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

Summary Presentations

Workshop for Universities
Hilton Hotel, Gaithersburg, MD
March 4-5, 2004

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

Dr. James J. Laidler

Advanced Fuel Cycle Initiative

Separations

Argonne National Laboratory

Workshop for Universities
Hilton Hotel, Gaithersburg, MD
March 4-5, 2004

THIS RESEARCH AREA INCLUDES

- Development of aqueous and hybrid aqueous - pyrochemical separations technologies for the processing of spent nuclear fuel from commercial light water reactors
- Development of spent fuel treatment processes for the processing of spent fuel discharged from advanced (Generation IV, NGNP) nuclear reactors
- Development of improved storage forms for the temporary or permanent storage of low-level and high-level nuclear wastes
- Conceptual design of future spent fuel treatment plants and advanced processing technologies
- Conditioning of spent EBR-II fuel and blankets for disposal

FY03 ACCOMPLISHMENTS

- Conducted hot laboratory-scale demonstration of complete UREX+ separations process
- Tested SANEX III and SANEX IV processes for extraction of americium and curium
- Completed design study for 2000 t/y large spent fuel treatment facility
- Processed 26 kg of EBR-II driver fuel and 455 kg blanket fuel
- Evaluated dry storage options for Cs/Sr and Am/Cm products

WORK IN PROGRESS FOR FY04

- Laboratory-scale hot demonstration of the optimized UREX+ process (co-decontamination flowsheet)
- Demonstration of alternative process for Am/Cm separation
- Optimization of Cs/Sr extraction process and selection of Cs/Sr storage form
- Development of processing concept for treatment of coated-particle fuels
- Development of hybrid aqueous/pyrochemical process for LWR spent fuel treatment
- Conditioning of EBR-II driver fuel and development of improved method for blanket processing
- Demonstration of uranium crystallization head-end process

PLANS FOR FY05-07

- Select reference flowsheet for LWR spent fuel processing
- Demonstrate one-group TRU extraction process
- International demonstration of LWR spent fuel processing
- Demonstrate Am/Cm separations processes and select reference process
- Initiate accelerated EBR-II blanket treatment using advanced processing technology
- Select reference storage/disposal forms for U, Pu/Np, Am/Cm, and Cs/Sr

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

Dr. Kemal O. Pasamehmetoglu

Advanced Fuel Cycle Initiative

Fuels

Los Alamos National Laboratory

Workshop for Universities
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THIS RESEARCH AREA INCLUDES

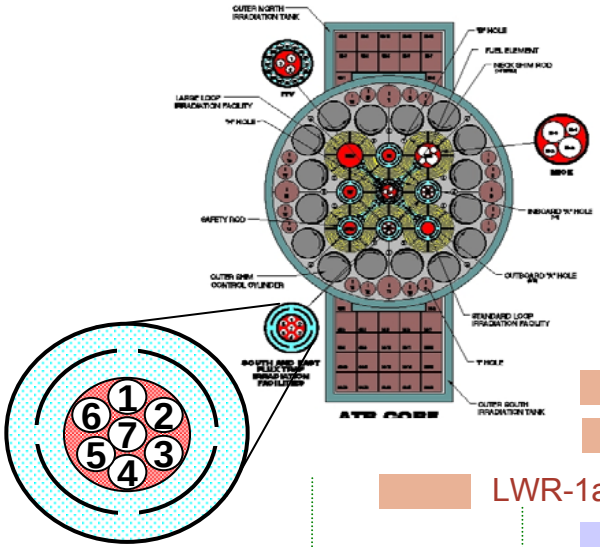
ADVANCED FUEL DEVELOPMENT FOR LWRs, GEN-IV REACTORS (thermal and fast) and DEDICATED TRANSMUTERS(Accelerator Driven Systems or low conversion ratio fast reactor)

- Fabrication, characterization, performance testing, PIE and modeling of TRU bearing Mixed Oxide and Inert Matrix fuels for LWR use.
- Fabrication, characterization, performance testing, PIE and modeling of UCO TRISO fuels for VHTR.
- Fabrication, characterization, performance testing (in-pile, out-of-pile), PIE and modeling of TRU-bearing nitride, metal, CERCER and CERMET fuels for fast-spectrum systems
  - ✓ Including fertile-free and low-fertile versions.
- Safety analyses for different advanced fuel types
  - ✓ Emphasis on TRU-bearing fuels
  - ✓ Transient testing
- Remote fuel fabrication assessment
- Development and selection of advanced clad materials

FY03 MAJOR ACCOMPLISHMENTS

- Fabricated and Characterized
  - non-fertile (Pu, Np, Am, Zr) and low-fertile metal fuel samples and initiated ATR irradiation (AFC-1 B, C and F tests).
  - non-fertile (Pu, Np, Am, Zr) and low-fertile nitride fuel samples and initiated ATR irradiation (AFC-1 AE test).
  - Np bearing mixed oxide fuel samples and fuel pins for irradiation in ATR (LWR-1A test). For reference, also fabricated weapons-grade and reactor grade MOX samples for the same test.
- Started atomistic-scale and continuum-scale model development for nitride and oxide transmutation fuels. Hosted the first International Fuel Modeling workshop.
- Feasibility studies for fabrication and performance modeling of micro-dispersion fuels. Patent application.
- Completed the conceptual design of the AGR-1 (shakedown) test for UCO TRISO fuels.
- Fabricated Depleted Uranium kernels and surrogate kernels for coating and compact development tests.

MAJOR WORK IN PROGRESS FOR FY04
PLANS FOR FY05-07



FUTURIX-MI (Phenix)

FUTURIX-FTA (Phenix)

LWR-2a: TRU-MOX, IMF, Am target (medium burnup)

LWR-2a: TRU-MOX, IMF, Am target (medium burnup)

LWR-1c: TRU-MOX, WG-MOX, RG-MOX (high-burnup)

LWR-1b: TRU-MOX, WG-MOX, RG-MOX (medium-burnup)

LWR-1a: Np-MOX, WG-MOX, RG-MOX (low-burnup)

GFR-1: Dispersion fuel with U (high-burnup)

GFR-2a: Dispersion fuel with U (medium-burnup)

AFC-1G: Low-fertile and non-fertile nitride (high-burnup)

AFC-1H: Low-fertile and non-fertile metal (high-burnup)

GFR-1: Dispersion fuel matrix irradiation (low-burnup)

AFC-1F: Low-fertile metal (low-burnup)

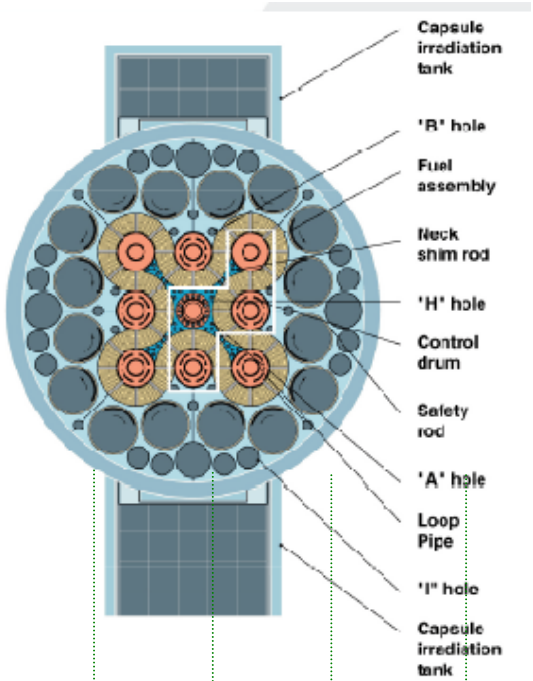
AFC-1AE: Non-fertile and low-fertile nitride (low-burnup)

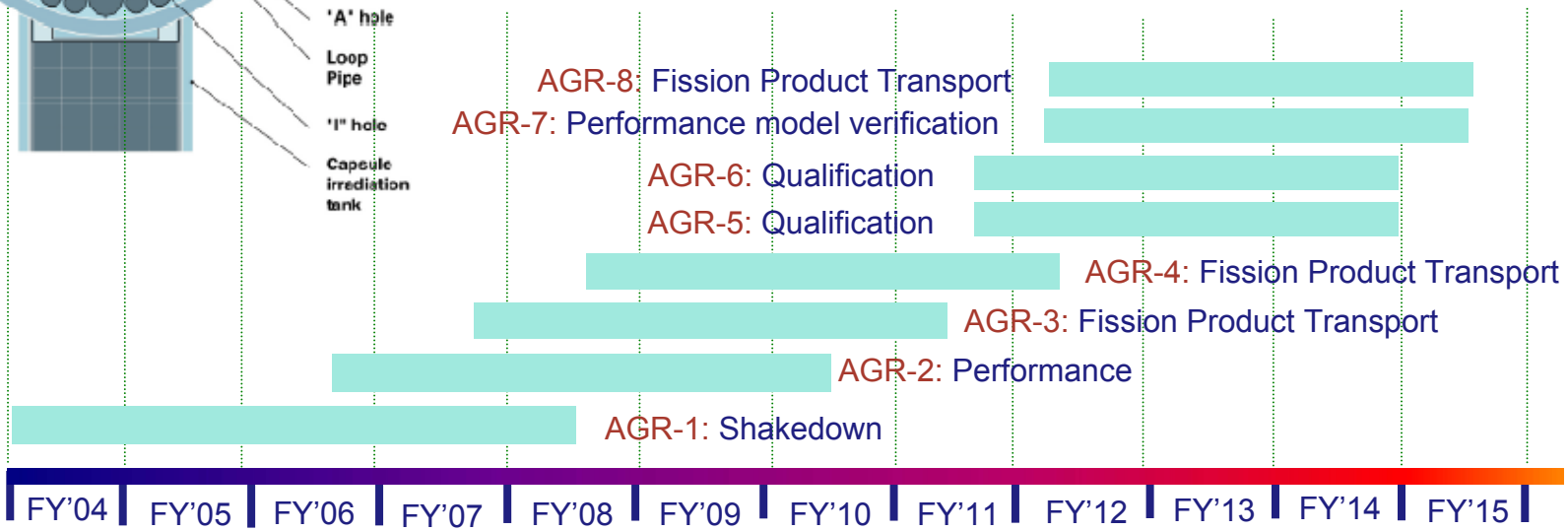
AFC-1D: Non-fertile metal (low-burnup)

