

Next Generation Nuclear Plant System Requirements Manual

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September 2007



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operated by Battelle Energy Alliance

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**Prepared for the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517**

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Next Generation Nuclear Plant Project

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INL/EXT-07-12999

September 2007

Approved by:

A handwritten signature in black ink, appearing to read 'R. Soto', is written over a horizontal line. The signature is enclosed within a hand-drawn oval.

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9/19/07

Date

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ACRONYMS

ALWR	Advanced Light Water Reactor
ASME	American Society of Mechanical Engineers
BOP	Balance Of Plant
CFR	Code of Federal Regulation
DBA	Design Basis Accident
DOE	(United States) Department of Energy
EAB	Exclusion Area Boundary
EPRI	Electric Power Research Institute
EPZ	Emergency Planning Zone
FIMA	Fissions per Initial Metal Atom
GA	General Atomics
GT-MHR	Gas Turbine – Modular Helium Reactor
H2-MHR	Hydrogen Production - Modular Helium Reactor
THE	High Temperature Electrolysis
HTGR	High Temperature Gas-Cooled Reactor
HTS	Heat Transport System
HyS	Hybrid Sulfur
IAEA	International Atomic Energy Agency
IHX	Intermediate Heat Exchanger
INL	Idaho National Laboratory
MHR	Modular Helium Reactor
NGNP	Next Generation Nuclear Plant
NP-MHTGR	New Production – Modular High Temperature Gas Reactor
NRC	Nuclear Regulatory Commission
PCS	Power Conversion System
PPMP	(NGNP) Preliminary Project Management Plan
QA	Quality Assurance
SCS	Shutdown Cooling System
SI	Sulfur-iodine
SOEC	Solid Oxide Electrolyzer Cell
SRM	System Requirements Manual
TBD	To be determined
TRISO	TRi-ISOtropic coated fuel particle design with three materials in coating system (low-density PyC, high-density PyC, and SiC)

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1. INTRODUCTION AND SCOPE

1.1 Introduction

The Energy Policy Act of 2005 (H.R. 6), which was signed into law by the President in August 2005, required the Secretary of the U.S. Department of Energy (DOE) to establish a project to be known as the Next Generation Nuclear Plant (NGNP) Project. According to the Energy Policy Act, the NGNP Project shall consist of the research, development, design, construction, and operation of a prototype plant (to be referred to herein as the NGNP) that (1) includes a nuclear reactor based on the research and development activities supported by the Generation IV Nuclear Energy Systems initiative, and (2) shall be used to generate electricity, to produce hydrogen, or to both generate electricity and produce hydrogen. The NGNP Project supports both the national need to develop safe, clean, economical nuclear energy and the Bush Administration's National Hydrogen Fuel Initiative, which has the goal of establishing greenhouse-gas-free technologies for the production of hydrogen. The DOE has selected the helium-cooled High Temperature Gas-Cooled Reactor (HTGR) as the reactor concept to be used for the NGNP because it is the only near-term Generation IV concept that has the capability to provide process heat at high-enough temperatures for highly-efficient production of hydrogen. The DOE has also selected the Idaho National Laboratory (INL), the DOE's lead national laboratory for nuclear energy research, to lead the development of the NGNP under the direction of the DOE.

1.2 Scope

The System Requirements Manual (SRM) is the top-level design document for the NGNP. The SRM serves as the roadmap document that identifies the source of the NGNP top-level requirements (i.e., mission needs and objectives), and how these top-level requirements flow down through subordinate requirements at the plant, system, subsystem, and ultimately the component level. The scope of this pre-conceptual SRM has been limited to a flow-down of NGNP requirements to the plant level (see Section 3); deferring lower-level requirements definition until after NGNP concept down-selection during the follow-on design phases of the project.

Design requirements for the NGNP include both institutionally imposed and functionally derived requirements. At the top level, the requirements define the objectives for the plant, and at lower levels they specify how the objectives will be achieved. The topmost requirements include the project mission as defined in the Energy Policy Act of 2005 and the NGNP Project objectives as defined by DOE/INL in the NGNP Preliminary Project Management Plan (PPMP) (Ref. 1). At the next level are the high-level functions and requirements defined by the INL (Ref. 2), as modified based on the recommendations of the Independent Technology Review Group (ITRG) (Ref. 3). The high-level functions and requirements establish the performance definitions for what the NGNP will achieve, and are intended to serve as the basis for preconceptual design. Achievement of these high-level functions and requirements will be accomplished through implementation of plant-level requirements derived from the high-level requirements and other institutional sources such as utility/user requirements for commercial reactors, or that are developed through plant-level functional analysis including trade studies, plant performance analyses, engineering decisions, etc. The plant-level requirements are either allocated directly to the systems to which they apply or are used as the basis for developing more-specific requirements for the plant systems, subsystems, and components.

The organization of this SRM and the approach used for requirements flow-down are based on the Plant Design Requirements Document (Ref. 4) developed by General Atomics (CEGA) for the NP-MHTGR and the Overall Plant Design Specification (Ref. 5) developed by General Atomics for the GT-MHR. Section 2 of the SRM identifies the institutional requirements that comprise the basis for the NGNP design. These requirements include the mission statement, the mission objectives, and the high-level functions and requirements established by the INL. Section 2 also identifies other institutional requirements that must be considered in defining the NGNP plant-level requirements. These institutional requirements include DOE/INL programmatic requirements, regulatory requirements, environmental and safety requirements, utility/user recommendations for the NGNP, and utility/user requirements for a commercial MHR. The latter requirements are particularly pertinent given that a primary mission of the NGNP is to serve as a prototype for a commercial HTGR. Section 3 lists the plant-level requirements derived from the high-level institutional requirements identified in Section 2.

The primary purpose of the SRM at this early stage of the project is “to define the design independent high-level requirements that establish the framework within which subsequent work will be performed to establish the specific design attributes of the NGNP (e.g., type of reactor, direct versus indirect power conversion, hydrogen production processes, etc.)”. These requirements include, for example, reactor plant power level, primary coolant conditions, secondary coolant conditions, thermal power split between the power conversion system and the hydrogen production system, hydrogen plant heat flow and temperature requirements, hydrogen production goals, etc.

Given the purpose of the initial version of the SRM, it is appropriate to limit the scope of this SRM to a flow-down of NGNP requirements to the plant level (see Section 3); deferring lower-level requirements definition until after NGNP concept down-selection during the follow-on design phases of the project. As such, requirements listed in Section 3 have been assigned individual tracking numbers. This will be done during the Conceptual Design phase of the project as the lower-level requirements are finalized.

Table 1 presents a set of preliminary selections for the NGNP design that are based preconceptual design studies. These preliminary selections serve as the point of departure for the NGNP conceptual design effort and are the basis for the design-specific system-level requirements presented in Section 4.

