PROPOSED PLAN FOR

ADVANCED REACTOR RESEARCH

Office of Nuclear Regulatory Research
March 2007

Enclosure 1

ML070740607

Technical Review Infrastructure Development Plan
(See Enclosure 2, Section III.1)

Objective: Develop the technical review infrastructure to support the review of high-temperature gas-cooled reactor (HTGR) or very high temperature reactor (VHTR) applications. This could involve aspects such as draft Standard Review Plans, draft regulatory guides, and U.S. Nuclear Regulatory Commission (NRC) licensing policy decisions related to increased use of a plant's probabilistic risk assessment (PRA) in developing the plant's licensing basis.

Selected Major Milestones and Schedule		
Major Milestone	**Target**	**Bin***
Develop technical review infrastructure		
• The development of the technical review infrastructure needs to support the review of HTGR or VHTR applications and will, in the near term, be informed by the technical review infrastructure development needs identified by the NGNP licensing strategy. Should the NGNP licensing approach provide for greater use of probabilistic information for establishing the NGNP licensing basis (e.g., selection of licensing-basis events, selection of safety-related SSCs) of the sort proposed by PBMR, Pty. Ltd., for the PBMR, the staff will develop a specific research and development (R&D) plan to identify the technical review infrastructure that will be needed to support the review of the applicant's proposed approach for making greater use of the PRA. The development of this infrastructure will be based on the staff's completed work on developing the technology-neutral framework, stakeholder comments on the framework, PBMR preapplication review insights, and Commission policy decisions.	TBD	1,2,3

*The NRC staff organized each activity into one or more of the following four bins:

(1) Develop adequate staff technical knowledge, expertise, and capabilities to independently review and effectively evaluate the acceptability of the application, including the safety analysis and the technical basis for the safety analysis.

(2) Independently confirm the technical basis for the requirements and criteria needed for plant licensing as well as the regulatory guides and Standard Review Plans needed for developing an acceptable application and an effective and efficient staff review.

(3) Develop an independent analytical capability to confirm both safety analysis evaluation methods and safety analysis results as well as the adequacy of proposed resolutions of safety issues and/or the development of the technical basis for staff-proposed reactor safety enhancements.

(4) Adequately confirm or interpret existing technical information for which there is significant uncertainty or adequately validate and scope out technical issues involving significant safety or risk implications to justify the need for followup resolution by the applicant.

(See Enclosure 2, Section III.2.1.1)

Objective: Develop the necessary review guidance to ensure the applicant's PRA is of sufficient technical acceptability to support the licensing basis. this could involve development of PRA tools and data.

Selected Major Milestones and Schedules		
Major Milestones	**Target**	**Bin**
Develop HTGR PRA regulatory guidance and standard review plan • Develop the regulatory guidance and standard review plan for HTGR PRAs that provides an acceptable approach for determining whether the PRA is of sufficient technical adequacy to support its use in licensing of HTGRs (e.g., PBMR, NGNP reactor). This guidance should of sufficient scope and detail so that the staff review will result in (1) a focused and consistent review process in determining the technical acceptability of the PRA, and (2) an understanding of the strengths and weaknesses in the plant design, and ultimately its operation, as it relates to public health and safety. In conjunction with this guidance, development of the necessary standards, associated detailed technical guidance, and data will be developed, particularly in such areas as passive systems, digital instrumentation and control, accident progression. • Development new tools and methods as needed to support the development of the review guidance and standard review plan.	TBD	1, 4
Develop PRA tools and insights, as needed, to support review of operating HTGRs. • Develop baseline probabilistic systems analysis tool (SPAR model) in support of PBMR or NGNP operations oversight. • Incorporate data and generate insights to support staff evaluation of PBMR or NGNP operational events.	TBD	4

Instrumentation and Controls Research and Development Plan
(See Enclosure 2, Section III.2.1.2)

Objective: Develop realistic evaluation methods to identify and assess technical and safety issues as they apply to advanced reactor instrumentation and controls (I&C) systems such as those for the PBMR, NGNP reactor, fast liquid metal reactors and other Global Nuclear Energy Partnership (GNEP) facilities. Investigate capabilities that could potentially provide new methods for ensuring system safety.