AFC-1B: Non-fertile metal (medium burnup)

FY'03 | FY'04 | FY'05 | FY'06 | FY'07 | FY'08 | FY'09

MAJOR WORK IN PROGRESS FOR FY04
PLANS FOR FY05-07





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

Dr. Mike Cappiello

Advanced Fuel Cycle Initiative

Transmutation

Los Alamos National Laboratory

Workshop for Universities
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Transmutation Science and Engineering

Transmutation Science and Engineering:

- **Provides critical research and development to support AFCI Intermediate-term and AFCI Long- term, specifically in the areas of:**
  - **1) transmutation physics,**
  - **2) transmuter materials and coolants, and**
  - **3) accelerator-driven systems (ADS).**
- **Transmutation is a process by which long-lived radioactive species; particularly actinides (but also certain fission products) are converted to short-lived nuclides by either neutron fission or capture.**

FY03 ACCOMPLISHMENTS

Physics:

- Completion of evaluations on Np-237 and Am-241
- Data measurements on Fe and Ni gas production
- Issue MCNPX

Materials and Coolants:

- Completion of DELTA loop construction and commissioning
- Development of robust oxygen sensor
- Completion of STIP-I post irradiation examination
- Initiate radiation damage modeling effort

Accelerator Driven Systems:

- Complete MUSE-4 coupling experiments
- Target design for TRADE project
- Design of MEGAPIE target

WORK IN PROGRESS FOR FY04

Physics:

- Complete evaluations of Am-242
- Complete N-237 capture and fission cross section measurements
- Complete Fe and Ta gas production cross section measurements
- Complete initial dpa measurements
- Perform integral data analysis

Materials and Coolant Technology:

- Post irradiation exam of FFTF and STIPII steels
- Atomistic model development
- Complete 1,000 hr LBE corrosion test and evaluate oxide passivation of proposed alloys

Accelerator Driven Systems:

- Collaborate with EuroTrans on the XADS design, TRADE and MEGAPIE experiments

PLANS FOR FY05-07

FY05:

- Perform data measurements of Am, integrate CINDER and MCNPX, update VARIANT, retrieve FFTF samples, optimize surface treatment, XADS conceptual design

FY06:

- Perform data measurements of Cm, Initiate FUTURIX-MI materials irradiation, complete 6,000 hr corrosion test, install MEGAPIE target

FY07:

- Perform data measurements of Pu, complete FFTF PIE, issue materials handbook, commission TRADE experiment

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

Dr. Steve Herring

Advanced Fuel Cycle Initiative

Systems Analysis

Idaho National Engineering and Environmental Laboratory

Workshop for Universities
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AFCI Systems Analysis Includes

AFCI Systems Analysis has tasks in:

- Broad System Studies
  - AFCI Criteria and Assessment
  - Scenario Evaluations and Trade Studies
  - Repository Benefits
  - Economic Benefits
  - Industry Interaction
- Transmutation Systems Studies and Integrated Model Development
  - Transmutation Criteria
  - Transmutation Options and Analyses
  - Integrated Model Development
  - Nonproliferation and Safeguards
- Fuel Cycle Safety Assessment
- Participating Labs are:
  - ANL, INEEL, BNL, LANL, LLNL, ORNL, PNNL, Sandia, and SRS

FY03 ACCOMPLISHMENTS

- **Analysis of Spent Nuclear Fuel Management options**
  - Interfacing with the Fuel, Separations and Transmutation activities of the AFCI
  - Repository thermal limitations for various strategies
  - Comparison of options
    - Thermal v. fast reactor transmutation
    - Transmutation v. storage
    - Disposition of minor actinides (e.g., Np, Am, Cm, …)
    - MOX v. Inert Matrix Fuels
    - Dynamic modeling of options
  - Addressing specific questions from Congress and DOE

WORK IN PROGRESS FOR FY04

- **Criteria for comparing recycle strategies**
  - Radiotoxicity
  - Long-term dose
  - Plutonium isotopics
  - Repository thermal capacity
  - Single pass v. repeated passes
  - Thermal v. fast reactors
  - MOX v. IMF
- **Matching Strategies with possible nuclear futures**

Nuclear Futures		Legislative Limit	Existing License Completion	Extended License Completion	Continuing Level Energy Generation	Continuing Market Share Generation	Growing Market Share Generation
Cumulative discharged fuel in 2100 (MTiHM)		63,000	90,000	120,000	240,000	600,000	1,300,000
		Existing Reactors Only <-----|			|-----> Existing and New Reactors		
Fuel Management Approach		**Number of Repositories Needed**					
------> No Recycle	Current Management Approach	1	2	2	4	10	20
	Expand Repository Capacity	1	1	2	3	6	13
	Efficiency Improvements + Capacity Improvements	1	1	~1	~2	~5	11
Reprocess and Recycle <------	Separations, Limited Thermal Recycle, Capacity Improvement	1	1	1	~1	~3	~5
	Separations, Repeated Thermal Recycle	1	1	1	1	1	2
	Separations, Repeated Fast Recycle	1	1	1	1	1	1

PLANS FOR FY05-07

- Provide analysis to support report on fuel cycle infrastructure needs (March 2005)
- Provide recommendations on fuel types and reactor systems from the standpoint of the overall fuel cycle (continuing)
- Provide analyses as input to recommendation on need for second repository (2007)

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

Dr. Jacopo Buongiorno

Gen IV Initiative

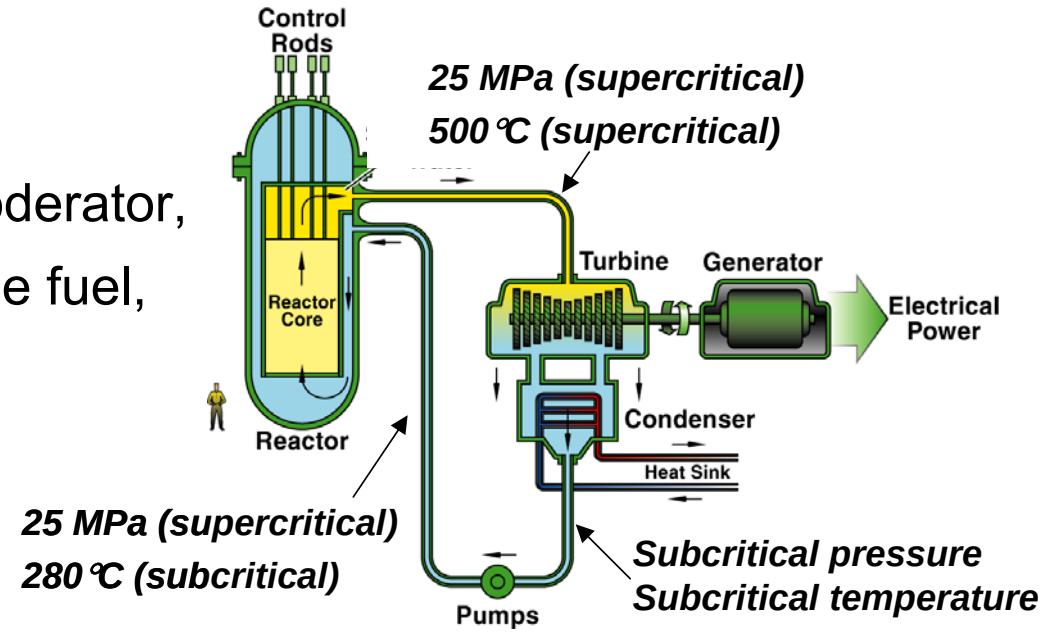
Supercritical Water-Cooled Reactor (SCWR)

Idaho National Engineering and Environmental Laboratory

Workshop for Universities
Hilton Hotel, Gaithersburg, MD
March 4-5, 2004

THIS RESEARCH AREA INCLUDES

- **Demonstrating technical feasibility of a LWR operating above the critical pressure of water, and producing low-cost electricity.**
- **The U.S. program assumes:**
  - Direct cycle,
  - Thermal spectrum,
  - Light-water coolant and moderator,
  - Low-enriched uranium oxide fuel,
  - Base load operation.



FY03 ACCOMPLISHMENTS

1) The SCWR can make substantial use of existing LWR technology in the nuclear island. (e.g., the design and materials for RPV and containment).

2) The SCWR can achieve high thermal efficiencies making extensive use of available supercritical fossil plant technology in the balance of plant (e.g., the materials and design for the power conversion cycle as well as the start-up and shutdown procedures).

3) Based on preliminary one-dimensional analyses, the SCWR appears to be stable with respect to thermal-hydraulic and thermal/nuclear oscillations because of its relatively low coolant reactivity feedback coefficient.

4) The importance of the loss of feedwater as a key abnormal (possibly limiting) event has been recognized.

5) Limited corrosion and stress-corrosion testing of traditional stainless steels in high-temperature water has shown that finding materials that would perform satisfactorily in the SCWR environment will be a challenge.

In summary, the basic assumptions contained in the Generation-IV Roadmap Report have been confirmed and no new potential showstoppers have been found. The key feasibility issues for the SCWR remain the development of in-core materials and the demonstration of an adequate safety level.

