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NGNP and Hydrogen Production Preconceptual Design Report

EXECUTIVE SUMMARY REPORT

Revision 1

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I NGNP BACKGROUND

Over the past decade, the US has cooperated with other countries in the development of advanced nuclear energy systems that are envisioned to follow the Advanced Light Water Reactor (ALWR) systems that are now leading the resurgence of nuclear power. These advanced non-ALWR systems have been coined "Generation IV" (Gen IV) concepts. An international forum of these countries and a framework for cooperation have been established – the Generation IV International Forum (GIF).

The GIF model envisions that individual countries will take the lead for developing and demonstrating Gen IV nuclear systems in which they have particular interests, and that other countries will provide support through implementing agreements. The first of such implementing agreements have been recently signed. Early in the process, the US took the lead for developing the High Temperature Gas-Cooled Reactor (HTGR) – also referred to as the Very High Temperature Reactor (VHTR) within the GIF forum.

The HTGR technology offers enhanced safety features based on inherent material properties and passive design features, plus improved reliability, proliferation resistance, security and waste management capabilities. Further, the HTGR is evaluated to be competitive for a broad range of applications, including small-to-medium high efficiency power generation that is well suited for dry cooling, cogeneration and water desalination, plus unique high temperature process heat applications such as bulk hydrogen production. High pressure steam, well beyond the temperatures available with water reactor systems, can also be provided to displace natural gas for enhanced oil recovery and tar sands production - all without greenhouse gas emissions. Accordingly, HTGR plants can promote the utilization of indigenous coal and uranium resources and extend domestic oil and gas resources, thereby reducing dependence and costs associated with imported oil and natural gas.

Within the US, the Department of Energy (DOE) has focused the development of the HTGR technology through the Next Generation Nuclear Plant (NGNP) Demonstration Project which is the dominant part of the US Gen IV Program. From the start, the NGNP Project was centered at the Idaho National Laboratory (INL) and, initially, the goals were set for at least 1000ºC core outlet temperatures to drive Brayton cycle gas turbines and/or water splitting processes for the production of hydrogen.

Relatedly, in the 2003 State of the Union Address, President Bush launched a new National Hydrogen Fuel Initiative to provide domestically produced, clean-burning hydrogen to the transportation sector as an alternative to imported oil.

The NGNP Project was subjected to a critical review by a group of experts known as the Independent Technology Review Group (ITRG) over the period November 2003 through April 2004. The objective was to provide a critical review of the proposed NGNP Project and to identify areas of R&D that needed attention. In the report, the ITRG observations and recommendations focused on overall design features and important technology uncertainties. A key recommendation was to reduce the core outlet temperature to the range of 900 to 950ºC and, hence, reduce the technology uncertainties to achieve a more timely deployment plan.

Energy Policy Act of 2005

In July of 2005, Congress passed the Energy Policy Act of 2005, which was signed into law by President Bush in August of 2005. Under Section 641, the Act states, "The Secretary shall establish a project to be known as the Next Generation Nuclear Plant Project." Guidelines for the NGNP Project designate that it shall be sited at INL and shall provide the capability for hydrogen production and/or electricity generation, using advanced technologies based on Generation IV concepts. INL was identified as the lead National Laboratory and directed to organize a consortium of industrial partners that would participate in the development of the NGNP and share in its cost, consistent with their roles in the Project. Major project elements were identified, including high-temperature hydrogen production, energy conversion technology, nuclear fuel, and materials, plus design of the reactor and the other elements of the plant.

Two phases were identified in the Act for the NGNP Project. The objectives identified for the first phase were:

- Select the technology
- Carry out research
- Determine whether it is appropriate to combine electricity generation and hydrogen production in a single demonstration plant
- Conduct initial demonstration plant design

During the second phase, a final design will be selected through a competitive process and the plant will be constructed, licensed and operated.

The Act calls for the maximum technical interchange and transfer of technologies and ideas into the Project, including the nuclear power industry, the chemical processing industry and relevant international efforts. With regard to the latter, the Act directs that the Secretary shall seek international cooperation, participation and financial contribution for the Project. For example, INL may contract for assistance from specialists or facilities from member countries of the GIF or other countries as deemed cost effective.

With regard to licensing, the NRC shall have such authority and, by August 2008, the Secretary and the Chairman of the NRC shall jointly submit to Congress a licensing strategy for the Project which will include:

- A description of ways in which current requirements relating to LWRs need to be adapted for the specific nuclear technology of the Project
- A description of the analytical tools that the NRC will have to develop to independently verify design and performance characteristics of components, equipment, systems or structures associated with the Project
- Other R&D activities that may be required by the NRC in order to review a license application for the Project
- An estimate of the budgetary requirements associated with the licensing strategy

The Secretary shall seek the active participation of the NRC throughout the duration of the Project.

With regard to funding, the Act authorizes $1.25B for the period of fiscal years 2006 through 2015, and such sums as are necessary for each of fiscal years 2016 through 2021.

Overall Project Objectives

As presented in the Energy Policy Act of 2005, there is a national strategic need to foster further reliance on safe, clean, economical nuclear energy. The combination of these strategic objectives and the objectives of the National Hydrogen Fuel Initiative are uniquely supported with the NGNP Project. More broadly, the Project will enable the expanded use of nuclear energy as a greenhouse gas-free option for a broad range of process heat applications, including the production of hydrogen, thereby supporting DOE’s broad strategic objectives for a diverse supply of clean energy options.

Accordingly, the primary objectives of the NGNP are to develop and demonstrate design, performance, operational, licensing and economic viability of HTGR and leading process heat technologies and, thereby, to support timely commercialization. Key near-term tradeoffs address:

- Balancing performance objectives, development risk and schedule for commercialization
- Assessing alternatives in design concepts to minimize development risks
- Establishing a reference commercial configuration for NGNP development and licensing

To realize such, the Project must demonstrate the commercial potential of the HTGR and the related technologies, establish the commercial vendor/owner/user infrastructure, and support the timely Design Certification by the NRC such that successful commercialization is assured. Toward that end, a public/private partnership is being formed to focus the development and deployment of the NGNP. The partners are DOE and an evolving NGNP Alliance of end-users, vendors and other private stakeholders. A cost/risk sharing model between the DOE and industry will assure a new commercialization phase for nuclear energy for production of process heat and bulk hydrogen - without carbon emissions.

II BASIS FOR PRECONCEPTUAL DESIGN

In July 2006, DOE/INL issued a Request for Proposal (RFP) for Preconceptual Design and Engineering Services for the NGNP Project. The RFP was the culmination of planning and preparation conducted by the INL management team to establish high-level functions and requirements for the Project and a preliminary Project Management Plan.

Consistent with Energy Policy Act requirements for the first phase of the NGNP Project, the following key objectives were specified for the preconceptual design:

- Assist in focusing the technical scope and priorities for research and development activities for the NGNP.
- Provide a basis for subsequent development of the technical and functional specifications for the facilities for the NGNP.

The Statement of Work (SOW) specified in the RFP provided for an initial series of "Special Studies" that would address fundamental issues and tradeoffs. The following were specifically noted:

- Reactor Type (Pebble/Prism)
- Power Level and Key Operating Parameters
- Process Heat Transfer and Transport
- Power Conversion Concept
- Licensing Strategy
- Hydrogen Production

Based on the results of the Special Studies, a Preconceptual Design was to be developed to establish the basic geometry, layout and operating parameters of a single module NGNP demonstration plant that represents the optimal basis for serving as a "commercial scale prototype reactor" for electrical power generation, optimal hydrogen production and other industry applications of high-temperature process heat. The resulting design was to be documented in a Preconceptual Design Report (PCDR) that was outlined in the RFP.

Initial plant-level assessments of the resulting Preconceptual Design were specified, such as availability, maintainability, etc. Assessments of complexity and risk were also identified for inclusion.

A further emphasis of the SOW was the identification of R&D requirements and the associated schedule and cost requirements for the corresponding R&D program. A licensing assessment was identified to consider options for licensing a first-of-a-kind Generation IV advanced reactor in the U.S.

Based on the above, a schedule was to be developed for the design, construction, licensing and initial operation of the NGNP, plus the supporting R&D activities. Cost estimating requirements included design, licensing, R&D, equipment, construction, startup and operating costs. The cost estimating activity was also to include a lifecycle analysis of the economic viability of corresponding commercial plants.

Finally, the SOW requested inputs supporting the definition of follow-on development phases. Of particular note in this regard were:

- Proposed scope, schedule and cost for Conceptual Design
- Initial definition of the supporting R&D program, including schedule and cost

III APPROACH

In response to the RFP, three competing vendor teams submitted proposals, which have resulted subsequently in three contracts with INL for preconceptual design and engineering services for the NGNP Project. The first and primary contract was awarded to the Westinghouse NGNP Team on September 29, 2006. This Team builds upon the Westinghouse equity position with the Pebble Bed Modular Reactor (Pty) Ltd. that is underway with the deployment of the Pebble Bed Modular Reactor (PBMR) version of the HTGR concept in South Africa. This report and a companion Special Studies Report are the resultant products from this initial contract with the Westinghouse NGNP Team.

In addition to Westinghouse, the Team consists of Pebble Bed Modular Reactor (Pty) Ltd. and M-Tech Industrial (Pty) Ltd., both of South Africa; The Shaw Group (Shaw); Technology Insights; Air Products and Chemicals, Inc.; Nuclear Fuel Services, and Kadak Associates. The Team members have substantial experience and expertise in all of the areas to execute not only the preconceptual engineering services for the NGNP, but also to serve as the core Team to implement the Project through to detailed design, licensing, construction, startup and operations – with the commitment to follow-on commercialization.

PBMR Baseline for NGNP Success

The proposed PBMR-based NGNP builds upon the substantial and ongoing design, technology and licensing development plus related facility investments to build a PBMR Demonstration Power Plant (DPP) in South Africa – designated a National Strategic Project by the South African Government. The PBMR DPP is a 400 MWt / 165 MWe all-electric plant that utilizes the advanced Brayton power cycle. To date, over $500 million have been invested in the design, technology and related fuel and test facilities to advance the PBMR DPP. Approximately 700 full-time equivalent staff are currently engaged in South Africa and approximately 1200 people total are working on the PBMR DPP Project worldwide.

Long-lead component manufacturing is underway, start of construction is scheduled for early 2009 and commercial operation in 2014. Figure ES-1 through Figure ES-4 highlight the design concept, major components in manufacturing and the related fuel and test facilities. Note that the PBMR fuel manufacturing facility will be able to supply the initial core and early reloads for the NGNP and hence eliminate otherwise major costs and risks to the NGNP Project. The fuel supply strategy is elaborated in PCDR Section 5. Likewise the PBMR test facilities are elaborated in Section 16.

Figure ES-1: Rendering of PBMR DPP – National Strategic Project in South Africa

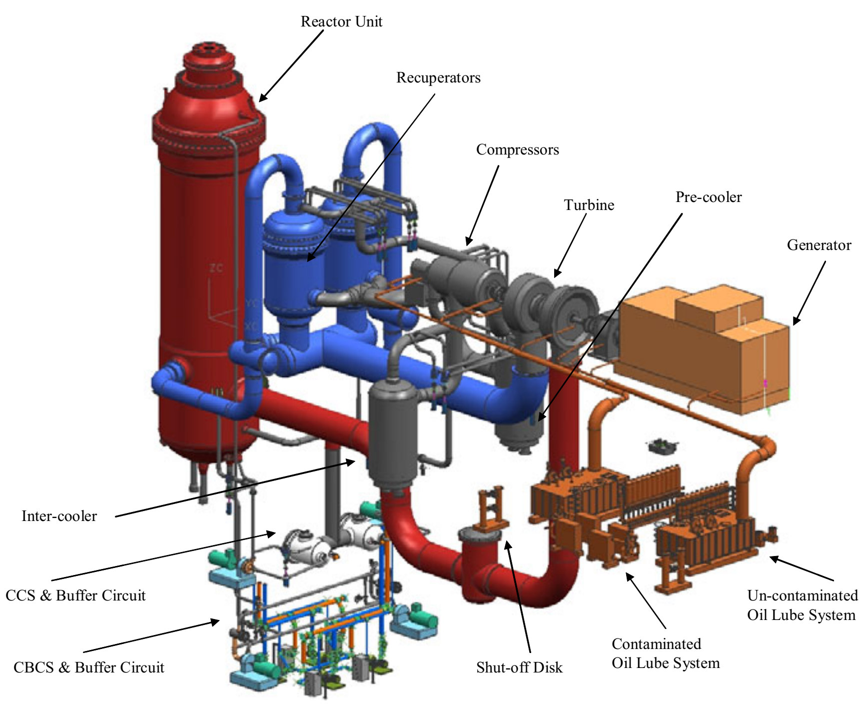

Figure ES-2: Cutaway of Main Power System for PBMR DPP

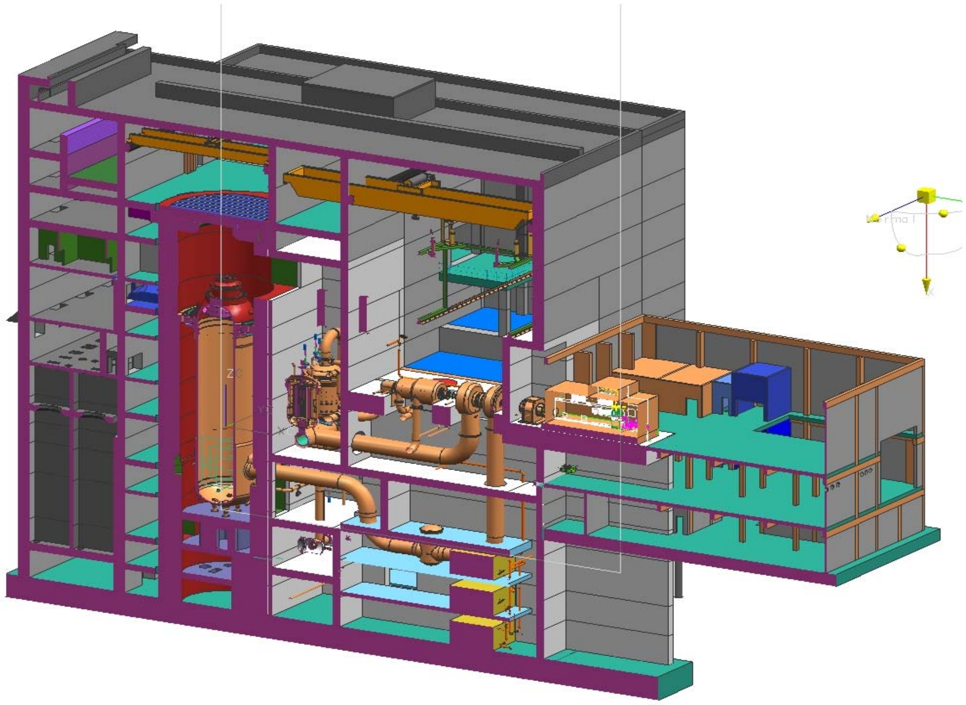

Figure ES-3: PBMR DPP Building Cutaway

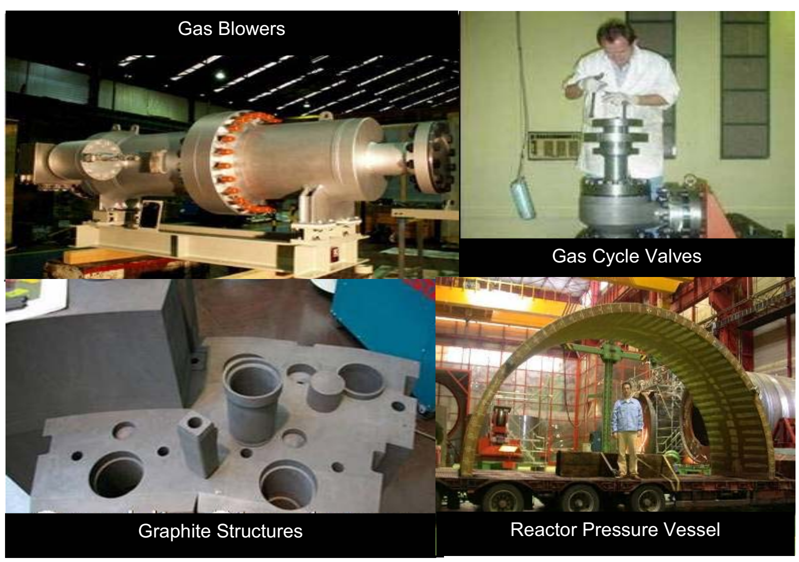

Figure ES-4: PBMR DPP Long-Lead Components in Manufacturing

Eskom, the State utility in South Africa, selected the PBMR technology based on the proven experience with pebble bed reactors in Germany, particularly the superior pebble bed-based fuel performance experience, plus the baseline of common HTGR technology developed in the US, Japan and elsewhere. Eskom has signed a letter-of-intent to deploy an initial capacity of follow-on, multi-module commercial PBMR power plants representing a backlog of at least 24 modules.

As elaborated in the related sections of this report, the proposed PBMR-based NGNP concept adapts the PBMR DPP reactor and fuel designs, with minimal incremental development and testing costs. Additionally, the systems, materials and component designs used in the PBMR DPP have been chosen based on proven operating experience from prior gas-cooled reactors and light water reactors. This approach reduces the technical and commercial risks to the PBMR DPP project, and is directly translatable to benefit the NGNP Project. This knowledge and experience has been factored into the preconceptual design for the PBMR based NGNP. On the other hand, advanced materials and component R&D programs required for the PBMR NGNP have been addressed herein.

Another key PBMR baseline to build upon for NGNP success is the ongoing PBMR Design Certification Pre-Application Program with the NRC, as elaborated in the Licensing section. In addition, a US-based PBMR team has been developing preconceptual designs and performing economic evaluations of various process heat applications with the PBMR technology. These applications have been developed with potential end-users as a basis for moving forward with further project feasibility assessments and serve as potential commercial follow-on projects or fall-back options to the NGNP.

Building upon the PBMR DPP reactor and fuel experience along with the US base of vendor/supplier Team members plus the Pre-application Program and other project initiatives offers a compelling opportunity for the US, South Africa and others to deploy a PBMR-based NGNP for the least costs and risks, plus an assured commercial outcome. The Westinghouse Team is proud to present the PCDR and is ready, capable and committed to proceed with the Path Forward for the PBMR-based NGNP.

IV KEY ASSUMPTIONS

Each of the PCDR design and assessment sections lists the related assumptions as a means of tracking and future reference. Key generic assumptions that apply to the institutional and programmatic arrangements for the NGNP Project are consolidated below as part of this Introduction:

- A NGNP Alliance is established to consolidate the User stakeholder interests and support.
- A Public (DOE led) / Private (Alliance led) Partnership (PPP) entity is the Project Manager and Applicant.
- DOE owns the NGNP plant and receives offsetting revenues from the sale of power, hydrogen, and oxygen.
- INL provides staff support to the PPP, including the coordination of US Laboratory based R&D.
- NRC licenses the plant and conducts selected R&D needed to independently verify the safety performance of the design.
- A PPP selected vendor team provides the full scope of plant design, delivery and startup, plus fuel supply and services.
- The vendor team concurrently advances follow-on commercial projects with User clients.
- A PPP selected commercial based nuclear operator operates the plant.
- The NGNP will serve a long-term mission to demonstrate multiple advanced hydrogen production technologies, plus serve as a test bed for advanced fuels, materials, components, etc.

Likewise, key assumptions that are PBMR-specific for the NGNP Project are consolidated below:

- The Reactor Facility is the first unit outside South Africa and has full advantage of the PBMR DPP experience. In particular, the Reactor and Fuel related design and R&D are incremental to the PBMR DPP effort.
- The Heat Transport System, including the IHX and helium circulators, is the first-of-a-kind full scale demonstration unit.
- The Hydrogen Production Facility is the first-of-a-kind commercial size train unit.

- The initial core and reload fuel for the first 6 years is provided by Pebble Bed Modular Reactor (Pty) Ltd.'s pilot fuel plant in South Africa.
- Reload fuel thereafter will be provided by a commercial fuel plant in the US established by PBMR (Pty) Ltd., Westinghouse and NFS as the PBMR market expands in the US.

V SPECIAL STUDIES

The documentation of the NGNP preconceptual design performed by the Westinghouse PBMR Team consists of the Special Study Reports, the Preconceptual Design Report (PCDR), and this Executive Summary Report.

The first segment of the NGNP preconceptual design effort centered on six Special Studies:

- A comparative evaluation of the pebble and prismatic core – based on high temperature process heat delivery capability,
- A power level trade study to select the PBMR-PHP core output rating,
- A heat transport trade study to select the configuration for coupling the reactor system with the preferred hydrogen production system and the preferred power conversion system,
- A power conversion system study,
- A licensing and permitting strategy study, and
- A hydrogen demonstration sizing study that also evaluated the by-products and effluents.

It is noted that the heat transport special study combined the prescribed "20.3 High Temperature Process Heat, Transfer and Transport Study" with the "20.5 Primary and Secondary Cycle Concept Study" in the SOW. Per agreement with INL, the logic was that it was inefficient and very difficult to separate the topics of primary and secondary cycles from the special study on transfer of the nuclear reactor heat to the hydrogen production and electricity generation systems.

V.A REACTOR TYPE COMPARISON

The objective of this special study was to provide a comparative assessment of the relative merits of the pebble and prismatic modular HTGR core designs. Both fundamentals and design specifics were addressed with the latter based on process heat delivery at 950ºC.

The fundamental differences between the pebble and prismatic fuel designs can be grouped into those related to fuel-graphite geometry in the fuel elements, the fuel element-coolant geometry, core refueling, and equilibrium core conditions. The major fundamental differences between the pebble and the prismatic cores can be summarized as follows.

