Assessment of the Cost and Performance of the Next Generation Nuclear Plant Project during the Period FY 2006 through Mid-FY 2010

Final Report

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1 – Executive Summary

The Manager of the Next Generation Nuclear Plant (NGNP) Project initiated this effort to establish an independent assessment of the cost and performance of specific NGNP research and development (R&D) and engineering activities conducted in the time period from the beginning of fiscal year (FY) 2006 through mid FY 2010. This independent assessment evaluates selected activities and their associated costs performed within the NGNP project scope to:

1. Separate non-recurring (infrastructure improvement and one-time development costs) from recurring experiment costs.
2. Determine if the current INL incurred cost systems effectively relate costs to associated technical activities.
3. Determine the reasonableness of costs incurred for the associated technical activities accomplished.

The NGNP Manager requested the assessment team to:

1. Review the INL -prepared incurred cost reports for selected NGNP R&D and Engineering activities. The activities selected include:
    a. Fuel Development and Qualification experiments (R&D):
        a) AGR-1
        b) AGR-2
    b. Graphite Development and Qualification experiments (R&D):
        a) AGC-1
    c. Pre-Conceptual Design (Engineering)
    d. Technology Development Roadmaps (Engineering)
    e. Risk Management (Engineering).
2. Assess effectiveness of the NGNP work breakdown structure (WBS) for allocating costs into appropriate categories that can be used as the basis for future cost estimates of similar work.
3. Identify comparable R&D and Engineering projects, both publicly and privately funded, as potential benchmarks for the selected NGNP activities.
4. Compare the costs of identified NGNP Project R&D and Engineering tasks with the identified publicly and privately funded projects.
5. Prepare a report summarizing the cost assessment, findings, observations and recommendations.
6. Provide additional support on an as-requested basis.

Based on our assessment of the specific areas within the NGNP Project, we conclude the following:

- The NGNP Project scope of activities and spending during the time of the assessment (FY02006 through mid-FY2010) for the work accomplished was reasonable.
- The NGNP Project Management System, including its Earned Value module, is robust and found to be adequate.
- The need to demonstrate high temperature reactor (HTR) technology for producing low carbon emission process heat remains high.

- Given the long-term nature of HTR development and the wide array of risks associated with the NGNP, the public-private partnership envisioned by EPAct05 is still the preferred strategy for development.

Based on our assessment of the specific areas within the NGNP Project, we recommend the following:

- The project should expand its risk management focus to encompass programmatic risk.
- The elements of the NGNP power plant not field proven need a component proof testing strategy and associated infrastructure.

2 - Introduction and Objectives

The Manager of the Next Generation Nuclear Plant (NGNP) Project initiated this effort to establish an independent assessment of the cost and performance of specific NGNP research and development (R&D) and engineering activities conducted in the time period from the beginning of fiscal year (FY) 2006 through mid FY 2010. Members of the review committee, see Appendix 1, represent a broad range of backgrounds, but collectively have extensive experience in government, industry and academic R&D. The report covers the bases for the NGNP Project, which include the design, licensing, construction and operation of a demonstration, high temperature gas cooled reactor. This type of reactor produces heat of sufficient quantity and temperature (>750^{o} C) suitable for a range of industries and applications, including chemical, petro-chemical, refining, inorganic fertilizer, non-conventional hydrocarbon production, and eventually hydrogen production. Deployment of such reactors extends the near-zero greenhouse gas (GHG) emission nuclear technology beyond the generation of electricity, replacing the combustion of fossil fuels for these purposes.

The primary objective of the assessment is to determine, as quantitatively and objectively as possible, the effectiveness of the NGNP Project in stewarding the resources authorized by the Energy Policy Act of 2005 (EPAct05) law. To this end, the assessment begins with a review of the federal law language of EPAct05, the follow-on annual guidance provided by the Department of Energy Office of Nuclear Energy (DOE NE) and the implementation plans developed by the NGNP Project team. The NGNP funding is part of the larger Generation IV Reactor development funding. Several key R&D and engineering activities were examined by the authors including incurred costs, results achieved, and benchmarks of similar size and scale industrial and federally funded projects. Finally, the NGNP Project is examined from an earned value perspective. The assessment team draws a number of conclusions and makes a series of recommendations for the NGNP Project for the work that is currently underway and the tasks remaining in the project.

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        a) AGR-1
        b) AGR-2
    b. Graphite Development and Qualification experiments (R&D):
        a) AGC-1
    c. Pre-Conceptual Design (Engineering)
    d. Technology Development Roadmaps (Engineering)
    e. Risk Management (Engineering).
2. Assess effectiveness of the NGNP work breakdown structure (WBS) for allocating costs into appropriate categories that can be used as the basis for future cost estimates of similar work.
3. Identify comparable R&D and Engineering projects, both publicly and privately funded, as potential benchmarks for the selected NGNP activities.
4. Compare the costs of identified NGNP Project R&D and Engineering tasks with the identified publicly and privately funded projects.

5. Prepare a report summarizing the cost assessment, findings, observations and recommendations.
6. Provide additional support on an as-requested basis.

The NGNP Project key events are shown in the following figure. Note this assessment covers the time period from the beginning of FY2006 and Mid-FY2010 as shown on the timeline.

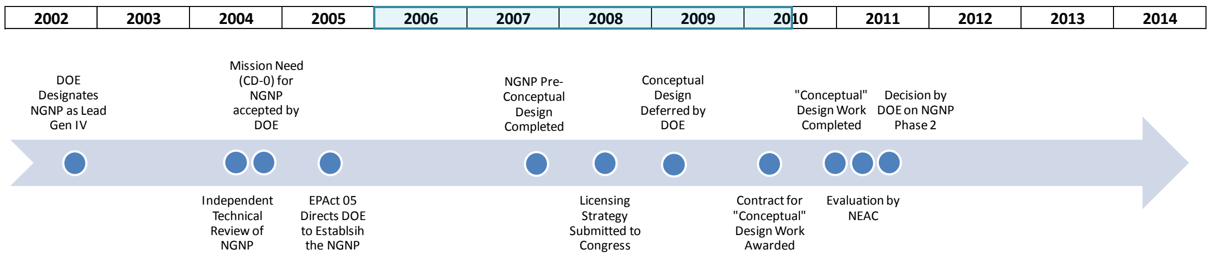

Figure 2-1 Key Events in the NGNP Project

When the project began in FY 2005, it was envisioned as a public-private partnership which would begin as a publicly funded capital construction project and transition into a privately funded demonstration project after the establishment of the private consortium. The vision was to have a roughly 50:50 cost share between the partners. The federal funds would support the initial segments, which include the R&D, the design and the licensing. The private funds would follow with the cooperative support of the construction of the plant and transition to complete support for the operation and maintenance of the plant.

4 - NGNP Project Spending

While the EPAct05 authorized the NGNP Project, Congress appropriated the funds for the work to the Office of Nuclear Energy of the Department of Energy under the Generation IV Program. The goal of the Generation IV Program is "to address the fundamental research and development (R&D) issues necessary to establish the viability of next-generation nuclear energy system concepts to meet tomorrow's needs for clean and reliable electricity, and non-traditional applications of nuclear energy."