WORK IN PROGRESS FOR FY04

8 organizations, $900k

1) **Safety system and containment design**
2) **Stability analysis**
3) **RELAP analysis of start-up equipment/procedures**
4) **Corrosion and SCC testing**
5) **Water chemistry control system conceptual design**
6) **Program management and design support**

PLANS FOR FY05-07

Focus of the program for the next 3 years will be on:

- **SCWR core neutronic, thermal and mechanical design, including investigation of non-conventional approaches (e.g., solid moderators, hydride fuels, etc.)**
- **Design of safety systems and containment to cope with key abnormal events**
- **Evaluation of dynamic power/flow instabilities**
- **Investigation of basic thermal phenomena for the SCWR (e.g., heat transfer and critical flow experiments, CFD methods, etc.)**
- **Corrosion and stress-corrosion cracking testing of promising materials for the SCWR core and vessel internals.**

(more details in breakdown sessions)

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

Dr. Finis Southworth

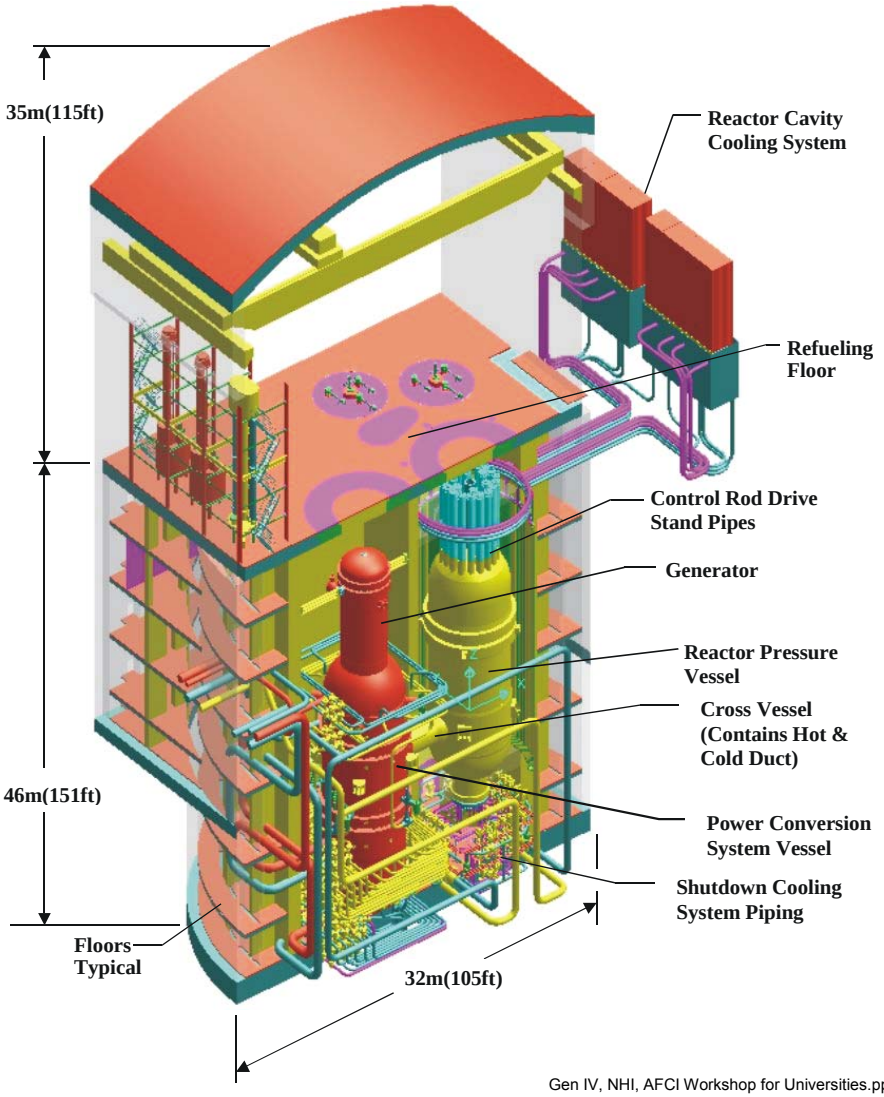
Gen IV Initiative
Next Generation Nuclear Plant

Idaho National Engineering and Environmental Laboratory

Workshop for Universities
Hilton Hotel, Gaithersburg, MD
March 4-5, 2004

THIS RESEARCH AREA INCLUDES

- The Next Generation Nuclear Plant is in the initial phase of project planning and scoping of R&D that will lead to the Design, Construction and Operation of an Advanced Nuclear Reactor-Hydrogen Cogeneration Demonstrator.
- The NGNP reference concepts are helium-cooled, graphite-moderated, thermal neutron spectrum reactors with a design goal outlet temperature of 1000 °C or higher.



THE NGNP RESEARCH OBJECTIVES ARE

- Demonstrate a full-scale prototype NGNP by the middle of the next decade
- Demonstrate high-temperature Brayton Cycle electric power production at full scale
- Demonstrate nuclear-assisted production of hydrogen (with about 10% of the heat)
- Demonstrate by test the exceptional safety capabilities of the advanced gas cooled reactors
- Obtain an NRC License to construct and operate the NGNP, to provide a basis for future performance-based, risk-informed licensing of high temperature gas reactors
- Support the development, testing, and prototyping of hydrogen infrastructures such as refueling stations, the "Freedom Car" initiative, petrochemical extension, heavy crude oil or tar sands "sweetening," and other industrial hydrogen applications.

THIS RESEARCH AREA INCLUDES

- NGNP reference - helium-cooled, graphite-moderated, thermal neutron spectrum reactors with a design goal outlet temperature of 1000 °C or higher
- Reactor core -prismatic graphite block or a pebble bed
- Molten-salt coolant is also being evaluated.
- NGNP will produce both electricity and hydrogen.
- IHX connects reactor loop to process heat loop
- Thermal power and core configuration designed to assure passive decay heat removal without fuel damage during hypothetical accidents
- The fuel cycle - once-through high burnup low-enriched uranium fuel cycle.

FY03 ACCOMPLISHMENTS

Programmatic & Project

- **Initial High-Level Objectives, Functions and Requirements, INEEL/EXT-03-01163**
- **Draft NGNP Program Management Plan, INEEL/EXT-03-01326**
- **Establish and Co-Chair GIF VHTR R&D Steering Committee**

System Design and Analysis Methodology

- **Initial Neutronics and Thermal-hydraulic Analysis for Prismatic and Pebble Bed Core Design Feasibility**

Materials Selection and Qualification

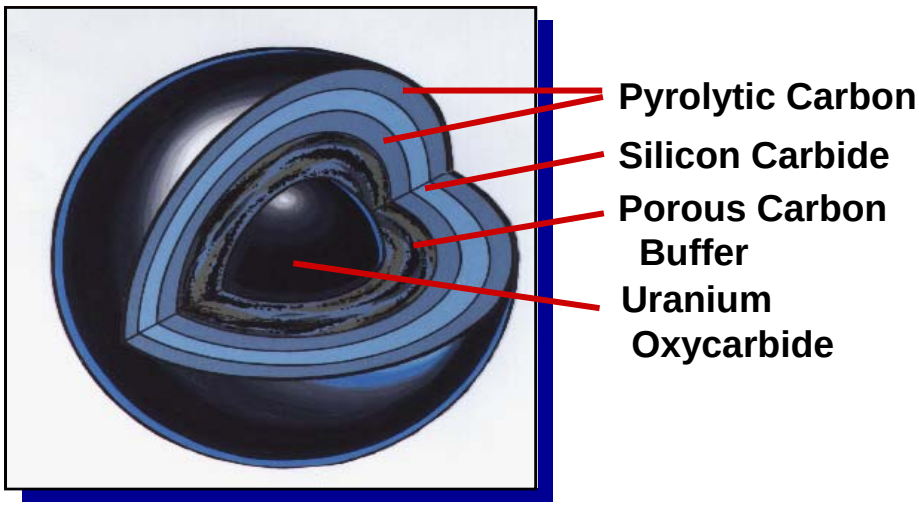
- **Draft Materials Selection and Qualification Program Plan, INEEL/EXT-03-01128**
- **Initial Survey of Candidate Structural Materials**
- **Initiated Irradiation of Graphite Materials at ORNL**

FY03 ACCOMPLISHMENTS (cont)

Fuel Development and Qualification

- Quality Assurance Plan, PLN-1468
- Project Execution Plan, PLN-1484
- Preliminary Fuel Product Specification, EDF-4198

- AGR-1 Conceptual Design Review Report
- Engineering Analysis of Coated Particles Under Accident Conditions using the INEEL PARFUME Code, EDF-4219
- Completed Trial NUCO Kernel Forming to Spec.



TRISO Fuel Particle

WORK IN PROGRESS FOR FY04

Programmatic & Project

- NGNP Programmatic Quality Assurance Plan (NQA-1)
- Independent Technology Review of Core Technology Options
- Co-Chair GIF VHTR R&D Steering Committee
- Update NGNP Program Management Plan
- Preconceptual Design Studies (by NE-ID)

