Idaho National Laboratory

September 25, 2008

CCN 214977

Mr. Trevor L. Cook
NGNP Project Manager
NE-33, Germantown Building
U.S. Department of Energy
19901 Germantown Road
Germantown, MD 20874

SUBJECT: Contract No. DE-AC07-05ID14517 – Completion of Level 2 Milestone - G-IN07NG08 "Prepare a Year-End Report Summarizing the Activities Undertaken by Next Generation Nuclear Plant Project to Support the Licensing Strategy"

Dear Mr. Cook:

This letter formally documents completion of the Next Generation Nuclear Plant Project (NGNP) Regulatory Compliance Work Package, Level 2 Milestone G-IN07NG08. The milestone description is:

> "*Prepare a Year-End Report Summarizing the Activities Undertaken by NGNP to Support the Licensing Strategy,*" due September 30, 2008.

The enclosed document "NGNP Licensing Strategy Support" provides objective evidence of completion of the above milestone. This summary has been enhanced with a set of tables that address the high priority issues identified by the NGNP Phenomena Identification and Ranking Table (PIRT) effort.

If you have any questions, please contact me at (208) 526-6063 or Jim Kinsey, Director, NGNP Regulatory Affairs (208) 526-6882.

Sincerely,

G. A. Gibbs

Greg Gibbs, Project Director
Next Generation Nuclear Plant Project

MH:CN

Enclosure

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NGNP Licensing Strategy Support

The *Energy Policy Act of 2005* (Title VI, Subtitle C, Section 644) (EPAct) states that the "Nuclear Regulatory Commission shall have licensing and regulatory authority for any reactor authorized under this subtitle." This stipulates that the Nuclear Regulatory Commission (NRC) will license the Next Generation Nuclear Plant (NGNP) for operation. As a result of this EPAct directive, the Department of Energy (DOE) has been working with NRC to develop a licensing strategy for the NGNP that eventually applies to commercial high temperature gas-cooled reactors (HTGRs). As the DOE's lead laboratory for development of nuclear energy, Idaho National Laboratory (INL) personnel have been supporting the Office of Nuclear Energy's (NE) efforts to develop the NGNP licensing strategy. This report summarizes their work for FY 2008. FY 2009 plans for licensing specification development are also discussed. In some cases, study results are provided that were obtained from the referenced reports.

1. Phenomena Identification and Ranking Table Activities

NRC, in collaboration with DOE and supported by INL, conducted Phenomena Identification and Ranking Table (PIRT) exercises to identify safety-relevant phenomena for NGNP and assess and rank the importance and knowledge base for each phenomenon. The overall objective was to provide NRC with an expert assessment of the safety-relevant NGNP phenomena, and an overall assessment of research and development (R&D) needs for NGNP licensing. The PIRT process was applied to five major topical areas relevant to NGNP safety and licensing:

1. Thermofluids and accident analysis (including neutronics)
2. Fission product transport
3. High temperature materials
4. Graphite
5. Process heat for hydrogen cogeneration.

PIRT is a systematic way of gathering information from experts on a specific subject, and ranking the importance of the information, in order to meet some decision-making objective such as determining what has highest priority for research on that subject. The PIRT methodology brings into focus the phenomena that dominate an issue, while identifying all plausible effects to demonstrate completeness.

The expert panels were organized around the five areas listed above. NRC and DOE personnel developed lists of acknowledged experts in each of the fields represented by the five panel topics, and invitations were extended to the recommended panelists. Panel participants included 25 experts from Argonne National Laboratory, INL, Oak Ridge National Laboratory, Sandia National Laboratory, Savannah River National Laboratory, Commissariat à l'énergie atomique, Institut de Radioprotection et de Sûrenté Nucléaire, Massachusetts Institute of Technology, Texas A&M, University of Manchester, UK, and University of Wisconsin. In addition, gas reactor technical experts from Areva, General Atomics, Technology Insights, and Westinghouse were invited to provide design information to the panelists, but were not allowed to vote during panel deliberations.

Two sets of meetings were held in Rockville, MD. The first meetings were held February 27 and 28, 2007, and the second meetings were held April 16–18, 2007. The results from these meetings were finalized and published in NUREG/CR-6944, "Next Generation Nuclear Plant Phenomena Identification and Ranking Tables (PIRTs)" that was published March 2008. The major panel findings are summarized below.

Accidents and Thermal Fluids Panel Findings

The panel concentrated on the thermal fluid phenomena, but also considered the neutronic phenomena where appropriate. The following operating and accident conditions were evaluated: (1) normal operations, (2), loss-of-forced-cooling (LOFC) events (both pressurized and depressurized), (3) air ingress, (4) reactivity insertion events, and (5) some phenomena associated with the process heat loop and intermediate heat exchanger. The most significant phenomena identified by the panel include the following:

- Primary system heat transport phenomena (conduction, convection, and radiation), including the reactor cavity cooling system performance, which impact fuel and component temperatures.
- Reactor physics phenomena (feedback coefficients, power distribution for normal and shutdown conditions) as well as core thermal and flow aspects. These often relate to the power-to-flow ratio and thus impact peak fuel temperatures in many events.
- Postulated air ingress accidents that, however unlikely, could lead to major core and core support damage.

