INL/EXT-11-23797

NGNP: High Temperature Gas-Cooled Reactor Key Definitions, Plant Capabilities, and Assumptions

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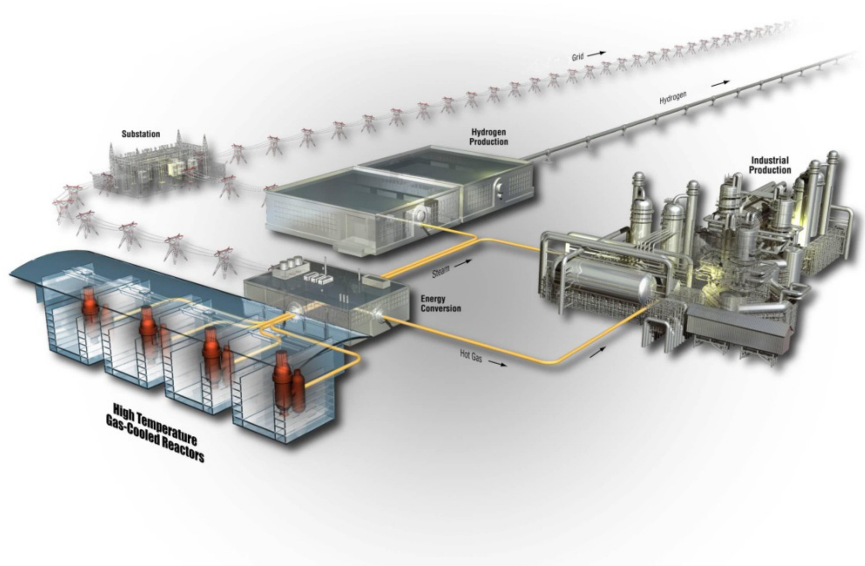

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Next Generation Nuclear Plant Project

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ABSTRACT

This document provides key definitions, plant capabilities, and inputs and assumptions related to the Next Generation Nuclear Plant to be used in ongoing efforts related to the licensing and deployment of a high temperature gas-cooled reactor. These definitions, capabilities, and assumptions were extracted from a number of NGNP Project sources such as licensing related white papers and previously issued requirement documents.

CONTENTS

ACRONYMS

AOO	Anticipated Operational Occurrences
BDBE	Beyond Design Basis Event
DBA	Design Basis Accident
DBE	Design Basis Event
EAB	exclusion area boundary
EPA	Environmental Protection Agency
F-C	Frequency-Consequence
FOAK	first-of-a-kind
HTGR	high temperature gas-cooled reactor
LBE	Licensing Basis Event
NHSS	nuclear heat supply system
NOAK	Nth-of-a-kind
NRC	Nuclear Regulatory Commission
NGNP	Next Generation Nuclear Plant
PAG	protective action guides
PRA	probabilistic risk assessment
SSC	structures, systems, and components
TLRC	Top Level Regulatory Criteria
TRISO	tristructural-isotropic

NGNP: High Temperature Gas-Cooled Reactor Key Definitions, Plant Capabilities, and Assumptions

1. INTRODUCTION

This document provides a Next Generation Nuclear Plant (NGNP) tool in which to collect and identify key definitions, plant capabilities, and inputs and assumptions to be used in ongoing efforts related to the licensing and deployment of a high temperature gas-cooled reactor (HTGR). These definitions, capabilities, and assumptions are extracted from a number of sources, including NGNP Project documents such as licensing related white papers [References 1–11] and previously issued requirement documents [References 13–15]. Additions or changes to this document will be as agreed upon by the NGNP Regulatory Affairs group's Licensing Working Group and Configuration Council.

The information herein apply to an HTGR-based nuclear heat supply system (NHSS) comprised of either a prismatic or pebble bed reactor concept, a graphite core, helium primary coolant, and necessary support systems and heat transport system interfaces with an energy conversion system and energy transfer systems. The energy demand can include the regional electric grid, which is supplied electricity; an industrial process requiring electricity and heat via steam or other high temperature fluid; a hydrogen production facility; special applications such as recovery of hydrocarbons from oil sands and oil shale; or some combination of these.

This document places an initial set of information related to key definitions, plant capabilities, and inputs and assumptions under configuration management. The body of information will be updated and expanded on as licensing and design efforts mature via controlled revisions to this document.