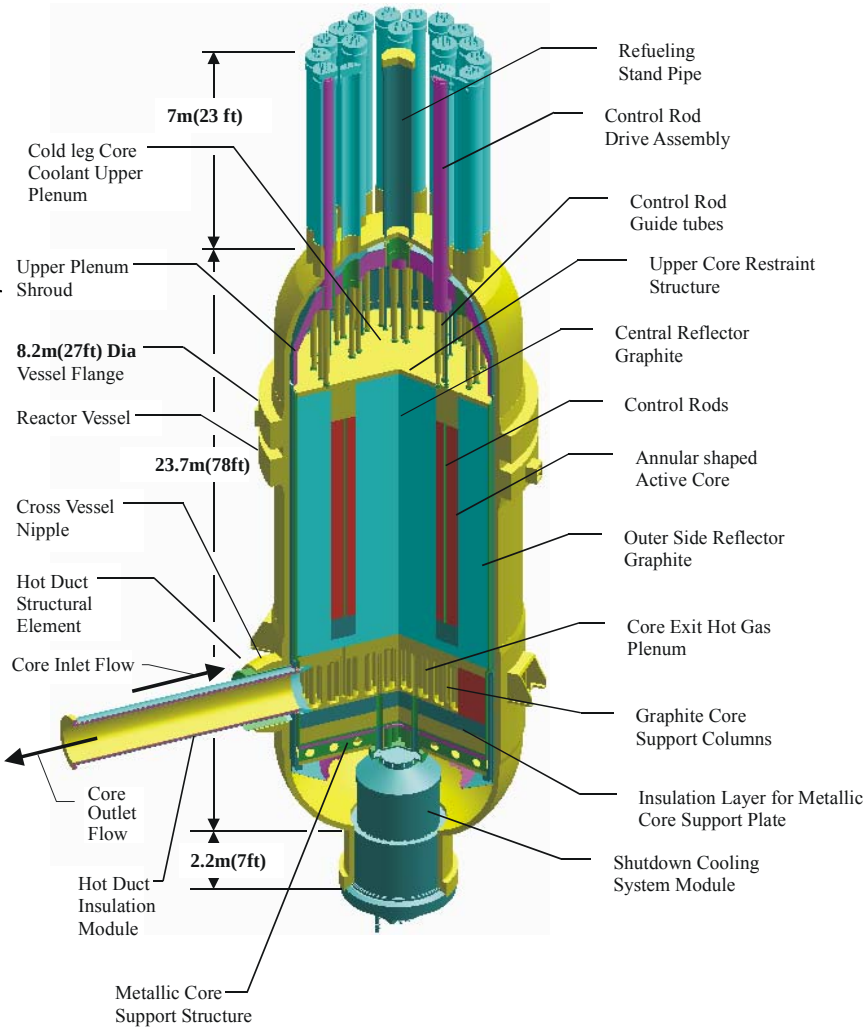
System Design and Analysis Methodology

- Prismatic Neutronic & Thermal-hydraulic Analysis to Support Fuel Specification
- Design Methodology and Evaluation Program Plan

WORK IN PROGRESS FOR FY04 (cont)

Materials Selection and Qualification

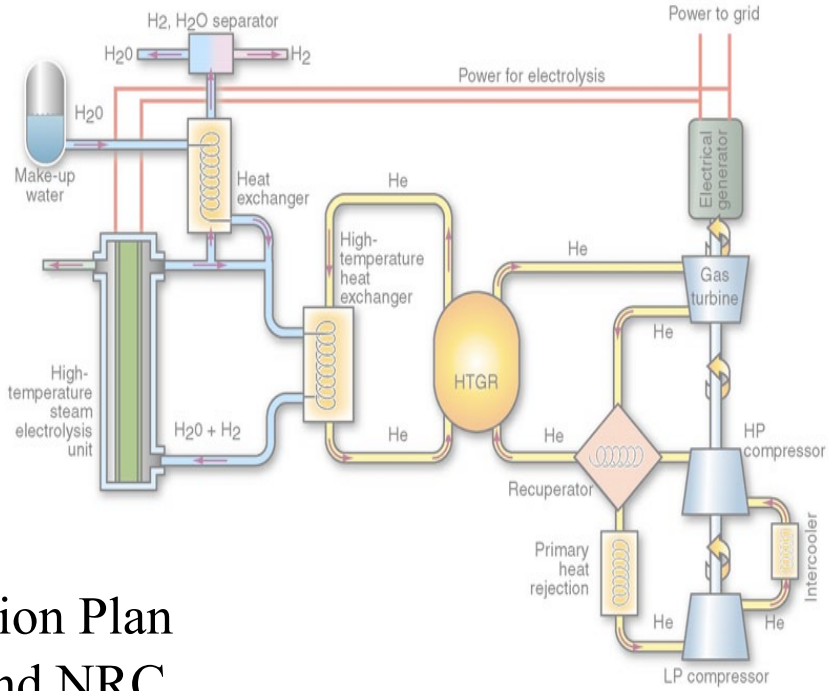
- Form Materials Review Committee (MRC)
- MRC Review of Materials Selection & Qualification Program Plan
- Continue Irradiation of Graphite Materials at ORNL
- Update Draft Materials Selection and Qualification Program Plan
- Fabricate Fuel Particles for AGR-1 Testing
- Complete Preliminary Design for AGR-1 Experiments



PLANS FOR FY05-07

Project Design

- **FY-2005**
  - Complete Preconceptual Design Report (NE-ID)
  - Initiate NEPA Actions
- **FY-2006**
  - CD-0, Approval of Mission Need
  - Initiate Conceptual Design
  - Initiate Hazards Analysis
- **FY-2007**
  - Complete Conceptual Design
  - Complete Project Risk Analysis
  - Complete Preliminary Project Execution Plan
  - Initiate Environ Permitting Actions and NRC Construction Permitting



PLANS FOR FY05-07 (cont)

System Design and Analysis Methodology

- **FY-2005**
  - Reactor Physics Phenomena Computer Code Acquisition & Development
  - Reactor Physics Methods Validation and Integral Testing
- **FY-2006**
  - Reactor Physics Phenomena Computer Code Acquisition & Development
  - Reactor Physics Methods Validation and Integral Testing
  - Definition of Phenomena Identification Ranking Table (PIRT) for Tools
- **FY-2007**
  - Reactor Physics Phenomena Computer Code Acquisition & Development
  - Reactor Physics Methods Validation and Integral Testing
  - Complete Separate Effects Experimental Program

PLANS FOR FY05-07 (cont)

Fuel Development and Qualification

- **FY-2005**
  - Complete Final Design, Fabrication and Assembly of AGR-1 Experiment
  - Fabricate LEU UCO Kernels for AGR-2, 3 & 4
  - Fabricate fuel compacts for AGR-1
  - Initiate Design for Production Scale Coater
- **FY-2006**
  - Initiate AGR-1 Irradiation Test
  - Complete Production Scale Coater Design and Testing
  - Fabricate Coated particles for AGR-2, 3 & 4
- **FY-07**
  - Fabricate Compacts for AGR-2,3,4
  - Complete Final Design, Fabrication and Assembly of AGR-2 Experiment

FUEL PARTICLES

COMPACTS

FUEL ELEMENTS

PLANS FOR FY05-07 (cont)

NGNP Research Program (to be discussed in the breakout sessions)

- **Validation of reactor physics and core design analyses tools**
- **Development and validation of reactor thermal-hydraulic and mechanical design analyses tools**
- **Power-conversion unit assessments**
- **Materials research**
- **Safety and risk analyses**

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

Dr. Mike Cappiello

Gen IV Initiative

Lead-Alloy Liquid-Metal-Cooled Fast Reactor

Los Alamos National Laboratory

Workshop for Universities
Hilton Hotel, Gaithersburg, MD
March 4-5, 2004

Lead-cooled Fast Reactor Program

- **Objective is small nuclear energy system for deployment in remote locations and in developing countries**
- **Desired attributes include**
  - proliferation resistance through long core lifetime, passive safety, modular factory construction, semi-autonomous load following
- **R&D elements are directed toward definition of the reference system and then selected to provide design information**
- **Design and R&D will be focused by preparation of a defendable safety case for the reactor system, which be subsequently used in licensing**
- **Envisioned licensing approach includes licensing through testing of a demonstration unit**

LFR Research Includes the Following

- **Materials**
  - Screen/assess Pb/Pb-Bi compatibility of materials with known or anticipated acceptable irradiation performance
  - Pb/Pb-Bi Coolant Technology
- **Coolant chemistry**
  - Flow measurement & modeling
  - Thermal hydraulic characteristics in representative geometries
- **System Design & Evaluation**
  - Long-life core design
  - Thermal hydraulic design for passive safety, natural circulation, and autonomous load following
- **Institutional and Deployment Issues**
  - Deployment and economic analysis
  - Non-proliferation requirements & assessment

FY03 ACCOMPLISHMENTS

- **Reactor Design & Coolant Technology**
  - Determined LFR attributes and recommend priorities for LFR R&D
  - Prepared LFR R&D plan
  - Sealed core reactor issues framework established
  - Licensing and safety approach document issued
  - First ultrasonic Doppler velocimetry measurement of LBE flow in DELTA
- **Materials**
  - Draft a materials needs document
  - Draft an irradiation testing needs document
  - Materials Screening Tests
    - Corrosion testing of MA957 ODS and SiC-SiC at 800°C in lead
    - Corrosion testing of ODS and V-4Cr-4Ti at 550°C in LBE
- **Institutional & Deployment Issues**
  - Economic studies initiated

WORK IN PROGRESS FOR FY04

- **Preconceptual trade studies**
  - Core design scoping studies, thermalhydraulic design, fuel form design studies, ± of SCO_2 Brayton cycle conversion
- **Deployment and institutional studies**
  - Mission/market evaluation
  - Evaluate Licensing and Safety Approach
- **Draft system requirements**
- **Operate DELTA loop; report on experiments, operation and corrosion test results**
- **Evaluate use of material coatings**
- **Prepare coolant technology development plan**
  - Including Pb vs. Pb-Bi considerations
- **Update LFR 10-Year Program Plan Draft, with input to LFR Material Selection and Qualification Plan**

PLANS FOR FY05-07 (shown as milestones)

- **FY05**
  - Establish point design for subsequent concept development
  - Issue document of economic requirements and proliferation-resistance principles
- **FY06**
  - Issues design and data needs document
  - Establish controllable range of oxygen content in lead/LBE
  - Update safety and licensing approach
  - Establish fuel qualification strategy
- **FY07**
  - Interim SCO_2 design requirements for LFR
  - Determine feasibility of autonomous load following concepts
  - Submit concept paper on implementation of fuel cycle centers

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

Dr. Kevin D. Weaver

Gen IV Initiative

Gas-Cooled Fast Reactor (GFR)