Fission Product Transport and Dose Panel Findings

The panel found that, at this early stage in the NGNP design, a wide range of transport options needed to be examined. The most significant phenomena identified were:

- Fission product contamination of the graphite moderator and primary circuit (including the turbine), which is not negligible for normal operation and constitutes an available source term.
- Transport of fission products into the confinement building and the environment. This is primarily a building leakage (and/or filtering) problem, but depends on the gaseous and suspended aerosol inventory of fission products.
- Behavior of the fission product inventory in the chemical cleanup or fuel handling system during an accident. An overheat event or loss of power may cause release from this system and transport by some pathway into the confinement building or environment.
- Transport phenomena (such as chemical reactions with fuel, graphite oxidation) during an unmitigated air or water ingress accident.
- Quantification of dust in the reactor circuit (from several sources). This may be easily released during a primary boundary breach. The highest dust quantities are expected in

the pebble bed core and the lowest in the prismatic core (at least an order of magnitude less).

High Temperature Materials

The major aspects of materials degradation phenomena that may give rise to regulatory safety concern were evaluated for major structural components and their associated materials. These materials phenomena were evaluated with regard to their potential for contributing to fission product release at the site boundary under a variety of event scenarios covering normal operation, anticipated transients and accidents, and the currently available state of knowledge with which to assess them. Key aspects identified by this panel were:

- High-temperature stability and a component's ability to withstand service conditions
- Issues associated with fabrication and heavy-section properties of the reactor pressure vessel
- Long term thermal aging and possible compromise of reactor pressure vessel surface emissivity as well as the reactor cavity coolant system
- High temperature performance, aging fatigue, and environmental degradation of insulation.

Graphite

It is expected that the behavior of the available graphites will conform to the recognized trends for near-isotropic nuclear graphite. However, the theoretical models still need to be tested against experimental data for the new graphites, and extended to higher neutron doses and temperatures expected of the NGNP. Significant phenomena noted by the panel were:

- Material properties (creep, strength, toughness, etc.) and the respective changes caused by neutron irradiation
- Fuel element coolant channel blockage due to graphite failures
- Consistency in graphite quality (includes replacement graphite over the service life)
- Dust generation and abrasion (especially noteworthy for pebbles, but of concern as well for the prismatic design).

Process Heat and Hydrogen Co-Generation

The panel found that the most significant external threat from the chemical plant to the nuclear plant is from a release of ground-hugging gases. Oxygen was determined to be the most important because (1) t is a significant by-product from all hydrogen production processes that start with water, and (2) it may be released continuously as a "waste" if there is no local market, which is because of its combustion aspects, plume behavior, and allowable concentration, and is consistent with the chemical safety aspects and known risks of oxygen plants.

Accidental hydrogen releases from the chemical plant were considered a lesser concern in terms of reactor safety because of the high buoyancy of hydrogen and its tendency towards dilution.

The panel was also concerned with the high importance of heat exchanger failures and associated phenomena for blow-down. These can have different types of impacts on the primary system such as pressure pulses and thermal consequences.

The detailed panel findings were screened to focus on those phenomena that were judged by the panel members to be of high importance and to have an associated low level of knowledge. Appendix A presents a summary of these high priority issues.

2. Congressional Report

Section 644(b) of the Energy Policy Act of 2005 (EPAct) states: "Not later than 3 years after the date of enactment of this Act, the Secretary and the Chairman of the NRC shall jointly submit to the appropriate committees of the Senate and the House of Representatives a licensing strategy for the prototype nuclear reactor, including:

1. A description of ways in which current licensing requirements relating to light-water reactors need to be adapted for the types of prototype nuclear reactor being considered by the Project;
2. A description of analytical tools that the NRC will have to develop to independently verify designs and performance characteristics of components, equipment, systems, or structures associated with the prototype nuclear reactor;
3. Other research or development activities that may be required on the part of the NRC in order to review a license application for the prototype nuclear reactor; and
4. An estimate of the budgetary requirements associated with the licensing strategy."

The NGNP Licensing Strategy Working Group (members consisted of DOE, NRC, and INL personnel) completed the draft Congressional report in May 2008 for management review and provided the final Report to Congress in August 2008. INL personnel participated in reviewing the basis documents related to the NGNP project descriptions, R&D activities, and analytical tool development.

In the fall of 2007, DOE held meetings with the three NGNP vendor teams to provide the teams with an overview of the strategy development process and to obtain feedback on the process. INL developed the draft presentation slides used for these meetings.

3. Working Group Meetings

The NGNP Licensing Strategy Working Group started its Congressional Report tasks in the second half of 2006. These activities included a series of meetings that were typically held monthly (with some gaps in the spring of 2008). Over the course of FY 2008, INL participated in six meetings; the focus of each of these meeting is provided below.

1. *October 29, 2007*. Discussed the status of the NGNP Licensing Strategy Basis Document, DOE's Baseline Case, the template for the Congressional Licensing Strategy Report, feedback from DOE's discussion with potential stakeholders, and the draft Section 644(c) MOU.