Table 1. Preliminary Selections for the NGNP Design

Property	Design Selection
Reactor type	Prismatic block or Pebble Bed
Reactor power	~500 MW(t) to 600 MW(t)
Power conversion cycle	TBD
Number of loops	TBD
Primary coolant	Helium
Core inlet helium temperature	350°C - 500°C
Core outlet helium temperature	850°C - 950°C
Secondary loop working fluid	Helium
Hydrogen production process	SI, HyS, HTE

The systems, the functions of the systems, and the design-specific requirements for these systems defined in this initial version of the SRM are preliminary in nature and will need to be updated as the design of the NGNP evolves.

2. INSTITUTIONAL REQUIREMENTS

This section identifies the mission and objectives of the NGNP Project and the high-level functions and requirements for the NGNP that define how the project objectives will be achieved. This section also identifies other institutional requirements including DOE/INL programmatic requirements, regulatory requirements, environmental and safety requirements, and utility/user requirements. The high-level requirements identified in this section are the basis for the plant-level requirements defined in Section 3.

2.1 NGNP Project Mission and Objectives

The NGNP project mission as defined by the Energy Policy Act of 2005 and by the DOE is to design, build, and operate a prototype plant, including a prototype HTGR nuclear reactor, that will be used to generate electricity, to produce hydrogen, or to both generate electricity and produce hydrogen in a cogeneration mode. The project objectives that support the NGNP mission and DOE's vision are defined in the NGNP Preliminary Project Management Plan (PPMP) (Ref. 1) as follows:

- a. Develop and implement the technologies important to achieving the functional performance and design requirements determined through close collaboration with commercial industry end-users
- b. Demonstrate the basis for commercialization of the nuclear system, the hydrogen production facility, and the power conversion concept. An essential part of the prototype operations will be demonstrating that the requisite reliability and capacity factor can be achieved over an extended period of operation.
- c. Establish the basis for licensing the commercial version of the NGNP by the Nuclear Regulatory Commission (NRC). This will be achieved in major part through licensing of the prototype by NRC, and by initiating the process for certification of the nuclear system design
- d. Foster rebuilding of the U.S. nuclear industrial infrastructure and contributing to making the U.S. industry self-sufficient for its nuclear energy production needs

Additional objectives that are not explicitly stated in Ref. 1, but should be considered applicable include:

- e. Provide a level of safety assurance that meets or exceeds that afforded to the public by modern commercial nuclear power plants
- f. Meet or exceed all applicable federal, state, and local regulations or standards for environmental compliance

2.2 High-Level Functions and Requirements

The high-level functions and requirements for the NGNP are defined in Ref. 2 in order to establish performance definitions for what the NGNP must achieve. These high-level functions and requirements were developed as input to the preconceptual design effort and were intended to provide the foundation on which to define the requirements for the NGNP. Ref. 2 was reviewed by the ITRG, as required by the Energy Policy Act of 2005. The ITRG evaluated the design features and technology risks associated with the design concepts that could satisfy the high-level functions and requirements and made recommendations for managing these risks (Ref. 3). The NGNP PPMP specifies that the high-level functions and requirements in Ref. 2, as modified based on the recommendations of the ITRG, are the

second set of requirements (after the Energy Policy Act) that are to be used as the basis for NGNP Project preliminary planning. Appendix B of the PPMP describes the impact of the ITRG review on these high-level functions and requirements.

The high-level functions for the NGNP, as defined in Ref. 2, are as follows:

- Develop and demonstrate a commercial-scale prototype HTGR
- Develop and demonstrate the production of electricity at high efficiencies
- Obtain licenses and permits to construct/operate the NGNP
- Develop and demonstrate the capability for efficient production of hydrogen
- Enable the demonstration of energy products and processes
- Provide the capability for future testing to enhance plant safety and operational performance

The requirements developed for these high-level functions are listed in a condensed form in Table 2. Ref. 2 provides the basis for each requirement.

Table 2. INL NGNP High-Level Functions and Requirements

Requirement Group	Design Requirement	Ref. 2 Section
Develop and demonstrate a commercial-scale prototype HTGR	Reactor shall be commercial scale with a power level consistent with passive safety	3.1.1
	Adequate passive safety systems to cool the core down from full power to safe shutdown mode and limit fuel temperatures under accident conditions to levels consistent with fuel performance requirements	3.1.2
	Prismatic or pebble bed reactor design	3.1.3
	Average reactor outlet temperature in the range 850°C to 950°C, with future capability to increase it to above 1000°C	Ref. 1, Sec. 3.3 ^(a)
	Reactor shall be graphite moderated	3.1.5
	Once-through uranium fuel cycle	3.1.6
	TRISO-coated uranium oxycarbide (UCO) or uranium dioxide (UO ₂) fuel. The fuel particles may be agglomerated into cylindrical compacts or into spherical pebbles. Qualified UO ₂ fuel may be acceptable for initial fuel loading, but should be replaced by UCO when it is qualified	3.1.7
	Uranium enrichment of less than 20% U-235	3.1.8
	Fuel burnup consistent with maximum fuel utilization while minimizing waste streams, optimizing fuel economics, and ensuring low proliferation risk	3.1.9
	Qualified fuel, including fuel product and fuel fabrication specifications, a QA plan, demonstrated irradiation performance and fuel performance codes to predict fuel performance as a function of operating condition	3.1.10
	60-year design life. Provisions shall be made for economic replacement of components that cannot be designed for 60-year operation	3.1.11
	Defense-in-depth design philosophy; eliminate need for off-site evacuation and sheltering	3.1.12
(a) Section 3.1.4 of Ref. 2 specifies an average reactor outlet temperature of $\geq 1000^{\circ}\text{C}$. However, INL reduced the reactor outlet temperature to a range of 850°C - 950°C in Ref. 1 in response to a recommendation by the ITRG.		

Table 2. INL NGNP High-Level Functions and Requirements (cont.)

