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

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Design and Evaluation Methods

Argonne National Laboratory

Workshop for Universities
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TOPICS: Design Analysis Methods

- **Design and safety analysis capabilities: modeling approaches, computer codes, databases**
  - Specify analytical capabilities needed to design Gen IV systems and characterize their performance
  - Identify and document relevant benchmark tests
  - Assess the adequacy of existing tools
  - Implement and qualify required improvements
- **Examples of modeling needs**
  - Validation of nuclear data for minor actinides, non-standard reactor materials
  - Representation of double heterogeneity of coated particle fuels
  - Accurate modeling of spectral transition regions at core/reflector interface
  - Simulation of small cores with significant global transport effects

TOPICS: Design Analysis Methods

- **Examples of modeling needs (cont'd)**
  - Reliable estimation of materials damage parameters for in-core and ex-core structures
  - Accurate resolution of SS and transient power, flow, and temperature distributions (reduce hot channel factors)
  - Simulation of systems with moving fuel (PBRs, MSRs)
  - Modeling of natural and mixed convection flows and flow regime transitions
  - Reliable estimation of reactivity feedback from expansion or displacement of reactor components
  - Confirming effectiveness of passive decay heat removal paths and systems (RCCS, RVACS)
  - Adequately simulating the progression and consequences of accident scenarios (e.g., SG tube rupture in LFR, air or water ingression in VHTR)

TOPICS: System Evaluation Methodologies

- **Methodologies for evaluating system 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., more comprehensive evaluation of sustainability)

TOPICS: Evaluation Methodologies, cont'd

- **Key needs in economics evaluation**
  - Standardized approach, yet with flexibility to treat specific features of different markets and systems
  - Represent new characteristics of Gen IV systems, e.g.,
    - Generation of hydrogen and other energy products
    - Closed fuel cycles with new processes implemented in centralized or on-site recycle facilities
    - Actinide management
  - Support evaluations of system cost estimates and optimization of economic performance

TOPICS: Evaluation Methodologies, cont'd

- **Key needs in PR&PP evaluation**
  - International consensus methodology (and related terminology)
  - Sufficiently comprehensive treatment
    - Consider the entire system and life-cycle of materials
  - Identify features of materials, processes, and facilities that contribute to increased PR&PP
  - Formulate limited number of high-level indicators of PR and PP
    - Aggregation of highly diverse characteristics that are inherent to the system (intrinsic features) and its protection (extrinsic measures)

Relationship to DOE-NE Program Priorities

- **Thrust of the Generation IV International Forum (GIF) is to develop and demonstrate the Generation IV systems**
  - vs. generic R&D
  - System committees formed for VHTR(NGNP), SCWR, GFR, LFR, and SFR
  - US participates in all, with NGNP receiving highest priority and funding
- **Early focus is on resolving key viability/feasibility questions**
- **Conceptual design development is an integral part of the R&D**
  - Provide focus for technology development (fuels, materials, processes)
  - Insure compatibility/integration of different technologies
  - Provide basis for evaluating performance

Relationship to DOE-NE Program Priorities

- **Analysis methods improvements needed to**
  - Accommodate “new” features of Gen IV systems
  - Reduce need for experimental programs and measurement of integral characteristics
  - Support design development and optimization
  - Characterize safety performance and accident behavior for regulatory review/licensing
- **Evaluation methodology advances needed to**
  - Measure performance relative to Gen IV goals
  - Provide basis for selecting among system options (e.g., prismatic vs. pebble VHTR, PV vs. PT SCWR, …)
  - Support funding requests (e.g., to OMB, Congress)
  - Attract commercial participation in system design and demonstration

ACCOMPLISHMENTS: Analysis Methods

- **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)

Workshop Findings and Conclusions

- **Existing tools largely adequate for pre-conceptual design and viability phase analyses**
- **Some modeling extension and improvement needs identified, e.g.,**
  - Modeling of natural and mixed convection flows
  - Modeling of flow mixing in outlet plenum of VHTR and GFR
  - Plant control and safety impacts of hydrogen (co-)generation
  - Re-evaluation of minor actinide data for high burnup and closed fuel cycle evaluations
  - Representation of double heterogeneity of coated-particle fuel in neutronic calculations
- **Some methodological improvements are needed, e.g.,**
  - Uncertainty propagation in Monte Carlo depletion analysis
  - Better representation of coupled phenomena
- **Need to preserve specifications and measured results of past experiments**
- **Need for systematic approach to prioritize future efforts**
  - International standard problems
  - Use of sensitivity and uncertainty analysis tools
  - Expert identification and ranking of phenomena