- The pebble core has a higher outlet temperature for a given normal operation maximum fuel temperature limit. Although there is a lower power density within the fueled region of the fuel element, there is lower resistance for heat transfer from the fuel to the fuel element surface, and greater heat transfer from the fuel element surface to the coolant.
- Because of its lower coolant volume, the prismatic core can achieve greater power within a given core volume and geometry, for a given fuel element (solid) power density, and a given Depressurized Loss of Forced Cooling (DLOFC) maximum fuel temperature limit.
- The pebble core can be taller than the prismatic core because it is not as limited by axial neutronic stability.
- Because of greater coolant mixing in the pebble core, hot streaks downstream from the core are a non-issue versus a major issue for the prismatic – particularly for core outlet mean temperatures greater than 900ºC.
- Because the pebble core has a higher resistance to flow, it requires a relatively larger circulator/compressor.
- The pebble core on-line refueling offers the basis for a higher capacity factor and simplifies fuel manufacturing, reload complexity, and quality assurance, plus it is compatible with continuous process heat applications.

For process heat applications and specifically for hydrogen production, reactor designs are optimized that take advantage of the above fundamentals of the fuel technology. There are significant differences in selections made for the pebble and prismatic reference process heat designs. These include reactor dimensions and power level, reactor operating parameters, fuel and structural (core barrel and reactor vessel) materials, and fuel maximum temperature limits. Specific differences between the pebble core-based PBMR Process Heat Plant (PBMR PHP) and the prismatic core-based Modular Helium Reactor for Hydrogen production (H2-MHR) are illustrated in Table ES-1. As an example of the first factor above, the pebble core has a power level of 500 MWt as opposed to 600 MWt for the prismatic core. Although the core outlet temperatures specified for both systems are identical (950^0C), both the core inlet temperatures and helium pressure are different. The fuel materials for the two systems are different - fissile UO_2 for the pebble versus fissile/fertile UCO for the prismatic. Another significant difference in the designs is that different maximum fuel temperature limits, both for normal operation and for DLOFC events, have been selected. Any comparison of specific reference designs is strongly influenced both by the pebble/prismatic fundamental differences discussed earlier and the vendor-specific design selections themselves.

Table ES-1: Reference Process Heat Design Selections

Parameter	PBMR PHP	H2-MHR
Inner/outer active core diameter (m)	2.0/3.7	2.96/4.83
Active core effective height (m)	11.0	7.93
Fueled region power density (w/cc)	16.9	32
Fuel element (solid) power density (w/cc)	9.8	8.3
Core power density (w/cc)	6.0	6.6
Core inlet/outlet coolant temperature (^oC)	350/950	590/950
Normal operation max. fuel temp. (^oC)	~1150	1250-1350
Off-normal max. fuel temperature (^oC)	~1670	<1600
Module power rating (MWt)	500	600
Primary He coolant inlet pressure (MPa)	9.0	7.1
Primary He flow rate (kg/s)	160	320
Core pressure drop (KPa)	202	58
Fuel composition	UO_2	UCO
Fuel enrichment (%)	5.0 startup 9.6 equilibrium	19.8 fissile 14.5 avg with fertile
Fuel burnup (GWd/mt U)	90	120

The comparison of the merits of these pebble and prismatic reference process heat designs requires that the designs be compared on the basis of specific and relevant discriminating criteria. The following criteria and their relative weight (WEIGHT) were selected:

- Readiness
  - Design maturity and limited enabling technology R&D required (HIGH)
  - Vendor/supplier infrastructure (MEDIUM)
- Performance
  - Process heat delivery (HIGH)
  - Capacity factor/investment protection (MEDIUM)
  - Public safety (HIGH)
  - Safeguards (MEDIUM)
  - Wastes and other environmental impact minimization (MEDIUM)
  - Cost competitiveness (HIGH)

- Enhancement Potential
  - Fuel cycle flexibility and enhancement opportunities (LOW)

The results of the comparison against these discriminating criteria led to the following conclusions:

- The pebble fuel PBMR PHP has a clear advantage over the prismatic block H2-MHR relative to R&D needs for fuel because of the German experience with UO2 fuels in the AVR and THTR and because of the pebble's fundamental lower normal fuel operation temperatures. DPP experience, especially the selection of LWR reactor vessel steels and other code-qualified materials, also results in much reduced R&D needs for the PBMR PHP.
- The advantage for process heat delivery also goes to the PBMR PHP because of the much lower risk for achieving the desired very high core outlet temperature (950^0C). Capacity factor for the PBMR PHP should also be superior to that for the H2-MHR because of on-line refueling. Safety in terms of potential radionuclide releases should also be better for the PBMR PHP because of the demonstrated superior performance of the fuel and its lower normal temperature of operation.
- The estimated unit capital cost for mature, multi-module plants is lower for the H2-MHR than for the PBMR PHP given identical assumptions. This is primarily because of the lower power level of the latter. However, resultant process heat or H2 costs should be lower for the PBMR PHP because of its higher capacity factor, simpler fuel cycle and lower O&M costs. Altogether, the PBMR PHP is competitive with the H2 MHR concept at much lower overall risks.

The evaluation of the PBMR PHP relative to the H2-MHR in terms of the discriminating criteria illustrates that for all of the discriminating criteria the PBMR PHP is better than or comparable to the H2-MHR.

In summary, pebble core technology offers many fundamental advantages over the prismatic core for high temperature process heat applications and adapts well qualified and demonstrated German-based fuel and on-line refueling experience. The PBMR PHP is superior in essentially all respects to the H2-MHR for the high temperature process heat/H_2 production NGNP. This is true primarily because of lower development costs and risks for the pebble fuel, minimization of development costs and risks because of the DPP baseline, a much stronger vendor/supplier infrastructure, and a higher performance capability. Lower fuel temperatures and normal operation radionuclide releases result for the same required process heat temperature and on-line refueling is consistent with continuous process industries. Finally, the PBMR PHP is attainable at lower overall forward costs and risks.

V.B PROTOTYPE POWER LEVEL

The prototype power level special study provides results for the recommended power level for the NGNP plant with a pebble bed high-temperature reactor.

The NGNP Project vision and mission is to launch commercial deployment of a worthy HTGR product(s). To achieve this mission, the Project must demonstrate key licensing, performance, economic and industrial infrastructure development objectives using a mature technology reference as the base. The shortcomings of achieving this mission with a small-scale NGNP test reactor (approximately 25-50 MWt) are the following.

The proposed Licensing Strategy of the PBMR-based NGNP seeks to apply Part 52 rules to demonstrate the one-step licensing process. This strategy builds upon the PBMR-DPP reactor design, licensing and deployment experience, plus it seeks the value for demonstrating such in support of early design certification for follow-on commercial projects. A small-scale NGNP test reactor would do little to advance these objectives.

Likewise, achieving the performance demonstration objectives of the NGNP is critical for commercial acceptance and requires a commercial-scale or scaleable reactor.

Economic objectives include minimizing the front-end development costs and risks as well as the product costs for the NGNP and particularly for the follow-on commercial plants. For the PBMR, a small-scale NGNP test reactor would forego the benefits of building on the PBMR-DPP development investment in exchange for the expected lower capital costs of the plant. Worse yet, the one-of-a-kind design development costs for a small-scale NGNP test reactor would have limited transfer value to any commercial design, and expected higher net costs.

Since four reactors of block and pebble fuel types have been built in the past, the foundation of basic performance, safety and operational issues derived from small reactors is well proven.

With regard to industrial infrastructure development objectives, a small-scale NGNP test reactor would be a resource distraction. Broad industry and government efforts are underway to form a utility and end-user-based NGNP Alliance as the private partner in a public/private partnership with DOE for deploying a commercial-scale NGNP. Such efforts are incompatible with a small-scale NGNP test reactor.

A small-scale (25-50 MWt) NGNP test reactor has little value for advancing the objectives of the NGNP, particularly for the PBMR-based NGNP. Therefore the Westinghouse Team recommends a commercial scale reactor.

Given the advanced state of the PBMR DPP in South Africa in terms of design, technology, licensing, project and infrastructure development, the strong recommendation of this power level study for a pebble bed-based NGNP is to build upon the PBMR 400 MWt reactor design as the most appropriate baseline for the NGNP design. The PBMR project in South Africa will demonstrate an advanced Brayton cycle for all electric applications. The PBMR-based NGNP will demonstrate the commercial scale PBMR PHP design at a 950ºC Reactor Outlet Temperature (ROT) targeted to support hydrogen production applications. Hence, the objective of this special study was to establish the appropriate power level for a commercial-scale PBMR-PHP for the NGNP in terms of whether it should be larger or smaller than the reference 400 MWt design.

The major design parameter difference between the proposed NGNP and PBMR DPP is the difference between the Reactor Inlet Temperature (RIT) and the reactor outlet temperature (ROT), i.e., 350°C/950°C for NGNP versus 500°C/900ºC for the PBMR DPP. The full range of energy of the reactor is utilized by process heat applications on the top end and by power generation applications on the lower end respectively. It is important to note that in the approach to determine the NGNP power level the German fuel envelope of burnup-fluence-temperature and the limitation of having the maximum fuel temperature lower than 1250°C during normal operation are still assumed. The aim is to perform limited R&D and design development for the NGNP to minimize impact on schedule.

The different options were evaluated according to discriminating criteria to determine the most suitable option. Readiness, Performance during off design conditions and Capital Cost carried the most weight in the evaluation.

Based on the analyzed cases a power level of 500 MWt was proposed for the conceptual design of the NGNP. The required R&D anticipated is limited to the qualification of the fuel performance for Depressurized Loss of Forced Cooling (DLOFC) operation up to 1700°C by the time of plant construction. Further it is suggested to keep the geometry similar to the PBMR-DPP after careful consideration of the following motivating factors:

- The PBMR-DPP reactor can be immediately used as the basis for NGNP design - within the operational envelope of the PBMR- DPP.
- The NGNP schedule will be met - minimal R&D required.
- Minimal design development required.
- A 25 percent higher power output is achievable for the NGNP reactor, without increasing the capital cost for the reactor and auxiliary systems and building from the base PBMR design.

In conclusion, a 500 MWt reactor with a core inlet temperature of 350ºC and a core outlet temperature of 950ºC utilizing the PBMR-DPP geometry is recommended for the NGNP design and the follow-on commercial application.

V.C HIGH TEMPERATURE PROCESS HEAT TRANSFER AND TRANSPORT

The objective of this study was to select a reference configuration for the NGNP Heat Transport System (HTS). The selection of a reference HTS configuration is, by necessity, accomplished in close coordination with the NGNP special studies addressing the Power Conversion System (PCS) and Hydrogen Production System (HPS). The PCS options to be considered in conjunction with the HPS and the minimum size and range of potential sizes of the HPS itself are obtained from companion NGNP special studies.

This special study includes two important sub-studies that have a significant bearing on HTS configuration options. The first is an evaluation of prospective Secondary Heat Transport System (SHTS) working fluids. The second is a specific evaluation of design and materials readiness for the IHX, a key HTS component. Note that the process coupling heat exchanger (PCHX), which transfers thermal energy to the PCS, is common to all HTS configuration options and, as such, is not directly assessed in this special study.

SHTS Working Fluid Options

The conclusion of this evaluation was that helium should be selected as the SHTS working fluid for the NGNP and that the PCHX should be located as close to the IHX as possible. If future demonstration of liquid salt (LS) thermal energy transport in the NGNP environment is desired, an option is to replace the PCHX with a secondary IHX and to add a tertiary LS loop to transport energy to a more distant location.

IHX Readiness Assessment

Both conventional shell-and-tube and compact heat exchangers were considered in this assessment. Taking into account design tradeoffs, the Printed Circuit Heat Exchanger (PCHE) has been selected on a preliminary basis for the NGNP IHX pre-conceptual design. The shell and tube HX was eliminated as not being commercially viable for a large IHX. Tradeoffs include: (1) More difficult inspection and maintenance, and (2) The need to establish design basis for Code acceptance. The assessment concludes the following:

- The reactor outlet temperature for the NGNP should not exceed 950ºC, based in part on IHX materials considerations.
- As a result of this assessment, it is concluded that non-replaceable metallic

components designed for the full plant lifetime (60 years) should be limited to ~850ºC versus 900ºC, as earlier recommended by the ITRG. Metallic components operating at temperatures higher than ~850ºC, notably including high-temperature sections of the IHX, are likely to have reduced lifetimes and should be designed for replacement.

- For configuration options with all of the reactor heat transferred through the IHX, a Two-Section IHX concept is proposed in which the sections operating at the highest temperatures are separated from those operating at lower temperatures (Figure ES-5).
- A metallic plate-type HX development program should be pursued for the NGNP IHX in conjunction with an appropriate design and materials development program. Other compact heat exchanger designs (e.g., plate-fin) should be given further consideration in follow-on design efforts.
- Alloys 617 or 230 are recommended for IHX construction depending on the stress and creep requirements of the design.
- NGNP-specific code cases should be developed to provide an ASME design and fabrication material basis for the NGNP IHX.
- While ceramic materials hold significant future promise, their selection for the initial NGNP IHX would pose an unacceptable risk to the NGNP schedule. Nevertheless, their potential for resolving the high-temperature issues associated with metals justifies an aggressive parallel development path.

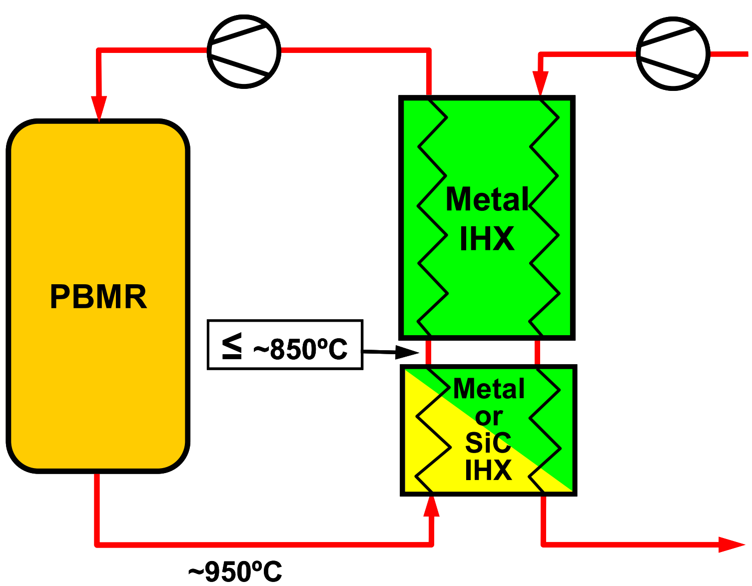

Figure ES-5: Two-Section IHX Concept

A range of HTS configurations were evaluated as candidates for the NGNP preconceptual design. The HTS options can be generally categorized in terms of the integration of the PCS relative to the primary coolant circuit and the process coupling. The application of a full-size IHX best represents and supports commercial designs, and provides the optimum basis for licensing/design certification of the nuclear heat source for commercial process heat applications. As a result of this evaluation, it is recommended that an indirect cycle be selected with a secondary heat transport system transferring the heat to a Process Coupling Heat Exchanger (PCHX) for hydrogen production and a bottoming Rankine cycle for electricity generation, as shown in Figure ES-6. The process heat application requires an IHX that has high temperature material challenges that could be aggravated by pressure swings that are inherent in the control of a Brayton cycle, whether on the primary or secondary side of the IHX. This is a key reason for the selection of the Rankine steam cycle after the high temperature heat is utilized by the HPS.

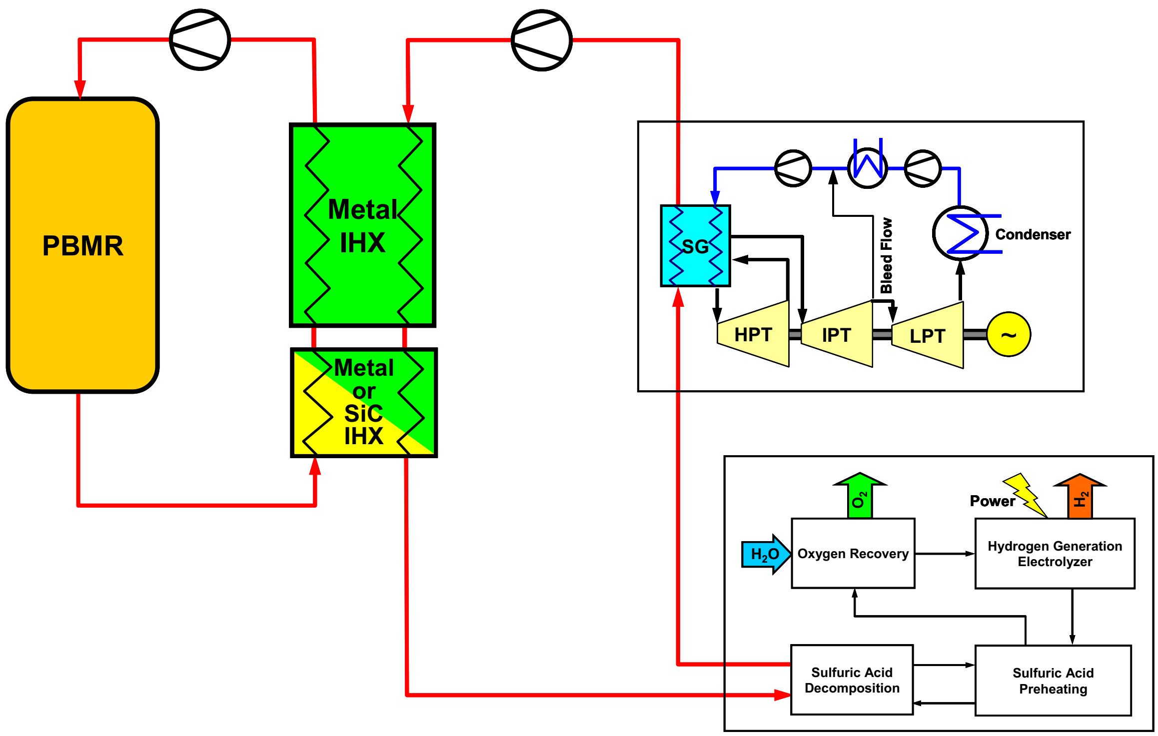

Figure ES-6: Recommended HTS Configuration

V.D POWER CONVERSION SYSTEM

The objective of this special study was to compare thermodynamic cycle configurations to identify representative Brayton, Combined and Rankine cycles for the NGNP. The most promising Brayton cycles, Gas-Turbine Combined Cycles (GTCCs) and Rankine cycles were analyzed and compared with respect to thermodynamic performance and practical considerations when employed in conjunction with the PBMR. A representative cycle was chosen for each group of cycle configurations.

For the Brayton cycle configurations, this study shows that a single-shaft cycle with inter-cooling would be the best option in terms of net cycle efficiency and turbo-unit size. The representative Brayton cycle selected, shown in Figure ES-7, has optimum net cycle efficiency and is achieved at an overall pressure ratio of approximately 3.2.

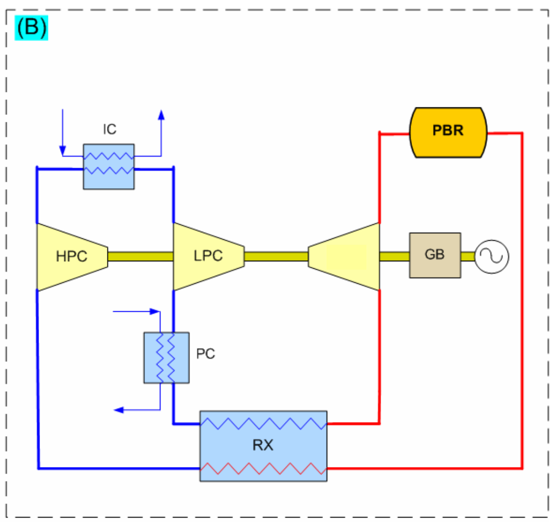

Figure ES-7: Representative Brayton Cycle

For the GTCCs, a single-shaft recuperative Brayton cycle without inter-cooling was found to be the most suitable cycle configuration. Although the cycle does not have the highest net cycle efficiency of the GTCCs under investigation, the turbomachine employed by the cycle builds on the PBMR DPP design. The cycle shown by Figure ES-8 was therefore chosen as the representative GTCC on the basis of readiness of technology.

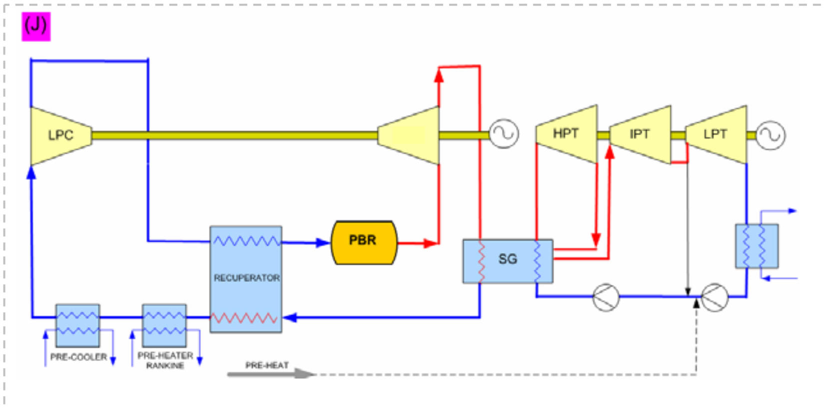

Figure ES-8: Representative GTCC

A single conventional Rankine cycle coupled to a PBMR through a steam generator was chosen as the representative Rankine cycle (Figure ES-9). The representative Rankine configuration uses proven Rankine cycle technology and has a net cycle efficiency of about 36%.

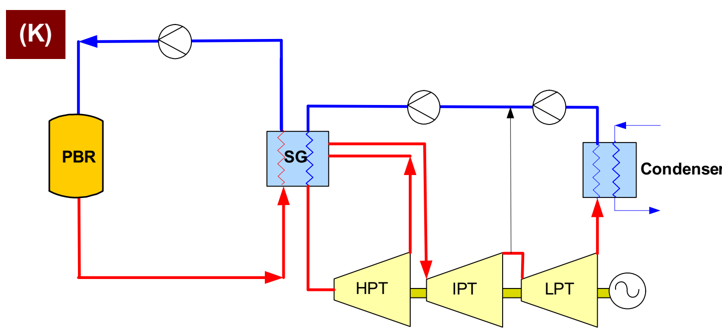

Figure ES-9: Representative Rankine Cycle

The influence of a direct versus indirect Power Conversion System (PCS) was also investigated for each group of cycle configurations. As expected, it was indicated that the net cycle efficiency of the cycles in each group decreases for an indirect configuration.