2. DEFINITIONS

This section is meant to capture useful definitions that specifically apply to discussions related to the licensing and deployment of an HTGR that are not necessarily found in other common source material such as the Nuclear Regulatory Commission (NRC) glossary, sets of definitions provided in national codes and standards, or NRC policy statements. This is not an attempt to duplicate all definitions already found in those source materials. The definitions related to modular plant configurations are consistent with those used by the NGNP Project in documentation related to commercial deployment of an HTGR.

These definitions may be revised and-or added to as additional definitions are developed.

Anticipated Operational Occurrence (AOO) – Licensing Basis Events (LBEs) that are those conditions of plant operation expected to occur one or more times during the life of the plant. Event sequences from the Probabilistic Risk Assessment (PRA) are classified as AOOs when their expected frequencies of occurrence are greater than 1×10^{-2} per plant-year. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

barrier – A feature that provides resistance to the transport and release of one or more fission product radionuclide species. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

Beyond Design Basis Event (BDBE) **–** LBEs that are not expected to occur during the lifetime of a large fleet of nuclear power plants, but are considered to assure that the risk to the public from low frequency events is acceptable. As used within this definition, event sequences from the PRA are classified as BDBEs when their expected frequency of occurrence is between 5×10^{-7} (5E-07) and 1×10^{-4} (1E-04) per plant year. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

Design Basis Accident (DBA) **–** LBEs that are postulated accidents for which a nuclear facility must be designed and built to withstand without loss to the structures, systems, and components (SSCs) necessary to ensure public health and safety. HTGR DBAs are analyzed in Chapter 15 of the Safety Analysis Report. DBAs are analyzed by assuming that only SSCs classified as safety-related are available to mitigate the consequences of the accident. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

design basis event (DBE) **–** DBEs are LBEs that are not expected to occur during the lifetime of a single nuclear power plant, but they may be encountered during the lifetime of a population of nuclear power plants of similar design. Event sequences from the PRA are classified as DBEs when their expected frequencies of occurrence are less than 1×10^{-2} per plant-year and greater than 1×10^{-4} per plant-year. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

designer **–** The entity that performs the design of the HTGR energy supply and supports the licensing activities by the operator. (Source: INL/EXT-10-19887, Section 4)

end user – The entity whose facility is being supplied the required energy in the forms specified and on whose property the HTGR energy supply is located. (Source: INL/EXT-10-19887, Section 4)

failed fuel particle – The degradation of fuel particle coating which occurs to the point that there is a pathway from the kernel to the outer surface of the particle. (Failed fuel particles still provide a significant radionuclide retention capability). (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

first-of-a-kind (FOAK) – FOAK may refer to either a module or a plant. The FOAK module will provide the basis for licensing of a particular HTGR-NHSS unit design. The FOAK plant may not have all modules constructed simultaneously and thus may contain modules that are either identical or that have some progression of component or configuration development. (Source: Generic usage, formally established herein)

functional containment – The multiple barriers to fission product release and radionuclide transport that limit the release of radionuclides to the environment. This functional containment is comprised of the kernel and coatings of the tristructural-isotropic (TRISO) coated fuel particles, fuel matrix and fuel element graphite, helium pressure boundary, and reactor building. Each of these barriers contributes to limiting the release of radionuclides to the environment to meet the NGNP Project Top Level Regulatory Criteria (TLRC). The contribution of each of the barriers in limiting the transport and release of radionuclides to the environment is calculated for each postulated event, depending on the response of the module to the event. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

functionally degraded fuel particle – Functional degradation of coated fuel particles refers to those circumstances under which fuel particle coating degradation occurs to the point that the radionuclide retention capabilities of the particle are reduced relative to an intact TRISO fuel particle. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

intact fuel particle – Fuel particles whose TRISO coatings remain structurally intact. It is recognized that the diffusion/release of some metallic fission products occurs from intact fuel particles (e.g., at rates associated with the fuel's time at temperature). (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

licensing basis events (LBEs) – The events derived from the HTGR technology and plant design that are considered by the licensing process and are used in the development of the license application. LBEs include AOOs, DBEs, DBAs, and BDBEs. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

mechanistic source terms – The event-specific mechanistic approach taken in developing radiological source terms for LBEs includes the quantities, timing, physical and chemical forms, and thermal energy of radionuclides released from the reactor building to the environment. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

module – An individual HTGR-NHSS unit. If the configuration includes a dedicated Energy Conversion System, the module may consist of the HTGR-NHSS and Energy Conversion System. (Source: Generic usage, formally established herein)