2. *November 29, 2007*. Discussed the status of the NGNP Licensing Strategy Basis Document and the Congressional report, covered comments on the baseline case and other sections of the Basis Document, and discussed the nature of the legal analysis necessary for the Basis Document.
3. *December 17, 2007*. Obtained feedback on the NGNP Licensing Strategy Basis Document, discussed the status of the development of the Congressional report, and discussed agendas for upcoming meetings with the Advisory Committee for Reactor Safeguards (ACRS) and the NRC Commission.
4. *January 29, 2008*. Obtained additional feedback on the NGNP Licensing Strategy Basis Document, discussed status of the development of the Congressional report, evaluated thoughts on improving the document schedule, and developed plans for upcoming meetings with the ACRS and the NRC Commission.
5. *May 8, 2008*. Discussed initial management comments and obtained agreement on the proposed April version of the Congressional Report and Revision 16 of the Basis Document; also discussed the process for issuing the Licensing Strategy to Congress.
6. *June 18, 2008*. Wrapped up remaining comments on the June version of the Congressional Report and Revision 17 of the Basis Document; also, finalized plans for issuing the Licensing Strategy to Congress.

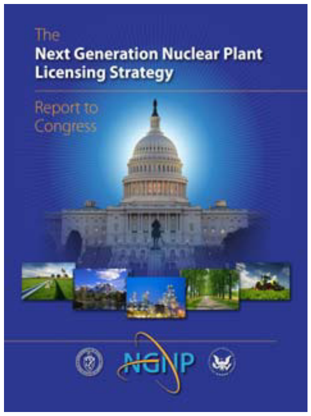
Much of June, July, and early August was spent obtaining concurrence from DOE and NRC management as final inputs and revisions were accommodated. As noted above, the NGNP Licensing Strategy Report to Congress was submitted August 15, 2008.

4. Congressional Report Cover Development

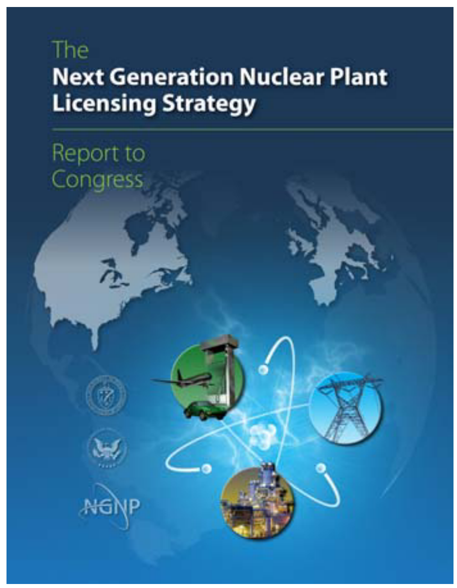
At the request of DOE-NE, the NGNP project developed a cover sheet to be used for the NGNP Licensing Strategy Report to Congress. The project coordinated with INL's graphic design department in order to develop two conceptual designs for the report cover.

The premise of the representations is the use of imagery to evoke the goals of the NGNP project. This resulted in two project-related interpretations for the Congressional report cover. The cover on the left uses images representative of industries identified as having potential nuclear process heat application paired with strong environmental images to illustrate the positive impact of limiting industrial carbon emissions. The cover on the right features an illustration depicting the three components of the NGNP facility: hydrogen and process heat production and electricity co-generation integrated into an atom. The illustration is then set against a partially transparent globe to represent the vast energy challenges and a position of global leadership.

The second image was selected as the basis for the final cover page design. The style of the heading was adapted from the cover page on the left. The other change made to the design was simplifying the graphic representing electricity to include only the transmission line.



The final illustration (below) bridges the application of the NGNP project with the licensing strategy for the facility. The completed cover design was sent to DOE-NE for the NGNP Licensing Strategy Report to Congress on June 16th, 2008.



5. Licensing Risk Reduction Study

The Licensing Risk Reduction Study used the on-going pebble bed modular reactor (PBMR) preapplication interactions with the NRC to identify HTGR-specific, long-lead licensing issues, thereby identifying methods for minimizing licensing risks for the NGNP project. This task also established the content and schedule for engineering and organizational prerequisites that were determined to be necessary for effective NGNP preapplication engagement with the NRC. The work scope included the following tasks:

1. Conduct NGNP Team Licensing Workshop
2. Establish content of NGNP preapplication program
3. Advance the NGNP licensing strategy

4. Propose licensing milestones and logic
5. Revise the licensing schedule.

The following study results can be found in report NGNP-LP1 WEC-LIC, Revision A, "Licensing Risk Reduction Study," dated April 2008.

Licensing is recognized as a major cost and schedule risk for the NGNP project and its follow-on commercial plants and, therefore, this study was conducted to identify the means by which that risk can be reduced. The areas of risk addressed are (1) the regulatory process and logic, (2) project and engineering support of the schedule, and (3) NRC interactions, including preapplication programs and R&D coordination. The licensing strategy will be based on 10 CFR 52, for which the major elements will be applications for an NGNP Combined License (COL) and Design Certification (DC) of follow-on commercial plants. Early Site Permit (ESP) and Limited Work Authorization (LWA) applications are considered to enable further management of schedule risk and are included in the current strategy, but a final recommendation on their use cannot be made until detailed project schedule studies are completed.

