May 9, 2012

Mr. Jim Kinsey, Director
Regulatory Affairs
Next Generation Nuclear Plant Project
Idaho National Laboratory
P.O. Box 1625
2525 North Fremont Ave
Idaho Falls, ID 83415

SUBJECT: NEXT GENERATION NUCLEAR PLANT – ASSESSMENT OF WHITE PAPER ON HIGH TEMPERATURE MATERIALS

Dear Mr. Kinsey:

This letter forwards a report assessing the contents of a white paper submitted by the Next Generation Nuclear Plant (NGNP) Project and the Project's responses to initial requests for additional information (RAIs) submitted by the Nuclear Regulatory Commission (NRC) after preliminary review. Specifically, this report assesses the Project's "NGNP High Temperature Materials White Paper" (ADAMS accession number ML101800221).

The assessment report was developed by a working group composed of the NRC staff from the Office of New Reactors (NRO) and the Office of Nuclear Regulatory Research (RES). Note that this assessment reflects the opinions of the members of the working group and should not be construed as formal staff positions in the context of future licensing activities.

The assessment is necessarily preliminary, consistent with the high level at which the approaches have been presented, the ongoing status of the associated development and testing programs, and the lack of detail on the proposed NGNP design and how its safety-related performance will be analyzed for evaluation against appropriate criteria.

The working group has noted a number of areas where the proposed approaches could be strengthened and where technical issues and design choices could potentially affect implementation of the approaches. The working group is aware of the related research and development activities led and conducted by Idaho National Laboratory (INL). The working group members have also regularly participated in INL meetings and conferences to provide input to part of the technical knowledge development.

The working group recognizes that the objective of the white paper was not to solicit a regulatory decision. Accordingly, the assessment report does not reach any final conclusions regarding the design and qualification of any NGNP components, materials, or their use in the plant design. Furthermore, the enclosed assessment does not constitute staff endorsement or rejection of any aspect of the ASME Code. Such endorsement is typically made via rulemaking in accordance with NRC's processes. The staff will not provide a final conclusion regarding the design and qualification of any NGNP components, materials, or their use in the plant design, until a NGNP combined license or design certification application is received and reviewed.

Many of the issues identified in the assessment can be addressed within the context of the Project's ongoing and planned development activities. It bears noting, however, that some of the more challenging potential issues might be most effectively resolved by conducting prototype-specific programs of operational testing, monitoring, surveillance, and inspection in the NGNP prototype reactor.

Please contact Jeffrey Cruz (Jeffrey.Cruz@nrc.gov, 301-415-0599) or Donald Carlson (Donald.Carlson@nrc.gov, 301-415-0109) if you have questions regarding the enclosed assessment report.

Sincerely,

/RA/

Michael E. Mayfield, Director
Division of Advanced Reactors and Rulemaking
Office of New Reactors

Project No.: 0748

Enclosures:
Assessment of White Paper Submittal on
High Temperature Materials

cc: COL - NGNP Mailing List

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ASSESSMENT OF WHITE PAPER SUBMITTAL ON HIGH TEMPERATURE MATERIALS

NEXT GENERATION NUCLEAR PLANT

PROJECT 0748

1. INTRODUCTION

The Next Generation Nuclear Plant (NGNP) Project was established by the U.S. Department of Energy (DOE) as required by Congress in Title VI, Subtitle C, of the Energy Policy Act of 2005 (EPAct). The mission of the NGNP Project (i.e., the Project) is to develop, license, build, and operate a prototype high temperature gas cooled reactor (HTGR) plant that generates high temperature process heat for use in hydrogen production and other energy-intensive industries while also generating electric power. To fulfill this mission, the Project is considering a modular HTGR with either a prismatic block or pebble bed core and safety features described as follows:[1]

> *"To achieve the safety objectives for the NGNP Project, the HTGR relies on inherent and passive safety features. Modular HTGRs use the inherent high temperature characteristics of TRISO-coated fuel particles, graphite moderator, and helium coolant, along with passive heat removal capability of a low-power-density core with a relatively large height-to-diameter ratio within an uninsulated steel reactor vessel to assure sufficient core residual heat removal under loss-of-forced cooling or loss-of-coolant-pressure conditions."*

