May 31, 2002

Kevin Borton, Licensing Manager
Exelon Generation
200 Exelon Way
Kennett Square, Pennsylvania 19348

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION (RAI) ON ANALYTICAL CODES AND SOFTWARE CONTROL; CORE DESIGN AND HEAT REMOVAL AND; OPERATIONAL MODES AND STATES FOR THE PEBBLE BED MODULAR REACTOR (PBMR)

Dear Mr. Borton:

The US Nuclear Regulatory Commission's (NRC's) objectives for the Pebble Bed Modular Reactor (PBMR) pre-application review are to obtain information from Exelon on the PBMR design and its technical bases in order to: (1) identify significant technical issues, safety issues and policy issues and, (2) identify a path for resolution of the issues. Achieving these objectives is expected to enhance the effectiveness and efficiency of the staff's review of an actual PBMR license application and to provide guidance to Exelon that is useful in the preparation of an application.

Since June 2001, the NRC staff has conducted periodic public meetings with the Exelon Generation Company (Exelon) and the United States Department of Energy (DOE) to receive presentations and obtain information on a range of technical and programmatic topics supporting the PBMR pre-application review. These periodic meetings provided a starting point for obtaining information from Exelon on the PBMR design and its technical bases and for identifying significant issues for which staff resolution guidance would be pursued.

Early in the pre-application review, the staff requested Exelon to document the information that had been informally presented in these meetings and to formally submit it for staff review. Accordingly, between October 2001 and March 2002 Exelon formally submitted the requested documents as technical "white papers." As shown in Enclosure 1, Exelon submitted white papers for most of the technical and programmatic topics that were presented at the public meetings.

Exelon requested that the staff provide feedback on the technical, safety or policy issues, including staff questions related to each of the submitted technical white papers and associated presentations. The white papers, including any updates and formal responses to staff identified issues and questions, were to provide the primary basis for the staff's pre-application review findings, conclusions, positions and guidance.

The purpose of this letter is to provide the staff's feedback on technical, safety or policy issues in terms of requests for additional information (RAIs) on selected technical white papers and the associated meeting presentations. The selected white papers (and number designations) are: "PBMR Analytical (Computer) Codes Data Table" (5); "PBMR Design and Heat Removal Preliminary Description" (6) and; "PBMR Operational Modes and States" (7).

Enclosure 2 contains the RAIs for each of the three white papers. The RAIs for each paper have been grouped into one of two categories. The RAIs in Category 1 are those that are considered relevant to either policy issues or significant safety or technical issues that are the focus of the PBMR pre-application review. Category 2 RAIs involve safety or technical issues for which responses would be required if a PBMR license application were to be submitted. Additionally, selected RAIs in Category 2 considered significant to support the development of the NRC's infrastructure of tools, data and expertise that would be needed to conduct a PBMR license application review. These have been identified with an asterisk (*) and any responses would be of most benefit to the staff if provided in advance of a license application. All RAIs in Enclosure 2 have been identified by white paper number and RAI category.

The staff recognizes Exelon's announced plans to end its participation in the PBMR project in South Africa when the current PBMR feasibility study is completed, and that Exelon plans to terminate its PBMR pre-application review activities with the staff. Therefore, the staff understands that in most cases Exelon does not plan to respond to the enclosed RAIs. Even so, we believe that there is a mutual desire to address and document the current PBMR pre-application review work in manner which would be of benefit to the staff, to others who might seek to resume PBMR pre-application review activities and to interested stakeholders. Therefore, the staff is transmitting the enclosed RAIs to formally document the results of the staff's review of these white paper topics to date and to place them on the public record.

It is requested that you review the enclosed RAIs and respond as to whether or when the requested information will be provided by Exelon to the NRC.

The reporting and/or record keeping requirements contained in this letter affect fewer than ten respondents; therefore, OMB clearance is not required under P.L. 96-511.

Please contact me (301-415-7499) or Stuart Rubin (301-415-7480) if you have any questions on this request.