The influence of the coupling configuration of the HPS with the PCS, as well as the size of the hydrogen production plant, was also considered. The sensitivity of cycle efficiency to the hydrogen plant size was compared for Brayton and Rankine cycles. It was found that the net cycle efficiency of the representative Rankine cycle is not as sensitive to the coupling configuration and hydrogen production plant size as the representative Brayton cycle.

Finally, the design point parameters for the representative cycle configurations are presented together with a diagram showing the major components of each cycle.

V.E NGNP LICENSING AND PERMITTING STUDY

This special study addressed specific tasks related to NGNP licensing given in the Statement of Work. Pertinent NRC regulations and the corresponding industry experience were reviewed and recommendations made. The key recommendations from this study are:

- Build on Pebble Bed Modular Reactor (Pty) Ltd.'s pre-application interactions with the NRC, which are based on risk-informed, performance-based licensing methods,
- Adopt an NGNP licensing strategy, based on Part 52, to obtain an Early Site Permit with an embedded Limited Work Authorization followed by a Combined License. Maintain a Part 50 fallback strategy for a two-step license pending the success of the pre-application interactions.
- Use License-By-Test as warranted by expected benefits to achieve timely full-power operation of the NGNP, and Design Certification for the Commercial plant.
- Establish and demonstrate the licensing requirements commensurate with the chosen hydrogen production design(s) reflecting separation distance and facility interactions stemming from such design(s).

EPA, state and local permitting are not expected to present any significant licensing impediment for the NGNP.

It is also recommended that: (1) NRC progress on licensing rulemakings (i.e., Part 50, Part 52) be followed and results incorporated into the NGNP Licensing Strategy, (2) licensing research and development needs specific to the NGNP safety analysis evaluation models be identified as the basic design is developed and (3) the "site selection" report for the New Production Reactor site at INL be reviewed to identify any limiting environmental conditions.

The above recommendations and the actions identified are inputs to this area in the PCDR, whose major objective is the development and recommendation of an overall licensing strategy for the NGNP, including approximate cost estimates and schedule impacts. This approach will support development and receipt of a Design Certification for follow-on commercial plants due to the valuable precedents established in the NGNP licensing.

V.F HYDROGEN DEMO PROCESS SIZING, BY-PRODUCTS AND EFFLUENTS STUDY

This study identified and quantified the products, by-products and waste streams produced by the NGNP facilities and identified potential markets or other disposition of these streams. Quantification as well as characterization of these streams is necessary to identify markets or proper disposal. Therefore, the capacity of the hydrogen production facility must be estimated to quantify products and waste streams.

The hydrogen production facility is intended to be a commercial demonstration and must therefore meet all the appropriate requirements for such an installation. This study enumerates these requirements, determines the smallest practical size that could be considered for such a plant, and considers an option of making the demonstration a full-scale commercial train. These options are considered for each of the leading water-splitting technologies: High-Temperature Steam Electrolysis (HTSE), the Hybrid Sulfur (HyS) thermo-electrical cycle and the Sulfur-Iodine (S-I) thermo-chemical cycle.

Once the hydrogen and oxygen capacities are identified, potential markets for these gases as well as the power generated are surveyed and potential revenue streams estimated. In addition, industrial gas markets depend upon the purity of the products produced. Achieving the required purity generally requires further processing. Additional purification processing of the products is therefore identified for each of the products and water-splitting technologies. Furthermore, this additional processing usually produces additional waste streams that may not be evident from the main process mass balances.

The PBMR, hydrogen production and product purification generate wastes that must be disposed of properly. This study finally examined the nature, quantity and disposal options for these streams.

This study makes recommendations in those cases for which it is possible at this early stage of design development. In several other cases, firm recommendations are not advisable. The study recommendations are shown below:

1. The size of the NGNP Hydrogen Production Facility should be a full commercial train. The capacity of this train has been determined based on a full commercial size PCHX. An appropriate size was estimated to have a thermal duty of 50 MW.
2. A local market for the product hydrogen must be developed. A fleet of buses using hydrogen in internal combustion engines should be investigated, and a clear product

specification for this market should be developed.

3. Feed pre-treatment, product purification, waste treatment and disposal should be included in the Hydrogen Production Facility conceptual design.
4. Focus research and development by selecting a preferred NGNP water-splitting technology by the beginning of the NGNP Conceptual Design Phase and executing a process design for the hydrogen plant including items in the recommendation above.
5. Focus attention on developing practical flowsheets, gathering vital thermodynamic and phase equilibrium data, obtaining converged mass and energy balances, developing materials of construction, equipment design and involving industrial partners in the effort.

VI NGNP AND HYDROGEN PRODUCTION PRECONCEPTUAL DESIGN REPORT OUTLINE

The contents of the Preconceptual Design Report (PCDR) are shown in Table ES-2. After the Top Level Requirements (Section 2), the framework for Functional Analyses and Plant Level Integration is established in Section 3. The design for the major systems plus the Fuel follow (Sections 4, 5, 6, 7, 8, 9 and 10), followed by the Plant Level Assessments (Sections 11, 12, 13, 14, and 15), and finally the R&D, Licensing and Permitting, Schedule and Economic Assessment topical sections (Sections 16, 17, 18 and 19).

Table ES-2: NGNP and Hydrogen Production Preconceptual Design Report Road Map

Section Number	Section Title
	EXECUTIVE SUMMARY
1	INTRODUCTION
2	TOP LEVEL REQUIREMENTS
3	PLANT LEVEL DESIGN AND INTEGRATION
4	NUCLEAR HEAT SUPPLY SYSTEM
5	REACTOR FUEL
6	HEAT TRANSPORT SYSTEM
7	HYDROGEN PRODUCTION SYSTEM
8	POWER CONVERSION SYSTEM
9	BALANCE OF PLANT SYSTEMS
10	SITE, BUILDINGS AND STRUCTURES
11	OVERALL NGNP OPERATION
12	MAINTAINABILITY
13	AVAILABILITY
14	SAFETY
15	SAFEGUARDS AND SECURITY
16	TECHNOLOGY DEVELOPMENT
17	LICENSING AND PERMITTING
18	PROJECT SCHEDULE
19	ECONOMIC ASSESSMENTS
Appendix A	APPENDIX A. ACRONYMS
	SPECIAL STUDIES

VII PLANT DESIGN

The process for the preconceptual design of the NGNP is initiated with top level requirements that flow down to plant level design and integration and are allocated to four Facilities and to the Balance of Plant. This Plant Level section presents those requirements, the preconceptual designs of the Facilities and key plant level assessments.

VII.A PCDR SECTION 2 - TOP LEVEL REQUIREMENTS

The top-level requirements provide design, licensing and mission-specific requirements for the NGNP to serve as the demonstration plant for follow-on multi-module commercial plants. While NGNP Project emphasis is on hydrogen production, the commercial PBMR PHP design will supply nuclear-generated process heat for a broad range of applications. These top level requirements draw from and consolidate information from the following sources:

- Recent NGNP Public/Private Partnership Working Group perspectives and plans for a NGNP Alliance of end-users to support Project development and drive deployment.
- DOE guidance via the INL/BEA issued NGNP related Project Management Plan, High-Level Functions and Requirements (as modified by the Independent Technology Review Group (ITRG) report), and Statement of Work documents, plus related DOE requirements associated with the NGNP being a DOE-owned facility on a DOE site.
- User requirements from past utility/user groups engaged with High-Temperature Gas-Cooled Reactor (HTGR) development as well as Advanced Light Water Reactor (ALWR) design and certification efforts. Such efforts have also served to provide a user perspective on the commercial PBMR PHP market incentives, needs, opportunities and development strategy.
- Utility/user requirements and experience from the PBMR Demonstration Power Plant (DPP) Project in South Africa.
- Ongoing user interactions with PBMR process heat project initiatives.
- Ongoing regulatory experience in the US and South Africa, which builds upon the decades of experience in the US, Germany and elsewhere.
- Special Studies and analyses conducted by the PBMR-based team at the front-end of the BEA preconceptual design and engineering services contract that have served to establish key plant design features.

Figure ES-10 depicts the inputs to the top level requirements. Note that they include the results of the special studies discussed in Section IV. The key top level requirements for the PBMR PHP-based NGNP Project are:

- The NGNP Project shall develop, license, build, test and operate a one module PBMR PHP as a demonstration for subsequent multi-module commercial plants.
- The NGNP Project shall support the timely Design Certification (DC) of the standard NHSS suitable for a broad range of applications and an envelope of site conditions.
- The NGNP Project shall develop, permit, build, test and operate a reference hydrogen process at the full commercial train scale as a demonstration for multi-train commercial plants.
- The NGNP Project shall also accommodate the demonstration of other advanced hydrogen production processes and process heat applications as well as follow-on advanced fuels, components and systems plus serve to train future operators.

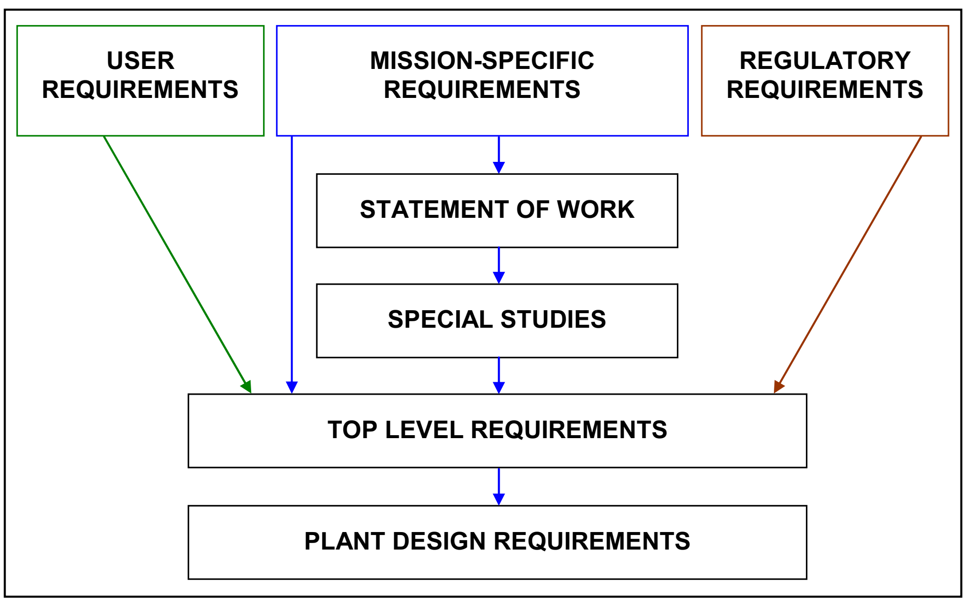

Figure ES-10: Requirements Flow Down to Design

Further development of the top level requirements will be conducted in concert and cooperation with the development of the user-based NGNP Alliance.

The sources of these top level requirements for the NGNP Project and the relationship to the Plant Design Requirements plus the overall relationships of the other sections of the PCDR are illustrated in Figure ES-11.

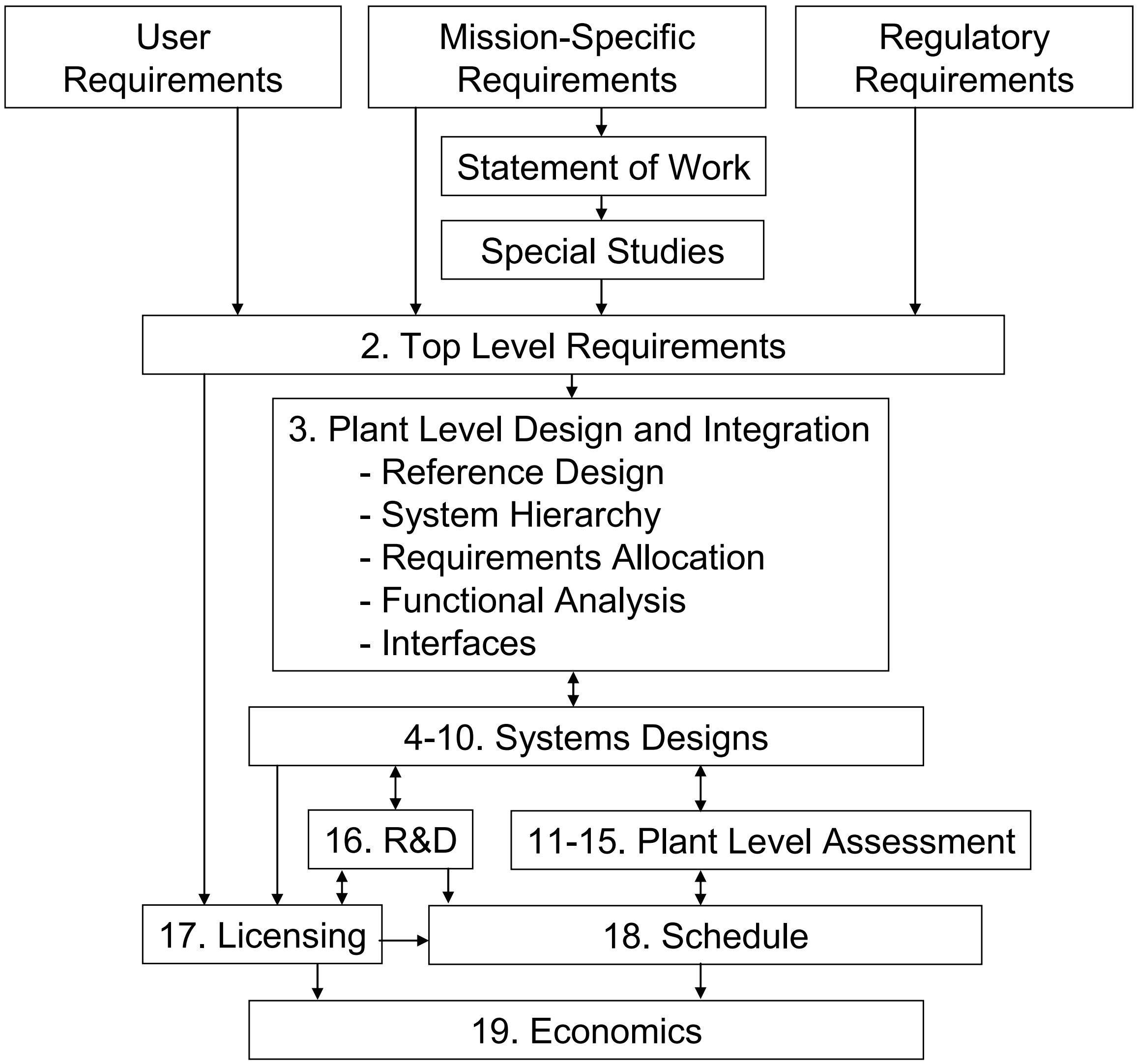

Figure ES-11: Requirements Flow Down to Pre-conceptual Design Development (PCDR Sections Identified)

VII.B PCDR SECTION 3 - PLANT LEVEL DESIGN AND INTEGRATION

The top level requirements development leads to plant level design and integration with the development of a preconceptual design reference, system hierarchy, requirements allocation, functional analyses, and plant system interfaces.

The plant level design and systems integration utilizes systems engineering, a disciplined approach to managing and designing complex systems, for the successful attainment of the Project Goals across the divergent nuclear reactor, hydrogen process, and power conversion engineering technologies and disciplines.

The plant level design and systems integration utilizes systems engineering, a disciplined approach to managing and designing complex systems, for the successful attainment of the Project Goals across the divergent nuclear heat supply system (nuclear reactor and heat transport), hydrogen process, and power conversion engineering technologies and disciplines.

The core of the systems integration process in the preconceptual and conceptual design phases is the development of design requirements. The process is vital at the beginning of the design process, and system integration needs to be maintained as a process during design, capturing, linking, analyzing, and managing changes to requirements and their traceability. Successful system integration also ensures conformance to the plant user's goals and the compliance of the resulting design with regulations and standards.

This process and the resulting requirements flow-down are one step down from the "top" of the documentation "pyramid" and at the convergence of the documentation of the Overall Systems. Documentation includes:

- Summary Description of the Reference Design
- The Plant Work Breakdown Structure
- Organization of the Plant Systems
- Identification of Critical Systems, Structures and Components
- Allocation of Top Level Requirements to Overall Systems
- Allocation of Functions to Overall Systems
- Tabulation of Plant Interfaces
- Tabulation of Overall System to System Interfaces

The plant level design and integration effort is the starting point for the subsequent sections on system and building descriptions.

VII.C PCDR SECTION 4 - NUCLEAR HEAT SUPPLY SYSTEM

The NHSS configuration is based on the PBMR DPP reactor design. The NHSS provides heat to the Primary Heat Transport System (PHTS) by means of the nuclear heat generation in the Reactor Unit System (RUS). The PHTS circulates the primary coolant from the NHSS to the Intermediate Heat Exchanger (IHX), where the heat from the NHSS is transferred to the Secondary Heat Transport System (SHTS). The SHTS transports heat to the HPS and the PCS, where the heat is either utilized or, in certain plant operating modes, rejected to the environment via the air cooled condenser. A proposed layout of the Reactor Unit in relation to the rest of the plant is shown in Figure ES-12. This section discusses all of the NHSS systems with the exception of the PHTS and SHTS, which are discussed in PCDR Section 6.

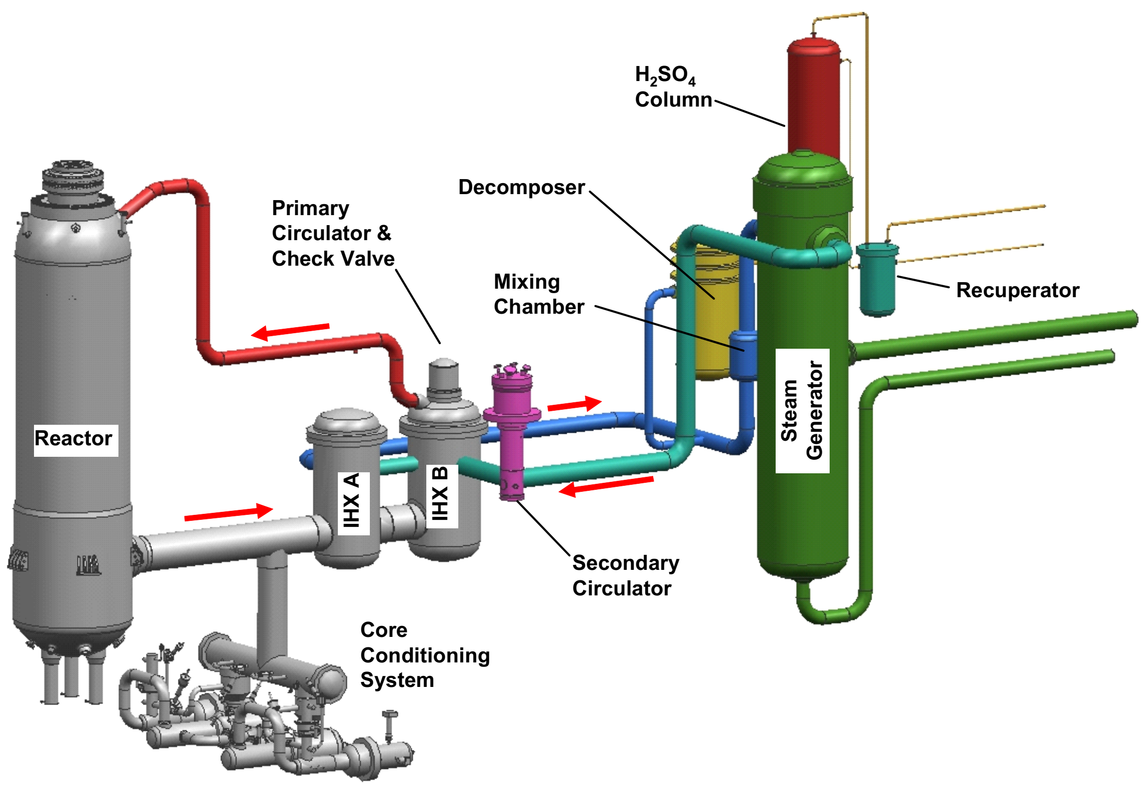

Figure ES-12: Proposed Layout of the Reactor Unit System in Relation to the PHTS, SHTS, SG and PCHX

The NHSS consists of the Reactor Unit System and all the support and auxiliary systems required for its operation and maintenance. The Reactor Unit System consists of the following systems:

- Core Barrel Assembly
- Core Structure Ceramics
- Reactor Pressure Vessel
- Reactivity Control System
- Reserve Shutdown System
- In-Core Delivery System

The support and auxiliary systems for the Reactor Unit System are:

- Core Conditioning System
- Reactor Cavity Cooling System
- Fuel Handling and Storage System
- Helium Services System
- NHSS Control and Instrumentation System
- NHSS Cooling Water System
- NHSS Electrical System
- Nuclear Heat Supply Building HVAC System
- Primary Loop Initial Clean-up System.

For application in the NGNP project, the most significant change to the PBMR DPP reactor is an uprating of the continuous power level from 400 MWt to 500 MWt. The reactor inlet/outlet temperatures changed from 500ºC/900ºC to 350ºC/950ºC, while the reactor mass flow reduced from 193kg/s to 161kg/s. Details have been provided in NGNP Special Study 20.2.

Another important change to the PBMR DPP reactor for NGNP application is that the Core Barrel Conditioning System (CBCS) is not necessary, due to the lowering of the reactor inlet temperature. In the NGNP, the function of the CBCS is fulfilled by rerouting the flow path of the primary coolant, which is at a lower temperature than in the PBMR DPP. The change in primary coolant flow path necessitates moving the Primary Heat Transport System cold pipe (reactor inlet) from the bottom part of the Reactor Unit (as it is on the PBMR DPP reactor) to the top of the Reactor Pressure Vessel.

Thus, the main focus of design and development for the NHSS is determining the implications of the increased power level, neutron flux and decay heat during shutdown on systems that were developed for the PBMR DPP, including component design lifetime. The increased power level also implies a higher processing rate of fuel, which impacts the Fuel Handling and Storage System.