Nth-of-a-Kind (NOAK) – NOAK refers to a mature and standardized configuration of a module or a plant. The NOAK module or plant is one where the design, licensing process, and capital costs are well established. (Source: Generic usage, formally established herein)

nuclear heat supply system (NHSS) – The NHSS includes the nuclear island (e.g., the reactor, primary coolant system, and supporting systems) and the heat transfer/transport system of each HTGR module. (Source: INL/EXT-10-19887, Section 1)

operator – The entity that is licensed to operate the HTGR energy supply. (Source: INL/EXT-10-19887, Section 4)

owner controlled area – The area surrounding and including the modular HTGR plant governed by the operator's normal operating procedures. This area will likely defined by a fence at the site's boundaries that is controlled by the plant's security forces. (Source: Generic usage, formally established herein)

passive cooling path – The cooling path designed and relied on in the safety analysis for achieving a *safe stable state* condition is the reactor cavity cooling system rejecting heat to the ultimate heat sink. The ultimate heat sink is nominally the atmosphere surrounding the HTGR module. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

plant – The overall configuration of one or more HTGR-NHSS modules with associated energy conversion and balance-of-plant systems. (Source: Generic usage, formally established herein)

safe stable state – A plant state, following an initiating event, in which plant conditions are maintained at or near established values and within the success criteria for maintenance of safety and design bases. (Safe stable states correspond with successful plant response end states in the PRA modeling of event sequences.) (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

special treatment – Special treatment requirements help ensure that the frequencies and consequences of the LBEs fall within the TLRC as well as reduce the uncertainties about SSC reliability and performance in the context of the safety functions they perform in preventing and mitigating LBEs. The purpose of special treatment is to increase the level of assurance that the SSCs will perform as predicted under expected LBE conditions with the assessed uncertainties. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

3. PLANT CAPABILITIES

The plant capabilities described in this section provide an initial set of high-level design inputs associated with an HTGR concept and configuration such that the HTGR-NHSS is based on either a prismatic or pebble bed reactor concept using helium as the primary heat transport medium, TRISO coated particle fuel, a graphite core and metallic reactor pressure vessel with dimensions and operating plant conditions which support a safety basis that does not primarily rely on active safety-related systems to maintain the reactor fuel within limits under normal, abnormal, and accident conditions. The HTGR-NHSS primary helium circuit shall be physically separated from steam or high temperature gas supplied to the process by a primary heat exchanger consisting of either an intermediate heat exchanger or steam generator.

The initial set of high-level design inputs for the HTGR plant concept shall:

1. Achieve NRC siting criteria and Environmental Protection Agency (EPA) Protective Action Guides (PAGs) that will protect the health and safety of the public and the environment such that under no postulated accident condition would public evacuation or sheltering be required. To achieve this objective, the NGNP must meet the:

   - NRC siting criteria for both the plant exclusion area boundary (EAB) and low population zone (10 CFR 52.47/50.34) at a nominal distance of 400 m from the reactor centerline.
   - Early phase EPA plume exposure PAGs at the plant EAB.

   This objective will also protect the food and water supplies from being unacceptably impacted by radionuclide contamination by either meeting the intermediate phase EPA ingestion pathway PAGs at the plant EAB, or by assuring, through the specific siting analyses and related administrative controls, that no food or water supplies exist in the area immediately surrounding the EAB. (Source: Generic NGNP Project Objectives. See (1) NGNP Regulatory Affairs Configuration Council, July 26, 2011, (2) INL-EXT-11-22708, Section 3, (3) INL/EXT-11-24034, Section 1)

2. Limit event contamination levels of co-located facilities associated with postulated events such that industrial facilities can be returned to operation with efforts acceptable to the licensee and the industrial plant(s) owners. This will be addressed (in part) through use of a frequency/consequence curve for investment protection. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)

3. Interface with energy conversion systems such that the HTGR-NHSS design is capable of interfacing with multiple potential energy conversion configurations such as:
   - Electricity supplied to the regional grid and/or to support process operations
   - Steam to supply steam turbine generators or for general use throughout the facility
   - Process heat in the form of high temperature fluid to offset the emissions of greenhouse gases, (e.g., attendant to the burning of natural gas and waste gases in industrial processes)

   Not all applications will require the supply of all of these forms of energy, but the fundamental plant design shall be capable of providing any mix of these forms as required by each specific application. (Source: INL/EXT-10-19887, Section 3.3)

