclear Plant Project Fuel Qualification and Mechanistic Source Terms White Papers," CCN 223977, May 3, 2011.
4. NRC RAI Letter Number 002 (Request for Additional Information No's. 5771 and 5772, Revision 0), June 7, 2011.
5. NRC RAI Letter Number 003 (Request for Additional Information No. 5895, Revision 0), July 25, 2011.
6. Next Generation Nuclear Plant Project Submittal – Response to Nuclear Regulatory Commission Request for Additional Information Letter No. 002 Regarding Next Generation Nuclear Project Fuel Qualification and Mechanistic Source Terms, CCN 224915, August 10, 2011.
7. Next Generation Nuclear Plant Project Submittal – Response to Nuclear Regulatory Commission Request for Additional Information Letter No. 003 Regarding Next Generation Nuclear Plant Project Fuel Qualification and Mechanistic Source Terms – NRC Project # 0748, CCN 225363, September 21, 2011.

F-4.2 Risk Informed Performance Based Approach

1. Next Generation Nuclear Plant Project Licensing White Paper – Next Generation Nuclear Plant Project Defense-in-Depth Approach – NRC Project #0748 (ML 093480191), December 9, 2009.
2. USNRC, Next Generation Nuclear Plant (NGNP) – Request for Additional Information Letter No. 001 Regarding Defense in Depth – NRC Project #0748 (ML102020580), July 26, 2010.
3. Next Generation Nuclear Plant Project Defense-in-Depth Approach – Response to Nuclear Regulatory Commission Request for Additional Information Letter No. 001 – NRC Project #0748, CCN 222027, September 15, 2010.
4. Next Generation Nuclear Plant Project Licensing White Paper – Next Generation Nuclear Plant Project Licensing Basis Event Selection - NRC Project #0748, CCN 222013, September 16, 2010.
5. Next Generation Nuclear Plant Project Licensing White Paper – Next Generation Nuclear Plant Project Structure, Systems, and Components Safety Classification – NRC Project #0748, CCN 221997, September 21, 2010.
6. NRC RAI Letter Number 005 (Request for Additional Information No's, 5903, 5904, and 5911), August 3, 2011.
7. Next Generation Nuclear Plant Probabilistic Risk Assessment White Paper– NRC Project #0748, CCN 224329, September 20, 2011.
8. Next Generation Nuclear Plant Project Submittal – Response to Nuclear Regulatory Commission Request for Additional Information Letter No. 005 Regarding the Risk-Informed, Performance Based Licensing Approach – NRC Project #0748, CCN 225601, October 14, 2011.

F-4.3 Emergency Planning

1. Next Generation Nuclear Plant Project White Paper, "Determining the Appropriate Emergency Planning Zone Size and Emergency Planning Attributes for a High Temperature Gas Reactor" – NRC Project 0748 – October 28, 2010, CCN 222327.

F-4.4 Nuclear-Industrial Facility Boundaries

1. Next Generation Nuclear Plant Project Nuclear − Industrial Facility and Design Certification Boundaries − NRC Project #0748, July 22, 2011, CCN 224753.

F-4.5 License Structure for Multi-Module Facilities

1. Next Generation Nuclear Plant Project Licensing White Paper - License Structure for Multi-Module Facilities – NRC Project #0748, August 10, 2010, CCN 221425.
2. NRC SECY-11-0079, "License Structure for Multi-Module Facilities Related to Small Modular Nuclear Power Reactors," June 12, 2011.

F-4.6 High Temperature Materials

1. "Next Generation Nuclear Plant – High Temperature Materials White Paper," CCN 221269, June 25, 2010.
2. NRC RAI Letter Number 004 (Request for Additional Information No's. 5901, 5898, 5800, 5899, and 5900), dated July 25, 2011.
3. Response to Nuclear Regulatory Commission Request for Additional Information Letter No. 004 Regarding Next Generation Nuclear Plant Project High Temperature Materials White Paper — NRC Project #0748, CCN 225396, September 27, 2011.

F-4.7 Safety Basis and Approach

1. Next Generation Nuclear Plant Project Nuclear − Modular High Temperature Gas-cooled Reactor Safety Basis and Approach − NRC Project #0748, September 6, 2011, CCN 225061.

F-5. SITE HAZARDS ANALYSES

The NGNP project team has completed two site hazards assessments. The objectives of the assessments were to screen representative end-user sites to identify challenges and restraints to be addressed in the NGNP design and licensing processes; assure the HTGR technology can be deployed at a variety of sites for a range of applications; summarize the actions necessary to mitigate impacts of identified hazards; and, provide key insights that can inform the plant design process. A four reactor module nuclear plant (2000 to 2400 MW [t]), that co-generates steam, electricity for general use in the plant, and hot gas for use in a nearby chemical processing facility, to provide the requisite performance and reliability, was assumed for the assessments. The assessments were conducted using a procedure[8] developed by the NGNP Project.

The results of the two assessments are summarized in References [9] and [10]. In general, the assessments concluded that the more significant external hazards and challenges to be considered by the plant designers were in the areas of site seismic characteristics and response, groundwater management, potential site flooding, and area industrial hazards (bulk chemical storage, transient rail line hazards, nearby natural gas lines, etc.). Site 2 hazards also included the potential impacts from a nearby commercial nuclear power plant facility.

F-5.1 Site Hazards Analyses – Path Forward

Reactor designers, potential license applicants, and other interested project parties should be familiar with the results from the hazards assessments, and use those insights as inputs as project deployment evaluations and design work commence. It is noted that no further site assessment activities are planned by the NGNP Project at this time, since the two sites assessed provide a very representative overview of challenges that could be expected at typical HTGR deployment sites.

F-6. REFERENCES

1. Next Generation Nuclear Plant Licensing Strategy - A Report to Congress, August, 2008.
2. NGNP Licensing Plan, PLN-3202, June, 2009.
3. Potential Policy, Licensing, and Key Technical Issues for Small Modular Nuclear Reactor Designs, NRC SECY-10-0034, March, 2010.
4. Memorandum of Understanding Between the US-NRC and the US-DOE for US-NRC Participation in the Next Generation Nuclear Plant Project, executed August, 2008.
5. NGNP Project Regulatory Gap Analysis for Modular HTGRs, INL/EXT-11-23216, September, 2011.
6. MHTGR PSID.
7. NGNP-LIC-ETR-PROC-0001, "Procedure for Performing the Regulatory Gap Analysis."
8. Procedure for Site Hazards Evaluation and Impact Assessment, NGNP-LIC-ETR-RPT-0001, Revision 1, September, 2009.
9. NGNP Site 1 Hazards Assessment, NGNP-LIC-ETR-RPT-0004, Revision 0, March, 2011 **(Restricted distribution).**
10. NGNP Site 2 Hazards Assessment, INL/EXT-11-23178, Revision 0, October, 2011.

Appendix G

Quality Assurance

Appendix G—Quality Assurance

G-1. QUALITY ASSURANCE PROGRAM

The Next Generation Nuclear Plant (NGNP) Project is in compliance with Batelle Energy Alliance, LLC (BEA) Management and Operating Contract number DEAC07-051D14517, which requires compliance with 10, CFR 830, Subpart A, "Quality Assurance Requirements," and Department of Energy (DOE) Order 414.1C, "Quality Assurance." BEA contract uses the consensus standard National Quality Assurance (NQA)-1-2000 as the baseline. On August 3, 2010, Idaho National Laboratory (INL) submitted the NGNP Project Next Generation Nuclear Plant Quality Assurance Program Description (QAPD)[1] to the Nuclear Regulatory Commission (NRC) for initial feedback (CCN 221673). The QAPD is based on the requirements and guidance of American Society of Mechanical Engineers (ASME) NQA-1-2008, 1a-2009, Parts I and II, with specific reference to selected sections of Parts III and IV through a phased implementation described in the NGNP Quality Assurance Program Description Implementation Plan.[2] NRC provided its feedback regarding that submittal in a letter to NGNP dated November 10, 2010. On May 19, 2011, INL submitted Rev. 3 of the NGNP QAPD, which addressed the two items of interest from NRC letter that required clarification and established the quality assurance (QA) policy for the NGNP (CCN 224107).

The NGNP and Very High Temperature Reactor (VHTR) Quality Assurance Program Plans (QAPP)[3,4] were developed to address additional requirements serving three purposes:

- Identify unique NGNP Project QA requirements
- Identify a set of management controls for NGNP Project systems, structures, and components, and related quality-affecting activities. Work conducted under the NGNP QA program is intended to support eventual licensing of the NGNP reactor design by NRC.
- Identify which procedures are used to implement the INL Quality Assurance Plan (QAP) requirements through the use of LWPs and which requirements are implemented using NGNP specific procedures.

The second tier documents in the NGNP QAPP3 are the Program Requirements Documents (PRD). These PRDs organize QA requirements found in ASME NQA-1-2008,[5] 1a-2009,[6] 10 CFR 830, Subpart A,[7] and DOE O 414.1C.[8] The NGNP QAP[9] is implemented using third tier Management Control Procedures (MCPs). The phased implementation status and schedule is provided in PLN-3635. Known deficiencies in implementing NQA-1-2008, 1a-2009 requirements are managed through the INL Issues and Corrective Actions Management System (ICAMS) process.[10]

G-1.1 Procurement and Supplier Quality

Acquisition of items and services is obtained from qualified suppliers as needed to support NGNP activities. Supplier qualification and evaluation is performed by Purchaser and Supplier Quality ([PSQ]; an INL support organization) in accordance with procedure LWP-4503.[11] PSQ maintains supplier histories for all approved suppliers on a qualified suppliers list for all INL activities. Table G-1 provides a list of NGNP qualified suppliers, current as of this writing.

Table G-1. NGNP Qualified Suppliers.

Supplier and Authorized Location	Restrictions (Authorized Goods/Services)	Eval Type*	Eval Basis	Rev	Criteria	Vendor Number	Annual Review Date	Expiration Date
AREVA Federal Services, LLC, Lynchburg/VA	Supply QL-1 engineering and design services to include computer software and hardware, under the AREVA Federal Services QA Program. For Packaging and Transportation, and 10 CFR 71 Subpart H items and services, see AFS, Tacoma, WA.	I	NQA-1	2000	BRs 1-8, 10-18, SR1 (All), SR2 (All), SR3 (All), SR4 (All), SR6 (All), SR7 (All), SR8 (200), SR11 (All), SR13(200), SR15 (200, 300, 400), SR17 (200, 500, 600, 800), SR18 (All), SubPart 2.7, pps 100, 200, 300, 402-406, 500, 600	030303201	12/14/2011	12/14/2012
Argonne National Laboratory, Chicago/IL	Supply QL-1 testing to determine creep rupture properties of specimens machined from material containing gas tungsten arc process welds and other INL supplied specimens performed.	I	ASME NQA-1	2000	BRs 1, 2, 6, 8, 11, 12, SR2 (200), SR11 (200, 300, 500, 600), SR12 (200-400)	030497300	2/23/2012	2/23/2013
Babcock & Wilcox Nuclear Operations Group, Inc., Lynchburg/VA	Develop and manufacture fuel in support of NGNP fuel initiatives, ATR and University Fuels Programs. This qualification shall include fuel development, fabrication, manufacturing and design.	I	NQA-1 and Subpart 2.7	2000	BRs 1 - 18, SR1 through SR18 (All) to include Subpart 2.7	020259002	12/1/2011	12/1/2012
Dirats, Westfield/MA	Provide specimen preparation, materials testing, analytical testing and property characterization services.	I	NQA-1	2000	BRs 1, 2, 5, 8, 11, 12, 13, 15, SR11 (200, 300), SR12 (All),	030495000	2/9/2012	2/9/2013
Evans Analytical Group LLC, Syracuse/NY	Elemental analysis by volume and percentage, including trace elements of solid samples, as required to support the Next Generation Nuclear Plant experiments and other ATR irradiation programs.	I	NQA-1	2000	BRs 1, 2, 4-8, 11-13, 15; SR2 (200), SR11 (100-300, 500), SR12 (All)	030517500	6/17/2011	6/17/2013

Supplier and Authorized Location	Restrictions (Authorized Goods/Services)	Eval Type*	Eval Basis	Rev	Criteria	Vendor Number	Annual Review Date	Expiration Date
General Atomics TRIGA /NGNP, San Diego/CA	Provide engineering/design services and TRIGA non fuel bearing reactor components. This qualification extends only to GA's primary facility located at 3550 General Atomics Court, San Diego, CA.	I	NQA-1 and SubPart 2.7	2000	BRs 1-18, SR1 (All), SR2 (All), SR3 (All), SR4 (All), SR6 (All), SR7 (200-600), SR9 (All), SR10 (All), SR11 (All), SR12 (All), SR15 (All), SR17 (All), SR18 (All) , SubPart 2.7 201-204, 302, 401, 402, 402.1, 404, 405, 406, 407, 204, 400	020272001	7/7/2012	2/24/2014
General Products Machine Shop, Inc., Pocatello/ID	Supply QL-2/PQL-3 machining services of INL supplied material, to exclude design, heat treating, welding, and procurement of material.	I	ISO-9001	2008	All	030223400	8/13/2011	8/13/2012
GrafTech International Ltd., Parma/OH	To provide laboratory quantity graphite specimens for R&D purposes only. This qualification does not include production graphite manufacturing, but does include analytical verification services of graphite specimens manufactured at other qualified production facilities.	I	NQA-1	2000	BRs 1, 2, 4-8, 11, 12, 15-18, SR 11 (200), SR 12 (All), SR 17 (200, 600)	030271100	8/17/2011	8/17/2012
Idaho Laboratories Corp., Idaho Falls/ID	QL-1/PQL-1Manufacturer and supply mineral insulated cable for thermocouples and heaters; specialty and custom Thermocouples; multi-point thermocouples; and Resistance Temperature Detectors (RTD).	I	ASME NQA-1	2000	BRs 1-18, SR9 (200), SR10 (600, 700), SR11 (200, 500, 600), SR12 (All)	061135000	12/17/2011	12/17/2012
Pacific Northwest National Lab (PNNL), Richland/WA	Manufacture and supply fluence wires, melt wires, and measurement of neutron fluence exposure.	I	NQA-1	2000	BRs 1,2,4-8,11-13,15-18, SR11 (200, 600), SR12 (All)	027732600	8/12/2012	8/12/2012
Japan Atomic Energy Agency, Oarai	HTTR test, operational data to include physics and thermal fluid data by existing instruments installed on the HTTR, and maintenance data in support of NGNP.	I	NQA-1	2000	BRs 1,2, 4-8, 11, 12, 14-17, SR2 (200), SR7 (200), SR8 (200), SR11 (200, 500, 600), SR12 (All), SR17 (200, 600, 800)	030545300	12/1/2011	12/1/2013