Sincerely,

/RA/

Farouk Eltawila, Director
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

Project No. 713

Enclosure: As stated

cc w/encl:

Standard Service List Addresses

Letter dated: 05/31/02

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Division of Systems Analysis and Regulatory Effectiveness
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Project No. 713
Enclosures: As stated
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Letter dated: 05/31/02

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Table 1: PBMR Pre-Application Review Technical and Programmatic Topics Presented and Documented by Exelon

Meeting Date	Meeting Presentation Technical Topic	Exelon Technical White Paper		
		Title of Paper	Transmittal Date	No.
Jun 12-13, 2001	Fuel Overview -Design, Manufacturing, QC and Qualification	PBMR Nuclear Fuel	11/16/01[1]	8
		Fuel Fabrication Quality Control Measures and Performance Monitoring Plans for PBMR Fuel	1/31/02	9
Jul 17-18, 2001	Design Codes and Standards	Summary of PBMR Design Codes and Standards	10/30/01	3
		RPV and Connecting Piping - White Paper	12/17/01	4
	Fuel Irradiation Program	(See Technical White Paper No.10)	3/18/02	-
Aug 15-16, 2001	Analytical Codes and Software Control	PBMR Analytical (Computer) Codes Data Table	10/30/01	5
	Fuel Design Logic	None	11/16/01	-
	Core Design	PBMR Design and Heat Removal Preliminary Description	3/04/02	6
	Heat Removal			
Oct 25, 2001	High Temperature Materials Graphite	Graphite Presentation to USNRC in Support of PBMR Pre-application Activities	10/23/01	1
	Control of Chemical Attack	Control of Chemical Attack in the PBMR	10/23/01	2
	Systems Design Approach and Status	None	N/A	-
	High Temperature Materials	None	N/A	-
Nov 29-30, 2001	Operational Modes and States	PBMR Operational Modes and States	11/27/01	7
	Testing Requirements for a Combined License	Testing Requirements for Issuance of a Combined License	11/27/01	11
Mar 28 2002	Fuel Qualification Test Program	Pebble Bed Modular Reactor Fuel Qualification Test Program	3/18/02	10

[1] Paper was later withdrawn.

Request for Additional Information
PBMR Analytical (Computer) Codes Data Table
(White Paper No. 5)

5. Analytical Codes and Software Control

Note: Specific RAIs relating to the uses of computational models for predicting certain processes and phenomena in the PBMR system are included under the corresponding white paper topical areas (e.g., PBMR Design and Heat Removal Preliminary Description, PBMR Operation Modes and States) and are not repeated below.

5.1 Category 1 RAIs are considered relevant to either potential policy issues or significant safety issues or technical issues that are the focus of the PBMR pre-application review.

PANAMA:

5.1.1 Discuss how the code predictions will be used for calculating failed particle fraction in PBMR fuel elements in the PBMR licensing safety analysis and compare this with the failed particle fractions that can be provided for the PBMR licensing safety analysis by the statistical analysis of the PBMR fuel irradiation test program particle failures.

5.1.2 Discuss how, if at all, the code will be used (vis-a-vis PBMR fuel irradiation test program data) for determining PBMR fuel-related limiting conditions for operation, safety limits and input to the accident source term.

5.1.3 Discuss how will the mechanistic failure models of the code will be verified or adjusted, if at all, based on the PBMR fuel irradiation testing experimental data, including the specific conditions (e.g., irradiation temperature) of these tests.

5.1.4 Cite and discuss any other sources of experimental data that are used to establish the mechanistic failure models. Discuss the applicability of this data to the PBMR fuel.

5.1.5 Discuss the quality assurance procedures that were or will be used in the experiments that provide the data used to establish the mechanistic failure models.

FRESCO:

5.1.6 Discuss the experimental data base that is used for developing and/or validating the models (i.e., for intact coated particles, for failed coated particles, for fuel elements).

Discuss the PBMR fuel coated particle and PBMR fuel element test data that will be used for developing and/or validating these models.

51.7 Diffusion through the graphite matrix is a significant factor in the release of metallic fission products. German fuel irradiation and post-irradiation heat-up tests show that matrix graphite diffusion coefficients for metallic fission products for normal operation and accident temperature conditions can differ by an order of magnitude or more, depending on the graphite used. In this regard, the original petroleum coke source that was used to make the German fuel matrix graphite is no longer available for making the matrix graphite for the PBMR production fuel. Accordingly, the PBMR production fuel matrix graphite will be different from that used in the German fuel (i.e., tests). Discuss any plans for developing or validating the PBMR fuel matrix graphite diffusion coefficients for use in the metallic fission product release calculations.

PANAMA and FRESCO:

5.1.8 Discuss how the temperature and power cycling associated with multi-pass pebble fuel cycling is treated in modeling and calculating fission product diffusion and release in FRESCO.

5.1.9 Discuss the key assumptions and boundary conditions (e.g., burnup, accident temperature, fission product concentration at the outer surfaces of layers and pebble graphite matrix) in using FRESCO for the conservative mechanistic calculation of integrated core-wide fission product release based on fission product diffusion and release from fuel.

