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Preconceptual Engineering Services For The Next Generation Nuclear Plant (NGNP) With Hydrogen Production

NGNP System Requirements Manual

Prepared by General Atomics
For the Battelle Energy Alliance, LLC

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LIST OF 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
HTE	High Temperature Electrolysis
HTS	Heat Transport System
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)
VHTR	Very High Temperature Reactor

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 Very High Temperature Reactor (VHTR) 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.

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 by INL 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 INL high-level requirements and other institutional sources such as utility/user requirements for commercial reactors, or that are developed though 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 GA (CEGA) for the NP-MHTGR and the Overall Plant Design Specification (Ref. 5) developed by GA 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 VHTR. Section 3 lists the plant-level requirements derived from the high-level institutional requirements identified in Section 2. Section 4 performs the critical function of translating the plant-level requirements stated in Section 3 into design requirements applicable to the plant systems. This flow down of requirements is intended to ensure that the individual plant systems will be designed such that the plant as a whole will meet its requirements.

INL has defined the primary purpose of the SRM at this early stage of the project as being “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 INL-stated purpose of the initial version of the SRM, it would be appropriate to limit the scope of this SRM to a flow-down of NGNP requirements to the plant level; deferring lower-level requirements definition until after NGNP concept down-selection at the end of the preconceptual design phase of the project. However, in recognition of past DOE-sponsored work by General Atomics that has resulted in a relatively-mature definition of the GT-MHR concept (Refs. 5 and 6) and preconceptual designs for both SI-based and HTE-based commercial H2-MHR plants (Refs. 7 and 8), the authors have expanded the scope of this initial version of the SRM to include design-specific requirements developed for the GT-MHR and the H2-MHR. The previous work on the GT-MHR included essentially the same concept selection studies that are being performed currently as part of the scope of NGNP preconceptual design.

Table 1 presents a set of preliminary selections for the NGNP design that are based on the GT-MHR and H2-MHR design studies. These preliminary selections serve as the point of departure for GA's NGNP preconceptual design effort and are the basis for the design-specific system-level requirements presented in Section 4.

Table 1. GA Preliminary Selections for the NGNP Design

Property	Design Selection
Reactor type	Prismatic block
Reactor power	550 MW(t) with stretch capability to 600 MW(t)
Power conversion cycle	Direct, Brayton cycle gas turbine
Number of loops	2
Primary coolant	Helium
Core inlet helium temperature	490°C - 590°C
Core outlet helium temperature	850°C - 950°C
Secondary loop working fluid	Helium
Hydrogen production process	SI, 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. Nevertheless, the authors considered it appropriate to incorporate the GT-MHR and H2-MHR information into the SRM at this time in order to provide guidance to the NGNP pre-conceptual design effort and to establish a methodology and framework for further development of the requirements for the NGNP.

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 VHTR 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

INL defined the high-level functions and requirements for the NGNP 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 by INL 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 VHTR
- 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 by INL 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 VHTR	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 850ºC to 950ºC, 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
	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 ≤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

(a) Section 3.1.4 of Ref. 2 specifies an average reactor outlet temperature of ≥1000°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 the production of electricity at high efficiencies	Generate electric power using a Brayton cycle power conversion system	3.2.1
	The overall energy conversion efficiency shall be at least 45% in the all-electric mode. 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 50 MW(t) of the reactor's thermal energy used for hydrogen production	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 50 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 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

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

Requirement Group	Design Requirement	Ref. 2 Section
Include provisions for future testing	Sufficient flexibility to allow for the future investigation of safety and operational performance margins in plant responses to anticipated operating occurrences and risk-important events	3.5.1
	Provisions for incorporating and evaluating investment protection systems that are separate and independent of plant safety and control systems	3.5.2
	Optimize the human-machine interface based on human factors engineering principles and operating experience without compromising plant safety	3.5.3
	Minimize the need and maximize the time available for operator actions in response to plant transients, and other routine/non-routine activities during normal operation, startup, shutdown, and surveillance/testing	3.5.4
	Permit reactor operators to take control of the reactor and support processes from within the single integrated control room using the manual mode at any time	3.5.5
	Optimize the staffing needed for integrated operation and maintenance activities without compromising plant safety	3.5.6
Enable demonstration of energy products and processes	Establish a test bed for evaluating various uses of hydrogen produced by the hydrogen production plant(s)	3.6.1
	Establish hydrogen storage and distribution systems adequate to support the needs of the hydrogen infrastructure test bed; demonstrate the safety and economics of the different hydrogen storage and distribution technologies	3.6.2
	Include provisions for later addition of an indirect supercritical-CO_2 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%	3.6.3

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 and testing of the NGNP should be completed 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 420.1A, 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 VHTR. 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. GA has updated these key utility/user requirements for inclusion in this SRM based on recent discussions with members of GA's Utility Advisory Board (UAB) and Academic Advisory Group (AAG). In the course of these discussions, the UAB and AAG provided GA with the following recommendations with respect to the mission of the NGNP.

1. The NGNP should be a full-size prototype of a commercial VHTR 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 Fig. 1.

Key Utility/User Design Requirements for a Commercial MHR Plant

Application

• Commercial plant objective	Reference plant size: 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
• Fuel cycle	Once-through uranium cycle with enrichment <20% Capable of utilizing alternate fuel cycles (Pu fuel, deep-burn of LWR spent fuel, etc.)
• Licensing objective	NRC design certification of the standard power module design
• Public safety objective	Passive safety design: No reliance on the operator, the control room and its contents, or any AC-powered equipment to satisfy NRC design basis accident limits/requirements 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 $< 5 \times 10^{-7}$ per plant year Maximum Accident Dose Limit < 1 rem total effective dose equivalent to the whole body < 5 rem thyroid (EPA Protective Action Guidelines)

Plant Performance

• Plant service life	≥ 60 years
• Load follow	Automatic over the range 50 – 100% power
• Rapid load change	±5% per minute over the range 50 – 100% power
• Step load rejection	100% - house load without trip
• Cold shutdown to hot critical (or vice versa)	24 hours

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

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

Availability

● Design capacity factor	≥94%, from start up after refueling to shut down for refueling (i.e., breaker to breaker
● Fuel cycle length	≥ 18 months, from startup to startup (after refueling), shall be 18 months
● Refueling outage	≤ 30 days

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 issues shall be strongly considered in plant equipment layout
● Security staffing	Security staffing shall reflect reduced safety-related systems needing security surveillance (relative to LWRs)

Constructibility

● 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

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

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

Key site parameters

● Soil parameter	Shear wave velocity: ≥ 305 meters per second
	Bearing capacity: ≥ 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 completion of 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, Fig. 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, Fig. 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 VHTR

PLT 3.1.1 - The reactor concept to be used for the NGNP shall be the helium – cooled Very High Temperature Reactor (VHTR). [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 a prismatic block 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. 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 3.1.1.6 - 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 VHTR 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 550 MW(t) with a stretch capability to about 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, Fig. 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, Fig. 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

- During normal operation, offsite radiation doses to the public shall be < limits specified in Appendix I of 10 CFR 50 and 40 CFR 190
- Occupational radiation exposures shall be ≤10% of the limits specified in 10 CFR 20
- 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, Fig. 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 m^3, annually (excluding replaceable reflector elements). [U/U Requirement, SRM Section 2.3.5, Fig. 1]

PLT 3.1.11 - The NGNP shall be capable of demonstrating the operational and safety performance of a commercial-scale VHTR 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 ≥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, Fig. 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) (±5%)	800,000
Tie line thermal backup (±20%)	60 up/60 down
Load rejection	100
Rapid load ramp (5%/min) (50-100%)/(100-50%)	1500/1500
Step load changes (±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, Fig. 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, Fig. 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, Fig. 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, Fig.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 VHTR to be sited with dry cooling at low economic penalty. [U/U Requirement, SRM Section 2.3.5, Fig. 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 Brayton cycle power conversion system. [Ref. 2, Section 3.2.1]

PLT 3.2.2 - The electric power conversion system, in the all-electric mode, shall have an overall efficiency (defined as net electrical output divided by net thermal output at the reactor outlet) of at least 45% to convert reactor thermal power to electrical. 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, Fig. 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, Fig. 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 50 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 process and 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 shall be the sulfur-iodine (SI) process.

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 50 MW(t) of thermal energy from the reactor to an intermediate heat exchanger (IHX) for transfer to a secondary loop.

PLT 3.4.4 - The NGNP shall include a Secondary Heat Transport System that uses helium as the working fluid to transport the heat transferred from the primary coolant via the IHX to the hydrogen production system.

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 50 MW(t).

PLT 3.4.4.3 - Leakage of the Secondary Heat Transport System helium 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 Helium Purification System to maintain the purity of the Secondary Heat Transfer System (HTS) helium.

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 50 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 or found in drinking water does not exceed EPA 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 CFR1910.1000, 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 {TBD} metric tons.

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^{o}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-CO_2 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 ≥540°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 H_2 production and/or a methanol production process) to develop/demonstrate the utilization of process steam and/or process heat produced by the NGNP.

4. SYSTEM FUNCTIONS AND REQUIREMENTS

Each NGNP system must perform certain functions that provide for the operational integration of the overall plant and contribute to safe and efficient plant operation. Requirements are imposed on the design of each system to ensure that the system is capable of performing these functions. These system-level functions and requirements flow down from the plant-level requirements defined in Section 3, which in turn flow down from the institutional requirements defined in Section 2.

This section performs the function of translating the NGNP plant-level requirements into design requirements applicable to the individual plant systems, buildings and structures. This flow-down of requirements is intended to ensure that the individual plant systems will be designed such that the plant as a whole will meet its requirements. Allocation of the plant-level requirements is accomplished in two ways. If a plant-level requirement is sufficiently specific and applies to multiple systems, it is allocated without further interpretation or analysis to the systems to which it applies using a table like that shown in Figure 2 in Section 4.1. This format is used to eliminate the need to restate the requirement in the sections for all of the various systems to which the requirement applies. Plant-level requirements that are not sufficiently specific for direct allocation to systems are further developed through trade studies, plant performance evaluations, engineering analyses and decisions, etc. The resultant requirements are then allocated to the appropriate plant systems in Sections 4.2 through 4.55. Therefore, a complete set of requirements for a given system is obtained by combining the plant-level requirements allocated to the system in Section 4.1 and the requirements for the system that are given in the section for that system below.

As discussed in Section 1, the authors have elected to include design-specific requirements developed for the GT-MHR and H2-MHR designs in this initial version of the SRM in order to provide guidance to the NGNP pre-conceptual design effort and to establish a methodology and framework for further development of the requirements for the NGNP. The authors considered this appropriate because a primary mission of the NGNP is to serve as a prototype for a commercial VHTR, thus the NGNP should be designed in accordance with many of the requirements defined for the GT-MHR.

However, the NGNP mission includes objectives other than electricity production, and these objectives are reflected in plant-level requirements that require systems that are not included in the GT-MHR. These systems include a Primary Heat Transport System to transport thermal energy from the reactor to an intermediate heat exchanger (IHX), a Secondary Heat Transport System to transport the heat transferred from the primary coolant by the IHX to the hydrogen production system, a Secondary Helium Purification System, SI-based and HTE-based

Hydrogen Production Systems, and a Hydrogen Storage System. The addition of these systems will have an impact on the design of other plant systems defined for the GT-MHR. The authors have made some modifications to the system-level functional and design requirements defined for the GT-MHR to reflect these differences, but this effort was not comprehensive. Additionally, GA is still in the process of performing NGNP concept selection studies, the results of which could have an impact on the preliminary selections for the NGNP design shown in Table 1 in Section 1. Thus, the systems, the functions of the systems, and the specific design 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.

Because allocation of the plant-level requirements to the individual systems would be premature at this early stage of the NGNP design process, a requirements allocation table has not been completed in Section 4.1. Instead, Figure 2 in Section 4.1 provides an illustration of such a table as an example of a methodology that could be used to flow down the plant-level requirements to the individual plant systems. This table should be completed early in conceptual design to provide clear guidance to the individual systems designers as to the applicability of the plant-level requirements to their systems. Also, the system-level requirements in this initial version of the SRM have not been numbered. When the system-level requirements are updated following completion of preconceptual design, the requirements must be numbered to facilitate flow down of the requirements to the subsystem and component levels, and to maintain requirements traceability. Requirements numbering is also necessary for requirements identification in the System Design Descriptions that will be prepared during conceptual design.