Supplier and Authorized Location	Restrictions (Authorized Goods/Services)	Eval Type*	Eval Basis	Rev	Criteria	Vendor Number	Annual Review Date	Expiration Date
Mersen USA St. Marys-PA Corp., St. Marys/PA	Manufacture QL-1 graphite and graphite products.	I	NQA-1	2000	BRs 1-2, 4-8, 11-17; SR4 (200), SR6 (200), SR7 (200), SR8 (200), SR11 (200, 500, 600), SR12 (All), SR13 (300, 600)	030559200	4/7/2012	4/7/2014
Metcut Research Inc, Cincinnati/OH	Machine and mechanical test for tensile and fatigue INL provided test specimens.	II	ISO-17025	2005	All	021405500	4/14/2011	4/14/2012
Precision Custom Components, York/PA	QL-2/PQL-3 Construction of Class 1,2,3 and MC Vessels; Class 1,2, and 3 pumps; Class 2 and 3 Storage Tanks; Class CS Core Support Structures; and Class 1,2, and 3 Shop Assembly at York, PA facility only.	II	ASME IX, Section III, Division 1	Current	All	030514700	5/27/2011	5/27/2013
Toyo Tanso Co. Ltd., Kita-ku, Osaka	QL-1/PQL-1 specialized "Isotopic and Near Isotopic Nuclear Graphite" material. This qualification shall also include graphite characterization data services in accordance with ASME NQA-1 specified requirements.	I	NQA-1	2000	Specified Requirements	030524200	7/26/2011	7/26/2013
UT Battelle (ORNL), Oak Ridge/TN	Supply QL-1 material evaluation and characterization studies as a part of Next Generation Nuclear Plant (NGNP) Materials Program Research and Development; and coated particle fuel fabrication, characterization, and fuel compacting development for the Advanced Gas Reactor (AGR) Program, to exclude the use of software.	I	ASME NQA-1	2000	NGNP BRs 1, 2, 4 - 8, 10 - 17, SR 1 (200 and 300), SR 7 (200), SR-10 (600 and 700), SR 12 (200, 300 and 400), SR 13 (600), SR-17 (200) and SubPart 4.2, AGR: BRs 1-18	029804200	2/9/2012	2/9/2013
Westmoreland Mechanical Testing and Research, Inc., Youngstown/PA	Supply QL-1 materials testing, property characterization, and specimen machining, to include support for the VHTR TDO programs.	I	NQA-1	2000	BRs 1, 2, 5, 8, 10-13, 15, SR11(200, 600), SR12 (All)	030495200	2/9/2012	2/9/2013

* Evaluation Type I is a comprehensive on-site evaluation of quality system documentation, system implementation and technical capability including facilities, equipment, tooling, capacity, personnel, etc essential to the deliverables and/or work scope.

Evaluation Type II is a comprehensive evaluation of quality system documentation and available qualitative and quantitative information for suppliers with or without an approved Quality Management System. This evaluation does not include surveillance of facilities or work areas.

Contractor Assurance

The Assurance Portfolio for Nuclear Science and Technology[12] identifies VHTR organizational and management-system risks and the assurance activities used to monitor three specific areas of research and design: fuel development and qualification, materials testing and qualification, and design methods and validation. The risk basis determination and associated assurance activities are recorded and managed through the Integrated Assessment System.

Contractor Assurance activities are documented and records maintained in accordance with LWP-13740 Performing Inspections,[13] LWP-13745 Performing Surveillances,[14] LWP-13750 Performing Management Assessments,[15] and LWP-13760 Performing Independent Assessments.[16] Assessment issues, observations, and notable practices are documented and resolved through the INL ICAMS system in accordance with LWP-13840, Management of Issues, Observations, and Noteworthy Practices. Lessons Learned are documented in accordance with LWP-13850, Processing Lessons Learned and Operating Experience Information.[17]

G-2. PATH FORWARD

The NGNP quality assurance program adaptation of ASME NQA-1-2008, 1a-2009 will continue, through a phased implementation described in the NGNP QAP Implementation Plan (PLN-3635). A schedule for that activity is provided in Appendix A of PLN-3635.

The quality program will continue to provide expertise in implementing quality requirements over specific aspects of the Project including Fuels Development, Post Irradiation Examination (PIE), Graphite Characterization, and High Temperature Metals Characterization. Inspections and document reviews will continue to be performed for all Advanced Graphite Creep and Advanced Gas Reactor experiments assembled at the Test Train Assembly Facility at the Advanced Test Reactor facility.

All quality purchases and contract requisitions will continue to be reviewed and approved by NGNP quality. As required by NQA-1, all activities will continue to be reviewed and observed annually including preparation for the annual DOE audit. Corrective action will be managed through the ICAMS system.

On November 1, 2011, NGNP received notification that NRC will need additional information to complete their assessment of PDD-172. A number of Requests for Additional Information (RAIs) are associated with the paper’s commitment to certain aspects of the draft version of Nuclear Energy Institute (NEI) 11-04, “Nuclear Generation Quality Assurance Program Description.”[18] A number of the exceptions that have been committed to in the QAPD (PDD-172) have been incorporated into the draft version of NEI 11-04, which has not been fully reviewed or approved by NRC and is subject to change. NGNP is cognizant of any changes to NEI 11-04, as well as any RAIs issued by NRC staff during their review of the document and must evaluate any impact on the QAPD. The project is currently drafting responses to those RAIs and is scheduled to formally submit those responses during FY 2012 first quarter.

The NGNP project scope could be transitioned to another entity (license applicant). In that case, a quality assurance program implemented and maintained by that entity will be required. Selected portions of the remaining INL quality affecting work scope (presumably R&D activity) would be subject to review and acceptance by that entity.

G-3. REFERENCES

1. PDD-172, “Next Generation Nuclear Plant Quality Assurance Program Description.”
2. PLN-3635 “NGNP Quality Assurance Program Description Implementation Plan.”
3. PLN-2021 “Quality Assurance Program Plan for the Next Generation Nuclear Plant Project.”
4. PLN-2690 “VHTR Technology Development Office Quality Assurance Program Plan.”
5. ASME NQA-1-2008, “Quality Assurance Requirements for Nuclear Facility Applications.
6. ASME NQA-1a-2009, “Addenda A to Quality Assurance Requirements for Nuclear Facility Applications.”
7. 10 CFR 830, Subpart A, “Quality Assurance Requirements.”
8. DOE Order 414.1c, “Quality Assurance.”
9. PRD-350 “2.0 NGNP Quality Assurance Program.”
10. LWP-13840 “Management of Issues, Observations, And Noteworthy Practices”
11. LWP-4503 “Supplier Evaluation and Qualification.”
12. PLN-3174 “Assurance Portfolio for Nuclear Science & Technology.”
13. LWP-13740 Performing Inspections.
14. LWP-13745 Performing Surveillances.
15. LWP-13750 Performing Management Assessments.
16. LWP-13760 Performing Independent Assessments.
17. LWP-13850, Processing Lessons Learned and Operating Experience Information.
18. NEI 11-04, “Nuclear Generation Quality Assurance Program Description.”

Appendix H

NGNP Engineering Studies References

Appendix H—NGNP Engineering Studies References

Table H-1. AREVA Engineering Studies and Reports.

No.	Doc No.	Title	Date
1	12-9045308-000	NGNP with Hydrogen Production Reactor Type Comparison Study	19-Apr-07
2	12-9045442-001	NGNP with Hydrogen Production Power Level Special Study	19-Apr-07
3	12-9045707-001	NGNP with Hydrogen Production Primary and Secondary Cycle Concept Study	19-Apr-07
4	12-9052076-001	NGNP with Hydrogen Production Preconceptual Design Studies Report, Executive Summary	21-Jun-07
5	12-9072397-000	High Temperature Gas Reactor Component Test Facility Mission Needs and Requirements - BEA Contract No. 000-60209	13-Mar-08
6	12-9075581-000	NGNP Risk Evaluation of Major Components, BEA Contract Number 000-60209	30-Apr-08
7	12-9076324-001	NGNP with Hydrogen Production RPV and IHX Pressure Vessel Alternatives, BEA Contract Number 000-60209	30-Apr-08
8	12-9076325-001	NGNP with Hydrogen Production IHX and Secondary Heat Transport Loop Alternatives, BEA Contract Number 000-60209	30-Apr-08
9	12-9076931-000	NGNP component test facility conceptual configuration, cost and schedule estimate	31-Mar-08
10	12-9077148-001	NGNP Fuel Design Special Study, BEA Contract Number 000-60209	30-Apr-08
11	12-9084392-000	NGNP Reactor Parametric Study	30-Jun-08
12	12-9088427-001	NGNP Conceptual Design Studies Reactor Building Design, Containment Issues, and Embedment Effects	15-Sep-08
13	12-9094881-000	NGNP with Hydrogen Production Conceptual Design Studies Power Conversion System Study	21-Nov-08
14	12-9094881-001	NGNP with Hydrogen Production Conceptual Design Studies Power Conversion System Study	6-Feb-09
15	12-9097506-001	NGNP Component Test Facility Test Loop Pre-Conceptual Design Executive Summary	17-Dec-08
16	12-9097512-001	NGNP Component Test Facility Test Loop Pre-Conceptual Design	17-Dec-08
17	12-9102279-001	NGNP Conceptual Design DDN/PIRT Reconciliation	23-Feb-09
18	12-9104512-000	NGNP Conceptual Design Power Level and Number of Loops Trade Study Plan, Technical Data Record	20-Mar-09
19	12-9122757-001	NGNP High Temperature Materials White Paper	19-Oct-09
20	12-9124116-000	NGNP Design Data Needs for AREVA 750°C Prismatic Reactor Concept	21-Sep-09
21	12-9127825-001	NGNP Heat Transport Small Scale Testing – Review and Assessment of TDRM Identified Tests	6-Jan-10
22	12-9127826-001	NGNP Heat Transport Small Scale Testing – Loop Technical and Functional Requirements	7-Jan-10
23	12-9142633-000	Initial Infrastructure Readiness Assessment for the NGNP	13-Aug-10
24	12-9142633-001	Infrastructure Readiness Assessment for the NGNP	1-Dec-10
25	12-9142633-002	Infrastructure Readiness Assessment for the NGNP	7-Dec-10
26	12-9149697-000	Pebble Bed Reactor Plant Design Description	31-Jan-11
27	12-9149863-000	Pebble Bed Reactor Scoping Safety Study	31-Jan-11

Table H-1. (continued).

No.	Doc No.	Title	Date
28	12-9151202-000	Pebble Bed Reactor Cost and Schedule Report	31-Jan-11
29	12-9151202-001	Pebble Bed Reactor Cost and Schedule Report	8-Feb-11
30	12-9151714-000	Pebble Bed Reactor Technology Readiness Study	31-Jan-11
31	12-9152036-000	Key Pebble Bed Reactor Design Requirements	19-Jan-11
32	12-9155160-000	Pebble Bed Reactor Assessment Executive Summary	16-Feb-11
33	51-9072396-000	NGNP Conceptual Design Studies Baseline Document for Indirect Steam Cycle Configuration	27-Mar-08
34	51-9072396-001	NGNP Conceptual Design Studies Baseline Document for Indirect Steam Cycle Configuration	2-Sep-08
35	51-9103803-002	NGNP Conceptual Design Baseline Document for Conventional Steam Cycle for Process Heat and Cogeneration	28-Apr-09
36	51-9105791-000	NGNP Conceptual Design – Plant Design Duty Cycle	19-Mar-09
37	51-9105791-001	NGNP Conceptual Design – Plant Design Duty Cycle	28-Apr-09
38	51-9105936-001	NGNP Nuclear Heat Source System Boundaries and Interfaces	29-Apr-09
39	51-9106032-001	NGNP Plant Design Requirements Document	11-Jun-09
40	51-9106211-001	NGNP Conceptual Design – Point Design	27-Apr-09
41	PD-3001047-00	NGNP Engineering Conceptual Design Work Plan, SOW-6447 Rev.0, prepared by AREVA	15-Oct-08
42	PD-3001185-000	NGNP TDRM Schedule and Cost Estimate	5-Dec-08
43	PD-3001186-000	NGNP Conceptual Design Studies Work Plan	20-Nov-08
44	PD-3001289-000	NGNP Component Test Facility Cost and Schedule Report	19-Jan-09
45	PD-3001289-001	NGNP Component Test Facility Cost and Schedule Report	1-May-09
46	PD-3002052-000	Work Plan for Heat Transport Small Scale Testing for Prismatic Block	29-Sep-09

Table H-2. General Atomics Engineering Studies and Reports.

No.	Doc No.	Title	Date
1	911102	NGNP System Requirements Manual	2-Mar-07
2	911103	Preconceptual Engineering Services for the NGNP with Hydrogen Production NGNP Reactor Type Comparison Study	25-Apr-07
3	911104	Preconceptual Engineering Services for the NGNP with Hydrogen Production NGNP Reactor Power Level Study General Atomics	6-Apr-07
4	911105	Preconceptual Engineering Services for the NGNP with Hydrogen Production NGNP High Temperature Process Heat Transfer and Transport Study	6-Apr-07
5	911106	Preconceptual Engineering Services for the NGNP with Hydrogen Production NGNP End-Products Study General Atomics	6-Apr-07
6	911107	NGNP and Hydrogen Production Preconceptual Design Studies Report	10-Jul-07
7	911117	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, NGNP Contamination Control Study, Subcontract Number 00060845	23-Apr-08
8	911118	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, RPV and IHX Pressure Vessel Alternatives Study Report, Subcontract Number 00060845	23-Apr-08
9	911119	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, NGNP IHX and Secondary Heat Transport Loop Alternatives Study, Subcontract Number 00060845	23-Apr-08
10	911120	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, NGNP Steam Generator Alternatives Study, Subcontract Number 00060845	23-Apr-08
11	911123	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, NGNP IHX and Secondary Heat Transport Loop Alternatives Study - Confidential Report, Subcontract No. 0006084	23-Apr-08
12	911125	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, NGNP Composites R&D Technical Issues Study	13-Oct-08
13	911127	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, NGNP Parametric Fuel and Reactor Pressure Vessel Temperature Calculations	11-Sep-08
14	911128	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Reactor Containment, Embedment Depth, and Building Functions Study	24-Sep-08
15	911131	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Power Conversion System Alternatives and Selection Study	5-Dec-08
16	911133	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan for Reactor Control Equipment	9-Dec-08
17	911134	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan - Control Rods	9-Dec-08
18	911135	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan for the Reactor Core Assembly	9-Dec-08
19	911136	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan for Reactor Graphite Elements	9-Dec-08
20	911137	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan - Reactor Pressure Vessel	9-Dec-08

Table H-2. (continued).