5.2 Category 2 RAIs are considered relevant to safety issues or technical issues for which responses would be required when a PBMR license application is submitted.

5.2.1. With respect to the analytical computer programs that will be used for engineering analysis.

a. State which of these computer programs will be used for the high-temperature stress analysis of the graphite components.

b. For each program include a detailed description of the capabilities, analytical methodology, as well as the methods and problems that were used for verification and compliance with engineering quality assurance requirements.

5.2.2. The referenced list includes the computer program ADAMS. This program is not found on the MSC Software website. Was the intended computer program ABAQUS? Provide the purpose of this program, a detailed description of the analytical methodology, as well as the methods and problems that were used for verification and quality assurance.

5.2.3. During the meeting with the staff of August 16, 2001, Exelon indicated that three computer codes (Patran, Nastran and ADAMS (ABAQUS?)) will be used to analyze the PBMR structures under various loading conditions including seismic loads. The staff's understanding is that for seismic analyses, computer codes Nastran and ADAMS can only handle the dynamic analysis of lumped-mass structural models with fixed base (hard rock sites) or lumped soil springs to represent the soil foundations (no embedment). Therefore, the applicability of these codes to the analysis of structures founded on layered soil sites with deep embedment such as PBMR becomes questionable. If the staff's understanding regarding the limitation of these codes is correct and if these two codes are to be used to perform seismic analyses of PBMR structures founded on soil sites, Exelon should: (a) justify that the lumped soil spring models can properly represent the layered soil site conditions and deep structural embedments, (b) demonstrate that these codes or the combination of these codes can reasonably calculate the seismic responses of PBMR structures, with deep embedment, founded on sites other than hard rock sites, and (c) provide the validation package of these codes for review.

<u>General Issues</u>:

5.2.4* The following information request pertains to all uses of analytical codes and methods for predicting safety-related processes and phenomena (e.g., reactivity, heat generation, heat transfer, fluid flow, temperatures, pressures, material stresses, strains, fuel burnup, fuel performance, material fluence, material damage, activation, radiation shielding, radionuclide transport, source terms, releases) under normal and off-normal conditions in the PBMR system:

(a) Identify and provide the existing experimental, testing, and operational data that are used for validating the PBMR computational methods through benchmark comparisons. Describe the measured configurations, data, and data uncertainties in adequate detail to permit the staff to perform benchmark comparisons and analyses with similar codes and methods. Identify the areas of data applicability and associated parameter ranges (e.g., temperatures). To justify the applicability of measured data for use in validating a particular analysis or analysis method, compare the physical processes and phenomena that govern the measured data with those that govern the corresponding computed results for the safety analysis.

(b) Describe any additional measurement data from testing and monitoring on the first demonstration PBMR module (or subsequent modules) that will be used for confirmatory benchmark validation of computational codes, methods, and predictions. Discuss how any such additional benchmark data will be factored into the safety analyses that will support the NRC license application (e.g., any reductions in the assumed computational biases and uncertainties).

(c) Provide a concise discussion of the methods (e.g., code scaling and uncertainty methods) by which potential biases and uncertainties in the computed results are estimated and considered in the safety analyses. The discussion should address how the results from measured and analytical benchmarks are used to assess the potential computational biases and uncertainties and how the results of this assessment are accounted for in the safety analysis results. Provide comparisons of input parameters used in the benchmark calculations against those used for the safety calculations and justify any differences.

5.2.5* Describe how all codes and related method applications will conform to the guidance provided in DG-1096 and SRP 15.0.2. Note that the guidance includes providing the source code in electronic form for all code reviews.

General Issues:

5.2.6 The following information request pertains to all uses of analytical codes and methods for predicting safety-related processes and phenomena (e.g., reactivity, heat generation, heat transfer, fluid flow, temperatures, pressures, material stresses, strains, fuel burnup, fuel performance, material fluence, material damage, activation, radiation shielding, radionuclide transport, source terms, releases) under normal and off-normal conditions in the PBMR system:

Provide all documentation, such as code user's guides, theory manuals, assessment reports, and analysis reports, necessary to describe the code models, specific input models, and analysis sequences in sufficient detail to permit a technical review of the analytical approach by a reviewer familiar with the technology and the respective technical disciplines. The code documentation should describe how the respective phenomena and processes are represented by the code, including theory, empirical correlations, equations, approximations, numerical methods, and any embedded assumptions. Documentation of problem-specific input models should describe the input modeling approximations and assumptions, including values of input parameters and technical justifications for using those values in the respective application.

