DOE Hydrogen Program

Nuclear Reactor/ Hydrogen Process Interface

Steven R. Sherman, Ph.D.

Idaho National Laboratory

5/16/2007

INL/CON-07-12488

Project ID #PD23

Overview

Timeline

- Start date: 2004
- End date: 2016-2018
- On-going mission to support DOE NHI and NGNP Project

Budget

- Total project funding
  - DOE share: $10.3M cumulative since inception by DOE NHI
  - Contractor share: $0
- Funding received in FY06: $2.9M
- Funding for FY07: $2.7M

Barriers

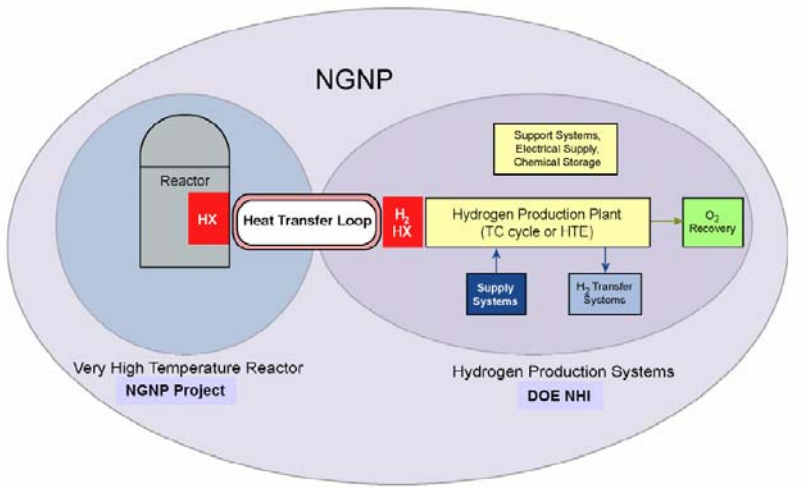
- Barriers addressed
  - High-temperature thermal technology
  - High temperature robust materials
  - Effective/efficient coupling method(s) for linking high temperature heat source with high-temp water splitting processes

Partners

- ANL, INL, ORNL, SNL
- UNLV, MIT, UC-B, U Wis, U Mo, JH, UCLA
- General Atomics, Ceramatec
- CEA, KAERI, JAEA

Objectives

- Overall Project Objectives
  - Guide the development of technologies to enable the connection of a Very High Temperature [nuclear] Reactor (VHTR) to a high-temperature hydrogen plant
  - Resolve technical issues and challenges offered by the DOE Nuclear Hydrogen Initiative (NHI) and Next Generation Nuclear Plant (NGNP) Project in regard to nuclear connection design, construction, operation, safety, economics, and nuclear plant licensing
  - Work closely with NHI Thermochemical and High-Temperature Electrolysis areas to define and test components and systems



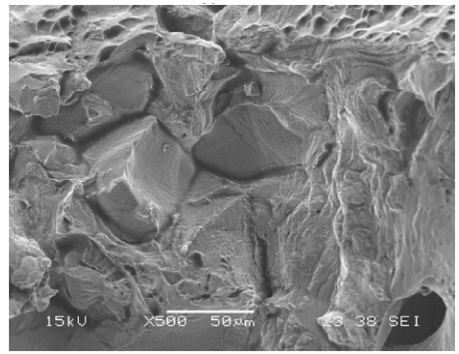
Approach

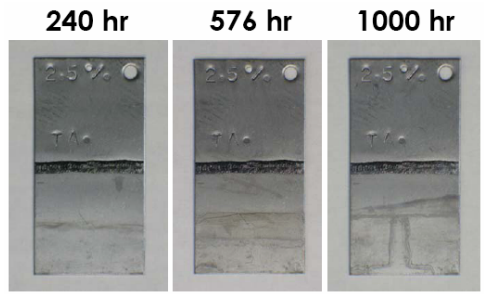
Materials	HXs/Conduits/ Components	Modeling	Safety
•**Metals:** tensile properties, creep, creep-fatigue, weldments, corrosion •**Ceramics:** properties, manufacturing methods, reliability •**Fluids:**support down-select	•**Detailed Modeling**: stresses, heat/mass transfer, functionality •**Lab-scale testing** •**Prototype testing**	•**Whole system modeling**: flow sheeting, steady-state analysis •**Transient modeling**: start-up, shutdown, off-normal, control systems	•**PRA/QRA** •**Analysis of industry practices** •**Codes & Standards** •**Programmatic support:** Eventual NRC license application, EIS, etc.