Table 6 identifies the anticipated NGNP plant systems, buildings, and structures by name and number. Generally, the system names and numbers for the GT-MHR design, as defined in Ref. 4, have been retained in order to maintain consistency with the relatively well-developed GT-MHR design concept. However, as noted in Table 6 (and above), there are a number of new systems that have been added to accommodate the additional mission of the NGNP (relative to the GT-MHR) to demonstrate cogeneration of electricity and hydrogen. The system numbers are included (parenthetically) in the section titles below.

Table 6. Plant Systems, Buildings, and Structures

System No.	System Name
11	Reactor System
12	Vessel System
13*	Primary Heat Transport System
14	Shutdown Cooling System
15	Shutdown Cooling Water System
16	Reactor Cavity Cooling System
21	Fuel Handling and Storage System
22	Spent Fuel Cooling Water System
23	Nuclear Island Cooling Water System
24	Helium Services System
25	Radwaste and Decontamination System
26	Power Conversion Cooling Water System
31	Reactor Protection System
33	Investment Protection System
34	Plant Control, Data, and Instrumentation System
35	Plant Monitoring System
41	Power Conversion System
42*	Secondary Heat Transfer System
43*	Secondary Helium Purification System
44*	SI-Based Hydrogen Production System
45*	HTE-Based Hydrogen Production System
46*	Hydrogen Storage System
51	Reactor Complex
53	Helium Storage Structure
54	Remote Shutdown Building
55	Nuclear Island Warehouse
61	Operations Center
62	Balance of Plant Complex
63	Circulating Water Pumphouse
64	Makeup Water Pumphouse and Discharge Structure
65	Fire Protection System Pumping Station
66	Balance of Plant Warehouse
71	Balance of Plant Cooling Water System
72	Circulating Water System
73	Water Supply and Treatment System
74	Balance of Plant Hot Water Heating System
75	Balance of Plant Chilled Water System
76	Plant Fire Protection System
81	Nuclear Island HVAC System
82	Balance of Plant HVAC System
83	Instrument and Service Air System
84	Waste Water System
85	Yard Drainage System
86	Sanitary Drainage and Treatment System

Table 6. Plant Systems, Buildings, and Structures (Cont.)

System No.	System Name
91	Essential AC Electrical System
92	Plant AC Electrical System
93	Grounding, Lightning, Heat Tracing, and Cathodic Protection System
94	Essential DC Electrical System
95	Plant DC Electrical System
96	Communications System
97	Plant Security System
98**	Plant Un-Interruptible Power Supply
99**	Standby Power System
100**	Lighting and Service Power Supply System

* New systems added for NGNP

** Part of the Plant AC Electrical System in the GT-MHR design

4.1 Requirements Applicable to Multiple Systems, Buildings, and Structures

As noted above, allocation of the plant-level requirements to the individual systems would be premature at this early stage of the NGNP design process. Instead, Figure 2 provides an illustration of a methodology for flowing down plant-level requirements that are sufficiently specific to be allocated without further interpretation or analysis to the multiple systems, buildings, and structures to which they apply. This format is useful to eliminate the need to restate requirements that are applicable to multiple systems in all of the sections for the systems to which the requirements apply. A table of this type should be completed early in conceptual design to provide clear guidance to the individual systems designers as to the applicability of the plant-level requirements to their systems.

Plant Level Req't No.	System Number																																																						
	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	41	42	43	44	45	46	51	53	54	55	61	62	63	64	65	66	71	72	73	74	75	76	81	82	83	84	85	86	91	92	93	94	95	96	97	98	99	100
PLT x.x.1	●	●	●	●	●	●			●									●						●	●				●					●	●	●	●					●				●	●	●	●	●					
PLT x.x.2	●	●							●					●	●			●	●	●	●	●	●						●	●	●										●			●											

Illustration of a requirements allocation table

Figure 2. Illustration of a requirements allocation table for allocating plant-level requirements applicable to multiple systems, buildings, or structures

4.2 Reactor System (11)

System Functions

The primary functions of the Reactor System are to produce heat energy, transfer heat from the reactor to the primary coolant, ensure the maintenance of a controlled flow-path for the primary coolant through the system, provide a level of control over the effects of radiation emitted from the core, and maintain the reactor in a safe shutdown condition. The Reactor System supports the function of maintaining the integrity of the primary coolant pressure boundary by shielding the reactor vessel from core radiation and by limiting reactor vessel temperatures. The Reactor System also includes equipment that provides for remote removal, replacement, inspection, maintenance, and storage of various reactor system components and parts.

System Configuration and Essential Features Requirements

The Reactor System heat source shall be a modular helium reactor with a prismatic fuel element core.

The Reactor System shall be designed for a nominal thermal power output of 550 MW with a potential stretch capability to about 600 MW.

The reactor shall use TRISO-coated uranium oxycarbide (UCO) or uranium dioxide fuel. The fuel particles shall be agglomerated into cylindrical compacts. Qualified uranium dioxide fuel may be acceptable for initial fuel loading, but shall be replaced by UCO, when it is has been qualified.

The Reactor System shall be designed to include provisions (i.e., means for re-directing the hot helium coolant exiting the reactor) that permit expansion of the NGNP functions to include the capability to produce ≥540°C steam to develop/demonstrate the production of high-temperature process steam to replace coal, oil and natural gas use in process industries such as petrochemical plants, refineries, aluminum mills, and steel mills. The provisions included in the Reactor System design to enable NGNP high-temperature steam production shall also enable the capability to produce a sufficient quantity of high-temperature process heat to develop/demonstrate the production of high-temperature process heat to replace natural gas use in making steel, substitute pipeline gas, ammonia, and methanol.

Operational Requirements

The Reactor System shall be designed to operate with an average core outlet coolant temperature of 850°C to 950°C.

The reference fuel cycle shall be based on the use of a once-through uranium fuel cycle with U-235 enrichment no greater than 19.9%.

The Reactor System shall achieve fuel burnup consistent with maximum fuel utilization while minimizing waste streams, optimizing fuel economics, and ensuring low proliferation risk

The design minimum fuel cycle length, from startup to startup (after refueling), shall be 18 months.

The fuel cycle shall be optimized for a capacity factor for electricity generation of ≥94% over the plant operating period from startup following a refueling to shutdown for refueling (i.e., “breaker-to-breaker”).

The Reactor System shall be capable of utilizing alternate fuel cycles (Pu fuel, deep-burn of LWR spent fuel actinides, etc.).

The Reactor System shall be designed to operate continuously at 100% of its rated capacity. The System shall be capable of operating at any stable power level from zero-power critical, to the maximum design power level.

The reactor shall be designed to accommodate the duty cycle events identified in Table 4 in Section 3.

The Reactor System shall be designed to operate within applicable steady-state performance envelopes defined in [TBD].

The reactor core shall exhibit a negative temperature coefficient of reactivity under all operating and shutdown conditions.

The reactor shall be designed such that it can be refueled within a ≤30 day period with the reactor core shut down and maintained in a safe shutdown condition, and with the Vessel System depressurized.

The design of the reactor shall contain sufficient reactivity margin to allow refueling to commence one month earlier or one month later than scheduled, relative to what the design interval would normally require, without perturbing the overall fuel cycle. However, operating beyond the design refueling interval may require reduced power output.

Structural Requirements

The Reactor System shall be designed to accommodate all combinations of operating conditions bounded by the performance envelopes defined in Ref. [TBD].

The Reactor System shall be designed for the maximum acoustic pressure resulting from operation of the Power Conversion System, operation of the Shutdown Cooling System, operation of an add-on process heat system, or operation of the heat transport systems.

The Reactor System shall be designed for the maximum flow-induced forces resulting from operation of the Power Conversion System, operation of the Shutdown Cooling System, operation of an add-on process heat system, or operation of the heat transport systems.

Surveillance and In-Service Inspection

The Reactor System design shall provide for access to components within the reactor coolant pressure boundary to permit in-service inspection and surveillance per Ref. [TBD].

Maintenance Requirements

An auxiliary service cask shall be provided for use in remotely removing and installing the neutron control assemblies in the vertical penetrations in the top head of the reactor vessel.

Core service tools shall be designed for transport and remote positioning using either the fuel handling machine or the auxiliary service cask.

Safety Requirements

The Reactor System shall assure that the top-level radionuclide control requirements of PLT 3.1.9 are satisfied by:

- Limiting peak time-average fuel temperatures during normal operation to {1250ºC} and peak fuel temperatures during accident conditions to 1600ºC in order to maintain fuel particle coating integrity, thereby retaining radionuclides within the coated fuel particles

- Achieving reactor shutdown by moveable poison control employing both primary and diverse control capability to regulate heat generation within the core.

- Conducting and radiating heat from the reactor core to the reactor vessel, and maintaining the geometry necessary for such transfer of heat transfer.

- Mitigating the effects of air and moisture ingress in order to limit fuel oxidation and hydrolysis

The Reactor System shall be designed to achieve a cold shutdown status in the reactor core under any credible set of plant operating conditions. This condition shall be maintained as required to perform required maintenance or inspection procedures and to support routine refueling of the reactor.

The Reactor System design shall incorporate two independent and diverse means of reactivity control by which to achieve a reactor shutdown.

4.3 Vessel System (12)

System Functions

The primary functions of the Vessel System are to contain the primary coolant inventory and to maintain the integrity of the primary coolant pressure boundary. The Vessel System also structurally supports the Reactor System, the Power Conversion System, and the IHX that transfers heat from the primary coolant to the Secondary Heat Transport System. The Shutdown Cooling System heat exchanger and circulator are housed and supported at the bottom of the reactor vessel. The Vessel System may also provide for housing and support of additional heat transfer equipment, such as may be utilized in future development and testing, through which process heat can be conveyed to other users to demonstrate other process heat applications.

The radionuclide control related functions of the Vessel System are to maintain the geometry of the reactor core with respect to the reactor vessel, to maintain the alignment of the reactor vessel with respect to the Reactor Cavity Cooling System (RCCS) during core conduction cooldown, to maintain the geometry of the core and movable poisons in order to control heat generation, and to limit air ingress and consequent oxidation of the fuel and other core components.

System Configuration and Essential Features Requirements

The Vessel System shall consist of vertically oriented cylindrical steel vessels, connected by horizontal cross vessels, that contain the primary coolant and house the reactor system, the power conversion system, the shutdown cooling heat exchanger and associated circulator, and the primary heat transport system equipment that effects heat transfer from the primary coolant to the secondary heat transport system for use in the production of hydrogen and other uses.

The vessel that houses the Reactor System shall be located such that the thermal center of the reactor core is at a higher elevation than the thermal centers of the other vessels.

The Vessel System design shall provide access to the reactor primary coolant pressure boundary to facilitate in-service inspection (ISI) as required by Section XI of the ASME Code.

The vessels housing the power conversion system and the primary heat transport system equipment shall be designed to support both the dead weight of the housed equipment and to accommodate the dynamic forces associated with operation of the equipment.

Safety Requirements

The Vessel System shall assure that the top-level radionuclide control requirements of PLT 3.1.9 are satisfied by:

- Maintaining the geometry of the reactor core and moveable poisons with respect to the reactor vessel in order to control heat generation.

- Convecting, conducting, and radiating heat from the core through the reactor vessel wall to the RCCS in order to remove reactor core heat.

- Providing a reliable barrier against air ingress into the core in order to prevent chemical attack of the fuel.

4.4 Primary Heat Transport System (13)

System Functions

The Primary Heat Transfer System (HTS) is located within the reactor primary coolant pressure boundary and has the principal function of transporting thermal energy released in the reactor core to the intermediate heat exchanger for transfer to the secondary heat transport system. The system also provides an alternate means (in addition to the SCS) for removing reactor decay heat whenever the reactor is shutdown or is being refueled, and when the PCS is not available for heat removal.

System Configuration and Essential Features Requirements

The Primary HTS shall include an intermediate heat exchanger (IHX) sized for efficient transfer of up to [50] MW(t) of reactor thermal power output to the Secondary HTS.

An electric-motor-driven helium circulator shall be used to circulate the primary coolant around the system. The helium circulator shall be supported on magnetic bearings.

Operational Requirements

The Primary Heat Transport System shall be designed to operate continuously, as required to provide the heat input needs of the hydrogen production plant, or to supply the required thermal energy for other process heat applications.

The Primary Heat Transport System shall be designed to operate at a nominal reactor coolant outlet temperature in the range of 850^{o}C to 950^{o}C. The system shall be capable of transporting helium primary coolant from the reactor core outlet plenum to the IHX, and from the IHX to the reactor core inlet plenum.

Structural Requirements

The IHX and helium circulator shall be housed and supported within a vessel belonging to the Vessel System that constitutes the primary coolant pressure boundary.

Instrumentation and Control Requirements

The system shall include instrumentation to continuously monitor system performance and to detect component malfunctions.