ACCOMPLISHMENTS: Economic Modeling

- **Implemented 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 documented in FY 2003 milestone report "*Cost Estimating Guidelines for Generation IV Nuclear Energy Systems*"**
  - Rev 0 report under review by GIF Expert Group
  - Report will be revised to reflect group's progress

ACCOMPLISHMENTS: PR & PP Evaluation

- **Formulated and documented methodology requirements**
- **Developed/adopted consensus terminology (consistent with IAEA)**
  - PR, PP, intrinsic features, extrinsic measures, …
- **Developed and documented an initial (skeletal) PR&PP assessment methodology**
  - Threat characteristics (actor, motivation, aspirations, capabilities)
  - High level measures to express a system's PR and PP
  - Probabilistic pathway analysis method for assessing system response

Threats → ***System Characteristics*** → ***Outcomes***

PR&PP Measures

  - Progressive evaluation approach (qualitative → increasingly quantitative)
- **Initial methodology documented in December 2003 report "*Progress Report on the Development of an Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems*"**

ACCOMPLISHMENTS: PR Measures

- ***Proliferation Technical Difficulty*** – inherent sources of difficulty that increase the technical sophistication and materials handling capabilities required to overcome the multiple barriers to material acquisition by diversion or undeclared production, processing to directly usable form, and fabrication of nuclear explosives
- ***Proliferation Resources*** – economic and manpower investment required to overcome the multiple technical barriers to proliferation including the use of existing or new facilities
- ***Proliferation Time*** – minimum time required to overcome the multiple barriers to proliferation; i.e. the total time planned by the State for the project
- ***Fissile Material Quality and Quantity*** – total quantity or rate at which potentially weapons-usable material with specified characteristics can be acquired by the State and the degree to which the quality of the material affects its utility for use in nuclear explosives
- ***Detection Time*** – the time following the initiation of diversion or undeclared production, for detection resources to detect irregularities and to provide adequate confirmation that diversion or undeclared production has occurred or is occurring
- ***Detection Resources*** – manpower, technology, and funding required to apply international safeguards

ACCOMPLISHMENTS: PP Measures

- ***Operational Accessibility*** – the frequency and duration of access to vital equipment, systems, and zones, required for operations, surveillance, and maintenance activities performed by privileged personnel.
- ***Adversary Delay*** – the time required to overcome intrinsic barriers to accessing and disabling a vital equipment target set (radiological sabotage) or to removing materials (theft);
- ***Consequences and Mitigation Potential*** – the consequences of a failure to neutralize a threat, and the potential for mitigation of those consequences;
- ***Detection Time*** – the time required, after intrusion by outsiders or unauthorized action by insiders, for physical protection system alarms to be received and verified;
- ***Interruption Delay*** – the additional delay time created by protective force response prior to neutralization;
- ***Physical Protection Resources*** – the manpower, capabilities, and costs required to provide physical protection (background screening, detection, interruption, and neutralization) and the sensitivity of these resources to the changes in the threat sophistication and capability.

WORK IN PROGRESS FOR FY04: Analysis Methods

- **FY04 work on analysis methods is directed mainly to meeting design development and safety confirmation needs for the NGNP**
- **Work packages**
  - **Program Technical Direction (A0801)**

    Planning and oversight of work, reporting on progress, coordination with other DOE programs (AFCI, NERI, I-NERI), development of international collaborations, …
  - **Modeling Improvement (A0802 and I0802)**

    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)

    Participation in planning of French CEA critical experiments (MASURCA facility)