VII.D PCDR SECTION 5 - REACTOR FUEL

The NGNP fuel core evolves from the core of the PBMR DPP. The DPP fuel core consists of uranium fuel elements which generate heat by means of fission reactions. The fuel elements are spherical and consist of a matrix graphite body pressed into a spherical shape. A fuel sphere is divided into two regions, the inner spherical “fuel” region and an outer shell surrounding the fuel region, known as the “fuel-free” region. The fuel region of each fuel sphere contains approximately 14,500 of evenly dispersed spherical particles known as coated particles, in which the fuel is contained, while there are no coated particles in the fuel-free region.

Each coated particle consists of a spherical kernel of uranium dioxide (UO_2) surrounded by four coating layers. The innermost coating layer is known as the buffer layer and it is followed in turn by a pyrocarbon layer known as the inner pyrocarbon (IPyC) layer, a silicon carbide (SiC) layer, and another pyrocarbon layer known as the outer pyrocarbon (OPyC) layer. This coated particle design is known as the TRISO design.

The general design layout of the PBMR/NGNP fuel sphere is presented in Figure ES-13.

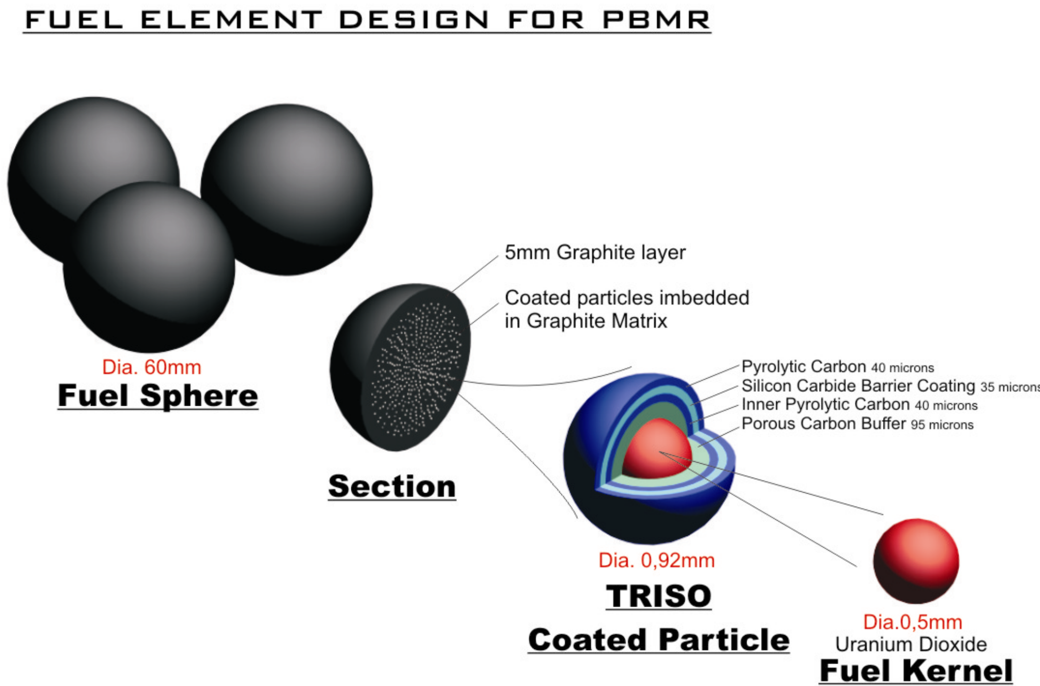

Figure ES-13: Diagram of the General Layout of the PBMR Fuel Sphere Design

The fuel provides the primary barrier against the release of fission products. This section shows the ability of the fuel to provide sufficient retention for the conditions expected in the fuel core during normal operation and credible accidents as calculated by the nuclear and thermodynamic design.

The PBMR DPP operates at 400 MWt with an inlet temperature of 500ºC and an outlet temperature of 900ºC. As part of a Special Study it was concluded that the optimum power level for the NGNP is 500 MWt with an inlet temperature of 350ºC and an outlet temperature of 950ºC. The selected power level was chosen because it builds on the PBMR DPP reactor and fuel technology, meets the NGNP schedule, requires no design development, and achieves higher power levels at the same cost and with minimal fuel qualification.

Since the NGNP fuel requirements in terms of operating conditions are higher that those of the German program, it is foreseen that more testing will be required.

The testing and qualification strategy being followed by PBMR can be summarized as:

- Fuel and Matrix Graphite irradiation to envelope normal operating conditions

- Fuel heating tests to envelope accident conditions

A reliable supply of high quality fuel that is available when required is critical to the success of the NGNP project. Based on the Westinghouse Team review of: (1) the NGNP target schedule, (2) a detailed fuel development program and (3) the large database of German operating experience for the TRISO fuel design, it is concluded that the only way to meet the NGNP schedule is to use fuel provided by Pebble Bed Modular Reactor (Pty) Ltd. PBMR fuel is based on the proven German fuel design and a modern fuel manufacturing process which is equivalent to the demonstrated German manufacturing process.

The PBMR fuel qualification and test program will demonstrate that the fuel manufacturing process is equivalent to or better than the German manufacturing process. In addition, the PBMR test program will statistically strengthen the German database.

In parallel with the PBMR DPP test program, some additional testing of the fuel will be required to meet the higher operating fluence and accident temperatures predicted for the NGNP. The development program would be carried out on production fuel under conditions that would envelope NGNP conditions. The Westinghouse Team recommends that such additional testing be done as part of a collaborative effort with INL to: (1) complete NGNP fuel qualification, (2) advance domestic manufacturing capability as the commercial market develops and (3) develop advanced fuel manufacturing processes for the reference UO_2 fuel as well as for advanced fuel designs.

VII.E PCDR SECTION 6 - HEAT TRANSPORT SYSTEM

The HTF is one of the four key plant facilities. It is closely aligned with the NHSF. The functions, requirements and interfaces flow down from the plant level design and integration. The HTS serves to transport thermal energy from the reactor, where it is produced within the NHSS, to the HPS and the PCS, where it is utilized or, in certain plant operating modes, rejected via the PCS. The HTS comprises a PHTS and a SHTS that are coupled by two IHXs in series. Figure ES-14 provides a schematic of the configuration.

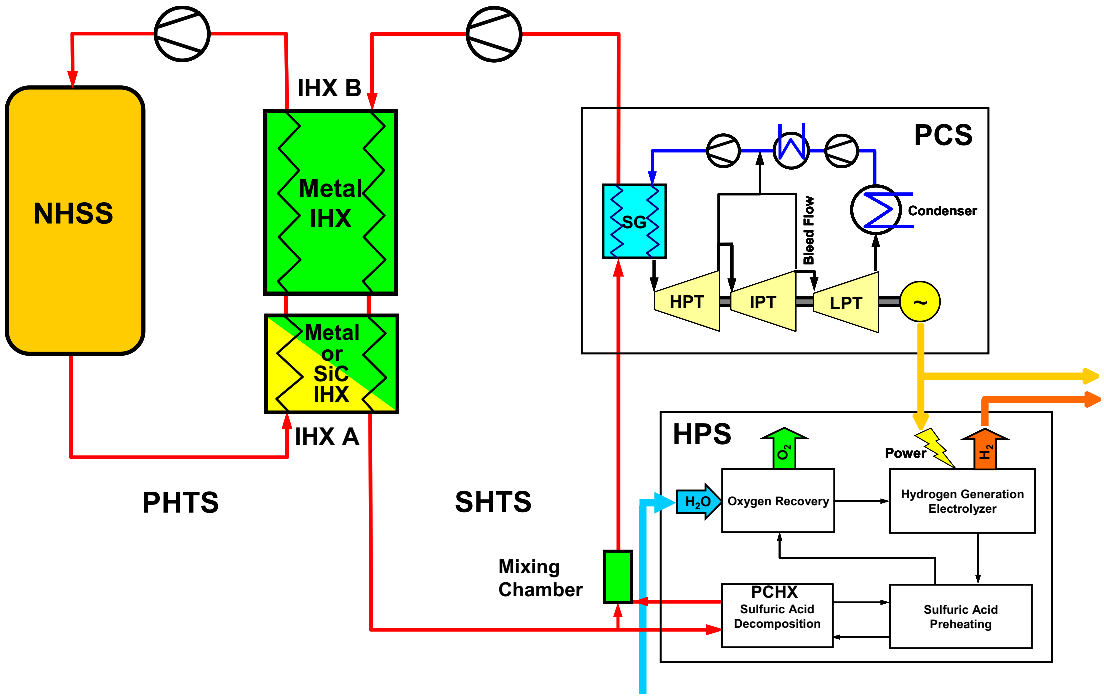

Figure ES-14: NGNP Demonstration Preconceptual Design Schematic

The PHTS includes the IHXs, the primary piping, its associated internal ducts, insulation and supports, the primary circulator and a check valve.

The SHTS comprises the secondary piping, its associated internal ducts, insulation and supports, the secondary circulator and a helium-mixing chamber. Helium from the secondary side of the IHXs is split into two paths. One-fourth of the flow is routed to the PCHX, which is the interface with the HPS. The remaining flow is routed directly to the SG of the PCS via the mixing chamber. After transferring thermal energy to the HPS, the stream exiting the PCHX is rejoined to the main stream at the helium-mixing chamber. A fixed orifice, upstream of the mixing chamber in the main helium flow path, is used to establish the relative flow rates to the PCHX and the SG.

The high temperature components of the HTS, and particularly the heat transfer core of the IHXs, pose significant design and development challenges for the NGNP; however, much foundation work has already been done. For metallic IHX options, the starting point for addressing materials challenges will be earlier work in Germany and both earlier and on-going work in Japan on high-temperature tubular heat exchangers and associated materials. The compact recuperator of the PBMR DPP provides an initial design basis, albeit at lower temperatures. For advanced heat exchanger materials, the IHX development will build on work underway within the Nuclear Hydrogen Initiative Program.

The HTS Special Study determined that the IHX should be split into high and low temperature sections, designated IHX A and IHX B. The high temperature section, IHX A, would be designed for replacement within the plant lifetime, whereas IHX B would be designed as a full lifetime component. The maximum temperature for IHX B has been tentatively specified at 760ºC to allow the use of established ASME Section III materials, based on Subsection NH for IHX B. The reference material specifically recommended for IHX B is Alloy 800H. Both the breakpoint temperature and the IHX B material are to be confirmed through future studies during conceptual design.

Significant Design Data Needs (DDNs) are associated with the IHX. Given both the critical nature and technical challenges associated with this component, multi-pronged development paths have been identified. The present reference for IHX A is a compact metallic heat exchanger design that uses Alloy 617 as the reference material. In addition to the operating temperature being above the established useful range for this material, the thin heat transfer cross-sections associated with compact exchangers pose difficulties with the large grain sizes associated with Alloy 617 of the current reference specification. DDNs identified with this material include both optimization of the current specification and extending the database to the required temperature range. An alternate material, Alloy-230, has also been identified for further optimization and characterization. Additional DDNs are identified to extend the available design methods and associated codes and standards to the higher temperature range required for the NGNP IHX. Performance verification of high temperature IHX modules is also identified in DDNs as a basis for confirming material suitability and design methods, as well as supporting the development of codes and standards.

Metallic materials are marginal for the IHX A at the highest temperatures of interest. For this reason, the parallel development of ceramic and/or composite heat exchangers has also been recommended and identified within the HTS DDNs. Other DDNs address design and technology gaps associated with the internal components of the highest temperature piping sections and the SHTS helium-mixing chamber.

The HTS piping also represents a critical focus of design and development. The designs of the highest temperature sections of the PHTS piping are based upon the high-temperature gas cycle piping of the DPP, which utilizes both insulation and active cooling. The NGNP-specific design is complicated by the higher reactor outlet temperature (950ºC versus 900ºC) and the higher temperatures of potential active cooling sources (350ºC at the PHTS circulator outlet versus 120°C at the high-pressure compressor outlet in the DPP). The complexities associated with active cooling also imply high costs. For this reason, passive insulation has been tentatively selected for the highest temperature sections of the SHTS. The technical and economic trade-offs of active cooling versus passive insulation for both the PHTS and SHTS will be addressed through future studies during conceptual design.

The complexities associated with insulation and cooling of piping and ducts in the highest temperature sections of the PHTS and SHTS pose both technical risks and high costs. These will be addressed both by R&D in response to DDNs, and by future studies to optimize the insulation and/or cooling designs and associated material selections.

Finally, the SHTS helium-mixing chamber, which is unique to demonstrating one train of the HPS in the NGNP, poses technical challenges related to both the high-temperatures of the streams to be mixed and the concerns with thermal cycling effects. These challenges will be addressed through further design and R&D in response to DDNs.

In summary, the HTS is a key system of the NGNP with significant technical barriers to its realization. The scope of these barriers and the challenges associated therewith have been narrowed and focused by reference design selections, notably the two-section IHX. Where technical issues are unavoidable, multiple design and development paths have been established to minimize and/or manage risks.

VII.F PCDR SECTION 7 - HYDROGEN PRODUCTION SYSTEM

The Hydrogen Production System (HPS) takes thermal energy from the Heat Transport System (HTS) and electrical energy and water from the Balance of Plant Systems (BOP), and decomposes the water into hydrogen and oxygen.

For the NGNP, three water-splitting technologies were evaluated: Sulfur Iodine (SI), Hybrid Sulfur (HyS), and High-Temperature Steam Electrolysis (HTSE). All three have advantages and disadvantages in terms of the technology available, the energy required, and the adaptability to commercial-scale operation, and a detailed comparison is provided in the PCDR.

For the NGNP, the HyS process was selected as the reference HPS process with HTSE as the backup technology, even though HyS has more technical challenges. This selection was made since HTSE will likely have both higher capital and final hydrogen costs than will the HyS process, and the NGNP program is aimed at a commercial demonstration of a hydrogen process. Both processes are recommended for consideration because the HTSE process has hardware that is already available while the HyS process still requires development work in both the sulfuric acid decomposition and the electrolysis cells.

The HyS chemical process is shown in Figure ES-15 below.

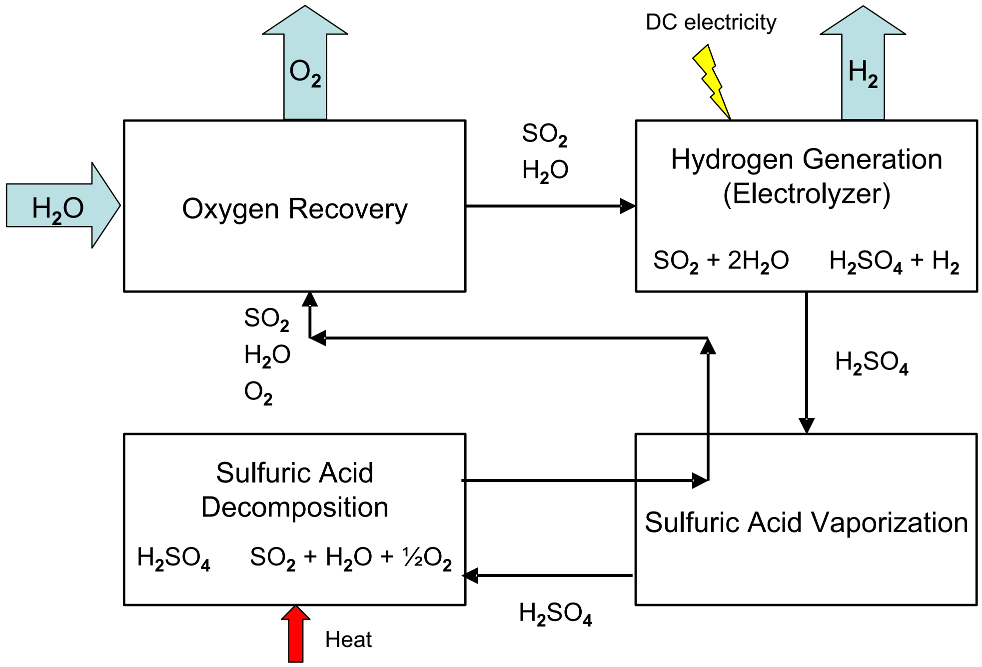

Figure ES-15: HyS Chemical Process

The interface of the HPS with the NHSS is defined by the helium inlets and outlets on the Process-Coupling Heat Exchanger (PCHX). The PCHX is therefore completely within the HPS.

The overall NGNP HPS is comprised of seven sub-systems: a Feed and Utility Supply System (FUS), a Sulfuric Acid Decomposition System (SAD), an Electrolysis System (ELE), a Product Purification System (PPU), a Product Storage and Delivery System (PSD), a Waste Treatment and Disposal System (WTD), and an Instrumentation and Control System (PCN).

The main components include the Sulfuric Acid Concentrator (Concentrator), the Sulfuric Acid Decomposer (Decomposer), the SOx Cooler, the SO2 absorbers (Absorbers) and the Electrolyzers.

The functions currently identified for the Feed and Utility Supply System (FUS) include the purification of feed water to the Electrolysis System (ELE) and the supply of sulfuric acid to the Sulfuric Acid Decomposition System (SAD) and caustic to the Product Purification System (PPU).

The Sulfuric Acid Decomposition System is made up of the Sulfuric Acid Storage Tank and the piping, equipment and pumps that deliver acid to the Concentrator. The Sulfuric Acid Concentrator and its associated Recuperator concentrate the sulfuric acid feed to the Decomposer. The Decomposer takes thermal energy from the HTS and uses it first to decompose sulfuric acid to sulfur trioxide and water and then to decompose the sulfur trioxide into sulfur dioxide and oxygen. The decomposed vapors consisting of oxygen, sulfur dioxide, sulfur trioxide and steam pass through the Recuperator and Concentrator to recover heat and are cooled and partially condensed in the SOx Cooler before being delivered to the Electrolysis System. The largest technology challenges associated with this technology are in this system.

The Electrolysis System consists of the Electrolyzers, Absorbers and their associated piping, pumps and auxiliary vessels. The sulfur dioxide-laden oxygen is separated from the condensed acid leaving the SOx Cooler. This oxygen passes up through five stages of absorption where the sulfur dioxide is scrubbed countercurrently from the product oxygen. The sulfur dioxide concentration is lowered between stages by oxidation to sulfuric acid at the Electrolyzer anodes. The oxygen is delivered to the PPU for final purification. The acid combined with the separated liquid from the SOx Cooler is returned to the Sulfuric Acid Storage Tank after being stripped of any remaining oxygen. Hydrogen, produced by reduction of protons at the cathodes of the Electrolyzer, is also sent to the PPU for purification. The main benefit of this technology over water or steam electrolysis is that the acid electrolyte reduces the voltage requirement significantly and thus improves the efficiency.

The Product Purification System (PPU) is made up of two sub-systems: an oxygen purification system and a hydrogen purification system. The oxygen system consists of a caustic scrubber and two sets of adsorption beds along with associated regeneration equipment. The hydrogen system adsorbs moisture from the gas stream, hydrogenates trace sulfur species to hydrogen sulfide and collects that in a zinc oxide adsorber / reactor. The effluent is further dried in a second adsorption bed. The oxygen is assumed to be vented to atmosphere. Commercially available technology can reach purities of 1 to 2 parts per million by volume (ppmv) of sulfur. It is not known whether it can reach 4 parts per billion by volume (ppbv) as is required by SAE J 2719, the specification for hydrogen fuel for use in transportation fuel cells. The requirements for this system depend heavily upon the final use of the products. Some industrial applications may not require a PPU at all.

The Product Storage and Delivery System (PSD) for the NGNP HPS takes hydrogen from the PPU and delivers it to a hydrogen pipeline at the plant battery limits. Any process blowdown required to maintain electrolyte purity as well as spent caustic from the Product purification system is sent to the Waste Treatment and Disposal System (WTD). This system treats these wastes by neutralization and sends them to the BOP facilities for evaporation and final disposal. The system consists of commercially available package units. The Instrumentation and Control System (PCN) performs the control function for the other systems.

The HyS System proposed for NGNP presents several technical challenges and risks, and requires additional component development, future studies, and alternative designs for parallel or fall-back positions. Materials of construction selection and development are a major task in the development of this technology. The closed-loop nature of the HyS process poses additional challenges. Possible impurity accumulation in the circulating loop is a concern that may require additional development.

VII.G PCDR SECTION 8 - POWER CONVERSION SYSTEM

The PCS for the NGNP demonstration uses a conventional turbine-generator operating with a non-reheat Rankine water vapor cycle and regenerative feedwater heating. The use of a conventional Rankine cycle provides a flexible, well proven, highly reliable system with the potential for process integration and use of waste heat from the HPS. The energy input to the system is via heat exchange with the NHSS through the PHTS and then the SHTS helium loop. A non-reheat cycle is chosen due to both the anticipated cost of a reheater, and the economics typical of a demonstration facility.

Key features of the PCS are:

- With the exception of the Steam Generator, the system is designed using commercially available components, to minimize R&D and technology development needs,
- High temperature helium piping is minimized to limit leakage and system heat losses,
- The system has capability to interact and accommodate operational transients associated with the Hydrogen Production Unit Facility,
- INL is a dry site so air cooled condensing is selected to reduce water requirements,
- The system is adaptable to commercial sized application of Hydrogen/Power cogeneration,
- The PCS for the demonstration unit is sized for full NHSS thermal power, allowing for additional power export during periods when the HPS is not in operation, and
- In the NGNP, the PCS is completely independent from the HPS. In the commercial facility, the cycle efficiency can be improved by recovering waste heat from the HPS effluent streams.

The Steam Generator is identified as a developmental component based on prior design development experience for other HTGR applications. The requirements, configuration, materials and design features of this component require that a number of development needs be satisfied for successful design, manufacturing, delivery and long term operation of the prototype and follow-on components.

VII.H PCDR SECTION 9 - BALANCE OF PLANT SYSTEMS

The BOP systems provide the mechanical and electrical support utilities for all areas and processes in the plant, and environmental control systems for those buildings in the PCS, HPS, and BOP buildings. Also included are the site security systems and environmental monitoring systems.

The pre-conceptual design of the BOP systems has been based on similar systems and components developed for the Advanced Light Water Reactor and systems used on typical power plant and industrial projects.