- All work must be integrated to support future pilot-scale and engineering-scale demonstration timelines and decision points

Accomplishments

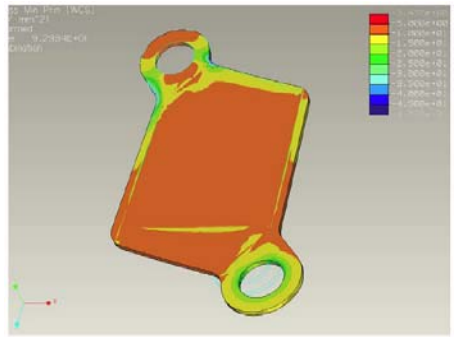
- Materials
  - Continued high-temp tensile testing and micrograph analysis of metals for high-temp heat exchangers
    - Down-select to Inconel 617 and Haynes 230 is forthcoming
  - Continued corrosion testing of alloys for HI decomposition section of the S-I process
    - Hastelloys B and C for vapor sections
    - Ta, Ta-2.5W, Ta-10W coatings and claddings for liquid sections containing iodine impurities work best
  - Continued studies of SiC, Si_3N_4, and Al_2O_3 properties and reliability for use in heat exchangers
    - Have shown excellent corrosion properties and physical properties at high temperatures
  - Static corrosion testing of high-temp alloys in FLiNaK (molten salt) is underway
    - Testing will concentrate on high-nickel alloys

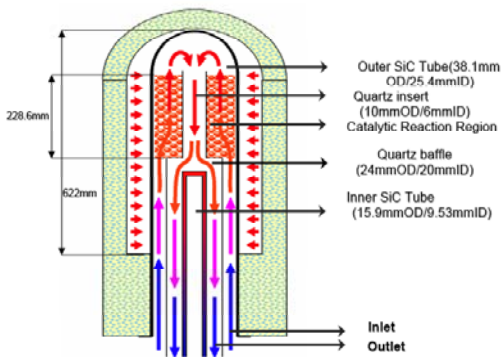


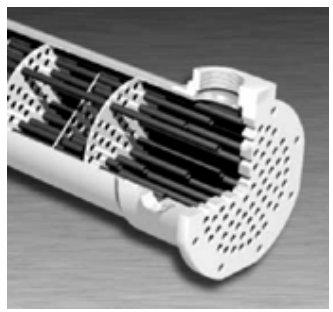


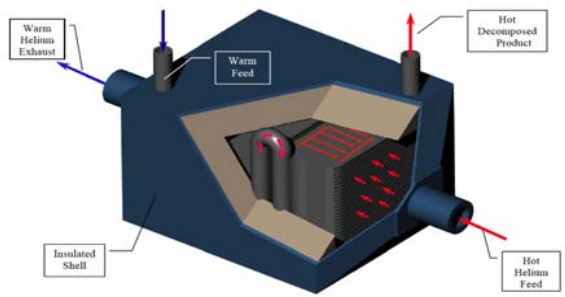
Accomplishments

- Heat Exchanger Designs
  - Thermal-hydraulic and stress analyses of three H_2SO_4 decomposer concepts performed
    - Sandia bayonet design
    - Shell and tube decomposer
    - Ceramatec compact decomposer design
  - C/SiC heat exchanger plates manufactured and bonded
  - Conceptual design of high-temperature oxygen cooler underway