The risk of a lengthy NRC review can be positively impacted by planning an aggressive review schedule and then pursuing design development, project management and the NRC support necessary to meet that schedule. The NRC review must be preceded by an extensive preapplication program that yields a quality application based on the preapplication agreements with NRC on the application contents.

Licensing risk can be further reduced through early planning for license application preparation and NRC review thereof. The currently ongoing PBMR preapplication program, when coordinated or combined with the NGNP preapplication program, provides a basis for early resolution of generic HTGR issues. It is recommended that the PBMR preapplication issues that are applicable to NGNP and are already under discussion with the NRC be accelerated to support the NGNP fast-track schedule. Further, the prior NRC reviews of HTGR designs (General Atomics' Modular High-Temperature Gas-Cooled Reactor and Exelon's PBMR) provide a basis for prompt NRC agreement on the approach to resolving those issues for the NGNP project. Therefore, a critical, base assumption for the ESP, LWA, COL, and commercial plant DC applications is that each will be preceded by a substantial preapplication program to get NRC input and alignment on focus topics necessary for preparation of successful applications. The risk of delays due to the R&D of technology necessary for completion of NRC safety reviews can be minimized by ensuring that the NGNP R&D program is coordinated with the needs of the NRC.

In order to meet the accelerated schedule summarized above, it is recommended that the following activities be initiated as soon as possible:

1. Initiate NGNP discussions with the NRC and advance the currently ongoing PBMR preapplication discussions that are applicable to NGNP onto a fast-track schedule.
2. Develop license application specifications and detailed deliverable schedules for support of the ESP/LWA, COL, and DC applications and their preapplication programs.

3. Establish an integrated Regulatory Technology Development Plan that is mutually agreed with by the NRC and which will serve to ensure that the related NGNP technology development programs satisfy regulatory requirements.
4. Integrate the fuel qualification program with the NGNP integrated licensing schedule.
5. Establish the industry partnership, DOE funding, and organizational interfaces that create a qualified applicant that can support the ESP/LWA, COL, and DC programs.

In regards to implementing the above actions, the most urgent needs are 1) the initiation of early interactions with the NRC, 2) the development of specifications for preparation of the NGNP ESP, LWA, and COL applications, and 3) confirmation that the engineering design and analysis work schedule supports critical licensing milestones.

6. Preapplication Review Planning/Licensing Specification Development

An NGNP vendor team is developing the detailed content and schedule for the licensing application products identified by the Licensing Risk Reduction study that was completed in April 2008. The results from this study will form the basis for licensing product planning activities. Benefits from previous PBMR preapplication interactions will continue to be evaluated for applicability to the designs under consideration for the NGNP. Phase 1 of the study that was completed at the end of September 2008, focused on activities that are expected to occur in the next 18 months (e.g., start of preapplication discussions with the NRC staff). Phase 2 adds detail to the Phase 1 results and will also provide detailed information that applies to the ESP and COL applications. It is anticipated that Phase 2 will be completed by April 30, 2009.

Analysis will include consideration of early preapplication review discussions with the NRC staff for each application, including a list of policy and technical issues that will need resolution early in the discussion process, needed documents/correspondence, and a proposed schedule. Also, any applicable insights gained from the effort in the Conceptual Design Work Plan task to reconcile items identified in the PIRT reports against identified project design data needs will be considered.

Document descriptions will identify the key engineering and R&D needs/interfaces that affect each section in the identified documents. The identified documents will include a list of suggested topical reports that would be used to support the license application, including (1) a description of the expected report format and contents, (2) the basis for why the topical report is needed, and (3) when the topical report would be needed to best support the applicable license application. Based on insights gained from the Licensing Risk Reduction Study, a detailed schedule for development of documents and safety analyses needed to support license applications (including support for the NRC review of each application) will be provided.

In addition, a detailed analysis that includes a reconciliation of the existing light water reactor regulatory requirements with the specific characteristics of a HTGR will be developed. The list of regulatory requirements will include 10 CFR 50, 10 CFR 50 Appendix A (General Design Criteria), 10 CFR 51, 10 CFR 52, 10 CFR 100, and applicable Regulatory Guides, Standard Review Plans, NUREGs, and NRC generic guidance. The detailed analysis will include whether each item is: applicable, partially applicable, not applicable, or an area where HTGR-specific technical guidance or policy issues need to be develop or resolved.

References

1. Energy Policy Act of 2005 (Public Law 109-58), dated August 8, 2005
2. NUREG/CR-6944, "Next Generation Nuclear Plant Phenomena Identification and Ranking Tables (PIRTs)," dated March 2008.
3. NGNP-LP1 WEC-LIC, Revision A, "Licensing Risk Reduction Study," dated April 2008