Surveillance and In-Service Inspection Requirements

Design features shall be included in the Primary Heat Transport System that permit in-service inspection of the IHX during refueling outages.

Maintenance Requirements

The IHX and the helium circulator shall be removable from the Vessel System as necessary to perform maintenance, repair, or replacement.

4.5 Shutdown Cooling System (14)

System Functions

The primary functions of the Shutdown Cooling System (SCS) are to provide an alternate active means of removing residual and decay heat from the reactor core whenever the reactor is in a shutdown condition, and to transfer this heat to the Shutdown Cooling Water System. The SCS also includes equipment, all or in part, as required to accomplish removal, replacement, inspection, and maintenance of the shutdown helium circulator and the shutdown cooling water heat exchanger.

System Configuration and Essential Features Requirements

The SCS shall consist of a heat exchanger, a motor-driven circulator, and a shut-off valve. This equipment shall be designed as a self contained unit and shall be installed in the bottom head of the reactor vessel. Primary coolant shall be drawn from the core outlet plenum, circulated through the heat exchanger, and returned into the reactor inlet plenum.

The SCS shall be designed to remove and transfer reactor core decay heat within the steady state performance envelopes defined in Ref. {TBD}.

Service equipment shall be designed to remove and replace the shutdown circulator and the shutdown heat exchanger, including the shut-off valve, through the bottom head of the reactor vessel.

Operational Requirements

The SCS shall provide an alternate forced convection means of removing reactor core decay heat.

The SCS shall have the capability to remove {TBD} MW(t) of core decay heat when the vessel system is pressurized with the full primary coolant helium inventory.

When the reactor core is being cooled through the normal operation of the Power Conversion System (PCS), the primary coolant bypass flow through the SCS shall be less than {TBD}% of the total primary coolant system flow.

The heat loss from the primary coolant to the shutdown cooling water system shall not exceed {TBD} MW(t) whenever the power conversion system is operating between {TBD}% and 100% of nominal primary coolant flow.

Structural Requirements

The SCS shall be designed to withstand the maximum acoustical pressure levels resulting from PCS or SCS operation.

The SCS shall be designed to withstand the maximum flow-induced forces resulting from PCS or SCS operation.

4.6 Shutdown Cooling Water System (15)

System Functions

The primary functions of the Shutdown Cooling Water System are to provide a heat sink for the SCS when it is operating to remove residual and decay heat from the reactor core, and to remove the parasitic heat input to the SCS (due to the small bypass flow of primary coolant into the SCS) during PCS operation.

The Shutdown Cooling Water System, in conjunction with the SCS, provides an alternate active means for removing reactor residual and decay heat when the reactor is shut down

System Configuration and Essential Features Requirements

The Shutdown Cooling Water System shall be designed as a forced circulation, closed loop system.

The Shutdown Cooling Water System shall be designed to remove and dissipate up to {TBD} MW(t) of heat whenever the SCS is in normal operation and the Vessel System contains the full primary coolant inventory. The system shall accommodate the heat absorbed from the bypass flow of primary coolant without undergoing boiling instability.

Operational Requirements

The Shutdown Cooling Water System shall remove and dissipate up to {TBD} MW(t) from the SCS during normal operation of the PCS.

4.7 Reactor Cavity Cooling System (16)

System Functions

The primary functions of the Reactor Cavity Cooling System (RCCS) are to protect the concrete structure surrounding the reactor vessel from overheating during all modes of operation and to provide an alternate means for removing reactor core decay heat when neither the PCS nor the SCS is available. In addition, the RCCS cooling panels form part of the barrier that separates the ambient atmosphere from the reactor cavity atmosphere.

System Configuration and Essential Features Requirements

The RCCS shall be designed to be a passive means of removing and dissipating reactor decay and residual heat.

The RCCS heat transfer surfaces shall be designed for installation between the reactor vessel and the reactor building walls that surround the reactor vessel. An annular free space shall be maintained between the reactor vessel and the RCCS to accommodate reactor vessel in-service inspection.

Operational Requirements

The RCCS shall operate continuously in natural circulation during all modes of plant operation.

The heat loss from the Vessel System to RCCS shall not exceed {TBD} MW(t) while the reactor is operating between {TBD}% and 100% of rated thermal power.

The RCCS shall be designed to remove {TBD} MW(t) under conditions when the Vessel System is pressurized, and {TBD} MW(t) when the Vessel System is depressurized while limiting the reactor vessel external wall temperatures to {TBD}^{o}C and {TBD}^{o}C, respectively.

The RCCS shall be designed to limit the reactor cavity concrete temperature to a nominal value no greater than 66^{o}C under all normally expected reactor operating conditions.

Structural Requirements

The RCCS shall be designed to accommodate the peak pressure differential that would be produced by a design basis failure of the primary coolant pressure boundary.

Safety Requirements

The RCCS shall be designed to assure that the top-level radionuclide control requirements of PLT 3.1.9 are satisfied.

4.8 Fuel Handling and Storage System (21)

System Functions

The principal functions of the Fuel Handling and Storage System are to refuel the reactor, to perform other fuel handling operations at the reactor site, to store new and irradiated fuel and reflector elements, and to prepare spent fuel and reflector elements for either storage onsite or shipment offsite.

The radionuclide control functions of the Fuel Handling and Storage System are to limit radionuclide release from the fuel handling and storage equipment, limit release from the reactor vessel during refueling operations, and to protect operating personnel from radiation exposure during all irradiated fuel handling and storage operations.

System Configuration and Essential Features Requirements

The plant shall be designed to receive new fuel and to ship spent fuel, either by road, or by rail.

The capacity of the irradiated fuel storage facility shall be consistent with the design fuel cycle and shall be adequate to store all of the irradiated fuel elements discharged from the reactor over a 10 year period of plant operation, plus an additional reactor core including all replaceable reflectors.

The design of the irradiated fuel storage facility shall permit expansion, without impact on plant power operations, to accommodate storage of all of the spent fuel and replaceable reflectors generated over the life of the plant.

The plant shall be designed to receive, inspect, and store new fuel and reflector elements prior to refueling in a manner consistent with the design fuel cycle.

The plant shall include a spent fuel sealing and inspection facility for preparing spent fuel and reflector elements for storage. The spent fuel sealing and inspection facility shall have the capacity for storage of up to {TBD} full-size reflector elements.

In-core handling equipment shall be capable of removing and replacing all of the fuel or replaceable reflector elements in a core column, including the bottom permanent reflector and core support post.

All movements of fuel and reflector elements shall be monitored and recorded with reference to location in the reactor core or in storage, and with respect to both type and serial number.

All fuel handling equipment status and operations shall be displayed and controlled from a single control and coordination center.

Reactor operating personnel located in the main control room shall have the capability to monitor and maintain reactor shutdown for the duration of refueling operations.

Human Factors Engineering techniques shall be applied in the design of the refueling control room and associated control equipment as required to optimize the overall refueling operation and to reduce the probability of operator error.

Operational Requirements

The fuel handling system shall be designed to accomplish reactor refueling within a time interval of ≤ 30 days.

The reactor shall be maintained in a reactor cold shut down condition while being refueled.

Structural Requirements

Portions of the Fuel Handling and Storage System that operate within the reactor vessel shall be designed to accommodate the performance envelopes contained in Ref. {TBD}.

Fuel handling components that communicate with the primary coolant and perform as an extension of the reactor coolant pressure boundary shall be designed to withstand {TBD} kPa internal pressure, and {TBD}^{o}C internal temperatures. Pressure relief shall be provided, with the effluent directed to the plant gaseous radwaste system.

Availability Assurance

The Fuel Handling and Storage System components and features shall be designed to accomplish a typical refueling of the reactor within a 30-day period, consistent with the design minimum fuel cycle length of 18 months.

Maintenance Requirements

The plant shall be designed to include facilities and features by which the operational readiness of the in-core fuel handling equipment can be assured. This includes periodic inspections, maintenance, testing, and demonstrations of integrated equipment operation. Such inspection, maintenance, testing, and demonstration shall not interfere with core refueling operations nor shall they cause any adverse effects on plant operation.

4.9 Spent Fuel Cooling Water System (22)

System Functions

The primary functions of the Spent Fuel Cooling Water System are to actively remove decay heat from the spent fuel elements within their storage containers, and to transfer that heat to a secondary coolant.

The system shall be capable of operating in a passive cooling mode to accommodate an unlikely short-term event when some or all of the critical spent fuel cooling system components may not be available.

System Configuration and Essential Feature Requirements

The spent fuel cooling water system shall consist of a closed loop arrangement that provides a supply of temperature-controlled water to a space surrounding the spent fuel storage containers. Heat absorbed by the system shall be dissipated through a heat exchanger to a separate secondary cooling system. Redundant pumps shall be included to ensure a constant supply of cooling water to the space surrounding the spent fuel containers.

Operational Requirements

The Spent Fuel Cooling Water System shall be designed to continuously remove and transfer {TBD} MW(t) of heat absorbed by the cooling water, at ambient atmospheric conditions

The Spent Fuel Cooling Water System shall be designed to operate continuously whenever spent fuel is located in storage.

Water quality requirements shall be maintained at all times.

4.10 Nuclear Island Cooling Water System (23)

System Functions

The functions of the Nuclear Island Cooling Water System are to remove heat from reactor plant components by way of a circulating cooling water system, and to transfer that heat to an ultimate heat sink.

System Configuration and Essential Features Requirements

The Nuclear Island Cooling Water System shall serve the needs of the reactor and its associated components, at all times, under full power operating conditions.

System makeup shall be provided from the plant Water Supply Treatment System.

Redundant components shall be provided for the Nuclear Island Cooling Water System as needed to support continuous operation of the reactor, and to provide for on-line maintenance of the cooling system components.

Operating Requirements

The maximum cold water supply temperature shall not exceed 31°C.

The system shall be designed to reject, at ambient atmospheric conditions, a maximum heat load of {TBD} MW(t).

4.11 Helium Services System (24)

The Helium Services System shall include a Primary Helium Purification Subsystem, a Helium Storage and Transfer Subsystem, and a Liquid Nitrogen Subsystem.

4.11.1 Primary Helium Purification Subsystem

Subsystem Functions

The primary functions of the Primary Helium Purification Subsystem are to process a small side-stream of primary coolant to remove chemical and radioactive impurities, and to provide a supply of purified helium for purge needs throughout the facility. Other functions are to process the primary coolant whenever the Vessel System inventory is reduced to maintain a given reactor power level (inventory control), or to depressurize the Vessel System prior to refueling or maintenance operations.

Subsystem Configuration and Essential Features Requirements

The Primary Helium Purification Subsystem shall consist of two identical trains of components. Either helium purification train shall be capable of supporting depressurization of the Vessel System.

A single helium purification regeneration train shall be provided to accommodate regeneration of the packed bed desiccant adsorbers and low temperature adsorbers in the helium purification trains.

Each helium purification train shall be designed to accommodate a mass flow rate equal to approximately four times the nominal subsystem flow rate during the initial stages of a Vessel System depressurization.

The design of the Primary Helium Purification Subsystem shall include redundant components as necessary to accommodate on-line regeneration of the subsystem adsorbers as well as to permit maintenance of the train elements.

Operational Requirements

The helium purification trains shall be designed to remove the following major chemical impurities: CO, CO_2, H_2 (including tritium), N_2, 0_2, H_2S, CH_4, and other hydrocarbons. Lesser amounts of impurities such as Br, I, H_2O, Kr, and Xe shall also be removed along with filterable particulates and certain metallic elements.

Each helium purification train shall process the primary coolant helium at a constant volumetric flow rate regardless of the primary coolant system pressure. At 100% of rated reactor power and vessel system pressure, the helium purification subsystem shall process primary coolant at a rate of {TBD} kg/s.

Each helium purification train shall be designed for a gross throughput sufficient to allow depressurization of the Vessel System within 24 hours following a reactor shutdown.

Each helium purification train shall be sized such that the purification constant r_p = (mass flow rate through the helium purification subsystem)/(total mass of circulating helium) is $\geq 2.9 \times 10^{-5}$ per second.

4.11.2 Helium Storage and Transfer Subsystem

Subsystem Functions

The functions of the Helium Storage and Transfer Subsystem are to transfer helium from the Vessel System to storage to accomplish inventory control and depressurization, to transfer helium from storage to the Vessel System to accomplish pressurization, and to maintain a high pressure supply of helium for makeup and various other station uses. The system receives makeup helium form external sources, and transfers that helium either into the Vessel System directly, or into the subsystem helium storage tanks.

Subsystem Configuration and Essential Features Requirements

The high pressure helium storage volume shall be sized to meet expected demand usage while requiring makeup directly from an offsite source at a frequency of less than once per month.

