Next Generation Nuclear Plant Licensing Strategy

A Report to Congress

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CONTENTS

NEXT GENERATION NUCLEAR PLANT LICENSING STRATEGY
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EXECUTIVE SUMMARY

The Energy Policy Act of 2005 (Public Law 109-58) (EPAct), Title VI, Subtitle C, Section 644, requires the Secretary of the U.S. Department of Energy (DOE) and the Chairman of the Nuclear Regulatory Commission (NRC) to jointly submit to Congress, within 3 years of enactment of the EPAct (August 8, 2005), a licensing strategy for the prototype Next Generation Nuclear Plant (NGNP). Furthermore, Title VI, Subtitle C, Section 641 of the EPAct directs DOE to develop the NGNP prototype for commercialization and Section 644(a) provides the NRC the licensing authority for the NGNP prototype. Section 641(b) of the EPAct states that the NGNP Project shall consist of the research, development, design, construction, and operation of a prototype plant, including a nuclear reactor that is based on research and development (R&D) activities supported by the Generation IV Nuclear Energy Systems Initiative and shall be used to generate electricity, produce hydrogen, or both.

DOE has determined that the NGNP nuclear reactor will be a very-high-temperature gas-cooled reactor (VHTR) for the production of electricity, process heat, and hydrogen. The VHTR can provide high-temperature process heat (up to 950 ºC) that can be used as a substitute for the burning of fossil fuels for a wide range of commercial applications. Since the VHTR is a new and unproven reactor design, the NRC will need to adapt its licensing requirements and process, which have historically evolved around light-water reactor (LWR) designs, for licensing the NGNP nuclear reactor. Thus, Section 644 of the EPAct recognized the need for an alternative licensing strategy. This report provides the recommended NGNP licensing strategy, jointly developed by the NRC and DOE. As the technology matures, the government/industry partnership evolves, and input is provided by the general public, revisions to the strategy may be necessary and appropriate.

The report addresses the four elements of the licensing strategy set forth in Section 644(b) of the EPAct. These elements are summarized below:

(1) a description of the ways in which current NRC LWR licensing requirements need to be adapted for the types of reactors considered for the project

(2) a description of the analytical tools that the NRC will need to independently verify the NGNP design and its safety performance

(3) a description of other research or development activities that the NRC will need to review an NGNP license application

(4) a budget estimate associated with the licensing strategy

A DOE and NRC working group was formed to develop the licensing strategy. This group conducted an in-depth analysis of LWR licensing process and technical requirements options, which was performed by the experienced senior staff of the two agencies. The methodology used in formulating the NGNP licensing strategy alternatives also included development of a phenomena identification and ranking table (PIRT) for a prototypical NGNP by subject matter experts in the nuclear field. The PIRT results assisted in the identification of key R&D needs.

Based on the detailed analysis of these alternatives and balancing schedule considerations with licensing risk and other pertinent factors, the Secretary of Energy and the Commission concluded that the following NGNP licensing strategy provides the best opportunity for meeting the 2021 date for initial operation of a prototype NGNP:

(1) The best alternative for licensing the NGNP prototype will be for the applicant to submit a combined license (COL) application under Subpart C, "Combined Licenses," of Title 10, Part 52 "Licenses, Certifications, and Approvals for Nuclear Power Plants," of the *Code of Federal Regulations* (10 CFR Part 52).

(2) The best approach to establish the licensing and safety basis for the NGNP will be to develop a risk-informed and performance-based technical approach that adapts existing NRC LWR technical licensing requirements in establishing NGNP design-specific technical licensing requirements. This approach uses deterministic engineering judgment and analysis, complemented by probabilistic risk assessment (PRA) information and insights, to establish the NGNP licensing basis and requirements. As discussed in this report, the selected approach provides significant advantages in meeting the schedule for licensing an NGNP while providing consistency with Commission policy guidance on the use of probabilistic risk information and insights.

(3) Analytical tools, models, and associated data in major technical areas of the NGNP design will be required to address VHTR safety-relevant phenomena and perform confirmatory analysis. Analytical tools for LWR accident analysis, including thermal-fluid analysis and fission products transport, can be modified for analyzing the NGNP by incorporating appropriate NGNP models and data. Ongoing R&D activities funded by DOE, as well as international cooperative R&D programs, are addressing many of these areas. The NRC will coordinate with DOE on these activities and, to the extent feasible and appropriate, participate in the R&D programs and use the information to develop its independent confirmatory analysis capability. Furthermore, the NRC will make extensive use of experimental data generated by an applicant and provided as part of the license submittal, as well as data available in the open literature.

(4) Areas expected to require regulatory infrastructure development include regulatory guides, standard review plans, codes and standards, reactor oversight process

development, and inspection programs. These guidance documents will need to address NGNP-specific issues involving security and safeguards, spent fuel, environmental matters, and inspection and startup testing. For a first-of-a-kind NGNP prototype plant, interim guidance based on LWR experience may be sufficient in many of these areas. Regulatory guides, standards, and similar documents for the commercial NGNP design can be developed subsequently based on the experience gained from the review of the prototype design.

(5) Other issues associated with the NGNP design and application may be identified in the future, and NRC will need to engage the NGNP applicant during the pre-application phase to address them. Most issues are expected to be in the technical areas related to the NGNP licensing.

(6) The NRC estimates that it will take 5 years to develop necessary analytical tools, data, and other regulatory infrastructure (e.g., regulatory guides, standard review plan, etc.) for confirmatory safety analysis and license review. The NRC also estimates that it will take 4-5 years to conduct the licensing review. In order to meet the statutory requirement to complete construction and operation of the NGNP by FY 2021, the NRC staff and the NGNP applicant will have to engage in a 3-year pre-application review starting in FY 2010, followed by a very aggressive 4-year license application review period starting in FY 2013.

(7) The NRC estimates that the total resources required to conduct the activities in item (6) above could be in the range of \$128 - \$149 million for the period FY 2009–2018. This resource estimate is based on a preliminary assessment of the license strategy requirements and should not be considered a request for funding. Resource requirements will be evaluated on an annual basis throughout the duration of the NGNP program and will be determined through the standard budget development processes.

> This licensing strategy uses very aggressive durations for such critical path items as design, licensing, and construction. DOE and the NRC recognize the industry's desire to outperform the currently estimated schedule and thus complete the project before 2021, but they also recognize that 2021 is already an ambitious goal for the design, development, licensing, and construction of a first-of-a-kind prototype NGNP.

The EPAct established an NGNP target date of September 30, 2021, to either (1) complete construction, and begin operations of the prototype nuclear reactor and associated process heat or hydrogen facilities, or (2) submit to Congress a report establishing an alternative date for completion. Accomplishing a thorough and comprehensive NRC staff review on a schedule that supports the EPAct target for facility operation will require rigorous adherence to the established licensing strategy. To meet such an aggressive review schedule, which accelerates the staff's normal review protocol by about 1–2 years, DOE and the NRC will need to facilitate and coordinate early exchanges of information that relate to the reactor design and the NGNP COL application. DOE and any partners in the NGNP application will need to adhere strictly to provisions detailed in sections 2.1.3 and 2.1.4, respectively, of this report to ensure that a full and complete COL application is submitted in a timely manner, and the NRC will need to process the NGNP application as outlined in this strategy. The following are key needs among these measures:

- Focus on key areas, including planning, training, design familiarization, and identification of programmatic and technical issues.

- Identify the specific reactor technology to be built in advance of the pre-application review. The strategy presented in this document is based on a single reactor technology proceeding through licensing.

- Expand the pre-application review for the specific NGNP design to a 3-year period starting in FY 2010 to address and resolve NGNP technical and programmatic issues, to the extent feasible, before the application is submitted.

This Report to Congress sets forth the DOE and NRC joint recommendations for an NGNP licensing strategy.