The period of interest for this assessment is from the beginning of fiscal year (FY) 2006 through the middle of FY 2010 (22 March 2010). During this period of time, the Generation IV Program was funded to a level of $606.7M. The funding flow to the NGNP Project at the Idaho National Laboratory (INL) is shown in the following figure:

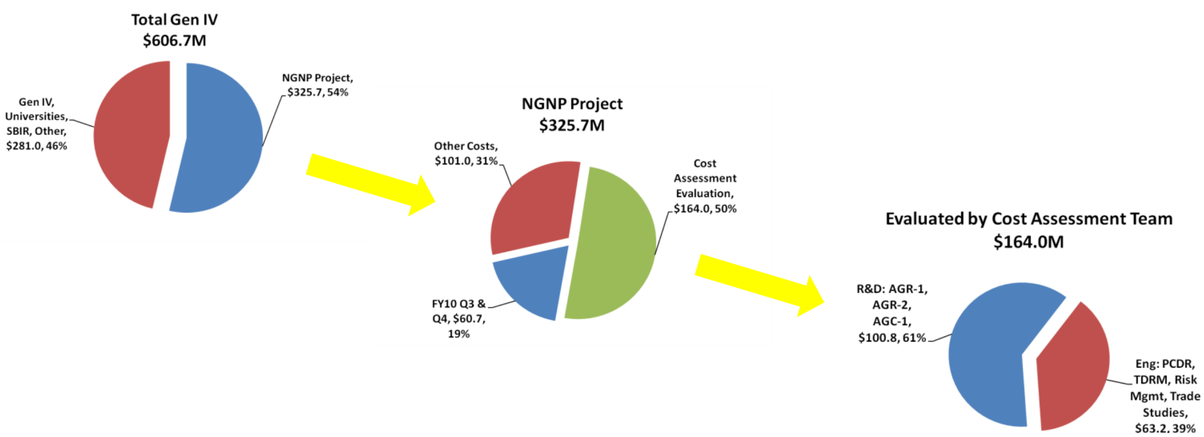

Figure 4-1: NGNP Project Funding Flow from Generation IV Funding

Of the $606.7M appropriated for the Generation IV Program, $325.7M has been directed to funding the NGNP Project. The details of the other funds can be found in the 2009 NGNP Status Report[1].

About $60.7M is scheduled to be spent during the second half of FY2010, therefore out of the scope of this assessment. The work covered in this report covers the remaining $265M. Of this amount, in-depth assessments are conducted in the R&D and Engineering disciplines totaling $164M.

The R&D in-depth cost assessment deals with the initial fuel and graphite experiments. The other R&D elements includes; codes and methods, high temperature materials and high temperature electrolysis to make hydrogen. The rationale for selecting the AGR-1, AGR-2 and AGC-1 experiments for this assessment is twofold. Firstly, the experiments are complicated and expensive and represent a

[1]Next Generation Nuclear Plant Project 2009 Status, INL/EXT-09-17505 /09-GA50911-01

significant portion of the incurred R&D costs. Secondly, there are sufficient cost data to track over several years.

The engineering in-depth cost assessments focus on the pre-conceptual design report (PCDR), the technology development roadmaps and the risk management guidelines. In addition, to the in-depth assessments, various engineering trade studies and the NGNP licensing strategy were reviewed. The rationale for the in-depth assessment is based on the following:

- The PCDR includes the pre-conceptual designs of the three potential vendors and their independent assessment by the NGNP Project staff. This report forms the foundation for the NGNP Project with a broad assessment of its scope, cost and schedule.
- The technology development roadmaps (TDRMs) provide a prioritized, risk-informed plan to bring the NGNP into fruition. The TDRMs define the essential R&D and engineering tasks to deal with the most significant technical impediments to the development of the NGNP.
- The risk management plan defines the process for assessing the maturity of the major technologies as applied to the identified, critical systems and structures. While the scope of the risk management plan encompasses technical and programmatic risk, only technical risks are detailed.

5 – High Level Earned Value Assessment

The assessment team reviewed the INL's Project Management System (PMS), including the Earned Value Management System (EVMS) at a high level.

All of the traditional elements of a high quality PMS appear to be in place and operating as intended on the NGNP at INL. These include:

> <u>A project WBS.</u> An overall project WBS was established and used for collecting budget and work activities. Detailed WBS structure were reviewed along with their associated budget and found to be adequate.
>
> <u>A functional Project Organization.</u> A very well defined project organization has been established. The project organization appears to have a "matrix" relationship with the R&D performers at the INL. However, the Project Management Plan describes the roles, responsibilities, accountabilities and authorities (R2A2s). In the R2A2s, the NGNP Project Director approves the R&D functions and is accountable for the results.
>
> <u>A formal Project Management System.</u> All the elements of a project management framework, earned value management system, and change controls system appear to have been in place and used by the project.
>
> <u>Project Schedules.</u> Various summary, working schedules for achievement of CD-1 and subsequent critical milestones were published. (Ref. PPMP 9/07, PPEP 9/09). In addition, we reviewed several detailed, "integrated" schedules down to WBS level 7, all of which showed exceptional insights into the specific technical tasks needed to complete CD-1.
>
> <u>Annual Cost reviews.</u> For FY07 thru FY10, monthly cost reviews against the "Annual plans" were conducted. Cost versus budget estimates were made, "ahead or behind schedule" comments were recorded but no impact of these variances against CD-1 completion or project critical path is reported.

6 – R&D Assessment

6.1 Overview

During FY06-10, $145M was spent on R&D; $101M of which went towards fuel and graphite development. Of the $101M, approximately $76M was expended on various elements of the fuel development and qualification program. The fuel development work included;

- fuel fabrication,
- process development,
- capability development at INL and ORNL,
- test fuel fabrication,
- fuel irradiation testing,
- fuel post-irradiation examination preparations,
- fuel performance model development, and
- fundamental understanding of fission product transport.

Figure 6-1 illustrates the breakdown of the R&D costs during the assessment period.

Another major R&D activity in this time frame is the graphite qualification program, expending $25M during this period. This program includes selection of graphite grades and manufacturers, irradiation over a range of fluences, stresses, and temperatures, and post-irradiation examination. The INL researchers designed and fabricated novel irradiation capsules which imposed a constant stress on many of the graphite samples while being irradiated. The researchers defined specific target temperatures and fluences to achieve different levels of materials damage in terms of displacements per atom (dpa).

Overall, the R&D has produced important outcomes and data with costs being reasonable. Specific examples are discussed below.

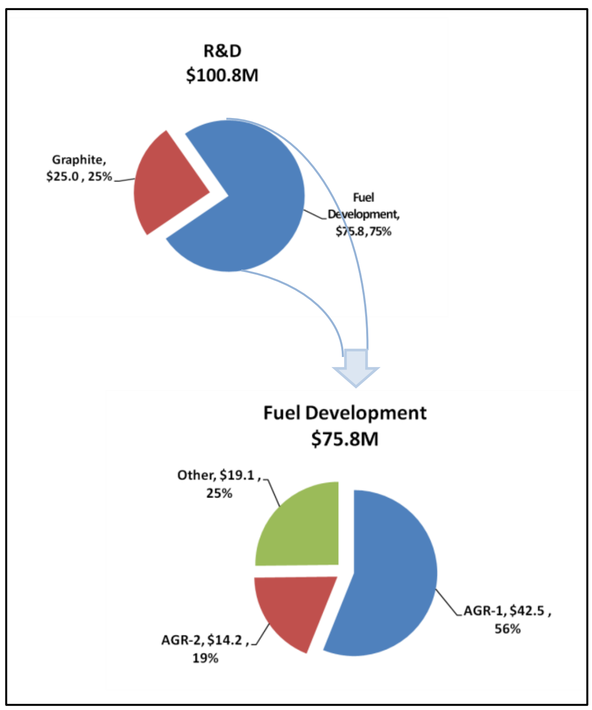

Figure 6-1: R&D costs incurred during the assessment period

6.2 AGR-1, First Fuel Irradiation Capsule

AGR-1 is the first of eight major irradiation capsules. It is designed to "shakedown" the entire design, fabrication, irradiation, disassembly and post-irradiation examination process. AGR-1 irradiates fuel produced on "laboratory scale" equipment. It has six independent cells, each capable of containing six fuel compacts with up to 90,000 fuel particles contained in each cell. Each of the six cells is independently instrumented for temperature monitoring, fission product release monitoring, and gas flow temperature control. This required a fair amount of facility modification at ATR.

The six cells contained six different fabrication variants—two different silicon carbide coating conditions combined with three different pyrocarbon coating conditions. These variants were designed to address issues observed in prior US TRISO fuel campaigns in the manner of coating.