As stipulated by the EPAct, the Project and the Nuclear Regulatory Commission (NRC) have been engaged in pre-licensing interactions on technical and policy issues that could affect design and licensing of the NGNP prototype. Such early interactions are encouraged by the Commission Policy Statement on the Regulation of the Advanced Nuclear Power Plants, which states in part the following:

> *"During the initial phase of advanced reactor development, the Commission particularly encourages design innovations that enhance safety, reliability, and security… and that generally depend on technology that is either proven or can be demonstrated by a straightforward technology development program. In the absence of a significant history of operating experience on an advanced concept reactor, plans for the innovative use of proven technology and/or new technology development programs should be presented to*

[1] INL/EXT-11-22708, "Modular HTGR Safety Basis and Approach," NGNP information paper submitted September 6, 2011, Project 0748, ADAMS accession number ML11251A169, excerpt page 8.

> *the NRC for review as early as possible, so that the NRC can assess how the proposed program might influence regulatory requirements."*

DOE's contractor, Idaho National Laboratory (INL), is conducting research and development in support of the Project and has prepared a series of white papers on aspects of the HTGR design and safety basis in order to obtain NRC feedback on design, safety, technical, and/or licensing process issues that could affect NGNP deployment.

On June 25, 2010, the Project submitted a materials white paper (MWP), designated as INL/EXT-09-17187 (ADAMS accession number ML101800221), addressing high temperature materials expected to be part of an eventual NGNP design. The cover letter for that submittal stated that the white paper

> …provides the result of reviews of existing policies, regulations and guidance associated with acceptable materials for HTGR reactor applications. It includes development of a process for high-temperature component material selection and evaluation, leading to recommendations for qualification and acceptance of the HTGR reactor components. Metallic and non-metallic materials proposed for high-temperature service within the NGNP are identified and assessed in terms of supporting codes and standards and the existing bases for design and qualification. As part of this assessment, the processes for establishing the expected material performance requirements under operating and accident conditions are also described.
>
> Following NRC Staff review of this paper, and pending resolution of associated follow-on questions or requests for additional information, the NGNP Project requests that NRC (sic) feedback and documentation of its review in a format that will facilitate resolution of key design, safety, and licensing issues in the high temperature materials area, and that can (sic) used as a firm for the preparation of future HTGR license application(s).

Section 5 of the MWP describes a series of "Outcome Objectives." These objectives are divided into two categories for metallic and non-metallic materials. The Project is seeking NRC staff review and feedback on these objectives in order to address materials issues in advance of a license application.

For metallic materials, the MWP requests that the NRC provide feedback on the suitability of the American Society of Mechanical Engineers (ASME) Code for design of reactor components that are expected to operate in conditions outside the envelope of existing power plants. The report describes prospective changes to the ASME Code to address these different operating conditions and the materials that may be used in the NGNP.

The ASME Code is also considering how to address graphite components in HTGRs. The MWP requests NRC feedback on proposed Code changes, along with the experimental program to characterize the effects of long term exposure to neutron irradiation and high temperatures on the graphite structures.

The MWP assessment was conducted by a working group composed of NRC personnel from the Office of New Reactors (NRO) and the Office of Nuclear Regulatory Research (RES). On July 25, 2011, the NRC working group provided a set of requests for additional information (RAI) consisting of general questions on the overall materials for NGNP, and questions on each of the materials, namely, high temperature metals and alloys, graphite, carbon-carbon and ceramic composites, and insulation materials (ADAMS accession number ML112030174).

The Project provided responses to the RAI questions on September 27, 2011 (ADAMS accession number ML11272A067). The current assessment addresses the RAI responses.

It should be noted that the NRC will not provide any final conclusions regarding the design and qualification of any NGNP components, materials, or their use in the plant design, until a NGNP combined license or design certification application is received and reviewed.

