HTGR Key Requirements
Design, Functional & Performance

Briefing for

Nuclear Energy Advisory Committee

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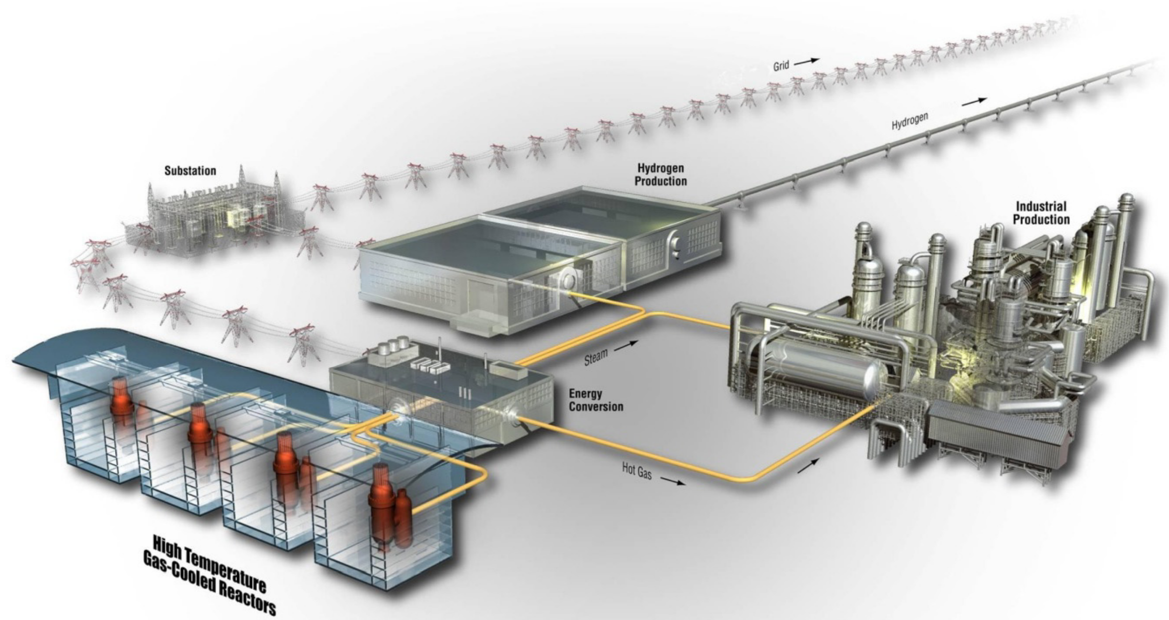
September 2010



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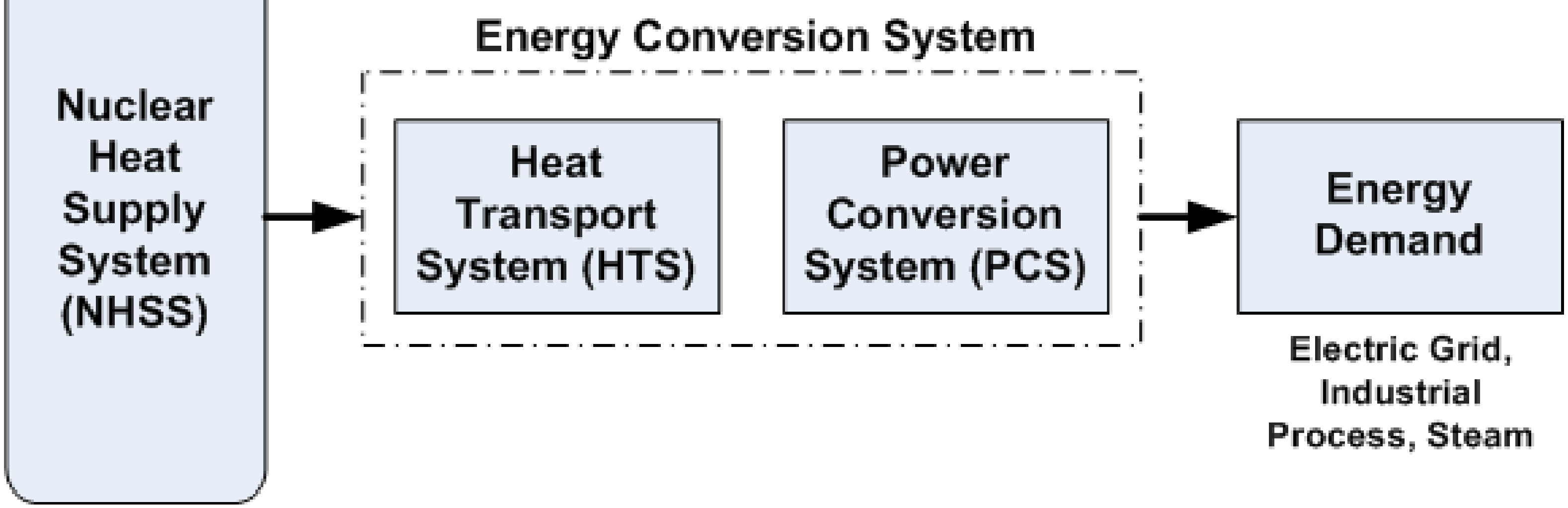
Outline