The AGR-1 was irradiated to maximum fluence and burn-up expected in the NGNP and at temperatures which would bound NGNP operation. No fuel particle failed in all six fuel fabrication variants throughout the irradiation. This achievement is extremely encouraging, as this result has never been attained in a US TRISO fuel irradiation over the past 40 years. It indicates that the program is on the right path, and gives confidence that subsequent pilot scale fuel fabrication and qualification may be similarly successful. The total cost of AGR-1 to date is $42.5M, and includes many one-time costs.

We reviewed the AGR-1 costs in detail. In particular, we asked for the incurred costs for AGR-1 to be divided into recurring (expected for each similar experiment) and non-recurring (one-time costs, typical of infrastructure upgrades, experimental process development) costs. Separating the recurring from the non-recurring costs provides the basis for improved estimates for future experiments and explains some of the apparently high costs of a first-of-a-kind experiment.

There were also some inefficiencies and controversies which increased the cost of AGR-1, but these are expected in any comprehensive R&D program. Similar controversies and costs were observed in past TRISO fuel development programs (e.g. NP-MHTGR). Overall, AGR-1 is already a strong success and has provided results of enormous importance at a fair cost. We estimate that the costs of AGR-1 may be somewhat higher, possibly up to 20% higher, than what might be expected in an equivalent, industrial experiment, where cost and schedule achievement are paramount. Nonetheless, this is a fairly cost-effective program, given its complexity and importance.

6.3 AGR-2, Second Fuel Irradiation Capsule

The AGR-2 capsule is the second in the series of eight fuel irradiation capsules. AGR-2 intends to demonstrate fuel performance under normal operating conditions with fuel fabricated with pilot scale equipment, as opposed to the laboratory scale equipment employed for AGR-1 fuel.

As such, AGR-2 is using fuel fabrication processes that must be "scaled up" or "industrialized" compared to the laboratory scale. This may result in elimination of toxic materials or changes in technique to achieve full scale reproducibility of product characteristics.

In the transition from the laboratory to pilot scale facility for the fuel, changes are required to achieve economic production. The project personnel should make final, concise decisions on the process changes with technical rigor. This requires clear roles, responsibilities, authorities and accountabilities. Absent such decision making, additional costs and delays can occur.

Four of the six cells contain pilot scale fuel fabricated at B&W. These 24 fuel compacts will provide adequate statistics to provide high confidence of the performance level of this fuel design and fabrication process. With reasonable success, AGR-2 will provide the direct basis for the qualification fuel to be tested in the 12 cells of capsules AGR 5 and 6. The other two cells will test fuel fabricated by PBMR at Pelindaba, South Africa, in one cell and fuel particles fabricated at Cadarache, France, by CEA, and compacted by AREVA (CERCA), in the other cell. This will provide good feedback to those early-stage fuel manufacturing programs.

Additional capsules AGR-3 and -4 are planned. These capsules contain designed-to-fail fuel in order to measure fission product transport in the fuel compact matrix and graphite. These capsules are not fuel qualification tests.

The cost to date for AGR-2 is $14.2 M.   This is significantly below the cost of AGR-1 at this point in its design and fabrication. As expected, the one-time costs incurred on AGR-1 are benefiting subsequent experiments. Therefore, the cost of AGR-2 appears reasonable and comparable to past benchmarks.

6.4 AGC-1, First Graphite Qualification Capsule

The irradiation of a large number and diversity of graphite coupons in AGC-1 will provide the first data points in the qualification of these various grades of graphite. Many grades were selected for irradiation in order to provide a diversity of types for future reactor designers, and to provide a range of potential suppliers. These include the graphites identified for fuel elements and structural elements (see Fig. 5.1, for example) in the reactor designs of the AREVA, General Atomics, and Westinghouse vendor teams.

AGC-1 is unique in that it provides target level fluence and radiation damage to graphite while at prototypic temperatures under constant stress. The stress is provided by a pressurized bellows system in the capsule which maintains a fixed stress through the long period of irradiation. This capsule design allows careful measurement of irradiation-induced creep and other behaviors of the graphite at a fixed stress.   Other capsules in the AGC series will address other, typically higher, ranges of temperature and a variety of target fluences.

Target temperature ranges are maintained by gamma heating, selective neutron shielding, selected inert sweep gas ratios of helium and argon in the gas jacket of the capsule, and varying gas channel widths in the vertical orientation. The center channel is used for non-stressed drop-in samples. The AGC capsule experiments will be conducted at 600^{o}C, 900^{o}C and 1200^{o}C. At each temperature, two different capsules will be irradiated to different dose levels; the first from 0.5 to 4 dpa and the second from 4-7 dpa.

The planned AGC capsule series include:

- AGC-1: Planned exposure was 600°C with an irradiation dose range of 4-7 dpa. The actual operating temperature is around 750°C. This higher temperature is the result of an analysis error caused by a flaw in the ABACUS code version being used[2]. This error resulted in a capsule design that operates at a higher temperature. However, the experimental data will still be useful. This is the first capsule and will be used as the "shakedown" capsule where any design optimization to make the capsule operate better will be undertaken.
- AGC-2: Planned exposure is 600°C with an irradiation dose range of 2-5 dpa.
- AGC-3: Planned exposure is 900°C with an irradiation dose range of 0.5 – 4 dpa.
- AGC-4: Planned exposure is 900°C with an irradiation dose range of 4-7 dpa
- AGC-5: Planned exposure is 1200°C with an irradiation dose range of 0.5 – 4 dpa.
- AGC-6: Planned exposure is 1200°C with an irradiation dose range of 4-7 dpa

Fig. 6.1: PBMR test assembly of some graphite structural elements

The cost of AGC-1 to date is about $25M and is higher than expected because significant design changes were made during its initial design phases. AGC-1, however, is a first of a kind design and a 'shakedown'

[2] All versions of ABACUS used by INL had been validated and verified by the developer, including the one used for AGC-1 design. A lessons learned from this experience has influenced NGNP's procedures on how to use vendor codes.

test for the series. Subsequent capsules of the same design should cost significantly less. We estimate that future graphite experiments should cost much less than AGC-1, due to one-time incurred costs.

Overall the graphite development and qualification program (INL/EXT-07-13165, September 2007) is well defined and appears to be appropriate for the objectives of the NGNP. The INL researchers estimated the overall cost to be about $130M, but provided no detailed cost breakdown. This total program cost seems reasonable and a significant portion is for post-irradiation examinations and analysis to support code case development.

6.5 Benchmarks and Other R&D Elements

We did not examine the other major R&D elements in detail. A key program is the Codes and Methods program, elaborated in INL/EXT-06-11804, January 2007. This program was estimated to cost about $120M, and the INL did not provide a detailed, resource loaded, schedule. The program cost estimate and objectives appear reasonable, but the funding of this program to date hasn't provided the visible, desirable progress. Given the high level schedule in the program plan, it does not appear that progress is sufficient to support design and licensing activities unless the effort is strongly accelerated.

Similar progress in testing capability has been developed for graphite qualification and high temperature materials testing. Based on a very high level look at the high temperature electrolysis method for producing hydrogen, the progress in improved efficiency, reliability, and lifetime enhancement is notable.

The assessment team obtained several benchmarks to compare to ongoing R&D efforts in the NGNP. These were concentrated in the fuel development and qualification area. These benchmarks were mostly given to us with the caution that we not quote the specific costs and programs because they are felt to be proprietary. In general, these programs were consistent but slightly lower than for the AGR program. One benchmark that was not proprietary was a survey that was conducted by Technology Insights, which estimated that $8B had been spent over the past 40 years on gas reactor development worldwide. Of this, $3B has been spent in the US during this time period. In the German pebble bed HTR program, it has been reported to us by a program participant that the equivalent of $1B was spent developing and qualifying pebble bed HTR fuel. Given the long background of HTR development in the US, under DOE-NE, DOE-NP, and self-funded by General Atomics, there may have been similar amounts expended in the US. It does appear that the current NGNP Fuel Development program, while *prima facie* an expensive program, is justified given its rigor, complexity, and, so far, excellent results. While the project did not provide to us an integrated fuel development and qualification program plan, we understand that the overall cost of the program is about $300M with about $100M being devoted to fission product transport and model development. The remaining $200M is for fabrication process development, fuel production, and fuel qualification.

