PROPOSED PLAN FOR

ADVANCED REACTOR RESEARCH

Office of Nuclear Regulatory Research
March 2003
Attachment 1

Advanced Reactor Framework Research Plan for non-Light-Water Reactors (non-LWRs)

Objective: To develop a technically-neutral (design independent) risk-informed regulatory structure for regulatory decision-making to protect the public health and safety. To meet this objective, four major tasks are envisioned: (1) development of a technology neutral process (guidance) for the regulatory structure, (2) subsequent derivation of technology neutral regulations, (3) formulation of guidance for applying the process on a technology specific basis, and, based on this guidance and the technology neutral regulations, (4) formulation of technology specific Regulatory Guides. Tasks (1) and (3) involve the development of a Process for Advanced Reactor Regulatory Risk-Informed Structure (PARRIS), while tasks (2) and (4) involve development of a product using the process developed in (1) and (3), respectively.

Selected Major Milestones and Schedule		
Major Milestone	**Target Dates[1]**	**Bin***
Circulate draft plan for comment	Completed	3
Implement plan to develop framework	Initiated	3
Develop rev 0 of a technology neutral guideline for regulatory structure	09/03	3
Develop rev 0 of technology neutral regulations	06/04	3
Develop rev 0 of guidance for applying framework on a technology specific basis	12/04	3
Formulate technology specific regulatory guides, revision 0	03/06	3

*Bin 1: Development and maintenance of computer codes and models (fuel behavior, reactor physics, thermal-hydraulics, severe accidents, and consequences) needed to support staff's independent assessment of an applicant's analyses and to explore issues that involve margins or are beyond the design basis.

Bin 2: Development of experimental data to validate codes and models identified above.

Bin 3: Forward-looking activities that relate to new or evolving technologies to identify issues that may become important for regulatory decisions and to provide the technical bases for regulatory requirements.

[1]TBD identifies proposed activities under management review for which a final decision has not been made.

Advanced Reactor Probabilistic Risk Assessment (PRA) Research Plan

Objective: To develop PRA methods, tools, data (including uncertainties), and expertise that is needed to support risk-informed regulatory decisions. This includes developing the approach and guidance that would be necessary to independently evaluate advanced reactor PRAs.

Selected Major Milestones and Schedules		
Major Milestones	**Target Dates**	**Bin**
Develop plan for performing PRA research on advanced reactors		3
• Circulate draft PRA plan for comment.	Completed	
• Implement PRA plan to address PRA technology gaps and issues identified in infrastructure assessment.	05/03	
• Perform assessments for advanced reactor technologies, for licensing expected to occur within the next 10–15 years, to gain insights on possible risk contributors which may require research in other areas, (e.g., thermal-hydraulic (MELCOR), assessments, consequence assessments and fuel performance. Survey risk or vulnerability studies that may have been completed by foreign designers or others to assist in these assessments. Where necessary, developing limited scope risk models will be considered.	03/05	
Develop PRA tools and insights as needed to support ACR-700 review		
• In coordination with NRR ACR PRA review plan, evaluate the state of PRA methods, data, and severe accident progression for CANDU designs to determine in what areas the current body of knowledge needs to be supplemented to support ACR-700 Design Certification Review. The current body of AECL PRA methods, data, and severe accident studies will be the starting point for this evaluation.	TBD	1
• Identify areas where additional PRA methods development, validation, or severe accident studies need to be conducted in order to provide a sound basis for the ACR PRA licensing review. In areas where the ACR vendor is unable to provide necessary enhancements, provide the systems analysis and tool development necessary to support PRA licensing review.	TBD	
• Incorporate data and generate insights to support ACR-700 design certification.	03/06	
Develop PRA tools and insights as needed to support ESBWR review	TBD	1
• Develop baseline probabilistic systems analysis tool in preparation for ESBWR design certification.		
• Develop PRA tools and insights as needed to support ESBWR review.		
• Incorporate data and generate insights to support ESBWR design certification.		
Develop PRA tools and insights as needed to support Gas Turbine-Modular Helium Reactor (GT-MHR) review	TBD	1
• Develop baseline probabilistic systems analysis tool in preparation for GT-MHR design certification.		
• Incorporate data and generate insights to support GT-MHR design certification.		