- **Objective**
- **Development of NHSS Requirements**
- **Summary of Key NHSS Requirements**
  - *General*
  - *End User*
  - *Design*
  - *Performance*
  - *Programmatic*
- **Conclusions**
- **Discussion**

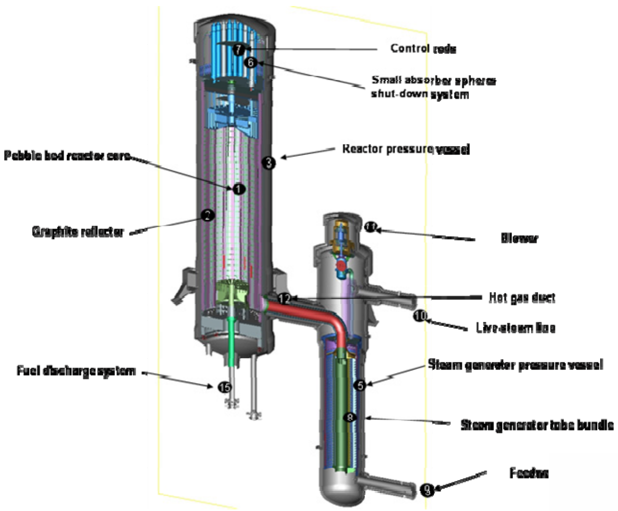
Objective

- **Focuses on the HTGR Nuclear Heat Supply System (NHSS)**
  - *Identifies key requirements that are judged to have significant effect on NHSS design*
  - *Review these requirements with Suppliers, End Users, Plant Owner/Operators to reach consensus*
  - *Maintain and update as required in the NGNP Systems Requirements Database*
- **Since the focus of this summary is on the NHSS it is not intended to be comprehensive; the NGNP Project System Requirements database is comprehensive**

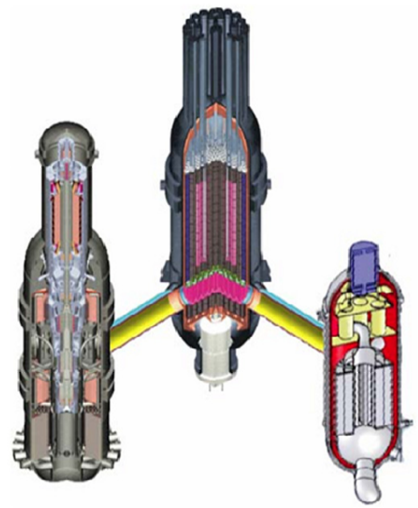
The Nuclear Heat Supply System



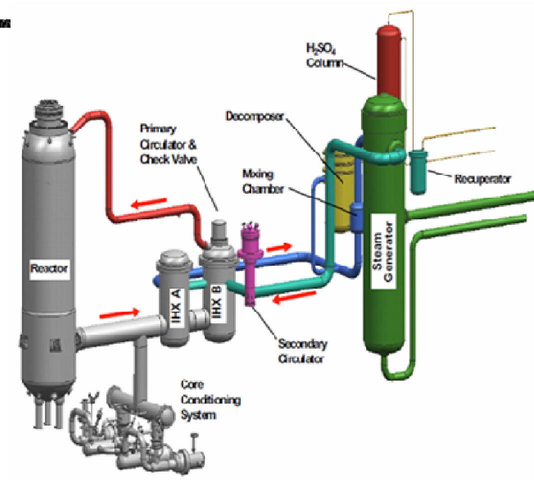
Multiple Configurations Developed by HTGR Suppliers