6.6 R&D Summary

In these R&D projects, a significant amount of progress has been achieved. The fuel development and qualification effort has shown progress in TRISO fuel manufacturing methods which achieve good performance over a broad range of coating process parameters. Also, UCO kernel manufacturing with variable sizes and enrichments has been manufactured while maintaining good kernel properties and stoichiometry. Concurrent with exceptional fuel performance results with laboratory scale fuel has been demonstrated; the ability of DOE laboratory facilities to test and examine these fuels before, during, and after irradiation has been established.

Similar progress in testing capability has been developed for graphite qualification and high temperature materials. Based upon our cursory review of the high temperature electrolysis method for producing hydrogen, progress has been notable.

Overall, the funds incurred for R&D have been productive and within the range of benchmarked efforts.

6.7 R&D References

1. "NGNP Graphite Selection and Acquisition Strategy", September 2007, ORNL/TM-2007/153, T.M. Burchell et. al.
2. Letter, D. Miotla, Fiscal Year 2010 Program Guidance, Generation IV Nuclear Energy Systems (Generation IV), March 2, 2010
3. "Preliminary Project Execution Plan", Project No. 23843, Next Generation Nuclear Plant", PLN-2825, September 30, 2009
4. "Next Generation Nuclear Plant Project, Preliminary Project Management Plan", INL/EXT-00952 (PLN-2489), Rev. 3, September 2007
5. "Next Generation Nuclear Plant Project, Preliminary Project Management Plan", INL/EXT-00952, Rev. 1, March 2006
6. "NGNP Cost Assessment, Fuels and Graphite Supplemental Information", a PowerPoint presentation, June 7, 2010
7. Various multiyear spreadsheets of costs versus WBS elements provided by the NGNP Project.

7 – Engineering Assessment

7.1 Overview

The NGNP engineering effort for the period of evaluation has focused on pre-conceptual design, follow-up trade studies of important design alternatives, risk management procedures and assessments, and development of a licensing plan. The costs incurred for the engineering activities are shown in Figure 7-1.

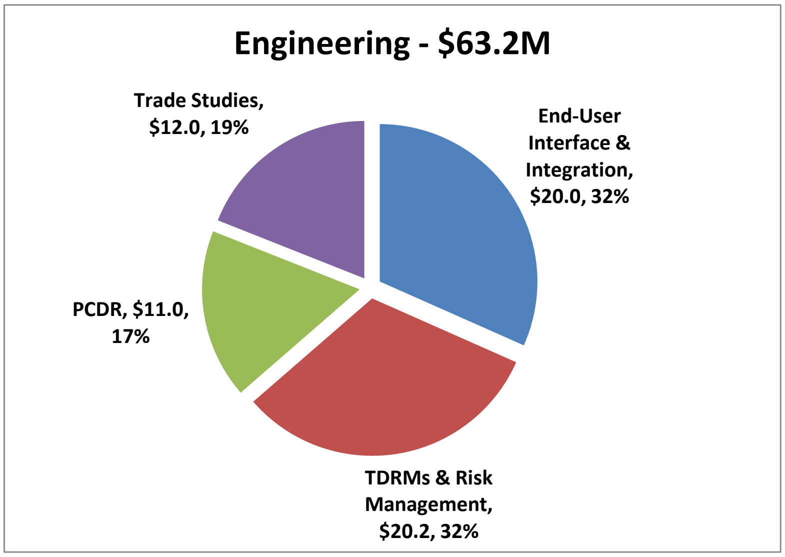

Figure 7-1 Incurred engineering costs during the assessment period

This effort has been built upon earlier development of performance requirements, independent review group evaluation of the technology, and decisions mandated by the Energy Policy Act of 2005.

Table7.1 identifies the principal engineering documents produced in the time period between FY06 and mid-FY10.

Importantly, the engineering results from the evaluation period provide a near-sufficient basis for reaching a number of significant project design and licensing decisions. However, decisions in these areas were not taken and implemented which could have resulted in reducing R&D complexity and design path alternatives which are now being maintained. The most important design decisions which are still pending:

1) reactor power rating
2) reactor concept – select between the prismatic and pebble bed cores
3) reactor outlet temperature –
    a. formally reduce from 950°C to the range 750-800°C, and
    b. eliminate the requirement that the achievement of a 950°C temperature level at a future time not be precluded

The documents reviewed in-depth were produced at a cost of $29.2M. Based upon other projects of a similar magnitude, the cost of these reports is considered to be well within the range of reasonable and customary costs.

Additionally, the principal products of the evaluation period are evaluated next.

7.2 NGNP Pre-Conceptual Design Report (INL/EXT-07-12967, Revision 1, September 2007)

This report was prepared by INL based upon pre-conceptual design studies by three reactor vendors. The INL PCDR evaluates principal design parameters and alternatives to determine prototype parameters important to support subsequent commercialization of NGNP technology. Parameters and alternatives evaluated included thermal power level, reactor coolant inlet and outlet temperatures, primary and secondary cycles (pressures, temperatures, fluids), reactor design concept, power conversion concept, process heat transfer and transport concepts and hydrogen production capability. The report also identifies a licensing strategy, performs a cost estimate, and provides schedule considerations.

Further, the PCDR identifies critical Structures, Systems and Components (SSC) and data needed to further direct and focus planned research and development in the areas of reactor safety and design methods, fuels, materials, and licensing.

Our assessment supports the project claims of the PCDR output. The vendor design conditions and configurations are clearly summarized and then followed by needed studies in 12 areas to complete a conceptual design. Principal technical risks are identified to which we would add the secondary side (water-steam) of the steam generator which will operate at a minimum temperature of 750-800°C, a level well in excess of the experience base in nuclear or fossil service.

Subsequent to the postponement of the conceptual design stage in April 2008, significant technology neutral trade studies were performed for the INL project by reactor vendors or by INL in collaboration with the vendors following the pre-conceptual design period. The assessment team familiarized itself with a selection of these studies involving heat exchanger design, reactor building, large-component test needs and licensing trade studies. The licensing trade studies include fission product transport/source term and emergency preparedness zone (400m) evaluation.   The trade and the licensing plan studies are summarized in Appendix 3. The assessment team had observations in two areas, namely, the INL licensing Plan and the large-component test needs:

1) Licensing Plan (ID: PLN-3202, Rev 0, 6/26/09)- While the Plan identifies the 4 key portions of the licensing timeline, it does not provide a schedule or even an estimate of the calendar period of each step nor comment on what periods of schedule time overlap can be anticipated . Further, given the project time delay which has occurred since the joint DOE- NRC Licensing Strategy was formulated in 2008, it is prudent that the Plan evaluate and likely affirm the intent to pursue the I0 CFR Part 50 versus Part 52 procedure for the demonstration NGNP plant

2) High Temperature Component Testing (INL/EXT-08-14150 (R.0) [4-28-08] "Component Test Facility"- In the course of the NGNP design work and trade studies, about 450 design data needs and 350 separate test requirements were identified. Most of the tests can be conducted at existing facilities. However, about 75 critical tests had no such facility available in the world. The components associated with these latter tests include gas circulators, heat exchangers, high temperature steam generators, valves, hydrogen production process equipment and instrumentation and control. The establishment of a stand-alone component test capability is recommended based upon prior experience with the existing LWRs. For example, steam generators for light water reactors operating at about 300°C were very problematic in the early stages of deployment. Since corrosion, the primary age-related damage mechanism in steam generators increases with temperature, the rule of thumb for LWRs is that for every 10°C increase in temperature, the corrosion rate doubles. In view of this experience, a high temperature test facility for steam generators is justified. In the case LWRs, small scale pot boiler tests were insufficient to identify the requirement of maintaining very tight secondary chemistry control to achieve reasonable steam generator life in service. Poor steam generator performance at 750-800°C can pose a major risk to the success of the HTR as a producer of process heat in the form of steam.