Selected Major Milestones and Schedules		
Major Milestones	**Target**	**Bin**
Analyze the requirements and potential safety issues involved with HTGR instrumentation. • Review the requirements for, and the development of, new instrumentation to support licensing reviews of the design, construction, and operation of an HTGR. Develop a better understanding of how the requirements were developed and what review methods are the most appropriate for new neutron detectors, temperature sensors, and other components in reactors such as the PBMR and NGNP reactor. Support the review of needed prototype plant instruments for use in HTGRs. • Provide revisions to regulatory review guidance.	TBD	3
Analyze the requirements and potential issues involved with NGNP reactor, advanced burner reactor and other GNEP facility instrumentation. • For NGNP and GNEP review the requirements for, and the development of, new instrumentation for monitoring very high temperatures and the process heat, hydrogen, and other unique aspects of these reactor systems. Develop the review guidance needed to support licensing of plants with these instruments. Investigate potential modifications of review guidance to support the review of these instruments. • Provide revisions to regulatory review guidance.	TBD	3
Develop models for autonomous control of advanced reactors. • Develop information and models needed to review and examine advanced autonomous control methods that will be used in advanced reactors. Review current methods used in other technologies, (e.g., natural gas power stations). • Provide revisions to regulatory review guidance.	TBD	3

Analyze control systems used to integrate the control of multiple module plants and review advanced control algorithms that may be used in safety systems in advanced reactors. • Investigate the degree to which, and the way in which, systems will be integrated in advanced reactor plants with multiple reactor modules. Investigate the points at which control and safety systems are integrated and the level of automated actions. Develop information on the current methods likely to be used in advanced reactors and investigate the potential issues associated with these algorithms when used in a reactor setting. • Provide revisions to regulatory review guidance.	TBD	3

Human Factors Research and Development Plan
(See Enclosure 2, Section III.2.1.3)

Objective: Develop methods and tools to evaluate advanced reactor human factors issues. Emphasize issues that involve various levels of change (e.g., dynamic function allocation, degraded I&C, and the role of the operator).

Selected Major Milestones and Schedules		
Major Milestones	**Target Dates**	**Bin**
Human Factors Engineering Methods and Tools (Dynamic Function Allocation and Operator Performance/Workload Modeling) • Use workload modeling of operations personnel to understand the capabilities and limitations of operators who have a variety of functions in the control and management of automated systems.	TBD	4
Disturbance and Emergency Management • Provide guidance regarding reactor operations under degraded I&C conditions.	TBD	3
System Maintenance and Change Management • Assess the effects on operations, maintenance, and training of more frequent changes attributable to design obsolescence.	TBD	3
Role of Personnel and Automation • Develop review guidance for computerized procedures.	TBD	3
Plant Design and Construction • Evaluate the human performance aspects of the design and evaluation of digital systems and software.	TBD	3
Normal Operations Management • Determine the impact of new designs on the safety culture.	12/12	4
Normal Operations Management • Develop guidance for the review of intelligent human-system interfaces. • Identify human-system interface issues for advanced reactors that are not included in NUREG-0700, Revision 2, "Human-System Interface Design Review Guidelines," issued May 2002, and determine need for review guidance revisions.	TBD	3

Nuclear Analysis Research and Development Plan*
(See Enclosure 2, Section III.2.2.2)

Objective: Develop independent technical insights and validated nuclear analysis tools to support HTGR and VHTR design certification and combined license reviews in the area of reactor nuclear analysis and associated fuel cycle and waste activities.