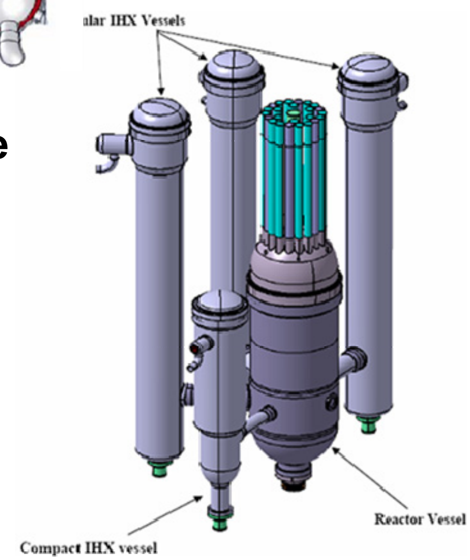
Steam Cycle



Electricity & Hot Gas Cycle

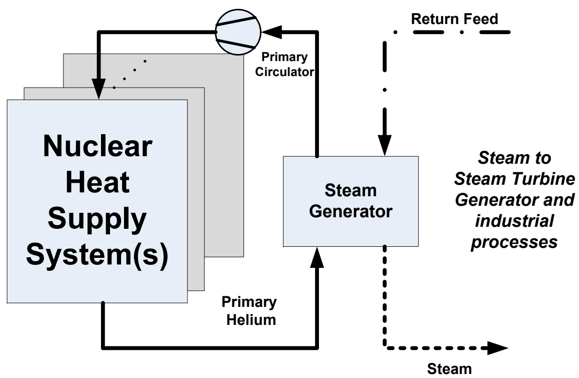


Steam & Hot Gas Cycle



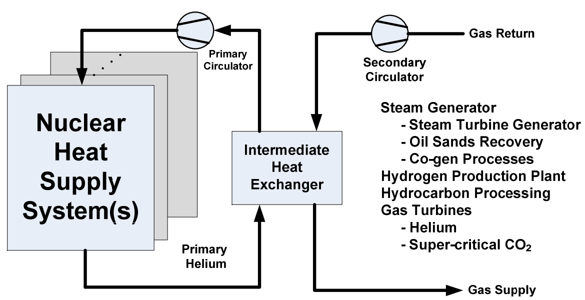
Steam & Hot Gas Cycle

HTGR Configurations



Direct Steam Cycle:

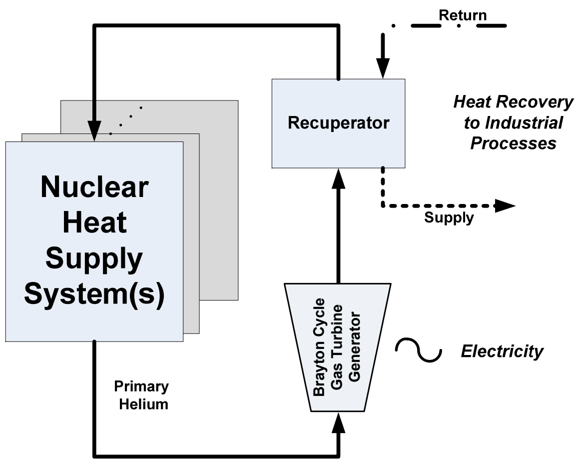
Energy is transferred from the reactor to the process using steam produced by a steam generator positioned in the primary helium circuit. The steam can be used, for example, to generate electricity using a Rankine cycle, supply industrial processes and for extraction of bitumen from oil sands.



Indirect Process Heat Supply:

Energy is transferred from the reactor to the process through a primary helium to secondary fluid intermediate heat exchanger. The secondary fluids of initial designs have included helium and helium nitrogen. It is anticipated that advanced designs could use CO_2 and liquid metals and molten salts. The secondary fluid can be used to supply a steam generator, support industrial processes, power gas turbines including a supercritical CO2 electric power generation system.

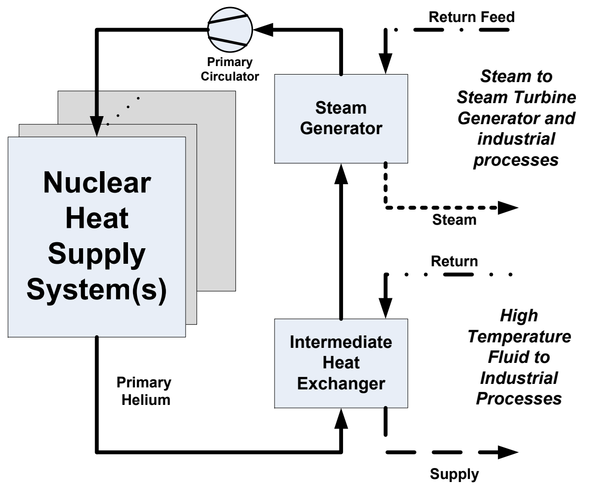
HTGR Configurations, cont'd



Direct Brayton Gas Turbine Cycle:

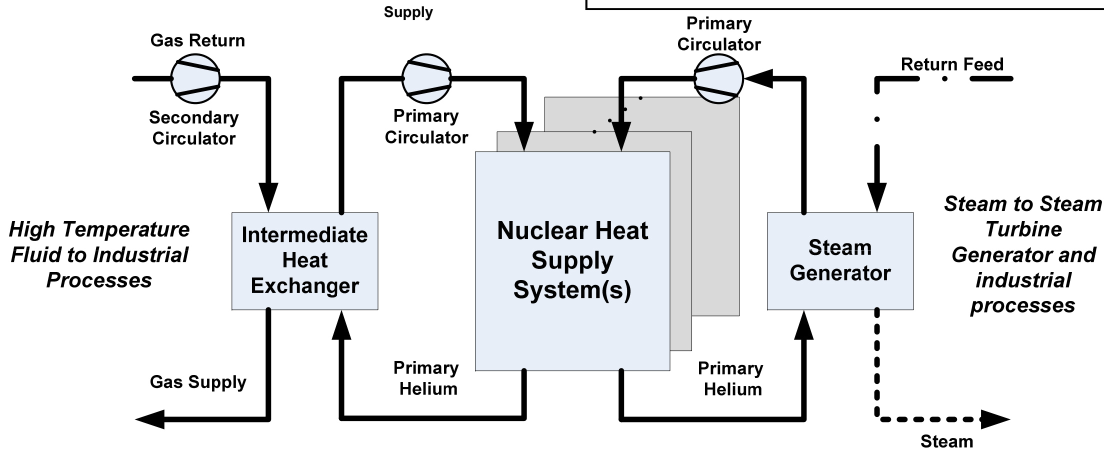
Energy is transferred in the forms of electricity and recovered heat. A Brayton cycle gas turbine generator is positioned in the primary helium circuit. The compressor of the gas turbine serves as the circulator as well as pressurizing the helium for expansion through the turbine. The recuperator recovers heat from the exhaust of the gas turbine for use in industrial processes.

Multiple Potential Energy Conversion System Configurations



Hybrid Cycles:

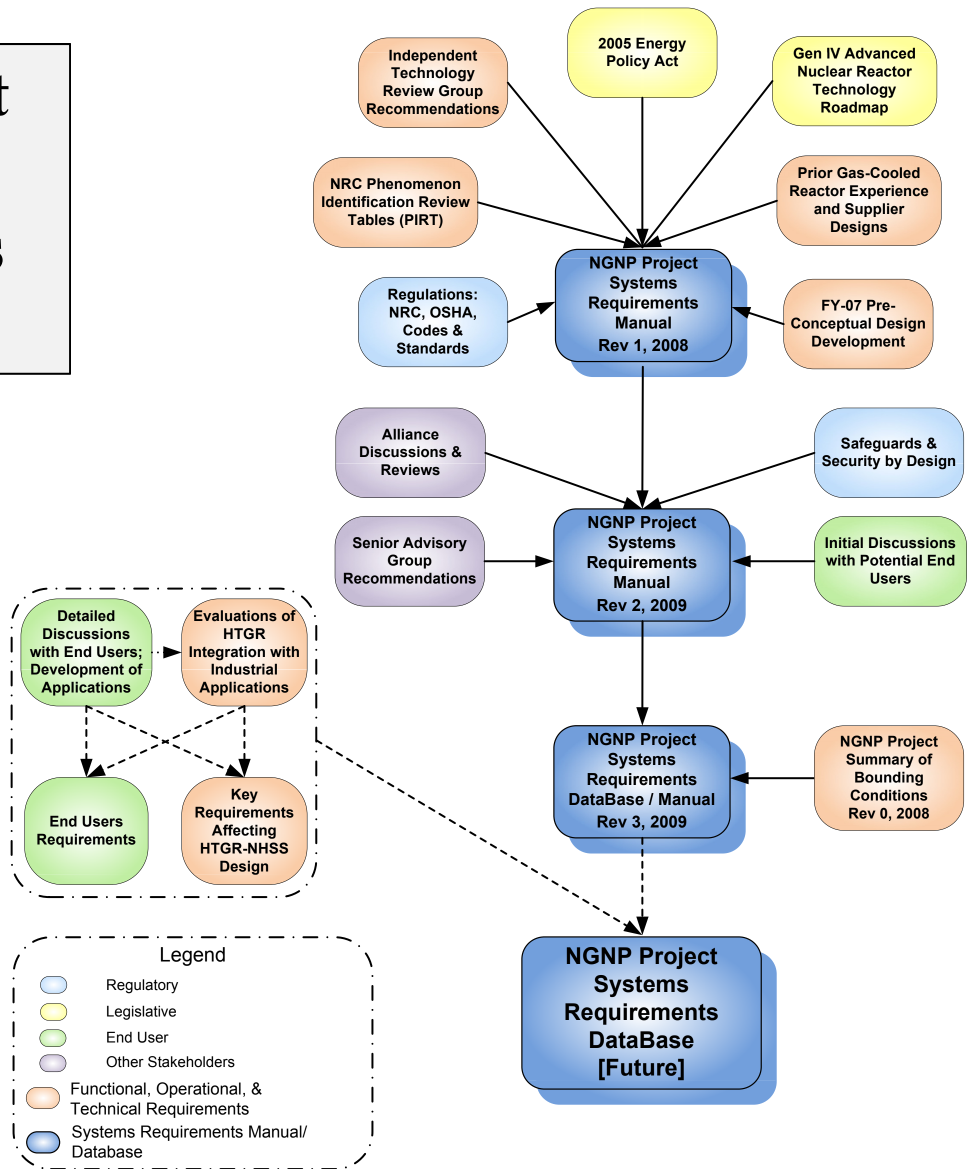
Energy is transferred from the reactor to the process through a primary helium to secondary fluid intermediate heat exchanger and a steam generator in either a series or parallel configuration. The steam and high temperature fluid are used to produce electricity and support industrial processes. The selection of the configuration, (e.g., series or parallel) depends on the reactor outlet temperature, (e.g., a series arrangement may be preferred for very high reactor outlet temperatures) , plant layout and plant control considerations.