Requirement Group	Design Requirement	Ref. 2 Section
Develop and demonstrate a commercial-scale prototype HTGR (cont)	Satisfy the following top-level requirements: During normal operation, offsite radiation doses to the public shall be < limits specified in Appendix I of 10CFR50 and 40CFR190 Occupational radiation exposures $\leq 10\%$ of the limits specified in 10CFR20 During DBAs, offsite doses at the site EAB shall be less than those specified in the Manual of Protective Action Guides and Protective Actions for Nuclear Incidents (EPA-520/1-75-001) for sheltering and evacuation	3.1.13
	Failures or upset conditions in the reactor primary system shall not result in failures or adverse impacts to the hydrogen production plant or other process heat systems	3.1.14
Develop and demonstrate the production of electricity at high efficiencies	Generate electric power using a TBD power conversion system.	3.2.1
	Overall energy efficiency shall be as high as possible, and consistent with other key commercial parameters	3.2.2
	Electric power production system shall be sized to produce electricity at commercial scale using 100% of the NGNP thermal energy	3.2.3
Obtain licenses and permits to construct/operate the NGNP	Obtain NRC license via 10CFR50 or 10CFR52 rules for operation by the middle of the next decade	3.3.1
	Use a risk-informed, performance-based approach to regulatory decision-making	3.3.2
	License application shall be supported by a full-scope probabilistic risk assessment analysis for internal and external events	3.3.3
Develop and demonstrate the capability for efficient production of hydrogen	The NGNP shall be designed for continuous operation in either the 100% electric power production mode or in the cogeneration mode with the equivalent of up to 65 MW(t) of the reactor's thermal energy used for hydrogen production, depending upon the size of the hydrogen plant.	3.4.1
	Demonstrate hydrogen production using a thermochemical process and a high-temperature steam electrolysis process	3.4.2
	The design shall ensure safe transition from all-electric power production at levels up to 100% to cogeneration of hydrogen and electric power where hydrogen production consumes up to 65 MW(t) without reactor shutdown	3.4.3
	Failures or upset conditions in the hydrogen plant shall not result in adverse impacts to the reactor	3.4.4
	Tritium migration from the reactor into the hydrogen production system(s) shall be limited such that the maximum amount of tritium released from the integrated facilities, or found in drinking water does not exceed EPA and NRC standards	3.4.5
	Minimize total concentration of radioactive contaminants in the hydrogen product gas and associated hydrogen production systems to ensure that worker and public dose limits for the integrated NGNP and hydrogen production facilities do not exceed NRC regulatory limits	3.4.6
	Hydrogen product gas purity levels shall be consistent with current industry standards for hydrogen applications	3.4.7

2.3 Other Institutional Requirements

2.3.1 Key Programmatic Requirements

The NGNP PPMP provides programmatic goals and guidance that must be considered in developing the design of the NGNP. Key requirements are listed below along with the PPMP section number (in brackets) in which they are stated.

The NGNP prototype concept shall be based on the lowest risk technology development that would achieve the needed commercial functional requirements to provide an economically competitive heat source and hydrogen production capability. Such concepts are preferred over other concepts that unacceptably increase the uncertainties for project completion on a schedule considered commercially unattractive. These more aggressive capabilities may form a longer-term goal beyond the NGNP Project where the risks can be accommodated. [Executive Summary]

Planning option 2 (balanced risk) has been selected as the basis for the preliminary NGNP Project schedule. Under this option, startup of the NGNP should be initiated in 2018. This option allows for a two to three year period of operation (prior to 2021) simulating a commercial power reactor operating cycle that is followed by an extensive outage during which the equipment performance is confirmed by detailed disassembly and inspection. This proof-of-principle operating period is intended to provide the basis for commercialization decisions by industry. [Section titled "Planning Options"]

DOE Order 413.3, "Program and Project Management for the Acquisition of Capital Assets," and Manual 413.3-1, "Project Management for the Acquisition of Capital Assets," will be followed to the extent possible, as they provide an excellent systems approach to managing projects. However, as planning continues through the Definition Phase and Preliminary Design, "tailoring" of the Order may be used to accommodate the unique requirements of the NGNP Project. [Section 3.4]

2.3.2 Applicable Regulations

Section 4.1.2 of Ref. 2 identifies the following regulations as having specific applicability to the NGNP. The authors have added the italicized text to identify the applicable sections of certain of the CFR's.

- 10 CFR 20, Standards for Protection against Radiation
- 10 CFR 50, Domestic Licensing of Production and Utilization *Facilities (Appendix I, "Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion As Low as is Reasonably Achievable for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents" and Part 34(a), "Content of Applications (Technical Information: Radiological Dose Consequences)"*
- 10 CFR 50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Processing Plants
- 10 CFR 51, Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions (*NRC regulations implementing the National Environmental Policy Act*)
- 10 CFR 52, Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants

- 10 CFR 73, Physical Protection of Plants and Materials
- 10 CFR 74, Materials Control and Accountability of Special Nuclear Material
- 10 CFR 75, Safeguards on Nuclear Material – Implementation of US/IAEA Agreement
- 10 CFR 95, Security Facility Approval and Safeguarding of National Security Information and Restricted Data
- 10 CFR 100, Reactor Site Criteria
- 29 CFR 1910, Occupational Safety and Health Standards, Subpart H – Hazardous Materials
- 40 CFR 50 – 99, Clean Air Act
- 40 CFR 100 – 149, Clean Water Act
- 10 CFR 835, Occupational Radiation Protection
- 40 CFR 1502, Environmental Impact Statement
- 40 CFR 190, “Environmental Radiation Protection Standards for Nuclear Power Operations.”

Other applicable regulatory documents that are not listed in Section 4.2 of Ref.2 include:

- Reactor Safety Goal Policy Statement: As documented in Federal Register, Vol. 51, No. 149, pp. 28044-28049, August 4, 1986
- EPA-400-R-92-001, “Manual of Protective Action Guides and Protective Actions for Nuclear Incidents,” U.S. Environmental Protection Agency (EPA)

2.3.3 Applicable DOE Orders

Per Section 4.1.1 of Ref. 2, codes and standards applicable to the design and construction of the NGNP shall where practical be commercial codes and standards. However, to the extent that the NGNP will be built within a DOE facility and will interface with existing facilities, the project must evaluate DOE Orders for applicable requirements to ensure that the NGNP can interface with the DOE site and be acceptable to the DOE. DOE Orders that potentially apply include, but are not limited, to the following list.

- DOE O 413.3, Program and Project Management for the Acquisition of Capital Assets
- DOE O 420.1, Facility Safety
- DOE O 435.1, Radioactive Waste Management
- DOE Policy 450.4, Safety Management System Policy

2.3.4 General Design Requirements

INL has also specified general design requirements for the NGNP. Table 3 provides a summary of these requirements in condensed form. The detailed requirements can be found in Sections 4.2 and 4.3 of Ref. 2.

Table 3. INL General Design Requirements for the NGNP

Requirement Group	Design Requirement	Ref. 2 Section
Architectural engineering standards	Buildings and structural design for the NGNP non-nuclear facilities shall comply with the applicable DOE, Federal, state, and local codes	4.2.1
Industry codes and standards	Commercial codes and standards applicable to design and construction shall be followed, as appropriate, for all structures and systems including the reactor, power conversion unit, and the hydrogen plant	4.2.2
Reliability, availability, maintainability, and inspectability	The NGNP shall be designed for high reliability, availability, maintainability, and inspectability (RAMI). Innovative designs to maximize RAMI and minimize human error shall be considered, including techniques for remote maintenance and easy replacement or repair of components	4.2.3
Safeguards	Measures shall be incorporated as necessary to prevent unauthorized access to nuclear material, theft, diversion, other malevolent acts, including sabotage intended to release radioactivity or disrupt operations	4.2.4
Security	Provisions for site security shall be provided for the protection of the reactor, reactor fuel, spent fuel, electrical power, and hydrogen	4.2.5
Hydrogen safety design	The hydrogen production and storage facilities shall comply with 29 CFR 1910.103. If the hydrogen facility produces and stores significant quantities of oxygen, compliance with 29 CFR 1910.104 is required	4.2.5
Quality Assurance	The NGNP project shall use the U.S. national consensus standard ASME NQA-1-1997 and Subpart 4.2 of ASME NQA-1-2000 for project specific development R&D activities. Licensing and construction phase activities shall be in accordance with 10 CFR 50, Appendix B	4.3.1 (and Ref.1, C-5)