1. INTRODUCTION

1.1 Background

The Next Generation Nuclear Plant (NGNP) demonstration project forms the basis for an entirely new generation of advanced nuclear plants capable of meeting the Nation's emerging need for greenhouse-gas-free process heat and electricity. The NGNP is based on the very-high-temperature gas-cooled reactor (VHTR) technology, which was determined to be the most promising for the U.S. in the medium term. The determination is documented as part of the Generation IV implementation strategy in a report submitted to Congress in 2003[1] following an extensive international technical evaluation effort[2]. The VHTR technology incorporates substantive safety and operational enhancements over existing nuclear technologies. As required by the Energy Policy Act of 2005 (EPAct), the NGNP will be a prototype nuclear power plant, built at the Idaho National Laboratory (INL). Future commercial versions of the NGNP will meet or exceed the reliability, safety, proliferation-resistance, and economy of existing commercial nuclear plants. It is envisioned that these advanced nuclear plants would be able to supply cost-competitive process heat that can be used to power a variety of energy intensive industries, such as the generation of electricity, hydrogen, enhanced oil recovery, refineries, coal-to-liquids and coal-to-gas plants, chemical plants, and fertilizer plants.

The U.S. Nuclear Regulatory Commission (NRC) is responsible for licensing and regulating the construction and operation of the NGNP. The EPAct authorizes the U.S. Department of Energy (DOE) to build the NGNP at the Idaho National Laboratory and charges INL with responsibility for leading the project development. The project's completion depends on the collaborative efforts of DOE and its national laboratories, commercial industry participants, U.S. universities, and international government agencies as well as successful licensing by the NRC. At present, and pending further evaluation as the NGNP proceeds through Phase 1 in cost-shared collaboration with industry as required by the EPAct, DOE has not made a final determination on

[1] The U.S. Generation IV Implementation Strategy (2003)
[2] A Technology Roadmap for Generation IV Nuclear Energy Systems (2002)

whether the license applicant will be DOE or one or more entities that reflect a partnership between DOE and private sector firms.

Under the provisions of Section 644 of the EPAct, the Secretary of Energy and the Chairman of the Nuclear Regulatory Commission are to jointly submit to Congress a licensing strategy for the NGNP within 3 years of the enactment of the Act on August 8, 2005. This report addresses the requirement by outlining a NGNP licensing strategy jointly developed by the NRC and DOE. The scope of the document includes all four elements of the NGNP licensing strategy described in Section 644 (b) of the EPAct:

(1) a description of the ways in which current NRC light-water reactor (LWR) licensing requirements need to be adapted for the types of reactors considered for the project.

(2) a description of the analytical tools that the NRC will need to develop in order to independently verify the NGNP design and its safety performance.

(3) a description of other research or development activities that the NRC will need to conduct for the review of an NGNP license application.

(4) a budget estimate associated with the licensing strategy.

1.2 Licensing Strategy Components

NGNP reactor technology will differ from that of commercial LWRs currently used for electric power generation. LWRs have a well-established framework of regulatory requirements, a technical basis for these requirements, and supporting regulatory guidance on acceptable approaches an applicant can take to show that NRC requirements are met. The NRC uses a Standard Review Plan to review licensing applications for these reactor designs. Additionally, the NRC has a well-established set of validated analytical codes and methods and a well-established infrastructure for conducting safety research needed to support its independent safety review of an LWR plant design and the technical adequacy of a licensing application.

New nuclear power plants can be licensed under either of two existing regulatory approaches. The first approach is the traditional "two-step" process described in Title 10, Part 50, "Domestic Licensing of Production and Utilization Facilities," of the *Code of Federal Regulations* (10 CFR Part 50), which requires both a construction permit (CP) and a separate operating license (OL). The second approach is the new "one-step" licensing process described in 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," which incorporates a combined construction and operating license (COL). Both of these processes allow a deterministic or risk-informed performance-based approach to technical requirements.

Many of the regulatory requirements and supporting review guidance for LWRs are technology-neutral; that is, they are applicable to non-LWR designs as well as LWR designs. However, certain LWR requirements may not apply to the unique aspects of a VHTR design. Accordingly, in developing the NGNP licensing strategy, the NRC and DOE considered the various options available to the NRC staff for adapting current NRC LWR licensing requirements for the NGNP

VHTR. These options related to legal, process, technical, research, and regulatory infrastructure matters and included an examination of historical licensing activities. These considerations led to selection of a licensing strategy that would comply best with the considerations identified in the EPAct.

The licensing strategy outlined in this report is composed of two distinct aspects. The first aspect is a recommended approach for how the NRC will adapt the current LWR technical requirements to apply to a VHTR. The second aspect is a recommended licensing process alternative that identifies which of the procedural alternatives in the NRC regulations would be best for licensing the NGNP. To arrive at these recommendations, NRC and DOE evaluated a number of options and alternatives.

Options for Adapting Existing NRC Technical Requirements

In evaluating how NRC LWR technical licensing requirements may need to be adapted for the types of reactors considered for the NGNP project, many issues were considered, including (1) which section of the Atomic Energy Act (AEA) should be used as the basis for the NGNP reactor license application, (2) which NRC reactor licensing process should be followed for the NGNP reactor license application, and (3) how current NRC LWR technical, regulatory, operation and maintenance, administrative, and other nontechnical requirements should be adapted for the NGNP reactor license application.

Within this regulatory framework, there are several technical options for establishing the NGNP licensing basis, each placing progressively greater emphasis on the use of probabilistic risk assessment (PRA) techniques and risk insights. With the exception of the last option (option 4), all other options adapt existing LWR requirements for licensing an NGNP. The last option entails rulemaking to develop a new body of risk-informed and performance-based regulations. These options are described below. The recommended option is identified and described in more detail in Section 2.1.1 of this report.

(1) ***Option 1: Deterministic Approach.*** This option uses deterministic engineering judgment and analysis to establish the licensing basis (including selection of events) and licensing technical requirements. This approach has been used for licensing operating LWRs and involves no use of PRA information and insights.

(2) ***Option 2: Risk-Informed and Performance-Based Approach.*** This option uses deterministic engineering judgment and analysis, complemented by NGNP design-specific PRA information, to establish the licensing basis (including selecting licensing basis events) and licensing technical requirements. The use of the PRA would be commensurate with the quality and completeness of the PRA presented with the application.

(3) ***Option 3: Risk-Informed and Performance-Based Approach (with greater emphasis on PRA).*** This option places greater emphasis on the use of the NGNP design-specific PRA in complementing deterministic engineering judgment and analysis, to establish the licensing basis (including selecting licensing basis events) and licensing technical requirements. As in Option 2, the use of the PRA would be commensurate with the quality and completeness of the PRA presented with the application.

(4) ***Option 4: New Body of Risk-Informed and Performance-Based Regulations.*** This option would use a new body of regulations to establish the licensing basis (including selecting licensing basis events) and licensing technical requirements. The new body of regulations would make extensive use of the risk-informed and performance-based regulatory structure, and would require rulemaking to be implemented.

Alternatives for NGNP Licensing Procedure

New nuclear power plants can be licensed under either of two existing regulatory approaches. Within this context, the NRC and DOE evaluated in detail six specific licensing process alternatives for the NGNP:

(1) ***Alternative 1: 10 CFR Part 50 Licensing Process (CP/OL)—Preliminary Design Provided.*** This alternative would start with an application for a CP to be issued under 10 CFR 50.35(a) that would contain site safety information, a complete environmental report (ER), preliminary design information, and a preliminary plan for operational programs. Once the CP is issued, an OL application would be submitted under 10 CFR 50.35(b) with a description of the final design information and operational programs (with implementation schedules). Once construction is complete and the OL is issued, the NRC would grant authorization to load fuel.

(2) ***Alternative 2: 10 CFR Part 50 Licensing Process (CP/OL)—Final Design Provided.*** This alternative would start with an application for a CP to be issued under 10 CFR 50.35(b) that would contain site safety information, a complete ER, final design information, and a preliminary plan for operational programs. Once the CP is issued, an OL application would be submitted under 10 CFR 50.34(b) with a description of the operational programs (with implementation schedules). Once construction is complete and the OL is issued, the NRC would grant authorization to load fuel.