7.3 Technology Development Roadmap for 750-800°C Reactor Outlet Temperature (INL/EXT-09-16598, Revision O, August 2009)

This INL report is an update of a January 2009 (report based on 950°C reactor outlet temperature which documents the critical Plant, Areas, Systems, Subsystems and Components (PASSCs), Technology Readiness Levels (TRLs), and the specific Technology Development Roadmaps (TDRMs) necessary to mature the technologies needed for a high-temperature gas reactor with an outlet temperature of 750-800°C. As well it documents other requirements and operating conditions consistent with those found in the Systems Requirements Manual (SRM), Revision 2.

Importantly, this report focuses on 16 critical PASSCs identifying the functions performed, design options, and discriminators, technological readiness status (TRL) and the technology maturation path for each. The TRL proposed by the project for each of the 16 critical PASSCs has been assigned on a consistent, conservative basis which in all cases is equal to or lower than that proposed by even the most conservative vendor estimate.

All aspects of this report are well done. Importantly, it provides a sound and convincing basis for selection of the 750-800°C range for NGNP reactor outlet temperature.

There is no additional follow-on work envisaged, other than maintaining the TDRM up-to-date as the NGNP Project progresses.

7.4 Risk Management Plan (INL: PLN-3247 Rev 1D:O, September 30, 2009)

This plan provides a structural approach for identifying, managing, and closing above-normal risks which could prevent the NGNP from achieving its objectives. It is based upon and follows the guidelines of the

INL laboratory – wide procedure (LWP-7350 Project Risk Management) and the DOE risk management guide (DOE G 413.3-7 Risk Management Guide).

The plan identifies the critical PASSCs for both the 950°C Reactor Outlet Temperature (ROT) and the 750-800°C ROT. It then provides a methodology to quantify the risk level and assess the Technology Readiness level for each PASSC. Thus as project work reduces known uncertainties or increases technology maturity, the change in risk level can be tracked. The tracking is illustrated by means of a Risk Waterfall Chart, e.g. Figure 11. This overall methodology is applied to the Pebble Bed Reactor with a 950°C ROT in 18 Risk Matrices in the Appendix of this Plan.

The risk management procedure proposed is objective and quantitative. Its application to the 950°C Pebble Bed ROT case demonstrates its functionality. However, the risk management procedure needs to be applied to the 750-800°C ROT as soon as possible to quantify the risk, since this effectively is the project reference ROT.

Further, the methodology is not yet definitive because it incorporates a weighting factor, W, in the calculation of the Risk Number which is present to give emphasis to risks with high consequence. A reference is cited justifying its inclusion (pg. 23) to allow mitigation of risks with high consequence. While this logic is reasonable, the methodology to assign a value to the factor W has been deferred. Thus the current Plan methodology, while acceptable at this stage of the project, is incomplete.

Further, while the Plan stresses that programmatic risks exist in parallel with technical risks, a methodology for assessing and mitigating programmatic risks is not included in this Plan. Given the importance of such risks in the NGNP, this omission is of significance.

There are two follow-on actions recommended for the risk management plan. First, it is desirable that for assessing technical risk, methodology to assign the needed numerical values to the weighting factor W be developed. Second, methodology development and its prompt application to characterize programmatic risk are very timely and necessary.

7.7 Engineering References

Some of the key NGNP engineering documents are shown in the following table, Table 7.1. The table provides the year of publication and the discipline area. The assessment period is also shown.

Table 7.1 Engineering References Used in Assessment

Discipline	2003	2004	2005	2006	2007	2008	2009	2010
Requirements		1				4	7,8	
Independent Review			2					12,15
Design						5	9,10	
Risk Assessment						6		13
Licensing							11	14
Public Law				3				

References cited in table:

(1) *Next Generation Nuclear Plant - High-Level Functions and Requirements*, Rev 0, INEEL/EXT-0301163, Sept 24, 2003.

(2) Independent Technical Review Group, *Design Features and Technology Uncertainties for the Next Generation Nuclear Plant*, INL/EXT-04-01816, Idaho National Laboratory, June 30, 2004.

(3) Energy Policy Act of 2005, Public Law No. 109-58, U.S. Congress, August 8, 2005.

(4) *NGNP System Requirements Manual*, INL-EXT-07-12999, September 2007

(5) *Next Generation Nuclear Plant Pre-Conceptual Design Report*, INL/EXT-07-12967, September 2007

(6) *Technical Risk Management for the NGNP Project*, INL/EXT-07-13148, September 2007

(7) Idaho National Laboratory (2008a), *NGNP System Requirements Manual*, INL/EXT-07-12999, Revision 1, June 2008.

(8) Idaho National Laboratory (2008b), *Summary of Bounding Requirements for the NGNP Demonstration Plant F&ORs*, INL/EXT-08-14395, June 2008.

(9) Mizia, R. E., *Next Generation Nuclear Plant Heat Exchanger Acquisition Strategy*, INL-EXT-08-14054, Idaho National Laboratory, April 2008.

(10) Mizia, R. E., *Next Generation Nuclear Plant Reactor Pressure Vessel Acquisition Strategy*, INL/EXT-0813951, Idaho National Laboratory, April 2008.

(11) *NGNP Licensing Strategy Report to Congress,* August, 2008.

(12) INL/EXT-08-15148, *Next Generation Nuclear Plant Project Technology Development Roadmaps: The Technical Path Forward*, Idaho National Laboratory, January 2009.

(13) LWP-7350, *Project Risk Management*, Revision 1, Idaho National Laboratory, August 3, 2009.

(14) *NGNP Licensing Plan, Project No. 29980,* ID: PNL-3202, Rev O, June 26, 2009.

(15) INL/EXT-09-16598, *Next Generation Nuclear Plant Project Technology Development Roadmaps: The Technical Path Forward for 750–800°C Reactor Outlet Temperature*, Idaho National Laboratory, August 2009.

8 – Conclusions and Recommendations

From our analysis of the pertinent areas of the NGNP Project during the period from the beginning of FY2006 through mid-year 2010, we **conclude**:

1. **The need to demonstrate high temperature reactor (HTR) technology for producing low carbon emission process heat remains high.** The consumption of imported crude to supply our transportation fuel needs costs the nation's taxpayers between $500B and $1,000B annually. The recent oil spill in the Gulf of Mexico illustrates the potential costs of producing domestic crude in deep, offshore wells. The US has the largest coal and oil shale deposits in the world. Deployment of HTRs could assist in the production of these indigenous resources. The deployment of nuclear energy beyond the generation of electricity to displace hydrocarbons for process heat is important to reducing the nation's carbon footprint.

2. **Given the long-term nature of HTR development and the wide array of risks associated with the NGNP, the public-private partnership envisioned by EPAct05 is still the preferred strategy for development.** The NGNP is the first of a kind high temperature gas cooled reactor (HTR) intended to serve new markets for nuclear power, beyond electricity, and which requires business models which are different from the traditional nuclear power plant. Commercializing this technology and deploying it to the point of profitably will require sustained investment for about twenty years, before any significant repayment of that investment will be seen. This long time period required to develop the project, coupled with the technology and business risks create a situation which is well beyond the means of any commercial enterprise[3]. The twenty year period starts with the dedicated design and licensing of the NGNP. Technology risks and licensing risks can be ameliorated by government sponsored R&D, if they are tied to the design and licensing activities of the private sector. As the leading, near-term Generation IV technology identified in the Generation IV Roadmap (2002), the US chose to pursue the HTR technology. The HTR conveys many common benefits which will require government investment to obtain. Given the required close coordination of government and private activities to bring about these benefits, a collaboration between DOE and an industry consortium, interested and committed to commercializing the HTR, is required. This partnership was envisioned in the Energy Policy Act of 2005, which called for the DOE to stimulate the formation of an industry consortium to guide and commercialize the technology represented by the NGNP.

   This partnership of government with an industry consortium will develop common agreement for methods and means to reduce technology risks, business risks, licensing risks, and completion risks. The industrial consortium within the partnership will include end-users, owner operators, and vendors, such that all elements of the evolving business models are addressed.

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[3] c.f. page 12, Bill Gates et al, A Business Plan for America's Energy Future, American Energy Innovation Council, June, 2010.