Advanced Reactor I&C Research Plan

Objective: To stay abreast of developments in the instrumentation and control (I&C) field. Develop realistic evaluation methods to identify and assess technical and safety issues as they apply to next generation reactor I&C systems. Investigate capabilities that could potentially provide new methods for assuring system reliability.

Selected Major Milestones and Schedules		
Major Milestones	**Target Dates**	**Bin**
Prepare lessons learned report on the use of modern I&C for advanced reactors		3
• Review experience that has been gained in the development, implementation, and licensing of modern I&C equipment in evolutionary reactor designs in other countries, such as the N4 and advanced boiling-water reactor, and prepare draft report	05/03 08/03	
• Assess areas where past experience has lead to implementation or licensing concerns, and provide recommendation on ways they can be avoided		
Develop new risk models for advanced I&C systems		1
• Review current methods and those under development for evaluating and modeling I&C systems, including the University of Maryland, University of Virginia, Halden, Brookhaven National Laboratory and the Electric Power Research Institute R3 group, and provide draft report	04/04 09/04	
• Develop new methods to support regulatory review of advanced I&C based on current state of the art and experience documented in lessons learned reports		
Develop models for autonomous control of advance reactors		3
• Develop information and models needed to review and examine advanced autonomous control methods that will be used in advanced reactors. Review current methods in use in other technologies, such as natural gas power stations.	09/05	
• Provide recommendation on revision to regulatory review guidance	09/06	
Analyze on-line monitoring systems and diagnostic methods needed to support advanced LWR's		3
• Review both current and developmental methods and systems proposed for advanced light-water reactors and their integration into safety systems and systems important to safety	09/05	
• Provide recommendation on regulatory review guidance	09/06	

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Advanced Reactor Human Factors Research Plan

Objective: To stay abreast of new human factors issues as they relate to advanced reactor designs. To develop methods and tools to evaluate human factors advanced reactor issues, specifically to assess the role of the operator and staff requirements for advanced reactors.

Selected Major Milestones and Schedules		
Major Milestones	**Target Dates**	**Bin**
Develop insights report on the role of human performance in advanced reactors		3
• Examine operation concepts and use of automation in avoiding human error	04/03	
• Review the applicability of existing requirements to advanced designs	05/03	
• Assess the need for human performance research facilities to address human error in advanced reactor designs	06/03	
• Prepare final insights report	07/03	
Develop staffing requirements for advanced reactors		1
• Evaluate analytical and modeling approaches to develop and review control room staffing needs using performance based techniques, draft guidance	03/03	
• Provide final guidance on analytical and modeling approaches	10/03	
• Determine the variability and qualifications of individuals needed to safely operate and maintain advanced modular reactor designs. (design dependent)	10/04	
• Provide recommendation on rule-making for advanced designs	10/06	
Analyze and assess the impact of operations and maintenance tasks that differ from current generation designs	Ongoing through FY 06	3
Review advanced reactor training and qualification issues and determine need to revise 10 CFR 55, 10 CFR 50.120, Regulatory Guide (RG) 1.8, RG 1.149, and NUREG-1220 (design and license submittal schedule dependent)	Ongoing through FY 06	1
Develop review guidance for computerized procedures and modify NUREG-0899 and Standard Review Plan (SRP) Chapter 13 (design and license submittal schedule dependent)	Ongoing through FY 06	3
Identify human-system interface issues for advanced reactors that are not included in NUREG-0700, Rev. 2 and determine need for review guidance revision (design and license submittal schedule dependent)	Ongoing through FY 06	3

Advanced Reactor Systems Research Plan for High-Temperature Gas-Cooled Reactors

Objective: To independently develop and validate thermal-hydraulic, neutronics, and severe accident models and computer codes needed to support design certification review of high-temperature gas-cooled reactors (HTGRs).