4. Support multiple module configurations. The HTGR-NHSS shall be designed as a standalone module that is capable of being combined with other modules in a multiple module configuration with varying module configurations to meet energy demand requirements that exceed the rating of an individual module. (Source: INL/EXT-10-19887, Section 3.4)
5. Limit normal maintenance exposure to no more than 50 person-REM/year per module. (Source: INL/EXT-10-19887, Section 3.7)
6. Achieve performance capabilities for normal and emergency demand transients such that when operating at power, the HTGR Plant is capable of responding to the following process transients without interruption or degradation of supply:
   - Steam Headers
     - Step Change: ±10%
     - Maximum rate of change: 20% / min decreasing
     - Maximum rate of change: 20% / min increasing
   - Electric Power
     - Step Change: ±10%
     - Maximum rate of change: 10 MWe/min decreasing
     - Maximum rate of change: 10 MWe/min increasing
   - High Temperature Fluid
     - Step Change: ±10%
     - Maximum rate of change: 20% / min decreasing
     - Maximum rate of change: 20% / min increasing
   - The Plant shall be capable of accepting a full load rejection from either steam, electrical or high temperature gas demand. (Source: INL/EXT-10-19887, Section 4.7)
7. Achieve availability requirements supporting commercial process heat usage. (Source: INL/EXT-10-19887, Section 4.8)
8. Accomplish passive residual heat removal to the environment in a way that maintains fuel temperatures and core and plant structures, including concrete, within acceptable limits when neither the primary helium circulator nor the shutdown cooling system is available under normal, abnormal, and accident conditions (the nuclear system safety basis shall not depend on active cooling systems during AOOs and postulated accident conditions). (Source: INL/EXT-10-19887, Section 5.5)
9. Provide reactor outlet temperatures capable of supporting process heat usage. The HTGR-NHSS reactor gas outlet temperature shall be in the range of 750 to 950°C. The HTGR-NHSS shall be designed for operation at the highest temperature achievable for the reactor core design (pebble bed, the prismatic cores) and to satisfy required safety margins. (Source: INL/EXT-10-19887, Section 6.1)

4. MAJOR ASSUMPTIONS

The major assumptions regarding meeting the plant capabilities discussed in Section 3 are as follows:

1. *Exclusion Area Boundary*. For design purposes, the EAB is established as approximately 400 meters from the reactor centerline. (Source: INL/EXT-10-19887, Section 3.6) (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)
2. *Event Response*. The use of all available systems and associated operator actions can be assumed when evaluating the HTGR response to events other than DBAs, to satisfy the TLRC and/or EPA PAG limits. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)
3. *Uncertainty*. Uncertainty, when used in event evaluations, is applied as follows:
   a. All AOOs, DBEs, and BDBEs have an uncertainty distribution on both their frequency and consequence evaluations.
   b. On the TLRC Frequency Consequence (F-C) chart, the lower bound (5%), mean, and upper bound (95%) uncertainty distributions of each AOO, DBE, and BDBE are displayed.
   c. The mean value of the AOO consequences is compared to the dose limit shown in the F-C chart based on 10 CFR 20 at the EAB
   d. The 95% upper bound of DBE consequences is compared to the dose limit shown in the F-C chart based on 10 CFR 50.34 at the EAB
   e. The 95% upper bound of the deterministic DBA consequences is compared to the 10 CFR 50.34 limit at the EAB
   f. The mean value of the DBEs and BDBEs is compared to the PAG limit shown in the F-C chart at the EAB
   g. The cumulative mean value of all AOOs, DBEs, and BDBEs is compared to the Qualitative Health Objective risk limits at the specified distances. (Source: NGNP Regulatory Affairs Configuration Council, July 26, 2011)
4. *Dispersion Factors*. The atmospheric dispersion factors provided in Reference 16 shall be used when performing dose estimating analyses at the site boundary and beyond. (Source: INL/EXT-11-24034)
5. *HTGR-NHSS Lifetime*. The HTGR-NHSS shall have a plant design lifetime of 60 years (calendar). This corresponds to 500,000 hours of operation for construction code compliance. (Source: INL/EXT-10-19887, Section 5.1)
6. *Construction Rules for Nuclear Facility Components*. The HTGR-NHSS shall be designed to the construction rules of Reference 17. (Source: Generic assumption formally established herein)
7. *Reference Nuclear Fuel*. The HTGR reference fuel shall be TRISO coated particle fuel, LEU-based (UCO or UO_2) with an enrichment limited to <20.0% (in mass) and with a peak burnup limited to 20% fissions per initial metal ion. (Source: INL/EXT-10-19887, Section 5.2)

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