Helium storage capacity shall be sufficient to accommodate the full primary coolant inventory when the Vessel System is depressurized, plus a 20% reserve volume.

The Helium Storage and Transfer Subsystem shall be equipped with one or more helium transfer compressors, each of which shall have sufficient capacity to accomplish a Vessel System pressurization or depressurization within a specified time interval as required to support a plant startup or shutdown.

Operational Requirements

High-pressure helium for general plant use shall be provided at a source pressure of approximately 15.5 MPa (2250 psig) under ambient conditions.

The high-pressure helium inventory shall be capable of supplying a minimum volume of 10% of plant inventory per year to replace routine plant consumptive and leakage losses, following the initial system fill.

The Helium Storage and Transfer Subsystem shall be capable of supplying makeup helium to all users, either from the high-pressure helium supply tanks, or from the helium storage system (via the transfer compressors, if necessary), or directly from an outside source.

The Helium Storage and Transfer Subsystem shall be capable of receiving helium directly from the discharge of a helium purification train over a pressure range from slightly sub-atmospheric, to the highest Vessel System pressure expected.

4.11.3 Liquid Nitrogen Subsystem

Subsystem Functions

The primary functions of the Liquid Nitrogen Subsystem are to supply liquid nitrogen to support cryogenic operation of the low temperature adsorbers in the helium purification subsystem, and to provide a source of cryogenic liquid for use with the plant analytical instruments. This subsystem also provides a source of gaseous nitrogen for various component lay-up purposes and other uses around the facility.

Subsystem Configuration and Essential Features Requirements

Sufficient onsite liquid nitrogen storage capacity shall be provided to meet the normal operating needs of the liquid nitrogen subsystem and other facility uses.

Liquid nitrogen shall be stored in a cryogenic tank within close proximity to the helium purification systems. Additional liquid nitrogen storage capacity may be provided in suitably located cryogenic tanks.

Redundant components (tanks, pumps, recondensers, etc.) shall be provided as required to support continuous operation and on-line maintenance of the subsystem.

The liquid nitrogen refrigeration subsystem shall be designed to accommodate a minimum liquid nitrogen temperature of -196^{o}C at a pressure of 0.41 MPa.

Operational Requirements

The liquid nitrogen subsystem shall be designed to supply liquid nitrogen at a maximum temperature of -179^{o}C, depending upon pressure, at the low temperature absorbers in the helium purification trains.

The liquid nitrogen subsystem shall be capable of continuously meeting the simultaneous needs of the helium purification subsystem, and all other users, whenever the reactor is operating under full power conditions.

Liquid nitrogen flow rates shall be sufficient to maintain the low temperature adsorbers in the helium purification subsystem at normal cryogenic operating temperatures during the initial high helium flow conditions that exist at the initiation of a Vessel System depressurization.

4.12 Radwaste and Decontamination System (25)

System Functions

The primary function of the radwaste portion of the system is to provide for collecting, storing, processing, and monitoring, radioactive (or potentially radioactive) liquid and gaseous wastes, including various forms of solid waste generated within the plant. The decontamination portion of the system provides equipment and procedures to remove radioactive surface contamination from components as necessary to facilitate control and minimize migration of radioactive contamination, and to limit personnel exposure to radionuclides.

System Configuration and Essential Features Requirements

The Radwaste and Decontamination System shall be located within a Radioactive Waste Management Building.

The Radwaste and Decontamination System shall collect radioactive and potentially radioactive floor and equipment liquid runoff. These waste streams shall be routed to the liquid radioactive waste subsystem.

Radioactive liquid wastes generated throughout the plant shall be collected in receiver tanks located in the Radioactive Waste Management Building.

Provisions shall be included to reduce activity levels contained in collected liquid effluent.

Highly tritiated liquid effluent from the helium purification train(s) or other source(s) of highly concentrated radioactive liquid waste shall be collected in a tank separate from the low-activity liquids.

All liquid receiver tanks shall be surrounded by a curbing system to prevent an uncontrolled spread of liquid waste in the event of a leak in the tank.

Radioactive liquid waste system components shall be redundant to provide for both system reliability and on-line maintenance.

Component elements of the gas waste processing, handling, and storage system shall be located in the Radioactive Waste Management Building.

The gaseous waste processing portion of the system shall incorporate two separate flow paths:

1) Effluents that do not require a decay period or whose activity levels are known to be minimal shall be monitored and released.

2) Effluents not meeting the prescribed federal release standards shall be accumulated in storage tanks for subsequent processing and disposal.

The gaseous effluent release path for monitored releases shall be through the Nuclear Island HVAC system exhaust flow. Release rates for this waste stream shall be based on both content and activity levels of the gaseous waste stream being released.

The gas waste portion of the radwaste system shall have sufficient storage capacity to allow for radioactive decay prior to release.

The radwaste system design shall provide for compressing solid waste, solidifying high-activity liquid wastes, cutting up large items, or otherwise packaging radwaste materials for disposal.

Solid waste storage shall be provided in the form of sealed drums.

Decontamination equipment shall be skid-mounted. Each decontamination skid shall provide steam, wash water (including detergent and/or other additives), rinse water, drying air, and vacuuming service.

Decontamination system wastes shall be collected locally and routed to the appropriate radwaste subsystems.

All radioactive wastes generated within the facility shall be collected, monitored, treated, and processed onsite, prior to shipment offsite.

Operational Requirements

The radioactive liquid waste system shall be designed to provide for monitoring of all radioactive liquid releases both before and during a release. Automatic termination of a release shall be initiated upon detection of activity levels in excess of established limits. Detection of an activity level above the limits shall cause the discharge flow to be terminated before the detected portion of high activity liquid reaches the system discharge valve.

Radioactive effluents that cannot be processed or diluted to meet discharge standards shall be solidified to allow for disposal as solid waste.

Radioactive, and potentially radioactive gases shall be collected and monitored prior to and during release.

The design of the radioactive gas waste system shall provide for automatic termination of a release upon detection of activity levels in excess of established limits. Termination of the release shall occur before the detected high activity effluent reaches the HVAC system exhaust duct.

Radioactive gases known to be of high concentration (e.g., regeneration gases from the helium purification regeneration subsystem) shall be processed directly to the radioactive gas waste storage tanks for hold-up and monitoring prior to release.

The radwaste system shall have the capability to handle low-level radioactive dry and wet wastes, up to a processed volume of 3.6 m^3 per year, for shipping offsite, excluding core replaceable reflectors.

4.13 Power Conversion Cooling Water System (26)

The primary functions of the Power Conversion Cooling Water System are to remove waste heat from the helium coolant that drives the Power Conversion System, and to transfer that heat to the plant Circulating Water System for rejection to the local outside atmosphere. Heat is absorbed by the Power Conversion Cooling Water System from various heat exchangers within the Power Conversion System such as the pre-cooler and intercooler, and the generator cavity helium coolers.

The system also functions as a barrier to prevent the direct release of primary coolant fission products into the plant Circulating Water System in the event that a leak should develop in any of the heat exchangers within the primary system pressure boundary.

System Configuration and Essential Features Requirements

The Power Conversion Cooling Water System shall be dedicated to the Power Conversion System heat exchangers that it serves.

Waste heat shall be transferred directly from the Power Conversion Cooling Water System to the plant Circulating Water System for ultimate rejection to the local atmosphere.

The Power Conversion Cooling Water System shall be designed as a closed-loop arrangement.

The Power Conversion Cooling Water System flow shall be confined to the tube side of the heat exchangers that transfer the waste heat to the plant Circulating Water System.

Operational Requirements

The Power Conversion Cooling Water System shall be designed to transfer sufficient heat from the turbo-machine compressor pre-cooler and intercooler to maintain the helium temperature at the outlet of the intercooler at a nominal temperature of {TBD}°C, with the turbomachine operating between {TBD%} and 100% of rated output.

The system shall be designed to maintain the helium temperatures in the generator cavity between {TBD]°C over a load range between {10%] and 100% of the rated MVA output of the generator.

The system shall be designed such that the operating pressure of the cooling water contained in the piping and heat exchangers can be maintained {TBD} MPa lower than the turbomachine turbine outlet pressure. The cooling water pressure shall be variable as necessary to meet this requirement.

System components shall be designed with redundancy as necessary to meet system availability requirements and to accommodate on-line maintenance.

4.14 Reactor Protection System (31)

System Functions

The primary functions of the Reactor Protection System are to sense process variables within the system to detect and alarm the onset of abnormal conditions, and to actuate equipment that will prevent these process variables from exceeding the prescribed limits that assure an acceptable level of safety to the general public.

System Configuration and Essential Features Requirements

The Reactor Protection System shall be functionally, physically, and electrically independent from the plant process control systems.

Operational Requirements

The design of protective features shall provide for periodic functional testing. However, such testing shall not interfere with normal plant operation, or otherwise place the logic of the plant protective features in an unacceptable “minimum degree of redundancy” condition.

The Reactor Protection System shall sense process variables to detect abnormal plant conditions and to automatically initiate actions that will maintain parameters within damage threshold levels that have been established for components essential to the protection of public health and safety.

Safety Requirements

By continually sensing plant process variables, The Reactor Protection System shall assure that the Top-Level Regulatory Requirements are not exceeded. Upon detection of unacceptable plant conditions, the Reactor Protection System shall cause corrective action to be taken, or if necessary, a reactor trip shall be initiated to terminate heat generation within the reactor.

The Reactor Protection System shall be designed with the capability to activate redundant and diverse reactivity control systems to accomplish a safe shutdown of the reactor.

4.15 Investment Protection System (33)

System Functions

The primary functions of the Investment Protection System are to sense, monitor, and alarm process system variables, and to notify plant personnel as to the existence of abnormal plant conditions. Equipment shall be activated automatically that will maintain plant parameters within certain limits that have been established for maintaining an acceptable level of plant investment risk. The system provides interlocks to prevent inadvertent operations that could result in unacceptable plant or system conditions. The Investment Protection System also verifies that "safety-related” systems remain fully operable under all normal, abnormal, and accident conditions through continuous monitoring of plant safety and investment parameters. The system also provides the capability to manually shutdown the reactor from a remote shutdown location.

System Configuration and Essential Features Requirements

The Investment Protection System shall be functionally, physically, and electrically independent from the plant process control systems.

Operational Requirements

The design of protective features within the Investment Protection System shall provide for periodic functional testing to meet readiness and operability requirements. Such testing shall not interfere with normal plant operation, nor shall it place the protective feature logic in an unacceptable "minimum degree of redundancy" condition.

The Investment Protection System shall sense process variables to detect and alarm abnormal plant conditions, and to initiate actions that will maintain parameters within threshold levels that have been established for the safe operation of components, thereby assuring protection of the plant investment.

The Investment Protection System shall be designed to ensure protection of the plant investment by sensing those process variables that detect abnormal reactor conditions, and initiating a reactor trip when any of those variables exceed established limits.

4.16 Plant Control, Data, and Instrumentation System (34)

System Functions

The functions of the Plant Control, Data, and Instrumentation System are to accept control inputs, monitor plant status, make control decisions, effect plant control, and report information.

System Configuration and Essential Features Requirements

Protective monitoring and protective features for major components and equipment shall be functionally independent from plant process control.

The Plant Control, Data, and Instrumentation System shall incorporate features necessary to accomplish control and monitoring of the plant from the control room during startup, normal operations, off-normal operations, and shutdown of systems and components. The system shall also provide for prompt shutdown of major plant systems and components by the operator, to both limit investment risk and to assure protection of plant operating personnel.

Provisions shall be made to perform automatic identification and continuous documentation of all significant sequences of events that occur during plant operation. Typical sequences include variations in control inputs, changes in the operational state of major systems and components, any changes in major system variables, or the initiation of protective trips, etc.

The Plant Control, Data, and Instrumentation System shall contain equipment to monitor plant status, configuration, and performance, and for detecting and diagnosing malfunctions that can be used as a basis for predictive maintenance planning and decision making.

Operational Requirements

The Plant Control, Data, and Instrumentation System shall be designed to control and maintain plant parameters during all operating modes, (e.g., shutdown, refueling, startup or shutdown, and during routine power operation).

The design of the main control room operator interface shall provide for temporary control room staff increases as may be needed to support simultaneous operational evolutions.

Features shall be included at the control room operator-machine interface level to facilitate operator-initiated functions of both the Reactor Protection System and the Investment Protection System.

4.17 Plant Monitoring System (35)

The Plant Monitoring System consists of the Nuclear Island analytical instrumentation, radiation monitoring equipment, seismic monitoring instruments, meteorological monitoring instruments, and Balance of Plant monitoring systems.

