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Subject: Presentation to the ACRS Subcommittee on HTGR Fuels Research

Attached are the handouts for the subject presentation. The plan will continue to evolve over the summer to address program office input, prioritization activities, budget decisions, ACRS comments, etc.

The final version of the plan sent to the Commission this fall will reflect these inputs.

Stu

CC: John Flack

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Advanced Reactor Research Plan: HTGR Fuel Analysis

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Outline

- Fuel Safety Objective
- Fuel Safety Research Issues
- Purpose of Fuel Safety Research
- Scope of Planned Research
  - Irradiation Testing
  - Accident Condition Testing

- Analytical Codes and Methods Development
- Fabrication Knowledge and Information

- Expected Regulatory Applications

HTGR Fuel Safety Objective

The fuel safety objective is to reliably contain and retain the radiologically important fission products within the TRISO coated fuel particles during all reactor conditions within the licensing basis. These conditions are: (1) normal operation; (2) design-basis accidents; and (3) potential severe accidents beyond the design-basis.

Fuel Safety Research Issues

- Completeness of previous **irradiation test** conditions (margins)
- Completeness of previous **accident condition test** conditions (margins)
  - Core heat-up performance and limits
  - Prompt supercritical reactivity pulse behavior and limits
  - Chemical attack performance behavior and limits
- **Fabrication** process to achieve quality and performance
  - Key process variables and acceptable ranges
  - QA product characterizations and statistical analysis methods
- Applicability of historical **testing methods**
  - Accelerated vs real-time irradiation testing
  - Ramp-hold vs actual temperature history accident condition testing
- Applicability of **performance models and methods**
  - Availability of irradiated materials property data
  - Particle failure and FP transport for mechanistic source term
- Prediction of maximum operating/accident temperatures
- Applicability of previous performance data to new fuel and plant designs
  - Q/A used for previous testing programs

Purpose of Fuel Research

- Explore limits (i.e., margins) of TRISO coated fuel particle performance and fission product retention capability
- Independently assess applicant claims of fuel performance and fission product release
- Develop information to support the review of applicant fuel qualification test plans and methods
- Develop independent tools to predict fuel fission product release and TRISO particle failure for licensing basis conditions
- Understand the effects of fuel fabrication on fuel performance

Scope of HTGR Fuel Research

- Irradiation testing
- Accident condition testing
- Analytical models and methods
- Fabrication process knowledge and information
- Staff technical expertise and information

Objectives for HTGR Fuel Irradiation

and Accident Condition Testing

- Explore the limits/margins of fuel performance and fission product retention capability during irradiation and accidents
- Support evaluation of applicant fuel qualification program irradiation and accident condition test plans, methods and results
- Support development of independent analytical tools to predict fuel performance during operations and accidents
  - TRISO coated particle failure models
  - Fission Product transport/release models (source-term)

Potential Fuel Performance-Limiting Factors

- Pressure induced ("Pressure Vessel") particle failure (E)
- Fission product diffusion through coatings and matrix graphite (E)
- Coating defects arising from manufacture (e.g., "weak fuel") (M)
- Kernel/coating interactions (fuel "kernel migration") (E)
- SiC disassociation, increased porosity (at high temperature) (E)
- Fission product chemical interaction with SiC (e.g., Pd attack) (E)
- Matrix graphite interactions with coated particles (E)

- Heavy metal contamination of the graphite matrix or OpyC (M)
- Chemical attack (e.g., oxygen) of silicon carbide layer (E)
- Large energy deposition (reactivity pulse) (E)

Explore the Limits/Margins of Fuel Performance and Fission Product Retention Capability

<u>Irradiation Conditions Beyond the Expected Design Basis</u>:

- Irradiation Temperature
- Burn-up
- Fast Fluence

- Coated Fuel Particle Power level

Explore Limits/Margins of Fuel Performance and Fission Product Retention Capability (Cont.)

Monitor Fission Gas Release During Irradiations:

- Diffusion through intact coating particles and matrix
- Release from failed coated particles

Conduct Post-Irradiation Examinations:

- Characterize fuel condition, particle failure mechanism(s)

Evaluate Applicant Fuel Irradiation Test Methods

- Accelerated vs Real-Time Irradiation Testing
- Obtain Knowledge/Experience in Irradiation Testing

Explore the Limits/Margins of Fuel Performance and Fission Product Retention Capability

Accident Conditions: Beyond the Expected Licensing Basis:

- Heatup Events:
  - Fuel Irradiated Beyond Design Conditions
  - Temperatures Beyond the Design-Basis
- Reactivity Events:
  - Bounding Supercritical Reactivity Pulse
- Chemical Attack Events:
  - Fuel Irradiated Beyond Design Conditions
  - Oxidation Beyond the Licensing-Basis

Explore Limits/Margins of Fuel Performance and Fission Product Retention Capability (Cont.)