(3) ***Alternative 3: 10 CFR Part 52 Licensing Process (COL).*** This alternative would begin with a COL application filed under Subpart C, "Combined Licenses," of 10 CFR Part 52 that would contain site safety information, a complete ER, final design information with inspections, tests, analyses, and acceptance criteria (ITAAC), and a description of the operational programs (with implementation schedules). Once the COL is issued and ITAAC are met, the NRC would grant authorization to load fuel.

(4) ***Alternative 4: 10 CFR Part 52 Licensing Process (Design Certification Rule (DCR)/COL).*** This alternative would start with a DCR application filed under Subpart B, "Standard Design Certifications," of 10 CFR Part 52 that would contain non-site-specific

parameters, final design information with ITAAC, and generic technical specifications. Subsequently, a COL application would be submitted that would reference the DCR and contain site-specific safety information, a complete ER, final design information for the site-specific design features, and a description of the operational programs (with implementation schedules). Once the COL is issued and ITAAC are met, the NRC would grant authorization to load fuel.

(5) ***Alternative 5: 10 CFR Part 52 Licensing Process (Early Site Permit (ESP)/COL***). This alternative would start with an ESP application filed under Subpart A, "Early Site Permits," of 10 CFR Part 52 that would contain site-specific safety information, an ER, design parameters, and a demonstration of the feasibility of emergency plans. Subsequently, a COL application would be submitted that would reference the ESP and contain any remaining environmental information, final design information with ITAAC, and a description of the operational programs (with implementation schedules). Once the COL is issued and the ITAAC are met, the NRC would grant authorization to load fuel.

(6) ***Alternative 6: 10 CFR Part 52 Licensing Process (DCR/ESP/COL).*** This alternative would start with DCR and ESP applications filed under Subparts A and B of 10 CFR Part 52. Subsequently, a COL application would be submitted that would reference the DCR and ESP and contain final design information for the site-specific design features, any remaining environmental information, and a description of the operational programs (with implementation schedules). Once the COL is issued and the ITAAC are met, the NRC would grant authorization to load fuel.

2. NEXT GENERATION NUCLEAR PLANT LICENSING STRATEGY

2.1 Recommended Approach for Licensing Next Generation Nuclear Plant for Operation by 2021

2.1.1 Description of the Recommended Strategy

Based on the evaluation of the technical requirement modification options and the licensing process alternatives summarized in Section 1.2, the Secretary of Energy and the Commission have determined that the overall NGNP licensing strategy should comprise Option 2 – a risk-informed, performance-based approach to adapting technical requirements, and Alternative 3 – license applications submitted under the 10 CFR Part 52 Licensing Process.

Although an NGNP applicant could use any of the licensing process alternatives described in Section 1.2, after balancing schedule considerations, technology development status, licensing risk, resource expenditure, and efficiency in conducting the licensing review, the best process alternative for licensing the NGNP prototype would be Alternative 3, i.e., submittal of a COL application under Subpart C of 10 CFR Part 52, which refers to 10 CFR Part 50 for technical licensing requirements. This alternative will provide for the most effective and efficient use of

NRC and applicant resources while reducing licensing and financial risk and optimizing the review and construction schedule.

Under this recommended licensing process approach, the applicant will file a COL application under Subpart C of 10 CFR Part 52 that contains site-specific safety information, a complete environmental report, appropriate final design information for required safety-significant systems with ITAAC, and a description of the operational programs (with implementation schedules). The final design information is defined as the level of information that is sufficient to resolve all safety issues. The applicant is not required to complete a detailed design at this stage of the review.

Once the COL is issued, the applicant will coordinate construction with the NRC staff to ensure that the ITAAC are met. Once construction is completed and the NRC staff finds that the ITAAC have been or will be met, the NGNP applicant will be authorized to load fuel. An application reviewed under the 10 CFR Part 52 COL licensing review process requires a mandatory hearing before the COL license is issued and an opportunity for a second hearing limited to addressing contentions alleging that the ITAAC had not been met.

Both licensing risk and attendant financial risk associated with this approach are greatly reduced relative to other licensing options considered. Risks are reduced because the NRC will approve the final design for required safety-significant systems, site selection, verification criteria, and operational and procedural aspects of the application before any significant safety system construction begins.

With regard to technical licensing requirements, the Secretary of Energy and the Commission determined that the best option for licensing the NGNP prototype would be to use a risk-informed and performance-based technical approach, in particular, Option 2 (i.e., use of deterministic judgment and analysis, complemented by NGNP-specific PRA information) to adapt the existing LWR technical requirements and to establish the NGNP-unique requirements that are not addressed by existing LWR requirements and guidance. Given the current state of VHTR technology design, development and experience, and the quality and completeness of the associated NGNP design-specific PRA, Option 2 is the preferred option for licensing the NGNP prototype, which makes primary use of deterministic judgment and analysis complemented by NGNP-specific PRA to establish the licensing basis and requirements. The use of the PRA would be commensurate with the quality and completeness of the PRA presented with the application. Once the NGNP technology is demonstrated through successful operation and testing of the NGNP prototype, and a quality PRA including data becomes available, greater emphasis on design-specific PRA to establish the licensing basis and requirements will be a more viable option for licensing a commercial version of the NGNP reactor.

The following is the estimate of the schedule to develop, review, and construct an NGNP under this recommended licensing strategy:

2008–2011	Programmatic and key technical issues identified, design underway
2011–2013	Design and COL application developed
2013	COL application submitted

2016	Applicant begins site preparation activities
2017	COL issued and safety-related construction begins
2021	Construction complete and fuel loading begins

2.1.2 Evaluation of the Recommended Strategy

The recommended licensing process (Alternative 3) is expected to reduce both licensing risk and attendant financial risk compared to other licensing options considered. Risks would be reduced because the NRC will approve the final design, site, verification criteria, and operational and procedural aspects of the application before any significant construction begins. This licensing process will result in conducting the mandatory hearing on a final design with an ITAAC before any significant construction begins. A potential hearing before fuel load would be limited to contentions alleging that the ITAAC had not been met. Therefore, this licensing approach is expected to ensure the most effective and efficient use of NRC and applicant resources while minimizing licensing risk and taking no longer than other alternatives to complete. This licensing approach should also reduce financial risk to the industry stakeholders who may decide to fund the project.

The recommended approach for adapting NRC LWR technical requirements (Option 2) has the advantage of limiting adverse impacts on the NGNP licensing schedule, as well as limiting regulatory and licensing uncertainty, while providing consistency with the Commission policy guidance on the use of PRA. This approach also provides the NGNP designer with flexibility in optimizing the NGNP design for performance and safety, while contributing significant lessons learned toward the goal of developing risk-informed criteria for a future commercial NGNP design.

Given the state of technological readiness and DOE schedule estimates for submittal of a licensing application and construction duration, the NRC was challenged to devise a licensing schedule that would support the NGNP startup in 2021. The NRC staff has estimated that any review of a COL application for a design that was not previously reviewed would take 33-60 months to complete, depending on the uniqueness of the design, whether there is a need for testing and the extent of the testing program, whether programmatic matters need to be addressed, and other issues. Because the NGNP will be a first-of-a-kind non-LWR review with programmatic, regulatory, and technical issues that must be identified and resolved during the licensing review, the NRC established a set of requirements for early identification and disposition of key technical, regulatory, and programmatic issues to be addressed during a 3-year pre-application review. Such early resolution of key issues will permit a COL safety review for the NGNP to be completed in just 48 months, including 12 months for mandatory public hearings. This schedule is optimistic, but can be accomplished provided that the COL application is complete and of high quality, and all the conditions required for success identified in this report are met. Any non-mandatory hearing activities that are available to the public before startup will occur near the end of construction of the NGNP. These activities are included in the 4-year estimate for the construction of the facility.