No.	Doc No.	Title	Date
21	911138	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan for Helium Circulators (PHTS, SCS, SHTS)	9-Dec-08
22	911139	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan - Intermediate Heat Exchanger PCHE Type	16-Dec-08
23	911140	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan -Shutdown Cooling Heat Exchanger	16-Dec-08
24	911141	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan for the Reactor Cavity Cooling System	16-Dec-08
25	911142	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan - Steam Generator Helical-Coil Design	16-Dec-08
26	911143	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan - Power Conversion System Equipment for a Direct Combined Cycle	16-Dec-08
27	911144	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan for S-I Hydrogen Production System (HPS)	9-Dec-08
28	911145	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan - Fuel Handling and Storage System	16-Dec-08
29	911146	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan for Primary Circuit and Balance of Plant Instrumentation	9-Dec-08
30	911147	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan for RPS, IPS and PCDIS	9-Dec-08
31	911160	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Final Report - NGNP Core Performance Analysis, Phase 1	16-Mar-09
32	911167	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Nuclear Heat Supply System Point Design Study for NGNP Conceptual Design	21-Apr-09
33	911168	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Technical Basis for NGNP Fuel Performance and Quality Requirements	18-Sep-09
34	911169	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Specification/Procedure Evaluation of Tritium Behavior in the HTTR	29-Apr-09
35	911169	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Specification/Procedure Evaluation of Tritium Behavior in the HTTR	12-Jun-09
36	911169	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Specification/Procedure Evaluation of Tritium Behavior in the HTTR	12-Feb-10
37	911172	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan - Upper Core Restraint for 750°C Reactor Outlet Helium Temperature	11-Jun-09
38	911173	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan - Reactor Pressure Vessel for 750°C Reactor Outlet Helium Temperature	11-Jun-09

Table H-2. (continued).

No.	Doc No.	Title	Date
39	911174	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan - Steam Generator for 750°C Reactor Outlet Helium Temperature	11-Jun-09
40	911175	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Effect of Reactor Outlet Helium Temperature on the Need for Composites in the NGNP	11-Jun-09
41	911176	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Interim Report - NGNP Core Performance Analysis, Phase 2; prepared by General Atomics	15-Sep-09
42	911177	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan - Hot Duct and Insulation for 750°C Reactor Outlet Helium Temperature	12-Jun-09
43	911178	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Test Plan - High Temperature Valves for 750°C Reactor Outlet Helium Temperature	12-Jun-09
44	911184	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Final Report - NGNP Core Performance Analysis, Phase 2	18-Sep-09
45	PC-000541	Advanced Gas Reactor Fuel Development and Qualification Program - Radionuclide Transport in a Vented Low-Pressure Containment	30-Apr-07
46	PC-000543	NGNP Umbrella Technology Development Plan	10-Jul-07
47	PC-000544	General Atomics- Executive Summary Report- NGNP and Hydrogen Production Preconceptual Design Studies Report	10-Jul-07
48	PC-000545	Pre-Conceptual Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production; NGNP and Commercial H2-Mhr Cost Information	10-Jul-07
49	PC-000566	Engineering Services for the Next Generation Nuclear Plant (NGNP_ with Hydrogen Production, White Paper - Characterizing the Effect of NGNP Operating Conditions on the Uncertainty of Meeting Project	23-Apr-08
50	PC-000570	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Reconciliation of NGNP DDNS with NRC PIRTS	19-Sep-08
51	PC-000571	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Work Plan for NGNP Conceptual Design	16-Oct-08
52	PC-000580	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, NGNP Technology Development Road Mapping Report	16-Dec-08
53	PC-000586	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Technology Development Road Mapping Report for NGNP with 750°C Reactor Outlet Helium Temperature	11-May-09
54	PC-000587	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Assessment of Russian Federation Test Facilities Capabilities To Support NGNP R&D	5-Feb-10
55	PC-000589	Engineering Services for the Next Generation Nuclear Plant (NGNP) with Hydrogen Production, Technology Development Plan for Utilization of JAEA Facilities, Data, and Experience	10-Dec-09

Table H-3. Westinghouse Engineering Studies and Reports.

No.	Doc No.	Title	Date
1	NGNP Special Applications Study	Updated NGNP Special Applications Study - Westinghouse Team	6-Apr-07
2	NGNP-20-RPT-001	NGNP and Hydrogen Production Preconceptual Design Report, Special Study 20.1 Reactor Type Comparison	31-Jan-07
3	NGNP-20-RPT-002	NGNP and Hydrogen Production Preconceptual Design Report, Special Study 20.2 Prototype Power Level	30-Jan-07
4	NGNP-20-RPT-003	NGNP and Hydrogen Production Preconceptual Design Report, Special Study 20.3: High Temperature Process Heat Transfer and Transport	26-Jan-07
5	NGNP-20-RPT-004	NGNP and Hydrogen Production Preconceptual Design Report, Special Study 20.4:Power Conversion System	26-Jan-07
6	NGNP-20-RPT-005	NGNP and Hydrogen Production Preconceptual Design Report, Special Study 20.5: NGNP Licensing and Permitting Study	29-Jan-07
7	NGNP-20-RPT-006	NGNP and Hydrogen Production Preconceptual Design Report, Special Study 20.6: NGNP By-Products and Effluents Study	31-Jan-07
8	NGNP-CDWP TI-DDN	Next Generation Nuclear Plant Conceptual Design Study, Design Data Needs (DDNs) Reconciliation Against PIRTS	9-Apr-09
9	NGNP-CTF 20-CTF	NGNP and Hydrogen Production Preconceptual Design Study, HTGR Component Test Facility (CTF) Feasibility and Recommendations	14-Feb-08
10	NGNP-CTF MTECH-TDRM	NGNP and Hydrogen Production Conceptual Design Study, NGNP Technology Development Road Mapping Report	2-Dec-08
11	NGNP-CTF MTECH-TDRM-017	NGNP and Hydrogen Production Conceptual Design Study, NGNP Technology Development Road Mapping Report, Section 17; Integrated Schedule and Cost Estimate	2-Dec-08
12	NGNP-CTF MTECH-TLDR	NGNP and Hydrogen Production Conceptual Design Study, NGNP CTF Test Loop Preconceptual Design Report	16-Dec-08
13	NGNP-CTF MTECH-TLDR	NGNP and Hydrogen Production Conceptual Design Study, NGNP CTF Test Loop Preconceptual Design Report	26-Feb-09
14	NGNP-CTF MTECH-TLDR-0010	NGNP and Hydrogen Production Conceptual Design Study, NGNP CTF Test Loop Preconceptual Design Report, Section 10: System Integration	7-Aug-09
15	NGNP-ESR-RPT-001; NGNP-19-RPT-001	NGNP and Hydrogen Production Pre-Conceptual Design Report-Executive Summary Report Rev.1, Section 19, Rev.0; Economic Assessments	22-Jun-07
16	NGNP-HPS SHAW-HPA	NGNP Hydrogen Plant Alternatives Study	19-Mar-09
17	NGNP-HTS 60-IHX	NGNP and Hydrogen Production Preconceptual Design Study, IHX and Heat Transport System	1-Apr-08
18	NGNP-HTS-RPT-TI001	NGNP Conceptual Design Study: IHX and Heat Transport System	1-Apr-08
19	NGNP-IN-RPT	NGNP and Hydrogen Production Preconceptual Design Report	22-May-07
20	NGNP-LIC-GEN-RPT-L-00020	Next Generation Nuclear Plant - Emergency Planning Zone Definition At 400 Meters	21-Jul-09

Table H-3. (continued).

No.	Doc No.	Title	Date
21	NGNP-LP1 WEC-LIC	NGNP and Hydrogen Production Preconceptual Design Study, Licensing Risk Reduction Study	30-Apr-08
22	NGNP-NHS 100-RXBLDG	NGNP and Hydrogen Production Conceptual Design Study, Reactor Building Functional and Technical Requirements and Evaluation of Reactor Embedment	16-Sep-08
23	NGNP-NHS 50-CC	NGNP and Hydrogen Production Preconceptual Design Study Report, Contamination Control	22-May-08
24	NGNP-NHS 90-PAR	NGNP Conceptual Design Study: Reactor Parametric Study	7-Aug-08
25	NGNP-NHS TI-COMP	NGNP Conceptual Design Study: Composites R&D Technical Issues	31-Oct-08
26	NGNP-NHS-HTS-RPT-M-00004	Next Generation Nuclear Plant: Intermediate Heat Exchanger Development and Trade Studies	18-Sep-09
27	NGNP-NHS-TI-RISK	Metallic Component Schedule Risk and Cost Uncertainty Assessment	21-May-08
28	NGNP-P01 SHAW-CDWP	Conceptual Design Work Plan, Task Work Plan Outline and Content, Conceptual Design Phase FY 09 and 10 Next Generation Nuclear Plant	20-Oct-08
29	NGNP-PLD-GEN-RPT-N-00007	Next Generation Nuclear Plant: Plant Level Assessments Leading to Fission Product Retention Allocations	6-Oct-09
30	NGNP-PRG-GEN-RPT-G-00030	Infrastructure Readiness Assessment for Next Generation Nuclear Plant	31-Dec-10
31	NGNP-TDI-GEN-DDN-G-00025	NGNP: Design Data Needs List for the PBMR	10-Nov-09
32	NGNP-TDI-GEN-FRD-G-00021	Technical and Functional Requirements Heat Transport Small Scale Testing Loop	15-Sep-09
33	NGNP-TDI-GEN-RPT-G-00022	TRL Advancement Through the Use of Heat Transport Small Scale Testing (HTSST)	15-Sep-09
34	NGNP-TDI-TDR-RPT-G	Next Generation Nuclear Plant, NGNP Technology Development Roadmapping Report - Steam Production at 750–800°C	30-Jul-09
35	NGNP-TDI-TDR-RPT-G-00003	Next Generation Nuclear Plant, Report on Update of Technology Readiness Levels and Design Readiness Levels for NGNP Steam Production an 750–800°C	25-May-09
36	NGNP-TDI-TDR-RPT-G-00023	NGNP Technology Development Roadmapping Report - Steam Production At 750–800°C	31-Jul-09
37	NGNP-TDI-TDR-RPT-G-00024	NEXT GENERATION NUCLEAR PLANT, NGNP TECHNOLOGY DEVELOPMENT ROADMAPPING REPORT - STEAM PRODUCTION AT 750ºC-800ºC (COMBINED REPORT)	18-Sep-09
38	NGNP-TRL and DRL Report	NGNP and Hydrogen Production Report on Design Readiness Levels and Design Technology Readiness Levels	21-Sep-07
39	NGNP-TRL and DRL Report	Next Generation Nuclear Plant, Report on Technology Readiness Levels and Design Readiness Levels for NGNP Steam Production At 750-800°C	23-Apr-09
40	NGNP-TRL and DRL Report Supplemental Documentation	Supplemental Documentation Regarding the Discussion of Changes in the TRL Ratings from the First TRL Report Not Due to ROT	18-May-09

Table H-4. INL Studies and Reports.

No.	Doc No.	Title	Date
1	INL/EXT-07-12441	Assessment of Next Generation Nuclear Plant (NGNP) Fuel Acquisition Strategies	1-Oct-07
2	INL/EXT-07-12727	NGNP Engineering White Paper: Power Conversion System Trade Study	1-Apr-07
3	INL/EXT-07-12728	NGNP Engineering White Paper: By-Products Trade Study	1-Apr-07
4	INL/EXT-07-12729	NGNP Engineering White Paper: Reactor Type Trade Study	1-Apr-07
5	INL/EXT-07-12730	NGNP Engineering White Paper: NGNP Project Pre-Conceptual Heat Transfer and Transport Studies	1-Apr-07
6	INL/EXT-07-12731	NGNP Engineering White Paper: Power Level Trade Study	1-Apr-07
7	INL/EXT-07-12732	NGNP Engineering White Paper: Primary and Secondary Cycle Trade Study	1-Apr-07
8	INL/EXT-07-12967	Next Generation Nuclear Plant Pre-Conceptual Design Report	20-Sep-07
9	INL/EXT-07-12999	Next Generation Nuclear Plant System Requirements Manual	27-Jun-08
10	INL/EXT-07-13146	NGNP Engineering White Paper: High Temperature Fluid Flow Test Facility	1-Sep-07
11	INL/EXT-08-13951	Next Generation Nuclear Plant Reactor Pressure Vessel Acquisition Strategy	30-Apr-08
12	INL/EXT-08-14054	Next Generation Nuclear Plant Intermediate Heat Exchanger Acquisition Strategy	30-Apr-08
13	INL/EXT-08-14132	Pre-Conceptual Facility Configuration Study of the High Temperature Gas-Cooled Reactor Component Test Facility	22-Aug-08
14	INL/EXT-08-14150	Technical and Functional Requirements for the High Temperature Gas-Cooled Reactor (HTGR) Component Test Facility (CTF)	28-Apr-08
15	INL/EXT-08-14193	Next Generation Nuclear Plant Project, Maintaining a Technology-Neutral Approach to Hydrogen Production Process Development Through Conceptual Design of the Next Generation Nuclear Plant	30-May-08
16	INL/EXT-08-14370	Summary of Bounding Conditions for Development of the NGNP Project	4-Jun-08
17	INL/EXT-08-14395	Summary of Bounding Requirements for the NGNP Demonstration Plant F&ORs	27-Jun-08
18	INL/EXT-08-14799	Heat Exchanger Design Options and Tritum Transport Study for the VHTR System	23-Sep-08
19	INL/EXT-08-14825	Instrumentation and Control and Human-Machine Interface Functional Requirements Description for the Next Generation Nuclear Plant	24-Sep-08
20	INL/EXT-08-14842	NGNP - Creating Validated TRL and TDRMS for Critical Systems, Subsystems, and Components	25-Sep-08
21	INL/EXT-08-14903	Next Generation Nuclear Plant Critical Decision (CD)-1 Documentation Preliminary Overview	30-Sep-08
22	INL/EXT-08-15148	Next Generation Nuclear Plant Project Technology Development Roadmaps: the Technical Path Forward	9-Jan-09
23	INL/EXT-09-15620	Evaluation of Integrated High Temperature Component Testing Needs	30-Apr-09

Table H-4. (continued).