Appendix A

Priority 1 PIRT Issues Table

Priority 1 PIRT Issues: High Importance & Low Knowledge Level

Item	Topic Area	Issue	Figure of Merit	Plant Condition or Accident Mode	Basis for High Importance/Low Knowledge Determination	Comments
1.	Thermal Fluids & Accident Analysis	Core coolant bypass flow; Determines active core cooling; affects the max temp of the fuel.	• Fuel time at temp • Fuel failure fraction	Normal Operations	• Bypass flow varies with shifts in block gaps; no way to measure it; • Instrumentation in PBRs not considered practical; • Bypass flows vary axially, difficult to measure temperatures; • Need to understand graphite shrink/swell effect on bypass flow.	Vol. 2, Table 2-1, ID No. 1
2.	Thermal Fluids & Accident Analysis	Pebble bed core wall interface effects on bypass flow; Diversion of some core cooling flow; the number of pebbles across impacts the interface effects.	• Fuel time at temp • Fuel failure fraction	Normal Operations	• Combination of cooling anomalies and flux peaking creates uncertainties; • Pebble bed pressure drop equations have large uncertainty bands; • Larger uncertainties in wall friction correlations; • Need additional experimental data; • PBMR is doing experiments in HPTU/HTTF • Different packing fraction at walls; • Void fraction has large uncertainty.	Vol. 2, Table 2-1, ID No. 8
3.	Thermal Fluids & Accident Analysis	Outlet plenum flow distribution; Affects mixing and thermal stresses in plenum and downstream outlet pressure distribution.	• Worker dose • Core support structures	Normal Operations	• Localized hot spots; excessive thermal gradients may lead to structural problems and thermal streaking may lead to problems with downstream components such as a turbine or IHX; • This problem led to failures at THTR; • Very complex turbulent mixing with incoming jets over large temperature spans; • PMR geometry contributes to the uncertainties in the pressure distribution.	Vol. 2, Table 2-1, ID No. 13

Priority 1 PIRT Issues: High Importance & Low Knowledge Level

Item	Topic Area	Issue	Figure of Merit	Plant Condition or Accident Mode	Basis for High Importance/Low Knowledge Determination	Comments
4.	Thermal Fluids & Accident Analysis	Reactivity-temperature feedback coefficients; Affects core transient behavior.	• Worker dose • Fuel failure fraction • Fuel time at temperature • Core support	Normal Operations	• Important for estimating control rod worth and power defect; • Limited available experimental data for validation of reactivity temperature effects, particularly direct measurements of reactivity coefficients rather than overall transient response of the system and for high burnup fuels; • High temperature of HTR systems magnifies errors in differential feedback coefficients over that of relatively well-known systems; • Evidence of difficulty in prediction of power coefficients in recent startup experiments; • Physical phenomenon that may be important in accurate calculation of neutron capture in resonances is not accurately modeled in spectral codes; may have a significant impact of reactivity coefficients (resonance scattering); • Lack of understanding or resonance capture phenomena at high temperatures; • Need for graphite reactor critical experiments with high burnup; • Evidence of miscalculation of power coefficients.	Vol. 2, Table 2-1, ID No. 21
5.	Thermal Fluids & Accident Analysis	Fuel performance modeling; Fuel type dependent. Crucial to design and siting. Depends on performance envelope, QA/QC, etc.	• Fuel failure fraction	Normal Operations	• Primary barrier to fission product migration; • Many unknowns; • Kernel migration; • Silicon carbide morphology relation to release.	Vol. 2, Table 2-1, ID No. 24
6.	Thermal Fluids & Accident Analysis	Ag-110*m* release and plateout; Affects maintenance dose. May be dependent upon fuel design, columnar grains vs. pearl grains. Will be dependent upon fuel temperature.	• Worker dose	Normal Operations	• Coupled with fuel performance modeling and fission product transport; • Large uncertainty band.	Vol. 2, Table 2-1, ID No. 25
7.	Thermal Fluids & Accident Analysis	Reactor vessel cavity air circulation and heat transfer; Affects upper cavity heating, assume controls inserted either through automatic or manual action relatively quickly.	• Vessel and vessel support integrity	General Loss-of-Forced Circulation Event	• RCCS performance; heat distribution, and location of hot spots; • Lack of applicable prototypic data; • Difficult to predict local hot spots with CFD and other codes; • Lack of codes for modeling conjugate heat transfer.	Vol. 2, Table 2-2, ID No. 7