WORK IN PROGRESS FOR FY04: Analysis Methods

Comparison of Lattice Codes for Cross Section Generation for NGNP

	MICROX	DELIGHT	WIMS8	DRAGON	APOLLO	MCNP
Solution Options	CP	CP	CP/ S_n /MOC	CP/MOC	CP/MOC/ S_n	Monte Carlo
Energy Groups	193 (pointwise data for resonances)	111	172 or 69	172/69 or variable	172	Continuous
Problem Geometry	Unit cell	Unit cell	Whole assembly	Whole assembly	Whole assembly	General
Treatment for double heterogeneity (DH)	Yes	Yes	Yes	Yes	Yes	Explicit particles
Geometry of DH treatment	1-D cylindrical cell	1-D cylindrical cell	1-D cylindrical cell	Assembly	Assembly	Full geometry
Usage Issues	Lacks assembly modeling	Lacks assembly modeling. ENDF/B-III and IV data	Separate unit cell and whole assembly calculations	No library distributed (allows various types)		σ's at limited temperatures. Lattice modeling of particles
State of Use	Used for high temperature reactor designs	Used for HTTR (Japan) design	Not extensively used	Not extensively used	Not extensively used	Generally used
Availability	At code centers	At code centers	Commercial code	Open distribution	CEA-France code	At code centers
Testing of Model, V&V	IAEA benchmarks. Reactor startup. Critical experiments	Critical experiments and reactor startup	IAEA benchmarks	Comparison to MONK and WIMS8. IAEA benchmarks	Code-to-code comp. IAEA benchmarks. Critical experiments	IAEA benchmarks. Critical experiments and reactor startup

CP: Collision probability
MOC: Method of Characteristics
S_n: Discrete Ordinates

WORK IN PROGRESS FOR FY04: Economics Modeling

- **FY 2004 EMWG activities**
  - **Developing specifications for an integrated economic model**
  - **Software implementation of the methodology and associated (international) databases**
  - **Verification testing of software (MS Excel and Fortran programs)**
  - **Initiating work on sub-models for non-electricity energy products and plant scale optimization**

- **Work Packages**
  - **One DOE Laboratory WP (O0803)**

    Supports participation of K. Williams (ORNL)
  - **Contracts administered by NE-ID (D0803)**

    Support industry and university participants

    G. Rothwell (Stanford U economist) is an EMWG member

WORK IN PROGRESS FOR FY04: PR & PP

- **Further developing the assessment methodology through application to an example case "E-SFR"**
- **Work Packages**
  - **DOE Laboratories**

    A0804: Supports participation of J. Roglans (ANL) as technical director of the PR&PP expert group

    Y0804: Supports application of methodology by BNL to an example case (ALWR once-through fuel cycle)
  - **Contracts administered by NE-ID (D0804)**

    Support industry and university participants

    University participants are P. Peterson (UC Berkeley, co-chair) and M. Golay (MIT)
- **Group additionally has US participants sponsored by the NNSA (NA-241), GIF sponsored participants, and representatives of US-DOS, US-NRC, and the IAEA**
  - R. Bari (BNL) and R. Nishimura (AECL, Canada) are co-chairs

PLANS FOR FY05-07

- Improve NGNP analysis capabilities and their validation status
  - Deterministic lattice physics and whole-core diffusion/depletion tools
  - Benchmarks based on measurements in critical facilities and operating reactors
  - System code for modeling coupled phenomena in transient and accident scenarios (coordinated with NGNP system design and evaluation activities)
  - Assessment of CFD simulation for modeling complex flows (e.g., in outlet plenum)
- Define fast reactor modeling needs as GFR and LFR designs are further specified
  - Available tools generally adequate for viability phase scoping analyses
  - Perform selected assessments to further define needs for modeling closed FR fuel cycle, e.g.,
    - Use of integral measurements to test nuclear data for minor actinides, GFR fuel matrix materials, Pb, Bi
    - Preparation of covariance data for actinides to support assessment of data related uncertainties in predicted reactor and fuel cycle parameters

PLANS FOR FY05-07

- **Advance evaluation methodologies for application to Gen IV systems and selection of preferred system options**
  - **Economics: Models for non-electricity energy products and for comparing economics of small modular vs. large monolithic plants**
  - **PR&PP: Methods for "calculating" PR&PP measures**

Key FY 2005 Milestones

- **Identify and document integral experiments applicable to validating nuclear data and analysis methods**
- **Identify and prioritize phenomena to be represented in T-H and safety analysis codes; compile relevant data, correlations and integral measurements**
- **Develop economic evaluation model for non-electricity energy products**
- **Verify application of PR&PP methodology to Generation IV nuclear energy systems**

PLANS FOR FY05-07, cont'd

Milestones for FY2006 - FY2007

- **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**
- **Further develop, test and release PR&PP evaluation methodology**

Budgets for FY 2003 and FY 2004

Allocation by Organization ($K)

	ANL	BNL	INEEL	ORNL	Contracts w/ university & industry participants
D&EM Technical Direction					
FY 2003	100				
FY 2004	100				
Design Analysis Methods					
FY 2003	275		0		
FY 2004	360		125 +150*		
Economic Evaluation					
FY 2003				50	210
FY 2004				75	180
PR & PP Evaluation					
FY 2003	100	0	50		190
FY 2004	100	150	0		100

** From NGNP budget*