Selected Major Milestones and Schedules		
Major Milestones	**Target Date**	**Bin**
Conduct phenomena identification and ranking tables (PIRTs) to identify, rank, and prioritize all the phenomena and issues that are important to development of codes for HTGR analysis	01/04-09/05	3
Develop and validate neutronics code for HTGR analysis		1,2
• Identify physics issues	12/04	
• Develop lattice physics	09/05	
• Develop decay heat, sensitivity and uncertainty analysis	09/07	
• Perform analysis	TBD	
Develop and validate thermal-hydraulics code for HTGR analysis		1,2
• Identify models and experimental data needs	09/05	
• Develop models and validation	12/07	
• Perform safety analysis	TBD	
Develop and validate severe accident analysis tool for HTGR		1,2
• Identify models and experimental data needs	01/03-09/05	
• Assess the adequacy of experiments for the development of fission products release and transport models	10/05-12/07	
• Evaluate the severe accident source term (comparable to the NUREG-1465 source term used for LWRs) for HTGR provided by the licensee	TBD	
• Perform severe accident analysis	TBD	

Advanced Reactor Fuels Research Plan for High Temperature Gas-Cooled Reactors (HTGRs)

Objective: To develop the infrastructure that will be needed to support design certification review of HTGRs. Includes methods, tools, data, and expertise that would enable independent analysis of HTGR: (1) fuel performance and fission product transport during transients and severe accidents, (2) fuel irradiation and accident simulation test programs, and (3) fuel production and fabrication process.

Selected Milestones and Schedules		
Major Milestones	**Target Date**	**Bin**
Fuel performance phenomena		
• Conduct a PIRT to identify, rank, and prioritize all the phenomena and issues that are important to fuel failure and fission product release from HTGR fuels	07/03	3
Fuel performance analysis		
• Review and evaluate existing and available HTGR fuels codes used for predicting HTGR fuel performance and fission product transport for potential further development and use by NRC as an independent tool for analyzing GT-MHR fuel performance and fission product release.	12/03	1
• Further develop the models for the selected code(s) to simulate the known significant particle failure mechanisms and transport phenomena. Obtain material, physical, chemical, and fission product transport data sets appropriate for GT-MHR and other HTGR fuels. Enter the data sets into the improved codes.	12/06	1
• Benchmark codes against existing experimental failure data and release data and international benchmark studies.	12/07	1
• Conduct design-specific sensitivity studies for significant design, manufacturing, operational and accident variables influencing performance and fission product release.	TBD	1
• Compare calculated fuel failure fractions and fission products releases with the measured failure fractions for fission product releases from design-specific fuel irradiation tests and accident simulation tests.	TBD	1
• Conduct comparative analyses between the NRC code predictions and the applicant's code predictions for fuel failure fractions and fission product releases for selected licensing basis events.	TBD	
Fuel fabrication effects on fuel quality and performance		
• Review existing literature of descriptive information, analyses, studies, experience reports, fuel development and qualification plans, and fabrication quality assurance/quality control (QA/QC) programs to assess the material specifications, fabrication process parameters, fabrication equipment characteristics, product specifications, product characteristics and QA/QC aspects that are particularly important to ensuring fuel quality and performance.	12/04	3
• Support the review of design-specific applicant fuel fabrication safety analysis documents for ensuring adequate fuel fabrication quality and performance and the development of regulatory oversight program (e.g., fabrications technical specifications, inspection procedures)		3

Advanced Reactor Fuels Research Plan for High Temperature Gas-Cooled Reactors (HTGRs) (continued)

Major Milestones	Target Date	Bin
Fuel irradiation testing and postirradiation examination (PIE) • Conduct cooperative fuel irradiation testing and PIE on design-specific HTGR fuels to assess safety margins relative to: operating temperature, burnup, fluence substantially in excess of the design-specific licensing-basis operating conditions. Conduct cooperative irradiation testing to assess the applicability of traditional accelerated irradiation testing.	12/05-12/07	2
Fuel accident condition testing and PIE • Conduct cooperative fuel accident condition testing and PIE on design-specific HTGR fuels to assess safety margins relative to accident temperatures substantially in excess of the design-specific licensing-basis operating conditions. Conduct cooperative accident condition testing to assess the applicability of traditional accident condition testing methods.	12/05-12/07	2

Advanced Reactor Materials Research Plan for HTGRs

Objective: To develop independent research capability for evaluating the use of materials in advanced reactor designs. Address the uncertainty in behavior of materials under HTGR environments by testing, analysis, and modeling of metals and graphite components under simulated HTGR environments. Generate results to update materials specifications, codes, and standards and input for HTGRs' probabilistic risk assessments.