Priority 1 PIRT Issues: High Importance & Low Knowledge Level

Item	Topic Area	Issue	Figure of Merit	Plant Condition or Accident Mode	Basis for High Importance/Low Knowledge Determination	Comments
8.	Fission Product Transport	Matrix permeability, tortuosity	• Graphite • Core materials	Normal Operations and under transient/accident conditions	• Needed for first principle transport modeling; • Fission product holdup as barrier, release as dust; expected from material PIRT.	Vol. 3, Table 10, ID No. 10 Modeling Status: major need
9.	Fission Product Transport	Fission product transport through matrix	• Graphite • Core materials	Normal Operations and under transient/accident conditions	• Effective release rate coefficient (empirical constant) as an alternative to first principles; • Fission product holdup as barrier, release as dust; expected from material PIRT.	Vol. 3, Table 10, ID No. 11 Modeling Status: major need
10.	Fission Product Transport	Fission product speciation in carbonatious material	• Transport in reactor coolant system and confinement	Normal Operations and under transient/accident conditions	• Chemical form in graphite affects transport; • Knowledge is uncertain and/or incomplete.	Vol. 3, Table 10, ID No. 23 Modeling Status: major need
11.	Fission Product Transport	Ag-110*m* generation and transport	• Transport in reactor coolant system and confinement	Normal Operations and during maintenance	• Radioisotope; significant O&M dose on cool, metallic components; • Limited data; • Unknown transport mechanism.	Vol. 3, Table 10, ID No. 29 Modeling Status: major need
12.	Fission Product Transport	Aerosol growth	• Transport in reactor coolant system and confinement	Normal Operations and under transient/accident conditions	• Low concentration growth can lead to high-shape factors and unusual size distribution; • Regime has not been studied previously.	Vol. 3, Table 10, ID No. 32 Modeling Status: major need
13.	Fission Product Transport	Fission product diffusivity, sorbtivity in nongraphite surfaces	• Transport in reactor coolant system and confinement	Normal Operations and under transient/accident conditions	• Determines FP location during operation; acts as a trap during transient; • Little information on materials of interest.	Vol. 3, Table 10, ID No. 35 Modeling Status: major need
14.	Fission Product Transport	Resuspension	• Transport in reactor coolant system and confinement	Transient/accident conditions	• Flow/vibration induced, saltation; • Mechanical forces can release fission products from pipe surface layers/films; • Lack of data and models for anticipated conditions.	Vol. 3, Table 10, ID No. 38 Modeling Status: major need
15.	High-Temperature Materials	Crack initiation and subcritical crack growth	• RPV integrity	Breach during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load	• 9 Cr–1 Mo steel (grade 91) must be assessed for phenomena due to transients and operationally induced–thermal loading, pressure loading, residual stress, existing flaws (degradation of welds, cyclic loading, low cycle fatigue); • There is a limited database from fossil energy applications at these temperatures; • Low cycle fatigue data in air, vacuum, and sodium (ANL unpublished data) at $482°C show life is longest in sodium, followed by vacuum and air; • Aging in helium (depending on impurities) will most likely be greater than in air. Aging in impure helium may perhaps depend on impurity type and content.	Vol. 4, Table 7, ID No. 5

Priority 1 PIRT Issues: High Importance & Low Knowledge Level

Item	Topic Area	Issue	Figure of Merit	Plant Condition or Accident Mode	Basis for High Importance/Low Knowledge Determination	Comments
16.	High-Temperature Materials	Compromise of emissivity due to loss of desired surface layer properties	• RPV integrity • Peak fuel temperature	Inadequate heat transfer during: • Startup • Shutdown • Steady state • Helium inventory control	• To ensure passive safety, high emissivity of the RPV is required to limit core temperatures—must maintain high emissivities on both inside and outside surfaces; • Formation and control of surface layers must be considered under both helium and air environments; • There are limited studies on SS and on 508 that show potential for maintaining high emissivity.	Vol. 4, Table 7, ID No. 11
17.	High-Temperature Materials	Field fabrication process control	• RPV integrity	Breach, excess deformation during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load • Pressurized loss of forced circulation • Depressurized loss of forced circulation	• Fabrication issues must address field fabrication because of vessel size [including welding, post-weld heat treatment, section thickness (especially with 9 Cr–1 Mo steel) and preservice inspection]; • Fossil energy experience indicates that caution needs to be taken. On-site nuclear vessel fabrication is unprecedented.	Vol. 4, Table 7, ID No. 16
18.	High-Temperature Materials	Property control in heavy sections	• RPV integrity	Breach, excess deformation during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load • Pressurized loss of forced circulation • Depressurized loss of forced circulation	• Heavy-section properties are difficult to obtain because of hardenability issues; • Adequate large ingot metallurgy technology does not exist for 9 Cr–1 Mo steel; • Maintaining fracture toughness, microstructural control, and mechanical properties in through-thickness of heavy sections, 9 Cr materials must be maintained; • Very limited data, not much over 3 to 4 in. thickness; • Few data available for specimens from 300-mm-thick forgings show thick section properties lower than thin section.	Vol. 4, Table 7, ID No. 17

Priority 1 PIRT Issues: <u>High</u> Importance & <u>Low</u> Knowledge Level

Item	Topic Area	Issue	Figure of Merit	Plant Condition or Accident Mode	Basis for High Importance/Low Knowledge Determination	Comments
19.	High-Temperature Materials	Piping: aging, fatigue, and environmental degradation of insulation	• Peak fuel temperature	Insulation debris generation during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load	• Concern is about insulation debris plugging core cooling channels, causing damage due to chunks of internal insulation falling off (ceramic sleeves or carbon–carbon composites would be most likely source of problems); • Little system-relevant information about insulation failure mechanism is available.	Vol. 4, Table 7, ID No. 30
20.	High-Temperature Materials	IHX: Crack initiation and propagation [due to creep crack growth, creep, creep-fatigue, aging (with or without load), subcritical crack growth]	• Integrity of IHX; • Secondary loop failure/breach	Breach to secondary system during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load • Pressurized loss of forced circulation • Depressurized loss of forced circulation	• Environmental effects on subcritical crack growth—impacts of design issues, particularly for thin-section must be addressed; • Stresses on IHX (both thin and thick sections) can lead to these failure phenomena; thermal transients can cause toughness concerns and carbide redistribution as a function of thermal stress can change through-thickness properties; • More is known about 617 from HTGR and industry usage than for 230; • Both environment and creep play significant roles in initiation and cyclic crack growth rate of 617 and 230; • Mechanistic models for predicting damage development and failure criteria for time-dependent phenomena have to be developed to enable conservative extrapolation from short-term laboratory test data to long-term design life.	Vol. 4, Table 7, ID No. 35
21.	High-Temperature Materials	IHX: Primary boundary design Methodology limitations for new structures (lack of experience)	• Integrity of IHX; • Secondary loop failure/breach	Breach to secondary system during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load • Pressurized loss of forced circulation • Depressurized loss of forced circulation	• Time-dependent design criteria for complex structures need to be developed and verified by structural testing; • ASME Code approved simplified methods have not been proven and are not permitted for compact IHX components; • No experience for the complex shape IHX; • No experience for designing and operating high-temperature components in the class 1 environment; • Difficulties of design and analyses of compact IHX are discussed in the references.	Vol. 4, Table 7, ID No. 36

