ADVANCED REACTOR, FUEL CYCLE, AND ENERGY PRODUCTS WORKSHOP FOR UNIVERSITIES

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Reactor / Hydrogen Production Process Interface

Idaho National Engineering and Environmental Laboratory

Workshop for Universities
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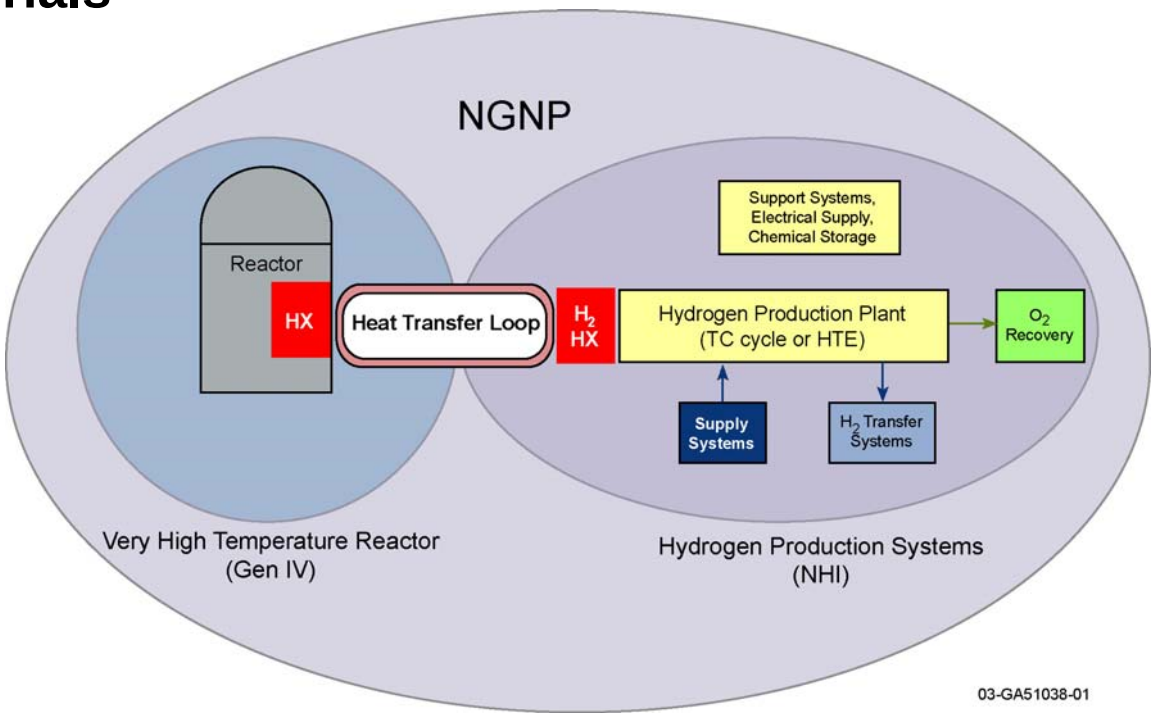
Systems Interface & Balance of Plant - Scope

- **Process-side high-temperature heat exchanger (HX)**
- **Implications of intermediate heat transfer loop on process**
  - Heat transfer medium (corrosion, isolation, connection, etc)
- **High-temperature materials**
- **Support systems**
  - Hydrogen management
  - Oxygen management
  - Instrumentation
  - Control systems
  - Utilities
  - Chemicals
  - Secondary waste



Systems Interface & Balance of Plant – R&D

Systems Interface and Balance of Plant *R&D* will focus on coupling the high-temperature reactor to the hydrogen production process, including:

- Process-side heat exchanger
- Interface with the intermediate heat transfer loop
- Materials issues

Systems Interface & Balance of Plant – R&D

Research and Development

- Thermochemical (TC)
- High Temperature Electrolysis (HTE)
- Systems Interface and Balance of Plant