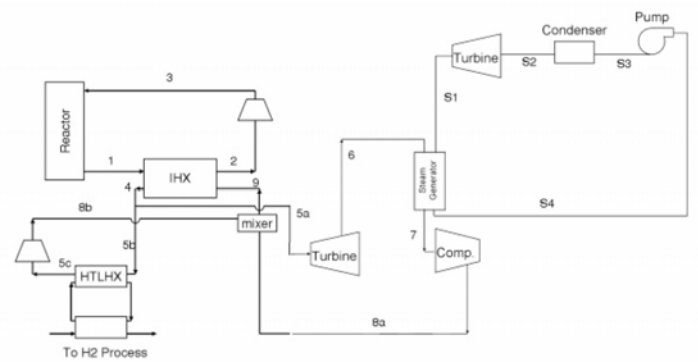






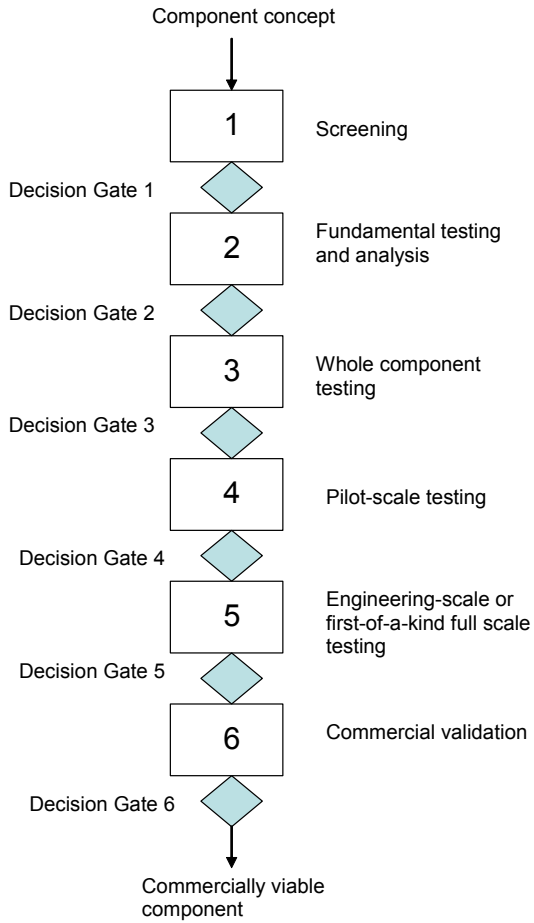
Accomplishments

- Modeling
  - Alpha testing of HyPEP model underway
    - Joint project between ANL, INL, and KAERI
  - Transient modeling efforts are now underway
    - ANL and MIT
- Safety
  - Revision of minimum nuclear plant/hydrogen plant spacing report confirmed 60-110 meter minimum required spacing



Accomplishments

- NHI Materials and Components Development Plan completed
  - Decision process and assessment system to guide component development tasks
  - Component-centric but supported by on-going materials development/testing work
  - Component concepts are reviewed and assigned technical readiness levels (TRLs)
  - Advancement is controlled by peer- or expert-reviewed decision gates
  - Imposes flow sheet version control
  - Component information stored in Component Case Files
  - Case Files will be managed in an NHI Component Database



Accomplishments

- UNLV HTHX Program re-organized to better coordinate with NHI and, indirectly, the NGNP Project
  - UNLV HTHX Project annual budget is $2M/year
  - Key professors have been names Associate Technical Directors and assigned specific technology areas
    - High-temperature materials
    - Component design and modeling
    - Molten salt systems
    - Chemistry and surface analysis
  - Work packages developed jointly with national NHI technical leaders
  - UNLV research will be used to push boundaries of current technologies

Accomplishments

- Tighter coordination of research planning and tasks with NGNP Project
  - R&D on heat transfer loop (NHI) and energy conversion unit (NGNP Project) now being managed by same person (Steve Sherman)
  - NGNP Project-sponsored pre-conceptual design studies performed in FY07 will be used to drive research priorities for future NHI work on the heat transfer loop
    - Teams
      - Areva
      - General Atomics
      - Westinghouse
    - Some early conclusions
      - Initial IHX will likely be metallic
      - Initial heat transfer loop will likely use helium as a heat transfer fluid

Future Work

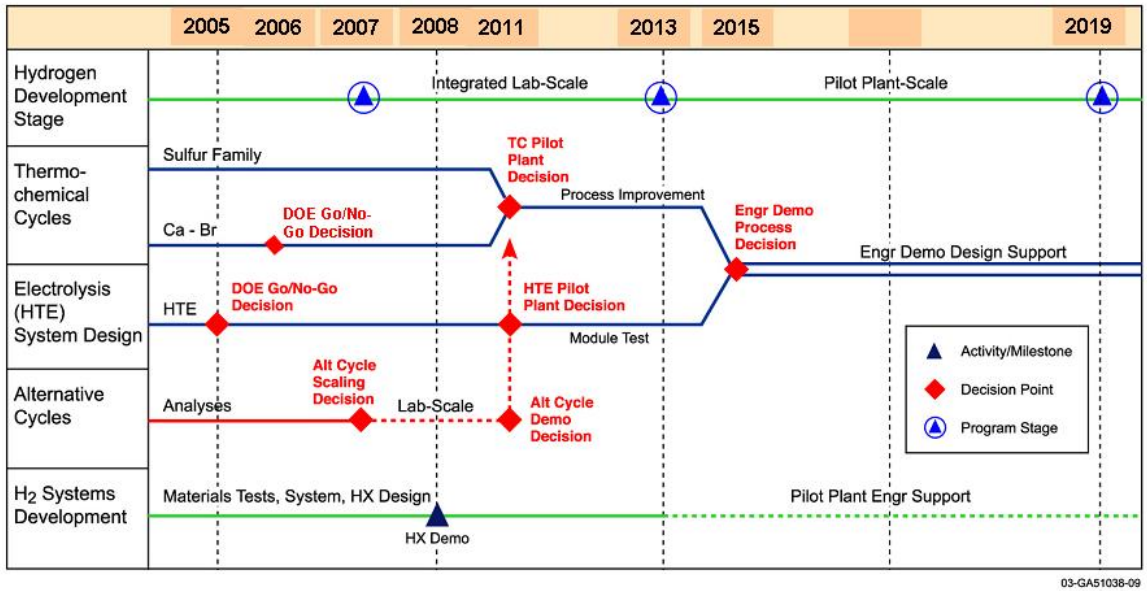
- Remainder of FY07
  - Prepare HyPEP Model for beta testing in FY08
  - Begin construction of NHI Components Database to support implementation of NHI Materials and Components Development Plan
  - Implement new round of research at UNLV
    - Materials
    - HX and conduit design and analysis
    - Molten salt system studies
    - Chemistry and surface analysis
  - Update research plans with input from NGNP Project industry pre-conceptual design information
  - Complete initial tritium transport modeling in cooperation with JAEA