No.	Doc No.	Title	Date
24	INL/EXT-09-15620	Evaluation of Integrated High Temperature Component Testing Needs	27-May-09
25	INL/EXT-09-15691	MPR-3181, Survey of HTGR Process Energy Applications	2-May-08
26	INL/EXT-09-16036	Conceptual Design Studies for the NGNP with Hydrogen Production NGNP-HTGR Combined License Application Writers Guide	20-May-09
27	INL/EXT-09-16040	Capabilities to Support Thermochemical Hydrogen Production Technology Development	28-May-09
28	INL/EXT-09-16598	Next Generation Nuclear Plant Project Technology Development Roadmaps: the Technical Path Forward for 750–800°C Reactor Outlet Temperature	17-Aug-09
29	INL/EXT-09-16606	NGNP Technology Development Roadmapping Report - Steam Production At 750–800°C Electric Company, LLC	31-Jul-09
30	INL/EXT-09-16702	NGNP Component Test Capability Design Code of Record	28-Sep-09
31	INL/EXT-09-16743	Development and Verification of Tritium Analyses Code for a Very High Temperature Reactor	29-Sep-09
32	INL/EXT-09-16942	Integration of High Temperature Gas-Cooled Reactors Into Industrial Process Applications	30-Sep-11
33	INL/EXT-09-17139	Next Generation Nuclear Plant Defense-In-Depth Approach	9-Dec-09
34	INL/EXT-09-17187	NGNP High Temperature Materials White Paper	25-Jun-10
35	INL/EXT-09-17436	Transforming the U.S. Energy Infrastructure	15-Jul-10
36	INL/EXT-10-18282	Review of Nuclear-Integrated Process Application Flow Sheets, prepared by URS Corporation	25-Mar-10
37	INL/EXT-10-19037	High Temperature Gas-Cooled Reactor Projected Markets and Preliminary Economics	16-Aug-10
38	INL/EXT-10-19037	High Temperature Gas-Cooled Reactor Projected Markets and Preliminary Economics	24-Aug-11
39	INL/EXT-10-19329	High Temperature Gas-Cooled Reactors Lessons Learned Applicable to the Next Generation Nuclear Plant	15-Sep-10
40	INL/EXT-10-19329	High Temperature Gas-Cooled Reactors Lessons Learned Applicable to the Next Generation Nuclear Plant	25-Apr-11
41	INL/EXT-10-19359	Next Generation Nuclear Plant Resilient Control System Functional Analysis	21-Jul-10
42	INL/EXT-10-19533	NGNP Reactor Coolant Chemistry Control Study	8-Nov-10
43	INL/EXT-10-19607	Scoping Analyses On Tritium Permeation to VHTR Integrated Industrial Application Systems	3-Mar-11
44	INL/EXT-10-19645	HTGR Resilient Control System Strategy	9-Sep-10
45	INL/EXT-10-19706	HTGR Industrial Application Functional and Operational Requirements	23-Aug-10
46	INL/EXT-10-19808	End User Functional and Performance Requirements for HTGR Energy Supply to Industrial Processes	15-Sep-10
47	INL/EXT-10-19887	Key Design Requirements for the High Temperature Gas-Cooled Reactor Nuclear Heat Supply System	16-Sep-10
48	INL/EXT-11-20973	NGNP Infrastructure Readiness Assessment Consolidation Report	17-Feb-11
49	INL/EXT-11-21397	Assessment of NGNP Moisture Ingress Events	21-Apr-11

Table H-4. (continued).

No.	Doc No.	Title	Date
50	INL/EXT-11-21537	Optimum Reactor Outlet Temperatures for High Temperature Gas-Cooled Reactors Integrated with Industrial Processes	11-Apr-11
51	INL/EXT-11-21545	Summary of Planned Implementation for the HTGR Lessons Learned Applicable to the NGNP	30-Sep-11
52	INL/EXT-11-21817	Progress Report for Diffusion Welding of the NGNP Process Application Heat Exchangers	21-Apr-11
53	INL/EXT-11-21868	Mixed Stream Test Rig Winter FY 2011 Report	21-Apr-11
54	INL/EXT-11-22425	Comparison of Tritium Permeation Analysis Code Results with Tritium Mass Balance Data From the High Temperature Engineering Test Reactor	27-Jun-11
55	INL/EXT-11-22715	An Overview of Nuclear vs. Non-Nuclear Design Code Requirements for a Candidate Steam Supply System for Commercial Applications	2-Apr-11
56	INL/EXT-11-22903	SPECTR System Operational Test Report	18-Aug-11
57	INL/EXT-11-23008	Integration of High Temperature Gas-Cooled Reactors Into Selected Industrial Process Applications	29-Aug-11
58	INL/LTD-09-17394	Evaluating Use of HTGR Technology As An Energy Supply for Petrochemical Facilities, prepared by Dow Chemical, Entergy and Battelle Energy Alliance	24-Sep-09
59	INL/LTD-11-22462	Verification of TPAC Model Predictions with HTTR Tritium Data From JAEA	30-Jun-11
60	Meeting minutes	Teleconference Notes, Minutes of the Circulator Telecon, between Howden UK and Battele Energy Alliance	27-Oct-09

Appendix I

Integrated Schedule—Level 5

Appendix I
Integrated Schedule—Level 5

NGNP INTEGRATED PLANNING SCHEDULE

10-1-2009 Draft

Activity ID	Planned Start	Planned Finish
Q NGNP Projects	23-Jul-07	26-Mar-26
Q.10 Next Generation Nuclear Plant	01-Oct-07	26-Mar-26
Q.10.10 Owners Engineer	01-Oct-07	26-Mar-26
Q.10.10.10 Program Management	01-May-08	26-Mar-26
Q.10.10.10.01 Conceptual Design PM Support	01-May-08	03-Aug-12
Q.10.10.10.02 Preliminary Design PM Support	25-Nov-11	19-Aug-14
Q.10.10.10.03 Final Design PM Support	19-Aug-14	04-May-18
Q.10.10.10.04 Construction PM Support	04-May-18	20-Dec-21
Q.10.10.10.05 Start-Up PM Support	20-Dec-21	01-Aug-22
Q.10.10.10.06 Operations PM Support	15-Aug-22	26-Mar-26
Q.10.10.12 Program Engineering	01-Oct-07	08-Dec-22
Q.10.10.12.01 Conceptual Design PE Support	01-Oct-07	17-Jan-12
Q.10.10.12.02 Preliminary Design PE Support	09-Feb-12	05-Aug-14
Q.10.10.12.03 Final Design PE Support	10-Feb-14	18-Jul-17
Q.10.10.12.04 Construction PE Support	04-May-18	14-Oct-21
Q.10.10.12.05 Start-Up PE Support	20-Dec-21	04-Jul-22
Q.10.10.12.06 Operations Engineering	09-Feb-17	08-Dec-22
Q.10.10.13 Procurement Planning & Overhead	03-Aug-12	05-Aug-14
Q.10.10.13.01 Procurement Planning & Overhead	03-Aug-12	05-Aug-14
Q.10.15 Licensing & Regulatory	07-Jul-08	28-Oct-22
Q.10.15.00 Licensing Schedule Drivers	02-Oct-09	22-Jun-10
Q.10.15.00.01 Schedule Drivers	02-Oct-09	22-Jun-10
Q.10.15.01 Licensing - Pre-Application Phase	07-Jul-08	20-Feb-15
Q.10.15.01.01 Pre-Application Phase	07-Jul-08	03-Jun-13
Q.10.15.01.02 Licensing High-Priority Issues	10-Jun-09	20-Feb-15
Q.10.15.02 Early Site Permit (ESP)	01-Oct-09	06-Dec-18
Q.10.15.02.01 ESP Planning	02-Oct-09	15-Nov-13
Q.10.15.02.02 ESP Pre-Application Program	01-Oct-09	11-Dec-12
Q.10.15.02.03 Site Selection	02-Jan-12	30-Sep-13
Q.10.15.02.04 Site Characterization	02-Jan-12	02-May-14
Q.10.15.02.05 Environmental Report Development	31-Dec-12	02-May-14
Q.10.15.02.06 Site Safety Analysis Report Development	31-Dec-12	02-May-14
Q.10.15.02.07 Emergency Planning	03-Apr-13	04-Aug-14
Q.10.15.02.08 Complete ESP Application	06-Nov-12	08-Oct-15
Q.10.15.02.09 NRC Site Safety Review	09-Oct-15	08-Jun-17
Q.10.15.02.10 NRC Environmental Review	09-Oct-15	31-Oct-17
Q.10.15.02.11 State & Local Permits	31-Dec-12	29-Sep-16
Q.10.15.02.12 ESP Legal Process	09-Oct-15	09-Nov-17
Q.10.15.02.13 ESP Application Approval	09-Nov-17	06-Dec-18
Q.10.15.03 Limited Work Authorization (LWA)	31-Dec-12	28-Apr-17
Q.10.15.03.01 Limited Work Authorization (LWA)	31-Dec-12	28-Apr-17
Q.10.15.04 Combined License (COL) - Prismatic	01-Oct-09	08-Jul-19
Q.10.15.04.01 COL Pre-Application Program	01-Oct-09	31-Oct-13
Q.10.15.04.02 COLA Preparation	23-Nov-10	11-Dec-14
Q.10.15.04.03 COLA Internal Technical Review	12-Dec-14	16-Apr-15
Q.10.15.04.04 Topical Report Submittals	02-Apr-12	26-Sep-14
Q.10.15.04.05 COLA Acceptance Review	17-Apr-15	09-Jul-15
Q.10.15.04.06 COLA Environmental Review	17-Apr-15	05-Jan-17
Q.10.15.04.07 COLA Technical/Safety Review	17-Apr-15	09-Jul-18
Q.10.15.04.08 Administrative & Public Hearing Process	17-Apr-15	08-Jul-19
Q.10.15.05 Combined License (COL) - PBR	01-Oct-09	22-May-20

Remaining Level of Effort | Actual Work | Critical Remaining Work
Actual Level of Effort | Remaining Work ◆ | ◆ Milestone

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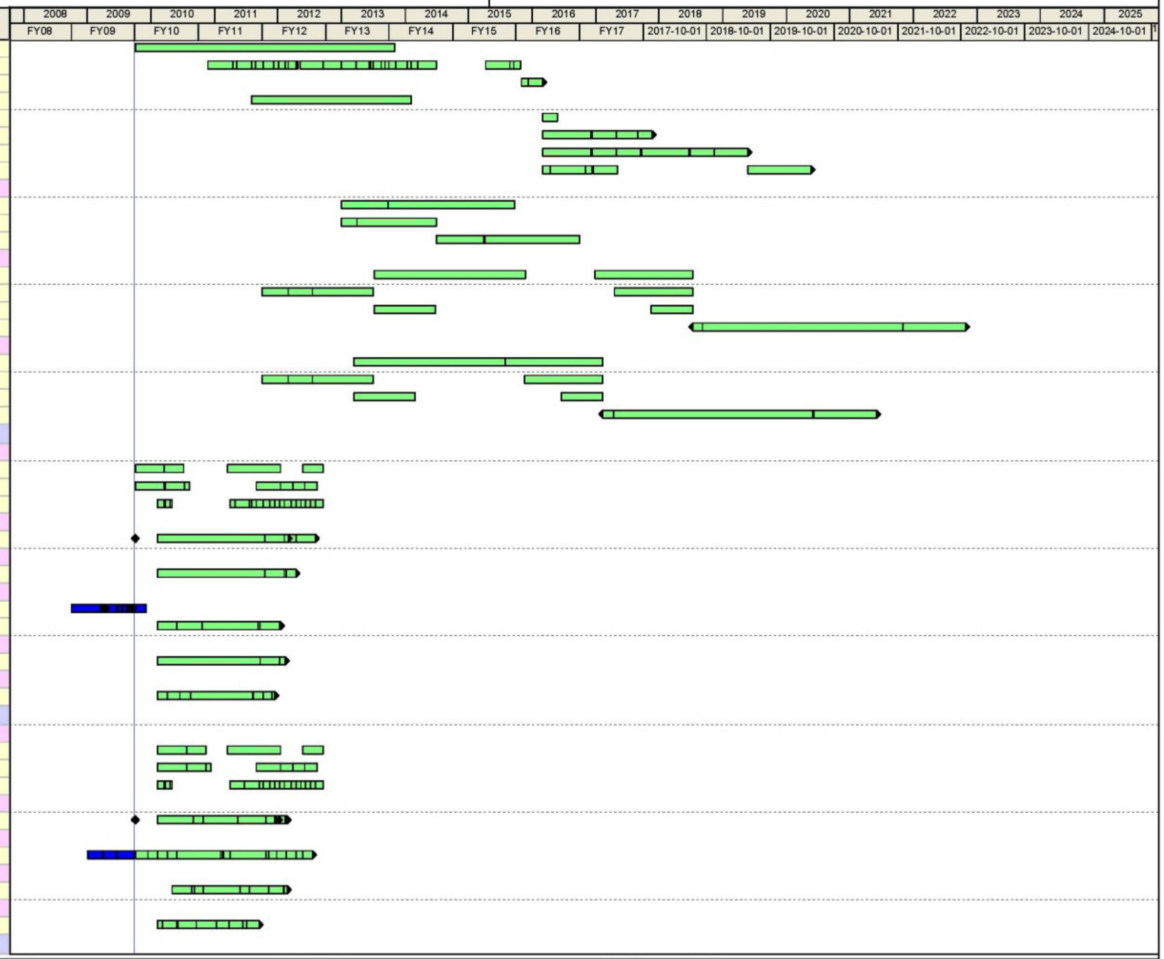
Activity ID	Planned Start	Planned Finish
Q.10.15.05.01 COL Pre-Application Program	01-Oct-09	31-Oct-13
Q.10.15.05.02 COLA Preparation	23-Nov-10	28-Oct-15
Q.10.15.05.03 COLA Internal Technical Review	29-Oct-15	02-Mar-16
Q.10.15.05.04 Topical Report Submittals	04-Aug-11	07-Feb-14
Q.10.15.05.05 COLA Acceptance Review	03-Mar-16	25-May-16
Q.10.15.05.06 COLA Environmental Review	03-Mar-16	22-Nov-17
Q.10.15.05.07 COLA Technical/Safety Review	03-Mar-16	24-May-19
Q.10.15.05.08 Administrative & Public Hearing Process	03-Mar-16	22-May-20
Q.10.15.06 State and Local Permits	31-Dec-12	29-Sep-16
Q.10.15.06.01 Plant Except H2 Facility	31-Dec-12	24-Sep-15
Q.10.15.06.02 H2 Facility	31-Dec-12	01-Jul-14
Q.10.15.06.03 Permits For Operation	02-Jul-14	29-Sep-16
Q.10.15.07 Prismatic Commercial Design Certification (	03-Oct-11	28-Oct-22
Q.10.15.07.01 Commercial Plant Design and Analysis	09-Jul-13	09-Jul-18
Q.10.15.07.02 DC Pre-Application Program	03-Oct-11	09-Jul-18
Q.10.15.07.03 DC Application Preparation	09-Jul-13	09-Jul-18
Q.10.15.07.04 DC NRC Review	09-Jul-18	28-Oct-22
Q.10.15.08 PBR Commercial Design Certification (DC)	03-Oct-11	02-Jun-21
Q.10.15.08.01 Commercial Plant Design and Analysis	15-Mar-13	09-Feb-17
Q.10.15.08.02 DC Pre-Application Program	03-Oct-11	09-Feb-17
Q.10.15.08.03 DC Application Preparation	15-Mar-13	09-Feb-17
Q.10.15.08.04 DC NRC Review	09-Feb-17	02-Jun-21
Q.10.20 Prismatic Conceptual Design	01-Oct-08	14-Sep-12
Q.10.20.14 Prismatic Safety Analysis Documents	01-Oct-09	14-Sep-12
Q.10.20.14.01 Safety Analysis	01-Oct-09	14-Sep-12
Q.10.20.14.02 Heat Transport Failures & Thermal Events	01-Oct-09	13-Aug-12
Q.10.20.14.03 Probabilistic Risk Assessment	09-Feb-10	14-Sep-12
Q.10.20.20 Prismatic Nuclear Heat Supply System (NHS)	01-Oct-09	03-Aug-12
Q.10.20.20.01 Prismatic NHS Conceptual Design	01-Oct-09	03-Aug-12
Q.10.20.30 Prismatic Heat Transport System (HTS)	09-Feb-10	13-Apr-12
Q.10.20.30.01 Prismatic HTS Conceptual Design	09-Feb-10	13-Apr-12
Q.10.20.40 Hydrogen Production System (HPS)	01-Oct-08	17-Jan-12
Q.10.20.40.01 Systems Engineering Down Select/Decisior	01-Oct-08	04-Dec-09
Q.10.20.40.02 HPS Conceptual Design Report	09-Feb-10	17-Jan-12
Q.10.20.50 Prismatic Power Conversion System (PCS)	09-Feb-10	10-Feb-12
Q.10.20.50.01 Prismatic PCS Conceptual Design	09-Feb-10	10-Feb-12
Q.10.20.60 Prismatic Balance of Plant Systems (BOP)	09-Feb-10	14-Dec-11
Q.10.20.60.01 Prismatic BOP Conceptual Design	09-Feb-10	14-Dec-11
Q.10.21 Pebble Bed Reactor (PBR) Conceptual Design	01-Oct-09	14-Sep-12
Q.10.21.14 PBR Safety Analysis Documents	09-Feb-10	14-Sep-12
Q.10.21.14.01 Safety Analysis	09-Feb-10	14-Sep-12
Q.10.21.14.02 Heat Transport Failures & Thermal Events	09-Feb-10	13-Aug-12
Q.10.21.14.03 Probabilistic Risk Assessment	09-Feb-10	14-Sep-12
Q.10.21.20 PBR Nuclear Heat Supply System (NHS)	01-Oct-09	22-Feb-12
Q.10.21.20.01 PBR NHS Conceptual Design	01-Oct-09	22-Feb-12
Q.10.21.30 PBR Heat Transport System (HTS)	01-Oct-09	17-Jul-12
Q.10.21.30.01 PBR HTS Conceptual Design	01-Oct-09	17-Jul-12
Q.10.21.50 PBR Power Conversion System (PCS)	04-May-10	22-Feb-12
Q.10.21.50.01 PBR PCS Conceptual Design	04-May-10	22-Feb-12
Q.10.21.60 PBR Balance of Plant Systems (BOP)	09-Feb-10	14-Sep-11
Q.10.21.60.01 PBR BOP Conceptual Design	09-Feb-10	14-Sep-11
Q.10.30 Prismatic Preliminary Design	22-Jul-11	19-Aug-14