Development of Requirements

- **Initial requirements derived from:**
  - *U.S. Gen IV Implementation Strategy selecting gas-cooled reactor for NGNP (2003)*
  - *ITRG Review of technology capabilities (2004)*
  - *2005 Energy Policy act*
  - *NERAC Review of NGNP (2006)*
  - *FY07 Pre-Conceptual Design work*
  - *NRC PIRT (2004 – 2008)*
  - *Prior Gas-cooled Reactor Designs (1960s – present)*
- **Requirements Updated:**
  - *Senior Advisory Group Recommendations*
  - *Review of end user requirements and assessment of Project technical and schedule risks*
  - *Evaluations of HTGR Integration in industrial processes*
- **Current End User Requirements and Key Requirements Affecting HTGR-NHSS Design developed to guide continuing design development**
- **All requirements (programmatic and technical) controlled in the NGNP Project Systems Requirements Database**

NGNP Project Systems Requirements Evolution



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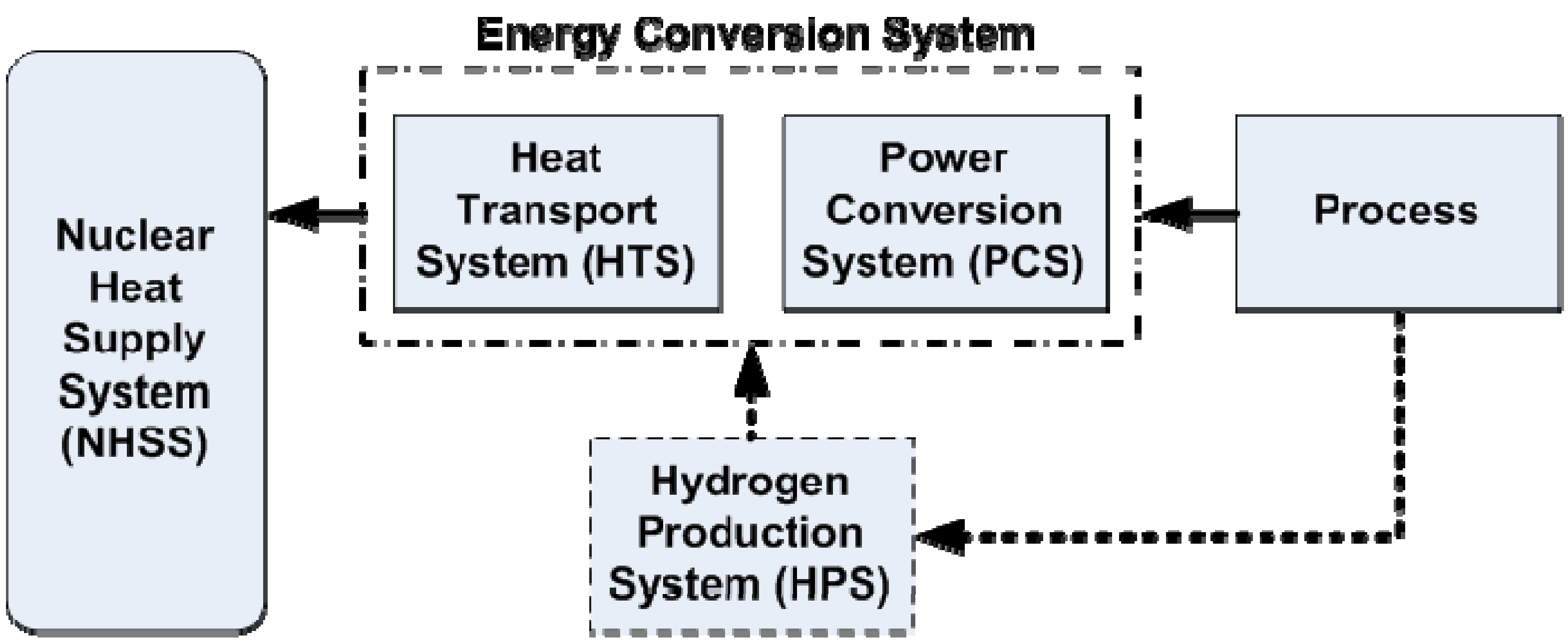
NGNP Next Generation Nuclear Plant