2.3.5 Utility/User Requirements for the GT-MHR and the NGNP

Document DOE-GT-MHR-100248, “Utility/User Incentives, Policies and Requirements for the Gas Turbine – Modular Helium Reactor,” (Ref. 9) provides utility/user requirements for a commercial GT-MHR. These requirements were developed from Utility requirements for advanced light water reactors (ALWRs) (Ref. 10), from input provided by constituents of the GT-MHR Program, and from pertinent information from IAEA-TECDOC-801, “Development of Safety Principles for the Design of Future Nuclear Power Plants”. These requirements have not been imposed directly by INL/DOE, but they are pertinent to the NGNP because a primary mission of the NGNP is to serve as a prototype of a commercial HTGR. Thus, these requirements have been considered in developing the plant-level and system-level requirements specified in Sections 3 and 4 of this SRM.

The Utility/User requirements presented in DOE-GT-MHR-100248 are extensive and are presented under the following categories: plant configuration, performance requirements, fuel, site parameters and external interfaces, safety and licensing, reliability and availability, control/man-machine interfaces, maintenance and ISI, design process requirements, plant fabrication/construction, plant staffing, and plant decommissioning. The key utility/user design requirements for a commercial GT-MHR are summarized in Table ES-2 of DOE-GT-MHR-100248. General Atomics updated these key utility/user requirements for inclusion in this SRM based on recent discussions with members of General Atomics’ Utility Advisory Board (UAB) and Academic Advisory Group (AAG). In the course of these discussions, the UAB and AAG provided General Atomics with the following recommendations with respect to the mission of the NGNP.

1. The NGNP should be a full-size prototype of a commercial HTGR module.
2. The initial power level for the NGNP could be somewhat lower than the power level for a commercial MHR module, but the NGNP should be designed for up-rating to the full commercial MHR module power level
3. The mission of the NGNP should include demonstration of process-heat applications, including steam methane reforming for hydrogen production. From a utility/users viewpoint, process heat applications are a more important near-term mission than demonstration of hydrogen production.
4. The NGNP should be capable of demonstrating use of alternate fuels, including Pu-based fuel and actinide-based fuel (i.e., “deep-burn” fuel) from re-processed LWR spent fuel.
5. The NGNP should be designed to demonstrate a commercial MHR that meets the key Utility/User design requirements for a commercial MHR as stated in Figure 1.

<p style="text-align: center;">Key Utility/User Design Requirements for a Commercial MHR Plant</p>	
<u>Application</u>	
<ul style="list-style-type: none"> • Commercial plant objective • Fuel cycle • Licensing objective • Public safety objective 	<p><u>Reference plant size:</u> Four MHR power modules with each module having a nominal output of 250 – 300 MWe Brayton power conversion system with > 40% thermal conversion efficiency <\$1500/kwe overnight plant capital cost (mature plant, not including owner's costs) Capable of being sited with dry cooling at low economic penalty Once-through uranium cycle with enrichment <20% Capable of utilizing alternate fuel cycles (Pu fuel, deep-burn of LWR spent fuel, etc.)</p> <p>NRC design certification of the standard power module design</p> <p><u>Passive safety design:</u> No reliance on the operator, the control room and its contents, or any AC-powered equipment to satisfy NRC design basis accident limits/requirements</p> <p>The plant shall not disrupt the public's normal day-to-day activities. Specifically, no need for public sheltering, evacuation drills Exclusion Area Boundary (EAB) = Emergency Planning Zone (EPZ) = 425 meters Probability of exposure exceeding the Protective Action Guides at or beyond the EAB shall be < 5 x 10⁻⁷ per plant year</p> <p><u>Maximum Accident Dose Limit</u> < 1 rem total effective dose equivalent to the whole body < 5 rem thyroid (EPA Protective Action Guidelines)</p>
<u>Plant Performance</u>	
<ul style="list-style-type: none"> • Plant service life • Load follow • Rapid load change • Step load rejection • Cold shutdown to hot critical (or vice versa) 	<p>≥ 60 years</p> <p>Automatic over the range 50 – 100% power</p> <p>±5% per minute over the range 50 – 100% power</p> <p>100% - house load without trip</p> <p>24 hours</p>
<u>Availability</u>	
<ul style="list-style-type: none"> • Design capacity factor • Fuel cycle length • Refueling outage 	<p>≥94%, from start up after refueling to shut down for refueling (i.e., breaker to breaker)</p> <p>≥ 18 months, from startup to startup (after refueling), shall be 18 months</p> <p>≤ 30 days</p>

Figure 1. Key utility/user design requirements for a commercial MHR plant

Key Utility/User Design Requirements for a Commercial MHR Plant (cont.)

Investment Protection

- Likelihood of event resulting in conditions outside the licensing basis $<1 \times 10^{-5}$ /plant-year

Operation and Maintenance

- Plant personnel exposure <70 person-rem/GWe-year
- Spent fuel storage 10 years operation plus one core, and on-site area reserved to accommodate storage of all spent fuel and reflectors for plant design life
- Radioactive waste < 14.3 cubic meters per year, excluding replaceable reflectors
- Major equipment Design shall include provisions for replacement of major equipment and components
- Plant staffing Plant staffing shall be consistent with reduced safety-related systems resulting from passive safety design, and shall be $<$ one-half man per MWe

Security

- Design objective Plant shall comply with security requirements as established by NRC regulations
- Security staffing Security issues shall be strongly considered in plant equipment layout
Security staffing shall reflect reduced safety-related systems needing security surveillance (relative to LWRs)

Constructability

- Construction practice Modular construction techniques as appropriate to reduce cost and risk
- Schedule (single module) < 36 months from the start of site work to full commercial operation

Key site parameters

- Soil parameter Shear wave velocity: ≥ 305 meters per second
Bearing capacity: $\geq 73,000$ Kg per square meter
- Seismic Safe shutdown earthquake: 0.30 g
Seismic margin evaluation level: 0.50 g
Shutdown evaluation level: 0.10 g

Figure 1. Key utility/user design requirements for a commercial MHR plant (cont.)

3. PLANT-LEVEL REQUIREMENTS

This section identifies NGNP plant-level requirements. These plant-level requirements are either institutional requirements from Section 2 or functionally-derived requirements established through trade studies, plant performance evaluations, engineering analyses and decisions, etc. If the plant-level requirement is an institutional requirement, the source of the requirement is given in brackets following the requirement. If a source is not shown following the statement of the requirement, the requirement is a functionally-derived requirement. A number is assigned to each requirement for identification purposes. The identification number has the format 3.x.y where 3.x is the SRM section number and y is the requirement number. If a requirement is subordinate to a higher-level requirement (i.e., it stems from the higher-level requirement), the subordinate requirement has the format 3.x.y.z, where 3.x.y is the identification number for the higher-level requirement and z is the unique number for the subordinate requirement. Brackets { } are used herein to identify a value that is preliminary in nature because of design uncertainty or insufficient documentation, or that requires verification. TBD is used as a placeholder for information that is to be added in a future revision of the SRM.