The BOP systems interface with the NHSS, HTS, HPS, and PCS major systems to supply and receive electric power, make up water, cooling water, waste water, compressed air, control and supervision, solid and liquid waste, compressed gases and laboratory support.

In order to minimize water consumption by the BOP systems, it is proposed to use closed circuit cooling towers for the component cooling water heat sink, and to use air-cooled chillers for Heating Ventilation and Air Conditioning (HVAC) chilled water. This approach reduces evaporation, blow-down, and drift losses associated with standard cooling towers.

It has been determined that the HPS system makeup needs and evaporative coolers for the NHSS, PCS, and HPS call for a very significant amount of water requiring treatment and recycling. The wastewater treatment system is designed to use an evaporator to remove solids and recover water for reuse by the Plant (Service) Water system.

The CCSS is a non-nuclear safety related system. It is not relied upon or credited to function during or mitigate any NHSS design basis event or initiating event. The CCSS is isolated from all systems that are required to mitigate design basis events. The CCSS is located outside the vital area security boundary.

The electric power systems supply power to the plant safety and non-safety equipment for normal plant operation, startup and normal shutdown, and for accident mitigation and safe shutdown as required. High voltage systems provide Alternating Current (AC) power from the turbine generator to large components such as main transformers and large motors (i.e., Helium Circulators) on site and off site to the utility grid. High voltage power is also fed from off site when the turbine generator is not operating. Medium voltage systems provide electrical power to major system components (> 600 V motors). Low voltage systems power small motors, control systems, and lighting. The HPS electrolyzers require dedicated Direct Current (DC) power at low voltage, but very high amperage. Dedicated AC/DC converters are provided for this function.

VII.I PCDR SECTION 10 - SITE, BUILDINGS AND STRUCTURES

The NGNP site selection process and characteristics as well as arrangement of buildings and systems are addressed. The NGNP is located on the former site for the New Production Reactor (NPR). The selection of the NPR site is based primarily on maximizing the distances from site boundaries, volcanic areas, and existing INL facilities.

The Advanced Test Reactor (ATR) is located on the INL site. That facility has an Exclusion Population Zone (EPZ), and the NPR site falls within this EPZ. This concern will be addressed as required during conceptual design. The NPR site is located far enough from the other facilities at INL that it requires new self contained utilities, with the exception of electric power. A Plot Plan showing the arrangement of buildings and systems is included as Figure ES-12.

Key considerations in the development of the plot plan are:

- The Nuclear Heat Supply Building (NHSB) is based on development of the PBMR DPP and the PHP designs,
- The location of the HPS Acid Decomposer and PCS Steam Generator is kept close to the NHSB to minimize helium piping length,
- The NHSB is partially embedded into the rock site to provide a stable foundation and to reduce seismic amplified response. A future study is recommended to optimize the depth of burial taking into consideration, seismic design, and requirements to protect the NHSS from natural and manmade phenomena,
- The portions of the HPS handling hydrogen are located at least 100 meters away from the NHSB,
- Non-nuclear Structures, Systems, and Components (SSC) are placed outside security areas required by 10CFR73, and
- The control building is located upwind and separated from chemical locations.

The layout accommodates adaptation to commercial scale by use of multiple trains using a slide along arrangement, or expansion of single systems where appropriate.

The primary buildings on the site are shown on Figure ES-16; a detailed list of the buildings is provided. Figure ES-17 is a commercial site key plan which shows the potential arrangement of a commercial scale plant with four NHSS modules and sixteen HPS modules.

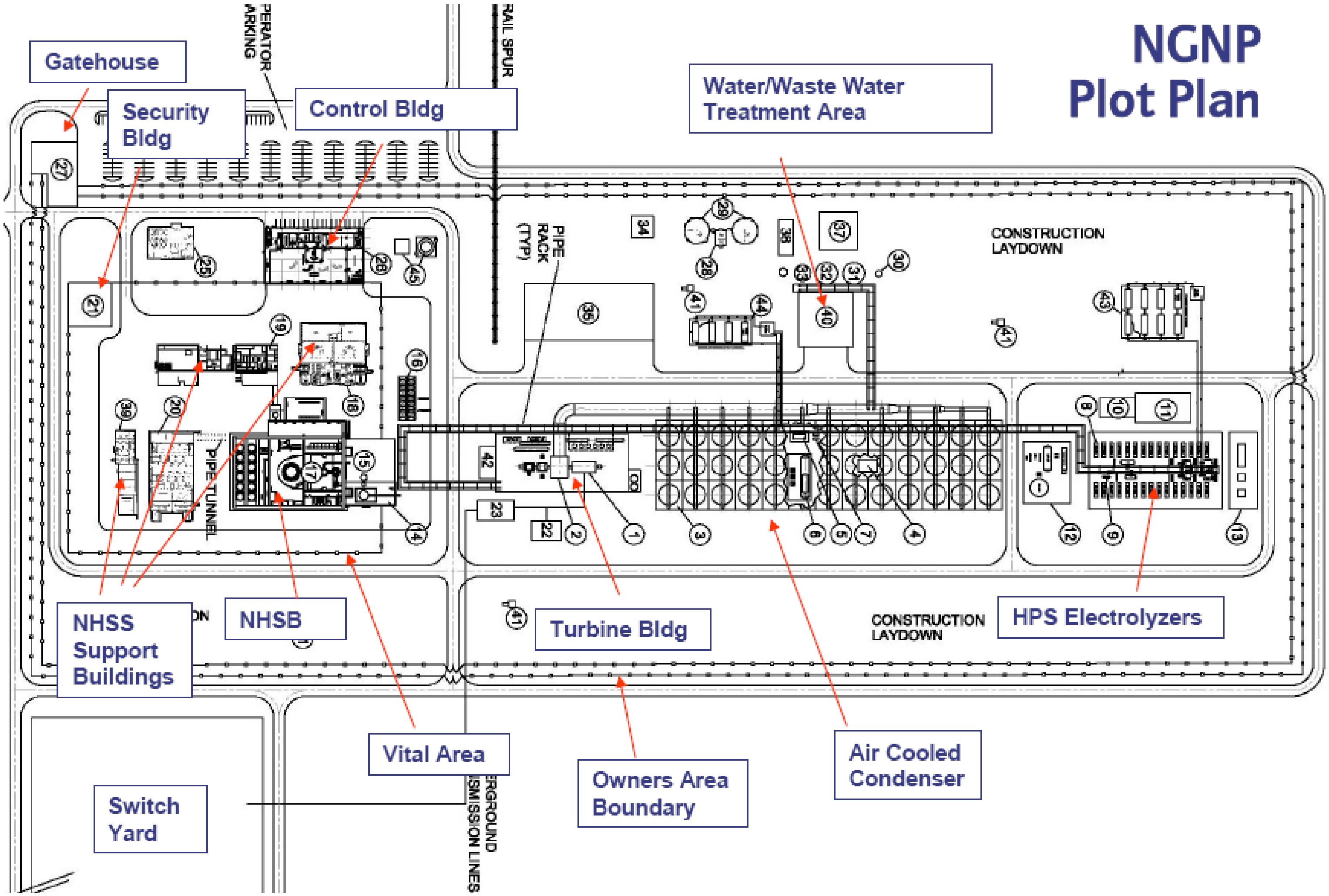

Figure ES-16: NGNP Plot Plan

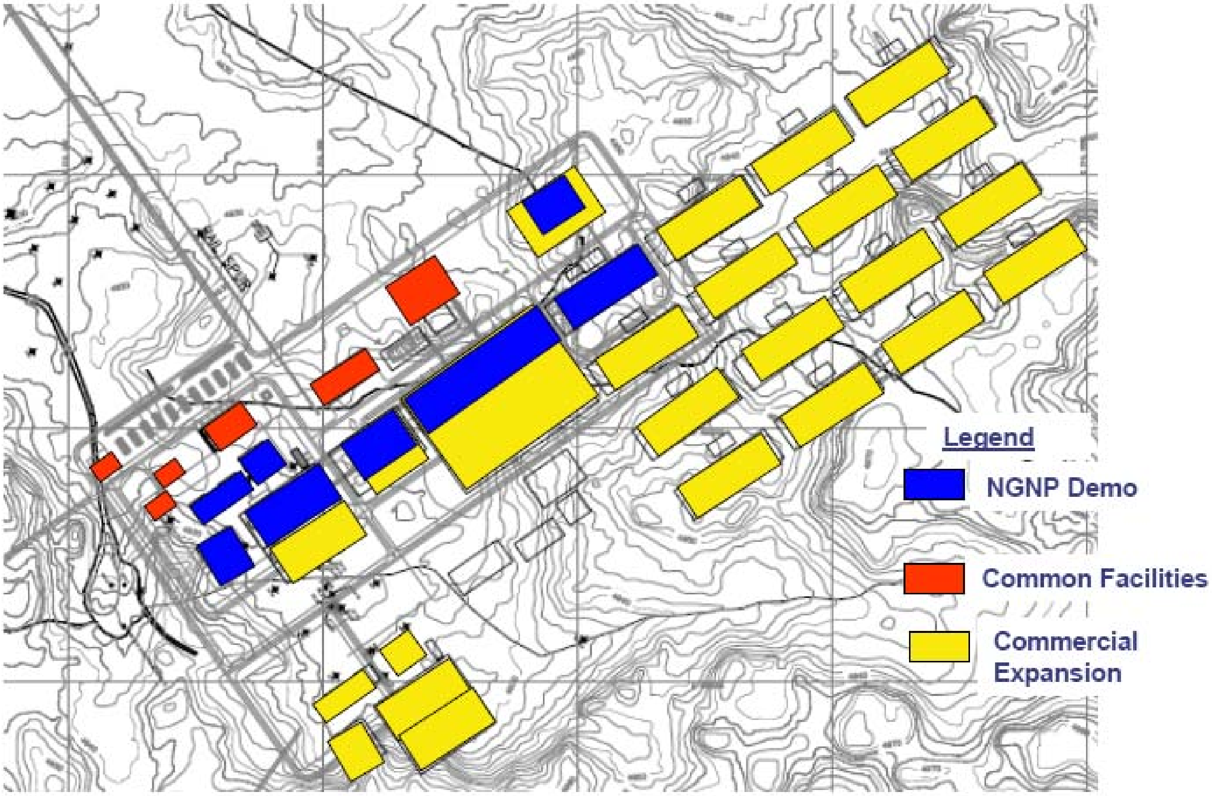

Figure ES-17: Commercial PHP Site Key Plan

VII.J PCDR SECTION 11 - OVERALL NGNP OPERATION

A description of the integrated NGNP operational and control philosophy as well as a description of the NGNP plant simulator are provided. Various modes of operation, performance and control philosophies as defined and described for the facilities, i.e., the NHSS, HTS, HPS and PCS will be integrated into an overall NGNP operational and control philosophy. This philosophy includes interdependencies that include the steady state, transition and transient operation suitable for a preconceptual design level.

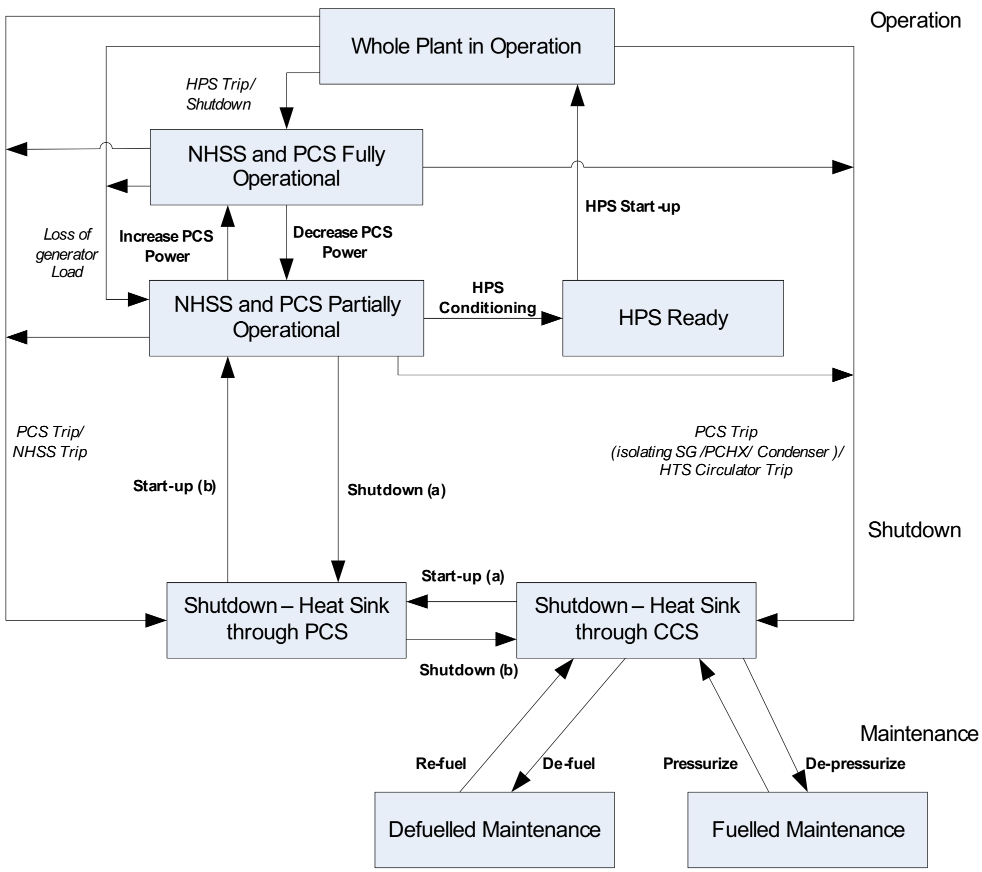

Figure ES-18: Modes Diagram

The integrated design requirements for the NGNP simulator will be specified as well as the simulator operational requirements to ensure that the plant simulator for the NGNP can be used to:

- Design, integrate and verify plant control philosophies before plant construction and commissioning to ensure safe plant operation.
- Train plant operators and test their skill levels before they operate the actual plant.
- Test the impact of modifications on the plant after commissioning.
- Develop operating procedures.

It is concluded that the NGNP demonstration plant will be able to operate in a stable and reliable manner. The different modes of operation, however, as well as transition and transient events, will be further investigated in the conceptual design phase. An integrated simulation tool capable of simulating the steady state and transient operation of the entire plant is required to perform detailed simulations of the identified transition and transient events. The prediction of the plant performance during these events will aid in the design of the different components in the various systems. The simulation tool will also be used to test the overall control strategies of the plant.

VII.K PCDR SECTION 12 - MAINTAINABILITY

The NGNP is to be monitored, inspected, tested, assessed and maintained to ensure that structures, systems and components function as per name plate specification. Preventive and predictive maintenance must be scheduled so that optimal performance of components is maintained and corrective maintenance is minimized. The planning and execution of preventive, predictive and corrective maintenance must be done such that outage time is minimized and the capacity factor and availability requirements are met.

In order to meet the availability and capacity factor requirements, SSCs must be designed for maintainability. Aiding the design for maintainability with respect to the SSCs of the NGNP, this section provides the anticipated maintainability concept and strategy for the NGNP. The maintenance principles, inspectability approach and access requirements are described.

Anticipated maintenance requirements are described along with the maintenance approach for systems and subsystems to ensure trouble free operation and radiation dose to personnel that does not exceed regulatory and statutory limits.

The major systems of the NGNP which dominate the maintainability are identified, and time intervals of 5 years are proposed between maintenance outages. This interval is mainly influenced by the anticipated replacement of the Intermediate Heat Exchanger A (IHX) after 10 years. The possibility of longer time intervals between maintenance and inspection could be considered if the IHX A can be replaced at intervals longer than 10 years.

The basic maintenance requirements for the major components are described to give the anticipated level of inspection required.

VII.L PCDR SECTION 13 - AVAILABILITY

The assessment and allocation of plant availability requirements for the preconceptual design of the NGNP is structured to correspond to the four facilities and BOP systems and buildings.

This initial allocation of plant availability resulted in target availability factors and target capacity factors for several modes of operation. For the plant operating mode with both PCS and HPS in operation (electric power and hydrogen being produced) and with the planned outages for the NHSS, HTS, PCS and HPS fully coordinated, the target availability factor is ~85%. For this operating mode, the target capacity factor is ~83%.

For the plant operating mode with only PCS operation (electric power being produced, but no hydrogen), the corresponding target availability factor is ~90%. For this operating mode, the target capacity factor is ~88%.

This plant level assessment will be further evolved and expanded into a stand-alone plant reliability and availability assessment report during the conceptual design phase.

VII.M PCDR SECTION 14 - SAFETY

The safety design approach for the NGNP is addressed together with the safety evaluations that will be performed to confirm that the principles of the safety design approach are fulfilled and that the Top Level Requirements associated with safety and licensing are achieved. The risk-informed and performance-based safety design approach is derived from that developed by Pebble Bed Modular Reactor (Pty) Ltd. in support of the design certification for future U.S.-sited plants.

The safety design philosophy is to apply the principles of defense-in-depth at a fundamental level in which a diverse combination of inherent reactor characteristics, passive design features and SSCs, active engineered systems, and operator actions are deployed to maintain the integrity of robust passive barriers to radionuclide release. The reactor-specific key safety functions are derived in a top-down manner with the objective of protecting the integrity of the multiple barriers to radionuclide release; these include the control of heat generation, control of heat removal, control of chemical attack, and maintenance of reactor geometry. A fundamental aspect of the safety design philosophy is to provide the capability to perform safety functions first through the selection of inherent reactor characteristics and engineered systems that operate on passive design principles and then to support these safety functions with combinations of diverse active engineered systems and operator actions. This sequence of priorities is reversed from that of currently licensed reactors whose engineered safety features are framed to compensate for rather than complement the inherent characteristics.

The safety design approach for the NGNP is derived from a risk-informed and performance-based model of defense-in-depth. This approach recognizes three major elements: Plant Capability Defense-in-Depth, Programmatic Defense-in-Depth, and a Risk-Informed Evaluation of Defense-in-Depth. These three elements enable the examination of a plant's defense-in-depth capability from different perspectives including those of:

- Designing the plant and the capabilities of its SSCs that perform safety functions.
- Defining the programs that ensure the plant will be built as designed and will operate safely throughout the plant lifetime while preserving the intended defense-in-depth capabilities.
- Evaluating how the plant performs its safety functions in the prevention and mitigation of accidents and determining the adequacy of defense-in-depth.

The NGNP safety design approach is framed in terms of reactor-specific safety functions that were developed from the top goal of containing the inventory of radioactive material and then considering the specific functions that when satisfied would protect the integrity of the fuel and other radionuclide transport barriers. The required safety functions include those to:

- Maintain control of radionuclides
- Control heat generation (reactivity)
- Control heat removal
- Control chemical attack
- Maintain core and reactor vessel geometry
- Maintain reactor building structural integrity

The safety evaluation for the NGNP during the conceptual design phase will be performed using a risk-informed and performance-based approach. The key elements of this technology-neutral approach include: (1) the use of accident frequency vs. radiological dose criteria that are derived from current U.S. licensing requirements, referred to as Top Level Regulatory Criteria (TLRC), (2) use of a full-scope Probabilistic Risk Assessment (PRA) to select the Licensing Basis Events (LBEs), (3) development of reactor-specific functions, selection of the corresponding safety-related Structures, Systems, and Components (SSCs), and their regulatory design criteria, (4) deterministic design conditions and special treatment requirements for the safety-related SSCs, and (5) a risk-informed evaluation of defense-in-depth.

The approach to the treatment of hazards associated with the HPF in the safety evaluation of the NGNP is comprised of the following elements:

- Performance of a Process Hazards Assessment to support the design of the HPF, which includes the HPS and buildings
- Preliminary screening evaluation of event sequences associated with HPS process hazards

- Detailed risk analysis of event sequences associated with HPS process hazards

There are several complexities and risks which must be addressed during the conceptual design and subsequent licensing phases. These include:

- Lack of experience with licensing non-LWR power plants.
- Lack of experience with licensing non-electric power plants.
- Lack of experience with PRA involving combustible material facilities.

During the conceptual design of the NGNP, the above issues will be specifically addressed in the successful completion of the safety evaluation. A key element of that evaluation will be the completion of the conceptual design phase of a full scope PRA that addresses all internal and external hazards, including those associated with the HPF and other facilities of the NGNP.

VII.N PCDR SECTION 15 - SAFEGUARDS AND SECURITY

The various aspects of Safeguards and Security related to the PBMR NGNP are described and the design requirements and features for security are integrated into the preconceptual design of the plant. It is based upon the lessons learned while developing the Combined License Application for the Westinghouse AP1000 Reactor. Many aspects of security are now included in various rules of Title 10 of the Code of Federal Regulations (CFR). Other details and expectations are embedded in documentation that is classified as Safeguards and Confidential. The efforts for this preconceptual phase of NGNP are unclassified. The results of these efforts are guidance and recommendations for layout to enhance the potential to pass a rigorous security assessment.

The NRC has mandated that licensees must establish and maintain physical protection systems that protect against radiological sabotage and theft and diversion of special nuclear materials. This mandate is included in the rules of Title 10 and in subsequent NRC regulations and orders. As a result of the attacks of September 11, 2001, the NRC issued a number of Interim Compensatory Measures (ICMs) related to security that had the force of rule in advance of the revised rules being processed. Since that time, operating plants have made revisions to their physical and operational security features and programs. NRC has audited these modifications and has performed Force-on-Force exercises to evaluate their effectiveness. Both the NRC and the nuclear industry, with the lead of the Nuclear Energy Institute (NEI), have established lessons learned programs and industry templates for compliance with the current expectation of the NRC.

Insights and guidelines are provided to the designers and reviewers of the PBMR NGNP related to the physical security of the fuel and the power plant itself. The focus of this section is on physical design, since operational programs, such as security force makeup, training, fitness for duty, etc., will be established at the time of plant licensing and are not directly dependent upon the physical design. It is an abbreviated compilation of primary requirements, criteria, NRC guidance and industry practice. It will be updated and maintained in conceptual design.

Security of the fuel including its transport and handling at site, Nuclear Heat Supply Facility security related to the Design Basis Threat (DBT), and aspects of the beyond DBT features currently implemented by operating and new nuclear power plant designs in response to the attacks of September 11 are discussed.