System Functions

a. Nuclear Island Analytical Instrumentation

The function of the Nuclear Island analytical instrumentation is to monitor for the presence of selected primary coolant chemical impurities, plus circulating and plate-out radionuclides.

b. Radiation Monitoring

The functions of the Nuclear Island radiation monitoring equipment are to measure, indicate, and alarm dose rates at various locations within the plant, including radiation concentrations within selected onsite effluent streams, as well as dose rates and selected radionuclide concentrations at the plant site boundary.

c. Seismic Monitoring

The function of the seismic monitoring instrumentation is to provide information for prompt determination of the vertical and horizontal accelerations associated with a seismic event. This information can then used to make a comparison between the imposed acceleration and response of the event relative to the data used in the design basis.

d. Meteorological Monitoring

The function of the meteorological monitoring equipment is to acquire and process meteorological data for use in assessing the effects that ambient meteorological conditions could have on airborne releases of radioactivity.

e. Balance of Plant Monitoring

The functions of the Balance of Plant monitoring equipment are to sample, measure, indicate, record, and alarm selected chemical parameters associated with various Balance of Plant water systems.

Equipment Configuration and Essential Features Requirements

a. Nuclear Island Analytical Instrumentation

Analytical instrumentation shall be capable of detecting and quantifying certain specific chemical and radioactive impurities circulating in the primary coolant helium.

The analytical instrumentation shall have the capability to allow for the acquisition of primary coolant helium samples, and other process gas stream grab samples, as needed to perform suitable laboratory analyses.

Spent sample gases from the Analytical Instrumentation System shall be discharged to the Radwaste and Decontamination System.

Condensable radionuclide analyses shall be accomplished by means of plate-out probes located in the hot circulating primary coolant flow stream.

Operational Requirements

The analytical instrumentation shall be capable of performing on-line analyses.

Continuous leak detection monitoring within the analytical instrumentation equipment shall be provided, such that a leak in a sensing line can be isolated immediately upon identification.

b. Radiation Monitoring

Operational Requirements

Radiation monitoring equipment installed at fixed locations shall be capable of continuous operation.

Local and remote alarm indication shall be provided to allow for prompt notification of plant personnel as to the existence of high radiation conditions and/or equipment malfunction.

The plant radiation monitoring equipment shall have the capability to monitor radiological conditions, as well as other conditions that provide information for classification of site emergency conditions. Emergency action levels can then be identified and the status of corrective actions and restoration procedures can be determined.

The radiation monitoring equipment capability shall include:

1. The means to assess radiological release conditions during site emergencies.
2. The means to assess plant conditions that could affect site radiological emergencies.
3. The display of emergency information.

Equipment Configuration and Essential Features Requirements

Fixed location radiation monitoring equipment shall be provided that is capable of continuously detecting, indicating, alarming, and reporting radionuclide concentrations and radiation levels in the process fluids.

Radiation sensing equipment shall provide for the following types of monitoring: Area ambient gamma radiation, airborne radioactivity, process effluent radioactivity, and radiation (and possible contamination) levels at the plant site boundary.

The radiation monitoring equipment shall include a mix of fixed location and portable devices.

c. Seismic Monitoring

Operational Requirements

The seismic monitoring system shall operate continuously to detect, indicate, and report seismic activity during all modes of plant operation.

Seismic acceleration as a function of time shall be recorded for playback and analysis, and comparisons shall be made with seismic acceleration data used for operating basis earthquake and system shutdown earthquake analyses.

d. Meteorological Monitoring

Equipment Configuration and Essential Features Requirements

Meteorological data shall be acquired by means of instrument sensors mounted on a tower whose height shall exceed that of the tallest structure on the plant complex.

The meteorological tower shall be located in the immediate vicinity of the plant, at a distance sufficiently far from the plant buildings that wake effects are of no significance.

Operational Requirements

At a minimum, data shall be acquired continuously to accumulate historical records of the following variables:

- Wind speed and direction
- Ambient air dry bulb temperature
- Dew point
- Solar radiation
- Precipitation

e. Balance of Plant Monitoring

Equipment Configuration and Essential Features Requirements

The Balance of Plant (water) monitoring equipment shall be designed to monitor, indicate, record, and alarm selected water quality parameters for the various Balance of Plant water systems.

Operational Requirements

Balance of Plant water samples shall be analyzed and the results recorded during both steady-state operations and transient operating conditions whenever Balance of Plant systems are in service.

4.18 Power Conversion System (41)

System Functions

The primary functions of the Power Conversion System (PCS) are to convert thermal energy to electricity and to provide the motive power to transport the thermal energy released in the reactor to the PCS. The PCS also provides the motive power required to initiate and maintain primary helium circulation during reactor startup and shutdown. The PCS, in conjunction with the Power Conversion Cooling Water System and the Circulating Water System, provides a means to remove reactor decay heat when the reactor is shutdown and/or being refueled.

System Configuration and Essential Features Requirements

The PCS design shall be based on a recuperated, intercooled Brayton cycle.

The PCS shall be located within the reactor primary coolant pressure boundary.

The PCS generator shall be variable speed and shall be designed to operate in helium within the primary system pressure boundary.

The system shall include a frequency converter to provide generated electricity at 60 Hz.

The PCS shall be designed to operate at its full design output with a maximum overall (total) $\Delta P/P$ of {TBD}%.

The PCS turbomachine shall utilize a coupled generator and turbomachine rotor design and shall be designed to operate continuously at a nominal turbine inlet temperature of 950^{o}C.

The PCS turbomachine and generator rotors shall be supported by magnetic bearings.

The PCS turbomachine compressor design shall incorporate a single stage of intercooling.

The PCS recuperator heat exchanger shall be designed to achieve a minimum effectiveness of {95%}.

The PCS precooler and intercooler assemblies shall be designed to maintain a nominal helium outlet temperature of {TBD}°C or less under all steady-state operating conditions per the applicable point design.

Operational Requirements

The design of the PCS generator shall permit its use as a variable speed motor during power unit startup and shutdown and to continuously remove reactor decay heat when the reactor is shutdown and is being refueled.

The PCS components and their supporting auxiliaries shall be designed for continuous operation at rated electrical output at the generator terminals.

The PCS shall be designed to produce a nominal gross output of 300 MW(e) at a 90% Power Factor at the generator terminals when power output of the reactor is 600 MW(t).

The PCS shall provide approximately {TBD MWe} of electric power to the HTE-based Hydrogen Production System or {TBD MWe} to the SI-based Hydrogen Production System to provide for the electrical consumption of the hydrogen production process.

Structural Requirements

The combination of the turbo-machine, generator, and associated support equipment shall be designed to allow it to be supported and operated within the Vessel System that defines the primary coolant pressure boundary.

Instrumentation and Control Requirements

The PCS components and their supporting auxiliary systems shall include the instrumentation necessary to continuously monitor the operational performance of the system and to detect and diagnose possible malfunctions.

Surveillance and In-Service Inspection Requirements

For those surveillance or inspection activities that require the PCS components to be removed from service, features shall be included in the design to allow such surveillance or inspection to be completed during planned maintenance outages.

Maintenance Requirements

PCS components shall be designed for remote installation and removal from within the primary coolant pressure boundary as may be required to facilitate inspection, repair, and/or replacement.

4.19 Secondary Heat Transport System (42)

System Functions

The function of the Secondary Heat Transport System (HTS) is to transport heat that has been transferred from the primary coolant by the intermediate heat exchanger (in the Primary HTS) to the process heat exchanger(s) in the hydrogen production system. The Secondary HTS could also perform the function of transferring heat to other process-heat application systems as might be added to the NGNP.

System Configuration and Essential Feature Requirements

The Secondary HTS shall use helium as the working fluid.

The process heat transferred from the primary coolant shall be transported by an appropriate secondary coolant piping system installed between the intermediate heat exchanger and the hydrogen production facility.

A circulator installed on the cold leg side of the transport system piping shall provide the motive power to circulate the secondary coolant between the IHX and the hydrogen production facility.

The need for isolation valves in the Secondary HTS piping to prevent off-normal conditions in the hydrogen production system from influencing or damaging either the heat exchanger or the heat transport lines shall be considered in designing the system.

A helium purification system similar to that designed for the primary coolant helium shall be provided to maintain the purity of the secondary coolant helium. This purification system shall be installed in the Reactor Service Building adjacent to the primary coolant purification system to minimize duplication of services required by the systems.

The Secondary HTS shall be designed such that any event that might occur within the hydrogen production facility will have no affect on the operation of the nuclear portion of the plant, and vice versa.

Operational Requirements

The Secondary HTS circulator will utilize magnetic bearings to eliminate any possible contamination of the secondary coolant due to equipment lubricants.

The Secondary HTS shall deliver the process heat at the temperature and pressure conditions required by the hydrogen production process.

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%}.

Leakage of the working fluid used to transport the heat shall be less than {10%} per year. Radionuclide release associated with working fluid leakage shall be within the occupational and public dose limits specified in 10 CFR 20.

4.20 Secondary Helium Purification System (43)

System Functions

The function of the Secondary Helium Purification System is to process a small side-stream of helium from the Secondary HTS to remove chemical and radioactive impurities.

Subsystem Configuration and Essential Features Requirements

The Secondary Helium Purification System shall consist of a helium purification train(s) of similar design to the helium purification trains in the Primary Helium Purification Subsystem, except that low temperature adsorbers may not be required.

The Secondary Helium Purification System components shall be sized based on the Secondary HTS side-stream flow fraction to be processed by the system.

The Secondary Helium Purification System shall be installed adjacent to the Primary Coolant Purification Subsystem in order to minimize duplication of services required by the systems.

Operational Requirements

The helium purification trains shall remove the following major chemical impurities: CO, CO_2, H_2 (including tritium), N_2, 0_2, H_2S, CH_4, and other hydrocarbons. The helium purification trains shall also remove filterable particulates and certain metallic elements.

The helium purification train shall process the secondary coolant helium at a constant volumetric flow rate. The Secondary HTS side-stream flow fraction to be processed by the Secondary Helium Purification System shall be determined primarily by the tritium specification for the hydrogen product gas.

4.21 SI-Based Hydrogen Production System (44)

System Functions

The primary function of the hydrogen production system is to convert feedstock material into gaseous hydrogen using process heat supplied by the NGNP reactor. The sulfur-iodine (SI) thermochemical process produces hydrogen by three chemical reactions that result in dissociation of water into hydrogen and oxygen. Iodine, sulfur dioxide, and water are combined to obtain sulfuric acid and hydrogen iodide via the Bunsen Reaction at about 120^{o}C. The process heat provided by the Secondary HTS is used to decompose the sulfuric acid into sulfur dioxide, water, and oxygen at about 800°C. The hydrogen iodide product is decomposed into free hydrogen and iodine at a temperature of about 350^{o}C. The iodine is recycled to the Bunsen Reaction. The hydrogen is purified and either transferred to an end user or sent to the hydrogen storage system. The oxygen produced as a by-product of the process may be also be purified and transferred to a storage facility, or it may be discharged to the atmosphere. The hydrogen production system rejects the waste heat from the SI thermochemical process to an ultimate heat sink.

System Configuration and Essential Features Requirements

The structure housing the SI-based hydrogen production system shall be located adjacent to the reactor complex with a separation distance adequate to ensure that the operation of either facility cannot impact the safety of the other.

The hydrogen product system shall be organized as three subsystems according to the three chemical reactions by which the hydrogen is produced.

The subsystems shall consist of the vessels, piping, pumps, compressors, flow reactors, packed columns, phase separators, liquid/vapor expanders, and energy recovery turbines as required to carry out the process as defined in the reference process flowsheet (Ref. {TBD}).

All system components shall be protected from environmental and natural phenomena hazards.

Operational Requirements

The purity of the product hydrogen gas shall be a minimum of {98%}

Chemicals used in the production of hydrogen shall be re-cycled to the maximum extent practical to minimize the quantity of chemical waste.

Corrosion allowances for all engineering materials used in chemical processing shall be {2.95} mil/year for tubing and valves, and {19.7} mil/year for vessels and columns.

The design shall include means to reject {TBD} MW(t) of waste heat.

Emissions from the hydrogen plant shall not exceed established EPA limits on the amount of sulfur dioxide and other hazardous pollutants that can be discharged to the local atmosphere. Requirements stated in the Clean Air Act/Air Programs (CAA), and in 40 CFR 5099 shall also apply to the design and operation of the plant. All applicable state and local environmental protective requirements shall also be recognized and incorporated during the design of the plant.

The hydrogen plant shall comply with OSHA requirements contained in 29 CFR 1910.119 to prevent or minimize the consequences that could occur during catastrophic releases of toxic, reactive, flammable, or explosive chemicals (e.g. hydrogen gas, liquid sulfur dioxide, sulfur trioxide, and sulfuric acid) in excess of threshold quantities.