Requirements that apply to the overall NGNP plant, including the systems that accomplish the hydrogen production mission, are listed below. Requirements that are specific to achievement of the six NGNP high-level functions identified in Section 2.2 (as defined in Ref. 2) are listed in Sections 3.1 through 3.6.

PLT 3.0.1 - The NGNP shall include a nuclear reactor based on the research and development activities supported by the Generation IV Nuclear Energy Systems initiative. [Energy Policy Act of 2005]

PLT 3.0.2 - The NGNP shall be used to generate electricity, to produce hydrogen, or to both generate electricity and produce hydrogen. [Energy Policy Act of 2005]

PLT 3.0.3 - The NGNP design shall be based on the lowest risk technology development that would achieve the needed commercial functional requirements to provide an economically competitive heat source and hydrogen production capability. [Ref. 1, Executive Summary]

PLT 3.0.4 - The NGNP design shall accommodate a licensing strategy and construction schedule that allows for NGNP startup and testing by a date (currently given as 2018) that is commercially attractive and consistent with the NGNP Project schedule. [Ref. 1, Section titled "Planning Options"]

PLT 3.0.5 - The NGNP shall comply with all applicable requirements of the regulations identified in Section 2.3.2. [Ref. 2, Section 4.1.2]

PLT 3.0.6 - Buildings and structural design for the NGNP non-nuclear facilities shall comply with the applicable DOE, Federal, state, and local codes. [Ref. 2, Section 4.2.1]

PLT 3.0.7 - Commercial codes and standards applicable to design and construction shall be followed, as appropriate, for all structures and systems including the reactor, power conversion unit, and the hydrogen plant. [Ref. 2, Section 4.2.2]

PLT 3.0.8 - The NGNP shall be designed for high reliability, availability, maintainability, and inspectability (RAMI). Innovative designs to maximize RAMI and minimize human error shall be considered, including techniques for remote maintenance and easy replacement or repair of components. [Ref. 2, Section 4.2.3]

PLT 3.0.9 - The NGNP shall be designed for an operating life of ≥ 60 calendar years from the date of authorization to operate. Provisions shall be made for economic replacement of components that cannot

be designed for 60-year operation. [Ref. 2, Section 3.1.11; U/U Requirement, Ref. 9, Section 3.1.2 and SRM Section 2.3.5, Figure 1]

PLT 3.0.10 - The plant shall be designed to locate the power unit systems, structures and components (SSCs) that perform nuclear safety functions within a nuclear island that is physically separated from the balance of the plant. [U/U Requirement, Ref. 9, Section 3.1.1, paragraph 4]

PLT 3.0.11 - Provisions for site security shall be provided for the protection of the reactor, reactor fuel, spent fuel, electrical power, and hydrogen in accordance with NRC and other applicable regulations. Plant security shall be a consideration in developing plant equipment layouts. [Ref. 2, Section 4.2.5; U/U Requirement, SRM Section 2.3.5, Figure 1]

PLT 3.0.12 - NGNP design activities shall be conducted under a Quality Assurance Program that complies with the U.S. national consensus standard ASME NQA-1-1997 and Subpart 4.2 of ASME NQA-1-2000 for project specific development R&D activities, and with 10CFR50, Appendix B, when appropriate. [Ref. 2, Section 4.3.1]

PLT 3.0.13 – The design of the NGNP shall be based on the site parameters and external interfaces for the INL site selected for the NGNP. [Ref. 2, Section 1.1.5]

3.1 Develop and Demonstrate a Commercial-Scale Prototype HTGR

PLT 3.1.1 - The reactor concept to be used for the NGNP shall be the helium – cooled High Temperature Gas-Cooled Reactor (HTGR). [Ref. 2, Section 1]

PLT 3.1.1.1 - The NGNP reactor shall be graphite moderated. [Ref. 2, Section 3.1.5]

PLT 3.1.1.2 - The NGNP reactor shall have either a prismatic block or pebble bed core.

PLT 3.1.1.3 - The NGNP reactor system shall be designed to operate with an average core outlet coolant temperature range of 850°C to 950°C. [Ref. 1, Section 3.3]

PLT 3.1.1.4 - The NGNP shall use qualified TRISO-coated uranium oxycarbide (UCO) or uranium dioxide fuel. The fuel particles shall be agglomerated into cylindrical compacts or pebbles. Qualified uranium dioxide fuel may be acceptable for initial fuel loading, but shall be replaced by UCO, when it is has been qualified. [Ref. 2, Sections 3.1.7 and 3.1.10]

PLT 3.1.1.5 - The NGNP shall include a vessel system for ducting high temperature, high pressure helium coolant throughout the NGNP systems and for containing the components that interface with the helium coolant.

PLT 3.1.1.6 - The NGNP shall include a helium storage and transfer system.

PLT 3.1.1.7 - The NGNP shall include helium purification systems to maintain the helium coolant purity.

PLT 3.1.2 - The NGNP reactor shall be a full-size prototype of a commercial HTGR module. The reactor core power level shall be as high as possible consistent with the use of passive safety features. [Ref. 2, Section 3.1.1; SRM Section 2.3.5, U/U recommendation #1]

PLT 3.1.2.1 - The reactor shall have a nominal power level of 500-600 MW(t).

PLT 3.1.2.2 - The initial power level for the NGNP could be somewhat lower than the power level for a commercial MHR module, but the NGNP should be designed for up-rating to the full commercial MHR module power level. [SRM Section 2.3.5, U/U recommendation #2]

PLT 3.1.3 - The NGNP reactor shall have adequate passive safety systems to cool the reactor core down from full power to a safe shutdown mode and limit the fuel temperatures under accident conditions to levels consistent with limiting radionuclide releases and resultant doses to within regulatory requirements. [Ref. 2, Section 3.1.2]

PLT 3.1.3.1 - The reactor core configuration shall be designed to enable the core heat to be transferred from the active core to the reactor vessel (the vessel system component containing the core) by natural heat transfer mechanisms (conduction, thermal radiation, and natural convection).

PLT 3.1.3.2 - The reactor core power density (w/cc) shall be designed to limit the fuel temperatures under accident conditions to levels consistent with limiting radionuclide releases and resultant doses to within regulatory requirements (see requirement PLT 3.1.9).

PLT 3.1.3.3 - The reactor vessel shall be constructed of a metallic material to enable it to passively transfer accident event core heat by thermal radiation to a passive cooling system, that is located outside and is physically separate from the reactor vessel, for rejection of the core heat to the ultimate heat sink (the atmosphere).

PLT 3.1.3.4 - The reactor vessel shall be designed to maintain the reactor core in cool-able geometry for passive cool-down accident events (as well as during normal forced cooling operating conditions).