2. ASSESSMENT

The NRC working group has completed its assessment of the MWP and associated RAI responses. This assessment does not provide final regulatory conclusions on any aspect of the NGNP design or the completeness of requirements in technical data for design basis modeling of properties and their specific application to reactor operation. Such conclusions will be provided in the safety evaluation of a future license or design certification submittal. The feedback provided by the working group generally reflects the lack of detailed design information and the preliminary and pre-conceptual nature of limited reactor design information driving the contents of the MWP.

In developing this assessment report, the working group used:

- Information provided in the MWP
- RAI responses provided by the Project
- Follow-up discussions with Project technical staff

Potentially significant issues were identified in interactions outside the context of the RAI questions and responses. These issues concern the planned scope of graphite irradiation testing. The working group is concerned that the Project’s testing plans do not presently include graphite irradiation at temperatures in the range of 250 to 600 °C. The working group acknowledges that data needs at the lower end of this irradiation temperature range were not evident for the helium-turbine NGNP conceptual designs that the Project was considering several years ago. However, for steam-turbine NGNP conceptual designs like those presented by the Project in April 2011, irradiation temperatures as low as 250 to 300 °C would seem to apply to graphite located in the upper core and reflector regions. The working group thus sees potential needs for testing particularly at the lowest graphite irradiation temperatures. Associated needs for post-irradiation testing may include those for graphite mechanical properties as well as special measurements of graphite irradiation energy storage and release, specific heat, and thermal conductivity as may be needed to support the analysis of NGNP licensing basis events. Resolving this potential issue could necessitate significant additions or modifications to the Project's plans for graphite irradiation testing.

The remainder of this report presents the MWP assessment results under nine headings (I-IX) that categorize the Project's responses to specific RAI questions. The nine headings are explained as follows. Category I is used to classify responses that have provided enough clarifying information to satisfactorily address the technical concerns of the RAI. Category II is assigned when more research is needed to provide the information sought by the RAI. Category III is assigned when more work in the consensus codes and standards bodies (e.g. ASME) is needed to appropriately address the RAI. Category IV is used when the Project's response indicates that the RAI requests vendor-proprietary data or information that is beyond the scope of the white paper. Category V is assigned to a response that indicates that the information sought by the RAI is unavailable given that the conceptual NGNP design is not yet finalized. Category VI is assigned to responses that indicate that the technical concern of the RAI should be addressed during the actual design of the NGNP reactor. Category VII is used when the Project's response states that it will be revising the contents of the white paper pertaining to the RAI. Category VIII is assigned to responses that indicate the Project will withdraw portions of the white paper based on the RAI concern. Finally, Category IX is assigned to responses that do not adequately address the RAI. There are several cases in which the Project's response is applicable to multiple headings. Therefore, when applicable, the RAI response will be addressed under multiple headings of the report.

The working group notes that the use of the aforementioned categories is not intended to provide a regulatory decision on the acceptability of the white paper or the RAI responses. Given the preliminary and conceptual nature of the NGNP design, the NGNP Project should use the categories as a tool to guide its future efforts toward the resolution of the discussed issues. All RAI questions and responses are fully documented in the RAI response document referenced above (ADAMS accession number ML11272A067), which is duplicated in Appendix A of this report for more convenient reference.

Note: RAI coding schemes are: COMP - Composite materials; G - Graphite; HTM - High Temperature Materials; INS - Insulating Materials; GEN - General.