Idaho National Engineering and Environmental Laboratory

Workshop for Universities
Hilton Hotel, Gaithersburg, MD
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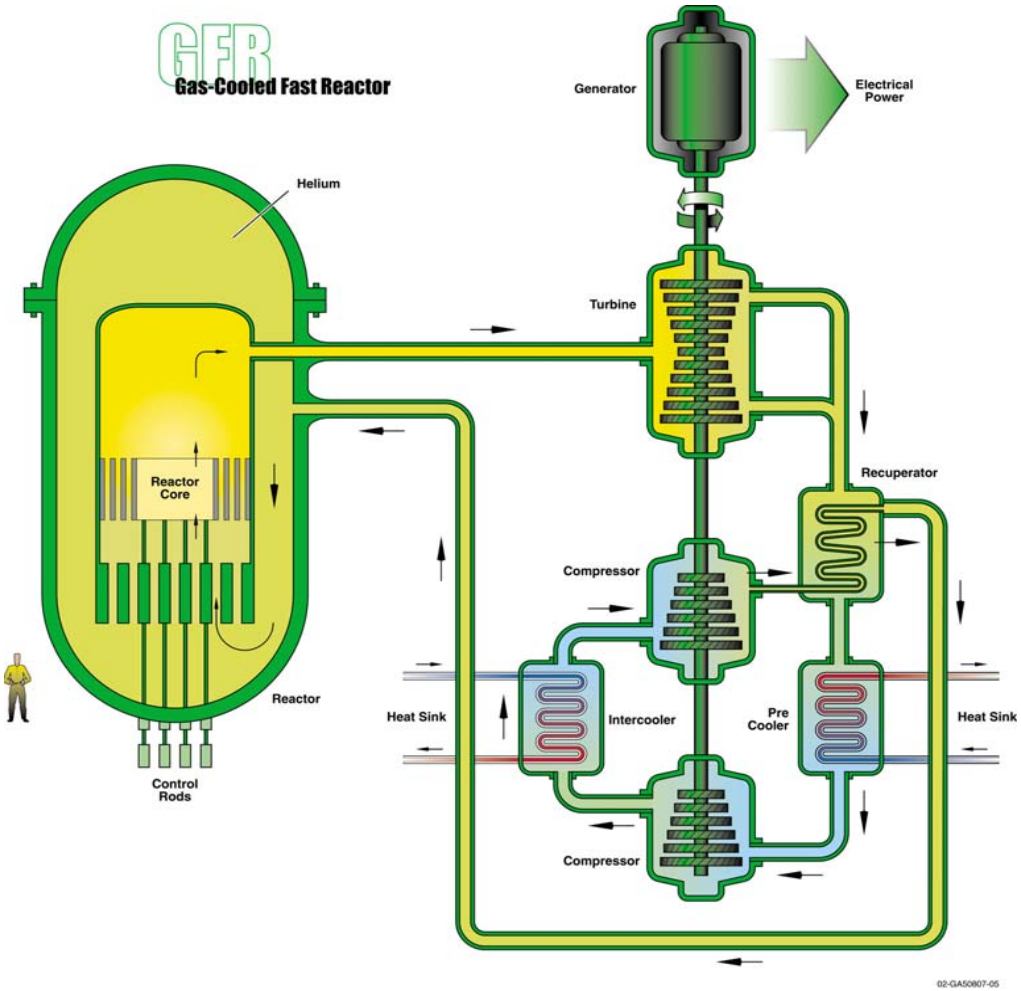
GFR Objectives

- High level of safety
- High sustainability with a closed fuel cycle and full TRU recycle
- Fast- spectrum core
- Direct Brayton cycle, high-efficiency energy conversion
- Production of H_2
- Estimated deployment time: 2025



THIS RESEARCH AREA INCLUDES

♦ GFR Design and Safety

- Define GFR reference design features (fuel technology, coolant, unit power) and operating parameters (power density, temperatures)
- Identify safety systems capable of decay heat removal

♦ GFR Fuels, Core Materials, and Fuel Cycle Processes

- Identify fuels and core materials capable of high temperature operations, high fission product confinement, and reasonable burnup/fluence
- Identify and test fuel treatment and refabrication processes

FY03 ACCOMPLISHMENTS

- **System Design and Safety**
  - Identification of possible passive/semi-passive decay heat removal systems
- **Materials**
  - Identification and initial testing of high temperature materials
  - Identification of CO_2 compatible materials, and initiation of supercritical CO_2 radiolysis
  - Initiated ODS steel joining studies
- **Energy Conversion**
  - Development of supercritical CO_2 power conversion cycle
- **Fuels and Fuel Cycle**
  - Identification of high temperature fuels
  - Preparation of candidate fuel matrix material irradiations

WORK IN PROGRESS FOR FY04

- **System Design and Safety**
  - Optimization of lead candidate safety systems
- **Materials**
  - Continuation of supercritical CO_2 radiolysis experiments
  - Continuation of ODS joining studies
- **Fuels and Fuel Cycle**
  - Initiation of fuel modeling work
  - Irradiation of candidate fuel matrix materials

PLANS FOR FY05-07

- Thermal-hydraulic and physics analysis
- Measurement of thermo-mechanical (physical properties) of candidate materials
- Materials testing
- Fuel performance modeling
- Ion and neutron irradiation of fuel matrix materials
- Preparation for fuels irradiations

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

Dr. Hussein S. Khalil

Gen IV Initiative

Design and Evaluation Methods

Argonne National Laboratory

Workshop for Universities
Hilton Hotel, Gaithersburg, MD
March 4-5, 2004

THIS RESEARCH AREA INCLUDES

- **Design and safety analysis capabilities: modeling approaches, computer codes, databases**
  - Specify analytical capabilities needed to design Gen IV systems and characterize their performance
  - Assess the adequacy of existing tools
  - Implement and qualify required improvements
- **Methodologies for evaluating performance against the Generation IV goals**
  - Economics—need to assess proponents' claims
  - Proliferation Resistance and Physical Protection—need to establish and gain consensus for a systematic methodology
  - Others (e.g., sustainability)

FY03 ACCOMPLISHMENTS

- **Workshops on Gen IV analysis needs and capabilities**
  - Three workshops organized and conducted in FY 2003:

Reactor physics design analysis	Feb 18-19, at ANL
T-H and safety analysis	Mar 18-19, at INEEL
Nuclear data needs	Apr 24-25, at BNL

  - Attended by lab, university and industry representatives
  - Conclusions and recommendations documented in record for each workshop and in FY 2003 milestone report
  - Outcome factored into ten-year program plan for Gen IV D&EM
  - International workshop on reactor physics planned in conjunction with PHYSOR Topical Meeting (April 2004, Chicago)

FY03 ACCOMPLISHMENTS

- **Developed and documented an initial (skeletal) PR&PP assessment methodology**
  - Terminology (PR, PP, intrinsic features, extrinsic measures, …)
  - Threat characteristics (actor, motivation, aspirations, capabilities)
  - High level measures to express a system's PR and PP, e.g.,
    - PR: "Acquisition time," minimum time required to overcome the multiple barriers to acquisition of the first significant quantity
    - PP: "Adversary delay," the time required to overcome intrinsic barriers to access and disable a vital equipment target set (radiological sabotage), or to remove materials (theft)
  - Probabilistic pathway analysis method for assessing system response
  - Progressive evaluation approach (qualitative → increasingly quantitative)

FY03 ACCOMPLISHMENTS

- **Implemented and documented revisions to existing capital, production and FC cost models, for application to Gen IV systems**
  - Eliminated or generalized system- and country-specific assumptions (e.g., treatment of depreciation tax shield)
  - Adopted uniform assumptions, e.g., concerning cost categories, commodity prices, labor rates, financial discount rates, licensing approach/costs, site requirements, plant capacity factor
  - Standardized approach for calculating total and levelized capital costs, O&M costs
  - Developed better models for contingency and learning effects

WORK IN PROGRESS FOR FY04

- **Work on analysis methods is directed mainly to meeting design development and safety confirmation needs of the NGNP**
  - Identification and documentation of relevant data and integral benchmarks (coordinated with relevant international efforts)
  - Assessment and improvement of deterministic reactor physics analysis tools
  - Identification of important phenomena and databases for T-H and system dynamic codes (also benefits GFR)
- **PR&PP expert group is further developing the assessment methodology through application to an example case "E-SFR"**
- **EMWG activities**
  - Developing specifications for an integrated economic model
  - Software implementation of the methodology and associated (international) databases
  - Initiating work on sub-models for non-electricity energy products and plant scale optimization

PLANS FOR FY05-07

- **Identify and report on integral experiments applicable to validating nuclear data and analysis methods (focus on GCRs and LFR)**
- **Identify and prioritize phenomena to be represented in T-H and safety analysis codes; compile relevant differential data, correlations and integral measurements**
- **Implement and qualify improvements to**
  - Monte Carlo and deterministic capabilities for neutronic, fuel depletion, and material damage (dpa, gas generation) analyses
  - T-H and coupled codes for system design and safety evaluations
- **Develop, implement and integrate economic evaluation models (e.g., non-electricity products)**
- **Further develop, test and release PR&PP evaluation methodology**

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

Dr. Bill Corwin

Gen IV Initiative

Materials

Oak Ridge National Laboratory

Workshop for Universities
Hilton Hotel, Gaithersburg, MD
March 4-5, 2004

THIS RESEARCH AREA INCLUDES

- Selection, development, and qualification of structural materials needed to design and build the advanced reactors being developed within the Gen IV Reactor Program
- These activities are part of the Gen IV Reactor Program and are closely coordinated with similar structural materials research for the AFCI and NHI Programs
- Materials needs will be addressed for the NGNP, GFR, SCWR, and LFR reactor systems, as well as for their energy conversion systems

FY03 ACCOMPLISHMENTS

- **Several Assessments of Materials Needs, R&D, and Qualification Plans Completed**
  - **NGNP Materials Selection and Qualification Program Plan**
  - **Survey of Materials Experience and R&D Needs to Assess Viability for SCWR**
  - **LFR Survey of Materials Research and Development Needs**
  - **Crosscutting R&D Plan For Development of High-Temperature Structural Design Technology for Gen IV Reactor Systems**
  - **Modeling and Microstructural Analysis: Needs and Requirements for Generation-IV Fission Reactors**
  - **Initial Generation IV Reactors Integrated Materials Program Plan**