PLT 3.1.3.5 - The plant design shall require no reliance on the operator, the control room and its contents, or any AC-powered equipment to satisfy the NRC design basis accident limits/requirements. [U/U Requirement, Section 2.3.5, Figure 1]

PLT 3.1.4 - The NGNP reactor shall be designed to achieve and maintain a cold shutdown condition. This condition shall be maintained as required to perform required maintenance or inspection procedures and to support routine refueling of the reactor.

PLT 3.1.5 - The NGNP reactor shall be designed with two diverse and independent means by which a complete shutdown of the reactor core can be achieved.

PLT 3.1.6 - The NGNP reference fuel cycle shall be a once-through uranium fuel cycle with uranium enrichment of <20% U-235. [Ref. 2, Sections 3.1.6 & 3.1.8; U/U Requirement, SRM Section 2.3.5, Figure 1]

PLT 3.1.7 - The NGNP shall be capable of utilizing alternate fuel cycles (Pu fuel, deep-burn of LWR spent fuel, etc.) [SRM Section 2.3.5, U/U recommendation #3]

PLT 3.1.8 - The NGNP shall be designed to achieve fuel burnup consistent with maximum fuel utilization while minimizing waste streams, optimizing fuel economics, and ensuring low proliferation risk. [Ref. 2, Section. 3.1.9]

PLT 3.1.9 - The NGNP shall be designed to satisfy the following top-level radionuclide control regulatory requirements

- a. During normal operation, offsite radiation doses to the public shall be < limits specified in Appendix I of 10 CFR 50 and 40 CFR 190
- b. Occupational radiation exposures shall be $\leq 10\%$ of the limits specified in 10 CFR 20
- c. During DBAs, offsite doses at the site EAB shall be less than those specified in the Manual of Protective Action Guides and Protective Actions for Nuclear Incidents (EPA-520/1-75-001) for sheltering and evacuation

[Ref. 2, Section 3.1.13 and U/U Requirement, SRM Section 2.3.5, Figure 1]

PLT 3.1.10 - The design of the NGNP systems and processes shall be such that the volume of low-level radioactive dry and wet waste, as shipped off-site, shall be less than 3.6 m³, annually (excluding replaceable reflector elements). [U/U Requirement, SRM Section 2.3.5, Figure 1]

PLT 3.1.11 - The NGNP shall be capable of demonstrating the operational and safety performance of a commercial-scale HTGR power unit over a range of normal and transient conditions and to provide the cost and performance characteristics required to demonstrate commercial plant economic performance. [Ref. 2, Section 3.1 and SRM Section 2.3.5, U/U recommendation 5]

PLT 3.1.11.1 - The NGNP shall be designed to demonstrate a capacity factor for electricity generation of $\geq 94\%$ over the plant operating period from startup following a refueling to shutdown for refueling (i.e., “breaker-to-breaker”). [U/U Requirement, SRM Section 2.3.5, Figure 1]

PLT 3.1.11.2 - The NGNP shall be designed to demonstrate the capability of the power unit to accommodate the duty cycle events identified in Table 4.

Table 4. Design Duty Cycles

Event	Number of Events
Start-up from cold conditions	240
Shutdown to cold conditions	240
Normal load cycle (0.5%/min) (50-100%)/(100-50%)	22,000
Frequency control (2%/min) ($\pm 5\%$)	800,000
Tie line thermal backup ($\pm 20\%$)	60 up/60 down
Load rejection	100
Rapid load ramp (5%/min) (50-100%)/(100-50%)	1500/1500
Step load changes ($\pm 10\%$)	3000 ⁽¹⁾
(1) Total number, up or down	

PLT 3.1.11.3 - The NGNP shall be designed with the systems and features necessary to accomplish reactor refueling within a time interval of ≤ 30 days. [U/U Requirement, SRM Section 2.3.5, Figure 1]

PLT 3.1.11.4 - The NGNP shall be designed with a shutdown cooling system, separate from the main cooling loop, to enable rapid cool down of the reactor for plant maintenance operations in the event the main cooling loop is not available. [U/U Requirement, Ref. 9, Section 3.6.2]

PLT 3.1.11.5 - The NGNP shall be designed to demonstrate a comparative advantage in the evaluated mean (or expected) levelized generation costs of electricity for reference commercial plants versus comparably sized, "clean" coal plant; i.e., a coal plant that meets environmental standards and regulations projected for deployment in the 2020s. Generation cost advantages are provided in Table 5 for the initial and final plants within a first series of commercial plants (nominally 16 modules in any combination of 2 or 4 module plants). [U/U Requirement, Ref. 9, Section 4]

Table 5. Commercial Plant Electricity Generation Cost Advantage (%) Over Comparably Sized Clean Coal Plants

Plant Size	First Commercial Plant	Mature Commercial Plant
1 Power Unit ~275 MWe	On Par	5
2 Power Units ~550 MWe	5	10
4 Power Units ~1100 MWe	10	20

PLT 3.1.11.6 - The NGNP shall be designed to demonstrate a probability of $< 5 \times 10^{-7}$ per plant year that offsite doses at or beyond the site EAB of 425 meters will exceed the limits specified in the Manual of Protective Action Guides and Protective Actions for Nuclear Incidents (EPA-520/1-75-001) for sheltering and evacuation. [U/U Requirement, SRM Section 2.3.5, Figure 1]

PLT 3.1.11.7 - The NGNP shall be designed to demonstrate plant personnel exposure of < 70 person-rem/GWe-year. [U/U Requirement, SRM Section 2.3.5, Figure 1]

PLT 3.1.11.8 - The NGNP shall be designed such that the likelihood of an event resulting in conditions outside the licensing basis is $< 1 \times 10^{-5}$ /plant year. [U/U Requirement, SRM Section 2.3.5, Figure 1]

PLT 3.1.11.9 - The NGNP design shall include provisions for controlling the plant environment and the man-machine interfaces as specified in Section 3.7 of Ref. 9. [U/U Requirement, Ref. 9, Section 3.7]

PLT 3.1.11.10 - The NGNP design shall include provisions for satisfying the maintenance and in-service inspection requirements as specified in Section 3.8 of Ref. 9. [U/U Requirement, Ref. 9, Section 3.8]

PLT 3.1.11.11 - The NGNP design shall include provisions for satisfying the design process requirements as specified in Section 3.9 of Ref. 9. [U/U Requirement, Ref. 9, Section 3.9]

PLT 3.1.11.12 - The NGNP design shall include provisions for satisfying the plant fabrication/construction requirements as specified in Section 3.10 of Ref. 9, including modular construction techniques as appropriate to reduce risk and cost. [U/U Requirement, Ref. 9, Section 3.10]

PLT 3.1.11.13 - The NGNP design shall include provisions for satisfying the plant staffing requirements as specified in Section 3.11 of Ref. 9. [U/U Requirement, Ref. 9, Section 3.11]