4.22 HTE- based Hydrogen Production System (45)

System Functions

The function of the HTE-based hydrogen production system is to convert high temperature steam supplied to a series of solid oxide electrolyzer cell (SOEC) modules into gaseous hydrogen and oxygen. The high-temperature steam is generated using process heat supplied by the NGNP reactor. The electricity needed by the electrolyzer cells is generated by the NGNP PCS. The hydrogen is either transferred to an end user or sent to the hydrogen storage system.

The hydrogen production system rejects the waste heat from the HTE-process to an ultimate heat sink.

Equipment Configuration and Essential Features Requirements

The structure housing the HTE-based hydrogen production system shall be located adjacent to the reactor complex with a separation distance adequate to ensure that the operation of either facility cannot impact the safety of the other.

The hydrogen production system shall consist of a series of SOEC modules, vessels, piping, pumps, circulators, heat exchangers, and instrumentation & control equipment as required to carry out the process as defined in the reference process flowsheet (Ref. {TBD}).

The HTE-based hydrogen production facility shall have ten or more SOEC modules in order to confirm viability of commercial operation.

A small steam-turbine-driven electric generator that operates using waste heat from the hydrogen production process shall be used to supply a portion of the house power consumed in the hydrogen production process. Additional electric power to support the HTE process shall be supplied, as needed, from the NGNP PCS.

Water purification equipment shall be provided in the hydrogen production facility to ensure that the quality of the water and steam fluids used in the HTE process shall remain at very high levels of purity at all times.

All system components shall be protected from environmental and natural phenomena hazards.

Operational Requirements

The purity of the product hydrogen gas shall be a minimum of {98%}

The operational life time of the SOEC modules shall be ≥ {10 years}

The HTE-based hydrogen production system shall utilize process heat delivered by the Secondary HTS at 800°C - 900°C to operate sweep heaters and super-heaters that support the hydrogen production process. Process flow shall enter the steam generator to provide steam at approximately {TBD^{o}C} from which pure hydrogen and oxygen gaseous end products are produced through a high temperature electrolysis process. The Secondary HTS shall provide a flow rate of approximately {TBD kg/sec} to the high temperature portion of the hydrogen production system.

Water shall be supplied in amounts up to {TBD} m^3/day to support the hydrogen production process.

4.23 Hydrogen Storage System (46)

System Functions

The functions of the hydrogen storage system are to accept output product from the hydrogen production system, and to store the hydrogen in high pressure tanks for subsequent distribution to the various users on a time schedule consistent with consumption rates.

Equipment Configuration and Essential Features Requirements

The storage system shall consist of a number of high pressure vessels oriented in an efficient arrangement, and located within a facility that provides protection for the vessels. The storage facility shall be installed below grade to prevent damage to the system due to adverse weather conditions or possible seismic disturbances.

The hydrogen storage vessels shall be located at a safe distance from the other NGNP facilities.

Pumps, compressors, or other transfer equipment shall be included in the system as required to provide for relocation of the product to an end user or a transport vehicle.

Appropriate instruments and controls shall be provided by which the status of the stored hydrogen can be ascertained at all times.

4.24 Reactor Complex (51)

System Functions

The primary functions of the Reactor Buildings and Structures (Reactor Complex) are to house and provide physical support for all equipment items required by the Reactor System, Vessel System, Power Conversion System, and the associated support systems. The Reactor Complex provides for lifting, handling, and/or transport of equipment items, and permits the establishment of an appropriate environment for the equipment items located within the complex. Additionally, the Reactor Complex protects both its own capabilities and those of the contained equipment from various hazards, both internally and externally generated.

Other functions are to control the spread of contamination and the release of radionuclides due to either component leakage or the production of activation products. To minimize occupational radiation exposure, the reactor complex shall be arranged so that personnel access is controlled in areas where radiation levels are known to exist, while also providing the requisite access for routine plant operation, maintenance, and inspection.

Additional functions are to provide inspection, repair, and maintenance facilities, and other capabilities that may be required for the servicing of reactor equipment, and to provide for the enclosure of radioactive waste processing and handling equipment, including provisions for the storage of spent fuel.

System Configuration and Essential Features Requirements

The Reactor Complex shall be located within the Nuclear Island. Headroom, pull-space, lay-down areas, and work space for the maintenance of Reactor Complex components and equipment shall be provided.

The Reactor Complex shall provide for ingress, egress, and circulation of personnel and equipment, including space requirements to allow for the physical movement of equipment from a normally installed permanent location to outside shop facilities.

The Reactor Complex shall include a Reactor Building and a Reactor Services Building served by a single traveling bridge crane capable of handling the heaviest component required to be lifted for routine maintenance and inspection.

The Reactor Complex design, equipment layout, and design features such as cranes, hoists, and monorails shall be arranged to facilitate maintenance, removal, installation, and replacement of major equipment items.

The Reactor Building shall house the entire vessel system within a reinforced concrete structure. Space shall be arranged within the Reactor Building to house the reactor vessel, the power conversion vessel, and the intermediate heat exchanger vessel. Additional space shall be provided for future installation of a process heat exchanger vessel. All of the vessels shall be connected to the reactor vessel by cross vessels.

The Reactor Building shall confine and/or filter gaseous releases following a reactor vessel depressurization event. The Reactor Building design release rate shall be equal to or less than one building volume/day.

Railroad and truck access shall be provided to the Reactor Complex.

The Reactor Complex shall include a Personnel Service Building that provides controlled personnel access, radiological monitoring, and decontamination facilities for the Reactor Complex.

The Personnel Service Building shall include facilities and features to support radiological monitoring and control for all activities carried out within the Nuclear Island.

The Radioactive Waste Management Building shall be included within the Reactor Complex.

Provisions shall be made in the Radioactive Waste Management Building for remote handling of specific equipment items that are identified as being highly contaminated or activated.

A designated storage, packaging, and shipping facility area for low-level contaminated radiological wastes shall be provided within the Radioactive Waste Management Building. This area shall be capable of handling various amounts of dry and wet waste, that when processed for shipping offsite would constitute a total volume of no more than 3.6 m^3 (125 ft^3) per year.

The Reactor Services Building shall include a hot service facility having the capability to provide decontamination services for core service tools, reactor equipment service facility tools, primary circulators, shutdown circulators and heat exchangers, and neutron control assemblies, as well as other plant equipment that might require radiological decontamination.

A hot service facility shall be included in the Reactor Complex. The hot service facility shall have the capability to support inspection, maintenance, checkout, and repair of contaminated plant equipment items.

The hot service facility shall incorporate lifting and handling features for all major equipment items that are expected to require the services of this facility.

Controlled personnel access shall be provided to the working areas within the hot service facility.

Neutron control assembly storage wells shall be provided for up to {TBD} assemblies.

Storage wells shall be provided for a shutdown cooling circulator and its associated loop isolation valve.

The Reactor Building shall accommodate installation and operation of the RCCS.

The Reactor Building shall be designed to provide access to the reactor coolant pressure boundary as required to facilitate in-service inspection (ISI) stipulated by Section XI of the ASME Code.

The Reactor Complex shall include features that provide for the physical protection of the plant against acts of sabotage.

The Reactor Complex shall be designed for the receipt of new fuel, and for the shipping of spent fuel, by road, or by rail.

The Reactor Services Building shall be designed to receive, inspect, and store new fuel and reflector elements prior to refueling in a manner consistent with the fuel design and fuel cycle.

The Reactor Services Building shall be designed to accommodate spent fuel storage. Storage containers shall be readily accessible for placement of spent fuel during a refueling outage.

All radioactive wastes generated within the facility shall be monitored, treated, and processed onsite, prior to shipment offsite.

Operational Requirements

A helium environment shall be maintained at all times in the fuel storage wells and in the equipment storage wells.

Visual inspection of irradiated components such as fuel elements and control rods shall be performed in the hot service facility.

Environmental Requirements

The Reactor Complex shall be designed with features to assure the maintenance of environmental conditions in specified areas and compartments during normal and transient operations. Certain environmental conditions shall also be maintained in specified areas during accident conditions to assure that habitability requirements are met for operator occupancy and for equipment, component, and instrumentation operability and maintainability.

Safety Requirements

The design of the Reactor Building and the Reactor Services Building shall be responsive to the Top-Level Regulatory Requirements. To assure that these criteria are not exceeded, structural support, environmental conditioning, and hazard protection (for both internally and externally generated events) shall be provided for all of the contained "safety-related" structures, systems, and components that influence the control of heat generation, removal core heat, and control of chemical attack on the fuel.

The design of the Reactor Building shall incorporate features to accommodate vented, low pressure containment.

4.25 Helium Storage Structure (53)

System Functions

The primary functions of the Helium Storage Structure are to accommodate and arrange spatially the major helium transfer and storage components that comprise the Helium Services System. This includes structural support, as well as access to the equipment items for maintenance, lifting, handling, and/or transport. The structure also permits the establishment of an appropriate environment for the major components of the Helium Services System. Additionally, the Helium Storage Structure protects both its own capabilities and those of the components it houses from various internal and external hazards.

System Configuration and Essential Features Requirements

The Helium Storage Structure shall be located within the Nuclear Island adjacent to the Reactor Services Building. The distance should be minimized between the discharge of the Helium Purification Subsystem in the Reactor Building and the Helium Services System equipment located in the Helium Storage Structure. Truck access to the Helium Storage Structure shall be accommodated.

Maintenance Requirements

Headroom, pull-space, lay-down area, and work space for component and equipment maintenance shall be provided within the building structure.

4.26 Remote Shutdown Building (54)

System Functions

The primary functions of the Remote Shutdown Building are to protect the ability of the plant operators to control reactor operation through access to the Reactor Protection System interface panels, and to permit communication of plant conditions to offsite authorities. The structure provides for protection of the building, the contained equipment, and safe occupation by the plant operators.

System Configuration and Essential Features Requirements

The Remote Shutdown Building shall contain features that assure the physical protection of the plant against acts of sabotage.

4.27 Nuclear Island Warehouse (55)

System Functions

The functions of the Nuclear Island Warehouse are to provide storage space, structural support of equipment, and the lifting, handling, and/or transport of spare parts, materials, equipment, and components. The building also allows for isolation of the warehouse environment and access control.

System Configuration and Essential Features Requirements

The Nuclear Island Warehouse shall be located within the Nuclear Island.

The warehouse shall provide for segregated storage between the Nuclear Island safety and non-safety-related material, parts, equipment, and components. Appropriate space shall be allocated for storage of the required amounts of spare parts, supplies, and equipment.

4.28 Operations Center (61)

System Functions

The functions of the Operations Center are to provide plant ingress and egress routes, personnel circulation areas, security administration of the plant, and operations and engineering office space. The center also includes the plant Control Room, areas for the central and secondary alarm systems, training rooms, conference rooms, and lunch areas. The Operations Center serves to protect the health and safety of the inhabitants during design basis events.

System Configuration and Essential Features Requirements

The Operations Center shall be located within the Balance of Plant area.

The Operations Center shall be configured to incorporate the control, security, and administration of building functions within a single structure.

The control portion of the Operations Center shall house the plant Control Room, the computer and data processing room, plus associated offices and other facilities.

Those portions of the Operations Center that house the plant security functions shall include the primary and secondary alarm stations, the nuclear plant reception and information areas and access facilities, plus the arms room and office space for plant security personnel.

The Operations Center shall provide accommodation for plant administration personnel.

The Control Room shall incorporate features and equipment necessary to accomplish operations that facilitate plant and system startup, shutdown, monitoring, and control.

The Control Room shall include provisions for manual shutdown of major systems and components by the control room operator as required to limit investment risk and to assure protection of plant personnel.

The Operations Center shall contain facilities to effect shielding, sheltering, and evacuation of plant personnel in the event of an emergency.

The Operations Center shall include features for the physical protection of the plant against acts of sabotage.

4.29 Balance of Plant Complex (62)

System Functions

The functions of the Balance of Plant (BOP) Complex are to provide those plant systems and components that are not located within the Nuclear Island boundary, and to provide sheltered space, facilities, and features that support maintenance, inspection, and repair of the BOP equipment.

System Configuration and Essential Features Requirements

The BOP Complex shall be served by road and rail.

The BOP Complex, including its equipment layout and design features, such as cranes, hoists, and monorails, shall be designed to provide for and facilitate removal and replacement of major equipment items.

Headroom, pull-space, lay-down areas, and work space for component and equipment maintenance shall be provided.