Priority 1 PIRT Issues: High Importance & Low Knowledge Level

Item	Topic Area	Issue	Figure of Merit	Plant Condition or Accident Mode	Basis for High Importance/Low Knowledge Determination	Comments
22.	High-Temperature Materials	IHX: Manufacturing phenomena (such as joining)	• Integrity of IHX; • Secondary loop failure/breach	Breach to secondary system during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load • Pressurized loss of forced circulation • Depressurized loss of forced circulation	• Compact heat exchanger (CHX) cores (if used) will require advanced machining, forming, and joining (e.g., diffusion bonding, brazing, etc.) methods that may impact component integrity; • Must assess CHX vs. traditional tube and shell concepts. However, these phenomena are generic and extend beyond the CHXs to all the very high-temperature heat exchangers (HXs); • HXs have not been used in nuclear applications; the candidate alloys and their joining processes not adequately established in nonnuclear applications.	Vol. 4, Table 7, ID No. 37
23.	High-Temperature Materials	IHX: Inspection/testing phenomena	• Integrity of IHX; • Secondary loop failure/breach	Breach to secondary system during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load • Pressurized loss of forced circulation • Depressurized loss of forced circulation	• Traditional nondestructive evaluation (NDE) methods will not work for CHXs because of geometrical constraints; • Proof testing of some kind will be required (maybe leak testing with tracer); • Preservice testing will be difficult, and in-service testing will be even harder; • Condition monitoring may be useful; • Preoperational testing, preservice inspection, fitness for service, issue with leak tests, have very little knowledge here. What is the margin?	Vol. 4, Table 7, ID No. 38

Priority 1 PIRT Issues: <u>High</u> Importance & <u>Low</u> Knowledge Level

Item	Topic Area	Issue	Figure of Merit	Plant Condition or Accident Mode	Basis for High Importance/Low Knowledge Determination	Comments
24.	High-Temperature Materials	Control Rods (nonmetallic): Composites structural design methodology limitations for new structures (lack of experience)	• Maintain insertion ability	Breach to secondary system during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load • Pressurized loss of forced circulation • Depressurized loss of forced circulation • Rupture with air ingress • Rupture with water ingress • Reactivity events	• Carbon–carbon composites are prime candidates, but need approved method of designing, proof testing, model testing, testing standards, and validation tests; • Some code work is being developed by ASME, ASTM and international partners; • Extensive aerospace industry design and usage can be assessed for applicability.	Vol. 4, Table 7, ID No. 43
25.	High-Temperature Materials	RPV Internals (metallic): Change in emissivity	• Maintain heat transfer capability	Inadequate heat transfer during: • Pressurized loss of forced circulation • Depressurized loss of forced circulation	• To ensure passive safety, high emissivity of the core barrel is required to limit core temperatures—need high emissivities on both inside and outside surfaces, and formation and control of surface layers in helium environments; • Limited studies on SS and on 508 show potential for maintaining high emissivity.	Vol. 4, Table 7, ID No. 46
26.	High-Temperature Materials	RPV Internals (metallic): Radiation-creep	• Maintain structure geometry	Excess deformation during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load • Pressurized loss of forced circulation • Depressurized loss of forced circulation	• Irradiation creep and dimensional changes particularly for alloy 800H at moderately low-dose should be assessed; • Little information on irradiation creep is available for Alloy 800H.	Vol. 4, Table 7, ID No. 47