Category I: *The Project's responses have addressed the technical concern of the RAI and there is no additional action needed to address the issue. In cases where further work is needed to implement the plans described in the RAI response, other categories are assigned as needed.*

a. For RAI G-4, the response states that, "an ongoing activity in NGNP Graphite Technology Development Plan (Reference 1) will provide the data to determine the parameters described above and their effects on the rate of oxidation. Further, various university research grants have been awarded in this area with the intent to determine the effects of oxidation on graphite performance, specifically at normal operating conditions. These data will be combined with the programmatic data generated from the NGNP graphite research and development program to ensure an adequate understanding of oxidation mechanisms in all three oxidation regimes." The working group considers this explanation satisfactory.

b. RAI G-8, RAI G-11, RAI G-12, RAI G-23, RAI G-30, and RAI G-49: The response answers in a satisfactory way the objective principle of the working group request for additional information. However, not all planned studies have been completed to date, and some modifications to this white paper could still evolve in the light of the last ongoing study developments, further actions by the ASME Code Committee to refine existing code, etc. These items are further discussed below under different categories.

c. On RAI HTM-3, the working group notes the Project's response that, "the higher pressure is on the outside of the hot gas duct, any leakage would be from outside (cold) to inside (hot)." The working group notes also that, "the thickness selected for the inner liner of the hot gas duct will include an allowance for corrosion and erosion that has not yet been established." This response has also been noted under Category VI.

d. For RAI HTM-8, the Project's response includes the statement, "Cobalt is the alloying element that would be of greatest potential concern for activation if it were carried through the core in the coolant stream. This element is in low concentration in Alloy 800H and has not been found to be present in significant quantity in the oxide scale. The microchemistry of the oxide scale resulting from environmental interaction with helium containing varying levels of impurities is being characterized in the NGNP Technology Development Program."

e. For RAI HTM-17, the working group considers the clarification provided as partially incomplete. Also, see comment under Category IX for this response.

f. RAIs HTM-1, HTM-2, HTM-18, and HTM-19: The Project's response answers in a satisfactory way the objective principle of the working group request for additional information. However, not all planned studies have been completed to date, and some modifications to this white paper could still evolve in the light of the last ongoing study developments, further actions by the ASME Code Committee to refine existing code, etc. These items are further discussed below under different groups.

g. RAI INS-2: The working group has noted the following response from the Project related to RAI INS-2: "The NGNP Graphite Technology Development Program does not have specifications for ASR-0RB or NBC-07 carbon, nor are the specifications outlined within ASTM standards or the ASME code. Presumably, there was a specification that was accepted by the Japanese regulatory authority for HTTR, but at the present time the

NGNP Project is not specifically requiring the use of these materials in the reactor core, and no information is currently available to the NGNP Project."

h. RAIs INS-1, INS-7, and INS-10: The Project's response answers in a satisfactory way the objective principle of the working group request for additional information. However, not all planned studies have been completed to date, and some modifications to this white paper could still evolve in the light of the last ongoing study developments, further actions by the ASME Code Committee to refine existing code, etc. These items are further discussed below under different groups.

Category II: *The Project's responses indicate that more research is being conducted or will be conducted that, when completed, will provide the information sought by the RAI. Essentially, the information sought are not available now and it is expected that the NGNP Project will inform the working group of any new information related to the technical concerns as it becomes available. Other headings are assigned as needed to appropriately categorize the unresolved issue.*

i. For RAI GEN-3, the Project states that, "Specific aging issues for the graphite and metallic components are being actively pursued within the Graphite and High Temperature Materials Research & Development (R&D) Programs (References 1-3). Specific aging issues include irradiation induced dimensional changes and creep within graphite components, creep-fatigue and creep within metallic components, long-term environmental degradation of metallic and graphite components, and loss of mechanical strength and fracture resistance in graphite due to long term irradiation dose. Information from these NGNP programmatic studies will determine the appropriate mitigation and inspection measures required to assure the safety case of the high temperature gas-cooled reactor (HTGR). The NGNP program is not directly assessing the aging issues of composite systems but is directing work being performed at university programs under the Nuclear Energy University Program (NEUP).

   However, specific aging monitoring programs, monitoring methods, periods, and examination areas of components can only be determined once the reference design, technical requirements, components, and material selections have been established. Aging management will be addressed as a part of the future license application process. "This is also noted under Category VI.

j. In responding to RAI GEN-6, the Project has stated that, "In general, the data needs and additional research and development needs identified in the PIRT (phenomena identification and ranking tabulation) reviews are consistent with the plans (Reference 1). Graphite oxidation from a steam incursion is being addressed through oxidation activities in the plan. Dust generation and tribology studies are being performed in university research programs under the NEUP program. The effects or probability of fracture failure leading to spallation of graphite components is being addressed under the multi-axial strength and failure mechanism development sections of the graphite technology development program."