The following is the estimate by the NRC and DOE staff of the review and construction duration for key milestones of the NGNP 10 CFR Part 52 COL licensing review:

Milestone	Time Increment (months)	Total Lapsed Time (months)
Pre-application review begins	0	0
Pre-application review conducted	36	36
COL application submitted	0	36
NRC staff conducts COL review	36	72
COL hearing conducted	12	84
COL issued	0	84
Safety-related construction begins	0	84
Construction complete (no significant changes to design)	48	132

2.1.3 Implementation of the Recommended Strategy

The EPAct establishes a target date of September 30, 2021, to either (1) complete construction and begin operation of the prototype nuclear reactor and associated process heat or hydrogen facilities or (2) submit to Congress a report establishing an alternative date for completion. Conducting a thorough and comprehensive NRC review on a schedule that supports the target date given in the EPAct will require rigorous adherence to the recommended licensing strategy. To implement the NGNP licensing strategy successfully and meet the congressionally mandated operation date of 2021, NRC and DOE expect that the following actions would be necessary:

- Funding requested in future President's Budget requests will identify the amount required to achieve annual program goals.

- DOE chooses a single design no later than March 2009 to support the pre-application review.

- NRC implements a pre-application review to identify and resolve policy, regulatory, and key technical issues for the NGNP. The NRC staff will gather information; identify and develop proposals for resolution of key design, safety, and licensing issues; and prepare papers identifying programmatic, regulatory, and key technical issues with recommendations for consideration and approval by the Commission. The typical 2-year pre-application review period must be increased to 3 years (i.e., starting in FY 2010) because of the major programmatic, regulatory, and technical issues this new VHTR design presents and the issues related to the use of a risk-informed methodology for identifying and evaluating accidents and safety systems.

- DOE identifies the applicant for the NGNP prototype by the start of the pre-application review in FY 2010.

- The applicant submits a regulatory gap analysis in FY 2010, which identifies which existing LWR requirements and guidance the design does or does not comply with, as well as other nontechnical NRC regulations that the applicant would not comply with or that are otherwise inappropriate to apply to the NGNP prototype. The analysis should propose detailed resolutions to address any gap. The analysis will allow the identification and resolution of programmatic, regulatory, and key technical issues.

- Programmatic, regulatory, and key technical issues identified during the pre-application review are resolved at least 1 year before the licensing application is submitted to ensure the incorporation of any design modifications. To achieve this, preliminary design descriptions of all safety-significant systems must be available at the beginning of the pre-application review (FY 2010), and the applicant must propose reasonable solutions to potential programmatic, regulatory, and key technical issues at that time.

- The extent to which the NGNP design will rely on offsite fabrication of large components and the timeframes for fabrication of such components as the reactor vessel are unknown. Typically, such manufacturing is done before a CP or COL license is granted, with major component procurement occurring as early as 24 months before construction. The applicant will need to inform the NRC of such procurement activities with sufficient notice to support appropriate staff inspection.

- The applicant submits a licensing application in FY 2013 for a prototype nuclear power plant (using 10 CFR 50.43(e)) that would be located at a remote INL site. The prototype may incorporate compensatory measures to address uncertainties in the design (caused by delayed demonstration testing). Such measures may include supplemental robust systems (i.e., containment), a staged startup process, limitations on operation imposed by technical specifications or license conditions, a limited duration of the license, and others. The license application must be a high-quality submittal, supported by sufficient R&D, consisting of a preliminary design (final for all safety-significant systems), sufficient for the Commission to resolve all safety questions associated with the design. The quality and completeness of the application and complexity of the issues under evaluation will affect the schedule.

- Necessary regulatory infrastructure changes must be in place to make the NGNP license application review more effective and efficient, including completing regulatory guidance updates, updating the Construction Inspection Program, and completing any code development or other technical and regulatory infrastructure activities necessary to conduct the review. Additionally, preparatory activities must be completed at a sufficient stage in the review process to support the NGNP licensing activities.

- Testing and code development necessary to support the licensing application for the prototype NGNP must be completed in time to support the license application. Test results conducted during the COL review must continue to confirm the adequacy of the NGNP design and require few design modifications.

- A complete and high-quality final design is prepared in parallel with the NRC staff's review of the preliminary design (final design for all safety-significant systems). The staff will be informed of the progress of balance-of-plant development as the review progresses, and amendments to the license application will be submitted periodically to reflect these design developments.

- The applicant responds to requests for additional information and fully addresses the staff's concerns in an expedited manner (i.e., 60 days or less versus the typical 90-day turnaround time).

- The applicant performs site preparation (NRC approval not required) and limited work authorization activities (conducted under 10 CFR 50.10(c)) during the license application review.

- The applicant completes construction of the NGNP in about 4 years after the NRC issues a COL.

The technical approach to establishing the NGNP licensing basis and requirements is expected to include the following:

- establishment of licensing-basis event categories (i.e., abnormal occurrences, design-basis accidents, and beyond-design-basis accidents) based on the expected probability of event occurrence; within each category, selection of licensing basis events using deterministic engineering judgment complemented by insights from the NGNP PRA.

- selection of the safety-significant systems, structures, and components (SSCs) relied on to prevent or mitigate the safety-significant licensing-basis events using deterministic judgment, complemented by insights from the NGNP PRA.

- establishment of conservative design and acceptance criteria for core and safety-significant SSCs, consistent with the applicable LWR requirements and recognizing the design and technology aspects unique to the NGNP.

- verification of adequate safety margins to the integrity and performance of core and safety-significant SSCs using a conservative analysis or a best-estimate analysis with consideration of uncertainties.

- establishment of special treatment requirements to ensure the required performance capability and reliability of the safety-significant SSCs using deterministic engineering judgment, complemented by insights and information from the plant PRA.

- use of consequence acceptance limits for onsite or offsite releases for licensing-basis events that are consistent with current dose limits for LWRs in 10 CFR Part 20, "Standards for Protection Against Radiation," and 10 CFR 50.34, "Contents of Construction Permit and Operating License Applications; Technical Information"; also, assessment of radiological consequences for licensing-basis events on the basis of event-specific mechanistic source terms.

- consideration of containment functional performance requirements as a radionuclide barrier in the context of design and performance of such NGNP features as the core, fuel, and cooling systems.

- establishment of defense-in-depth (DID) requirements using deterministic engineering judgment, complemented by risk insights, as appropriate.

To successfully implement the above technical licensing requirements, NRC expects that it will be necessary to resolve the following NRC licensing technical policy/programmatic issues and obtain Commission decisions on these matters:

- requirements and criteria for functional performance of the NGNP containment as a radiological barrier.

- allowable dose consequences for the licensing-basis event categories.

- approach for using the PRA to select licensing-basis events; establish special treatment requirements and establish DID requirements.

- acceptable basis for event-specific mechanistic source term calculation, including the siting source term.

The NGNP applicant is expected to meet the following technical and programmatic requirements:

- implementation of an acceptable fuel qualification test program to demonstrate the high levels of safety performance and reliability of the NGNP reactor fuel as a barrier to fission product release.

- fabrication quality control for fuel to ensure the requisite high level of in-reactor fuel safety performance over the lifetime of the NGNP fuel supply.

- use of verified and validated evaluation models, analytical tools, and methods used for the NGNP accident analysis, thermal-fluid and neutronic analysis, and confirmation of the acceptability of the models; also, adequate understanding and applicable data for significant radionuclide transport mechanisms for all sources and barriers and pathways to the environment, including containment design features.

- establishment of performance and reliability of the safety-significant NGNP reactor core ceramic structures using acceptable engineering codes and standards, including materials property requirements under irradiation and accident conditions.

- sufficient provisions, including in-service inspections, post-irradiation examinations, and testing, to adequately inspect, examine, and test the SSCs of the NGNP reactor and plant that are determined to be safety significant; also, instrumentation to accurately and reliably monitor the safety-significant parameters and conditions of the NGNP reactor and plant.

- an adequate startup test and commissioning program to validate the data and assumptions used in the design of the SSCs, to demonstrate their proper functioning, and to validate the design and safety analysis methods and calculations.

2.1.4 Other Key Assumptions

The recommended licensing strategy is predicated on other key assumptions delineated below. Deviations from these assumptions could adversely impact the ability to implement the licensing strategy and the corresponding estimated schedule.

- Although some review activities can be performed in parallel, tasks such as Advisory Committee on Reactor Safeguards reviews or Atomic Safety and Licensing Board hearings must be performed sequentially. The schedule estimates also account for the duration of certain activities, such as comment periods required by the National Environmental Policy Act.
- Although multiple contentions could emerge in an Atomic Safety and Licensing Board proceeding at either COL issuance or ITAAC completion, the NRC expects that only a few issues will require an evidentiary hearing.