FY03 ACCOMPLISHMENTS

- **Limited Experimental Materials Studies Were Also Initiated**
  - **Irradiation assessment of available nuclear graphites begun for NGNP service**
  - **Initial corrosion testing for SCWR applications demonstrated significant challenges remain**
  - **Materials were selected and corrosion exposure begun in Pb-Bi for LFR applications**
  - **Joining studies of advanced ODS alloys were begun for GFR applications**

WORK IN PROGRESS FOR FY04

$3015K, 16 Work Packages, 7 Organizations

1. **Materials for Radiation Service (ORNL)**
2. **Materials for High-Temperature Service (ORNL)**
3. **Microstructural Analysis and Modeling (ORNL)**
4. **High-Temperature Design Methodology (ORNL)**

5.-14. **Reactor-Specific Materials Technologies (ORNL, INEEL, ANL, LANL, LLNL, U. of Wisc., U. of Mich., Auburn, MIT)**

15. **Materials for Energy Conversion (ORNL)**
16. **National Materials Program Management (ORNL)**

WORK IN PROGRESS FOR FY04

Crosscutting Materials Work Packages

- **Develop GFR and NHI Materials Needs and R&D Plans (ORNL, INEEL, SNL, UNLV)**
- **Hold NE/SC Workshop on Impact of High-Performance Computing on Irradiation Modeling (ORNL)**
- **Complete Low-Flux RPV Irradiation Site Selection (ORNL)**
- **Initiate Gen IV Materials Database (ORNL, LANL)**
- **Assess Status of and Needs for Microstructural Models for Gen IV (ORNL)**
- **Develop Preliminary High-Temperature Simplified Design Methods for Gen IV (ORNL)**

WORK IN PROGRESS FOR FY04

Reactor-Specific Materials Work Packages

- **NGNP Materials–Materials Selection & Qualification Planning and Graphite Irradiations (ORNL, INEEL)**
- **GFR Materials–Materials Selection & R&D Planning, CO_2 Radiolytic Decomposition, and ODS Materials Joining (ORNL, INEEL, Auburn, MIT)**
- **SCWR Materials–Water Chemistry Control, Corrosion and SCC in SCW (ORNL, U. of Wisc., U. of Mich.)**
- **LFR Materials–Materials & Coolant Selection & R&D Planning, Corrosion in Pb-Bi, and Review of Surface Modification & Alternate Corrosion Control Methods (ORNL, ANL, LANL, LLNL)**

MATERIALS CROSSCUTTING PLANS FOR FY05-07

- Low-dose scoping irradiations of materials and PIE of RPV candidate materials
- Establishment of database for candidate materials for all Gen IV reactor systems
- Initiate high-temperature materials scoping studies and codification
- Modify models for nucleation of extended irradiation-induced defects & their evolution and initiate targeted supporting irradiations
- Develop initial data and rules for very high-temperature usage of leading Gen IV candidate materials, modified 9Cr-1Mo steel (Grade 92) and Alloy 617

REACTOR-SPECIFIC MATLS PLANS FOR FY05-07

- High-temperature testing, irradiations, and compatibility assessment of NGNP materials
- Develop initial simplified high-temperature design rules for NGNP components
- Materials compatibility of ODS alloys, refractory metals, and ceramics for GFR
- Mechanical properties and corrosion screening and initiate irradiation experiments for SCWR and LFR

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

Dr. Paul Pickard

Gen IV Initiative

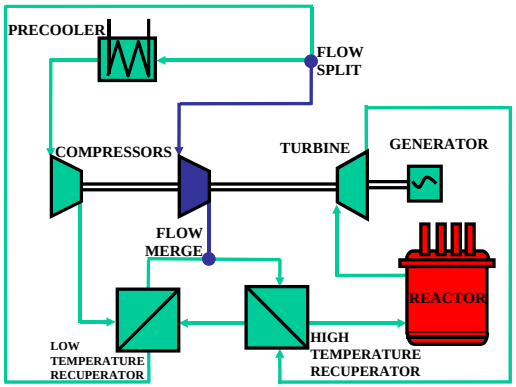
Energy Conversion

Sandia National Laboratories

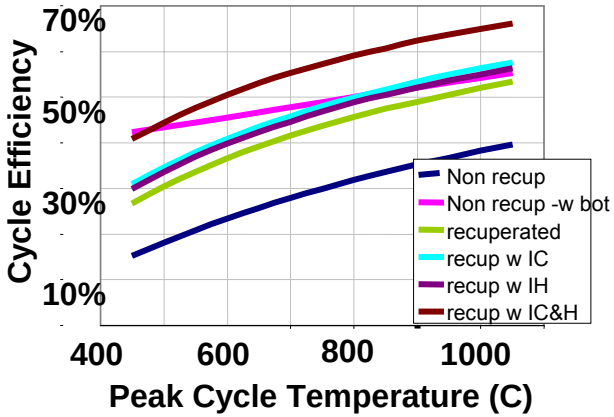
Workshop for Universities
Hilton Hotel, Gaithersburg, MD
March 4-5, 2004

GEN IV ENERGY CONVERSION RESEARCH AREA INCLUDES

- **Supercritical CO_2 Brayton cycles ~550-700 C. (GFR, LFR, SFR, MSR)**
  - System design studies
  - CO_2 TM design studies
  - Cost assessment



- **High-temperature He Brayton cycle options for improved efficiency. (~1000 C - VHTR)**
  - Inter-stage heating (IH)/cooling (IC)
  - Economic analysis to assess cost
  - Turbo-machinery (TM) design
  - NGNP power conversion options (FY04)



FY03 ACCOMPLISHMENTS

- **Supercritical CO_2 Brayton cycle**
  - Optimization scheme for gas turbine cycles
  - Adaptation of TM codes for near critical operating conditions
  - Selection of recompression CO_2 cycle, and identification of optimum operating conditions
  - Preliminary design – 47% (net) @ 650 C
  - Preliminary layout for 300 MW_e plant
- **High-Temperature He Brayton cycle options study**
  - Inter-stage heating, cooling efficiency improvement assessment for He, CO_2 and N_2
  - Comparison of cycle efficiencies as function of inlet temperature and configuration

WORK IN PROGRESS FOR FY04

- **Supercritical CO_2 cycle**
  - Turbine – compressor design studies
  - Thermodynamic and component optimization
  - Preliminary CO_2 cycle economic analysis
- **High-Temperature Brayton cycle options assessment**
  - IH, IC, heat exchanger (HX), and turbine compressor configurations
  - Scoping cost estimates for configuration options
- **NGNP power conversion options assessment**
  - Identify system and technology options and requirements
  - Options – direct/indirect, single/multi-shaft, etc.
  - Engineering trade studies for NGNP power conversion options

PLANS FOR FY05-07

- **Supercritical CO_2 Brayton cycle**
  - Complete system design, economic assessment for 300 MW_e CO_2 plant
  - Engineering – seals, ducting, materials, heat exchangers
  - Supercritical CO_2 Brayton demonstration experiment – validate key features of SC CO_2 cycle
    - Design FY05, fabricate FY06 and FY07

- **High-Temperature He Brayton cycle**
  - Design studies for turbo-machinery and heat exchangers
  - Engineering analysis - IH, IC configurations
  - Design small-scale demonstration experiment (turbo-machinery, HX)

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

Dr. Paul Pickard

Nuclear Hydrogen Initiative

Thermochemical Cycles

Sandia National Laboratories

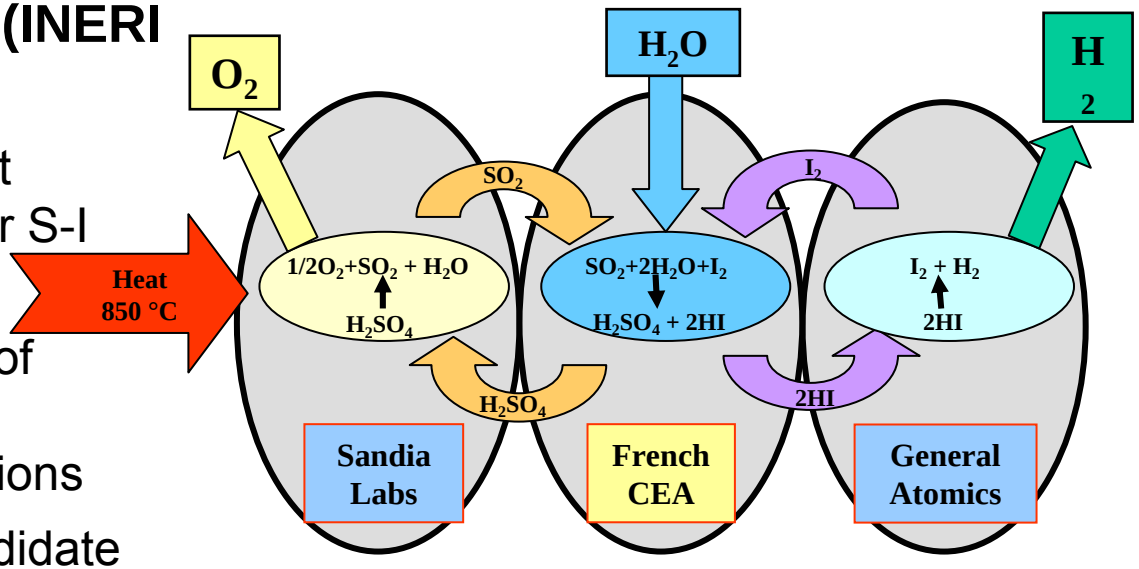
Workshop for Universities
Hilton Hotel, Gaithersburg, MD
March 4-5, 2004