5.2.7 Identify the technical and quality assurance (QA) standards used for developing and controlling the technical software that supports the applicant's PBMR safety analysis.

5.2.8 Describe how commercial "off the shelf" technical software is integrated into the applicant's software QA program for PBMR safety analysis.

6. Core Design and Heat Removal

6.1 Category 1 RAIs are considered relevant to either potential policy issues or significant safety issues or technical issues that are the focus of the PBMR pre-application review.

6.1.1 Describe what testing will be done on the first demonstration module to demonstrate that the maximum local fuel temperatures during normal PBMR operation are no higher than those considered in the fuel testing program and the reactor safety analysis. Describe any repeated testing that will be conducted to evaluate the variation (i.e., the expected increase) of maximum fuel operating temperatures during the transition from initial to equilibrium core loadings.

6.1.2 Provide a detailed analysis to identify and predict the worst-case reactivity and power transients in the PBMR. Included should be credible events involving seismic compaction, moisture ingress, ejection of rods and/or shutdown absorbers (e.g., from standpipe failure or sheering), withdrawal of rods and/or shutdown absorbers, and overcooling. The analysis should identify and address those initial conditions that lead to the most severe power and temperature transients. Demonstrate that the worst-case power and temperature transients are enveloped by conditions in the transient fuel testing program.

6.2 Category 2 RAIs are considered relevant to safety issues or technical issues for which responses would be required when a PBMR license application is submitted.

6.2.1* Provide a detailed description of the codes, methods, and modeling assumptions used in predicting the peak fuel temperatures arising in a subcritical DLOFC (depressurized loss of forced cooling) event. The description should address the following:

(a) Sources of after-heat in individual pebbles and graphite structures: Describe and justify the methods and assumptions used in computing after-heat power in the fuel pebbles and graphite structures as functions of the power and temperature histories during irradiation, time after shutdown, and the temperature history during the heatup event. For initial and equilibrium fuel pebbles (i.e., with 4 and 8 % initial enrichments, respectively), describe the predicted relative contributions from stored fission heat and all sources of after-heat, including: (i) the radioactive decay of specific fission products, actinides and activation products, (ii) subcritical neutron production, multiplication and absorption, and (iii) annealing of high-energy graphite damage during the heatup transient.

(b) Treatment of the pebble-to-pebble heat source variations in the models for heat removal: Describe in detail the techniques and underlying assumptions used in determining the averaged or smeared values of stored heat and after-heat power in the coarse meshes of the heat removal models, where each mesh contains a statistical packing of fuel pebbles with wide-ranging burnups and associated power densities and thermal conductivities.

(c) Heat removal analysis methods and modeling: Describe in detail and justify (i) the temperature- and fluence-dependent effective conductivities in the fuel kernel, coatings, and matrix graphite, (ii) the effective conductivity through individual fuel pebbles, (iii) the effective thermal conductivities and emissivities from pebble to pebble, considering local variations in pebble power and packing (e.g., each pebble touching 6 to 12 neighbors), (iv) the integral equivalence of results from a smeared coarse-mesh model of a pebble bed with those from a detailed pebble-by-pebble heat removal model, and (v) the prediction of peak pebble and fuel particle temperatures from a coarse-mesh heat-removal solution. The discussion on predicting local peak fuel temperatures should address the heat-source hot spots caused by chance clustering of low-burnup pebbles while considering the spatial nonuniformity of local heat removal characteristics (e.g., nonuniformity associated with local coolant flow instabilities, locally variable pebble packing fractions, and fluence-induced changes in pebble conductivity).

6.2.2* Describe the relevant experiments and demonstration-module tests that will be used for validating or confirming the prediction of after-heat sources in subcritical reactor heatup events. Describe how such validation benchmarks will be used to evaluate or estimate potential biases and uncertainties in the predicted after-heat sources. Describe how the estimated potential biases and uncertainties will be accounted for in the heat-source models used for predicting temperatures during the subcritical heatup transient.

6.2.3* Describe the relevant experiments and demonstration-module tests that will be used for validating the prediction of heat removal phenomena and temperatures arising in depressurized subcritical reactor heatup events. Describe how such validation benchmarks will be used to evaluate or estimate potential biases and uncertainties in the predicted temperatures. Describe how the safety analysis will account for the estimated potential biases and uncertainties in predicting maximum temperatures during the subcritical heatup transients.

6.2.4* Describe in detail the analysis codes, methods, and modeling assumptions used in predicting maximum local fuel temperatures during normal operation, at-power coolant flow transients, and reactivity transients.