> In an effort to understand industry markets, energy needs and commitments, DOE sought suggestions and comments on possible NGNP licensing alternatives and approaches from its three preconceptual design reactor vendors. Most comments and concerns revolved around the need for a more aggressive licensing review schedule and faster construction so that the technology could be more quickly deployed for commercial applications. Some expressed a preference for a licensing process under 10 CFR Part 50, while others preferred the process under 10 CFR Part 52. Driving the preference for the use of a Part 50 process was the perception that licensing the NGNP under Part 50 would facilitate more certainty for private-sector financing, an earlier start to construction, and ultimately an earlier startup date. Industry end users, particularly the petrochemical industry, want to see this technology commercially available as early as 2018.

2.1.5 Evaluation of Potential Alternative Licensing Processes

Section 1.2 of this report identified potential alternative licensing processes. An evaluation of these alternatives follows.

Compared to a COL application submitted under Subpart C of 10 CFR Part 52, each of the potential alternative licensing processes was judged to involve activities that made the alternative less optimal in terms of schedule, resource expenditure, and/or licensing and financial risk. Various factors, including schedule estimates, number and extent of hearing activities, resource expenditures, the NRC's experience with the licensing process, and effectiveness and efficiency of review, reduced the attractiveness of these alternatives for licensing the first NGNP prototype. For example, the review duration for those alternatives that involve design certification would result in the longest time to complete the review because the certification review would significantly extend the time to complete the review and construction of the facility. In addition, certification of a prototypical design would be inadvisable until all the demonstration testing is complete.

Another alternative involves the use of a licensing process in which the applicant submits a preliminary design for a CP under 10 CFR Part 50. This alternative presents the greatest risk to licensing success because, although such an application may appear attractive as it allows construction to start earlier than in the other alternatives, experience shows that whatever time is saved because of the early start of construction will be lost in the extra construction time required to account for construction rework made necessary by (1) simultaneous performance of the final design and construction, (2) modifications resulting from the subsequent OL review, and (3) the greater opportunity for identification of admissible hearing contentions at the OL stage of review. Should programmatic, regulatory, and key technical issues remain unresolved when the CP is issued because of the preliminary nature of the submitted design, significant design changes will likely be required during the OL stage of review.

Other licensing alternatives were determined not to be an effective and efficient use of NRC or applicant resources because they involve additional time and resources to conduct the review as the result of additional hearing activities; or they involve activities made unnecessary by the statutory requirements of the EPAct. In addition, some of the licensing approaches do not provide for inspection activities under the more predictable ITAAC process, where the acceptance criteria and inspection procedures are more clearly defined.

Therefore, for the reasons stated above, a COL application submitted under Subpart C of 10 CFR Part 52 was judged to provide the most effective and efficient use of NRC and applicant resources while minimizing licensing risk and taking no longer than other alternatives to complete. This licensing alternative may also provide more certainty for industry stakeholders who may fund the project.

Compared to a risk-informed licensing approach, each of the potential alternative approaches was judged to involve issues that made the alternative significantly less practicable. For example, a fully deterministic approach (which would make no use of PRA insights) was judged to be inconsistent with NRC endorsement of risk-informed approaches for regulatory decisions, whereby risk insights are considered together with other factors to establish requirements. Similarly, the use of a new body of risk-informed and performance-based regulations was judged to involve significantly lower licensing certainty because of the much more extensive use of the plant PRA, especially for the NGNP (which will have very limited operating experience or PRA experience at the time of licensing). Overall, each of the alternatives was judged to be less viable than the selected approach.

2.2 Statutory and Regulatory Authority

2.2.1 NRC Authority to License the Next Generation Nuclear Plant Facility

The NRC and DOE have reviewed applicable statutes and the NRC's licensing requirements for utilization facilities and conclude that there are no legal constraints that preclude NRC licensing of the NGNP under any of the development alternatives being considered. The determination of the applicable requirements, and compliance therewith, will be determined as part of the implementation of the NGNP licensing strategy. The following summarizes the legal analysis supporting these conclusions.

2.2.1.1 Energy Policy Act, Sections 641–644

Section 641 of the EPAct directs the Secretary of Energy to establish the NGNP Project to develop, design, construct, and operate a prototype nuclear plant with a nuclear reactor that will demonstrate the production of process heat that can be used to make electricity, hydrogen, and other energy intensive industrial products. Section 642 directs that the prototype nuclear reactor and associated plant developed under the project shall be built at the INL site in Idaho. The NGNP organization is addressed in Section 643. Section 644 requires the nuclear reactor authorized under Section 644 to be licensed and regulated by the NRC, in accordance with Section 202 of the Energy Reorganization Act (ERA) of 1974.

Section 202 of the ERA grants the NRC the authority to license and regulate certain DOE facilities prescribed in Section 202. Section 202(2) addresses DOE demonstration nuclear reactors and authorizes NRC regulation of such reactors (except those in existence before 1974) "when operated as part of the power generation facilities of an electric utility system, or when operated in any other manner for the purpose of demonstrating the suitability for commercial application of such a reactor." In accordance with Section 202 of the ERA, the NRC would have licensing and regulatory authority over any NGNP prototype reactor constructed, operated, or owned by DOE that is operated as part of a power generation facility of an electric utility system, or operated for purposes of demonstrating the suitability of the reactor for commercial application. Furthermore, without specifying what entity would be the license applicant, Section 643(b)(2) of the EPAct stipulates that the second phase of the NGNP Project is to include applications to the NRC for licenses to construct and operate the prototype nuclear reactor. There is nothing in the EPAct or elsewhere that diminishes the NRC's authority under existing law to license and regulate a commercial entity's construction and operation of a nuclear reactor. Lastly, Section 644 does not address or change existing law with respect to the licensing and regulation of nuclear materials generated or owned by DOE that may be incidental to the construction and operation of the NGNP.

2.2.1.2 NRC Licensing Authority under the Atomic Energy Act

Under the Atomic Energy Act (AEA) of 1954, as amended, the NRC is authorized to grant licenses to two types of nuclear facilities—(1) a utilization facility "useful in the conduct of research and development activities of the type specified in section 31 [of the AEA]..." (Section 104.c) and (2) a utilization facility for "industrial or commercial purposes" (Section 103). At present, DOE has not determined the detailed design and capabilities of an

NGNP reactor to decide whether an NGNP reactor would be engaged primarily in activities of a commercial or industrial purpose, or a demonstration R&D, or testing purpose. Regardless of the ultimate design of the NGNP reactor, a Part 52 licensing demonstration for the NGNP serves a beneficial purpose as a test case for future advanced non-LWR reactors that apply for licensing and regulation.

If the NGNP-generated electricity, hydrogen, or process heat is sold into the commercial market, utilized by an industrial user, or utilized by DOE at INL, the facility could obtain a Section 103 license. On the other hand, if the NGNP possesses the essential characteristics of reactors currently licensed and regulated by the NRC as non-power test or research reactors, the NRC will likely apply only those technically relevant NRC requirements to the NGNP that are analogous to those that the NRC applies to currently licensed research and test reactors. If decisions are made to downsize the NGNP reactor and its demonstration capabilities, then the reactor could be licensed and regulated as a test and research facility under Section 104.

If licensed and regulated as a test and research facility, the "technically relevant NRC regulatory requirements" for a test and research reactor would be the regulatory requirements for a commercial reactor, modified as appropriate and necessary to reflect reduced power and capabilities of the reactor. For example, a test reactor sited at INL may entail reduced risk to public health and safety, given the remote location of INL and the lowered nuclear materials risk, which may result in different and/or relaxed requirements. However, a downsized test reactor might not be sufficient to demonstrate the commercial suitability of the reactor design. Also, a test reactor licensing process will not demonstrate the practical application of the streamlined one-step licensing process inherent in 10 CFR Part 52. The Part 52 licensing demonstration for the NGNP serves a beneficial purpose as a test case for future advanced non-LWR reactors that apply for NRC licensing and regulation.