On this, the working group will still refer to at least one of the vendor DDNs, for example, General Atomics, which indicates that their design would potentially depend on the outcome of the DOE research. For example, General Atomics DDN states, "…possible strategy is to startup the NGNP without having obtained the complete data base as defined by the above DDNs and use data obtained during the startup phase (either from NGNP operation or ongoing testing at DOE laboratories) to satisfy some elements of these DDNs." (Ref: "Technology Development Road Mapping Report for NGNP with 750°C Reactor Outlet Helium Temperature", PC-000586, dated May 11, 2009, and available from INL portal website)

k. For RAI HTM-4, the Project's response includes the following statement: "The NGNP Project is currently investigating the potential loss of load bearing area for 800H materials under quasi-static environmental conditions to support the quantification of this effect. Quantification of erosion/corrosion effects will be determined later after further design details become known." This response is also noted under Category VI.

l. For RAI HTM-12, the working group notes the Project's response, "The standard atmosphere for generating data incorporated in the Code is laboratory air. Thus, the Code does not address other key requirements of the design of these components, such as the emissivity, corrosion resistance, thermal aging, and irradiation effects. All of these potential influences on the properties are being addressed in the NGNP Technology Development Program."

m. For RAI G-4, the response states that, "An ongoing activity in NGNP Graphite Technology Development Plan (Reference 1) will provide the data to determine the parameters described above and their effects on the rate of oxidation. Further, various university research grants have been awarded in this area with the intent to determine the effects of oxidation on graphite performance, specifically at normal operating conditions. These data will be combined with the programmatic data generated from the NGNP graphite research and development program to ensure an adequate understanding of oxidation mechanisms in all three oxidation regimes."

n. For RAI G-6, the response states that,". However, this initial estimate may change based upon the results from NGNP graphite irradiation experiments, wherein the onset of turnaround will be determined as a function of dose for each graphite grade that has been identified as a potential candidate for NGNP. Inspection of replaceable reflector elements removed from the reactor during refueling operations will provide additional information that will augment the replacement schedule decisions based upon irradiation experiments performed by the NGNP Technology Development Program."

o. For RAI G-14, the response states that, "The NGNP Graphite Technology Development Program will provide data on the behavior of directional orientation material property values for isotropic graphite types (i.e., IG-110, etc.) for the NGNP operating conditions of temperature, fluence, atmosphere (coolant chemistry) and residence time. These data will be generated from the AGC irradiation experiment, and some data will also be obtained from the as-fabricated baseline testing program once it is complete. Additional historical data on isotropic graphite types will be provided, if necessary, once a design has been established and an application is submitted".

p. For RAI G-16, the response states that, "The raw materials used to fabricate the graphite will be different, resulting in possible very small changes to the material properties between different batches. This variation between batches is one of the main research activities for the NGNP graphite program. Billets from different batches (and different raw material sources) will be compared to determine the variation in material properties as a function of batch. In addition, the irradiation testing program will use samples from different batches to ascertain the effects of raw material variation on irradiation induced material property changes. These changes will be determined from the NGNP Graphite Technology Development Program once irradiation testing is completed."

q. For RAI G-31, the response states that, "Further evidence of "pore generation" will become available through the NGNP Graphite Irradiation Program, where new X-ray tomography tools will be utilized to examine the pore structure of irradiated graphite. The mechanism of polycrystalline graphite crack/pore generation during irradiation is expected to be common to all NGNP candidate graphite grades, as is the form of the irradiation induced volume and dimensional change curves. However, the magnitude of the minimum volume shrinkage and the temperature dependent fluence at which the cohesive life limit is attained is expected to be somewhat different for the various candidate grades. Where the reactor design requires the graphite components to operate at high neutron doses and temperatures, data will be required to define the ASME code cohesive life limit for the graphite such that it has sufficient strength for replacement or decommissioning."