Remaining Level of Effort — Actual Work — Critical Remaining Work
Actual Level of Effort — Remaining Work ◆ — ◆ Milestone

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NGNP INTEGRATED PLANNING SCHEDULE

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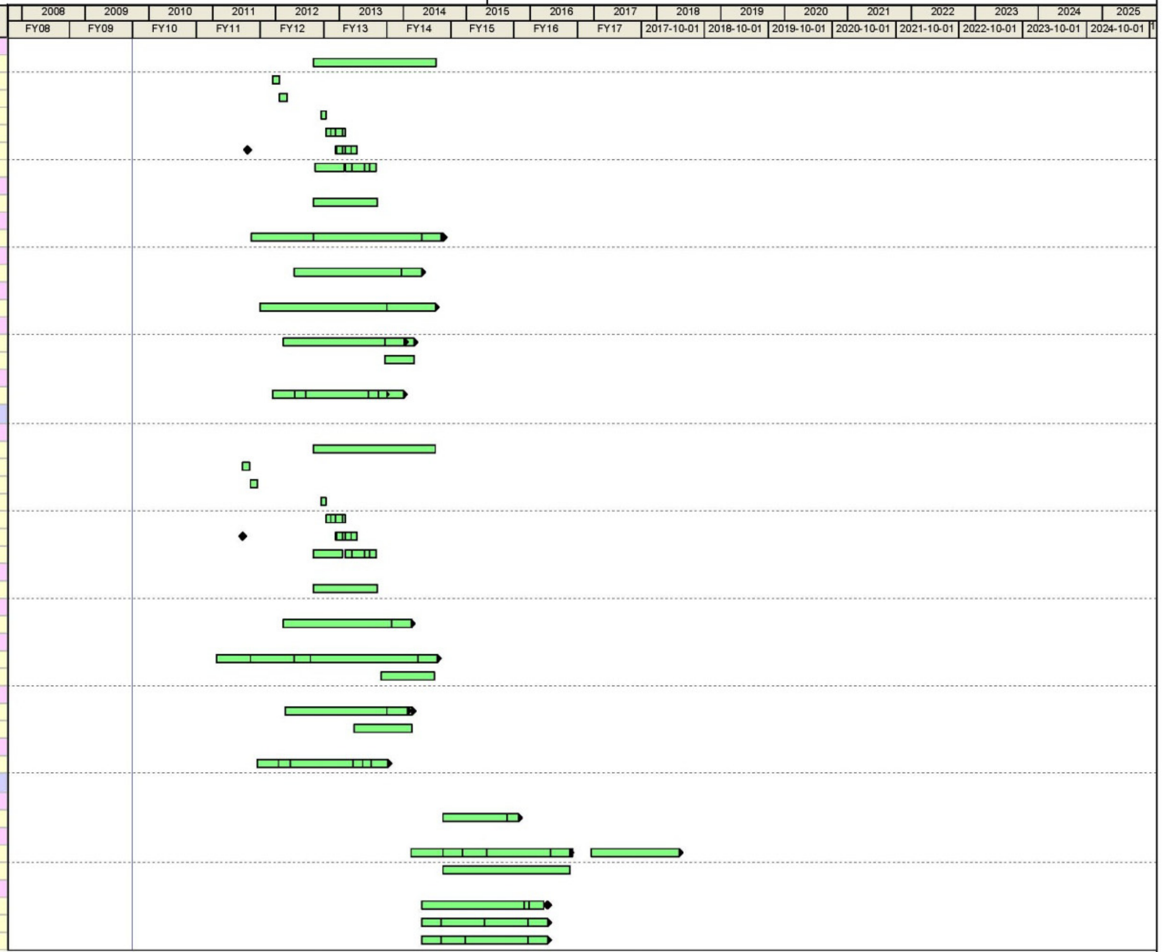
Activity ID	Planned Start	Planned Finish
Q.10.30.14 Prismatic Safety Analysis Documents	22-Jul-11	11-Jul-14
Q.10.30.14.01 Safety Analysis	03-Aug-12	11-Jul-14
Q.10.30.14.02 Prismatic Internal Events PRA Model	12-Dec-11	23-Jan-12
Q.10.30.14.03 Prismatic External Events PRA Model	23-Jan-12	05-Mar-12
Q.10.30.14.04 Prismatic Event Consequence Analysis	14-Sep-12	12-Oct-12
Q.10.30.14.05 Prismatic Risk Analysis	12-Oct-12	01-Feb-13
Q.10.30.14.06 Prismatic Design and Licensing Support & I	22-Jul-11	12-Apr-13
Q.10.30.14.07 Prismatic Heat Transport Failures & Therma	13-Aug-12	02-Aug-13
Q.10.30.16 Prismatic Construction and Fab Support Blc	03-Aug-12	05-Aug-13
Q.10.30.16.01 Construction and Fab Support Buildings	03-Aug-12	05-Aug-13
Q.10.30.20 Prismatic Nuclear Heat Supply System (NHS)	11-Aug-11	19-Aug-14
Q.10.30.20.01 Prismatic NHS Preliminary Design	11-Aug-11	19-Aug-14
Q.10.30.30 Prismatic Heat Transport System (HTS)	13-Apr-12	15-Apr-14
Q.10.30.30.01 Prismatic HTS Preliminary Design	13-Apr-12	15-Apr-14
Q.10.30.40 Hydrogen Production System (HPS)	03-Oct-11	04-Jul-14
Q.10.30.40.02 HPS Preliminary Design	03-Oct-11	04-Jul-14
Q.10.30.50 Prismatic Power Conversion System (PCS)	10-Feb-12	07-Mar-14
Q.10.30.50.01 Prismatic PCS Preliminary Design	10-Feb-12	07-Mar-14
Q.10.30.50.02 PCS Procurement	20-Sep-13	07-Mar-14
Q.10.30.60 Prismatic Balance of Plant Systems (BOP)	14-Dec-11	02-Jan-14
Q.10.30.60.01 Prismatic BOP Preliminary Design	14-Dec-11	02-Jan-14
Q.10.31 Pebble Bed Reactor (PBR) Preliminary Design	24-Jan-11	18-Jul-14
Q.10.31.14 PBR Safety Analysis Documents	24-Jun-11	04-Jul-14
Q.10.31.14.01 Safety Analysis	03-Aug-12	04-Jul-14
Q.10.31.14.02 PBR Internal Events PRA Model	24-Jun-11	04-Aug-11
Q.10.31.14.03 PBR External Events PRA Model	05-Aug-11	15-Sep-11
Q.10.31.14.04 PBR Event Consequence Analysis	14-Sep-12	12-Oct-12
Q.10.31.14.05 PBR Risk Analysis	12-Oct-12	01-Feb-13
Q.10.31.14.06 PBR Design and Licensing Support & Interf	24-Jun-11	12-Apr-13
Q.10.31.14.07 PBR Heat Transport Failures & Thermal Eve	03-Aug-12	02-Aug-13
Q.10.31.16 PBR Construction and Fab Support Bldg Pr	03-Aug-12	05-Aug-13
Q.10.31.16.01 Construction and Fab Support Buildings	03-Aug-12	05-Aug-13
Q.10.31.20 PBR Nuclear Heat Supply System (NHS)	15-Feb-12	21-Feb-14
Q.10.31.20.01 NHS Preliminary Design	15-Feb-12	21-Feb-14
Q.10.31.30 PBR Heat Transport System (HTS)	24-Jan-11	18-Jul-14
Q.10.31.30.01 PBR HTS Preliminary Design	24-Jan-11	18-Jul-14
Q.10.31.30.02 HTS Procurement	27-Aug-13	01-Jul-14
Q.10.31.50 PBR Power Conversion System (PCS)	22-Feb-12	21-Feb-14
Q.10.31.50.01 PBR PCS Preliminary Design	22-Feb-12	21-Feb-14
Q.10.31.50.02 PCS Procurement	22-Mar-13	21-Feb-14
Q.10.31.60 PBR Balance of Plant Systems (BOP)	14-Sep-11	03-Oct-13
Q.10.31.60.01 PBR BOP Preliminary Design	14-Sep-11	03-Oct-13
Q.10.40 Prismatic Final Design	22-Jul-13	04-May-18
Q.10.40.16 Construction and Fab Support Bldg Final De	19-Aug-14	28-Oct-15
Q.10.40.16.01 Construction and Fab Support Buildings	19-Aug-14	28-Oct-15
Q.10.40.20 Prismatic Nuclear Heat Supply System (NHS)	18-Feb-14	04-May-18
Q.10.40.20.01 Prismatic NHS Final Design	18-Feb-14	04-May-18
Q.10.40.20.02 Prismatic NHSS Procurement	19-Aug-14	18-Aug-16
Q.10.40.30 Prismatic Heat Transport System Final Desi	15-Apr-14	12-Apr-16
Q.10.40.30.01 Prismatic Heat Transport Final Design	15-Apr-14	12-Apr-16
Q.10.40.30.02 Primary Heat Transport System	15-Apr-14	12-Apr-16
Q.10.40.30.03 Prismatic Secondary Heat Transport System	15-Apr-14	12-Apr-16



Remaining Level of Effort — Actual Level of Effort — Actual Work — Remaining Work — Critical Remaining Work — Milestone