Selected Major Milestones and Schedule		
Major Milestones	**Target**	**Bin**
Develop Phenomena Identification and Ranking Tables (PIRTs)		
• Conduct Phenomena Identification and Ranking Tables (PIRTs) to identify and prioritize phenomena important to nuclear analysis for HTGR reactor, materials, and waste safety.	TBD	3
Adapt and validate lattice physics depletion code and T/H-coupled core neutronics simulator code for three-dimensional (3D), steady-state, and kinetics analysis of prismatic block and pebble bed HTGRs		
• Identify and examine physics issues. Use available codes to perform scoping and sensitivity studies of HTGR physics analysis issues and uncertainties in relation to safety margins.	TBD	1, 2
• Develop, test, and maintain nuclear data libraries. Use A Modular Code System for Processing X-Sections (AMPX) to process current data in the Evaluated Nuclear Data File, Volume B, into Shielding and Criticality Analysis for Licensing Evaluation (SCALE) continuous-energy and multigroup master libraries.	TBD	
• Adapt, test, and maintain lattice physics depletion code SCALE/Transport Rigor Implemented with Time-Dependent Operation for Neutronic Depletion (TRITON) for pebble bed and prismatic block HTGR core configurations.	TBD	
• Adapt, test, and maintain 3D core simulator code Purdue Advanced Reactor Core Simulator (PARCS) for pebble bed and prismatic block HTGR core configurations and operations.	TBD	
• Couple and test adapted PARCS code models to T/H code models for pebble bed and block-type HTGRs (GRSAC, MELCOR).	TBD	
• Analyze code-to-data and code-to-code benchmarks to qualify and validate TRITON-PARCS for pebble bed and prismatic block HTGR cores.	TBD	
• Evaluate code prediction biases and uncertainties from sensitivity and uncertainty analysis of validation benchmark results.	TBD	
• Develop and implement HTGR decay heat analysis methods and perform validation uncertainty analysis.	TBD	
• Develop and implement coupled graphite fluence damage analysis models for use in T/H and structural analyses.	TBD	
• Perform coupled T/H-neutronics analyses of HTGR steady-state operations, operating transients, and accidents.	TBD	

Nuclear Analysis Research and Development Plan (continued)

Perform literature and analytic studies to identify graphite-moderated fissionable materials and configurations potentially needing consideration in criticality safety evaluations for front- and back-end fuel cycle activities. Adapt and validate nuclear analysis codes and models for criticality safety analysis of HTGR fuel materials and spent fuels.	TBD TBD	1, 2
Adapt and validate nuclear analysis codes and models for decay heat and radiation shielding analysis of HTGR spent fuels.	TBD	1, 2

* Plan implementation activities to be closely coordinated with thermal-fluid (thermal-fluid) analysis and source term and fission product (FP) transport analysis model and tool development/validation R&D plan activities.

Thermal-Fluid Analysis Research and Development Plan
(See Enclosure 2, Section III.2.2.1)

Objective: Independently develop, validate, and verify thermal-fluid models and computer codes needed to support design certification and licensing reviews of HTGRs.

Selected Major Milestones and Schedules		
Major Milestones	**Target**	**Bin**
Develop Phenomena Identification and Ranking Tables (PIRTs)		
• Conduct PIRTs to identify, rank, and prioritize all phenomena and issues important to the development of models and codes for HTGR operational and accident condition thermal fluid analysis, including, but not limited to, molecular diffusion, natural circulation and buoyancy, graphite oxidation, pressure drop through pebble beds, core heat transfer, reactor cavity heat transfer, and reactivity insertions.	TBD	3
Develop thermal-fluid R&D action plan	TBD	3
• Using the results of the PIRTs, develop an action plan for HTGR thermal-fluid research, in close coordination with HTGR nuclear analysis, fuel performance analysis, and accident analysis staff members, that identifies tasks, schedules, and resource estimates to support HTGR safety R&D in each area.		
Implement thermal-fluid R&D action plan		
• Develop a detailed calculation framework for HTGR operational and accident condition thermal-fluid analysis based on the evaluation model concept in Regulatory Guide 1.203, “Transient and Accident Analysis Methods,” issued December 2005. Identify computer codes (e.g., MELCOR, GRSAC, FLUENT) and experimental data.	TBD	1, 3
• Establish the calculation framework for using and integrating HTGR operational and accident condition thermal-fluid analysis into both the operational and accident condition fuels performance analysis methods and the core FP release and transport analysis methods.	TBD	1, 3
• Assess selected computer codes against available HTGR operational and accident condition thermal-fluid data.	TBD	1, 3
• Generate integral and separate effects data through collaboration with domestic and international organizations.	TBD	1, 2, 3
• Develop computer code models and assess code against new data.	TBD	1, 2, 3
• Develop code adequacy report for the prediction of HTGR operational and accident thermal-fluid conditions.	TBD	1, 3
Conduct parametric studies		
• Perform parametric studies with various computer codes as needed to reduce computational uncertainties.	TBD	3, 4