r. For RAI G-33, the Project has responded: "Since the 3-dimensional temperature and dose profiles within the graphite components are design specific, the cumulative effect this has on graphite response will be addressed for all material properties once the design has been established. Once the proper conditions have been understood from the design, the variation in stress relief response (i.e., creep) as a function of this 3-dimensional temperature and dose variation can be effectively modeled based upon the results from the graphite irradiation program. The irradiation program will provide irradiation material property changes over a range of dose (0.5 – 7 dpa) at three nominal temperature levels (600, 900, and 1200 °C) and three different stress levels (7 MPa, 14 MPa, and 21 MPa). Using these empirically determined values and an appropriate analytical creep model (currently being developed by the NGNP Graphite Program), the material response over a range of dose, stress, and temperature can be calculated for all positions within the graphite core. As the dose (or temperature) evolves over time the material response can be calculated up to a dose level of 7 dpa. Operation times or doses over an accumulated dose of 7 dpa will require additional data to verify the model and calculations." This response has also been discussed under Category VI.

s. For RAI G-34, the Project's response states that, "The NGNP Graphite Program is investigating the various effects and mechanisms influencing creep (References 1-3). The measured creep rate as a function of dose/fluence and temperature for each major graphite grade is being investigated within the AGC irradiation program. Additionally, determination of the mechanisms responsible for irradiation induced creep is being pursued by the international graphite community (Reference 4). Specific creep data measurements for the NGNP major grades as well as further understanding of the mechanisms will be available from the Graphite Technology Development Program in the future."

t. For RAI G-35, the response has been stated as: "The issue of sub-sized test specimens is a recognized issue for the NGNP Project, and a number of activities are being conducted to determine any potential bias from utilizing samples with non-standard sizes. These activities include determining the effect of size (i.e., thickness) on thermal diffusivity measurements, the effect of grain size to sample test volume ratio for mechanical testing, the effect of sample size and geometry on fundamental frequency measurements of elastic properties, and sample oxidation rate changes as a function of test specimen size. Other scoping studies are either planned or anticipated in order to verify that the testing standards used for characterization are valid for these non-standard sized specimens. Results from these scoping study activities will be included in the data reports from the NGNP Graphite Technology Development once they are completed."

u. For RAI G-38, the response states that "The NGNP Project plan to provide sufficient data and information on the selected graphite types is outlined in the plan (Reference 1). The NGNP Graphite Technology Development Plan (TDP) outlines the development activities to qualify the major graphite types and provides a timeline of when the data are expected to be available for review."

v. For RAI G-39, the response states that, "Surface roughness of the graphite components does have an effect on the coolant flow and the extent of this effect is being investigated through university lead NEUP research projects." The working group has an additional question based on this response. Since surface degradation could potentially occur to graphite during reactor operation due to chemical reactions, such as oxidation, for example, does this imply that variations in coolant flow could potentially occur during reactor normal operation? If so, how will this be addressed in the design of graphite core components?

w. For RAI G-41, the Project's response is: "The NGNP Graphite Program is investigating the various effects and mechanisms influencing creep. Within the AGC irradiation program the measured creep rate as a function of dose/fluence and temperature for each major graphite grade is being investigated for dose levels up to turnaround levels (0-7 dpa). Over this dose range, the samples can be loaded in compression or tension without differences. Dose levels of ~7 dpa are estimated to allow 12— 15 years of active service for the graphite components receiving the highest flux levels for the current reactor designs. If the reactor design requires graphite components to receive doses exceeding 7dpa, additional tensile loaded irradiation experiments will be required to measure the creep rate of the major grades of graphite for dose levels past turnaround." This response is also noted under Category VI.