Bench & Lab Scale, and Materials Testing

Integrated Lab Scale

Pilot Plant Scale

5 MWt Thermochemical
0.5 MWt HTE

Engineering (commercial) Scale

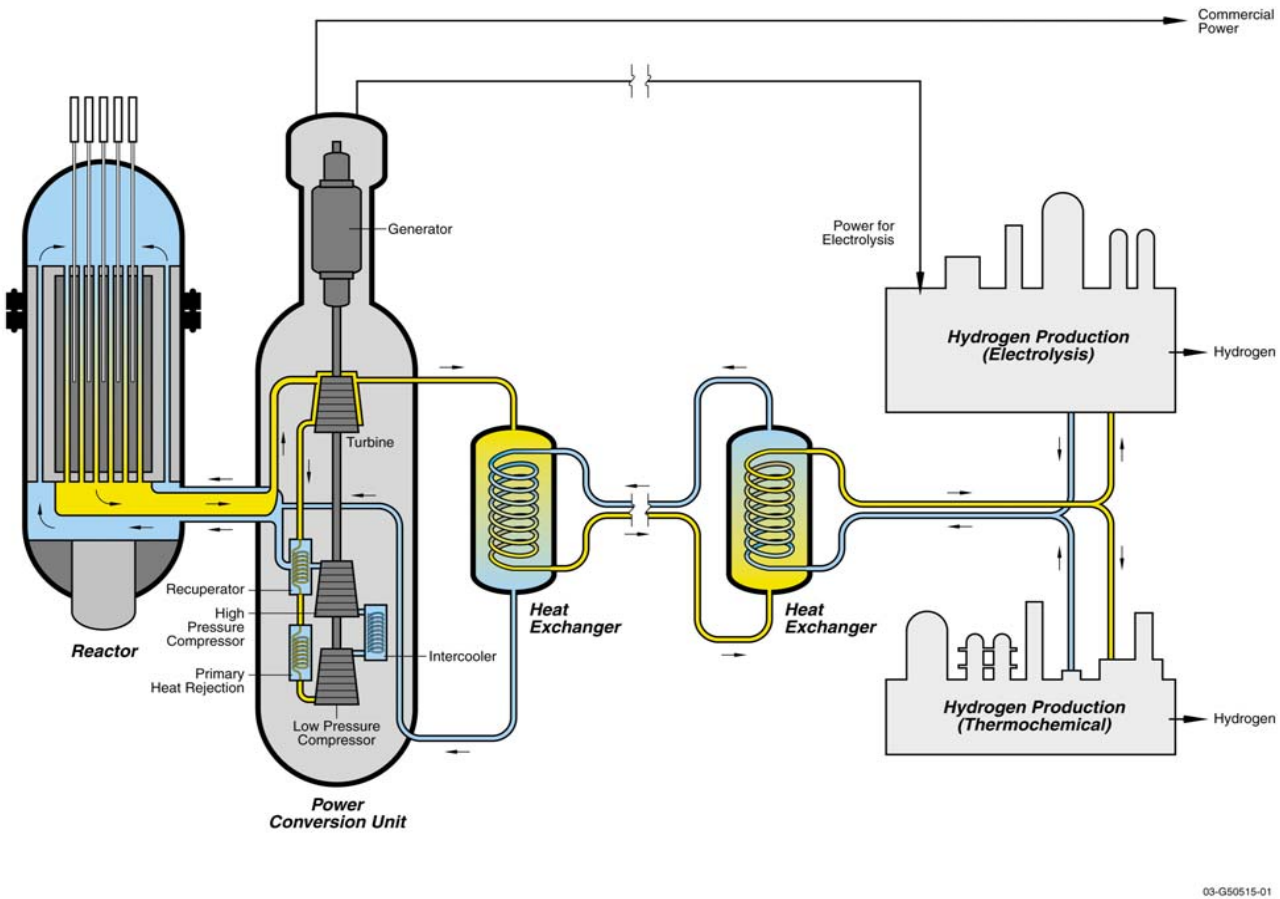
50 MWt Thermochemical
1-5 MWt HTE

10 x

Demonstration

Systems Interface & Balance of Plant

Next Generation Nuclear Plant (NGNP) Possible Layout



Systems Interface & Balance of Plant

NGNP Requirements

- Passive safety - within fuel performance capability
- Commercial-scale (~600 MWt)
- Prismatic or Pebble Bed reactor core
- 1000 ^{o}C outlet temperature
- Graphite moderated
- Once-through uranium fuel cycle (<20% enrichment)
- TRISO-coated uranium oxycarbide (UCO) fuel
- 60-year design life
- Safety-independence between facilities
- Electric generation using Brayton cycle ($\geq$45% efficiency)
- NRC Licensed