Source Term and Fission Product Transport Analysis Research and Development Plan*
(See Enclosure 2, Section III.2.2.3)

Objective: Independently develop and validate models and computer codes for calculating source term and fission product transport to support design certification review of HTGRs.

Selected Major Milestones and Schedules		
Major Milestones	**Target**	**Bin**
Develop Phenomena Identification and Ranking Tables (PIRTs)		
• Conduct PIRTs to identify, rank, and prioritize all phenomena and issues important to the development of models and computer codes for HTGR source term and fission product transport analysis.	TBD	3
Develop and validate source term and fission product transport and release analysis tool for HTGRs.		
• Identify models and experimental data needs (results from PIRT activity).	TBD	1, 2
• Implement HTGR core configuration (pebble, prismatic block fuel).	TBD	
• Expand material oxidation models.	TBD	
• Assess material oxidation models (based on licensee data).	TBD	
• Update materials properties models (based on licensee data).	TBD	
• Extend aerosols (including fuel matrix graphite dust) transport as well as fission product release and transport models (based on licensee data).	TBD	
• Evaluate the accident source term (comparable to the NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants," source term used for light-water reactors (LWRs)) for HTGR provided by the licensee.	TBD	
• Perform design-basis accident and beyond-design-basis accident confirmatory analyses.	TBD	

* Plan implementation activities to be closely coordinated with nuclear analysis and thermal-fluid analysis model and tool development/validation R&D plan activities.

Fuels Analysis Research and Development Plan
(See Enclosure 2, Section III.2.3)

Objective: Develop the necessary infrastructure to support the review of HTGR and VHTR design certification and combined license applications in the area of fuel technology. This includes methods, tools, data, and expertise that would enable independent analysis and evaluation of (1) fuel performance and fission product transport during normal operation, transients, and accidents, (2) fuel irradiation and accident simulation test programs, and (3) oversight of production fuel fabrication.

Selected Milestones and Schedules		
Major Milestones	**Target**	**Bin**
Develop fuel performance analysis tool and analyze fuel performance		
• Review/evaluate existing and available HTGR fuels codes used for predicting HTGR fuel performance and fission product transport for potential further development and use by the NRC as an independent tool for analyzing HTGR/VHTR fuel performance and fission product release. Select/obtain a reference fuels code.	TBD	1, 3
• Further develop the models for the selected codes to simulate the known significant particle failure mechanisms and transport phenomena. Obtain material, physical, chemical, and fission product transport data sets appropriate for design-specific fuels. Enter the data sets into the improved codes.	TBD	1, 3
• Benchmark codes against existing experimental failure data and release data and international benchmark studies.	TBD	1, 3
• Conduct design-specific sensitivity studies for significant design, manufacturing, operational, and accident variables influencing performance and fission product release. Assess the need/basis for fuel safety limits to ensure safety performance.	TBD	1, 2, 3
• Compare calculated fuel failure fractions and fission product releases with the measured failure fractions for fission product releases from design-specific fuel irradiation tests and accident simulation tests.	TBD	1, 3
• Conduct comparative analyses of the NRC code predictions and the applicant's code predictions for fuel failure fractions and fission product releases for selected licensing basis events.	TBD	1, 3