The NRC will likely be guided by historical practice in applying current NRC regulatory requirements to the NGNP. Thus, to the extent that the NGNP possesses the essential characteristics of a commercial or industrial reactor (with respect to design or nature of operation, or both), the NRC would likely apply technically relevant NRC regulatory requirements to the licensing of the NGNP regardless of whether it is licensed under either Section 103 or Section 104.c of the AEA.

2.2.1.3 Licensing of Multiple Entities

At present, and pending further evaluation as the NGNP proceeds through Phase 1 in collaboration with industry, DOE has not made a final determination regarding the cost-shared organization structure under which any NGNP prototype reactor would be licensed. Pending these decisions, DOE and NRC considered possible scenarios under which a license applicant could proceed and the effect, if any, on the NRC's authority to license and regulate an NGNP reactor and the attendant licensing strategy for such reactor.

If an entity in addition to DOE is the applicant to construct and/or operate the NGNP facility, that entity must have an appropriate NRC license in accordance with Sections 101 and 185 of the AEA. Regardless of NGNP ownership, the NRC licensing strategy for the NGNP facility under

10 CFR Part 52 will not change. However, certain NRC licensing findings may be different (e.g., financial qualifications) depending on whether the applicant is DOE or another entity.

The NRC findings that must be made with respect to each licensed entity will depend on the particular license authorities granted to each licensed entity, in accordance with Section 182 of the AEA. For situations involving multiple entities for a licensed facility, the NRC's practice has been to determine the applicability of NRC requirements and findings for each licensee on a case-by-case basis.

2.3 Conclusion

DOE and the NRC believe that the licensing and operation of the NGNP can be accomplished on the schedule set by, and in compliance with, the EPAct of 2005, provided that that all assumptions are realized. The following course of action is recommended to implement the licensing strategy in parallel with enlisting industry partners to drive the project to completion:

- As the technology matures, the government/industry partnership evolves, and input is provided by the general public, revisions to the strategy may be necessary and appropriate.

- DOE and the NRC will begin executing the licensing strategy as discussed in this report. DOE will identify a specific reactor technology for the NGNP, and the NRC will prepare to conduct the review.

- DOE will seek private sector partners to co-fund the NGNP Project. A decision will be made as to whether the license applicant will be DOE or one or more entities that reflect a partnership between DOE and private sector firms. DOE and the NRC will review the licensing strategy with any NGNP private sector partners and the general public as appropriate and make adjustments if needed.

- The NGNP Project will be executed in accordance with the licensing strategy recommended in this report.

3. NRC Analytical Tool Development

It is expected that certain analytical tools will need to be developed or modified in a number of technical areas to enable the review of NGNP license application, evaluate the safety case, and assess the safety margin. Given the early stage of the NGNP program, any information about potential analytic or regulatory development needs presented in this report should be considered preliminary projections. All program needs will be reevaluated on an ongoing basis.

The major technical areas for NGNP include accident analysis, high temperature materials including graphite, fuel performance and fission product transport, and process heat applications. Other areas that may require limited development of tools include structural analysis, human factors and human-machine interface, and probabilistic risk assessment. The potential needs for analytical tools in major technical areas as well as other areas are described below in more detail.

3.1 Introduction

The NRC is responsible for ensuring safety in the design, construction, and operation of commercial nuclear facilities, including power plants and research and test reactors, and in the other uses of nuclear materials, such as in medicine and industrial activities. As a key component of nuclear safety, the NRC carries out independent confirmatory research to provide the technical basis and expertise needed to support the agency's decision-making process and to identify and characterize important safety issues requiring resolution. The research program provides analytical tools and information for staff to identify and resolve safety issues, make regulatory decisions, develop regulations and guidance, and conduct independent analyses to support regulatory decisions. The research is also intended to reduce uncertainties in areas where safety margins are not well characterized and where regulatory decisions need to be confirmed.

For any reactor design, analytical tools and associated research and development (R&D) and data are needed for confirmatory safety analysis. For the NGNP, NRC will need to ensure tools are capable of verifying the adequacy of the NGNP design to address challenges to the following fundamental safety functions:

- adequate heat removal;
- reactivity control, and
- confinement of radioactivity.

The challenge to heat removal involves timely and sufficient cooling of the fuel element, the core, the reactor vessel, and the confinement and is critical to preventing failures of fission product barriers. The challenge to reactivity control involves maintaining the reactor in a stable condition. The challenge to confinement of radioactivity involves maintaining fuel particle integrity as well as that of core structures, the primary pressure boundary, and the reactor confinement structures, thus limiting the release of radioactivity to the environment. Additionally, chemical attacks on fuel particles and structural and other reactor components resulting from air and/or water ingress during a break in the primary system boundary or during the shutdown operations such as refueling pose a challenge for the NGNP design. The analytical tools must be able to verify the adequacy of NGNP design features to address these challenges.

Ultimately, analytic capability, R&D, experimental data, and other such needs will depend on the specific nature of the NGNP design and applications, which will be determined in more detail as the project moves forward. Therefore, the information provided in the report on potential needs must be considered preliminary.

Analytical tools, R&D, and other requirements will be evaluated on an ongoing basis and will be considered in the context of overall budget requirements and priorities. NRC and DOE will work with industry to determine how best to address future needs in these areas. See section 3.2.6 for additional information on this strategy.

3.2 Discussion of Major Analytical Tools

3.2.1 Accident Analysis Including Thermofluids and Neutronics

Accident analysis tools will be used to perform independent confirmatory analysis in support of the NGNP licensing safety review. The tools must be able to calculate heat transfer and fluid flow in reactor core, primary pressure boundary, confinement, and other components, including any multidimensional and asymmetric effects, so as to provide more reliable assessment of heat removal and cooling under normal operating, design-basis accident, and beyond-design-basis accident conditions. Moreover, models to calculate maximum fuel temperature and time-at-temperature distributions must be developed to provide critical inputs to fuel failure and source term or dose calculations. The tools must also be able to calculate pressure and temperature histories in the reactor confinement during accidents, particularly during depressurization accidents, which may result in air and/or water ingress into the reactor pressure vessel and core.

The accident analysis tools should include models simulating chemical reactions resulting from air and possibly water/steam ingress, including reactions with graphite and coupling between thermofluids and chemical kinetics. Models simulating large pressure pulses that could damage the reactor cavity cooling system, and potentially provide a fission product release path to the environment, should also be included. In the reactor physics area, the codes should provide multidimensional treatment of neutronics to account for core heterogeneity and to enable more reliable estimates of core power peaking distributions which are used as inputs to transient accident analysis.

The existing accident analysis tools for current reactor designs will be used to the maximum extent possible as the basis for the NGNP-specific analyses and modified, as appropriate, for applicability to NGNP analyses.

3.2.2 Fuel Performance and Fission Products Transport

Analytical tools will be used to simulate the principal phenomena of NGNP fuel performance and fission products transport, retention, and ultimate release into the environment. The modeling needed for use in NGNP fission products transport (FPT) analysis tools or codes depends on the safety role of the confinement or containment. The level of modeling fidelity for the FPT analysis can be evaluated properly when a conceptual design is available, and the safety functions of the reactor system and confinement or containment building are more precisely defined. The required functions of any suite of FPT models would include fission product release from the fuel; transport through and retention in graphite and fuel matrix materials, in primary circuit, and in confinement by various mechanisms; and chemical and physical forms of the released fission products.

The NGNP-specific fuel performance models will be used for reliable prediction of fuel integrity and otherwise, an estimate of fuel failure fraction, under both normal and accident conditions. Testing of NGNP-specific fuel will be necessary to generate the data required for development of reliable fuel performance models.

The FPT codes and models developed for LWRs may be applicable with few exceptions. Since neutron fluence strongly influences graphite properties, models for fission product retention and transport in structural graphite must adequately capture this influence. Fission product surface removal effects by steam and air also need to be modeled adequately, as potential uncertainties in this area could lead to design compromises if the fission product contamination of the reactor circuit is significant. Reliable modeling of FPT in the presence of dust, potentially generated in large quantities in the pebble bed reactor type, will be needed, since reactor circuit retention of fission products is very important to the safety case. Finally, materials data and models specifically focused on plate-out will be needed.