Future Work

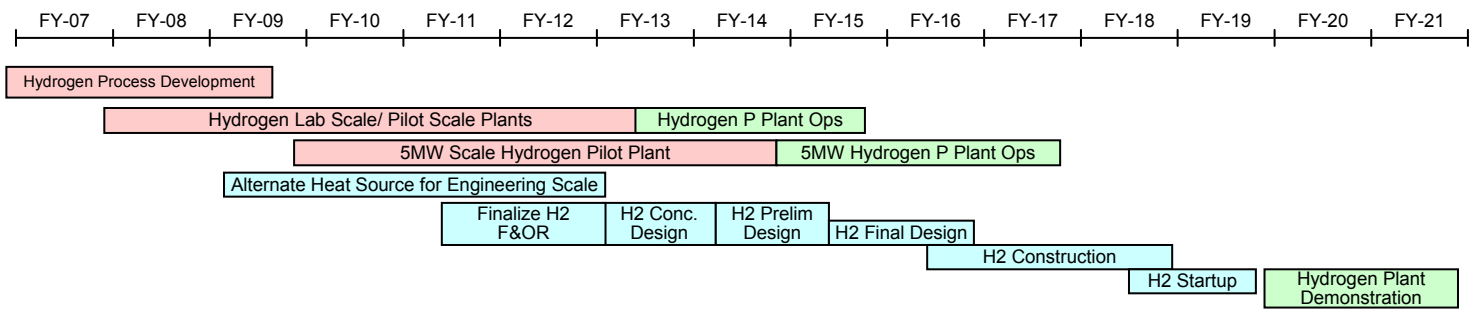
- FY08
  - Beta-test and finalize HyPEP model
    - Will be updated to include latest S-I flow sheet from General Atomics
  - Fully develop integrated system transient models
  - Implement NHI Components Database and Development Plan
  - Continue UNLV research projects
  - Initiate lab-scale prototype heat exchanger testing and testing of internal pipe insulation at high temperature
  - Continued modeling of tritium transport in NGNP system
  - Resume QRA of H_2 plant and heat transfer loop configurations
- FY09
  - Make recommendation on use of molten salt as a practical long-distance heat transfer medium

Future Work

NHI Long-term Schedule



NGNP Project Long-term Schedule for H_2 Plant



Future Work

- NHI long-term schedule and NGNP Project long-term schedule compare reasonably well, especially in the out-years
  - Nuclear connection technology demonstrations will be a part of the pilot plant efforts
  - Milestone dates will need to be reconciled
- NHI will pursue work that is both of immediate interest to the NGNP Project and for longer-term applications
  - Examples
    - Continued R&D of alternative hydrogen production cycles that require lower temperatures to operate than S-I, Hybrid Sulfur, high-temp electrolysis
    - Advancement of ceramic heat exchanger technologies
    - Further examination of long-distance heat transfer networks using fluids other than helium (molten salts, high-temp steam, etc.) for use in industrial heat applications

Summary

- Relevance
  - R&D in support of heat transport loop that will be needed to connect a VHTR to a high-temperature hydrogen production plant
- Collaborations
  - National laboratories, universities, private companies, and foreign institutions
- Approach
  - Converging pathways in materials, component design, modeling, and safety
  - Integration of information to support NHI/NGNP development timelines
- Accomplishments
  - Some preferred materials have been identified
  - Specific HX designs are under examination
  - Integrated system modeling efforts are going forward
  - NHI Materials and Components Development Plan
  - Re-organization of research management
- Future Work
  - “More narrow and deeper” on timelines consistent with NHI and NGNP Project schedules