Priority 1 PIRT Issues: High Importance & Low Knowledge Level

Item	Topic Area	Issue	Figure of Merit	Plant Condition or Accident Mode	Basis for High Importance/Low Knowledge Determination	Comments
27.	High-Temperature Materials	RPV Internals (nonmetallic): Composites structural design and fabrication methodology limitations for new structures (lack of experience)	• Maintain structure geometry	Core restraint failure during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load • Pressurized loss of forced circulation • Depressurized loss of forced circulation • Rupture with air ingress • Rupture with water ingress • Reactivity events	• Carbon–carbon composites are prime candidates, but need approved methods of designing, proof testing, model standard testing, and validation tests.; • Scalability probabilistic methods of design and fabrication issues must be addressed; • Large scale (meters in diameter) structures, as well as smaller ones, must be covered; • Extensive experience within the aerospace industry; applicability must be assessed.	Vol. 4, Table 7, ID No. 52
28.	High-Temperature Materials	RPV Internals (nonmetallic): Environmental and radiation degradation and thermal stability at temperature	• Maintain insulation capability	Fibrous insulation degradation during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load • Pressurized loss of forced circulation • Depressurized loss of forced circulation • Rupture with air ingress • Rupture with water ingress • Reactivity events	• Relatively low dose and exposure is expected, but LOFC can result in temperatures high enough to challenge stability of fibrous insulation such as Kaowool; • Need to assess effects on micro-structural stability and thermo-physical properties during irradiation and high temperature exposure in impure helium; • Limited commercial information available for conditions of interest.	Vol. 4, Table 7, ID No. 53

Priority 1 PIRT Issues: High Importance & Low Knowledge Level

Item	Topic Area	Issue	Figure of Merit	Plant Condition or Accident Mode	Basis for High Importance/Low Knowledge Determination	Comments
29.	High-Temperature Materials	Valves: Isolation valve failure	• Primary system pressure boundary integrity	Malfunction, failure to operate. and breach during: • Startup • Shutdown • Anticipated transient without scram (ATWS) • Depressurized loss of forced circulation	• Isolation valve failure (includes categories such as self-welding, galling, seizing) is possible; • Concerns about isolation valves are similar to 'breach to secondary' issues on IHX because they would provide barriers to secondary heat transport system; • Information possibly available from previously constructed HTGRs, but relevance needs to be assessed; • State of knowledge about helium-leak-tightness in large valves is unknown.	Vol. 4, Table 7, ID No. 56
30.	High-Temperature Materials	Valves: Valve Failure	• Primary system pressure boundary integrity	Failure to operate. and breach during: • Startup • Shutdown • Steady state • Helium inventory control • Anticipated transient without scram (ATWS) • Turbine trip • Loss of load • Pressurized loss of forced circulation • Depressurized loss of forced circulation • Rupture with air ingress • Rupture with water ingress • Reactivity events	• Concerns about a variety of valve failure mechanisms that will be design-dependent (includes categories such as self-welding, galling, seizing) will need to be assessed once design-specific details are available; • Helium-tribology issues must be considered; • Allowable identified and unidentified coolant leakage must be established; • Information available from previously constructed HTGRs but relevance needs to be assessed.	Vol. 4, Table 7, ID No. 57
31.	Graphite	Irradiation-induced creep (irradiation-induced dimensional change under stress) Could potentially reduce significantly internal stress?	• Ability to maintain passive heat transfer • Maintain ability to control reactivity • Thermal protection of adjacent components • Shielding of adjacent components • Maintain coolant flow path • Prevent excessive mechanical load on the fuel • Minimize activity in the coolant		• Required for graphite FEM stress analysis, acts to reduce stress; • It is essential that irradiation creep is better understood, mechanistic understanding essential; • There are interaction effects with CTE and maybe dimensional change and modulus; • New models are needed along with data on new graphites.	Vol. 5, Table 5, ID No. 7

Priority 1 PIRT Issues: High Importance & Low Knowledge Level

Item	Topic Area	Issue	Figure of Merit	Plant Condition or Accident Mode	Basis for High Importance/Low Knowledge Determination	Comments
32.	Graphite	Irradiation-induced change in CTE, including the effects of creep strain	• Maintain ability to control reactivity • Thermal protection of adjacent components • Maintain coolant flow path • Prevent excessive mechanical load on the fuel		• Essential input into irradiated graphite component stress analysis, also affected by irradiation creep; • Extensive database, some microstructural/mechanistic studies required.	Vol. 5, Table 5, ID No. 10
33.	Graphite	Irradiation-induced changes in mechanical properties (strength, toughness), including the effect of creep strain (stress). Tensile, bend, compression, shear (multiaxial), stress-strain relationship, fracture, and fatigue strength.	• Maintain ability to control reactivity • Thermal protection of adjacent components • Maintain coolant flow path • Prevent excessive mechanical load on the fuel		• Essential input into irradiated graphite component stress analysis, • Extensive database, some micro structural/mechanistic studies required; • Better understanding of fracture process required.	Vol. 5, Table 5, ID No. 11
34.	Graphite	Due to graphite failure, spalling Debris generated from within the graphite core structures.	• Maintain coolant flow path		• Two mechanisms: (a) component failure due to internal or external component stresses, (b) component failure due to very high irradiation and severe degradation of the graphite; • Generic graphite codes available for the prediction of internal stresses in irradiated graphite components, however, they require validation; • There are also whole-core models for component interaction; however, these are reactor specific; these codes will also require validation.	Vol. 5, Table 5, ID No. 25(b)
35.	Graphite	Due to graphite failure, spalling Debris generated from within the graphite core structures.	• Maintain ability to control reactivity • Thermal protection of adjacent components		• Generic graphite codes available for the prediction of internal stresses in irradiated graphite components; however, they require validation; • There are also whole-core models for component interaction; however, these are reactor specific; these codes will also require validation.	Vol. 5, Table 5, ID No. 27(b)