Since the work is unclassified, many such details of the NRC rules and regulations cannot be specified. Following preconceptual design, designers and reviewers will be required to obtain clearance from the NRC to review and handle Safeguards Information (SGI).

By its very nature, the PBMR design is inherently more resistant to attacks than LWR designs currently deployed and being licensed. Accordingly, it is envisioned that the current NRC rules and regulations for LWR-based security can be amended in the future to account for the relative inherent robustness of the PBMR design.

VIII TECHNOLOGY DEVELOPMENT

The PBMR NGNP technology development plans have been developed in response to Design Data Needs (DDNs) that were identified in the course of developing the NGNP preconceptual design. The technology development plans are based on a 2018 operational date for the NGNP. Many of these plans are driven by the procurement requirements for the respective components and require significant early R&D as a basis for completing the design of these components, since some have yet to be built and tested. The critical path components include the Intermediate Heat Exchanger (IHX), several components in the Hybrid Sulfur-based Hydrogen Production System, including the electrolyzer and decomposer, and the high-temperature Steam Generator (SG) of the Power Conversion System (PCS). Confirmatory testing of the fuel and graphite must be started as soon as possible, since demonstration that the fuel and graphite are capable of the extended operating envelope of the NGNP compared to the PBMR DPP is critical for early licensing acceptance. Most critical is the fuel. Early fuel spheres from a production-scale coater will be available from Pebble Bed Modular Reactor (Pty) Ltd. in early 2008 for characterization and pre-qualification testing and full production spheres will be available by 2012 for qualification testing.

It is noted that the technology development plans for the PBMR NGNP have focused on the “enabling” technologies which are considered essential in order to meet the NGNP schedules, and hence are the highest priority for funding. Further, these enabling technologies are incremental to the extensive past and ongoing R&D effort by PBMR in South Africa and at other research institutions around the globe to support the design and licensing of the PBMR DPP and the PBMR Pilot Fuel Plant. The differences between the DPP and NGNP designs have been identified in the NHSS and Fuel sections and the corresponding enabling DDNs are focused on addressing those differences.

To date, over $500 M has been invested in the overall DPP Project. Preliminary estimates of the past and forward investments related to the PBMR NHSS and fuel development and tests related to the fuel production facilities that serve to offset costs otherwise required for the PBMR NGNP are in the range of a total of $750 M. The incremental enabling technology development for the NHSS and Fuel are addressed in this section and the other incremental costs are addressed in Section 19.

The total incremental enabling Technology Development effort foreseen for the PBMR NGNP is in the range of $184 M (2007$) and will take about 8 years to complete. The overall summary schedule and cost for Technology Development is shown in Figure ES-19 and Table ES-3. Enhancing technology development candidates are also identified that need to be considered for product improvements and/or risk reduction.

As elaborated in Section 19, the cost estimates presented in this PCDR are considered "mean" or "expected" values whereby there is a 50% weighted probability of the actual costs being higher or lower. As appropriate, contingencies are included to achieve the expected value. Further, a percent range of high-to-low confidence is provided at the summary level in Section 19 to represent the relative degree of uncertainties.

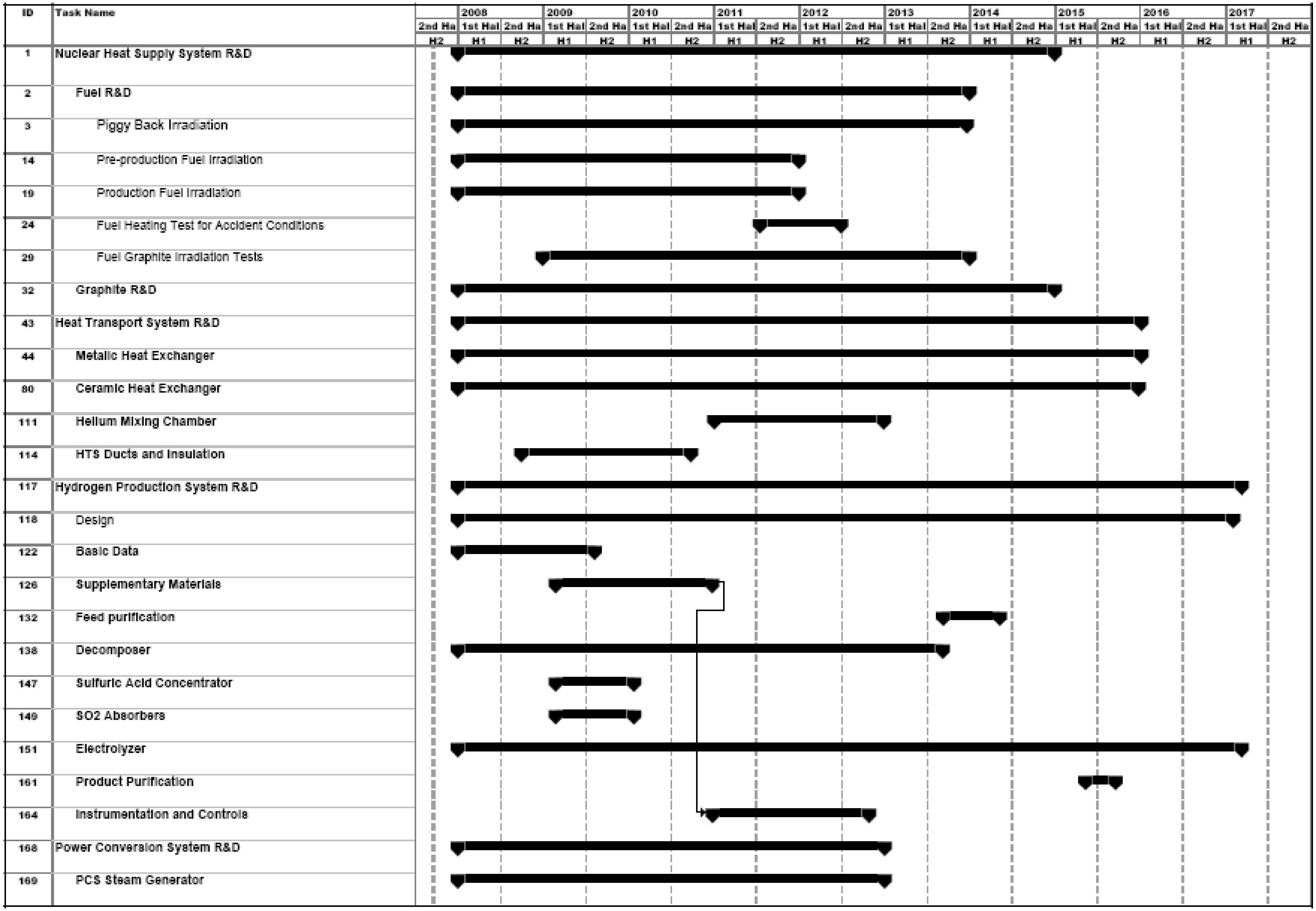

Figure ES-19: Overall Technology Development Schedule

Table ES-3: Technology Development Cost Schedule ($M)

	FY2008	FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	TOTAL
Nuclear Heat Supply System											
Fuel	0.5	4.5	6.5	6.5	6.5	5.5	3.5	3.5	3.5	4.5	45.0
Reflector Graphite	0.5	0.6	0.8	0.8	0.7	0.9	0.7				5.0
Subtotal	1.0	5.1	7.3	7.3	7.2	6.4	4.2	3.5	3.5	4.5	50.0
Heat Transport System											
Metallic IHX	3.9	6.9	6.0	2.0	0.3						19.0
Ceramic IHX	3.6	6.6	5.2	4.5	4.3	4.3	0.6	0.6			29.6
HTS Other	0.4	1.1	0.8	1.1	1.1						4.5
Subtotal	7.8	14.6	11.9	7.6	5.7	4.3	0.6	0.6			53.1
Hydrogen Facility											
Basic Data	1.0	0.3									1.3
Materials		3.3	2.7								6.0
Feed Purification				0.8							0.8
Decomposer	2.9	3.0	2.2	2.1	5.2	3.1					18.4
Concentrator and Absorber		1.1									1.1
Electrolyzer	1.6	2.6	2.8	3.4	4.4	3.2	8.1	2.8			29.0
Product Purification + Sensing and Control				1.3	0.14			0.2			1.7
Subtotal	5.5	10.3	7.8	7.6	9.7	6.3	8.1	3.1			58.4
Power Conversion Facility											
Steam Generator R&D	0.6	4.1	7.3	7.7	2.8						22.5
Total Technology Development	**14.9**	**34.1**	**34.3**	**30.2**	**25.5**	**16.9**	**13.0**	**7.2**	**3.5**	**4.5**	**184.0**

VIII.A NUCLEAR HEAT SUPPLY SYSTEM

Fuel Irradiation

DDNs have identified the need for additional fuel irradiation capsules that will provide confirmation of meeting the extended performance envelope of the NGNP and assure an adequate statistical database for the design and licensing efforts. It will require additional data covering the increased fluence and the operating and limiting accident temperatures of the reference UO_2 fuel. Burnups as high as 109 MWD/MT are to be tested at peak operating temperatures of 1300 C, with peak temperatures during accident conditions of 1800 C. Budget estimates are subject to irradiation facility plans and overall cooperative arrangements. The PBMR DPP baseline plans assume continued use of the Russian IVV-2M test reactor. In the near-term, process qualification fuel particles and spheres made with prototypical production equipment need to be characterized, including unirradiated fuel data and initial irradiated fuel data to confirm production specifications. This fuel will be available in 2008, and presents a mutual opportunity for INL and Pebble Bed Modular Reactor (Pty) Ltd. to collaborate on efforts that will help develop needed experience at INL/ATR and perhaps other facilities. Assuming a collaborative INL/PBMR fuel qualification program, a preliminary budget allowance for incremental fuel development is $45 M. Pilot plant production fuel for such capsules is projected to be available in the 2012 timeframe, and the baseline schedule for supplemental testing requires about 6 years.

Graphite

DDNs for the incremental graphite qualification program for the NGNP address gaps in data covering the fluence-temperature operating range at both low and high temperatures. In order to take mutual advantage of PBMR's ongoing program to qualify SGL graphite, plus INL's and PBMR's mutual interests to cooperate on graphite qualification with SGL and Graftek, efforts are underway to develop a collaborative INL/PBMR program. Priority activities in FY2008 include continued planning and preparation for the initiation of capsule irradiation tests at INL/ATR. Assuming a collaborative INL/PBMR graphite qualification program, a preliminary allowance for the budget is $5 M.

VIII.B HEAT TRANSPORT SYSTEM

The Intermediate Heat Exchanger (IHX) is a critical component of the NGNP and a fundamental enabling technology for high-temperature process heat applications in general. The IHX requires a significant development effort, largely in the materials area, to demonstrate that a design can be developed for the high temperatures, pressures and transients expected for the NGNP. Parallel efforts are recommended that address the most promising metallic and ceramic materials. The results will support an ASME code case and a final design for the IHX that will need to be prototyped and tested. The total cost for IHX development is estimated to be $53 Million, which includes approximately $10 M for an IHX test facility. The IHX technology development is projected to take about 8 years to complete.

VIII.C HYDROGEN PRODUCTION PLANT

The Hybrid Sulfur (HyS) process has been selected as the initial reference hydrogen production technology for the NGNP preconceptual design, on the basis that it has the best chance of early commercial deployment. However, the HyS technology poses significant research and development challenges. While the process has been demonstrated on a laboratory scale, converting the laboratory performance into a production plant requires significant R&D in the areas of basic thermo-chemical reaction and kinetic data and the development of key components, including the decomposer and electrolyzer, followed closely by the sulfuric acid concentrator and SO_2 absorber. The total technology development cost is $58 M which includes a pilot plant to test individual components, system dynamics and the effects of low levels of impurities on sensitive components. The scope of the R&D effort described herein is only a rough first estimate. With additional design, research, and study work, the scope may change in important ways. Development related to materials of construction appears at this point to be the most important source of risk.

VIII.D POWER CONVERSION SYSTEM

The power conversion cycle chosen for the NGNP is a Rankine cycle, requiring a steam generator. While helium-to-steam generators have been previously built, the NGNP Steam Generator requires incremental development, due to its larger size and the increased helium temperatures that would be present under some operating conditions. Since the Steam Generator is a long lead time procurement component, key elements of the Steam Generator Technology Development Program need to be started no later than FY 2009. Significant prototype testing is also included in the technology development plans. The total cost of the Steam Generator technology development is $22.5 M, and will take 5 years to complete.

VIII.E ENHANCING TECHNOLOGY DEVELOPMENT OPPORTUNITIES

As previously noted, the NGNP Technology Development Plan, described herein, is incremental to the presently ongoing PBMR DPP R&D effort and includes enabling technology development only. In this context, the term “enabling technology development” refers to the minimum required to design, license and operate the NGNP. Although not specifically scoped, scheduled or estimated in this plan, “enhancing technology” development opportunities were identified that would be useful for long term research to enhance the performance of the PBMR NGNP and/or further reduce cost and risk, particularly in follow-on commercial applications.

Areas in which enhancing technology development opportunities were identified include:

- Advanced Fuel Development
- Advanced Fuel Manufacturing
- Advanced Fuel Cycle Investigations
- Design Code Development Verification & Validation Collaboration
- Extended Graphite Development and Characterization
- Liquid Salt Heat Transport Media

It should be noted that the Technology Development needs for other process heat applications have not been included and will be the subject of future special studies.

IX LICENSING AND PERMITTING

Licensing is recognized as a major cost and schedule risk for the NGNP project. This section presents a licensing strategy for the PBMR-based NGNP project that seeks to mitigate such risks. Key elements include: (1) a license application strategy, (2) the treatment of risks, (3) regulatory compliance, (4) technical issue resolution and (5) strategy execution. Schedule and cost estimates for executing the NGNP licensing strategy are included in PCDR Sections 18 and 19, respectively. The resultant strategy supports a NGNP operation date of 2018, assuming adequate resources for the overall project plus NRC acceptance of the PBMR's nuclear safety concept. An overview of the strategy follows:

- The PBMR-based NGNP licensing strategy fulfills the requirements in the Energy Policy Act of 2005 for licensing by the NRC.
- The PBMR-based NGNP licensing strategy supports the NGNP strategy concurrently being advanced by the NGNP Working Group that seeks to establish a Public/Private Partnership between DOE and an end-user based Alliance that can serve as the applicant for the DOE-owned NGNP.
- The PBMR-based NGNP licensing strategy builds upon the ongoing PBMR Design Certification Pre-Application Program.
- An integrated NGNP pre-application program (of approximately 48 months duration) should be conducted with NRC.
- The license application strategy for NGNP should include: (1) review and receipt of an Early Site Permit (ESP) within about 21 months, (2) review and receipt of a Combined License (COL, for construction and operation) within about 36 months and (3) a Limited Work Authorization (LWA) for early site work.
- Implementation of risk-informed, performance-based methods provides a means for logical evaluation and resolution of regulatory compliance issues – especially those related to non-LWR technology.
- Successful collaboration with supporting industry programs is important to the timely resolution of safety issues with the NRC staff, including coordination of R&D with the NRC, national laboratories, and other supporting programs.
- The ESP and COL for the NGNP at INL will establish a precedent for applying Part 52 to a non-LWR design and, specifically, will provide a firm basis for timely Design Certification, licensing, and operation of follow-on NGNP derivative commercial plants.

The proposed licensing strategy is further developed in the conceptual design phase of the NGNP program including the following major activities:

Establish an integrated NGNP Licensing Strategy, including a project schedule, acceptable to all stakeholders.

Establish the NGNP Licensing Review Basis document to coordinate planning with the NRC.

- Establish an integrated Regulatory Technology Development Plan that will serve as the basis for any independent R&D needs by the NRC.
- Establish an integrated plan for the preparation of environmental permitting applications.

X SCHEDULE

The PBMR NGNP Project schedule establishes a project road map from conceptual design, through construction and startup of the demonstration plant by the end of FY 2018. The schedule identifies various activities and key milestones. Subsequent resource loading of schedule activities provides yearly funding profiles starting at the beginning of the conceptual design in 2008, and through the anticipated plant shutdown for inspection and analysis in 2021.

In general, the activities presented in the schedule are categorized into project level activities and facility level activities. For consistency with other NGNP-related work, project level activities are identified and grouped in accordance with the Work Breakdown Structure (WBS) provided by INL/BEA. The NGNP Project schedule integrates the project and facility level activities into a cohesive presentation for the execution of the project.

The schedule of activities for the Nuclear Heat Supply Facility (NHSF) has been developed with the project schedule for the PBMR DPP used as input. All NHSF activities, activity durations, and activity linking have been reviewed by Pebble Bed Modular Reactor (Pty) Ltd. and reflect NGNP Project-specific issues. The development schedules for both the Intermediate Heat Exchanger (IHX) and the Hydrogen Production Facility (HPF) represent the best available logic and expectations for achieving critical development targets. The schedules for the Power Conversion Facility (PCF) and BOP facilities represent conventional scheduling experience.

The NGNP Project schedule was prepared so as to be consistent with DOE Order 413.3 project and budget cycle and Critical Decision (CD) points (CD-0, CD-1, CD-2, etc.). The schedule shows two sets of critical decision points for the two plant facilities that will have most significant cost and/or risk impact associated with the NGNP mission: the NHSF and the HPF. Separate CD milestones are shown for the HPF, due to the differences in schedule logic. Preliminary Design and Final Design for the HPF need to wait for technology development to occur.

The overall NGNP Project schedule from start to full power is 11 years in duration, with an additional 3 years of operation thereafter. At the end of 3 years of operation there will be a one month shutdown for inspections. A summary of the NGNP Project Schedule is shown in Figure ES-20. The schedule begins with the start of conceptual design in early October 2007. The final completion date, meaning the completion of startup and testing activities and operation of the facility at full power, is at the end of September 2018.

Licensing activities, whether application preparation activities by the NGNP Project team or NRC review activities, occur during approximately the first 7½ years. The NRC licensing process includes both an Early Site Permit (ESP)/Limited Work Authorization (LWA) and a Combined Construction Operating License (COL) application review process. The anticipated

NRC review duration for each is anticipated to be 21 months and 36 months, respectively, and will occur during the latter part of the 7½ year period.

A critical path analysis of the schedule resulted in the identification of three potential critical paths:

1. NHSF engineering/design, safety analysis, licensing, and construction
2. IHX technology development
3. Hybrid Sulfur (HyS) technology development.

The first critical path results from analyzing the scheduled activities and identifying activities through precedent and antecedent links between activities. The second two potential critical paths are derived from an assessment of less tangible risks inherent in the schedule; specifically, the uncertainties associated with the technology development of the IHX and HyS process.

The approach adopted for the NGNP Project Schedule is one that assumes a balanced risk. Invariably, any risk inherent in the schedule will have an associated risk to the project cost estimate. Therefore, mitigation of schedule risks will not only ensure timely completion of the project, but also reduce the likelihood of significant cost variances from the estimated project cost. In brief, identified risks include:

- Licensing Cost and Schedule Risks;
- Technology Development Costs and Schedule Risks;
- Project Development Costs and Schedule Risks;
- Project Experience Risks;
- Adequate Resource Risks, and
- Commercial Infrastructure Risks.

The following recommendations concerning the NGNP Project Schedule are made in order to address the risks and reduce the uncertainty in meeting the project completion date at the end of fiscal year 2018:

- Begin implementation of the future studies and conceptual design, as soon as possible.
- Start NGNP pre-application interactions with the NRC as soon as possible to secure the licensing strategy basis for the schedule.
- Immediately implement the recommended technology development programs,

particularly in the areas of the IHX and limiting hydrogen production processes.

- Begin developing the acquisition strategies and long lead procurement programs for the major equipment identified in the schedule.
- Develop and implement risk mitigation strategies.

During the course of the preconceptual design effort, the Westinghouse Team developed more detail for conceptual design activities. A summary of the Conceptual Design schedule is shown in Figure ES-21.

The Conceptual Design schedule is arranged in a similar manner as the NGNP Project schedule, utilizing the BEA WBS as much as practicable. In addition to design activities, the schedule also shows programmatic activities such as program level plan and procedure development and design reviews by BEA at 35 and 90% Conceptual Design milestones. Other important activities shown include pre-application interactions with the NRC and the immediate start of essential technology development tasks, as recommended by the Team.