Selected Major Milestones and Schedules		
Major Milestones	**Target Date**	**Bin**
Metals		
Review and evaluate current national and international engineering design codes and standards for metallic components in HTGRs • Pressure Vessel Research Committee white papers on elevated temperature design as basis for American Society of Mechanical Engineers (ASME) codes • ASME Code Cases N-499 and N-201 • ASME Section III, Division 1 - Subsection NH on Class 1 Components in Elevated Temperature Service • Codes and Methodology developed in Germany, Japan, China, United Kingdom, and France	09/03	1
Review and evaluate existing research results developed since the 1980's that have not been incorporated in current codes • Assess new information and recommend improvement for incorporation into codes • Work with code bodies to implement recommended improvements	 12/03 12/05	2
Evaluate existing information on the effects of HTGR environments on degradation of metallic components. • Review existing literature and studies on HTGR materials and environmental effects to determine effects on degradation by creep, fatigue, creep-fatigue, stress-corrosion cracking, crevice corrosion, erosion-corrosion, carburization, decarburization, oxidation, aging, and the potential for low temperature sensitization	 09/03	2
Assemble a high temperature/high pressure helium generator to simulate HTGR coolant with impurities for testing of metallic components	12/03	3

Advanced Reactor Materials Research Plan for HTGR (continued)

Major Milestones	Target Date	Bin
Conduct long term environmental effects tests in the high temperature gas loop		3
• Conduct scoping tests and take advantage of existing research results for LWR environments to determine potential for reduction of fatigue life in HTGR environments	01/04-12/07	
• Conduct creep life testing and evaluate degradation due to the environment	01/04-12/07	
• Evaluate effects of environment on stress corrosion and crevice corrosion crack initiation	01/04-12/07	
• Incorporate results in codes and standards as needed	12/07	
Conduct crack growth rate testing program for HTGR component materials in high temperature/high pressure helium gas loop • Stress corrosion cracking • Crevice corrosion cracking • Cyclic crack growth	TBD	3
Evaluate components removed from service (assumes international cooperation) • Cracking • Aging • Fatigue usage • Creep usage	TBD	3
Evaluate inservice inspection effectiveness	12/06	3
Evaluate thermal aging & sensitization of metals under HTGR service conditions	TBD	3
Graphite		
Develop material specification standard for nuclear grade graphite		1
• White paper	06/02	
• Draft standard	12/02	
• Incorporate into American Society for Testing and Materials (ASTM) Standards	12/07	
Review graphite engineering design codes		1
• Review current codes and procedures from United States, Japan, Germany, United Kingdom, and China	12/03	
• Develop improved methods and practices and incorporate into national codes and standards	12/07	
Identify mechanics of pebble flow	12/07	3
Develop models for predicting irradiated graphite properties from as-received material properties and manufacturing process	01/05-12/07	3

Advanced Reactor Structural Research Plan

Objective: To stay abreast of developments in the technical community on structural designs, concepts, and analytical techniques as they apply to advanced reactor designs. To assess, extend, or develop new methods to address technical and safety structural issues unique to advanced reactor designs, (e.g., application of seismic soil-structure interaction (SSI) computer codes to deeply embedded or buried structures).

Selected Major Milestones and Schedules		
Major Milestone	**Target Date**	**Bin**
Review of existing practices • Review existing standards, tests, and practices that have been used in the design and analysis of deeply embedded or buried structures • Evaluate NRC seismic analysis guidelines outlined in the SRP in light of the proposed Advanced Reactor Designs (GT-MHR and other applicable designs)	02/03	3
Identify and gather earthquake data • Identify and gather earthquake downhole data, include but not be limited to the following sources: 1) Nuclear Power Engineering Corp and 2) Hualien Large Scale Seismic Test data	02/04	2
Develop benchmarks for soil-structure interaction models • Assess differences between rigid body motion of nuclear power plant structures at or near the ground surface against buried structures • Assess the significance of dynamic and passive earth pressure on deeply embedded structures • Determine whether better definitions are needed than currently used techniques in SSI analysis methods and computer codes (e.g., magnitudes and intensity levels at which dynamic and passive earth pressure are more prevalent for buried structures)	11/03 (Interim)	3
Conclusion and recommendations • Address pros and cons of currently available design criteria, analysis methods, and computer codes • Provide recommendation on existing licensing criteria	09/05	3