The partnership will have a common goal to enable the NGNP Project to be built as a timely step toward achieving reduced dependence on foreign energy resources and reducing carbon dioxide emissions. Ongoing technical development of future industrial applications is essential to ensure that the broadest practical energy sectors are supported by the HTGR technology for maximizing its benefit to the long term national energy strategy.

3. **The NGNP Project scope of activities and spending during the time of the assessment (FY02006 through mid-FY2010) for the work accomplished was reasonable**. The reasonableness was determined on the basis of evaluating public and private projects of similar scale and complexity coupled with the over 100 years of cumulative experience of the team in conducting and managing R&D and design projects. During FY06 to FY10, about $607M was appropriated for Nuclear Generation IV development and about $326M provided to the NGNP project office. The assessment team focused on $164M incurred costs; about $101M for R&D and $61M for engineering. Specific conclusions on the R&D and engineering costs assessments follow.

   R&D. The largest element of the R&D costs was the $76M for fuel development, fabrication, testing, and model development. Approximately $25M was expended on graphite qualification.

   The funds expended on fuel development appear to be a bit higher than might be expended commercially, but not significantly so. For example, much of the $76M was for one-time infrastructure and capabilities for testing. The remainder of the funds is comparable to fuel design and qualification in the commercial sector. For example, one of the benchmarks for LWR fuel assembly design changes and qualification indicate that a $150M cost over about ten years can be expected. The fuel fabrication development effort and the first of a kind 'six-cell' AGR-1 fuel irradiation capsule resulted in demonstrating very high integrity TRISO fuel, with no fuel particle failures throughout the irradiation. This was true of all six process variants included in the capsule. This exceptional result cost about $42M, including preparations and equipment for post-irradiation examinations, which will begin soon.

   The separation of costs into recurring and non-recurring categories is an effective means to assess the overall cost-effectiveness of a first-of-a-kind experiment. In addition, this separation of costs should provide a firmer basis for estimating the costs of similar, follow-on experiments.

   Subsequent experiments in this series (AGR-2, AGR-5 &6) will be less expensive, because they will not need to incur the non-repetitive costs associated with AGR-1 (basic capsule design, facility upgrades, etc.). This very promising program should be fully funded until fruition and has been generally cost effective.

   The graphite qualification program is also an expensive effort, but necessary for the development, design, and deployment of HTRs. The AGC capsules are complex and a first of a kind design. These capsules also irradiate a broad range of graphite types at one time. The first of these capsules, AGC-1, is presently under irradiation, and is operating at an average temperature above that anticipated in the design of the capsule. This appears to be due to an ABACUS code flaw, which has subsequently been corrected. It is reported that this higher temperature is acceptable to the qualification matrix and the results will be just as useful to the program.

The codes and methods program has expended $19M during this time frame, and reports of the outcomes of these efforts were either not prepared or not available for examination. It appears that a comprehensive program plan for codes and methods development does not exist, limiting the definition of progress in this area. Given the importance of this area to the design and licensing of NGNP and HTRs, goals and requirements for this program should be examined and refocused, if they are found not to support timely design and licensing.

Benchmarks for R&D include:

- Worldwide about $8B spent overall for HTGRs over 40 years.
- US spent $3B over 40 years; 1/3 for fuel is not unreasonable.
- Germans say they spent $1B on fuel development.
- South Africa had not done much R&D on fuel qualification.

Conclusion: funds spent on fuel qualification were reasonable and delivered good results.

Engineering: The technical NPNG Reports listed below were reviewed and found to be well done technically. Specifically their results were objective and credible. Except for the Risk Management Plan which focuses only on technical risk while simultaneously citing the need to identify programmatic as well as technical risks, the Reports are also complete regarding their proposed scope.

Reports reviewed:

- Pre-conceptual Design
- 750-800°C Reactor Outlet Temperature Technology Development Roadmap
- Risk Management Plan
- Trade Studies
- Licensing Plan

A Component Test Facility (CTF) would serve a vital need for plant component development and confirmation of design performance. The exact scope of needed capabilities in such a facility is subject to tradeoff, but it is reasonable to start now with the planning for a 1MW helium gas heat transfer loop at INL now.

The cost of this engineering work was commensurate with the value delivered.

4. **The NGNP Project Management System, including its Earned Value module, is robust and found to be adequate.** Individually, they were being used as intended. Much of the review of the PMS/EVMS was taken from a very high level perspective. But to test the fidelity of the high level perspective, the assessment team conducted several in-depth reviews of the data. The reviews substantiated the high level view. This conclusion focused only on the technical nature of each element of the system and how they were used by the project.

Based upon our review of the NGNP Project within the scope of this assessment, we **recommend** the following:

1. **The project needs to expand its risk management focus to encompass programmatic risk.** The current Risk Management Plan focuses only upon on technical risk, yet the Risk Management Plan states that programmatic risk is to be equally considered. Further and even more importantly, programmatic risks are now the determinant factors affecting the ongoing evolution of the NGNP project.

2. **A component proof testing strategy and associated infrastructure is needed for the elements that are not field proven**. Approximately 75 critical tests, identified in the design and trade studies, cannot be conducted anywhere in the world. The components associated with these tests include gas circulators, heat exchangers, high temperature steam generators, valves, hydrogen production process equipment and instrumentation and control. The establishment of a stand-alone component test capability is recommended based upon prior experience with the existing nuclear power plants.

Closing. The authors wish to thank the management of the INL for the support throughout this assessment. In particular, we acknowledge the support and assistance of Rafael Soto who worked tirelessly to provide the volumes of information requested by the authors.

Appendix 1 - The Assessment Team

Theodore U. Marston, PhD. (Team Lead). - Dr. Marston established Marston Consulting in June of 2006. His firm is dedicated to the innovation, development, demonstration and deployment of new technology to address two key issues facing developed and developing countries in the 21st century: energy independence and management of global climate change. His clients include venture capitalists, commercial and energy companies, R&D organizations, and U.S. and international national laboratories.

Previously, as Chief Technology Officer of the Electric Power Research Institute, he directed multi-hundred million dollar, international science and technology programs to improve the generation, transmission, distribution and utilization of electricity and reduce the associated environmental risks. Earlier, he led a large international program to develop utility requirements for advanced nuclear reactors, design certification for advanced light water reactors, first-of-a-kind engineering and siting of nuclear reactors. In addition to his nuclear experience, he developed international, independent, fossil-fueled power generation projects. Ted has over 35 years of global experience in the assessment and management of risk in a broad range of industrial facilities, including nuclear and conventional power plants, refineries, chemical plants, railroads, and defense facilities.

He received his BS (1969), MS (1970) and PhD (1972) in Mechanical Engineering from the University of Michigan and is a Fellow of the American Society of Mechanical Engineers.

William J. Madia, PhD. – Dr. Madia established Madia & Associates, LLC, a diversified consulting practice that serves a variety of science and energy customers in 2008. He is on the board of the US Enrichment Corporation, USEC (NYSE: USU) where he chairs the Technology and Competition Committee; chairs the Babcock and Wilcox R&D Advisory Committee; and is a member of the Advisory Board of EnerTech Capital Partners. He serves on the President's Advisory Boards at Princeton University, Michigan State University and the Massachusetts Institute of Technology Energy Innovation Project. He is also a Stanford University Vice President (50% time commitment) responsible for the oversight and governance of Stanford's contract with the Department of Energy to manage and operate the SLAC National Accelerator Laboratory.

Dr. Madia was with the Battelle Memorial Institute from 1975 to 2007. His responsibilities included: Executive Vice President for Laboratory Operations (2003-2007) responsible for Battelle's Laboratory Operations business including the management, or co-management with partners, of six Department of Energy (DOE) National Laboratories; President and CEO, UT-Battelle, LLC and Battelle Executive Vice President for Laboratory Operations and Director Oak Ridge National Laboratory (1999-2003); Director, Pacific Northwest National Laboratory (PNNL) and Battelle Executive Vice President for DOE programs (1994-1999); Senior Vice President and General Manager, Battelle's Environmental Systems and Technology Division (ESTD) (1992-1994); Senior Vice President for Internal Investments and Commercialization (1991-1992); President, Battelle Technology International (1989-1991); President and Director, Battelle's Columbus Laboratory (1986-1989); General Manager, Battelle Project Management Division (BPMD) and Battelle Vice President (1985-1986). He rose from research chemist to program director in the period (1975 to 1984) and was manager of the nation's high level nuclear waste repository siting effort for the DOE (1980).