6.2.5* Describe the relevant experiments and test data used in validating the prediction of fuel temperatures during normal operation, at-power coolant flow transients, and reactivity transients. Provide an evaluation of the potential temperature prediction biases and uncertainties based on such validation benchmark analysis. The evaluation should consider the implications of the melt-wire monitor-pebble tests that were performed at the AVR test reactor in Germany and note the similarities and differences between important phenomena in those tests and the PBMR (e.g., the AVR's shorter core, reflector noses, upward coolant flow, and lower pressure). Describe relevant additional tests that will or could be performed in other test facilities and the PBMR demonstration module (see also RAI 6.1.1) to validate the methods for predicting PBMR maximum local fuel temperatures during normal operation.

6.2.6* Provide detailed quantitative information on the predicted spectrum of fuel pebble transit times through the reactor. Of particular interest is a statistical characterization of maximum transit times, i.e., the upper tail of the spectrum. Describe in detail the technical basis (e.g., test data, code models) for the predicted spectrum. Describe the in-plant testing and monitoring that will be performed in the demonstration module and subsequent modules to validate or correct the predicted transit-time spectra and associated pebble flow profiles and to detect pebble flow aberrations such as might result from jamming of pebble fragments and localized pebble bridging. (Note that the THTR-300 in Germany experienced pebble flow velocity profiles that differed substantially from what had been predicted. That misprediction appears to have been caused in part by a prediction model that did not account for the strong temperature dependence of pebble-to-pebble friction in a helium atmosphere.)

6.2.7* Describe the technical basis for determining the discharge criterion for measured pebble burnup. The response should address target burnup and fluence limits for initial and equilibrium fuel pebbles, burnup measurement uncertainties, and a statistical characterization of the maximum burnup and fluence increments (i.e., considering maximum in-core residence time) on a pebble's final pass through the core.

6.2.8* Provide a detailed description of the computational models for fuel, geometry, pebble flow, and core composition in the initial, transitional, and equilibrium cores. Describe the approach for justifying the assumed number, sizes, and mixing compositions of pebble flow channels used in the core analysis models.

6.2.9* Describe the fuel loading strategies for transitioning from the initial core to equilibrium core loadings. Provide a detailed description of predicted fuel depletion compositions and flux and power profiles in the transitional cores as well as the initial and equilibrium cores.

6.2.10* Describe the computational models, experimental validation, and planned testing in the demonstration module and subsequent modules that support and confirm the determination of reactivity feedback effects from temperature changes in the fuel, moderator, inner reflector, and outer reflectors in the initial, transitional, and equilibrium cores. The response should address the positive temperature feedback contributions from Xe-135 and bred fissile plutonium, encompass normal conditions as well as maximum credible moisture ingress, and evaluate the spatial dependence of fuel and moderator temperature feedback effects (e.g., near the periphery and ends of the core).

6.2.11* Provide an analysis of stability against axial core power oscillations, including an evaluation of the degree of oscillation dampening. Include a detailed description of the analysis approach and modeling assumptions.

6.2.12* Describe the analysis and validation for predicting the reactivity insertion from credible moisture ingress events.

6.2.13* Provide an analysis of hot and cold shutdown margins with either or both shutdown systems functional in the initial, transitional, and equilibrium cores. The analysis should address normal dry conditions as well credible moisture ingress events and evaluate the sensitivity of in-reflector absorber worths to uncertainties and aberrations in pebble flow and mixing.

6.2.14* Describe the validation and testing for worths of control rods and shutdown absorbers, hot and cold, in the initial, transitional, and equilibrium cores, dry and with moisture ingress. Provide an evaluation of absorber worth sensitivities to tolerances in the radial positioning of absorbers in the reflector.

6.2.15* Describe the temperature measurement instruments and their locations in the demonstration module and subsequent modules.

6.2.16* Describe material fluence analysis and fluence monitoring, especially in areas potentially affected by neutron streaming through gaps formed through fluence-induced warping of graphite blocks in the outer reflectors.

6.2.17* Provide analyses of the thermal hydraulic issues associated with the porous central reflector, including core bypass flow, temperature gradients in the core support structures, pressure drops in the flow mixer, flow striping downstream, and natural circulation phenomena during pressurized loss of forced cooling events.

6.2.18* Provide a discussion on the potential need to include spurious block valve closure in the analyzed event sequences.

6.2.19* Describe RCCS (reactor cavity cooling system) analysis methods and validation. Describe temperature monitoring instrumentation on the vessel and at other locations in RCCS cavity of the demonstration module and subsequent modules.