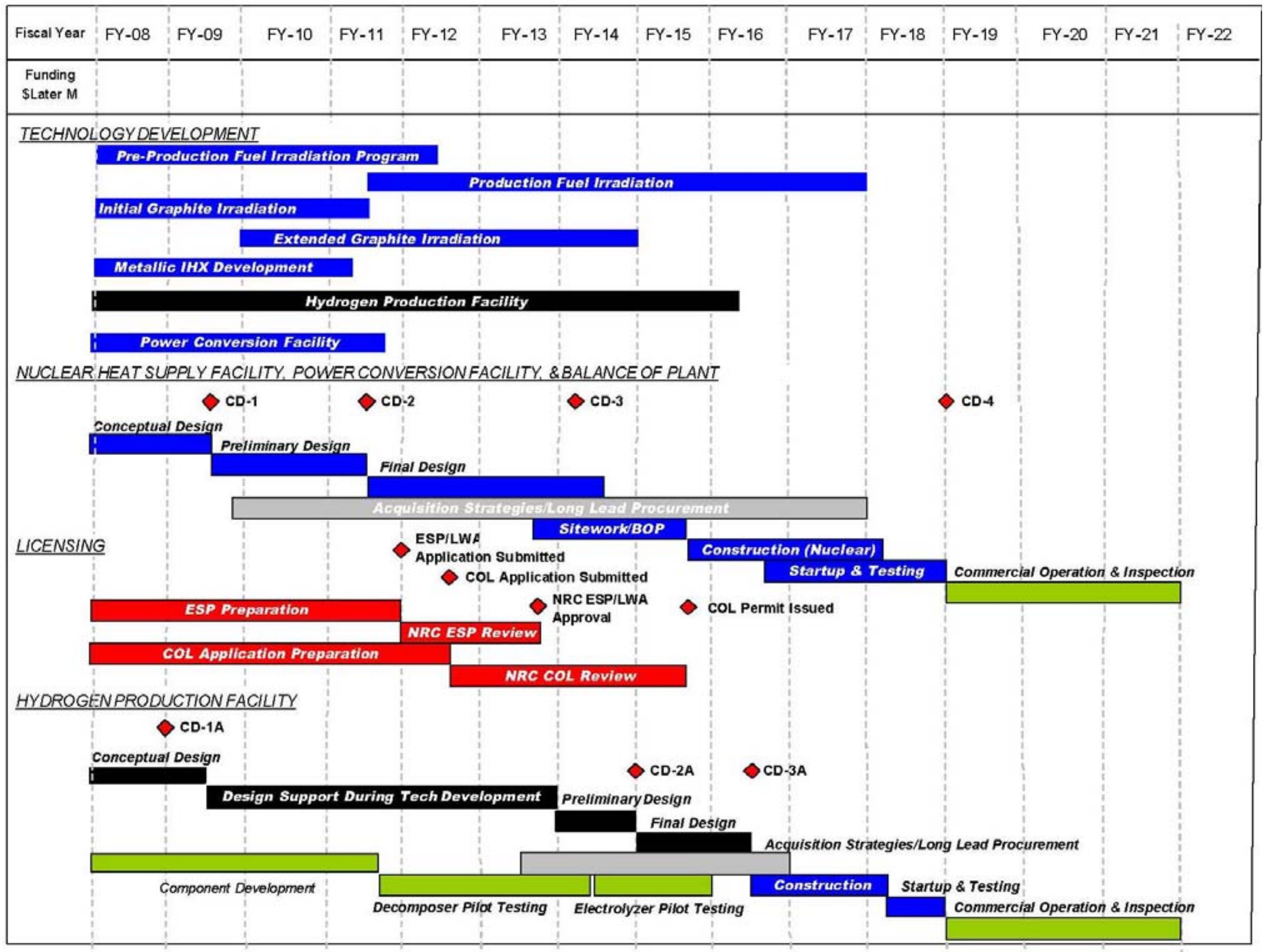

Figure ES-20: NGNP Project Schedule and Funding Profile Summary

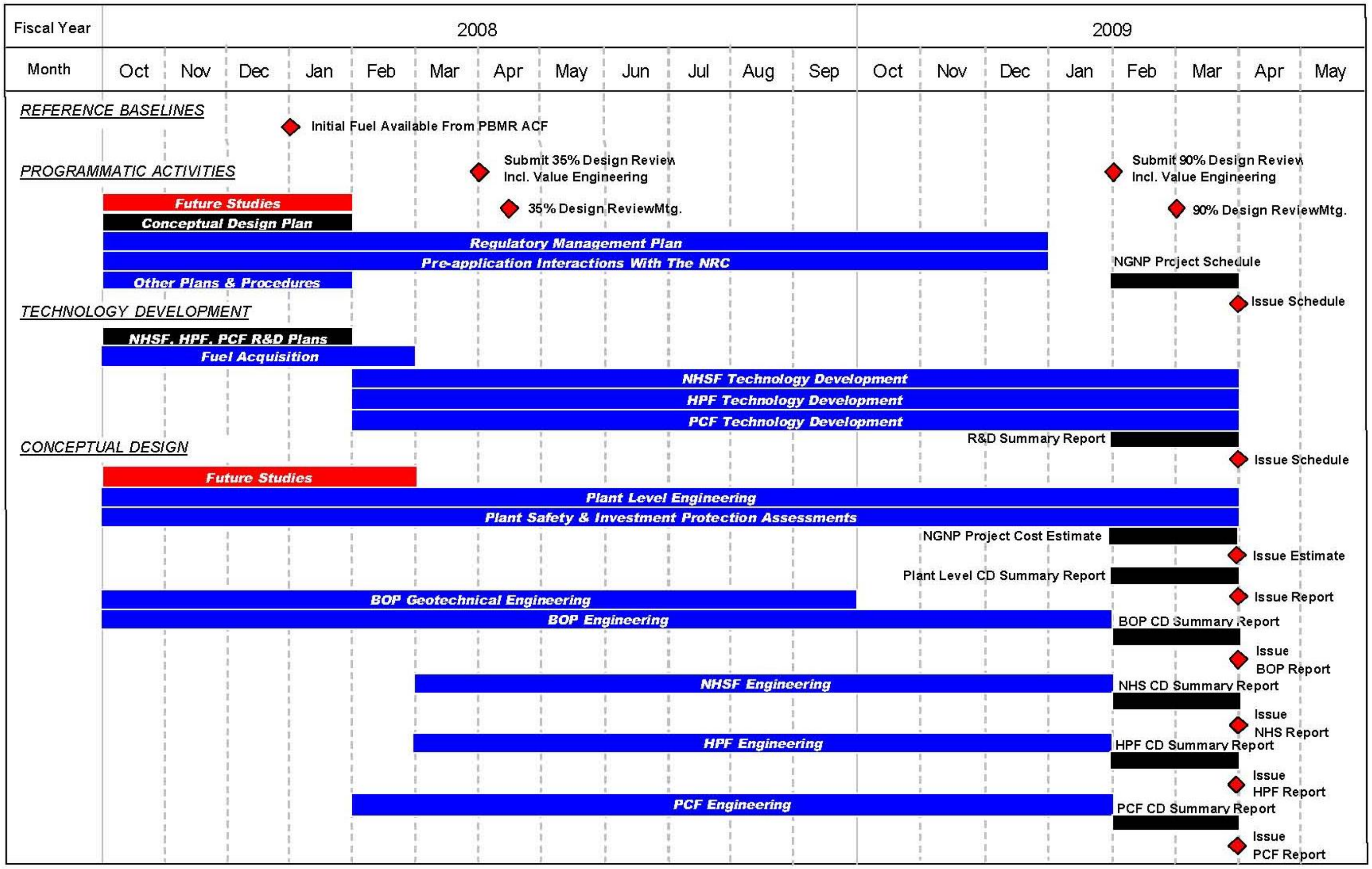

Figure ES-21: NGNP Conceptual Design Schedule Summary

XI ECONOMICS

This section investigates the capital costs, operating costs and the economic performance for the PBMR-based Next Generation Nuclear Plant (NGNP). This includes the development, construction and 6 years of operation of the NGNP integrated facilities as well as the future construction and operation of a mature full-scale, four-module commercial plant.

NGNP Demonstration Project

The capital costs are estimated based on the preconceptual design information presented in other sections of this report. The major capital cost components of these projects are:

- Nuclear Heat Supply Facility (NHSF),
- Hydrogen Production Facility (HPF),
- Power Conversion Facility (PCF), and
- Site and Balance of Plant (BOP).

Other significant initial expenditures included in the estimate for the NGNP Demonstration Project are:

- NGNP design development,
- NGNP licensing and permitting,
- Technology development (R&D),
- Project management for the design, licensing, construction and startup by the vendor/supplier team
- Project development and management by the evolving Public/Private Partnership (PPP) entity and INL/BEA staff support,
- Project startup costs including the plant operating staff, and
- First-of-a-kind (FOAK) reference commercial plant design and design certification of a standard NHSS and its associated auxiliaries and structures.

The NGNP Demonstration Project costs are applied to the schedule developed in Section 18 to calculate yearly cash flows beginning with Conceptual Design in 2008. The resulting summary schedule and fiscal-year, resource-loaded schedule are included in Appendix A of this section. Costs for labor and materials are identified at a summary level for the major WBS elements of the Project (e.g., Technology Development, Licensing, Design and Construction) for each of the major facilities and for Project management.

Operating revenues and expenses are projected for the NGNP Demonstration Project.

The NGNP Demonstration Project is projected to begin operation in 2018 with an anticipated plant shutdown in 2020 for inspection and maintenance. Afterwards, outage maintenance will be done on a six-year cycle.

The key results of this analysis are:

- The total cost for the PBMR-based NGNP Project is $2.08B in 2007$ plus an estimated $338 million in inflation plus escalation (based on an assumed 2%/yr underlying inflation with the assumption there is no escalation in capital above inflation). Total project expenditures by year are summarized in Figure ES-22. Costs by major area are shown in Figure ES-23. These estimates are sensitive to the uncertainty range for some of the major equipment cost estimates and related development costs, where such equipment is not currently available commercially.

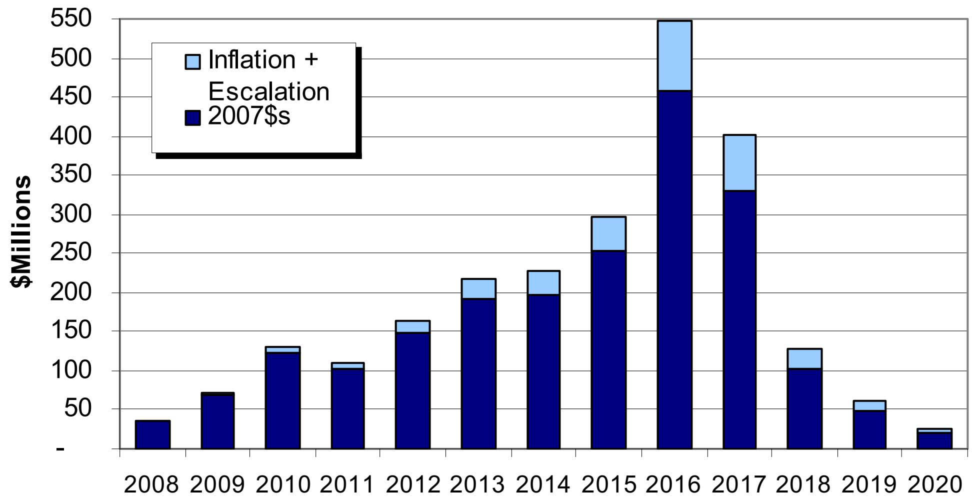

Figure ES-22: PBMR NGNP Demonstration Project Cash Flow

The PBMR nuclear reactor system plus related equipment and fuel will be demonstrated in South Africa with the PBMR Demonstration Power Plant (DPP). PBMR (Pty) Ltd. has provided provisional estimates for their expected scope of supply that builds on extensive ongoing work to support the DPP.

Major components of the Hybrid Sulfur Process, including the internals of the thermo-chemical reactor and the electrochemical cells, require further development and demonstration to confirm cost estimates that have been prepared based on experience with similar equipment and systems and inputs from suppliers. Costs of the electrochemical cells are based on expectations that appropriate materials and functional technology development objectives will be achieved.

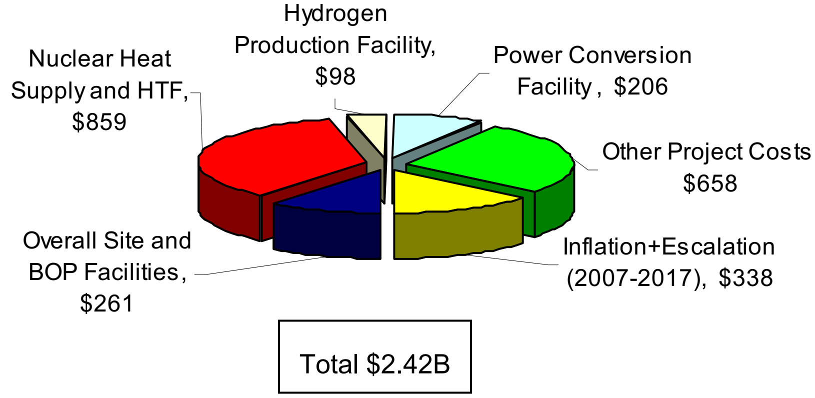

Figure ES-23: Summary of PBMR NGNP Demonstration Project Costs ($M)

Operating costs for the first six years of operation are shown in Figure ES-24. Operating costs include fuel costs, fixed costs and variable operating costs.

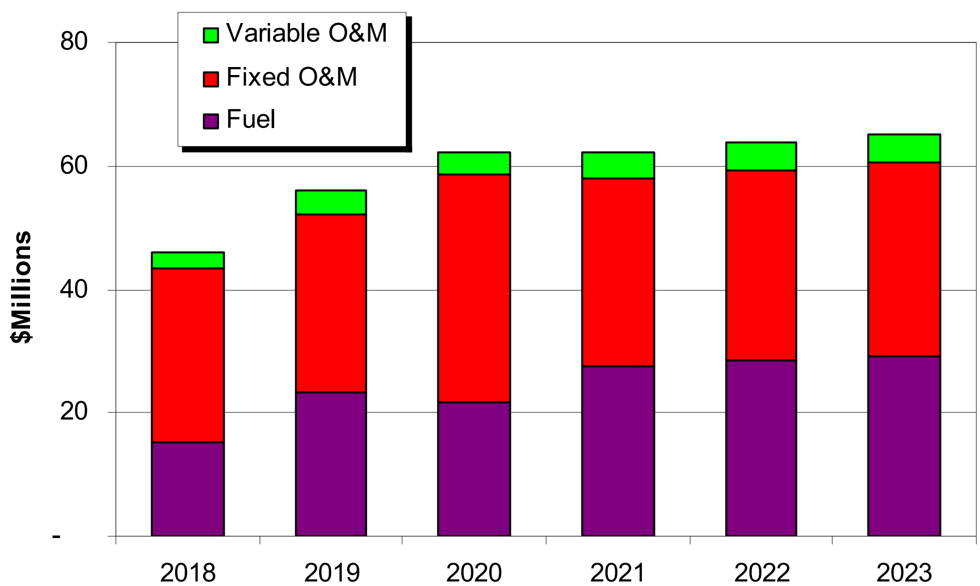

Figure ES-24: NGNP Demonstration Project Operating Costs (As-Spent $)

The revenues projected for the first six years of operation of the demonstration plant are shown in Figure ES-25. These include power, hydrogen and oxygen sales. The revenues are based on market prices of $2/kg for hydrogen with a 2%/yr real escalation, $50/MWh for power with a 1%/yr real escalation, $40/tonne for oxygen with a 0.5%/yr real escalation and $30/tonne for CO_2 credits with a 1.5%/yr real escalation. The drop in 2020 is due to a shutdown and inspection of the developmental components and systems plus first routine maintenance. Afterwards, schedule maintenance outages are done on a six-year cycle.

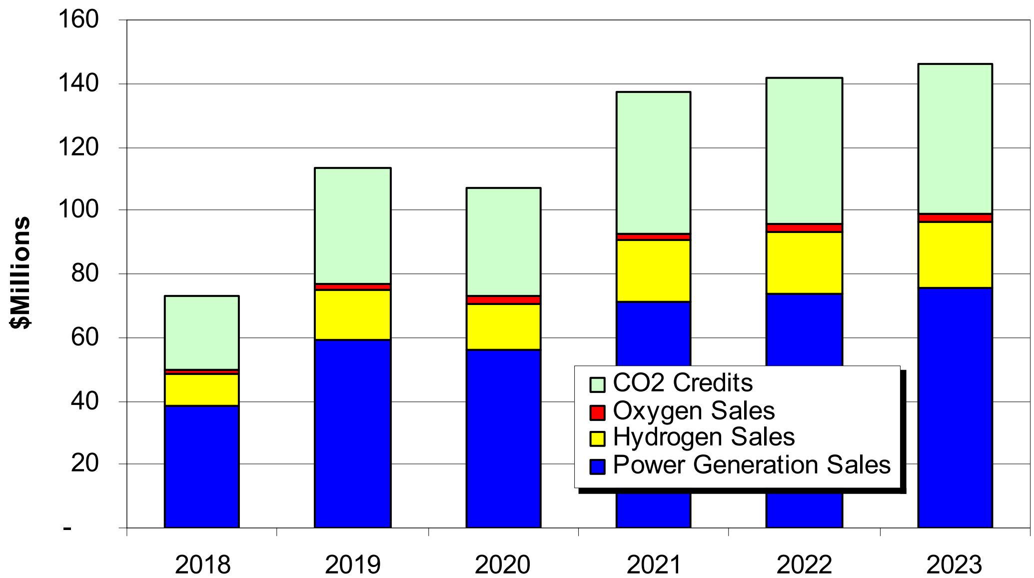

Figure ES-25: NGNP Demonstration Project Revenue Projections (As-Spent $)

If the costs and revenues presented above can be achieved, the NGNP Project should be able to operate with a net positive cash flow. Key uncertainties include:

- Ability to achieve the estimated operating costs,
- Ability to achieve plant output and availability,
- Access to markets for hydrogen, oxygen, power and CO_2 credits, and
- Ability to secure hydrogen, oxygen and power revenues plus CO_2 credits.

Commercial Plant Project

The mature Commercial Plant Project is projected to enter operation in 2026 and the life cycle costs are based on 40 years of operation. The resulting economic model for the commercial plant calculates the required price for hydrogen to recover the required return on investment and cover plant operating costs.

The design of the Commercial Plant Project is derived from the NGNP Demonstration Project with the following major differences:

- The NHSF includes four nuclear reactor modules and heat transport system modules, each module coupled to a dedicated HPF module and a single steam generator,
- A single turbine generator uses heat from all four HPF modules and is optimized to use recovered heat for feedwater heating,
- One larger IHX is provided per NHSS module vs. two smaller IHX's in the Demonstration plant; IHX service life is extended to match plant economic life,
- Each steam generator is sized for the amount of heat available with the HPF operating,
- A Gulf Coast site that provides lower labor cost and higher productivity, good access for heavy equipment delivery, ability to use wet cooling towers, and close access to power delivery for transmission and bulk pipeline distribution systems for hydrogen and oxygen delivery to industrial markets.

The cost for the Commercial Plant Project is summarized in Figure ES-26. The total cost is, \$3.72B in 2007\$ plus \$1.56 billion in inflation and escalation.

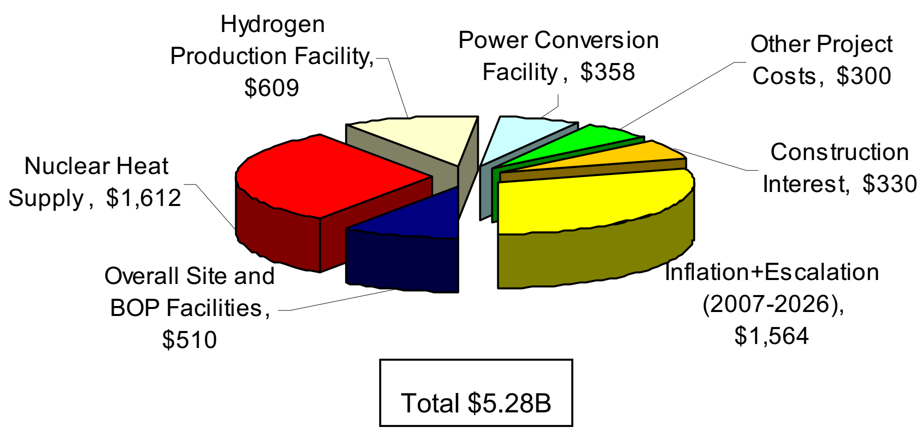

Figure ES-26: Summary of Commercial Plant Project Capital Cost (\$M)

A cash flow model was developed to determine the required price of hydrogen to cover the capital, fuel and operating costs of the Commercial Plant Project. As a mature "n-th plant" project, this assumes a number of other projects are successfully implemented between the time the NGNP is completed and before the mature Commercial Plant is deployed. The following key assumptions and targets illustrate the circumstances under which the Commercial Plant Project achieves economic viability:

- Positive outcomes of nuclear technology and design certification efforts that support plant simplification and staffing targets,
- Positive outcomes from technology development that support key plant design, performance and maintenance targets,
- Achievement of major gains in mature technology, supply chain and project experience that support project implementation and cost targets,
- Positive economic conditions that support the labor, material and equipment costing and other economic assumptions embedded in this analysis,
- Achievement of 95% average plant capacity factor through plant design, operations and preventive maintenance,
- Achievement of suitable project risk management approaches that support project financing through equity and debt arrangements associated with mature power projects, possibly in combination with some forms of public and/or regulated ratepayer risk sharing arrangements, consistent with the history of US nuclear and infrastructure projects that provide long term benefits to ratepayers and the public.
- Markets for new hydrogen and oxygen capacity that support revenue targets for the project,
- Markets for new power generation capacity and energy that support the power revenue targets for the project, and
- Continued real escalation of natural gas prices, hydrogen prices and power generation prices plus implementation of a CO_2 emission trading system that provides revenue from sale of credits.

These assumptions support an economic analysis of a mature Commercial Plant Project that can produce hydrogen at an equivalent 2007 base price of $2/kg, or at an equivalent natural gas price of about $7.75/MMBtu for a new conventional steam methane reforming plant producing hydrogen over the same period. These results are sensitive to the assumptions, e.g. a 2%/yr real escalation rate for hydrogen, applied for this analysis, which are described further in other parts of this report.

The required price of hydrogen is highly sensitive to the required equity Rate of Return ("ROR"). The required equity ROR reflects the amount of risk taken by investors compared to other investments available to them. A representative equity ROR of 16% is assumed as a base case value to reflect the cost of equity that is associated with mature projects covered by strong contracts that virtually eliminate construction risk and market risk. If these risks are not eliminated then investor perceptions may require higher equity ROR. Conversely, if some or all of the equity is replaced with investment secured by the public or by a regulated rate base, a lower return will acceptable which has a dramatic impact on the required price of hydrogen.

Figure ES-27 shows the sensitivity of required hydrogen price to variations in the ROR. A one percent reduction in the equity rate of return is roughly equal to $0.40/kg – $0.50/kg. This clearly demonstrates how critical the cost of capital is for capital intensive projects. If the project is financed entirely by government bonds, for example, the required cost of hydrogen would drop below current hydrogen pricing given the assumptions used in these calculations. Alternatively, if the equity has to carry a lot of risk, the high rate of return results in a cost of hydrogen well above expected market prices. This forms the philosophical basis for a public/private partnership with some combination of risk sharing that reflects the long term value of such a project to the public based on environmental and energy security benefits.