3.2.3 High-Temperature Materials and Graphite Performance

In the area of high-temperature materials and graphite performance, the NRC will need to assess the design adequacy of materials for safety performance. The tools include reliable predictive models for the pressure boundary and other critical component failures and mechanistic models for long-term damage progression based on extrapolation of short-term laboratory test data. The tools should be able to estimate margins to failures utilizing inservice inspection data or other related information.

Analytical tools are also needed for establishing material performance envelopes. Time-dependent failure criteria for NGNP materials need to be developed for ensuring safety and adequate operational life. Models for design analyses required by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code need to be developed. Adequacy and applicability of the current ASME Code allowable with respect to service times and temperatures need to be determined, and the current state of high-temperature design methodology needs to be addressed for structural materials and graphite. Also, ASME Code and design requirements for graphite core support structures need to be formulated. The vendor community is expected to develop most, if not all, analytical tools in this broad category in support of the NGNP design activity.

To support analytical tools and model development, experimental data will be needed in several areas including material behavior (e.g., creep, fatigue), effects of irradiation on material properties, structural stability during long-term aging in a radiation environment, and corrosion behavior of structural graphite and high-temperature material components during air ingress and otherwise in an impure helium environment. It is assumed that the applicant or the industry will generate all required experimental data pertaining to high-temperature materials and graphite to support the NGNP design development effort. It is also assumed that the NRC will have full access to the data to support its development effort for confirmatory tools and for an independent assessment of the safety performance of materials.

3.2.4 Process Heat Applications

The need for experimental data and analytical tools will depend on the specific nature of process heat applications and corresponding designs, particularly on the hydrogen production processes that are selected and associated design details. More design details are needed to adequately assess the impacts of the process heat aspect of the NGNP. Accidental unconfined releases of hydrogen from a hydrogen production facility are unlikely to be a major hazard for the nuclear plant, assuming some minimum separation distances. The NRC will use existing tools and engineering methods to evaluate the separation requirements between the reactor building civil structure and the hydrogen production plant. For confined hydrogen explosion and its effect on the reactor building structure, existing combustion physics models, experimental data, and computational tools can be used with appropriate modifications. Finally, the NRC will need tools for plume modeling of oxygen and other byproduct gases from the hydrogen plant and the effects of such plumes on the nuclear plant safety-related SSCs. To the highest degree possible, NRC will work with other agencies to utilize existing modeling tools and expertise, particularly in terms of plume modeling.

The NRC will need tools for reliable assessment of external loading of the reactor plant because of upset conditions in the hydrogen plant or cyclic loading of the reactor plant as the result of, for example, a load-following operation of the hydrogen plant to ensure safety. Moreover, any unwanted chemical addition to the reactor system resulting from process and/or intermediate heat exchanger failure or from leakage in the heat transport loop and the potential impact it would have on fuel performance and reactor system integrity will be assessed and may require model development and the generation of associated experimental data. Generally, for reactor safety analysis, the process heat aspects may be considered in the same category as external events with a strong coupling to the reactor plant.

3.2.5 Other Areas

3.2.5.1 Structural Analysis

The NRC will need to ensure that tools are capable of performing confirmatory structural analysis on NGNP structures because it is possible that certain structures will be subject to nonlinear response during horizontal and vertical earthquakes.

Concrete structures in NGNP can be subjected to sustained high temperature under accident conditions. Explosive spalling can occur when large volumes of concrete experience high heating rates. The NRC will use analytical tools (in particular, finite element models) to assess the transient aspects of high-temperature performance of reinforced concrete structures during heating and cooling.

3.2.5.3 Human Factors and Human Reliability

Automation can change the operators’ role in monitoring, detecting, and analyzing off-normal conditions, assessing situations, and planning responses. The NRC must consider the effect of these changes on operator safety performance. Also, the agency may need to formulate guidance to review the methods an applicant proposes for mitigating the effects of degraded instrumentation and monitoring systems on human safety performance. However, other than the high-temperature performance of instrumentation and monitoring systems, the research needs in human factors are not unique to the NGNP.

3.2.5.4 Probabilistic Risk Assessment

The PRA infrastructure development will involve regulatory guidance to provide an acceptable approach for evaluating whether a proposed plant PRA is adequate for making the licensing decisions. The scope and detail of the guidance will need to be sufficient for the NRC staff's review of the plant PRA with respect to its safety performance. The NRC will need to develop the necessary standards and associated detailed technical guidance and data, particularly in such areas as passive system performance. Advanced reactor designs, such as the NGNP, will make extensive use of passive systems and rely on inherent characteristics of the design to ensure safety and place little, if any, reliance on the use of active systems. As a result, potential errors and omissions during design, manufacture, fabrication, construction, or testing of plant SSCs could adversely impact plant safety performance.

3.2.6 Development Strategy

The NRC plans to use existing analytical tools to the extent feasible, with appropriate modifications for the intended purpose. For LWR safety analysis, the NRC traditionally uses its system-level MELCOR code, which is capable of performing thermal-fluid and accident analysis, including FPT and release. This code will be modified for the NGNP by incorporating many of the models discussed previously. In the past, the NRC has also used a simplified graphite reactor severe accident code for bounding analysis and sensitivity studies. Finally, as needed, computational fluid dynamics models and associated tools will be developed to investigate certain thermal-fluids phenomena in greater detail so as to reduce uncertainties in predictive capability.

The NRC uses PARCS, among other codes, for neutronic calculations which provide initial and boundary conditions to accident analysis codes such as MELCOR. The neutronic codes can be modified as appropriate for NGNP confirmatory analysis. The agency will need a fuel performance code to provide fuel-related initial and boundary conditions to accident analysis codes. DOE has ongoing R&D activities to support development of such a code. The NRC will explore inclusion of this code or, at a minimum, the fuel performance models in the code, in the agency's suite of codes.

In other technical areas (notably, high-temperature materials and graphite performance), the development strategy for confirmatory analysis tools will utilize various sources of information to the maximum extent feasible. Among these sources are ongoing American Society of Testing and Materials standards development activities, ASME codes and standards activities, and similar activities of the American Nuclear Society. Staff members from the NRC and DOE participate in many of these activities. Likewise, in process heat applications, structural analysis, human factors, and PRA areas, the development strategy will utilize available sources of information from other sectors of industry and R&D organizations.

Current R&D activities funded by DOE, as well as international cooperative R&D programs, are addressing many of these areas. To the extent that data and tools are available from these activities, the NRC will use this information in the development of its independent confirmatory analysis capability. Furthermore, the NRC will make extensive use of experimental data generated by an applicant and provided to the agency as part of the license submittal, as well as data generated under domestic and international programs, and other data available in the open literature.

4. OTHER REGULATORY DEVELOPMENT ACTIVITIES

NRC and DOE have identified other technical areas that may require attention as the NGNP project proceeds. NRC and DOE will work with industry to determine who should and how to cost-effectively and efficiently address future needs in these areas. Any potential Federal efforts will be considered in the context of overall budget requirements and priorities.

4.1 Licensing Review Infrastructure

4.1.1 Regulatory Requirements

The NRC made a preliminary assessment of 10 CFR Part 50 to identify areas where 10 CFR Part 50 requirements can be used directly, where these requirements can be applied with some modifications, and where these requirements are not applicable and new requirements will likely be needed. General provisions and most administrative, legal, and procedural requirements can be used directly. Many of the 10 CFR Part 50 regulatory requirements can be applied directly, or with some modification, to the NGNP.

Regulatory and licensing requirements that are not prescriptive allow the designer the flexibility to optimize the design and operations for performance and safety. The designer can use the PRA tools to identify the most important SSCs and human actions, as well as the reliability, availability, and performance goals that each needs to meet. The approach for using the plant PRA will influence the categorization of the current LWR requirements and the additional new requirements unique to the NGNP. The revised and new requirements would be written in a performance-based fashion to provide additional flexibility and facilitate plant oversight. Final determination of applicable LWR requirements and additional NGNP-specific technical requirements will be based on an actual NGNP application with design details and a proposed licensing and safety analysis approach. This determination will be made during the preapplication review.