Prior to his Battelle Memorial Institute career, he was responsible for the academic training phase of the Army's Nuclear Power Program (1970 to 1972). Dr. Madia received his BS (Chemistry) in 1969 and MS

(Chemistry) in 1971 from Indiana University in Pennsylvania and his PhD (Chemistry) from Virginia Polytechnic Institute (1972).

Finis H. Southworth, PhD. - Dr. Finis Southworth is the Chief Technology Officer for AREVA NP Inc. As Chief Technology Officer, he is responsible for Intellectual Property Management, Research and Development programs, University technical relationships, and corporate technical expertise. He is also responsible for their High Temperature Reactor business development and represents AREVA on the Board of Directors for the National Hydrogen Association. Dr. Southworth joined AREVA in 2006.

Before joining AREVA, Dr. Southworth was with the Idaho National Laboratory, serving as Director Project Management, Manager Systems Engineering, and, in the early 1990's, as Manager of Fuel and Target Technology Development for the gas cooled New Production Reactor (NP-MHTGR).

Previously, Dr. Southworth held several management positions within Florida Power and Light Company, including Core Design for their four nuclear units, then Maintenance Superintendent, and Plant Manager, Turkey Point Nuclear Plant. Finis also served as Assistant Professor of Nuclear Engineering at the University of Illinois from 1974-1977, with a research focus on fusion.

Dr. Southworth earned his doctorate in Nuclear Engineering Sciences from the University of Florida in 1974.

Prof. Neil E. Todreas, ScD. - Dr. Neil Todreas is the Korea Electric Power Corp. Professor of Nuclear Engineering (Emeritus) and a Professor of Mechanical Engineering (Emeritus) at the Massachusetts Institute of Technology. He has served at MIT for 40 years, including an eight-year period from 1981 – 1989 as the Nuclear Engineering Department Head. From 1975 to the current time, he has been co-director of the MIT Nuclear Power Reactor Safety summer course, which presented current issues of reactor safety significant to an international group of over 30 nuclear engineers each summer in a one week course. Dr. Todreas holds Bachelor and Master of Mechanical Engineering degrees from Cornell and the Sc.D. in Nuclear Engineering from MIT. His area of technical expertise is thermal and hydraulic aspects of nuclear reactor engineering and safety analysis.

Dr. Todreas has an extensive record of service for government (Department of Energy – DOE, US Nuclear Regulatory Commission – USNRC, and national laboratories), utility industry review committees, and international scientific review groups. Dr. Todreas started his professional career with nine years of service with the US Atomic Energy Commission, four years initially with Naval Reactors and a subsequent five years with Civilian Reactor Development. He is a member of the National Academy of Engineering and a fellow of the American Nuclear Society (ANS) and the American Society of Mechanical Engineers (ASME).

His current service is as a member of the DOE Nuclear Energy Advisory Committee, the chair of the INL LWR Sustainability Program Steering Committee, and vice-chairman of the CEA Nuclear Energy Division Scientific Committee.

Appendix 2 (EPAct05 Language)

[1] INDUSTRIAL PARTNERSHIPS.—
(A) IN GENERAL.—The Idaho National Laboratory shall organize a consortium of appropriate industrial partners that will carry out cost-shared research, development, design, and construction activities, and operate research facilities, on behalf of the Project.
(B) COST-SHARING.—Activities of industrial partners funded by the Project shall be cost-shared in accordance with section 988.
(C) PREFERENCE.—Preference in determining the final structure of the consortium or any partnerships under this subtitle shall be given to a structure (including designating as a lead industrial partner an entity incorporated in the United States) that retains United States technological leadership in the Project while maximizing cost sharing opportunities and minimizing Federal funding responsibilities.

Furthermore, Section 988 of the Act defines the required cost-share for industrial activities on the NGNP. **SEC. 988. COST SHARING.**
(a) APPLICABILITY.—Notwithstanding any other provision of law, in carrying out a research, development, demonstration, or commercial application program or activity that is initiated after the date of enactment of this section, the Secretary shall require cost-sharing in accordance with this section.
(b) RESEARCH AND DEVELOPMENT.—
(1) IN GENERAL.—Except as provided in paragraphs (2) and (3) and subsection (f), the Secretary shall require not less than 20 percent of the cost of a research or development activity described in subsection (a) to be provided by a non-Federal source.
(2) EXCLUSION.—Paragraph (1) shall not apply to a research or development activity described in subsection (a) that is of a basic or fundamental nature, as determined by the appropriate officer of the Department.
(3) REDUCTION.—The Secretary may reduce or eliminate the requirement of paragraph (1) for a research and development activity of an applied nature if the Secretary determines that the reduction is necessary and appropriate.
(c) DEMONSTRATION AND COMMERCIAL APPLICATION.—
(1) IN GENERAL.—Except as provided in paragraph (2) and subsection (f), the Secretary shall require that not less than
42 USC 16352.
42 USC 16351.
42 USC 16342.

PUBLIC LAW 109–58—AUG. 8, 2005 119 STAT. 911
50 percent of the cost of a demonstration or commercial application activity described in subsection (a) to be provided by a non-Federal source.
(2) REDUCTION OF NON-FEDERAL SHARE.—The Secretary may reduce the non-Federal share required under paragraph (1) if the Secretary determines the reduction to be necessary

and appropriate, taking into consideration any technological
risk relating to the activity.
(d) CALCULATION OF AMOUNT.—In calculating the amount of
a non-Federal contribution under this section, the Secretary—
(1) may include allowable costs in accordance with the
applicable cost principles, including—
(A) cash;
(B) personnel costs;
(C) the value of a service, other resource, or third
party in-kind contribution determined in accordance with
the applicable circular of the Office of Management and
Budget;
(D) indirect costs or facilities and administrative costs;
or
(E) any funds received under the power program of
the Tennessee Valley Authority (except to the extent that
such funds are made available under an annual appropriation
Act); and
(2) shall not include—
(A) revenues or royalties from the prospective operation
of an activity beyond the time considered in the award;
(B) proceeds from the prospective sale of an asset of
an activity; or
(C) other appropriated Federal funds.

Appendix 3 (Engineering Trade Studies plus Misc. Engineering Reports)

Significant trade studies were performed for the project by reactor vendors or the INL in collaboration with the vendors in the post Pre-Conceptual design period. The assessment team familiarized itself with a selection of these studies involving heat exchanger design , reactor building ,large-component test needs and licensing trade studies. The licensing trade studies include; fission product transport/source term, and emergency preparedness zone (400m) evaluation. These trade studies are summarized below.

Intermediate Heat Exchanger (NGNP-NHS-HTS-RPT-M-00004 (R.0) [09-18-09] " Intermediate Heat Exchanger Development and Trade Studies"). The objective of the IHX trade study is to define the architecture coupling the IHX to the HTS and to evaluate the single vessel compact IHX arrangement. The IHX is one of the major design challenges outside of the nuclear reactor since it must handle the entire heat output from the reactor and do so at reactor outlet temperatures and pressures above the current operating limit for existing materials. Several IHX concepts are being considered, including a variety of innovative compact designs and more traditional tube-in-shell devices. The basis for the present study was an indirect-cycle configuration ,the 750°C in reactor outlet temperature (ROT) appropriate for steam production, and a temperature of 800°C also specified the context of intermediate temperature direct heat applications.

