NGNP Technical Issues Safety Research Needs

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Subtitle C—Next Generation Nuclear Plant Project

NGNP Reactor "Licensing Strategy"

- How *NRC's licensing requirements* for LWRs need to be adapted
- The *analytical tools* the NRC will need to develop
- Other *research and development* activities NRC will need to conduct
- Jointly submitted to Congress by Chairman and Secretary by Aug 2008

NRC's Advanced Reactor Research Plan:

- SECY 03-0059 issued on April 18, 2003
- Modular HTGR technical, safety and licensing policy issues
- Research and development needed to review modular HTGRs

Safety R & D Arenas

- Licensing framework *
- PRA analysis methods *
- Nuclear, thermal-fluid, accident analysis methods *
- Coated particle fuel performance analysis *
- Accident source term calculation and basis *
- Graphite, composite, metallic component analysis *
- Human factors and advanced I&C
- Structural performance analysis
- Consequence analysis
- Fuel cycle nuclear materials safety
- Physical and materials protection

Licensing Framework

Technical Policy Issues:

- Required level of plant safety/risk, non-LWR risk metrics
- Selecting events for the licensing (safety analysis) basis
- Use of a mechanistic accident source term and data basis
- Safety classification and special treatment of SSCs
- Defense-in-depth required for known and unknown uncertainties
- Containment functional performance requirements
- Emergency planning requirements
- Safety, security and emergency preparedness integration
- PRA quality and completeness requirements

PRA

Technical Issues:

- Event initiation frequencies (e.g., rare events)
- Passive system performance and reliability modeling
- Rare event accident progressions, human intervention
- BOP event initiators, accident progressions, consequences
- PRA modeling (e.g., event trees and fault trees)
- Ex-core radionuclide sources to be included in PRA
- Consequence, dose, risk assessment uncertainties

PRA (cont.)

Safety Research:

- Generic or design-specific risk metrics
- Initiating events and initiating event frequencies, data
- Event sequences, accident progressions, consequences
- Passive SSC failure modes, reliability, performance
- Digital I&C models; uncertainties
- Analysis of applicable SSC data including uncertainties
- Human reliability analysis for long-term operator actions
- PRA standards for non-LWRs
- PRA for other radionuclide sources, operating states, BOP

Nuclear Analysis

Technical Issues:

- Nuclear data libraries for core physics analysis
- Annular core neutronic and decay heat analysis modeling
- Multi-pass refueling, statistical pebble packing, varying burn-ups; burnable poison, fissile and fertile CFP modeling
- Water ingress, control rod ejection, shutdown system withdrawal and pebble-bed seismic compaction reactivity modeling
- Mis-loading, anomalous pebble packing/clustering event analysis
- Local power density contributions to operating local hot spots and decay-power hot spots
- Pebble statistical burn-up distribution effect on pebble fission power

Nuclear Analysis (cont.)

Safety Research:

- Phenomena Identification and Ranking Tables (PIRTs)
- Nuclear data libraries for reactor/materials safety analyses
- Develop lattice physics model for pebble bed & prismatic cores
- Develop decay heat, sensitivity and uncertainty analysis
- Validate reactor core neutronics models with test data
- Review/use databases to validate depletion and decay heat analyses
- Coupling neutronics models to thermal fluid- analysis code
- Benchmark and validate coupled code against test data

Thermal-Fluid Analysis

Technical Issues:

- Separate effects experiments, models and data
- Coupled thermal-fluid-neutronic code validation, integral tests, data
- Predicting core local hot spots (e.g., AVR melt wire results)
- Core flow distributions, flow mixing, compressible flow modeling
- Core bypass flows during power operation
- Statistical treatment of pebble heat generation rates
- Graphite thermal properties versus fluence and temperature
- Graphite oxidation rates, multi-species diffusion/flow for air ingress
- Heat exchanger tube break water flow ingress phenomena
- Core exit helium coolant “hot streaking”
- RCCS local temperatures and heat transfer

Thermal-Fluid Analysis (cont.)

Safety Research:

- Phenomena Identification and Ranking Tables (PIRTs)
- Separate-effects, local phenomena test data
- Integral test data from scaled facilities and test reactors
- Systems transient analysis code development
- Systems code V&V using benchmarks and test data
- Air ingress (severe accident) experimental data
- Coupling fission product transport models to systems analysis code

Metallic Components

Technical Issues:

- Fatigue, creep, creep-fatigue interaction
- Coolant impurities, crevice concentration impacts
- Metal carburization, decarburization and oxidation
- Sensitization of austenitic steels
- Alloy aging behavior at elevated temperatures
- Adequacy of in-service inspection plans, methods
- ASME code case, data base applicability/adequacy
- PRA failure probabilities for vessels, pipes, components

Metallic Components (cont.)