Perform fuel production quality and performance assurance		
• Review existing literature of descriptive information, analyses, studies, experience reports, fuel development and qualification plans, and fabrication quality assurance/quality control programs to assess the material specifications, fabrication process parameters, fabrication equipment characteristics, product specifications, product characteristics, and quality assurance/quality control aspects that are particularly important to ensuring fuel quality and performance.	TBD	1, 2
• Support the review of design-specific applicant fuel fabrication safety analysis documents for ensuring adequate fuel fabrication quality and performance and the development of a regulatory oversight program (e.g., fabrications technical specifications, inspection procedures).	TBD	1, 2
• Assess options and develop specific technical scope and content of regulatory oversight (e.g., technical specifications, inspection procedures) for production fuel fabrication facilities.	TBD	1, 2

Fuels Analysis Research and Development Plan (continued)

Major Milestones	Target	Bin
Conduct fuel irradiation testing and postirradiation examination (PIE).		
• Conduct cooperative irradiation testing to assess the applicability of traditional accelerated irradiation testing.	TBD	4
Conduct fuel accident condition testing and PIE.		
• Conduct cooperative accident condition testing to assess the applicability of traditional accident condition testing methods and accelerated testing.	TBD	4

Materials Analysis Research and Development Plan
(See Enclosure 2 Section III.2.2.4)

Objective: Develop independent capability to assess materials performance in the safe operation of HTGRs. Provide technical bases on materials issues for regulatory decisions by addressing the uncertainty in behavior of materials under HTGR environments of metals and graphite components under simulated HTGR environments.

Selected Major Milestones and Schedules		
Metallic Component Major Milestones	**Target**	**Bin**
Enable the development of national design codes and standards for metallic components in HTGRs that ensure adequate safety margins. • Participate in ASME Codes and Standards Committees tasked with developing design codes and standards for high temperature materials • Share NRC-sponsored research results with ASME Code committees in order to ensure that adequate safety margins and defense in depth philosophy are appropriately incorporated in consensus codes.	TBD	1
Develop analytical capability to determine the frequency of structural failure due to all active material degradation mechanisms. • Develop and maintain a capability to perform independent finite element stress analysis for reactor vessel and reactor internal metallic components. • Develop methods for evaluating margin of safety for structural loads that includes failure criteria and flaw tolerance limits, as appropriate. • Develop method to incorporate fluence-, where appropriate, and time-dependent materials degradation data in structural integrity assessments. • Analyze industry and other data on material degradation under HTGR environments • Validate analytical models that provide technical information for structural integrity assessments. Working in cooperation with national and international cooperative research programs (e.g., industry, DOE, and others), identify and conduct selective research to provide data and technical information that confirm technical bases for regulatory decisions. Develop and maintain independent capability to: • Evaluate analytical models and experimental data on specific degradation, such as corrosion, stress corrosion cracking, creep, and fatigue, including generation of specific data, when necessary. • Provide microstructural and other data on specific degradation mechanisms to ensure that (industry) predictive models address such mechanisms. • Assess industry data on the probability of failure of specific materials and components for risk assessment evaluations. • Share NRC-sponsored research data and technical information with the national and international consensus codes and standards community to incorporate adequate safety margins for metallic components in service.	TBD	2,3