The key findings of this trade study are:

1. While at the intermediate temperatures assessed herein, the helical-coil shell-and-tube heat exchanger represents a robust and established technical option, the size of the individual heat exchangers and the requirement for multiple HTS loops imply significant economic penalties relative to the compact heat exchanger options ,
2. Based on the use of compact heat exchangers, such as the plate-fin heat exchanger (PFHE) technology evaluated, the PBMR NGNP IHX, with a nominal capacity of 512MWt, can be configured within a single vessel,
3. Comparisons of the single-stage IHX design developed with the corresponding design of the two-stage IHX previously developed for the higher temperature (950°C) hydrogen production application, suggest that the incentives for the two-stage design may be less than previously thought, especially when considering the added complexity and technical challenges introduced by the connecting piping,
4. Hastelloy X should be included as a primary candidate material for the IHX heat transfer surface in the intermediate temperature range based on the expectation of superior corrosion resistance.

The key recommendations of this trade study are:

1. Compact IHX designs should remain the reference basis for the PBMR NGNP IHX,

2. R&D characterizing the corrosion resistance of Hastelloy X, Alloy 800H and other candidate heat transfer surface materials (e.g., Alloy 617 at higher temperatures) in thin sections in the HTGR PHTS and SHTS environments should be undertaken with highest priority,
3. The pre-conceptual design of an IHX applying plate-type technology, such as the Heatric Printed Circuit Heat Exchanger (PCHE), should be developed and assessed in a trade study along with the PFHE design evaluated herein. The objective would be to provide a basis for selecting one of these concepts as the basis for the IHX,
4. High priority should be given to undertaking the insulation and cooling trade study for the PHTS and SHTS piping that was recommended previously, and
5. Additional transient studies, in conjunction with thermal and structural assessments should be utilized to more fully validate the structural adequacy of the IHX.

Reactor Building (NGNP-NHS 100-RXBLDG (R.0) [9-16-08] " Reactor Building Functional and Technical Requirements"). This study develops technical and functional requirements (T&FRs) for the Next Generation Nuclear Plant (NGNP) and High Temperature Gas-cooled Reactor (HTGR) Reactor Building (RB), including consideration of reactor embedment. The key findings of this study are summarized in three parts : Part A summarizes the overall technical and functional requirements for the reactor building and the evaluation of various design strategies for meeting these requirements; Part B) identifies criteria and requirements relevant to determining the degree of reactor building embedment and evaluates and ranks embedment depth alternatives; Part C) focuses on the role that embedment can contribute to meeting T&FRs .A key finding of this study is the evaluation of alternative Reactor Building concepts for the satisfaction of the building safety functions involving pressure relief for HPB leaks and breaks, retention of radioactive material that may be released from the fuel and the HPB, and the limiting of the potential for air ingress following large HPB breaks. A summary of the alternative concepts is provided and includes two alternatives for a vented and unfiltered building, three alternatives for a filtered and vented building, and two alternatives for a leak tight or pressure retaining reactor building.

High Temperature Component Testing (INL/EXT-08-14150 (R.0) [4-28-08] "Component Test Facility Requirements"; INL/EXT-08-14132 (R.1) [4-22-08] "Component Test Facility Configuration"). The objective of this study is to summarize the requirements and bases for large-scale component test capabilities to support the development of advanced nuclear reactor technologies and the hardware that has been developed to provide these capabilities. The need for the design and construction of a reasonably large-scale, high-temperature-gas test facility for component and materials testing had been identified by the NGNP Program Management Plan. This engineering-scale test capability was judged needed to test and qualify heat transfer system components (IHX, valves, hot gas duct, etc.) and reactor internals. The capability also was judged to be needed to perform hydrogen generation processing to mitigate associated technical risks and increase the technology readiness levels for hydrogen processing. It was found that existing test loops worldwide did not have the required capabilities. The larger loops (~10 MWt) are no longer operating and have been dismantled or mothballed. The smaller loops do not have the combined flow, pressure, and temperature capabilities, and are designed for very specialized and focused purposes. Other alternatives for obtaining the necessary large-scale and integrated testing were also considered. About 75 tests were identified for which no facilities exist. Hence a gap between component test needs and testing capabilities was identified during the development of test plans for first-of-a-kind components and systems for the NGNP. Thus the study found the need for large-scale testing capability to mitigate project technical, cost, schedule, and performance risks and thereby increase confidence in the success of the NGNP Project.

FISSION PRODUCTS (NGNP-PLD-GEN-RPT-N-00007 (R.0) [10-06-09] "Fission Product Retention Allocation"). This study provides an analysis of source term and fission product transport for a reference PBMR NGNP plant design thereby contributing to the development of radionuclide design criteria for Licensing Based Events (LBEs) that will assure compliance with top-level regulatory requirements. Three principal accomplishments were achieved- (1) development of an integrated plant model of the Nuclear Heat Supply System (NHSS) and the application of this model to establish operating conditions, modes and states, and plant transient conditions during expected frequent start-up and shutdown transients and mode transitions ,(2) evaluation of the radionuclide releases from a spectrum of leaks and breaks in the Primary Heat Transport System (PHTS) Helium Pressure Boundary (HPB) to advance the calculation of mechanistic source terms, and (3) development of design targets for radionuclide retention capabilities of the barriers to radionuclide release for the next phase of the NGNP design.

Emergency Planning Zone (EPZ). (NGNP-LIC-GEN-RPT-L-00020 (R.0) [07-21-09] " Emergency Planning Zone Definition"). The study objective is to establish a licensing strategy to simplify emergency planning requirements for the Next Generation Nuclear Plant (NGNP) that, when implemented, would principally: (1)permit distances for the plume exposure pathway EPZ and ingestion pathway EPZ that are less than the 10-mile and 50-mile zones currently used for large LWRs with the objective of significantly reducing the EPZs to distances more appropriate to HTGRs,(2) prepare arguments for sizing the exclusion area at a distance that allows for practical co-location of the nuclear (i.e., heat generation) and non-nuclear (i.e., heat application) facilities that comprise the NGNP (i.e., establish the EAB at about 400 meters from the reactor centerline)and (3)demonstrate that radiological releases during normal and accident conditions (required for plant siting and emergency planning purposes) are less than the EPA Protective Action Guides (PAGs). The study finds that in the normal operation steady-state and expected transient evaluations, all steady-state operating conditions and transients postulated are in principal achievable with careful design of the plant control strategies and the Core Conditioning System (CCS). Notable in the steady-state cases is the trade-off in size requirements for the CCS between the pressurized and depressurized shutdown states. The study recommends that reduction of the most onerous emergency planning requirements be pursued-specifically (1) a reduction of the plume exposure pathway EPZ to the EAB or the area encompassing industrial plant workers, whichever is larger, and (2) a reduction of the ingestion pathway EPZ (i.e., that for which action may be required to protect the food chain) to a smaller size appropriate to the accident source terms from an HTGR.

7.6 Licensing Plan (ID: PLN-3202, Rev O, 6/26/09)

The subject Plan is based on the licensing strategy developed jointly by DOE and NRC Next Generation Nuclear Plant Licensing Strategy – A Report to Congress, August, 2008 (http://www.ne.doe.gov/pdfFiles/NGNP_reporttoCongress.pdf) as mandated by the EPAct-2005. Its key finding is that "balancing schedule considerations with licensing risk and other pertinent factors," the licensing strategy that provides "the best opportunity for meeting the 2010 date for initial operation of a prototype NGNP" is by adopting

- the combined license process, IOCFR Part 52, and
- a risk-informed and performance-based technical approach.

Adopting these customer mandated conclusions, the INL Plan outlines an NGNP licensing plan which is based on the following elements:

- methodology for adopting LWR regulations including use of a PRA and performance of a regulatory gap analysis
- identification of 35 high priority pre-application issues and the process for their resolution with NRC
- establishment of a research program coordinated and integrated with the NRC Staff including update of Phenomena Identification and Ranking Tables (PIRTs) already developed
- establishment of the content of the COL application to NRC required for IOCFR52.

Finally, the Plan gives a schedule overview which identifies the 4 key steps of the licensing timeline:

- Establishment of R&D
- Resolution of Pre-application issues
- Development of an Early Site Permit (ESP) by the private-sector applicant – an optional step for NGNP
- Preparation of the COL by the private-sector applicant