ESBWR Summary Research Plan

Objective: To develop a research infrastructure to identify potentially important safety issues and technical basis for resolution as they apply to the ESBWR design. Upgrade TRAC-M computer code for use in auditing the applicant's safety analyses for design certification review. Perform Purdue University Multidimensional Integral Test Assembly (PUMA) condensation experiments and integral tests to validate TRAC-M. Assist the licensing office in pre-application and design certification reviews as they relate to the review of the applicant's codes and models and code validation. Identify potential confirmatory research needs to the program office.

Selected Major Milestones and Schedules		
Major Milestone	**Target Date**	**Bin**
Thermal-Hydraulics and Neutronics		
Support NRR User Need NRR-2002-032		
• Modify TRAC-M and Purdue Advanced Reactor Core Simulator to model modern BWR fuel channels	03/03	1
TRAC-M infrastructure tasks		
• Implement and assess new condensation model	09/03	1
• Modify the energy equation formulation	01/04	1
PUMA experiments and code assessment		
• Complete PUMA flow instability test report	06/03	2
• Complete PUMA facility modifications	06/03	2
• Assess TRAC-M against previous PUMA simplified boiling-water reactor (SBWR) tests	09/03	1
• PUMA condensation experiments and integral tests	01/04	2
TRAC-M-CONTAIN coupled calculations		
• Develop ESBWR Containment CONTAIN Deck	TBD	1
• Couple ESBWR CONTAIN Deck to TRAC-M Vessel	TBD	1
• Develop PUMA Containment CONTAIN Deck	TBD	1
• Couple PUMA CONTAIN Deck to TRAC-M PUMA Vessel	TBD	1
• Verify coupling concept using coupled PUMA TRAC-M-CONTAIN Model against PUMA test data	TBD	1
Containment		
• Confirm applicability of CONTAIN to vent clearing phase of ESBWR	TBD	1
• Perform long-term cooling assessment against data	TBD	1

ESBWR Summary Research Plan (continued)

Thermal-Hydraulics and Neutronics (continued)		
Major Milestone	**Target Date**	**Bin**
Code assessment		
• Assess TRAC-M against appropriate data	TBD	1
• Assess CONTAIN against appropriate data	TBD	1
• Assess coupled TRAC-M-CONTAIN against appropriate data	TBD	1
PIRT and scaling		
• Review SBWR scaling and PIRTS to determine applicability to ESBWR	TBD	3
• Develop PIRT for ESBWR	TBD	3
• Perform scaling analysis for ESBWR	TBD	1
Assist NRR in review of GE documents		
• Review scaling document, provide RAI's	05/03	2
• Review testing document, provide RAI's	05/03	2
• Review Testing and Analysis Program Description (TAPD) and PIRT documents, provide RAIs	05/03 08/03	1,2 2
• Review scaling document, provide technical evaluation report (TER)	08/03	2
• Review testing document, provide TER	08/03	1,2
• Review TAPD and PIRT documents, provide TER	11/03	2
• Review scaling document, support ACRS meetings	11/03	2
• Review testing document, support ACRS meetings	11/03	1,2
• Review TAPD and PIRT documents, support ACRS meetings		
Severe Accident Analysis		
Develop MELCOR input deck for ESBWR	TBD	1
Evaluate In-vessel Melt Retention	05/04	1

ACR-700 Summary Research Plan

Objective: To develop the research infrastructure that will enable the identification of potentially important safety issues, and technical basis for resolution of such issues as they apply to the ACR-700 design. Upgrade TRAC-M computer code for use in auditing the applicant's safety analyses for design certification review. Develop the necessary methods, and tools to perform independent calculations (verification) of the negative coolant density coefficient of reactivity and other reactivity feedback effects for the ACR-700. Assist the licensing office in pre-application and design certification reviews as they relate to the review of the applicant's codes and models and code validation. Identify potential confirmatory research needs to the program office.