NHI THERMOCHEMICAL CYCLE RESEARCH AREA INCLUDES

- **Thermochemical cycles (TC) for nuclear application**
  - Sulfur based cycles – Sulfur-Iodine (S-I), Sulfur- Bromine, Hybrid Sulfur
  - Calcium-Bromine cycles – UT-3, variants of UT-3
  - Alternative cycles with potential for operation at lower temperatures or that have higher efficiency
- **Flowsheet Methodology**
  - Consistent flowsheet methodology for comparison of thermochemical cycles
- **High-temperature interface requirements for heat exchangers and materials**

FY03 ACCOMPLISHMENTS

- **NHI Program Planning**
  - Nuclear Hydrogen R&D Plan (as part of Gen IV)
- **High-temperature heat exchanger studies (UNLV)**
- **Sulfur-Iodine cycle (INERI – CEA, GA, SNL)**
  - Develop component reaction sections for S-I process
  - Preliminary design of H_2SO_4 and HI decomposition sections
  - Assessment of candidate high-temperature materials



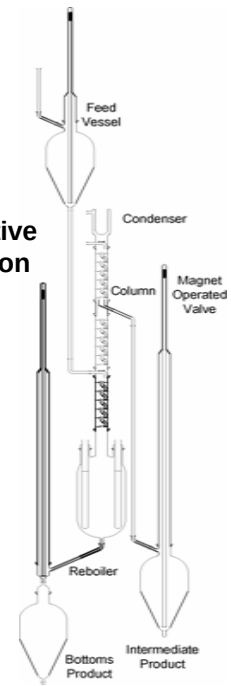
- **High-temperature heat exchanger studies (UNLV)**

WORK IN PROGRESS FOR FY04

- **Flowsheet Methodology Assessment**
- **Sulfur-Iodine Cycle**
  - S-I process flowsheet analysis for alternative designs
  - Conduct laboratory-scale experiments for HI and H_2SO_4 sections, including materials testing, design and fabrication
  - Membrane assessment for high temperature separations
- **Hybrid Sulfur**
  - Conceptual design, including electrolyzer technology assessment
- **Calcium – Bromine Cycle**
  - Flowsheet analysis of UT-3, modified UT-3 cycles
  - Conceptual design for most promising Ca-Br cycle

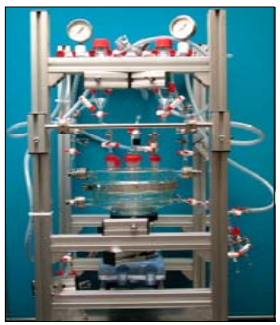
PLANS FOR FY05-07

- **Lab scale demonstration of candidate processes for pilot plant scaling**
  - Sulfur-Iodine
    - Component reaction tests
    - Integrated lab scale experiments
  - Hybrid Sulfur
    - Electrolyzer scale experiments
  - Calcium -Bromine
    - Substrate materials testing
    - Lab-scale experiments



HI Reactive Distillation Column

H2SO4 Boiler Decomposer



Primary Reactor (CEA)

- **Alternative thermochemical process evaluation**
- **Membrane development to increase process efficiency**