6.2.20* Describe first-module testing plans and instrumentation for validating or confirming the prediction of fuel and vessel temperatures arising in pressurized and depressurized loss of forced cooling events.

6.2.21* How is the average or mixed reactor outlet temperature monitored? Describe the monitoring system. Provide a discussion of monitoring reliability and uncertainties and an assessment of system effects from credible drift or failure of the monitoring instrumentation.

6.2.22* What testing is planned to demonstrate that the computational methods can adequately predict the mixed mean reactor outlet temperature?

6.2.23* What testing is planned to demonstrate that the codes can adequately predict the time-varying radial and azimuthal dependence of local coolant temperatures at the reactor outlet?

6.2.24* Provide a technical justification of the uncertainties assumed in the calculation of shutdown margin.

6.2.25* Pebble flow was evaluated by comparing German experiments and South African computer simulation. It is stated that agreement is within 10%. What parameters were compared? What is their safety significance?

6.2.26* Please justify why the German pebble flow experiments are applicable to PBMR computer simulation assessment. What are the figures of merit? How will the biases and uncertainties be estimated and how will they be ultimately incorporated into the VSOP code prediction of pebble flow?

6.2.27* Porosity distribution variations in the pebble bed of up to 10 % have been reported.

(a) What is the radial and axial variation in the porosity in the PBMR core?

(b) What is the variation in the porosity inward from the wall to two pebble diameters? What effect if any does this have on the estimate of the rod worth?

(c) At the wall the porosity goes to unity. Are transport corrections necessary and used at the wall in VSOP to compute rod worth? Is this taken into account in computing the shutdown margin?

(d) Is the porosity variation taken into account in computing the fuel temperature distribution and its uncertainty?

6.2.28* Since the size of the central reflector, and the mixing zone are strongly defined by the manner in which the pebbles are loaded, how do you benchmark the computation?

(a) Since one simulation takes ~4 months, parametric studies appear to be limited. So which calculations/simulations are the defining computations?

(b) Does the ANNABEK experiment (to which the PFC3D simulation was compared) contain a central reflector column? Please describe the experiment in detail, provide the experimental results, and describe its relevance to the PFC3D simulation.

6.2.29* What is the correlation between the local pebble flow velocity and the local porosity?

6.2.30* In VSOP calculations how are the regions associated with each fixed flow velocity and porosity sized appropriately?

6.2.31* Please describe the VSOP validation and verification process. In particular, describe the experiments used in the validation and the mathematical benchmarks used in the model verification and give the results.

6.2.32* Under the VSOP calculations section, there is a sentence with reads “After mixing, spheres are assumed to be mixed and available for reloading in any appropriate channel.” Where are the spheres mixed? No other discussion is provided; therefore, please elaborate on what is meant.

6.2.33* The uncertainties of 8 and 5 % used in determining the computed shutdown margin (Table 2.7-1) are based on the “German Practice”. What is the German practice and why is it appropriate for the PBMR design?

(a) What is the C/E and its uncertainty associated with the PBMR rod worth?

(b) Is the ASTRA facility in Russia that will be used to validate the control rod worth calculations sufficiently representative for the task? Are the rods in the reflector? Please explain.

6.2.34* It is mentioned that the control rods are chain driven. Please provide additional information on the control rod system, including a detailed description, operational characteristics, and material composition. Please provide similar information for the absorber sphere system. Please provide information regarding the modeling and the methodology for calculation the rod worths.

6.2.35* The aspect ratio (3 :1) of the PBMR core is significantly greater than what has been encountered in operating reactors of any type.

(a) What is the shape of the 1st harmonic of the flux distribution? Is it degenerate?

(b) How is this harmonic affected by a stuck rod?

(c) What is the 1st to fundamental mode eigenvalue separation?

(d) What role, if any, does the 1st harmonic play in postulated overpower transients and Xe swings?

(e) The core axial transit time for a change in the helium mass at the core inlet is much longer than the neutronic effect. Can you preclude stability problems?

6.2.36* Provide additional description of the fuel handling block valve system.

6.2.37* Describe the validation of the temperature coefficients quoted in Table 2.6-1.

6.2.38* Please provide additional description of the impacts both operational and neutronic of changing the pebble bed cycle number from 10 to 6.

6.2.39* Graphite changes dimensions under irradiation conditions. Justify that following graphite contraction, the absorber spheres will not achieve a greater packing fraction, exposing the top part of the core to reduced control. Also, explain how a clear pathway to the core bottom will be assured for the control rods and absorber spheres. Is a testing program being considered to ensure the pathway remains open throughout the reactor lifetime?