Safety Research:

- Fatigue, creep, creep-fatigue test data,
- Stress corrosion cracking test data
- Environmental characterizations
- Aging and embrittlement data
- Sensitization data
- Carburization, de-carburization, oxidation data
- ISI plans and methods, continuous monitoring
- Previous international research, information, data

Nuclear Graphite

Technical Issues:

- Coke sources, fabrication process effects on properties
- Structural qualification:
  - –Unirradiated properties data
  - –Irradiation effects: growth/shrinkage, strength, conductivity
  - –Irradiation behavior models
  - –Structural analysis methods and acceptance criteria
  - –PBR side reflector “exhaustion,” replacement
- Corrosion effects (e.g., air, water ingress)
- In-service inspection methods

Nuclear Graphite (cont.)

Safety Research:

- Graphite properties vs. irradiation, temperature, etc.
- Structural design codes/criteria, analysis methods
- Oxidation rate; effects on physical properties, strength
- Dust generation, heat generation rate, transport
- Property variation across thick vs. thin-wall components
- Consensus standards for material, design, fabrication
- ISI and surveillance methods
- Graphite dust generation/deposition data
- International R&D information, data, experience

Fuel Performance

Safety Issues:

- Qualification test program
- Fabrication quality over the fuel supply lifetime
- Fission product transport and release
- Performance analysis code/model validation
- Safety limits and/or administrative limits?
- Air ingress degradation/failures
- Operational performance monitoring

Fuel Qualification

Technical Issues:

- Selection of licensing-basis events
- Irradiation test program fuel (CFP) sample size
- Test fuel fabrication vs. production fuel fabrication
- Irradiation test conditions vs. actual in-core conditions
- Types of accidents that are simulated
- Accident test conditions vs. predicted accident conditions
- Test condition parameter biases and uncertainties
- FP release measurement biases and uncertainties
- PIE confirm/quantify behavior, predicted failure mechanisms
- Application of appropriate quality standards

Fuel Fabrication

Technical Issues:

- Necessary/sufficient product and process specifications to consistently meet fuel performance requirements
- Fabrication equipment; process instrumentation and controls
- Characterization methods
- Sampling and statistical analysis methods

Fuel Irradiation Testing and PIE

Safety Research:

- Accelerated vs. real time irradiation effects
- CFP failure rates and margins
- Failed and intact particle FP releases
- Materials properties changes of particle layers
- FP transport within the kernel
- FP transport in matrix materials
- CFP behavior/degradation; failure mechanisms

Fuel Accident Testing and PIE

Safety Research:

- "Ramp and hold" vs. transient heat-up test method
- CFP failure rates and margins
- FP release from failed and intact particles
- CFP failure rates and fission product transport with air ingress and steam ingress
- CFP failure rates and fission product transport for large rapid reactivity insertions
- CFP behavior/degradation; failure mechanisms

Fuel Performance Analysis

Technical Issues:

- Modeling relevant CFP structural, thermal, chemical interaction behavior and failure mechanisms; FP transport mechanisms
- Fuel manufacture-specific kernel and layer material, mechanical properties, fission product transport test data
- Behavior/failure models for air oxidation events
- Monte-Carlo methods for CFP variations from manufacture
- Code validation against integral irradiation and accident condition effects experimental data; PIE results
- Determination and treatment of code uncertainties and biases

Fuel Performance Monitoring

Technical Issues:

- Are there fabrication attributes that could cause “weak” fuel?
- Are there operating conditions that could “weaken” fuel?
- Can coolant activity monitoring detect weak or weakened fuel?

Source Term

Technical Issues:

- Qualified fuel that meets performance requirements
- Fuel performance analysis model (fuel integrity analysis)
- Fuel fission product transport mechanisms, models, data
  - Coated fuel particle (intact and failed, oxidation)
  - Compacts, matrix material, prismatic block, heavy metal contamination
- Primary coolant pressure boundary fission product transport mechanisms, models, data
  - Circulating activity, graphite dust
  - Plate-out, lift-off, adsorption, de-sorption, steam-induced vaporization
- Reactor building fission product transport mechanisms, models, data
- Accident analysis code suite verification and validation

Conclusion

- The NRC will need to conduct significant and challenging safety research and development in order to review and independently evaluate an NGNP license application.