PLT 3.1.11.14 - The NGNP design shall include provisions for satisfying the plant decommissioning requirements as specified in Section 3.12 of Ref. 9. [U/U Requirement, Ref. 9, Section 3.12]

PLT 3.1.12 - The NGNP shall be designed to demonstrate the capability for a HTGR to be sited with dry cooling at low economic penalty. [U/U Requirement, SRM Section 2.3.5, Figure 1]

PLT 3.1.13 - Failures or upset conditions in the reactor primary system shall not result in failures or adverse impacts to the hydrogen production plant or any other process heat systems. [Ref. 2, Section 3.1.14]

PLT 3.1.14 - Measures shall be incorporated in the NGNP design as necessary to prevent unauthorized access to nuclear material, theft, diversion, and other malevolent acts, including sabotage intended to release radioactivity or disrupt operations. [Ref. 2, Section 4.2.4]

3.2 Develop and Demonstrate High-Efficiency Power Conversion

PLT 3.2.1 - The NGNP shall generate electric power using a TBD power conversion system. [Ref. 2, Section 3.2.1]

PLT 3.2.2 - Overall efficiency shall be as high as possible, and consistent with other key commercial parameters, to optimize economics. [Ref. 2, Section 3.2.2]

PLT 3.2.3 - The power conversion system shall be designed and sized to produce electricity at commercial scale using 100% of the NGNP thermal energy from the reactor. [Ref. 2, Section 3.2.3]

PLT 3.2.3.1 - The NGNP shall nominally produce 250 - 300 MWe net of electricity at 60 Hz. [U/U Requirement, SRM Section 2.3.5, Figure 1]

PLT 3.2.4 - The power conversion system shall be designed for high reliability, to provide accessibility to system components for maintenance, and to allow for replacement of system components. [U/U requirement, SRM Section 2.3.5, Figure 1]

3.3 Obtain Licenses and Permits to Construct/Operate the NGNP

PLT 3.3.1 - The NGNP shall obtain an NRC license via 10 CFR 50 and/or 10 CFR 52 rules for operation by a date consistent with the NGNP Project schedule (currently the end of 2017). [Ref. 2, Section 3.3.1]

PLT 3.3.2 - The NGNP project shall use a risk-informed, performance-based approach to regulatory decision-making. [Ref. 2, Section 3.3.2]

PLT 3.3.2.1 - Licensing of the NGNP shall be based on the criteria and methodologies identified in ANS Standard 53.1, Nuclear Safety Criteria for the Design of Modular Helium-Cooled Reactor Plants (Draft).

PLT 3.3.3 - The NGNP license application shall be supported by a full-scope probabilistic risk assessment analysis for internal and external events. The analysis shall be conducted in accordance with the requirements of either 10 CFR 50 or 10 CFR 52. [Ref. 2, Section 3.3.3]

PLT 3.3.4 - The NGNP shall serve as the basis for obtaining NRC design certification of a commercial plant. The reference commercial plant design and certification envelope demonstrated by the NGNP shall provide the flexibility for deployment of from one to four power units of the same design as the NGNP.

3.4 Develop and Demonstrate Hydrogen Production

PLT 3.4.1 - The NGNP shall be designed for continuous operation in either the 100% electric power production mode or in the cogeneration mode with the equivalent of up to 65 MW(t) of the reactor's thermal energy used for hydrogen production. [Ref. 2, Section 3.4.1]

PLT 3.4.2 - Hydrogen production shall be demonstrated using a thermochemical, thermochemical hybrid process, or a high-temperature steam electrolysis (HTE) process. [Ref. 2, Section 3.4.2]

PLT 3.4.2.1 - The thermochemical process to be demonstrated by the NGNP may be the sulfur-iodine (SI) process, the Hybrid Sulfur Process, or other alternative process, as recommended by the DOE Nuclear Hydrogen Initiative.

PLT 3.4.2.2 - The hydrogen production plant(s) shall produce {TBD} metric tonnes of hydrogen per year.

PLT 3.4.2.3 - The hydrogen production plant(s) shall be capable of long-term continuous operation sufficient to demonstrate adequate process reliability and availability to potential hydrogen end users.

PLT 3.4.2.4 - The hydrogen product gas shall have purity levels consistent with current industry standards for hydrogen applications. [Ref. 2, Section 3.4.7]

PLT 3.4.3 - The NGNP design shall include a Primary Heat Transport System for transporting up to 65 MW(t) of thermal energy from the reactor to an intermediate heat exchanger (IHx) for transfer to a secondary loop that supplies the hydrogen process.

PLT 3.4.4 - The NGNP shall include a Secondary Heat Transport System to provide thermal energy to the hydrogen production plant.

PLT 3.4.4.1 - The Secondary Heat Transport System shall deliver process heat to the hydrogen production process at the required temperature and at pressure conditions that minimize the technical risk associated with the IHx, the process heat exchanger(s), and the hydrogen production process design.

PLT 3.4.4.2 - Heat losses to the environment associated with transfer of heat from the reactor to the hydrogen production system shall be limited to less than {1%} of 65 MW(t)

PLT 3.4.4.3 - Leakage of the Secondary Heat Transport System fluid shall be limited to {10%} per year, or to a lesser amount as necessary to ensure compliance with requirement PLT 3.1.9.

PLT 3.4.4.4 - The NGNP shall include a Secondary Fluid Purification System to maintain the purity of the Secondary Heat Transfer System (HTS) fluid.

PLT 3.4.5 - The interface between the NGNP reactor and the hydrogen production plant(s) shall be designed to allow for safe transitions between all-electric power production at levels up to 100% to the production of hydrogen and electric power in the cogeneration mode where the hydrogen production consumes up to 65 MW(t) without reactor shutdown. [Ref. 2, Section 3.4.3]

PLT 3.4.6 - The interfaces between the hydrogen production plant(s) and the NGNP reactor shall be designed to ensure that failures or upset conditions in the hydrogen production plant do not result in failures or adverse impacts to the NGNP reactor. [Ref. 2, Section 3.4.4]

PLT 3.4.7 - The interface system between the NGNP and the hydrogen production plant(s) shall be designed to ensure that tritium migration into the hydrogen production systems will be limited, such that the maximum amount of tritium released from the integrated NGNP facilities, including system leaks, or found in drinking water does not exceed EPA and NRC standards. [Ref. 2, Section 3.4.5]

PLT 3.4.8 - The total concentration of radioactive contaminants in the hydrogen product gas and associated hydrogen production systems shall be minimized to ensure that worker and public dose limits for the integrated NGNP and hydrogen production facilities do not exceed NRC regulatory limits. [Ref. 2, Section 3.4.6]

PLT 3.4.9 - The hydrogen production plant(s) shall be designed to contain industrial safety features that afford adequate protection to the public and plant workers. [Ref. 2, Section 4]

PLT 3.4.9.1 - The hydrogen production and storage facilities shall comply with 29 CFR 1910.103. If the hydrogen facility produces and stores significant quantities of oxygen, compliance with 29 CFR 1910.104 shall also be required. [Ref. 2, Section 4.2.5]

PLT 3.4.9.2 - Emissions from the hydrogen production plant(s) shall comply with all applicable requirements of the Clean Water Act/Water Programs (CWA), 40 CFR 100-149, as well as compliance with all state and local requirements. [Ref. 2, Section 4.1.2]

PLT 3.4.9.3 - Emissions from the hydrogen production plant(s) shall comply with the requirements of 40 CFR 61, National Emissions Standards for Hazardous Air Pollutants (NESHAP), and all applicable state and local air permit requirements. [Ref. 2, Section 4.1.2]

PLT 3.4.9.4 - Exposures to any given hazardous chemical shall not exceed the maximum acceptable levels as stated in OSHA 29 CFR 1910.1000, Subpart Z, plus other OSHA substance-specific standards.