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

Dr. Steve Herring

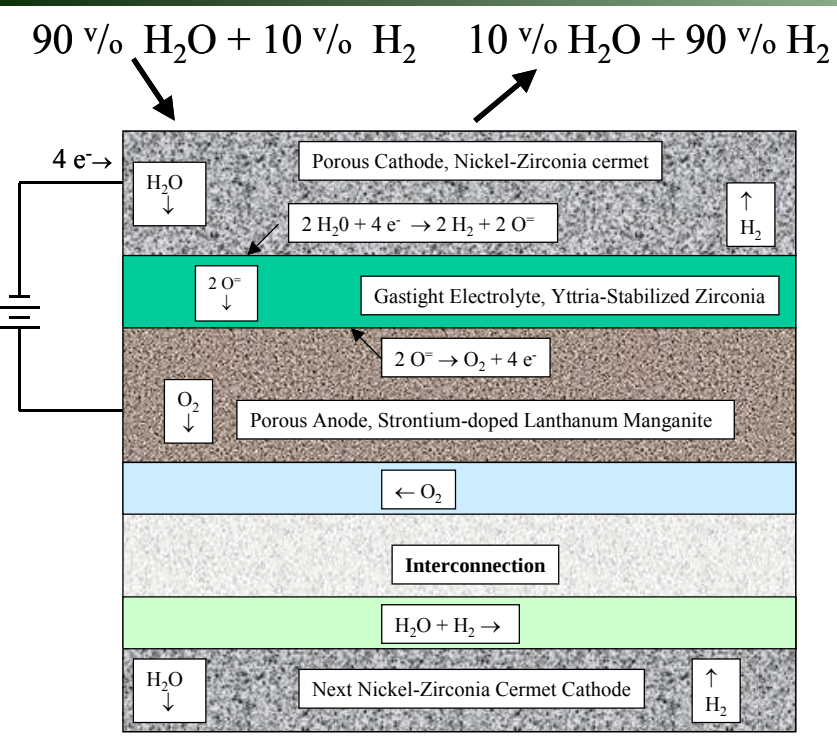
Nuclear Hydrogen Initiative

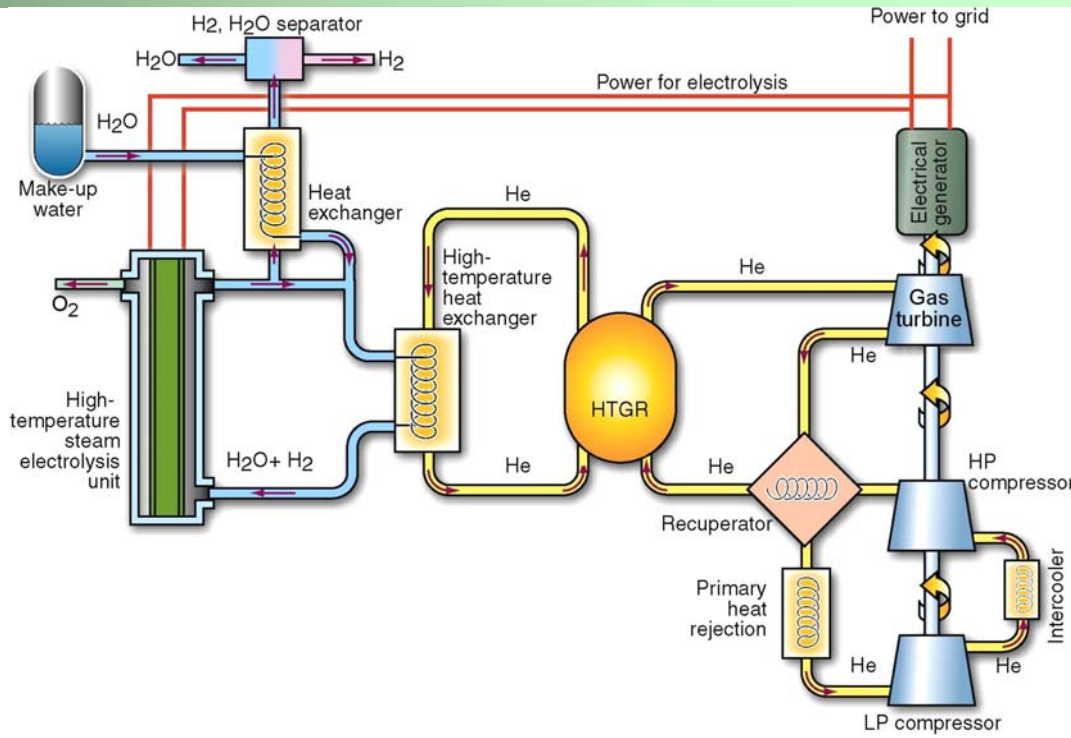
High Temperature Electrolysis

Idaho National Engineering and Environmental Laboratory

Workshop for Universities
Hilton Hotel, Gaithersburg, MD
March 4-5, 2004

Research on High Temperature Electrolysis Includes

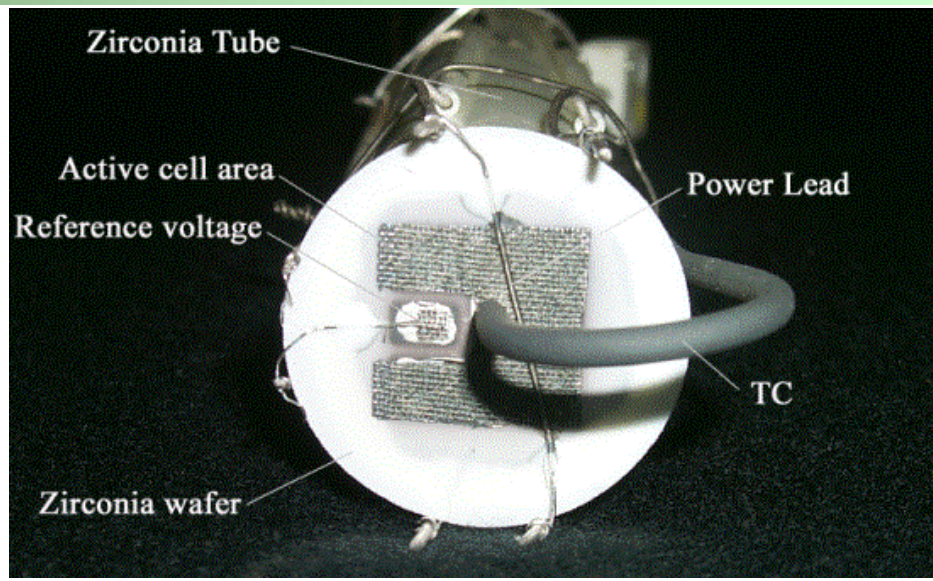


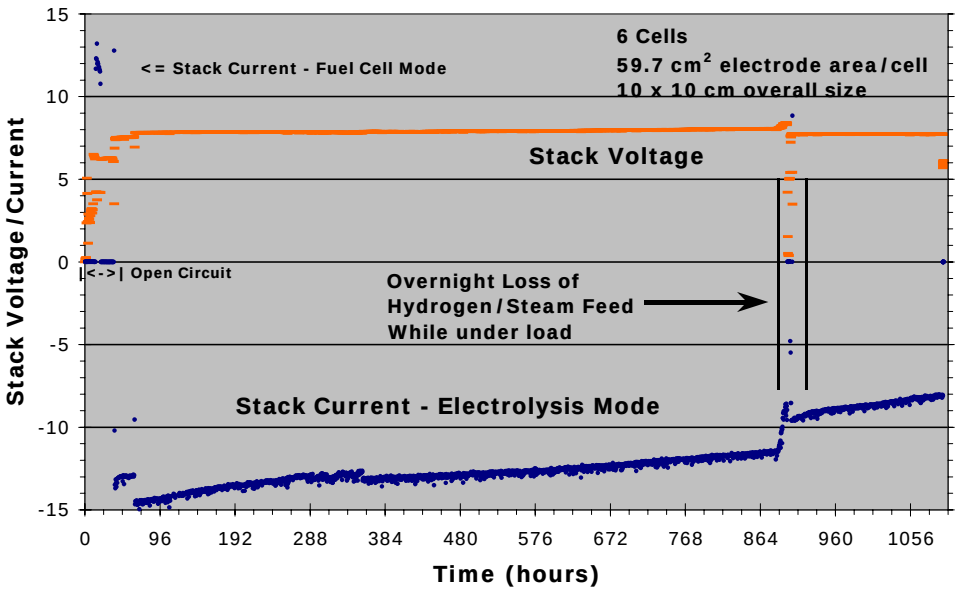


- Cell and stack experiments
- Design of lab-scale, pilot, demo and commercial plants
- Modeling of cell and plant dynamics
- Materials for cells, heat exchangers and separations

FY03 ACCOMPLISHMENTS

- Began experiments Jan 2003
- Button cell tests with yttria stabilized zirconia, LSM.
- Various electrode materials

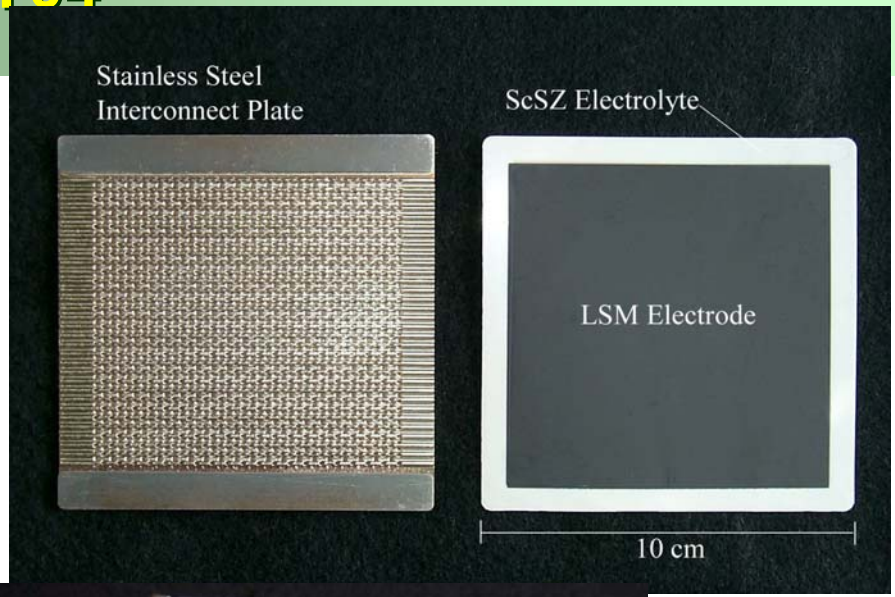


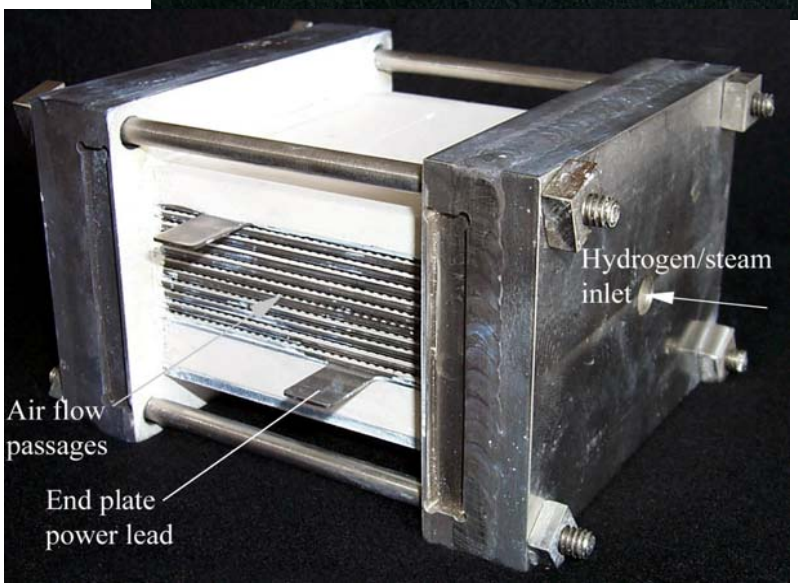


- 6-cell stack test produced 32 normal liters/hr for ~1100 hours, Oct-Nov.

WORK IN PROGRESS FOR FY04

- Complete button cell testing of candidate materials
- Continue stack tests
- Conceptual design of commercial plant, including support components
- Design of integrated bench (50 kW) and pilot plant (500 kW)
- Analyze materials performance





PLANS FOR FY05-07

- Complete HTE cell testing (05)
- Complete HTE stack / module tests (06)
- Complete design of integrated laboratory test (50 kW) (06)
- Complete assembly of integrated laboratory test for 2008 operation (07)
- Start pilot plant-scale experiment design for 2011 operation (07)
- High temperature heat exchanger and separations demo tests (06)

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

Dr. Charles V. Park

Nuclear Hydrogen Initiative

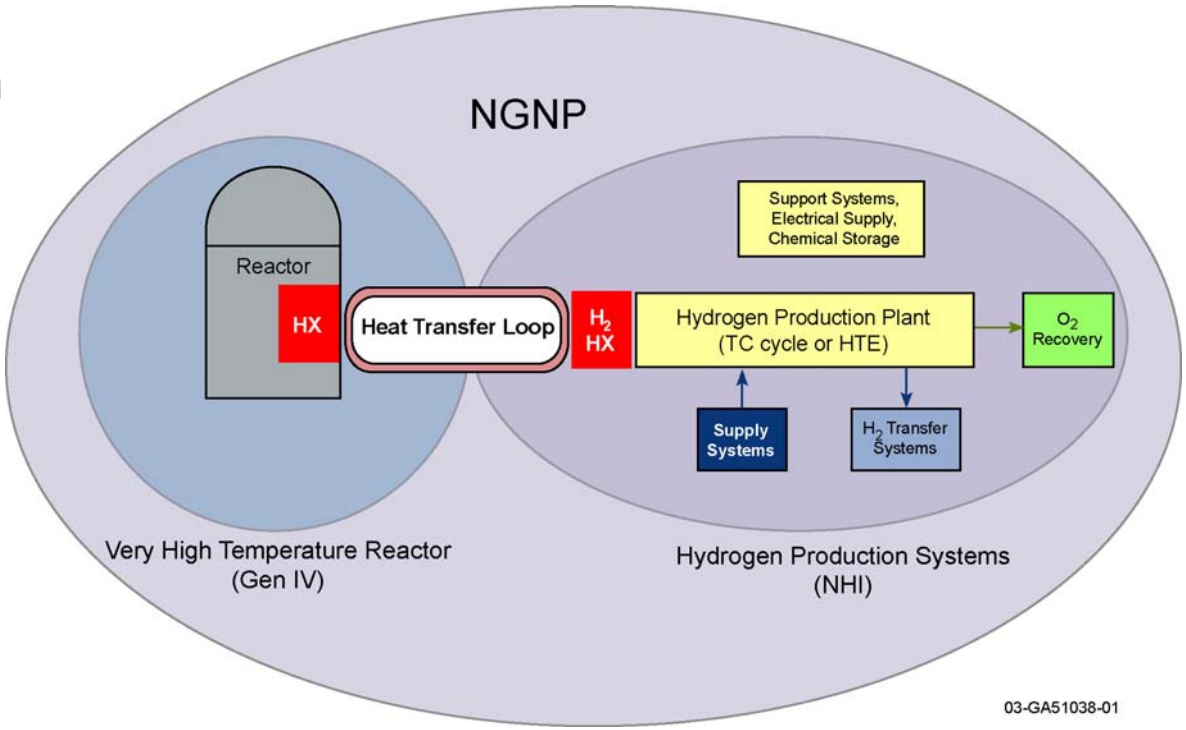
Reactor – Hydrogen Production Process Interface

Idaho National Engineering and Environmental Laboratory

Workshop for Universities
Hilton Hotel, Gaithersburg, MD
March 4-5, 2004

RESEARCH ON REACTOR-PROCESS INTERFACE INCLUDES

- **Process-side high-temperature heat exchanger (HX)**
- **Implications of intermediate heat transfer loop on process**
  - Heat transfer medium (corrosion, isolation, connection, etc)
- **Support systems**
  - Hydrogen and oxygen management
  - Control systems



FY03 ACCOMPLISHMENTS

- **Developed 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 the intermediate loop
- Complete initial <u>configuration studies</u> to define balance of plant components and systems for thermochemical or high-temperature electrolysis systems
- Complete high-level <u>infrastructure and facilities requirements</u> assessment for pilot scale experiments
- Complete assessment of <u>candidate facilities</u> and associate infrastructure for pilot scale demonstrations

PLANS FOR FY05-07

- **Laboratory-scale HX development for various high-temperature hydrogen production processes**
  - Design
  - Materials testing
  - Fabrication
  - Long-term HX materials testing
- **System support**
  - Process, infrastructure and facilities requirements assessment for pilot plant
  - Interface and Balance of Plant design for pilot plant