End User Functional and Performance Requirements

- **Fundamental Source of Functional & Performance Requirements**
- **Result from collaborating with potential end users of the technology & evaluating integration of HTGR technology with industrial processes**
  - *Co-generation of steam, electricity and process heat*
  - *Petro-chemical*
    - Cracking facilities
    - Ammonia Production
  - *Enhanced oil recovery*
    - Oil Sands
    - Oil Shale
  - *Hydrogen*
    - Hydrogenation
    - General industrial merchant market
  - *Synthetic fuels*
    - Coal to gasoline using MTG process
    - Coal to diesel
  - *Electricity Production*

NHSS Functional and Performance Requirements derived from End Users



End User Performance Requirements

- **Supply energy in the following forms either individually or in combination:**
  - *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 & processes*
  - *Process heat in the form of high temperature fluid to offset the emissions of greenhouse gases, (e.g., from the burning of fossil fuels in industrial processes)*

Plant Rating	Supplied Steam Condition	Electricity Requirements	High Temperature Fluid Conditions
250 to 6,900 MWth	>4,000 psig for super-critical applications, 2,500 psig for subcritical applications 540 to 630°C	Up to 2,500 MWe investigated to-date. As a supply to the electrical grid a wide range is possible depending on the location.	700 to 925°C 54 to 762 MWth

End User Requirements on Energy Supply Characteristics

- **Steam, Electrical & High Temperature Fluid Supply**
  - *Conditions – Pressures, Temperatures*
  - *Demand – Steady State & Variations*
  - *Chemistry*
  - *Interfaces*
- **Performance, (e.g., demand transient capabilities)**
  - *Step Changes*
  - *Ramp Transients*
  - *Load Trips*
- **Availability**
  - *N-x requirement*

General NHSS Technical Requirements

- These apply independent of the application and include:
  - **REACTOR CONCEPTS**
    - *Prismatic or pebble bed reactor concept*
  - **PRIMARY HELIUM CIRCUIT CONFIGURATION**
    - *Physically separated from steam or high temperature gas supply*
  - **INTERFACES WITH ENERGY CONVERSION SYSTEMS**
    - *Interfacing with multiple potential energy conversion configurations*
  - **MULTIPLE MODULE CONFIGURATIONS**
    - *Standalone module with the capability of being combined with other modules in a multiple module configuration*
  - **TOP LEVEL REGULATORY REQUIREMENTS**
    - *See table*
  - **PLANT EXCLUSION AREA BOUNDARY AND EMERGENCY PLANNING ZONE**
    - *Achieve a plant Exclusion Area Boundary of several hundred meters (~400 meters) and plume exposure Emergency Planning Zones equal to the Exclusion Area Boundary.*
  - **PLANT WORKER EXPOSURE LIMITS**
    - *The HTGR-NHSS shall limit normal maintenance exposure to no more than 50 person-REM/year*