PLT 3.4.9.5 - The plant shall comply with all applicable OSHA General Industry Standards, including 29 CFR 1910.132, .133, .135, and .136.

3.5 Include Testing Provisions

PLT 3.5.1 - The NGNP design shall include sufficient flexibility to allow for the future investigation of safety and operational performance margins in the plant responses to anticipated operating occurrences and risk-important events, as advancements and modifications for future designs are considered. [Ref. 2, Section 3.5.1]

PLT 3.5.2 - In addition to the control and investment protection requirements covered by PLT 3.1.11.9, the NGNP shall include provisions for assessing proposed new, improved or advanced investment protection systems. [Ref. 2, Section 3.5.2]

PLT 3.5.3 - In addition to the man-machine interface requirements provided by PLT 3.1.11.9, the NGNP design shall include provisions for evaluation of advanced control room designs for commercial plants based on human factors engineering principles and operating experience to the extent possible for a single integrated reactor and hydrogen plant without compromising plant safety. [Ref. 2, Section 3.5.3]

PLT 3.5.4 - In addition to the plant operator requirements provided by PLT 3.1.11.9, the NGNP design shall include provisions for evaluating methods to minimize the need and maximize the time available for operator actions in response to plant transients, and other routine/non-routine activities during normal operations, startup, shutdown, and surveillance/testing. [Ref. 2, Section 3.5.4]

PLT 3.5.5 - In addition to the requirements provided by PLT 3.1.11.9 requiring the capability for manual mode plant operation, the NGNP shall be designed to enable training of reactor operators for taking control of the reactor and support processes from within the single integrated control room using the manual mode at any time. [Ref. 2, Section 3.5.5]

PLT 3.5.6 - In addition to the plant staffing requirements provided by PLT 3.1.11.13, the NGNP facility shall include provisions for evaluations to optimize the staffing needed for integrated operation and maintenance activities to the extent possible without compromising plant safety. [Ref. 2, Section 3.5.6]

PLT 3.5.7 - The NGNP shall be designed to provide the capability for testing alternate and/or advanced lead fuel test assemblies. [PLT 3.1.1.3; PLT 3.1.7]

PLT 3.5.8 - For demonstration of commercial plant radiological source terms, the NGNP shall be designed to experimentally determine the fission product activity that could potentially be released should there be a rupture in the primary coolant boundary. [PLT 3.1.9; PLT 3.1.11.6]

3.6 Enable Demonstration of Energy Products and Processes

PLT 3.6.1 - The NGNP Project shall establish a test bed for evaluating various uses of hydrogen produced by the NGNP hydrogen production plant(s). [Ref. 2, Section 3.6.1]

PLT 3.6.2 - The NGNP Project shall establish hydrogen storage and distribution systems adequate to support the needs of the hydrogen infrastructure test bed, and designed to demonstrate the safety and economics of the different hydrogen storage and distribution technologies. [Ref. 2, Section 3.6.2]

PLT 3.6.2.1 - The NGNP shall have an onsite hydrogen storage capacity of at least {TBD} kg.

PLT 3.6.2.2 - The product hydrogen gas shall be supplied at a working pressure of {4.0 MPa}.

PLT 3.6.2.3 - The product hydrogen gas shall be supplied at a nominal temperature of {30°C}.

PLT 3.6.2.4 - The hydrogen storage facilities shall comply with 29 CFR 1910.103. [Ref. 2, Section 4.2.5]

PLT 3.6.3 - The NGNP shall include provisions for the later addition of an indirect supercritical-CO₂ Brayton cycle power conversion system that uses up to 50 MW(t) from the NGNP reactor to produce electricity at a target overall power conversion efficiency of 45%. [Ref. 2, Section 3.6.3]

PLT 3.6.4 - The NGNP shall include provisions for testing systems for utilization of the process heat capabilities of the plant to support future energy infrastructure R&D needs. [SRM Section 2.3.5, U/U recommendation #3]

PLT 3.6.4.1 - Provisions shall be included in the design of the NGNP to add capability to produce $\geq 540^{\circ}\text{C}$ (1000°F) steam to develop/demonstrate the production of process steam to displace coal, oil and natural gas use in process industries such as petrochemical plants, refineries, aluminum mills, and steel mills

PLT 3.6.4.2 - The provisions made in the NGNP design to add steam production capability shall be equally adaptable to adding additional capability for high temperature process heat to develop/demonstrate production of reducing gas for steel making, substitute pipeline gas, ammonia and methanol.

PLT 3.6.4.3 - The NGNP shall include provisions to add process systems (e.g., a steam-methane reformation process for H₂ production and/or a methanol production process) to develop/demonstrate

4. REFERENCES

1. "Next Generation Nuclear Plant Project, Project Management Plan," INL/EXT-05-00952, Rev. 1, Idaho National Laboratory, March 2006
2. "Next Generation Nuclear Plant – High Level Functions and Requirements," INEEL/EXT-03-01163, Idaho National Laboratory, September 2003
3. "Design Features and Technology Uncertainties for the Next Generation Nuclear Plant, Independent Technology Review Group," INEEL/EXT-04-01816, Idaho National Laboratory, June 30, 2004
4. "Overall Plant Design Specification; 600 MW(t) GT-MHR," DOE-GT-MHR-100001, Rev. 0, General Atomics, December 1994
5. "NP-MHTGR Plant Design Requirements Document, Preliminary Issue," CEQA-000002, Rev. 3 (Draft), General Atomics, June 25, 1993
6. "GT-MHR Conceptual Design Description Report, Document 910720, Rev. 1, General Atomics. July 16, 1996
7. "H2-MHR Pre-Conceptual Design Report: SI-Based Plant," Report GA-A25401, General Atomics, April 2006
8. "H2-MHR Pre-Conceptual Design Report: HTE-Based Plant," Report GA-A25402, General Atomics, April 2006
9. "Utility/User Incentives, Policies, and Requirements for the Gas Turbine-Modular Helium Reactor," DOE-GT-MHR-100248, Rev. 0, Technology Insights, September 1995
10. "Advanced Light Water Reactor Utility Requirements Document; Volume 1, ALWR Policy and Summary of Top-Tier Requirements," Electric Power Research Institute (EPRI), March 1990