6.2.40* Figures 3.6-1 and 3.6-2 in “PBMR Design and Heat Removal Preliminary Description” (Document number 010302-425) show graphs of fuel temperature versus time for a depressurized loss of forced cooling accident for the case with and without control rods (but with RCCS) and with and without RCCS (respectively). There is no discernable difference in the maximum fuel temperatures shown in these figures. The text associated with Figure 3.6-2 remarks that the heat sink in the no-RCCS case is the reactor cavity concrete. The reactor cavity concrete, of course, is a finite heat sink and it is anticipated that eventually the fuel temperature will begin to increase. A safety margin should be identified here for the length of time that the system can operate safely without RCCS operation. Figures 3.6-6 and 3.6-7 show a temperature profile for fuel, RPV, RCCS, and concrete for a PLOFC and DLOFC accidents, respectively. It would be useful to show similar results for the case with no active RCCS and with a dry RCCS. Also, more details regarding the heat removal calculations should be presented. Figure 3.6-5 illustrates the mesh used in the analysis, but other features of the analysis would also be enlightening.

6.2.41* Analytical studies should be presented that demonstrate the postulated function of the passive RCCS along with experimental confirmation of such analysis. A sequence of events is described in the white paper, but no indication of a scoping analysis was presented.

6.2.42* Analysis of the concrete temperatures in the reactor cavity should be presented along with experimental confirmation of such analysis. Comments were made (p. 34) that indicated that confirmatory work with the Japanese is in progress with regard to the HTTR data; the results of such work should be presented.

6.2.43* The RUCS system is directly connected to the RPV and uses water from the ACS. It is stated that when the RPV is isolated the RUCS system is used to remove decay heat from the vessel. At this point, the RPV and the coolant in the RUCS are at about the same pressure and some in-leakage from the RUCS systems to the RPV is possible. The white paper states that the water inventory of the RUCS is kept small "...to minimize consequences (e.g. corrosion and reactivity) from water ingress (p. 30)." How would a water coolant leak from the RUCS into the RPV be detected? What amount of water can be tolerated in the RPV to minimize consequences (that is: quantify "minimal consequences")? What are the effects of having water in the RPV during startup?

6.2.44* Provide a discussion on the planned uses of burnup credit in analyzing the criticality safety of systems for handling, storing, and transporting damaged fuel and spent fuel under normal and accident conditions (e.g., moisture ingress). Specify the level of burnup credit proposed (e.g., major actinides and fission products, or actinides only). Describe the validation data (e.g., relevant spent fuel isotopic assays, critical experiments) that will be provided to qualify the calculation of subcritical neutron multiplication factors while taking credit for the reduced fuel reactivity caused by burnup in the reactor.

6.2.45* Provide detailed design information regarding the reactor core conditioning system. If it has not been designed, please provide all the design criteria and the basis for them.

6.2.46* Code cases are discussed several times in the document. Please provide information on all the code cases used in the PBMR design.

6.2.47* How will core bypass flow be determined, validated, and monitored over the life of the PBMR?

6.2.48* What is the spatial distribution of the temperature coefficients in the PBMR for the initial cycle and the equilibrium cycle. Does the distribution change over the range of expected helium inventory changes? What effect does this have on the maximum fuel temperature during transients of interest to the safety of the PBMR?

6.2.49* The quantity of heat removed is regulated by blower speed and bypass valve manipulation. Can these be varied independently in such a way as to lead to unstable core response?

6.2.50* On reactor scram, the Brayton cycle collapses by opening the bypass valves. What are the consequences of on or more bypass valve sticking totally of partially shut?

6.2.51* It is stated that on load rejection the generator bypass valves prevent over-speeding. How is this achieved? Under what, if any, circumstances is over-speeding possible? What would be the reactivity and consequent temperature effects?

6.2.52* It is stated that, in an unplanned shutdown, within a few minutes the SBS is started for the continuous active heat removal. What are the rules with regard to failure to start the SBS and what are the consequences.

6.2.53* During maintenance, the RUCS keeps the core at the required temperature. What are the consequences of a failure of the RUCS during maintenance and how are such consequences addressed?

6.2.54* What is the assumed bypass flow in the quoted peak fuel temperature calculations? What is the sensitivity of the temperature to this assumption? Does the peak temperature vary linearly with the bypass flow assumption?

6.2.55 How does FLOWNET handle multiple fluid species? What species does it model? Can it address such issues as degraded heat transfer in the presence of multiple species, effects on critical flow, etc?