TASK filter: All Activities

NGNP INTEGRATED PLANNING SCHEDULE

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Activity ID	Planned Start	Planned Finish
Q.10.40.30.04 HTS Procurement	15-Apr-14	12-Apr-16
Q.10.40.40 Hydrogen Production System Final Design	04-Jul-14	19-Oct-17
Q.10.40.40.02 Final NGNP-Coupled Design	04-Jul-14	19-Oct-17
Q.10.40.50 Power Conversion System Final Design	07-Mar-14	21-Jul-16
Q.10.40.50.01 Prismatic PCS Final Design	07-Mar-14	21-Jul-16
Q.10.40.50.02 PCS Procurement	07-Mar-14	08-Mar-16
Q.10.40.60 Balance of Plant & Overall Site Final Design	22-Jul-13	07-Jul-16
Q.10.40.60.01 Prismatic BOP Final Design	22-Jul-13	07-Jul-16
Q.10.40.60.03 BOP Final Design		
Q.10.40.60.02 BOP Procurement	02-Jan-14	04-Jan-16
Q.10.41 Pebble Bed Reactor (PBR) Final Design	11-May-12	20-Dec-16
Q.10.41.16 PBR Construction and Fab Support Bldg Pr	19-Aug-14	19-Aug-15
Q.10.41.16.01 Construction and Fab Support Buildings	19-Aug-14	19-Aug-15
Q.10.41.20 PBR Nuclear Heat Supply System (NHS)	14-Feb-14	20-Dec-16
Q.10.41.20.01 PBR NHS Final Design	14-Feb-14	20-Dec-16
Q.10.41.30 PBR Heat Transport System (HTS)	11-May-12	03-Nov-16
Q.10.41.30.01 PBR HTS Final Design	11-May-12	03-Nov-16
Q.10.41.30.02 HTS Procurement		
Q.10.41.50 PBR Power Conversion System (PCS)	21-Feb-14	22-Jan-16
Q.10.41.50.01 PBR PCS Final Design	21-Feb-14	22-Jan-16
Q.10.41.50.02 PCS Procurement	20-Apr-15	05-Oct-15
Q.10.41.60 PBR Balance of Plant Systems (BOP)	03-Oct-13	23-Jul-15
Q.10.41.60.01 PBR BOP Final Design	03-Oct-13	23-Jul-15
Q.10.50 Construction	28-Oct-15	20-Dec-21
Q.10.50.16 Construction and Fab Support Building	28-Oct-15	06-Jul-16
Q.10.50.20 Nuclear Heat Supply System Construction	01-Mar-16	20-Dec-21
Q.10.50.20.01 Nuclear Heat Supply Component Testing	21-Dec-20	20-Dec-21
Q.10.50.20.02 Reactor Unit System Construction	01-Mar-16	21-Dec-20
Q.10.50.20.03 Shutdown Cooling System Construction	04-May-18	06-Mar-20
Q.10.50.20.04 Reactor Cavity Cooling System Construction	04-May-18	18-Oct-19
Q.10.50.20.05 Fuel Handling and Storage System Constru	04-May-18	06-Mar-20
Q.10.50.20.06 Helium Service System Construction	04-May-18	05-Mar-20
Q.10.50.20.07 Control and Instrumentation System Constr	04-May-18	18-Oct-19
Q.10.50.20.08 Cooling Water System Construction	04-May-18	17-Oct-19
Q.10.50.20.09 Electrical Distribution System Construction	04-May-18	17-Oct-19
Q.10.50.20.10 Reactor Building HVAC System Construction	04-May-18	17-Oct-19
Q.10.50.20.11 Primary Loop Initial Clean-up System Cons	04-May-18	17-Oct-19
Q.10.50.20.12 Component Handling System	04-May-18	17-Oct-19
Q.10.50.20.13 Radioactive Waste System	04-May-18	17-Oct-19
Q.10.50.20.14 Decontamination System	04-May-18	17-Oct-19
Q.10.50.20.15 In-service Inspection Equipment	04-May-18	17-Oct-19
Q.10.50.20.16 Reactor Control Room	04-May-18	17-Oct-19
Q.10.50.30 Heat Transport System Construction	06-Jul-16	09-Dec-21
Q.10.50.30.01 Heat Transport Component Testing	04-May-18	09-Dec-21
Q.10.50.30.02 HTS Primary Heat Transport System Constr	06-Jul-16	16-Oct-20
Q.10.50.30.03 HTS Secondary Heat Transport System Cor	06-Jul-16	16-Oct-20
Q.10.50.40 Hydrogen Production System Construction	04-May-18	17-Oct-19
Q.10.50.50 Power Conversion System Construction	06-Jul-16	11-Nov-21
Q.10.50.50.01 Power Conversion System Component Test	04-May-18	11-Nov-21
Q.10.50.50.02 Turbine Generator System Construction	06-Jul-16	04-Jul-18
Q.10.50.50.03 Main Steam System Construction	06-Jul-16	04-Jul-18
Q.10.50.50.04 Feed water and Condensate System Constr	04-May-18	10-Dec-20

Remaining Level of Effort | Actual Work | Critical Remaining Work
Actual Level of Effort | Remaining Work | Milestone

TASK filter: All Activities

NGNP INTEGRATED PLANNING SCHEDULE

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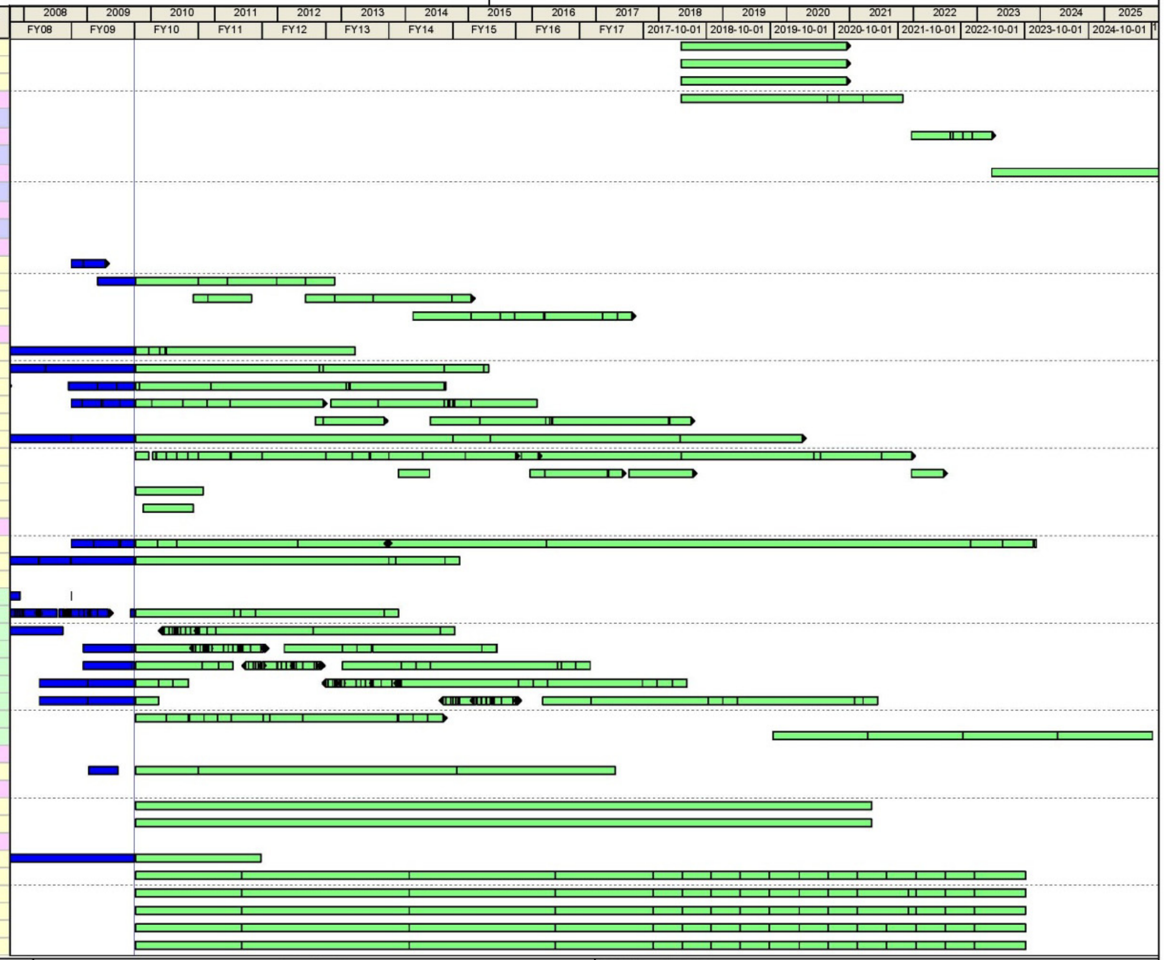
Activity ID	Planned Start	Planned Finish
Q.10.50.50.05 PCS Control and Instrumentation System C	04-May-18	11-Dec-20
Q.10.50.50.06 PCS Electrical Distribution System Constru	04-May-18	10-Dec-20
Q.10.50.50.07 Turbine Building HVAC Construction	04-May-18	10-Dec-20
Q.10.50.60 Balance of Plant & Overall Site Construction	04-May-18	28-Oct-21
Q.10.60 Start-up & Initial Operations	20-Dec-21	27-Mar-23
Q.10.60.01 Start-up & Initial Operations	20-Dec-21	27-Mar-23
Q.10.70 NGNP Hot Operations	27-Mar-23	26-Mar-26
Q.10.70.01 Hot Operations	27-Mar-23	26-Mar-26
Q.10.80 NGNP Turnover to Owner/Operator	26-Mar-26	26-Mar-26
Q.10.80.01 Turnover to Owner/Operator	26-Mar-26	26-Mar-26
Q.10.90 NGNP Research & Development	01-Oct-07	06-Oct-25
Q.10.90.02 HPS Research and Development	01-Oct-09	27-Jul-17
Q.10.90.02.01 Demonstrate Integrated Experimental Scale	01-Oct-09	14-Apr-10
Q.10.90.02.02 HPS Studies and Analysis	01-Oct-09	22-Nov-12
Q.10.90.02.03 Large Scale Hydrogen Experiments	02-Sep-10	15-Jan-15
Q.10.90.02.04 Engineering Scale Demonstration	14-Feb-14	27-Jul-17
Q.10.90.10 Fuels	01-Oct-07	20-Jun-22
Q.10.90.10.01 AGR-1 Irradiation Shakedown Small Coater	01-Oct-07	21-Mar-13
Q.10.90.10.02 AGR-2 Irradiation Pilot Scale Coater Fuel Pe	01-Oct-07	27-Apr-15
Q.10.90.10.03 AGR-3/-4 Irradiation Fission Product Transp	01-Oct-07	21-Aug-14
Q.10.90.10.04 AGR-5/-6 Irradiation Fuel Qualification	01-Oct-08	28-Jan-16
Q.10.90.10.05 AGR-7/-8 Irradiation Fuel Performance and I	01-Aug-12	29-Jun-18
Q.10.90.10.06 Fuel Performance Modeling	01-Oct-08	31-Mar-20
Q.10.90.10.07 Fission Product Transport & Source Term	01-Oct-07	20-Dec-21
Q.10.90.10.08 NRC Reports	25-Nov-13	20-Jun-22
Q.10.90.10.09 Special Fuel Studies	01-Oct-09	29-Oct-10
Q.10.90.10.10 Supplemental Fuel Characterization Capabi	16-Nov-09	03-Sep-10
Q.10.90.20 Materials	01-Oct-08	06-Oct-25
Q.10.90.20.01 High Temperature Metals	01-Oct-08	07-Dec-23
Q.10.90.20.02 Graphite Material Properties	01-Oct-08	10-Nov-14
Q.10.90.20.03 Advanced Gas Reactor Creep (AGC) Experi	01-Oct-08	06-Oct-25
Q.10.90.20.03.01 ATR Preparations	01-Oct-08	01-Oct-08
Q.10.90.20.03.02 AGC-1	01-Oct-08	22-Nov-13
Q.10.90.20.03.03 AGC-2	01-Oct-08	13-Oct-14
Q.10.90.20.03.04 AGC-3	05-Dec-08	15-Jun-15
Q.10.90.20.03.05 AGC-4	05-Dec-08	28-Nov-16
Q.10.90.20.03.06 AGC-5	01-Oct-09	11-Jun-18
Q.10.90.20.03.07 AGC-6	01-Oct-09	07-Jun-21
Q.10.90.20.03.08 HTV-1/2	01-Oct-09	07-Aug-14
Q.10.90.20.03.09 Modeling	15-Oct-19	06-Oct-25
Q.10.90.30 Fuel Fabrication Commercialization	01-Oct-09	21-Apr-17
Q.10.90.30.01 Fuel Fabrication Commercialization	01-Oct-09	21-Apr-17
Q.10.90.40 Additional Operations Support	01-Oct-09	06-May-21
Q.10.90.40.01 Operations Support/Production/Control/Tra	01-Oct-09	06-May-21
Q.10.90.40.02 Infrastructure/Equipment Upgrades & Maint	01-Oct-09	06-May-21
Q.10.90.50 Design Methods and Validation	01-Oct-07	05-Oct-23
Q.10.90.50.01 Reactor Design Selection	01-Oct-07	02-Apr-10
Q.10.90.50.02 MIR	01-Oct-09	05-Oct-23
Q.10.90.50.03 Plenum-to-Plenum	01-Oct-09	05-Oct-23
Q.10.90.50.04 Core Heat Transfer (CHT)	01-Oct-09	05-Oct-23
Q.10.90.50.05 Lower Plenum (LP)	01-Oct-09	05-Oct-23
Q.10.90.50.06 Air Ingress (AI)	01-Oct-09	05-Oct-23



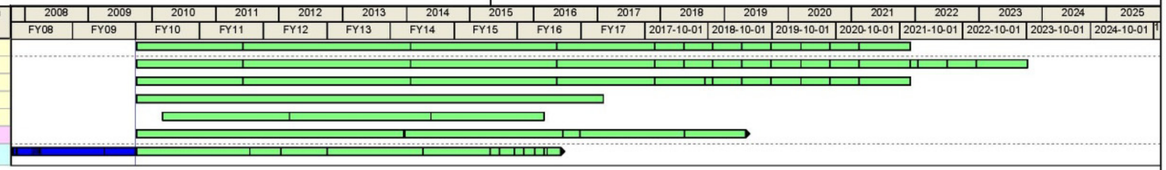
Remaining Level of Effort | Actual Work | Critical Remaining Work
Actual Level of Effort | Remaining Work ◆ | ◆ Milestone

TASK filter: All Activities

NGNP INTEGRATED PLANNING SCHEDULE

10-1-2009 Draft

Activity ID	Planned Start	Planned Finish
Q.10.90.50.07 RCCS	01-Oct-09	02-Dec-21
Q.10.90.50.08 Fundamental	01-Oct-09	05-Oct-23
Q.10.90.50.09 Integral	01-Oct-09	02-Dec-21
Q.10.90.50.10 Reactor Physics	01-Oct-09	06-Feb-17
Q.10.90.50.11 CTC Integral Scaled Test	01-Mar-10	04-Mar-16
Q.10.90.60 First Core	01-Oct-09	01-May-19
Q.20 HTGF Component Test Capability (CTC)	23-Jul-07	07-Jun-16



Remaining Level of Effort | Actual Work | Critical Remaining Work
Actual Level of Effort | Remaining Work ◆ | ◆ Milestone

TASK filter: All Activities

Appendix J

NRC HTGR Technology Training Syllabus

Appendix J
NRC Training Course—HTGR Design and Safety Basis

Module #	Topic
N/A	Introductory Remarks
	Part 1. Introduction and HTGR Overview
1	Introduction (Course Objectives & Structure)
2a	Background History and Evolution of HTGR Designs
	o Evolution of HTGR designs
	o Overview of current HTGR design concepts
	o Current HTGR programs and facilities
	o HTGR licensing and operational experience
2b	HTGR Motivations and Applications
3	Modular HTGR Safety Design Approach and Safety Systems
	o Fuel (and other) barriers to radionuclide release
	o Decay heat removal and reactivity control
	o Passive safety
	o Limiting chemical attack
	o Reactor building
	o Emphasis on accident prevention vs. mitigation
4	HTGR Licensing Approaches
	o HTGR licensing precedents
	o Risk-informed approach
	o Industry perspective on HTGR safety and licensing
	o Current international licensing activities
	Part 2. HTGR Fuel, Reactor, and Plant Design
5	**Prismatic HTGR Core Design and Thermal-Hydraulic Performance**
5a	Core Design Description
	o Core design description
	o Cylindrical vs. annular core
	o Coolant flow paths
	o Central reflector options
5b	Nuclear Design
	o Core nuclear design basics
	o Temperature coefficients
	o Decay heat
	o Analytical tools
	o Code verification and validation
5c	Thermal-Fluid Behavior
5d	Refueling Design
	o Basic core thermal/fluid attributes
	o Comparison with LWRs
	o T/F correlations
	o T/F modeling challenges
5e	T/F Aspects of Process Heat Coupling
6	**Pebble Bed HTGR Core Design and Thermal-Hydraulic Performance**
6a	Core Design Description
	o Cylindrical vs. annular core
	o Coolant flow paths
	o Central reflector options
6b	Nuclear Design
	o Core nuclear design basics
	o Temperature coefficients
	o Decay heat
	o Analytical tools
	o Code verification and validation
6c	Thermal-Fluid Behavior
6d	Refueling Design
	o Basic core thermal/fluid attributes
	o Comparison with LWRs
	o T/F correlations
	o T/F modeling challenges