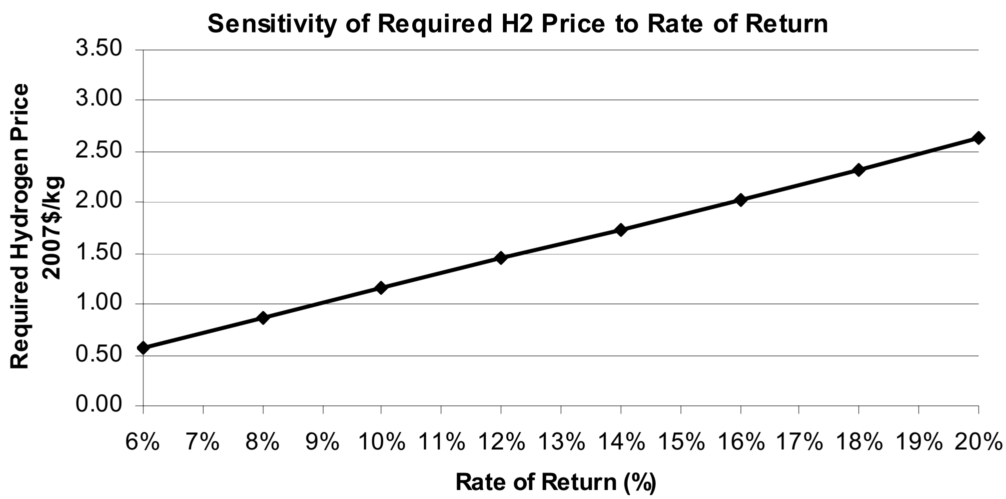

Figure ES-27: Sensitivity of Required Hydrogen Price to Equity ROR

XII RISKS AND APPROACH TO MITIGATION

Each of the PCDR design and assessment sections lists the related complexity and risks as a means of tracking alignment with the corresponding mitigation strategy that may warrant a R&D or programmatic priority. A summary of the top level risks follows per principal areas:

Licensing
Technology Development
Project Development
Project Experience
Adequate Resources
Commercial Infrastructure

For each of these principal areas, Table ES-4 identifies the risks, a summary of the basis for the risks; and the planned approach to mitigate them.

Table ES-4: Top Level Risks and Approach to Mitigation

	Risk Areas	Summary	Mitigation
A	**Licensing**		
1	NRC acceptance of NGNP licensing bases and strategy, plus R&D requirements for V&V and/or testing.	NRC's acceptance of the PBMR Pre-application design certification content plus requirements for safety related V&V are TBD.	A quality NGNP Pre-application Program and V&V Program provide satisfactory resolution, plus confirmatory testing potential with the NGNP.
2	NRC resources and commitment to support Project schedule.	NRC's resources may be inadequate to support the target NGNP schedule due to low commitment priority.	Priority to be assigned in the near-term by Users/Alliance, DOE, Congress, and as soon as possible by Applicant(s). Schedule acceptance by the NRC as soon as possible with appropriate cost and schedule contingency.
3	PBMR DPP licensing precedents and/or issues negatively impact the acceptance of NGNP licensing bases and strategy.	The PBMR DPP licensing approach and delays could create licensing issues with the NRC.	Continued PBMR priority to minimize such or at least reconcile any differences that preclude problematic precedent setting elsewhere.

	Risk Areas	Summary	Mitigation
B	**Technology Development**		
4	IHX development uncertainty.	IHX materials, performance, lifetime, nuclear codification and costs are uncertain.	Prioritize design, multi-materials qualification, V&V program and supplier development starting in FY08. Appropriate cost and schedule contingency included.
5	HyS development uncertainty.	HyS materials, performance, lifetime and costs for decomposer and electrolyzers are uncertain.	Prioritize design, multi-materials qualification, V&V program and supplier development in FY08. Appropriate cost and schedule contingency included. Stay positioned to adopt alternative hydrogen production technology if HyS technology proves impractical or too costly as R&D proceeds.
6	Fuel performance uncertainty.	Qualification of Pilot Fuel Plant reference UO_2 fuel for 500 MWt and 950C core outlet temperature is pending TBD fuel irradiation program for the NGNP.	Prioritize fuel qualification and source term programs in SA and the US. Contingency plans for improved fuel and/or reduced duty.
C	**Project Development**		
7	Cost of H_2 product for commercial PBMR plants versus incumbents and contemporary alternatives is uncertain.	Evaluated mature PBMR H2 PHP plant competitiveness is uncertain due to design and performance uncertainties associated with processes.	Continue priority on critical design and cost development and management plus economic analyses with candidate user interactions for early indicators of attractiveness.
8	NGNP Project costs and schedule exceed stakeholder acceptance.	Potential for DOE/INL overhead costs, NRC R&D costs and schedule extensions, extended multiple vendor team costs and required R&D costs being excessive.	Decisive Project management that focuses on critical path issues for Project implementation. Committed, capable Vendor/Operator/User team with cost/risk offsets and sharing. International cooperation via GIF focuses on related technologies.

	Risk Areas	Summary	Mitigation
9	Major increases in Project costs from current estimates.	Current estimating process is limited by the extent the Project can be defined, and by limited accuracy of estimating approaches applied during the preconceptual phase of work.	High costs and risks for reactor and fuel development are covered by the PBMR DPP and based on current supplier quotations. Appropriate contingencies are included in overall Project costs per the experienced team.
D	**Project Experience**		
10	Performance risk.	The plant may have to operate at lower power, lower temperature, or suffer higher than expected outages.	Thorough systems analyses and appropriate margins will be applied to cover performance uncertainties.
11	Operating cost risk.	Actual costs for operating, maintaining and repairing the plant may exceed current estimates.	Further work will be required to refine projected operating and maintenance costs, and the likely frequency and extent of periodic overhaul cycles. Current estimates are based on judgment and experience with similar projects.
12	Risk of shortened economic life.	Equipment problems or failures may make it too difficult or expensive to provide repairs to complete the life of the NGNP project as forecast.	Thorough RAM and investment protection analyses will be applied. Critical components (e.g., IHX) will be designed for relative ease of replacement. Design of the PCS and the HPS will be based on current power and process industry practices where the plant design supports long-term and economical replacement of parts and repairs.
E	**Adequate Resources**		

	Risk Areas	Summary	Mitigation
13	Adequate, sustained DOE funding support is currently missing and subject to annual political priorities and decisions.	The political decision-making process to support a Project through completion is a major risk to other stakeholders with the possibility of their investment in R&D and Project development being lost.	Innovative multi-year phased commitments are needed, e.g., Technology Investment Agreements. Joint commitments are needed within the US government and any supporting governments, plus the vendor/ operator/user team along with broad based political support from the user Alliance, academia, R&D institutes, etc. Multiple follow-on projects are advanced as backup demo Project candidates.
14	Sufficient private sector support for Alliance and Public/Private Partnership cost/risk sharing arrangements are TBD.	The Alliance/ Partnership concept builds on FutureGen precedents, with DOE ownership and INL siting, but is challenging for gaining end-user support.	HTGR community Working Group efforts are underway to develop the Alliance and Partnership concept in concert with Congressional/DOE budget support. Multiple follow-on projects are advanced as backup demonstration Project candidates.
F	**Commercial Infrastructure**		
15	Early commercial plant ownership and cost/risk sharing arrangements are TBD.	A likely merchant plant ownership for the first series of commercial plants and the roles of process heat users present major challenges.	Government risk sharing arrangements per NP2010 precedents.

XIII PATH FORWARD

Each of the PCDR design and assessment sections lists the related future studies which serve as priority scope candidates for the next phase of design development. The overall conceptual design scope and schedule is described in Section 18, and path forward priorities are noted below. Recommended future studies are also summarized as they will likely lead path forward activities.

XIII.A PATH FORWARD PRIORITIES

The following recommendations concerning the NGNP Project Schedule are made in order to address the risks and reduce the uncertainty in meeting the project completion date at the end of fiscal year 2018:

- Begin implementation of the future studies (see below) and conceptual design, as soon as possible.
- Start NGNP pre-application interactions with the NRC as soon as possible to secure the licensing strategy basis for the schedule.
- Immediately implement the recommended technology development programs, particularly in the areas of the IHX and limiting hydrogen production processes.
- Begin developing the acquisition strategies and long lead procurement programs for the major equipment identified in the schedule.
- Develop and implement risk mitigation strategies.

XIII.B FUTURE STUDIES FOR THE START OF CONCEPTUAL DESIGN

This section summarizes the major future studies recommended to be performed as part of the conceptual design. Section XIII.B.1 includes most of the future studies contained in the individual sections of the PCDR. Section XIII.B.2 addresses additional major future studies identified as a result of dialog during the PCDR 90% Design Review Meeting.

XIII.B.1 Major Future Studies Contained in Individual PCDR Sections

Consolidate Reference Top Level Requirements

A front-end, thorough review and comment resolution process with INL/BEA and other stakeholders on the top level requirements proposed for the reference commercial version of the PBMR NGNP is needed to assure that the conceptual design effort is well grounded. Additionally, the NGNP-specific requirements (e.g., site and demonstration related) need to be compared with those needed for a commercial plant for a generic site to assure that any differences are reconciled.

Applications Study

The portfolio of leading applications accessible with the reference NHSS design is needed for the advancement of the NGNP Alliance as well as for the development of additional and/or enveloping top level requirements for the NGNP. The Westinghouse Team will build upon past and ongoing internal work on such applications to effect a significant cost-sharing contribution to the overall effort. To date, the following applications have been identified for this task.

- Oil Sands (OS) Applications
- Enhanced Oil Recovery (EOR) Applications
- Steam Methane Reforming (SMR) Applications
- High Temperature Steam Electrolysis (HTSE) Applications
- Coal-to-Gas (CTG) and Coal-to-Liquids (CTL) Applications

For each family of applications, the following scope topics will be addressed:

- Describe the application and market conditions in order to frame the basic market opportunity for HTGR process heat in this market.
- Develop a reference summary level flowsheet and scoping economic assessment for coupling a PBMR-PHP for the applications.
- Develop a reference scoping economic assessment for the conventional fossil fired production systems envisioned as the comparative bases.
- Develop economic comparisons of the above and identify key drivers such as capital costs, price of natural gas and cost of CO_2 sequestration (or related tax).
- Characterize the environmental, energy security or other benefits and issues derived from the application of PBMR process heat in this application.

- Based on the economic potential above, develop one or more strategy options for demonstrating such applications as part of the NGNP Project, including cooperative initiatives with other stakeholders.

Building upon the results of the Preconceptual Design Report and the results from the above subtasks, this study will develop the likely integrated demonstration strategy for one or more of the applications, including the relative pros and cons. This study will also provide recommendations and rationale for overall NGNP Project and Alliance development.

Based on the results of the above, the top level requirements will be revised to envelope the mutually agreed-upon applications.

Initial Licensing Basis Events

This study extends the preconceptual design safety effort by determining an initial set of Licensing Basis Events (Anticipated Operational Occurrences, Design Basis Events and Accidents, and Beyond Design Basis Events) for use during conceptual design. This initial set of LBEs for the NGNP demonstration will be based on prior work and form the starting point for the iterative design – safety analyses process.

NHSS Configuration

This study revisits and more thoroughly evaluates the trade offs with the Reactor and HTS design selections of the preconceptual design. The scope of this NHSS study includes:

- Reactor inlet return piping location
- Concentric versus separate hot and cold piping
- Core Conditioning System (for forced decay heat removal) location, size, redundancy, and independence
- Number of IHXs and/or circulators
- Arrangement and replacement of the very high temperature section of the IHX
- Location of the secondary circulator(s)
- Safety functions of the Heat Transport System (HTS) and their allocation to Primary HTS/Secondary HTS Systems, Structures and Components
- Need for tritium and other cleanup systems for the SHTS

Plant Layout

This study extends the preconceptual design layout effort in the following areas:

- Reactor embedment – Identify all applicable requirements and regulatory sources pertaining to the protection of the Nuclear Heat Supply System against natural and man-made phenomena. This study will evaluate and assess alternatives for partially burying or not burying the NHSB.
- Separation distance vs. building design robustness vs. physical barriers – This study will evaluate cost/safety/licensing/security tradeoffs for NHSS building, HPS/decomposer component/building and PCS/SG component/building.
- Shared NHSS building walls and systems - Evaluate and assess alternatives for the degree of shared NHSS building walls and support systems.
- Control system design and layout - Evaluate and assess alternatives for the integrated vs. distributed control systems and their locations.
- Geotechnical data - Evaluate the acceptability of the current geotechnical data for the INL site – This study will review and assess the validity and acceptability of available geotechnical data obtained in the NPR program and by others for the INL site. This study will also determine the extent to which additional geotechnical investigations, including new borings and topographical surveys, are required to support foundation design for the PBMR NGNP site layout.
- Seismic Hazards Analysis data - Review and verify validity and applicability of existing Probabilistic Seismic Hazard Analysis data that have been assembled for other INL facilities. It is anticipated that the conclusion of this study would be that the design ground level response spectra developed for these other facilities is representative and bounding for application to the PBMR NGNP with respect to NRC regulatory standards. If this is the case, a site specific Probabilistic Seismic Hazard Analysis may not be required for the PBMR NGNP.

Hydrogen Process and Material Selections

This study will make a more detailed comparison of the HyS and HTSE technologies. This study will include a more detailed risk assessment of the HTSE process and compare the results with those for the HyS process. Additional process development for both HyS and HTSE will be carried out. The study will also pursue continued development of preferred hydrogen processes, design selections and materials, to prepare for a conceptual design that is both technically feasible and cost effective. In addition, this study will build upon the initial selections and findings in the PCDR and evaluate concept alternatives that may be more cost effective, evaluate the maximum temperature for the hydrogen process, perform a hazards analysis of decomposers, and expand studies on life cycle costs for alternate technologies.. Selection and validation of process concepts and materials of construction will take place during the conceptual design phase.

Value Engineering Study

This study involves performing a Value Engineering study within the first 6 months of the conceptual design work. Value Engineering is a systematic evaluation to find solutions which will improve system performance and/or reduce cost compared to the initial selections. The Value Engineering structured study would be at the facility or system level, or a combination, based on an initial screening process.

COLA Pre-application Strategy

This study is a follow-on to Licensing Special Study 20.6 and PCDR Section 17. It develops the plan for pre-application interactions with the NRC for the NGNP Combined License Application (COLA), building on the ongoing PBMR design certification pre-application interactions. The objectives, scope, cost, and schedule for the COLA pre-application interactions will be addressed, including the bases for the COLA schedule estimates. The generic white papers from the ongoing PBMR interactions will be supplemented with NGNP-specific topics that: 1) are necessary to obtain NRC feedback prior to the COLA and 2) are potentially critical path items, e.g., requiring long lead technology development. Candidate topics may include those related to the extension of the power rating to 500 MWt, the regulatory treatment of the IHX Helium Pressure Boundary, and the proximity of process hazards to the Nuclear Heat Supply System.

Construction Modularization Study

This study will build upon the pre-conceptual design, and evaluate alternative construction techniques that could potentially improve the onsite construction schedule, reduce the cost estimate,, and reduce the risk in both areas. The study will evaluate design concepts that would facilitate construction modularization, including but not limited to altering the site arrangement and/or building arrangements to enhance constructability, selecting different materials of construction, such as replacing conventional concrete forming concepts, preassembly of rooms and/or buildings, and preassembly of bulk materials and/or subsystems.

Water and Waste Water System Optimization Trade Study

This study will optimize the approach to water and waste water usage, treatment, and disposal. This recommended study is based on the assumption that the NGNP will be a zero liquid discharge site and knowing that: (1) large amounts of water are required for make up and cooling of HPS, PCS and BOP systems and (2) treatment is required for process waste water discharge and blow-down from these systems.

Steam Generator Design Trade Study

This study will evaluate alternative approaches for the steam generator including more conventional designs (e.g., refractory lined, U tubes) compared to the once-through helical SG proposed in the preconceptual design. Single vs. multiple trains will be evaluated. The results of the study will establish a path forward for design development of the steam generator.

Rankine Cycle Trade Study

Further engineering studies are recommended for the conceptual design stage to optimize the Rankine Cycle configuration and performance. The study will assess costs and performance benefits of more efficient cycles with steam reheat vs. more simple and less costly, but less efficient systems. The study will proceed in conjunction with the steam generator design trade study discussed above.

Major Equipment Transportation Trade Study / Major Component Field Fabrication

Detailed studies of the: (1) transportation routes and size constraints for transport of large components or sub-components such as the reactor and steam generator and (2) potential modularization for major components are recommended early in the conceptual design phase. This latter study will assess schedule and cost advantages and disadvantages of final assembly of major items at or near the site. These studies will influence the design of access roads and a rail spur shown on the site plan and plot plan as well as plans for modification to other roads in the vicinity of the INL site.

XIII.B.2 Major Future Studies Identified as a Result of the 90% Design Review Meeting

The following is an overview of additional future studies identified as a result of the 90% Design Review Meeting between INL/BEA and the Westinghouse Team.

Stochastic Analysis of the Pebble Bed Reactor

Prepare a white paper on the treatment of stochastic analysis of the behavior of the pebble-bed reactor in the safety analyses and associated uncertainties.

Evaluation of the Control Room Location

Perform an evaluation of the cost savings associated with placing the control room outside of the vital area including the cost of construction and cost impact on day-to-day operations. This would include analyzing the safety considerations of the control room and of required operator actions, and the impact of the rest of the plant on the control room. The safety hazard protection of the control room would be included. This study would also include evaluating the use of digital control systems.

Licensing Aspects of Nuclear Heat Supply System Connection with Other Plant Facilities

The licensing of the NHSS facility independent of other facilities needs to be further developed. This study includes developing a model to determine whether there is a safety case that isolates the NHSS from the rest of the plant. This has been discussed, but needs to be documented to determine the extent of interactions, and how it would impact the plant layout to keep the NHSF separate from and the HPF, PCF and BOP from a licensing perspective.

PBMR Reactor Building Requirements, Functions and Features

Prepare a white paper on the requirements, functions, and design features of the PBMR reactor building. Clearly identify all requirements, including performance, costs, investment protection and safety. Perform an analysis of the safety considerations of the PBMR designed with a confinement versus an LWR-type containment. Identify benefits and adverse consequences of selecting an LWR-type containment. Consider the citadel concept of the DPP for either alternative.

Dust Control

Prepare a white paper on dust control for the NGNP NHSS. Determine whether it is necessary to test the IHX for dust blockage and release during accidents. Consider similarities and differences with the DPP and its approach to dust management.

Post-Irradiation Examination Facility

Perform preconceptual design work and assess the cost for adding a Post-Irradiation Examination (PIE) facility to NGNP. This study will be to perform PIE on core ceramics and similar materials, but not fuel elements. The pre-conceptual PIE facility design would include the shielding concepts and the facility description.

Evaluation of the NPR Site versus Other Sites on INL

Evaluate the benefits of using the NPR site versus other available site locations at INL. Consider existing geotechnical and seismic data and analysis, water table, location relative to road, railroad access and electrical transmission lines, topography and other relevant factors.

Simulation Modeling

Survey potential simulation modeling tools for the PBMR NGNP configuration and implement an integrated simulation tool required to perform transient analysis of an integrated plant.

Transient Analysis of NHSS, HTS, and PCS

Perform a transient analysis to identify and analyze transient cases that could effect the design requirements of the PCS with respect to ensuring safety of the NHSS. Demonstration cases and commercial configurations will be assessed to ensure that the NHSS and HPS function within their design basis envelopes throughout the assumed transient conditions.

Water Availability

Evaluate water availability to determine whether air cooling is necessary for the INL site, considering the extra cost associated with the large cooling surface required for air cooling.

Air Ingress White Paper

Prepare a white paper on air ingress relative to meeting the NGNP safety offsite requirements under abnormal events. Consider similarities and differences with the DPP design and its approach to chemical attack.

Quality Assurance Considerations of Fuel

Evaluate the Quality Assurance considerations of German fuel and Russian test data for licensing with the U.S. NRC.

Cyber Security

Evaluate the cyber security impacts on the overall plant safeguards and security system.

Continuing Interaction Related to Technology Development

In addition to the above future studies, which are specific in nature to the individual topics, it is recommended that there be a task which fosters continued interaction with INL/BEA regarding technology development and related cost estimates.

XIV BENEFITS OF A PBMR NGNP

Traditionally, nuclear energy has been used for the production of bulk electricity using predominately LWR technology at a delivery temperature of about 300ºC. The deployment of ALWRs is underway which are ideally suited for large capacity additions of baseload power. The leading Generation IV nuclear technology is the HTGR which can provide high temperature, emission-free heat for industrial processes.

The NGNP Project will serve to demonstrate and commercialize the HTGR as the first Generation IV system. The PBMR offers a compelling opportunity for the NGNP Project. Its capability to deliver process heat at temperatures up to 900ºC with current reactor and fuel technology, plus the on-line refueling design, are key discriminating design features within the family of competing modular HTGRs. The PBMR technology also offers improved safety, reliability, proliferation resistance, security and waste management features. Further, the PBMR is evaluated to be competitive for a broad range of applications, particularly when displacing natural gas and taking credits for the elimination of CO_2 emissions. The NGNP Project will demonstrate such commercial potential of the PBMR and associated technologies plus support timely Design Certification and the related commercial infrastructure.

The Westinghouse NGNP Team of world-class developers, suppliers and users has supported the development of a user-based NGNP Alliance and the concept of such an Alliance and DOE creating a public/private partnership to drive the NGNP development and deployment. This effort has been conducted in parallel with this initial cost-shared contract with DOE/INL to develop a NGNP preconceptual design, cost and schedule, plus the related licensing strategy and R&D plan.

The Westinghouse Team's design for the NGNP adapts the reactor system and fuel from the Brayton cycle-based PBMR DPP which is nearing the start of construction in South Africa. Value transfer from the PBMR DPP Project and related fuel manufacturing and test facilities plus the ongoing PBMR pre-application program with the NRC and PHP project initiatives assure a new commercialization phase for nuclear energy for production of process heat and bulk hydrogen without carbon emissions – at the lowest costs and risks for the US taxpayers.

The PBMR DPP reactor and fuel value transfer along with the US base of vendor/supplier capability, the Pre-application Program and other project initiatives offer a compelling opportunity for the US, South Africa and others to deploy a PBMR-based NGNP for the least costs and risks, plus an assured commercial outcome. The Westinghouse Team is ready, capable and committed to this end.

REFERENCES

NONE

APPENDICES

NONE