In addition to the applicable regulatory requirements, supporting regulatory infrastructure changes will likely be needed, including development of licensing analysis guidelines; guidance on the use of PRA for the selection of design- and licensing-basis events; guidance on the verification of fuel performance and qualifications; guidance on SSC and equipment qualifications; inspection and startup testing program oversight; reactor oversight process (ROP); and integration of safety, security, and emergency preparedness. The NRC intends to use the existing LWR requirements for spent fuel management, aging management, and emergency planning for the purpose of licensing an NGNP reactor.

4.1.2 Fuel Performance and Qualifications

To ensure satisfactory fuel performance over the life of the plant, the regulatory requirements will need to include quality control at the fuel fabrication facility and fuel performance testing by an applicant. An acceptable fuel qualification test program shall demonstrate the high levels of safety performance and reliability of the NGNP reactor fuel as a barrier to fission product release during normal operation and for the selected accident conditions. To monitor the in-situ reliability and performance of the NGNP fuel, a surveillance program may be necessary.

4.1.3 Construction Inspection and Startup Test Programs

Many regulatory requirements (e.g., quality assurance, quality control) related to the construction inspection of the NGNP are expected to be similar to those used for LWRs. However, the NRC may need to develop certain inspection techniques and procedures for non-LWR aspects of the NGNP technology (e.g., coated particle fuel, graphite) and train agency inspectors in their use. Also, the role of the NRC in inspecting and regulating components fabricated outside the United States may need to be addressed because of the international aspects of the NGNP design and component fabrication. The NRC inspectors would focus on those aspects of fabrication and transportation that may affect safety and would establish requirements for the applicant to provide controls and inspections for non-U.S. vendors to ensure quality. Furthermore, the NRC may need to review international codes and standards during the pre-application phase on a case-by-case basis.

The NGNP applicant may propose the use of startup testing for the NGNP prototype design, in lieu of conducting extensive R&D, to develop information to resolve safety issues and confirm safety analysis. If so, the agency would use startup testing in this case as a substitute for separate R&D efforts. If the applicant proposes such an approach, the NRC would need to develop requirements to define how such tests shall be conducted and how the results would be used to make the safety case.

4.1.4 Reactor Oversight Process

NRC’s Reactor Oversight Process (ROP) for an NGNP will have the same structure as that used for LWRs, but would vary in its application because some technical elements are likely to be significantly different. The expected differences arise primarily from the technology aspects of the application. However, the process itself will continue to have an inspection program, objective performance metrics, and a decision matrix. The ROP may also offer a means to verify or validate aspects of the technology differences that designers of gas-cooled reactors claim to improve safety. The design review will address these aspects, but observations during the oversight phase will be important in drawing safety conclusions relative to any demonstration testing that the licensing process may include.

4.1.5 Security and Safeguards

For the NGNP, traditional security provisions (e.g., intrusion detections, delays, barriers, guards, security programs) will likely be similar to those for LWRs as codified in 10 CFR Part 73, "Physical Protection of Plants and Materials." As with any other new reactor design, the NGNP designer is expected to integrate security into the NGNP design and will need to conduct a security assessment to evaluate the level of protection provided. The NRC will need to review the NGNP security provisions and their technical basis and decide whether they are acceptable. In addition, should the NRC design-basis threat change, the physical security that provides a commensurate level of protection will be required for safety and security of the NGNP.

Likewise, material control and accounting safeguards requirements for the NGNP may be substantially similar to those for LWRs. Traditionally, the requirements for LWRs have been limited to the provisions in 10 CFR 74.19, "Recordkeeping." These will be appropriate and applicable for a prismatic core design; however, additional requirements may be needed for a pebble bed design, which has continuous refueling capability. The NRC will need to review the NGNP material control and accounting safeguards provisions and their technical basis to determine if they are acceptable.

One area where the NGNP poses a unique challenge with regard to safeguards is the boundary of the protection measures. The NGNP features a strong coupling between the reactor plant and the hydrogen plant. The NRC has no regulatory jurisdiction over a nonnuclear or chemical operation, such as the hydrogen plant. Thus, the NRC may need to implement additional security and safeguards measures at the reactor plant and the interface between the two plants to mitigate any adverse impacts. The NGNP offers a unique opportunity for the integration of physical security and material control and accounting safeguards measures during the facility design process and during the development of the applicant's security and safeguards programs.

4.2 Internal Commission Policy Issues

Based on a preliminary assessment of the NGNP technology and design concepts being considered, NRC will likely need to resolve the following internal Commission policy issues before licensing the NGNP prototype. These policy issues, with the exception of the second one below, relate to the management of fission products (i.e., retention of fission products and otherwise controlling its release) to ensure that the public and the plant workers are protected.

Defense in Depth

The requirements in 10 CFR Part 50 incorporate Defense in Depth (DID) measures specific to LWRs (e.g., pressure retaining, low-leakage containment). For non-LWRs licensed in the past (e.g., Fort St. Vrain), DID measures were determined on a case-by-case basis. For the NGNP, it will be necessary to determine the necessary DID measures and to develop appropriate requirements and guidance for licensing.

Use of Probabilistic Risk Assessment in the Licensing Process

The use of a risk-informed and performance-based licensing approach for an NGNP will require the applicant to develop, and the NRC to review, a design-specific PRA. It will also require the NRC to decide how to modify requirements to allow the use of risk information in their implementation. In the past, the Commission deliberated on the use of PRA to establish the licensing basis in a risk-informed and performance-based framework. While the Commission is already apprised of the subject, the use of a risk-informed and performance-based licensing approach in licensing an NGNP will likely require Commission decisions in some areas (e.g., the basis for and use of selected risk metrics and criteria and the quality and scope of the NGNP PRA).

Source Terms

Source terms are used for the assessment of dose to workers and the public and comparison against regulatory dose criteria (e.g., siting dose criteria, dose in the control room following an accident) and for assessment of equipment performance (e.g., equipment qualification). The Commission has previously deliberated on the use of design-specific and event-specific source terms. The NRC will need to establish such source terms for an NGNP and the conditions under which their use can be justified in licensing.

Containment Functional Performance

In developing the containment functional requirements for the NGNP, the NRC will need to identify the types of fission products barrier in an NGNP design and the role these barriers play in confining the radiological release. This will involve consideration of factors such as fuel quality and performance, plant transient behavior, DID, and security. Because of the prominent role traditional containment designs have played in reactor safety and analysis, actual experience, and public acceptance of nuclear power, this important technical policy issue will require resolution before the licensing of an NGNP.

4.3 Training and Knowledge Management

The knowledge needed in certain review areas for an NGNP is expected to differ to some degree from that needed for an LWR. The NRC and DOE will identify the critical areas where gaps exist or are projected to exist during the review of the prototype NGNP license application and use this information to inform future training and knowledge management decisions. The NRC staff will likely use staffing models based on its experience with LWR reviews to evaluate staffing needs.

5. BUDGET ESTIMATE

In Subtitle C of the EPAct, Section 644(b) requires that the licensing strategy for the prototype NGNP include a budget estimate for the licensing strategy described in this report. The NRC estimates that the total resources required to conduct the activities described in this report are approximately $128 - $149 million for the period FY 2009–2018. This resource estimate is based on a preliminary assessment of the license strategy requirements and should not be considered a request for funding. Resource requirements will be evaluated on an annual basis throughout the duration of the NGNP program and will be determined through the standard budget development processes.

The estimate includes the assumption that the experimental research to support the development of a confirmatory safety analysis capability will be primarily performed under cooperative cost-sharing arrangements or by other agencies or industry separately. These could include R&D programs that obtain data needed by the NRC (e.g., exploring safety margins), as well as the international programs that address NGNP and HTGR safety technology. NRC and DOE will work with industry to determine how best to address future needs in these areas. Wherever possible, the NRC will make extensive use of experimental data generated by an applicant and provided to the NRC as part of the license submittal, as well as data available in the open literature.