Module #	Topic
7	**TRISO Fuel Design and Fabrication**
7a	TRISO Fuel Design, Performance Requirements, and Specifications
	o Coating structures and properties
	o Fuel failure mechanisms
	o Fuel performance requirements and specifications
7b	Fuel Fabrication Technology
	o Fuel characterization techniques
	o Fuel Quality Control (statistical QC)
8	Fuel Performance History and Modeling
	o Fuel operating experience in HTGRs
	o Fuel irradiation and PIE
	o Safety criteria and performance limits
	o Fuel performance modeling
	o Fuel cycle issues
	o Regulatory challenges
9	Graphite
	o Role in HTGRs
	o Physical properties and irradiation effects
	o International graphite irradiation programs
	o Graphite oxidation and other chemical reactions
	o Erosion of graphite - tribology
	o Design of nuclear graphite for HTGRs
	o Graphite and graphite testing standards
	o Graphite performance modeling
	o Manufacturing processes
	o Regulatory challenges
	HTGR Component Technology - NGNP Designs
10a	Vessel System
10b	Steam Cycle Power Conversion System
10c	Helium Inventory and Purification System
10d	Reactor Cavity Cooling System
	HTGR Component Technology - Advanced Reactor Designs
10e	Intermediate Heat Exchanger
10f	Gas Turbine Power Conversion System
11	High Temperature Materials Performance
	o Design and material issues for components
	o High-temperature design methodology
	o High-temperature design codes and testing standards
	o High-temperature material performance modeling
	o Non-metallic components (i.e. composites) in HTGRs
	o Regulatory challenges
12	Instrumentation and Controls and Control Room Design
	o Digital instrumentation and control systems
	o Control room design
	Part 3. HTGR Safety Analysis
13	Fission Product Behavior in HTGRs
	o Release from coated particle fuel
	o Fission product transport
	o Radionuclide inventory
	o Occupational and site boundary doses
14	HTGR Accident Analyses
	o Accidents types
	o Licensing basis accident selection process
	o Accident analysis requirements and methods
15	HTGR Accident Analysis Tools
	o Modeling and phenomena involved
	o Review of accident analysis codes
	o Applications of CFD modeling
	o Accident simulation (LOFC, D-LOFC, ATWS, air ingress
	o Uncertainty analysis and sensitivity studies
	o Code verification and validation
	Discussion and Wrap Up
	Additional questions/answers on covered topics
	Identification of topics requiring follow-up

Appendix K

NGNP R&D Program Organization and Work Scope

Appendix K
NGNP R&D Program Organization and Work Scope

(Continuing critical development activities to preserve and increase the value of the considerable investment made by DOE to-date in HTGR development)

The Secretary's guidance in the October 17, 2011, letter to Congress reduces Next Generation Nuclear Plant (NGNP) Project's continuing scope to only critical parts of technology development and the preapplication discussions between NGNP Licensing and the Nuclear Regulatory Commission (NRC). This requires reconfiguring the NGNP Project organization into a research and development (R&D) program managed by the Idaho National Laboratory (INL) Very High Temperature Reactor Technology Development Office (VHTR TDO). This section summarizes the changes to the organization, scope, schedule, and estimated costs for the continuing workscope consistent with the Secretary's letter. In this regard, it should be understood that the work scope defined in this section is not sufficient to complete R&D and Licensing necessary to support commercializing the high temperature gas-cooled reactor (HTGR) technology. That scope is defined in the sections on R&D, Engineering and Licensing in the main body of this report. The parts of the full work scope not completed in this reduced scope will need to be completed later of the objective of commercializing the HTGR technology.

K-1. NGNP PROJECT ORGANIZATIONAL CHANGES

At the time of this writing the NGNP Project organization consists of Quality Assurance (QA), Regulatory Affairs, Engineering, and Project Integration organizations that report directly to the NGNP Project director, and an R&D organization that reports to the VHTR TDO which in turn reports to the NGNP Project Director as shown in Figure K-1. The R&D organization consists of the fuels and graphite R&D groups along with a related Experiment Design and Irradiations group, which supports testing in the Advanced Test Reactor, along with hydrogen and high temperature materials R&D groups. The R&D organization also includes design and safety methods validation, data management and analysis, QA, and project support groups. The charters for each organization and descriptions of the specific roles and responsibilities of organization members are included in the NGNP Project QA Manual (see Section 9).

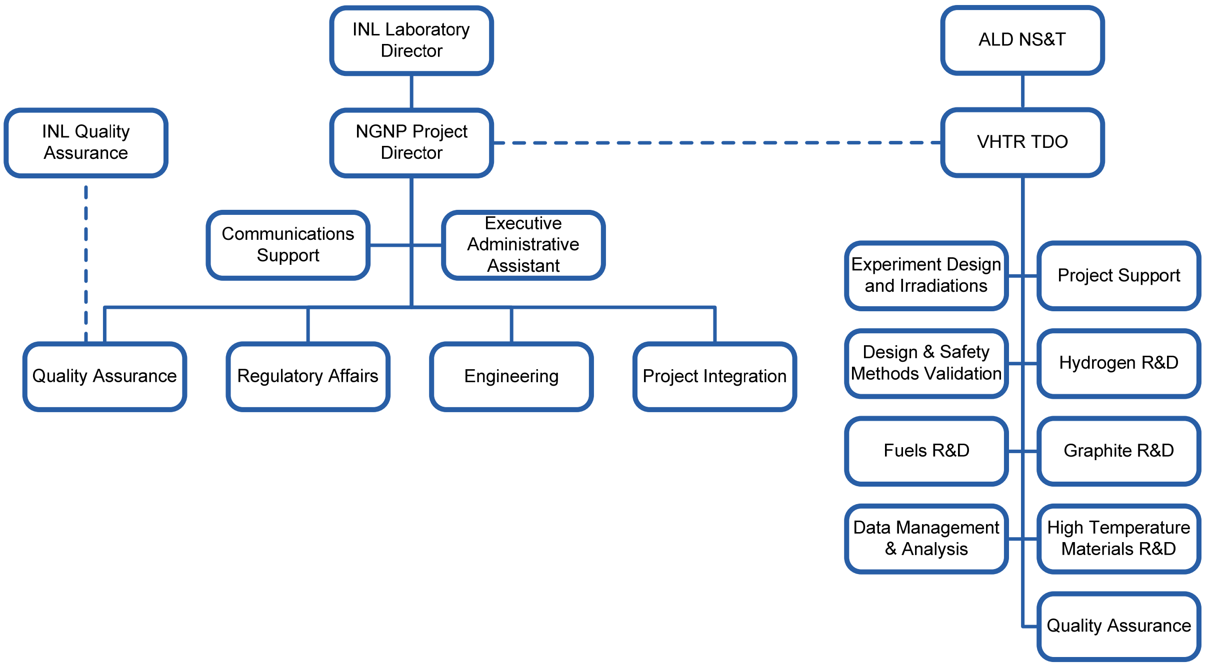


Figure K-1. NGNP Project organization chart.

Figure K-2 shows the reconfiguration of the organization to an R&D Program that will occur to manage the reduced work scope defined by the Secretary of Energy's letter. The INL QA Organization continues to support the ongoing activities, ensuring that documents and records have sufficient credentials to support future design and licensing activities. The R&D and Regulatory Affairs organizations will be managed by the VHTR TDO, which will also be the point of contact with Department of Energy (DOE) for the NGNP Technology and Pre-application Licensing Development Program. The Engineering and Project Integration organizations will be eliminated.

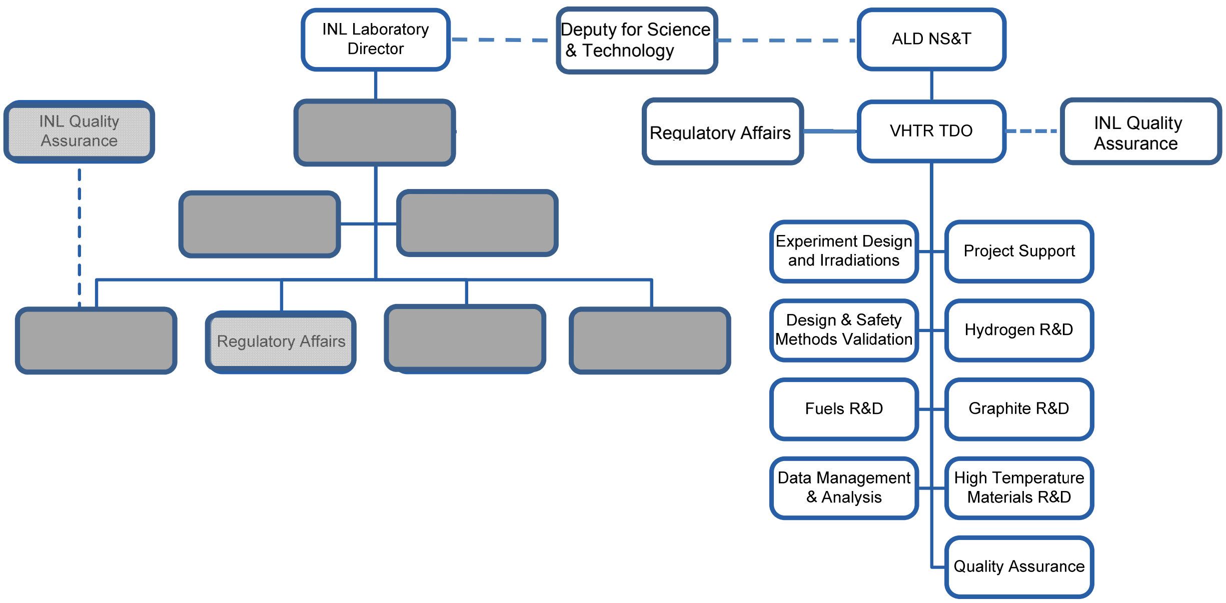


Figure K-2. NGNP R&D Program organization.

K-2. R&D REDUCED PROGRAM SCOPE OF WORK AND SCHEDULE

K-2.1 Research and Development

K-2.1.1 Objectives

The R&D organization has established the following objectives for the reduced work scope to continue with critical elements of the NGNP R&D Program:

- Resolve technology-specific technical issues associated with gas reactors to lower the barrier for when such a system is deployed and to provide the technical information required for development of the HTGR licensing framework.
- Reduce uncertainties and better define important attributes of the VHTR with outlet temperatures between 850 and 950°C.
- Perform R&D that adds value to the technology, has important cross-cutting value and/or supports the DOE Office of Nuclear Energy (NE) Roadmap and R&D Objective 2.
- Develop or support the development of improvements in the affordability of new reactors to enable nuclear energy to help meet the administration's energy security and climate change goals.
- Improve return on investment made over the past 9 years (~$ 250M) by continuing R&D in key areas:
  - Cover existing commitments (irradiations and post irradiation examinations [PIEs]).
  - Complete key activities that make sense (e.g., fuel fabrication) prior to closeout.

No additional infrastructure is required to execute the remaining graphite and high temperature materials work scope. Some additional infrastructure is required for tristructural-isotropic (TRISO) fuel PIE (e.g., moisture effects testing). Work plans discussed here leverage existing investments where possible.

Completion of these objectives will ensure that the significant investment made in the NGNP Project R&D Program through FY 2011 will not suffer the same outcome of similar investment made in the 1980s and 1990s on the New Production Reactor (NPR) and modular high temperature gas-cooled reactor (MHTGR) programs that were cut after considerable government investment without achieving program objectives.

The proposed R&D Program for the transition period covers the four major segments of R&D required to support commercialization of the HTGR technology. The following summarizes the status and the proposed path forward in each of these four areas.

K-2.1.2 Fuel Development and Qualification

K-2.1.2.1 Fabrication (90% complete)

- Finalize compacting technology by 2012.
- Fabricate kernels and coatings for TRISO qualification fuel for Advanced Gas Reactor (AGR)-5/6/7 in 2013 and compacts in early 2014 (depending on funding).
- Anticipate qualifying a fuel vendor (Babcox & Wilcox [B&W]) with complete fabrication capabilities (kernels, coatings, compacting) by early 2014—a major objective of the program. B&W activities will be closed out in 2014.
- Will not complete additional fuel fabrication optimization studies; a reduction in scope worth $10M.

K-2.1.2.2 Fuel Qualification Irradiations (60% complete)

- AGR-2 is still in the Advanced Test Reactor (ATR). Another 1.5 years is needed to complete performance demonstration of industrial scale U.S. UCO fuel and U.S., French, and South African UO_2 TRISO fuel.
- AGR-5/6/7 is in formal qualification and margin testing. This is the last irradiation needed for fuel qualification.
  - Design to start in 2012 (depending on budget).
  - Originally conceived as three separate irradiations in large B positions in ATR.
  - Enough space in Northeast flux trap to accommodate all three tests, saving ~$10M and 2 years in schedule.

K-2.1.2.3 PIE and Safety Testing (15% complete)

- AGR-1 PIE and Safety Testing is underway and will continue through 2013.
  - Safety testing is critical to demonstrate robustness of UCO TRISO fuel for HTGR use and to supply key data to support collocation of HTGRs with industrial facilities.
  - AGR-2 PIE is scheduled for 2014–2017.

K-2.1.2.4 Source Term Qualification (25% complete)

- AGR-3/4 irradiation will provide data on fission product release/retention from failed fuel.

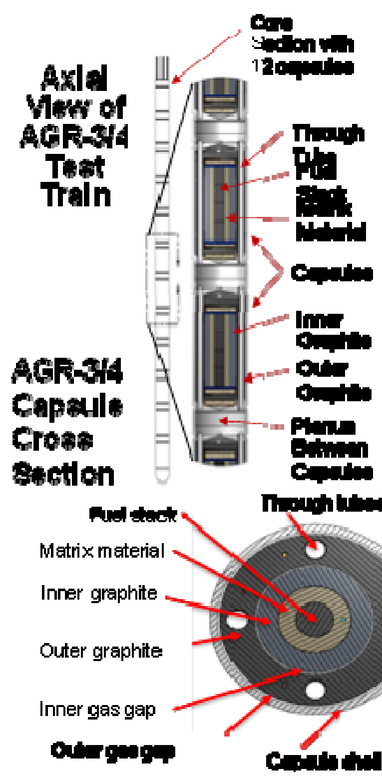


Figure K-3. AGR 3/4 capsule.