  (may be helium or molten salt cooled)

Systems Interface & Balance of Plant

Requirements – Hydrogen *

- Hydrogen production using up to 50Mw of the reactor's thermal energy
- Demonstrate thermochemical and high-temperature electrolysis hydrogen production
- Limit tritium migration into hydrogen production systems
- Limit radioactive contaminants in hydrogen product
- Produce hydrogen with industry-standard purity
- Establish a test-bed for other hydrogen production technologies
- Develop a hydrogen storage and distribution system to support the facility

* from NGNP High-Level Functions & Requirements Document September 2003

Systems Interface & Balance of Plant

Requirements - General

- Optimize human-machine interfaces
- Minimize need for operator accident response
- Include provisions for subsequent addition of a supercritical-CO_2 Brayton cycle power conversion system of up to 50 MWt

FY03 ACCOMPLISHMENTS

- **Developed the Nuclear Hydrogen R&D Plan**
  - Defined the reactor-hydrogen production system options
  - Identified near-term system design studies
- **Teamed with UNLV to develop a plan for high-temperature HX R&D consistent with NHI planning**

WORK IN PROGRESS FOR FY04

- Complete the assessment of <u>process interface requirements</u>
- <u>Identify key technical issues</u> for process heat exchangers and interface with the intermediate loop
- Complete initial <u>configuration studies</u> to define balance of plant components and systems to support thermochemical and high-temperature electrolysis systems
- Complete high-level <u>infrastructure and facilities requirements</u> assessment for pilot scale demonstration
- Complete assessment of <u>candidate existing facilities</u> and associated infrastructure for pilot scale demonstration

PLANS FOR FY05

Systems Studies	High-temperature HX	Intermediate Loop	Supporting Systems
Develop H2 plant configuration options for baseline processes. Perform initial isolation assessment. Compile applicable Codes and standards.	Develop process specific HX requirements for baseline processes. Develop conceptual design options for high H2SO4 decomposition HXs. Initiate materials testing for sulfur cycles.	Perform thermal, flow analyses for intermediate loop options.	Assess external (to nuclear hydrogen plant) interface requirements.

PLANS FOR FY06

Systems Studies	High-temperature HX	Intermediate Loop	Supporting Systems
Complete preliminary H2 system cost studies for baseline processes.	Initiate materials testing for Ca-Br or alternative cycles Scaled HX design and fabrication for S cycles and HTE.	Intermediate loop preliminary design.	Conceptual design for H2 system components and subsystems (pilot plant scale).

PLANS FOR FY07

Systems Studies	High-temperature HX	Intermediate Loop	Supporting Systems
Interface and BOP design for pilot plant. Thermal, structural, flow for baseline pilot plant designs.	Long term materials tests. High temp HX demo tests. Pilot plant HX design.	Intermediate loop materials testing.	Component development for pilot plant processes.

Systems Interface & Balance of Plant

Co-locating a chemical processing plant near a nuclear reactor introduces new considerations for mutual facility isolation.

Physical isolation (either separation distance or an acceptable physical barrier) must be sufficient to eliminate the propagation of accident consequences from one facility to the other.

Isolation issues may affect design, NRC licensing, environmental permitting, operation, emergency response, etc.

Systems Interface & Balance of Plant

Gen III **Gen IV**

Starting Line

Reactor

Hydrogen Production

NRC Licensing
Fuel Development, Qualification & Production
Materials Development (at 1000 C°)
EIS and Permitting

Production Rate Scale-up of
250,000 Times Greater

Finish Line

~ 30 Nℓ/hr
H_2

"Commercial-Scale"
(50 MWt)

Systems Interface & Balance of Plant

Backup Slides

Systems Interface & Balance of Plant

R&D and Design Considerations

Systems/ Components	Design / Interface Considerations
High-temperature Heat Exchangers	Production processes will likely drive HX requirements (rather than reactor coolant), HX type, operational conditions (temperature, pressure), efficiency, Must qualify high-temperature materials that are compatible with heat transfer medium and production process solution or medium.