6.2.56 It has been indicated that the power level is controlled through Helium Inventory Control System. If the system has been designed, please provide detailed system descriptions, design limits and operational interactions with the reactor control rod/sphere absorber system and the turbine/generator load control system.

If the system has not been designed, please provide the design criteria, expected system interactions and the considerations regarding the normal helium inventory loss through the system leaks.

It has been known that maintaining the helium inventory is a significant burden for operating an HTGR. What considerations have been given to developing a program to monitor, verify and compensate the helium loss through the system leaks during the normal operation?

6.2.57 Two turbine/compressor units and a turbine/generator unit will be used according to the current PBMR design. Traditionally, the turbine/compressor system operation characteristics are not the main focus of NRC's interest. However, the operational characteristics of these three turbine systems have significant impact on the reactor side control and response. Therefore, please provide the following design information about these three units:

(a) Operational characteristics of these units, e.g., inlet/outlet temperature/pressure versus power level, rotational speed of the turbine/compressor units versus power.

(b) Turbine/compressor bearing and seal design. The operating lifetime could be significantly affected by the performance of this part of the design. The allowable leakage flow rate may also affect the cycle efficiency and the balance of the plant.

(c) Turbine rotational speed control system information, particularly for the turbine/generator unit.

Request for Additional Information
PBMR Operational Modes and States
(White Paper No. 7)

7. PBMR Operational Modes and States

7.1 Category 1 RAIs are considered relevant to either potential policy issues or significant safety issues or technical issues that are the focus of the PBMR pre-application review .

7.1.1 On page 3 of the dialog accompanying the slide presentation prepared for the November 30, 2001, presentation on PBMR Operational Modes and States, the discussion of the possible sudden loss or partial loss of external electric load includes a discussion of the potential for unacceptable rotational speeds for the turbo-machinery and the stabilizing effects of having the compressor and turbine on a single shaft. Will the stress on the shaft in a loss of load event, due to the compressor's ability to arrest the speed up of the turbine be significant? Will a broken shaft of one of the turbo-compressors be included in the safety analysis for this plant? As a design basis event?

7.1.2 In the dialog accompanying the slide presentation prepared for the November 30, 2001, presentation on PBMR Operational Modes and States, the discussion of Flownet Nuclear, Simulink and State Flow code included a discussion of the Quality Assurance program for the development of the codes. It states that the codes have been developed in accordance with ISO 9001, ANSI/ANS-10.4 and NQA-1. Will the codes be submitted under Appendix B or will you request that the NRC accept the above listed QA programs? If the latter is the case, will PBMR discuss with the NRC in the pre-licencing discussion there plans for developing this argument?

7.2 Category 2 RAIs are considered relevant to safety issues or technical issues for which responses would be required when a PBMR license application is submitted.

7.2.1 On pages 10-12 of the dialog accompanying the slide presentation prepared for the November 30, 2001, presentation on PBMR Operational Modes and States, the discussion of Flownet Nuclear, Simulink and State Flow give a basic overview of the capabilities of the codes. It is stated the additional details can be obtained in the Flownet Nuclear User Manual. It is also stated that the Flownet Nuclear, Simulink, and State Flow suit will function as the "RELAP" of PBMR reactors. Additional detailed information on the codes will be needed for NRC to provide feedback as to possible issues associated with there use in the licencing on the Plant. Can the uses manuals, theory manuals and validation reports for these codes be made available to the NRC as part of the pre-application review?

7.2.2 In the dialog accompanying the slide presentation prepared for the November 30, 2001, presentation on PBMR Operational Modes and States, the discussion of operating modes, included on page 21, a review of the defuelled maintenance (0) to full shutdown (2a) transition. In this discussion there is no mention of the cold criticality issue. It is the NRCs understanding the as part of refueling the reactor an approach to critical procedure is planned to assure the correct number of pebbles are added to the reactor. This criticality while in shutdown mode might be approaches as a separate mode. How will PBMR develop operational procedures for this and other mode transitions? Additional details as to the off-loading and re-loading of the reactor would be useful in understanding if there will be regulatory issues involved with these procedures. It seems that generally reactivity and temperature limits are used to establish operation modes, are there any exception to this rules, such as the criticality in the mode 0 to 2a transition? How will this effect technical specification and operating procedures?

7.2.3* Given that stated goal of reduced staffing levels for the PBMR, it would seem likely that some of the level start up and mode transition for the PBMR will be much more automated than for current generation reactors. What level of automation of start up and mode transients will be used for the PBMR? Will recovery actions be automated? Will this effect the definitions of normal, off normal, and emergency procedures?