Top Level Regulatory Requirements

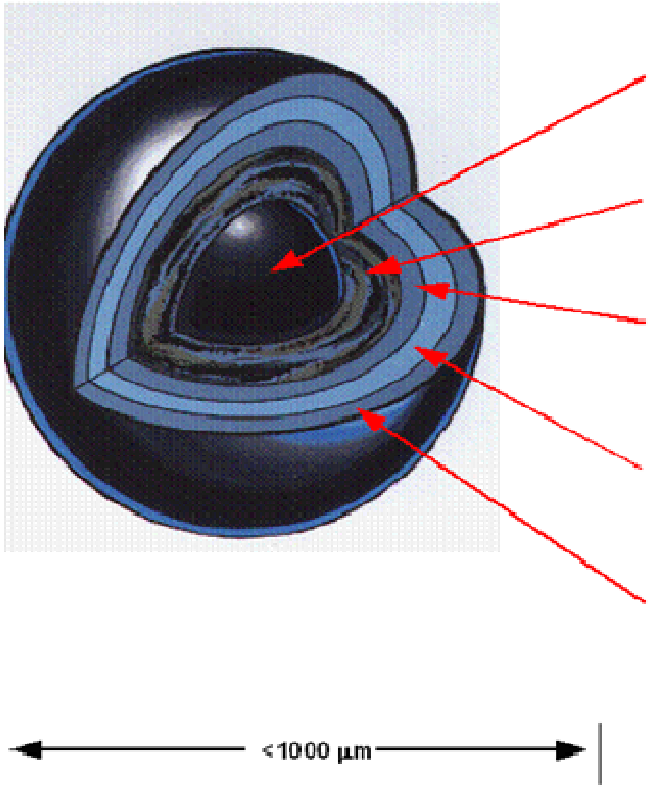
NGNP Project Requirements	
1	Occupational Exposures ≤10% of 10 CFR 20 Limits a. TEDE ≤0.5 rem/yr b. Organ Dose ≤5 rem/yr
2	Top Level Regulatory Criteria, including PAGs at the Exclusion Area Boundary for all events with a frequency ≥5 × 10^{-7}/yr
Top Level Regulatory Requirements	
1	10 CFR 50, Appendix I, Limits for Radionuclides in Plant Effluents: a. Whole Body Dose ≤5 mrem/yr b. Thyroid Dose ≤15 mrem/yr
2	10 CFR 20 Subpart C Occupational Dose Limits: a. Total effective dose equivalent (TEDE) ≤5 rem b. Organ Dose ≤50 rem
3	10 CFR 20 Subpart D Public Dose Limits: a. Annual TEDE ≤0.1 rem b. Hourly External Dose ≤0.002 rem
4	40 CFR 190 Subpart B Environmental Standards: a. Whole Body ≤25 mrem b. Thyroid Dose ≤75 mrem c. Organ Dose ≤25 mrem
5	10 CFR 52.47 Offsite Dose Limits for LBEs: a. TEDE ≤25 rem for 2 hours at the EAB b. TEDE≤25 rem for 30 days at the LPZ boundary
6	EPA PAGs for Radioactive Release for Public Sheltering & Evacuation (EPA 1992): a. TEDE ≤1 rem b. Thyroid Dose ≤5 rem
7	NRC Safety Risk Limits (NRC 1986)

NGNP Next Generation Nuclear Plant

Selected NHSS Design Requirements

- **HTGR-NHSS LIFETIME** – 60 YEARS
- **REFERENCE NUCLEAR FUEL –** TRISO COATED
- **FUNCTIONAL CONTAINMENT –** MULTIPLE BARRIERS
- **STEAM & HIGH TEMPERATURE FLUID RADIONUCLIDE CONTENT**
- **PASSIVE RESIDUAL HEAT REMOVAL**
- **SINGLE INTEGRATED CONTROL ROOM**
- **CONTROL ROOM OPERABILITY AND HABITABILITY**
- **IN-SERVICE INSPECTION**
- **PREDICTIVE MAINTENANCE** – ON-LINE DIAGNOSTICS
- **ADVANCED FABRICATION AND CONSTRUCTION TECHNIQUES**