Major Milestones	Target Date	Bin
Thermal Hydraulics		
Complete PIRT for ACR-700	01/04	1,2
Assess T/H codes for use in evaluating CANDU models	06/03	1
Assess ACR-700 experimental data base	06/04	2
Prepare TRAC-M for ACR-700 application	03/06	1
Severe Accidents		
Assess current state of CANDU PRA modeling, data, and severe accident progression knowledge through evaluation of AECL methodology and PRAs	TBD	1,2
Identify dominant severe accident scenarios	12/03	1,2
Review experimental data base and assess the need for additional data	06/04	2
Develop MELCOR models for severe accident application	03/06	1
Complete assessment of containment loadings	TBD	1
Neutronics		
Complete PIRT for nuclear analysis research (pre-application)	01/04	1,2
Complete PIRT nuclear analysis research (design certification)	TBD	1,2
Complete assessment and verification of the negative coolant density coefficient (pre-application)	12/03	1,2
Assess analysis issues for predicting reactivity feedback effects (design certification)	TBD	1
Provide pre-application assessment of experimental data base for reactor neutronics (pre-application)	06/04	2
Assess (and supplement as needed) the experimental data base applied to validation of reactor neutronics (design certification)	TBD	2
Provide initial neutronics models with nodal cross section tables for TRAC-M capability (pre-application)	02/04	1
Provide validated neutronics models with nodal cross section tables for TRAC-M capability (design certification)	TBD	1

Assumptions

- TRAC-M work is only to develop CANDU models and does not cover full range of code, scaling, applicability, and uncertainty (methodology).
- We have full access to Atomic Energy of Canada Limited thermal hydraulic, neutronic, containment, and severe accident experimental programs. We conclude, from our assessment of the ACR-700 data base and our PIRT, that major (of the order of $10M) new experimental programs will not be needed, but only limited separate effects tests.

AP1000 Summary Research Plan

Objective: To assist NRR in design certification review of the AP1000. (User Need 2002-029 requests RES assistance in the review of liquid entrainment as it effects the AP-1000 automatic depressurization system, and User Need 2002-031 requests support on severe accident issues.) To prepare and perform independent analyses and confirmatory research on several issues that relate to AP1000 performance and safety margins.

Major Milestone	Target Date	Bin
Task ½: Support NRR User Need NRR-2002-029; NRR-2002-031		1
Provide assistance and provide technical support on entrainment issue and preparation of SER	06/03	1
Task 3: Perform AP1000 Severe Accident Simulations		1
Complete MELCOR input deck	11/02	1
Complete severe accident simulations with MELCOR	03/03	1
Task 4: Integral Test Data for AP1000 Issue Resolution and Model Development		2
Review Oregon State University facility modifications and update test matrix	02/03	2
Complete Advanced Plant Experiment tests	04/04	2
Evaluate data and develop models for upper plenum thermal-hydraulics	01/05	2
Task 5: Code Development in Support of AP1000 Simulation		1
Develop coding for ATLATS derived entrainment models for TRAC-M	04/03	1
Task 6A: Perform AP1000 Large and Small Break LOCA Simulations		1
Complete AP1000 TRAC-M input deck for LBLOCA	11/02	1
Complete AP1000 TRAC-M input deck for SBLOCA	11/02	1
Complete double-ended guillotine cold leg (CL) LBLOCA calculation	12/02	1
Complete direct vessel injection break SBLOCA calculation	03/03	1
Task 6B: Confirmatory AP1000 Large and Small Break LOCA Simulations		1
Complete LBLOCA calculations with improved TRAC-M reflood model	10/03	1
Complete series of small LOCA calculations, including 10- inch CL break	10/03	1
Task 7: Evaluate AP1000 Containment Integrity		1
Evaluate thermal striping hydraulic behavior	01/03	1
Perform structural evaluation for AP1000 containment shell	03/03	1
Make recommendation on future containment testing	03/03	1
Task 8: Confirmatory Containment Simulations		1
• Complete CONTAIN uncertainty calculations	03/03	1