Monitor Fission Product Release During Accident Simulations:

- Diffusion through intact coated particles and matrix
- Release from failed coated particles

Conduct Post-Accident Simulation Examinations:

- Characterize fuel condition, particle failure mechanism(s)

Evaluate Applicant Fuel Qualification Accident Condition Testing Methods

- Accident condition heat up testing method:
  - Ramp-up and hold at constant temperature
  - Temperature vs time accident simulation
- Obtain knowledge/experience in accident condition testing

HTGR Fuel Testing Strategy

Leverage Resources with Cooperative Agreements and Technical Information Exchange:

- Cooperative Agreement with DOE
- Cooperative Agreement with the EC HTR-F
- Participate in IAEA Coordinated Research Project No. 6
- Cooperative Agreement with JAERI
- Information Exchange with INET

Objectives for Fuel Performance

Analysis Tool Development

Provide NRC staff with an independent capability to predict HTGR fuel performance:

- CFP Behavior/Failure During Normal Operation and Accident Conditions
- Fuel Fission Product Release During Normal Operation and Accident Conditions

Fuel Performance Analysis Tool Development Issues

- Coated particle irradiation and accident behavior (failure) depends on design, manufacture, irradiation environment
- PyC irradiated material properties data (e.g., dimensional change, creep, thermal expansion, Young's modulus) have uncertainties
- Important failure mechanisms require 3-D modeling (SiC surface flaws, layer de-bonding)
- Statistical variations of key properties associated with manufacture require Monte Carlo analysis
- Chemical interaction effects need to be included (e.g., SiC palladium attack)

Strategy to Develop HTGR Fuel Performance Analysis Tools

Establish cooperative agreements with organizations currently developing HTGR fuel performance analysis tools

- INEEL PARFUME Code
- MIT Fuel Performance Code
- EC HTR-F Fuel Performance Code
- Use Data from Cooperative Fuel Testing Agreements

Fuel Performance Analysis Tool Applications

- Assess applicant's in-core fuel particle integrity calculations (supplements empirical test data used in safety analyses)
- Assess applicant's predictions of in-core fuel fission product release calculations (for source term)
- Assess causes of in-reactor fuel performance anomalies and corrective actions
- Calculate fission gas release for input to NRC reactor accident and consequence analyses

Objectives for Fuel Fabrication Knowledge and Information

Provide NRC staff with in-depth knowledge of the key factors of fuel fabrication that ensure quality and performance of fuel over the plant (fuel supply) lifetime:

- Fuel fabrication *process* factors
- Fuel *product* factors (kernel, coated particle and element)
- Fuel process and product *quality control* measures

Strategy to Acquire Fuel Fabrication Knowledge and Information

- Cooperative agreement with the EC (HTR-F)
- Information exchange with DOE and ORNL on particle coating technology development
- Information exchange with INET (China) and JAERI (Japan)
- HTGR Pre-application review activities

Applications for Fuel Fabrication Knowledge and Information

- Input to policy decision on regulatory approach to ensure fuel quality and performance over the life of a plant
- Input to possible risk-informed performance-based fuel fabrication process/product technical specifications
- Input to risk-informed performance-based fuel fabrication inspection procedures
- Input to fuel fabrication facility inspector training

Research Products and Applications

- Review of fuel qualification programs
- Policy decision on fuel fabrication technical specifications
- Fuel fabrication facility inspection procedures
- Fuel safety limits and limiting conditions for operation
- Fuel condition on-line monitoring system evaluation
- Independent analysis and evaluation of fuel safety performance (licensing, operating experience)
- Fuel design and fuel process change evaluations
- Staff training on fuel technology

Summary and Conclusions

- Develops infrastructure of NRC analytical tools and data
- Explores TRISO fuel safety margins and performance
- Increases staff knowledge of key elements of fuel fabrication
- Builds on international knowledge and experience
- Centers on technical issues and research needs
- Reduces NRC resources and time by cooperative research
- Enhances NRC's capability to conduct HTGR COL reviews