Overhead cranes shall be designed to lift the heaviest piece of equipment or heaviest component part that would have to be handled for planned operations, maintenance, and inspection activities within the BOP Complex.

A Standby Power Building shall be included in the BOP Complex. The Standby Power Building shall be designed to house {TBD} standby power generators. Each generator shall be serviced by separate and independent sources.

The design of the Standby Power Building shall include features to assure that the building and its contents remain operational under all accident conditions.

A Maintenance Building shall be included in the BOP Complex. The Maintenance Building shall provide facilities for the following:

- Electrical repair shop
- Instrument repair shop
- Electronic shop
- Equipment handling facilities (cranes, dollies, etc.)
- Mechanical repair shop with tool racks, work benches, etc.
- Pipe shop
- Welding shop
- Sandblasting and paint shop
- Machine shop
- Personnel amenities--lockers, toilets, and lunch area

A Makeup Water and Auxiliary Boiler Building shall be included in the BOP Complex. The Makeup Water and Auxiliary Boiler Building shall accommodate an auxiliary heating boiler and related equipment and components, plus equipment associated with the Water Supply and Treatment System.

4.30 Circulating Water Pumphouse (63)

System Functions

The functions of the Circulating Water Pumphouse are to provide space and structural support for the Circulating Water System equipment, and for lifting, handling, and/or transportation of the equipment. The pumphouse also allows for access control, and provides for miscellaneous facilities associated with the Circulating Water System.

System Configuration and Essential Features Requirements

The pumphouse shall be located within the BOP area on the plant site.

The circulating and service water pumps shall take suction from their respective cooling tower basins.

4.31 Makeup Water Pumphouse and Discharge Structure (64)

System Functions

The functions of the Makeup Water Pumphouse and Discharge Structure are to provide space and structural support for Makeup Water System equipment, and for lifting, handling, and/or transportation of the equipment. The structure also permits access control, and provides for miscellaneous facilities associated with the Makeup Water System.

System Configuration and Essential Features Requirements

The Makeup Water Pumphouse and Discharge Structure shall be located adjacent to the plant natural water supply.

The water intake structure shall be configured to be partly below grade if required to utilize available onsite water sources.

4.32 Fire Protection System Pumping Station (65)

System Functions

The functions of the Fire Protection System Pumping Station are to provide space and structural support for the pumping system equipment, plus lifting, handling, and/or transportation of the equipment. This station also permits access control, and provides miscellaneous facilities that support the fire protection function.

System Configuration and Essential Features Requirements

The structure shall be located within the BOP area on the plant site.

4.33 Balance of Plant Warehouse (66)

System Functions

The functions of the BOP Warehouse are to provide space and structural support for the BOP spare parts, materials, equipment, and components, plus lifting, handling, and/or transportation of the warehouse items. This warehouse also provides for access control, including miscellaneous facilities that support the warehouse function.

System Configuration and Essential Features Requirements

The warehouse shall be located within the BOP area on the plant site.

The warehouse shall provide storage for raw materials, plant equipment, parts, and components as required for special and general non-safety-related maintenance purposes.

4.34 Balance of Plant Cooling Water System (71)

System Functions

The functions of the BOP Cooling Water System are to remove waste heat from systems and components within the BOP area and to convey that heat to the Circulating Water System.

System Configuration and Essential Features Requirements

The BOP Water System shall be a closed loop piping system employing the use of pumps and heat exchangers.

The BOP Cooling Water System shall transfer waste heat from BOP equipment items to the Circulating Water System.

System Operational Requirements

The design of the BOP Cooling Water System shall provide for continuous operation during all normal plant operations. The system is expected to remain in operation at all times. Partial outages for maintenance or surveillance shall be accommodated.

4.35 Circulating Water System (72)

System Functions

The function of the Circulating Water System is to remove waste heat from Nuclear Island cooling water heat exchanger(s), as well as from the BOP Cooling Water System. The Circulating Water System conveys the waste heat to a cooling tower where the heat is dissipated to the local atmosphere. The system also includes water chemistry and water inventory control functions.

System Configuration and Essential Features Requirements

The Circulating Water System shall collect and transport waste heat generated within the overall plant, including the Hydrogen Production System(s), for dissipation to the atmosphere via mechanical draft cooling tower(s).

The Circulating Water System shall be designed to remove waste

The Circulating Water System shall include mechanical draft cooling towers having adequate cooling capacity for all of the Nuclear Island and BOP equipment items that generate waste heat. The system shall provide a reserve cooling capacity for the addition of future equipment.

The Circulating Water System pumps shall be spared as required to accommodate on-line maintenance or replacement.

The Circulating Water System shall be designed on the basis that local natural water sources are inadequate to support once-through cooling.

A non-brackish water source shall be assumed to be available to support makeup requirements for the Circulating Water System.

The Circulating Water System shall be of an open-loop design.

The Circulating Water System cooling tower(s) shall be located within the BOP area on the plant site.

The cooling tower basin shall maintain an adequate inventory of circulating water to support routine operation of the system. This inventory shall drain toward the circulating water pump suction area as required to support normal operation of the circulating water pumps.

The hot circulating water discharged from the plant shall be released inside the cooling towers.

The cooling tower(s) shall be positioned on the plant site such that tower “drift” does not routinely pass over other buildings or structures, the switchyard, electrical transmission towers, or the hydrogen production facilities.

Operational Requirements

The maximum Circulating Water System design temperature at the discharge of the cooling tower(s) shall be {TBD}.

Overall system flow rate shall be established based on anticipated needs plus 30%.

4.36 Water Supply and Treatment System (73)

System Functions

The functions of the Water Supply and Treatment System are to provide water of proper chemical composition that can be used for makeup and flushing activities within various plant systems and processes, and to provide clarified and filtered water for domestic use.

System Configuration and Essential Features Requirements

A non-brackish makeup water source shall be used for the water supply.

The plant shall not rely on an offsite municipal water supply.

The Water Supply and Treatment System shall be capable of pre-treating raw water to produce water of the requisite quality for in-plant use, including the high-purity water required by the Hydrogen Production System(s).

The Water Supply and Treatment System shall use pre-treated process water for makeup to the demineralized water conditioning system, and shall maintain onsite a sufficient quantity of demineralized water for subsequent distribution to users.

4.37 Balance of Plant Hot Water Heating System (74)

System Functions

The function of the Balance of Plant Hot Water Heating System is to supply hot water to unit heaters and air-handling unit heater coils throughout the Balance of Plant area.

System Configuration and Essential Features Requirements

The Balance of Plant Hot Water Heating System shall provide for the maintenance of ambient environments at or above the minimum design temperature requirements specified for the various buildings and structures within the Balance of Plant areas.

Operational Requirements

The system shall have sufficient capacity to supply all of the Balance of Plant heating requirements for the conditions of ambient air temperature established for the facility.

4.38 Balance of Plant Chilled Water System (75)

System Functions

The function of the BOP Chilled Water System is to supply chilled water to unit coolers and air-handling unit cooling coils throughout the BOP areas.

System Configuration and Essential Features Requirements

The BOP Chilled Water System shall provide the required supply of chilled water to all users, at a temperature of approximately 7^{o}C.

4.39 Plant Fire Protection System (76)

System Functions

The functions of the Plant Fire Protection System are to prevent the initiation of fire, and to rapidly detect and annunciate the presence and location of combustion by-products, or the actual presence of fire, anywhere within the plant. The system also controls and extinguishes any fire that occurs, thereby providing protection for structures, systems, and components such that the required performance of safety functions is not compromised.

System Configuration and Essential Features Requirements

The Fire Protection System shall be designed in accordance with applicable sections of the NFPA code.

The plant shall not rely on offsite fire protection capability.

The water supply for the Plant Fire Protection System shall incorporate a high-pressure system capable of providing the overall plant with fire extinguishing services, including automatic sprinkler systems in hazardous areas and other areas where prompt response is required. Suitable hose stations and hydrants shall be located strategically throughout all of the plant buildings as well as at specific locations around the plant site.

The water supply for the fire protection system shall contain independent and redundant backup water supply storage tanks, pumps, valves, and piping.

Redundant fire pumps shall be equipped with diverse power drives, (e.g., electric, diesel, gas turbine, etc.).

The Plant Fire Protection System shall be designed to flood spaces occupied by equipment with carbon dioxide or another appropriate fire suppression gas as required to protect the equipment against fire.

The Plant Fire Protection System shall be capable of detecting the presence of fire through the use of various detection sensors located throughout the plant.

Signals from the fire sensors shall be routed to a central processing unit for analysis and alarm signal output.

Storage facilities for flammable liquids shall comply with NFPA 30, "Flammable and Combustible Liquids Code."

The Plant Fire Protection System shall establish specific fire areas that provide for separate, redundant safety divisions. These areas shall serve to isolate safety-related systems from fire hazards associated with non-safety-related areas, thus limiting the spread of fire between components that constitute major fire hazards within a safety division.

Operational Requirements

The Plant Fire Protection System shall remain in-service at all times.

Fire alarms shall be visual, audible, and unique.

Any failure within the system shall be alarmed.

The design of the Plant Fire Protection System shall ensure that a fire, anywhere within the facility, will not compromise the performance of essential safety functions.

4.40 Nuclear Island Heating, Ventilating, and Air Conditioning (HVAC) System (81)

System Functions

The primary functions of the Nuclear Island HVAC System are to establish and maintain acceptable building environments during normal and off-normal plant operations, to assure that environmental requirements are met for personnel occupancy, and to assure proper operation and maintenance of equipment, components, and instrumentation. The system provides protection for personnel due to releases of toxic gases, smoke, fumes, and dust, while also providing a path for controlled disposal of radioactive waste gases and particulates to the outside environment.

System Configuration and Essential Features Requirements

The system shall maintain environmental conditions (air quality, pressure, temperature, and humidity) in buildings and structures located within the Nuclear Island. The system shall maintain acceptable ranges for these conditions as required for component operability and personnel habitability during both normal and off-normal modes of plant operation.

The Nuclear Island HVAC system shall ensure habitability within areas of the facility that house equipment and controls essential to maintaining the safety response of the plant. The system shall control the temperature and humidity of the air in these spaces by removing noxious materials, particularly airborne dust, as well as radioactive smoke and gases.

The system shall assure that the Reactor Building and Reactor Service Building are maintained at a slightly negative pressure relative to the local outside atmosphere, and that all of the air leaving these buildings has been monitored and filtered before being released to the environment.

4.41 Balance of Plant HVAC System (82)

System Functions

The functions of the BOP HVAC System are to establish and maintain required building environments within the BOP area during both normal and off-normal plant operation, and to assure that environmental requirements are met for operator occupancy, equipment, component, and instrumentation operability, and for maintenance. The system also protects personnel from toxic gases, smoke, fumes, and dust.

System Configuration and Essential Features Requirements

The BOP HVAC System shall maintain environmental conditions (air quality, pressure, temperature, and humidity) in buildings and structures located within the Balance of Plant areas of the facility. The system shall maintain acceptable ranges for these conditions as required for component operability and personnel habitability during both normal and off-normal modes of plant operation. Special consideration shall be given to the necessity for removing and controlling chemical fumes, dust, smoke, particulates, and noxious gases.

4.42 Instrument and Service Air System (83)

System Functions

The function of the Instrument and Service Air System is to provide compressed air of suitable quality, quantity, and pressure for all instrumentation, controls, and services required by the plant.

System Configuration and Essential Features Requirements

The Instrument and Service Air System shall be operable from normal sources of plant electric power as well as from the station standby power generator(s).

Sufficient volumes of compressed air shall be maintained at all times.

The instrument air supply shall be dried and filtered to prevent the introduction of adverse moisture and particulates into the facility instruments, or create operational problems for other users of instrument air.

4.43 Waste Water System (84)

System Functions

The primary functions of the Waste Water System are to collect non-radioactive floor and equipment drain runoff, and to treat the accumulated waste water prior to offsite discharge. The system also processes regenerant waste water from the Water Supply and Treatment System prior to offsite discharge.

System Configuration and Essential Features Requirements

The plant shall not rely on offsite municipal waste water treatment. Non-radioactive plant wastes shall be processed, treated, and monitored onsite prior to disposal offsite.

4.44 Yard Drainage System (85)

System Functions

The functions of the Yard Drainage System are to collect storm water from yard surface drains and roof drains, and to deliver the accumulated water to a point of disposal.

System Configuration and Essential Features Requirements

The plant shall not rely on offsite municipal services to accommodate storm water runoff.

The use of site grading, plus the functions of the Yard Drainage System shall provide for handling of the maximum rainfall amounts expected for the site, without onsite flooding.