- Fuel is fabricated for the capsule as shown in Figure K-3.
- Final design of capsule is complete and irradiation preparations are nearing completion.
- Capsule is being assembled and is expected to be ready to insert by the end of 2011. Irradiation is scheduled December 2011–November 2013; PIE is scheduled for April 2014–April 2018.

- AGR-8 and fission product transport loop testing, which is devoted to qualification of the source term, *will not be completed* in this reduced scope of work; a reduction in scope of ~$100M. This will need to be completed at some time to support commercializing the HTGR technology.

K-2.1.3 Justification

- TRISO fuel has applicability beyond HTGRs in the DOE-NE portfolio. Other advanced reactor concepts like salt cooled graphite reactors use TRISO fuel.
- DOE-NE should have a fuel qualification program in their portfolio.
  - The depth, breadth and rigor inherent in a fuel qualification program is a critical skill set that will not be transferred to the next generation without the NGNP/AGR fuel qualification program.
- Even without an active NGNP Project, the HTGR remains the primary option for nuclear production of high temperature process heat.
- Establishing a pilot line fabrication capability (by early 2013) and producing design and licensing fuel performance and fission product behavior data (by 2018) are key to bringing ceramic fuel to a level where it can be used for any future advanced reactor system.
- Continuing the program will allow DOE to realize a more complete return on the $135M invested in TRISO fuel thus far.
- About $125M over the next 7 years would be required to qualify the fuel.
  - $45M for formal fuel qualification Note that this does not include the writing of technical reports required to support topical reports to be prepared by the Applicant as part of the Combined License Application (COLA) for the plant,
  - $80M to finish up irradiations and PIE in the pipeline today.

K-2.1.4 Graphite Development and Qualification

- Needed as the moderator for other high temperature applications (Advanced High Temperature Reactor) as well as the HTGR.
- There is scientific and engineering value in bringing graphite into a more mature standing as a nuclear material by:
  - Developing a more complete understanding of its behavior under irradiation, including estimates of its lifetime.
    - Knowledge today is limited on the role of irradiation induced creep in stress reduction.
  - Informing decisions in the future about degree of performance impact if grade changes.
  - Working to get code case data and approval by American Society of Mechanical Engineers (key pacing item for graphite).
- Significant investments have been made to date ($40M) and continued funding will allow good return on that investment.

- Eliminate irradiations Advanced Graphite Creep (AGC)-6 and HFIR-Target-VHTR (HTV)-2, since they are not representative of the conditions graphite will see in the core. ($14M).
- $71M to complete. Most activities complete by 2018.

K-2.1.5 High Temperature Materials

- Because of the role of high temperatures in achieving high thermodynamic efficiency, high temperature alloys (nickel based alloys 800H, IN-617) have value to other reactor concepts in DOE-NE portfolio.
- Infrastructure already exists.
- Reactor pressure vessel R&D to extend life to 60 years is useful to others.
- $25M has been spent to date. $37M to finish program. Most of work completed by 2016. Long term creep tests finish in 2018.

K-2.1.6 Design and Safety Methods Validation

- Refocus program on providing separate effects and integral data for code validation (High Temperature Test Facility [HTTF] experiment at Oregon State and reactor cavity cooling system (RCCS) experiment at Argonne National Laboratory).
- Utilize Nuclear Energy University Program to provide smaller scale experimental validation data
- Provide qualified data for validation of models being developed by Nuclear Energy Advanced Modeling and Simulation program.
- Bring the rigor of code uncertainty estimation and experiment uncertainty together to address the key issues associated with validation and meet NRC level requirements.
- About $31M total cost through 2017, $50M less than in the original plan.

K-2.1.7 Heat Transport Component Development

- Eliminate further design and fabrication method developments and testing for intermediate heat exchangers and Steam Generators.
- A reduction in cost of ~$110M .

K-2.1.8 Cost and Schedule to Complete

Table K-1 summarizes current and projected costs to complete NGNP Project work under the reduced work scope. The reduced work scope could be complete by the end of 2019 with the required annual funding profile shown in Figure K-4 and summarized in Table K-3.

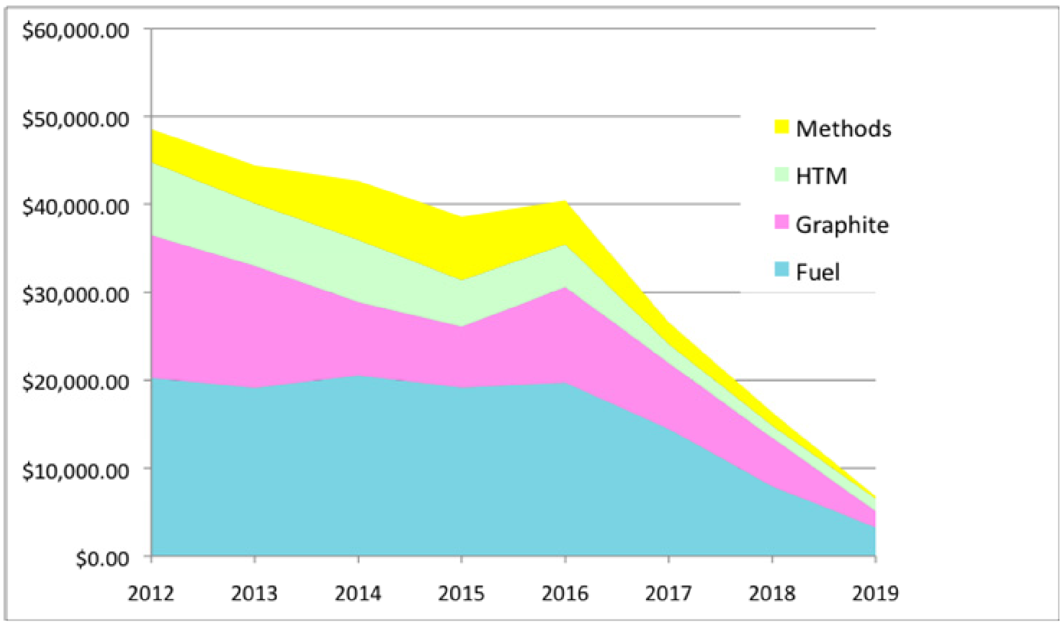
Table K-1. Summary of current and projected costs to complete NGNP Project work under the new work scope.

Description of Scope	$ Million
Spent thru FY 2011	250
Remaining scope proposed here	265
Scope delayed	285
Original total	800

This reduced work scope includes the following reductions from the full work scope required to complete R&D to support commercializing the HTGR technology:

- No AGR-8 or fission product transport work scope.
- No additional fuel fabrication optimization studies (closeout B&W in 2013).
- No AGC-6 or HTV-2 in graphite.
- Methods focused on HTTF and RCCS experimentation, analysis and code V&V.
- No intermediate heat exchanger or steam generator development
- About $285M less scope than in current NGNP program plans as shown in Table K-2.

As cited previously, these items will still need to be completed to support the full scope of work required in developing, licensing, and deploying the HTGR demonstration plant and in support of fully commercializing the HTGR technology.



	2012	2013	2014	2015	2016	2017	2018	2019	
Fuel	$20,268.95	$19,127.71	$20,560.65	$19,158.84	$19,724.89	$14,499.03	$7,930.03	$3,229.42	$124,499.52
Graphite	$16,237.18	$13,858.19	$8,355.27	$6,920.37	$10,881.41	$7,477.47	$5,540.76	$1,847.59	$71,118.25
HTM	$8,282.58	$7,093.22	$7,051.86	$5,288.69	$4,843.08	$2,138.95	$1,396.81	$1,438.49	$37,533.68
Methods	$3,724.10	$4,349.01	$6,706.40	$7,205.44	$4,950.32	$2,449.51	$1,503.40	$273.21	$31,161.39
Total	$48,512.81	$44,428.14	$42,674.19	$38,573.34	$40,399.69	$26,564.96	$16,371.00	$6,788.71	$264,312.84

Figure K-4. Proposed cost schedule to complete by the end of 2019.

K-3. LICENSING

K-3.1 Objective

The primary objective of the Regulatory Affairs organization is to complete development of the HTGR licensing framework through continued focused engagement with the NRC. Meeting this objective will provide all stakeholders with a clear understanding of the HTGR licensing requirements. The licensing framework significantly reduces project uncertainty and risk, and when implemented ensures that the HTGR is ready to support demonstration and commercialization, Accomplishing this objective requires continuation of the current NGNP pre-application program; building on past government and industry resource investments related to HTGR development and licensing (i.e., in development of the General Atomics MHTGR, the Pebble Bed Modular Reactor, the Exelon pre-licensing program for PBMR)

The licensing pre-application program description provided below summarizes the minimum activities needed to be continued to minimize the effort necessary to complete the program once the full scope of HTGR commercialization activities resume. This also provides a continuum of discussion with the NRC that preserves and advances progress already made in updating NRC regulation to be applicable to the HTGR technology.

K-3.1.1 Licensing Framework Activities

NGNP Project Regulatory Affairs will continue to engage with the NRC on resolving key issues affecting the licensing of the HTGR technology. The specific actions involved in the NRC interactions include:

- Address and resolve open items (where possible, based on available design and technical detail) identified in the NRC's pending policy issue assessment reports. These reports (expected in January 2012) will reflect the results of NRC's evaluation of the proposed HTGR policy issue resolutions contained in previous NGNP Project white paper submittals.
- Continue development of an initial draft of the HTGR Combined License Application Content Guide based on inputs from the previously completed regulatory gap analysis, and insights gained from the above NRC assessment reports. Engage the NRC in providing inputs, review, and overall concurrence with the Guide, similar to the process used by NRC and industry when establishing Combined License (COL) application guidance for LWRs. It is estimated that approximately 80 – 90% of the Content Guide can be developed based on the existing level of modular HTGR design information.
    - Completion of the remaining portions would require additional technical development work to first be completed. Examples of this technical work that have been identified to date are summarized below.
- Develop proposed updated or alternative regulatory guidance to address the multiple gaps identified in the regulatory gap analysis. It is estimated that resolutions can be proposed for approximately 40% of the identified gaps with the current level of available design information.
    - Completion of the remaining portions would require additional design and technical development work to be completed. The scope of technical support work identified below does not include sufficient design development to complete addressing all regulatory gaps. Additionally there is no design work planned that would support addressing the remaining gaps. The necessary design information needed would be consistent with a “Final Safety Analysis Report” (FSAR) level of detail (such as acceptance of an appropriate containment concept, multi-module control room staffing, reactor in-core instrumentation).
- Address and resolve NRC requests for additional information regarding the NGNP Project Quality Assurance Program Description (QAPD) to ensure that ongoing project activities can later be formally referenced and utilized to support the NRC license application and approval processes. Once resolved, facilitate NRC's issuance of a safety evaluation report documenting their approval of the QAPD.
- Continue to participate in the Nuclear Energy Institute's Small Modular Reactor Licensing Task Force, which is working with the NRC to address and resolve policy issues associated with advanced reactor designs (primarily small pressurized water reactors).

K-3.1.2 Required Technical Support Activities

As noted, the extent to which many of the open items with the NRC can be resolved and completion of the COLA Content Guide is limited because of the lack of design information on the HTGR Plant. Additional technical and design information will be needed to carry discussion of these items further with the NRC. Examples of areas in which additional technical and design information is needed to support discussions with the NRC and completion of HTGR regulatory framework development include:

1. Provide technical support, where required, to address and resolve NRC open items that are identified in the pending NRC assessment reports; supports resolution of key HTGR policy and technical issues.
2. Perform an initial vulnerability analysis to determine the capability of the “typical” HTGR design to withstand aircraft impact events as described in 10 CFR 50.150.
3. Establish a reactor outlet temperature and thermal power rating as a “reference” configuration for addressing specific licensing topics such as source term determination, materials qualification, etc.
4. Assess remaining uncertainties associated with establishing the mechanistic source term, and take action to further evaluate and reduce those uncertainties. This effort would be expected to focus primarily on fission product transport from the fuel to the environment (including the helium pressure boundary and the reactor building).
5. Develop a summary description of operator actions necessary when responding to licensing basis events, including the relative timelines assumed for completing those actions. Also provide a description of the capability to shelter operators in the control room and/or remote shutdown areas to satisfy the associated exposure limits (e.g. GDC 19).
6. Develop Specified Acceptable Fuel Design Limits (SAFDLs) for the HTGR particle fuel type, since the SAFDL structure that’s been established for LWR fuel can’t be applied to particle fuel.

Some of this information will be forthcoming as the R&D program progresses (e.g., establishing uncertainties in the calculation of the mechanistic source terms, and development of SAFDLs); however, additional engineering support will be needed to provide the remainder. An estimate of the costs for this engineering support is included in the following section.

K-3.1.3 Costs and Schedule

This phase of the licensing pre-application program is expected to continue for approximately 2 years through the end of 2013. Figure K-5 summarizes the funding requirement by year for this scope. To extend the pre-application work beyond 2 years will require identification of a license applicant and specific plant design information at the FSAR level. It should be noted that without additions to currently available funding, the Regulatory Affairs organization will be required to stop work at the end of March, 2012.

Costs (2 years total, ½ each year)

$9.0M Regulatory Affairs

$2.0M Technical Support

$6.0M NRC Review Charges

Item	Fiscal Year 2012	2013	2014	2015	2016	2017	2018	2019	Total, $M
Regulatory Affairs	3.25	4.5	1.25						9.0
NRC Review Charges	0.75	1.0	0.25						6.0
Technical Support	2.25	3.0	0.75						2.0
Totals, $M	6.25	8.5	2.25						17.0

Figure K-5 – Cost Schedule for Licensing Activities.

K-4. Total Cost Schedule

Figure K-6 summarizes the total funding required by year to support this reduced scope of work. Note that Licensing work does not proceed beyond the end of CY2013 because of the lack of plant design development. Note that this is the minimum annual funding required by the Project to complete the identified work and does not include amounts set aside from appropriations for DOE Nuclear Energy University Programs, Small Business Innovative Research, etc.

Item	Fiscal Year 2012	2013	2014	2015	2016	2017	2018	2019	Total, $M
Fuel	20.3	19.1	20.6	19.2	19.7	14.5	7.9	3.2	124.5
Graphite	16.2	13.9	8.4	6.9	10.9	7.5	5.5	1.8	71.1
HTM	8.3	7.1	7.1	5.3	4.8	2.1	1.4	1.4	37.5
Methods	3.7	4.3	6.7	7.2	5.0	2.4	1.5	0.3	31.1
Regulatory Affairs	3.25	4.5	1.25						9.0
NRC Review Charges	0.75	1.0	0.25						6.0
Technical Support	2.25	3.0	0.75						2.0
Totals, $M	54.75	52.9	45.0	38.6	40.4	26.6	16.4	6.8	281.3

Figure K-6, Total Cost Schedule for R&D and Licensing Activities.