Metallic Component Major Milestones (continued)	Target	Bin
Define inservice inspection and other surveillance needs to ensure that defense in depth is maintained and uncertainties in materials data, degradation, and structural analyses models are minimized. • Analyze industry data and international operational experience (Japanese HTTR , Chinese HTR, and others) and evaluate the efficacy of inspection methods in ensuring material and component condition required for safe operation. • On a selective basis, develop independent nondestructive and other examination capability to assess the validity of industry approaches to inservice inspection.	TBD	3
Nuclear Graphite Component Major Milestones		
Enable the development of national design codes and standards for nuclear graphite components in HTGRs. • Participate in ASME Codes and Standards Committees tasked with developing design codes and standards for high temperature materials. • Participate in ASTM standards committees tasked with developing materials specification and properties testing standards. • Share NRC-sponsored research results with ASME Code committees in order to ensure that adequate safety margins and defense in depth philosophy are appropriately incorporated in consensus codes.	TBD	1
Participate in national and international graphite irradiation experiments. Conduct a workshop to assess the status of ongoing and planned national and international graphite irradiation experiments. Identify additional specific data needs for regulatory safety information, based on operational experience of experimental reactors and U.K.'s graphite power reactors. Participate in national and international irradiation graphite irradiation programs and develop independent evaluation capability to: • Analyze industry and other data on graphite properties degradation under high fluence and high temperature. • Develop analytical models that provide technical information for structural integrity assessments. • Assess industry data on the probability of failure of specific graphite components for risk assessment evaluations.	TBD	1

Nuclear Graphite Components Major Milestones (Continued)	Target	Bin

Develop analytical capability to determine the frequency of structural failure of HTGR graphite components.
 	
• Develop and maintain a capability to perform independent finite element stress analysis for graphite components.
• Develop methods for evaluating margin of safety for structural loads that includes failure criteria and flaw tolerance limits, as appropriate.
• Develop method to incorporate fluence-, where appropriate, temperature, and time-dependent graphite materials properties in structural integrity assessments.
• Analyze industry and other data on graphite degradation under HTGR environments
• Validate analytical models that provide technical information for structural integrity assessments.
 	
Working in cooperation with national and international cooperative research programs (e.g., industry, DOE, and others), identify and conduct selective research needed to provide data and technical information that confirm technical bases for regulatory decisions. Develop independent evaluation capability to:
 	
• Analyze industry and other data on graphite properties degradation under HTGR environments.
• Evaluate analytical models and experimental data on the irradiation dependency of specific properties, such as thermal conductivity, specific heat, density, irradiation creep, and dimensional stability.
• Develop models for predicting irradiated graphite properties from as-received material properties and manufacturing process.
• Validate analytical models that provide technical information for structural integrity assessments.
• Assess industry data on the probability of failure of specific graphite components for risk assessment evaluations.
• Share NRC-sponsored research data and technical information with the national and international consensus codes and standards community to incorporate adequate safety margins for graphite components.
• Develop technical data and information on the mechanics of pebble flow.
  • Provide information on pebble movement for thermal hydraulics models and calculations, as appropriate.
  • Provide information on pebble movements to address wear and friction (tribology) that results in the generation of graphite dust.
	TBD	2,3

• Develop the capability to independently:
  • Evaluate industry or other data on high-temperature tribology of graphite pebbles and pebble graphite/moderator graphite interactions resulting in graphite dust generation and plate out
  • Evaluate the morphology of graphite dust (size and shape distribution) and establish adhesion-plate out correlations that have implications for dose calculations.
  • Evaluate (industry) air-oxidation and other severe accident loss of forced coolant (LOFC) model and data.
	TBD	2,3

Define inservice inspection and other surveillance needs to ensure that defense in depth is maintained and uncertainties in nuclear graphite properties data, degradation, and structural analyses models are minimized. • Analyze industry data and international operational experience (Japanese HTTR , Chinese HTR, and others), and evaluate the efficacy of inspection methods in ensuring graphite condition required for safe operation. • On a selective basis, develop independent nondestructive and other examination capability to assess the validity of industry approaches to inservice inspection of graphite components.	TBD	3

Carbon-Carbon and Ceramic Matrix Composite Component Major Milestones		
Working in cooperation with national and international cooperative research programs (e.g., industry, DOE, and others), identify selective research needed to provide data and technical information that provide technical bases for regulatory decisions. • Maintain staff awareness of the composite materials that are planned to be used in HTGRs. • Identify independent research needs and relevance for composite material behavior in HTGRs.	TBD	1