4.45 Sanitary Drainage and Treatment System (86)

System Functions

The function of the Sanitary Drainage and Treatment System are to collect all plant sanitary waste streams for processing prior to offsite discharge.

System Configuration and Essential Features Requirements

The plant shall not rely on the services of offsite municipal sewage treatment systems.

All non-radioactive wastes shall be monitored, treated, and processed onsite, prior to disposal offsite.

All non-radioactive sanitary wastes shall be processed, treated, and monitored onsite prior to disposal offsite.

4.46 Essential AC Electrical System (91)

System Functions

The function of the Essential AC Electrical System is to provide reliable and regulated electric power to reactor control and instrumentation loads that accomplish and maintain safe shutdown of the reactor.

System Configuration and Essential Features Requirements

The Essential AC Electrical System shall be designed with {TBD} independent and redundant channels.

The nominal voltage for the system shall be 120 VAC, single-phase, 60 Hz, two-wire, ungrounded.

The Essential AC Electrical System voltage and frequency variations shall be limited to 120 volts ± 2%, and 60 Hz ± 0.03 Hz, at the essential 120 VAC vital buses, for all modes of operation.

The maximum interruption time to allow for switching within the Essential AC Electrical System shall be one quarter of a cycle (4.2 msec).

The loss of normal input AC power to the Essential AC Electrical System shall not result in any degradation of the system for a minimum of {TBD} hours.

Safety Requirements

The Essential AC Electrical System shall be designed to provide defense-in-depth against the top-level radionuclide control regulatory requirements (PLT 3.1.9) being exceeded, by providing essential electric power to all structures, systems, and components that control heat generation and chemical attack of the reactor core.

4.47 Plant AC Electrical System (92)

System Functions

The functions of the Plant AC Electrical System are to deliver electric power generated by the plant to the offsite transmission network, and to draw power from the offsite transmission network as needed to support various plant operations. These operations include plant startup, the supply of backup power to select auxiliaries when both the plant power units and offsite power supplies are unavailable, and to provide regulated electric power to the plant 120 VAC control and instrumentation loads. The system also provides electric power to all plant auxiliary AC loads as necessary for startup, normal operation, and normal shutdown. The system also provides power for illumination throughout the plant, and to the various power receptacles for portable equipment.

System Configuration and Essential Features Requirements

The output of the Plant AC Electrical System shall be delivered to the operating utility at the low voltage bushings of main power transformers.

The system shall be designed to provide for receiving offsite generated electric power through the plant switchyard to support operation of the plant.

Physical separation shall be arranged between individual circuits that perform critical services such that no single event can result in the simultaneous loss of all of these circuits.

The switchgear buses shall be fed from the associated unit auxiliary transformers during normal plant operation, and from separate startup auxiliary transformers connected to the utility grid during plant startup and shutdown. {TBD} onsite backup generators shall be available to supply standby power to the investment protection loads.

Auxiliary power shall be delivered to the plant at the high voltage bushings of the plant startup auxiliary transformers.

Operational Requirements

Each circuit from the offsite grid shall have the capacity and capability to supply the connected plant loads during both normal and abnormal operating conditions, and during a plant shutdown.

The Plant AC Electrical System shall be available during all plant operating conditions, including fire situations, accidents, and the loss of offsite electric power.

The plant AC Electrical System shall be designed to accommodate unit and backup generator voltage and frequency variations of ±10% VAC, and ±5% Hz on a continuous basis during normal plant operation. Combined voltage and frequency variations shall not exceed ±10% provided the frequency remains within ±5%. During abnormal operation, voltage variation shall not decrease more than 20% for more than 60 seconds, and frequency variations of +3 Hz to -5 Hz shall not occur for more than 5 minutes. Utility grid variations of voltage and frequency shall not exceed +5% to -2% VAC and ±0.3% Hz, respectively.

The Plant AC Electrical System voltage at the load terminals shall not fall below 90% of nominal load voltage at full load, and shall not exceed 10% of nominal load voltage at no-load. The system voltage shall not fall below 80% of nominal load voltage during the time interval required for motor loads to reach rated speed.

Electric power generated by the plant at 13.8 kV shall be stepped up to {230} kV through the main power transformers for transmission to the grid.

The AC electric power system within the plant shall be designed to distribute power to plant auxiliary AC loads at 13.8 kV, 4.16 kV, 480V, and 120/240 V.

4.48 Grounding, Lightning, Heat Tracing, and Cathodic Protection System (93)

System Functions

The functions of the Grounding, Lightning, Heat Tracing, and Cathodic Protection System are to protect personnel and equipment from system faults and lightning strikes, and to minimize electrical noise in signal cables. The system also provides for the maintenance of minimum fluid temperatures in pipes and vessels, and reduces corrosion to various underground and underwater metallic structures and equipment.

System Configuration and Essential Features Requirements of the Grounding Function

The plant grounding system shall be designed to accommodate three separate grounding paths: (1) equipment (earth) grounding, (2) system grounding, and (3) signal (control-common) grounding.

Equipment grounding shall be designed to provide low impedance paths for system faults.

Neutral point grounds shall be designed to limit electrical system over-voltages to acceptable levels.

Signal grounding shall be designed to minimize the effects of electrical noise in signal cables.

System Configuration and Electrical Features Requirements of the Lightning Protection Function

The lightning protection system shall provide a metallic low impedance path between buildings and structures and the earth to accommodate direct lightning strikes.

System Configuration and Essential Features Requirements of the Heat Tracing Function

Heat tracing, in conjunction with insulation, shall provide for the maintenance of required minimum temperatures in pipes, vessels, and other equipment as necessary.

System Configuration and Essential Features Requirements of the Cathodic Protection Function

Cathodic protection shall be provided to reduce the potential for corrosion in underground and underwater metallic structures and equipment.

4.49 Plant DC Electrical System (94)

System Functions

The function of the Plant DC Electrical System is to provide a source of DC power for operating the plant auxiliary DC loads.

System Configuration and Essential Features Requirements

The Plant DC Electrical System shall be designed with {TBD} independent busses to supply plant DC loads.

The capacity of each Plant DC Electrical System bus shall be adequate to supply the DC loads of required by the entire facility.

The nominal voltage for the Plant DC Electrical System shall be 125 VDC, ungrounded, two-wire.

Operational Requirements

The voltage at the Plant DC Electrical System busses shall be maintained between 103 VDC and 142 VDC. The DC loads assigned to these busses shall operate between 90 V DC and 140 V DC.

Upon loss of normal input AC power to the Plant DC Electrical System, the system shall remain fully operable, without degradation, for at least three hours.

4.50 Essential DC Electrical System (95)

System Functions

The function of the Essential DC Electrical System is to provide reliable DC control and instrument power to various reactor system "safety-related" DC loads.

System Configuration and Essential Features Requirements

The Essential DC Electrical System shall be designed with {TBD} independent and redundant channels.

The Essential DC Electrical System shall supply continuous DC power to the main DC distribution switchboards that feed the reactor “safety-related” control and instrumentation DC loads.

The nominal voltage for the system shall be 125 VDC, ungrounded, two-wire.

Operational Requirements

The voltage at the Essential DC Electrical System busses shall be maintained between 103 VDC and 142 VDC. The essential DC loads assigned to these busses shall be capable of operating with supply voltages between 90 VDC and 140 VDC.

Upon loss of normal input AC power to the Essential DC Electrical System, the system shall remain fully operable, without degradation, for at least three hours.

Safety Requirements

The Essential DC Electrical System shall assure that the Top-Level Regulatory Requirements are met by providing electric power to all "safety-related" structures, systems, and components that control reactor heat generation and that control chemical attack of the reactor core.

4.51 Communication System (96)

System Functions

The functions of the Communication System are to provide intra-plant and plant-to-offsite communications during both normal and emergency conditions.

System Configuration and Essential Features Requirements

The intra-plant communication facilities shall be designed with separate, independent, and diverse types of communication systems.

The plant-to-offsite site communication facilities shall be designed with separate, independent, and diverse types of communication systems.

Operational Requirements

Failure of one type of communication system shall not impair the operational reliability of the other types of communication systems.

The communication system shall provide the means for notification of emergencies to other plant personnel, regulatory authorities, and to the general public.

4.52 Plant Security System (97)

System Functions

The primary function of the Plant Security System is to provide for the physical protection of the overall plant. Through the use of sensory, video, and alarm equipment, the Plant Security System provides for the detection and assessment of unauthorized entry within the plant boundaries, as well as tampering within the plant protected areas.

System Configuration and Essential Features Requirements

The design of the Plant Security System for the Nuclear Island shall provide physical protection of the plant against acts of industrial sabotage, including determined violent external assaults as well as internal threats.

Plant security for the Balance of Plant areas of the facility shall be designed to provide protection from casual intruders.

Operational Requirements

The design of the Plant Security System shall include security monitoring, perimeter interior intrusion detection, and closed-circuit television.

4.53 Plant Uninterruptible Power Supply (98)

System Functions

The function of the Plant Uninterruptible Power Supply is to provide a fully reliable source of backup electric power to critical users that are normally supplied power from the Essential AC Electrical System.

System Configuration and Essential Features Requirements

The Plant Uninterruptible Power Supply shall contain separate buses to supply regulated power to all plant control and instrument AC loads that must function at all times to maintain and protect the functions of critical operating systems.

The nominal voltage for the Plant Uninterruptible Power Supply shall be 120 V AC, single phase, 60 Hz, two-wire ungrounded.

Upon loss of the normal input AC power to the uninterruptible power supply buses, a series of storage batteries shall instantaneously provide power to the uninterruptible buses through an inverter system. During all normal operation of the plant Essential AC Electrical System, the storage batteries shall be in a charging status through a standard charging system powered by the Essential AC Electrical System.

The capacity of each uninterruptible bus shall be adequate to supply continuous power to the critical control and instrument AC loads assigned to that bus.

Voltage and frequency variations in the Plant Uninterruptible Power Supply shall be 120 ± 2% VAC, and 60 ± 0.03 Hz at the 120 VAC output buses, for all modes of operation.

The maximum system interruption time within the Plant Uninterruptible Power Supply to allow for switching shall be one quarter of a cycle.

Upon loss of normal AC input power to the Plant Uninterruptible Power Supply, the system shall remain fully operable, without degradation, for at least {3} hours.

4.54 Standby Power System (99)

System Functions

The function of the Standby Power System is to provide a readily available source of electric power for certain plant loads in the event that all outside power sources to the facility have been lost.

System Configuration and Essential Features Requirements

Standby power shall be provided by {TBD} backup generators, plus their auxiliary support systems. These generators shall supply limited backup power in the event that neither the plant electricity generator nor offsite power is available.

The backup generators shall provide power to the plant investment protection loads connected to the Plant AC Electrical System. The operating voltage of the generator shall be {TBD} kV.

The backup generators shall startup, reach synchronous speed, and assume load within {TBD} seconds following receipt of a start signal.

Each backup generator shall be capable of accepting the largest anticipated load without experiencing a voltage reduction in excess of {TBD} % for {TBD} seconds.

4.55 Lighting and Service Power Supply System (100)

System Functions

The function of the Lighting and Service Power Supply System is to provide electric power to all of the normal plant lighting circuits, to all of the emergency lighting equipment circuits, and to all of the service outlets located throughout the facility.

System Configuration and Essential Features Requirements

The design of the lighting portion of the Lighting and Service Power Supply System shall include provisions for normal AC lighting, emergency AC lighting, and emergency AC/DC lighting.

The service power portion of the Lighting and Service Power Supply System shall include service to all of the power service outlets in all plant areas. Such power service outlets shall support all routine operations and maintenance tasks, as well as those tasks assigned to fulfill specific requirements.

Emergency lighting circuits shall not be installed in the same raceways as those circuits assigned to normal lighting circuits.

Lighting fixtures and service power outlets in a building or area shall be fed from at least two separate power sources.

Both normal AC lighting and emergency AC lighting shall be fed from house loads. Emergency AC and DC lighting shall also be fed from house loads, and shall also be provided with self-contained power supplies.

Normal AC lighting shall be used throughout the plant in all areas required for normal plant operation, control, and maintenance of equipment, plus areas that support personnel ingress, egress, and circulation routes.

In cases where the normal plant AC power supply is lost, emergency AC-powered lights shall be energized automatically to provide standby illumination to general plant areas, the main control room, and all other areas of ingress, egress, and circulation, and to all exit signs.

Emergency AC and DC lighting shall be used to provide emergency and standby lighting in all areas required to support the operation of safe shutdown equipment and controls, fire fighting equipment, and to illuminate ingress/egress routes.

The service power portion of the Lighting and Service Power Supply System shall be supplied from house loads.

Exterior lighting shall be provided with automatic switching between normal and emergency power.

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