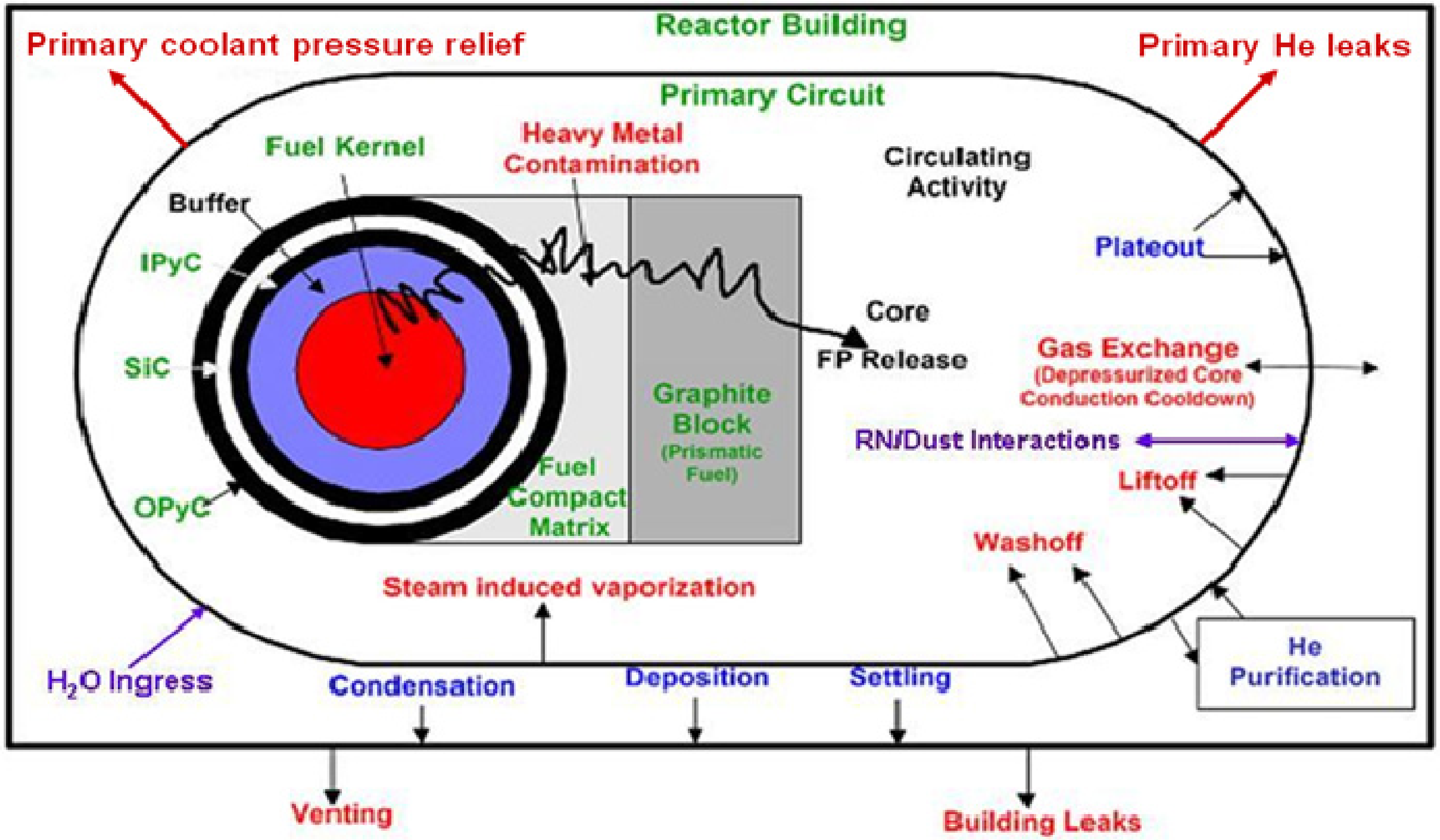
TRISO-Coated Fuel



COATING LAYER/PURPOSE

- Fuel Kernel
  - Contains fissile and fertile material
  - Retain fission products
- Buffer layer (porous carbon layer)
  - Void volume for fission gases
  - Accommodates kernel swelling
  - Attenuate fission recoils
- Inner Pyrocarbon (IPyC)
  - Prevent Cl attach of kernel during manufacture
  - Reduces tensile stress in SiC
  - Retains gaseous fission products
- Silicon Carbide (SiC)
  - Primary load bearing member
  - Retain gas and metal fission products
- Outer Pyrocarbon (OPyC)
  - Reduces tensile stress in SiC
  - Retains fission product gases
  - Protects SiC from core chemical environment
  - Provide bonding surface for compacting

Functional Containment



NHSS Performance Requirements

- **REACTOR OUTLET TEMPERATURE**
  - ***725 ºC TO 950 ºC***

- **SAFETY MARGIN**
  - *The core design shall result in a self-consistent set of parameters (e.g., power density, core delta T, reactivity temperature coefficient) and material choices (e.g., fuel, graphite, core barrel, reactor vessel) that demonstrate adequate safety margin in satisfying the Top Level Regulatory Requirements at the EAB when uncertainties in these parameters and in the associated calculation methods (typically at 95% confidence) are explicitly accounted.*

Programmatic Requirements

- **LICENSING**
  - *NRC under 10CFR52*
- **DESIGN CERTIFICATION**
  - *Multiple Energy Conversion Systems*
- **NRC/EPA REGULATORY DOCUMENTS**
  - *Regulatory gap analysis*
- **DOE DOCUMENTS**
  - *Public-private partnership terms & conditions*
- **SAFEGUARDS**
  - *Current regulations*

Conclusions

- **Key requirements affecting HTGR design, function and performance have been identified**
- **Comments, modifications, additions, etc. are being solicited from affected cognizant organizations**
  - *Consensus is being pursued among HTGR Suppliers, nuclear plant owner/operators & end users*
- **NGNP Systems Requirements database will be updated and reconciled based on the final NHSS requirements definition**
- **Periodic reviews will establish if modifications are required as the design of the HTGR plant progresses**

General Discussion