Systems Interface & Balance of Plant

High-Temperature HX - Technology Gaps & Proposed Research

Materials must be selected and qualified to contain the hydrogen production process fluids at the higher temperatures (i.e. 900°C versus 315°C for sulfuric acid, 850°C versus 550°C for hydrolysis, etc.).

Ceramic materials may be considered, however, the ceramics pose a major problem with seals. The seals or joints will most likely include sealing two materials due to required lining, bonding, etc. between the heat transfer surfaces.

Thermal, hydraulic, and structural analyses for the heat exchangers must also be evaluated. These analyses will be used to size the heat exchanger so that appropriate performance testing can be initiated. The needed temperature and pressure values, flow velocities, etc. should be established for the hydrogen process fluids by the time the material issues are resolved. Likewise the same parameters for the heat transfer medium should also be established.

"Printed Circuit Heat Exchangers (PCHE)" and "Printed Circuit Reactors (PCR)" may be a good starting point for the heat exchanger design. The Heatric Company currently manufactures these items with ratings up to 900°C and up to 9500 psi. Application-specific evaluation and development will be required.

Systems Interface & Balance of Plant

HX	Range of Conditions	Candidate Materials & Demonstrated Capability	R&D Needs
H_2SO_4 Concen-tration	300-700K, 0-50 Atm, 15-95% H_2SO_4 (impurities ferric sulfate, iodine species and phosphoric acid.	High silicon carbon steel - Gold or platinum plating, Higher corrosion rates observed for lower concentration acids. Al610, Incoloy 800H	Data on corrosion resistance with impurities (Alloys and plated alloys)
H_2SO_4 Vaporiza-tion	600-800 K, 2-50 Atm, H_2SO_4, potential small quantities of I and Br	Structural: Incoloy 800H, AL 610, high silicon carbon steel, silicon carbide Nonstructural: Ceramics, Pt, Au, fused quartz No metals with sufficiently low corrosion rates. Dry wall boiler design will reduce exposure to the corrosive acid, Ceramics not sufficiently developed for structural application	Integrated system and materials development activities to address severe corrosion environment. (Alloys and plating)
H_2SO_4 Decomp-osition	600-1100 K, 2-50 Atm, H_2O, H_2SO_4, SO_3, SO_2, O_2	Structural: Incoloy 800H, AL 610, Nonstructural: Ceramics, Pt, Au Catalysts: Pt, Cu, Fe_2O_3 Strongly oxidizing conditions, at high temperatures preclude the use of carbon steel alloys. Residual alloy strength at operating and upset conditions is a particular concern.	Studies on alloy attack by flowing mixtures of steam, sulfur oxides and oxygen over temperatures to 1200 K and pressures to 50 atms.

Systems Interface & Balance of Plant

Systems/ Components	Design / Interface Considerations
Heat Transfer Medium	Heat transfer conditions – temperature, pressure, pumping power, heat loss requirements, working fluids, corrosion, ingress compatibility
High-temperature Transfer Lines	Isolation configuration, materials, operating conditions (temperature, pressure, fluids), insulation, seals, auxiliary heating

Systems Interface & Balance of Plant

Heat Transfer Loop Interface - Technology Gaps and Proposed Research

Major technology gaps exist in materials development for use with the specific heat transfer medium (piping and seals), and circulator (pumps or blowers), and valve development. For helium use the materials issues should be solved by the reactor design activities, however, very large equipment and piping is likely. For molten salt, there are technology gaps for structural materials, pumps and valves where the properties of the material used in earlier systems (Hastelloy N) will probably not meet the new requirements by a hundred °C.

Additional technology gaps exist in the areas of piping joints (especially corrosion in heat affected zones in welds), in service inspection of piping, and leak detection and repair in double and triple wall piping. Unfortunately, the piping materials, that appear most promising from corrosion resistance and heat loss standpoints (i.e. ceramic, lined piping, etc.) are also the materials that provide the greatest challenges in making leak tight joints or welds.