x. For RAI G-43, the response states: “The NGNP Graphite Program will be measuring irradiation induced specific heat changes, if any, during post irradiation examination of the tested grades of graphite. As stated in the Graphite Technology Development Plan, there is minimal change expected from these samples exposed to high temperature irradiation. However, if significant changes are detected from the post irradiation examination (PIE) the graphite program will focus more attention on the measurements and mechanisms.”

y. For RAI G-44, the response states: “NGNP Project is working with various universities within the NEUP research program to measure any possible changes to the emissivity of graphite during exposure to the reactor core environment. If significant changes are discovered to actually occur, the program will perform additional activities to measure the extent of these changes (Reference 1).”

z. For RAI G-46, the response states that, “The replacement of fuel elements will be governed by the fuel cycle. The replacement of reflector blocks will be guided by the data from the AGC program, supplemented by examination of replaced blocks. Also, see the response to RAI G-29 for projected fluences at replacement.” This response is also noted in Category VI.

aa. For RAI-G-47, the response is stated thus: “In the next revision of the white paper, Section 3.3.6.4 (page 43) will be modified to clarify that the Petten experiments were not irradiated to greater than 20 dpa. The NGNP AGC program will be producing irradiation data on both fine and medium grained-graphite in the future. The following change will be made: Test specimens from these grades were irradiated at 750ºC (1382°F) up to fluences of approximately 10 dpa. A second phase of irradiation at 950ºC (1742°F) up to fluences of between 12 and 14 dpa has been completed. These irradiations at HFR Petten (Netherlands) aim to provide irradiated properties data that can be used to compare irradiation behavior and post-irradiation properties of the different reactor grades available today. When the HFR Petten irradiation data are publically released, NGNP will compare the Petten data with NGNP irradiation data.” This response is also included in Category VII.

bb. For RAI COMP-3, the Project’s response is: “…in general, the topic of composite degradation and the effects of degradation on the composite performance are being investigated by the NGNP Project primarily through research grants to university research programs (i.e., the Nuclear Energy University Program [NEUP]). Long term composite degradation mechanisms and effects have been listed as areas of research interest in the NEUP program for a number of years, and some research, both at universities and in national labs, has been undertaken for this issue. In general, the phenomenon of fatigue corrosion in C-C composites for nuclear applications has not been specifically addressed to date. It is anticipated that some data will be available from other non-nuclear applications such as C-C composite airplane braking pad development, composite aerospace applications, and other hi-tech applications utilizing composites.”

cc. For RAI INS-4, the response is stated as, "Past experience, based on thermal measurements taken by manufacturers, has shown that the addition of small amounts of boron carbide to ceramic insulating materials has minimal to no effect on the thermal conductivity of these materials. Additionally, in general, there is no indication that the addition of boron carbide to these materials significantly alters the lifetime thermal diffusivity/conductivity performance. Further testing and data will be collected for qualifying the material once a baked carbon insulation material type(s) is selected for use."

<u>Category III:</u> *The Project's response indicates that more work needs to be performed in the consensus codes and standards bodies(i.e. ASME) to respond to the RAI. This is really work in progress and it is expected that the NGNP Project will inform the working group of any new information related to the technical concerns as it becomes available.*

a. For all RAIs related to the high temperature materials section involving potential code application, the Project's responses state in general that, "….specific Code Cases will be modified to acknowledge the anticipated evolution from the present Code Cases to the new Division 5 rules. In the RAI responses below, references to Code Cases N-201-5 and N-499-2 should be understood in the above context. The modification to the white paper will be completed upon resolution of the issues raised in the RAIs."

b. For RAI HTM-11, the working group has noted the Project's response, "The Code allowable for design using 800H will be extended by ASME to a range of 850–900°C and up to 500,000 hours in air. This time and temperature will define the design limits for this alloy."

c. For RAI HTM-12, the working group has noted the Project's response, "The standard atmosphere for generating data incorporated in the Code is laboratory air. Thus, the Code does not address other key requirements of the design of these components, such as the emissivity, corrosion resistance, thermal aging, and irradiation effects."

d. For RAI HTM-26, the response states that, "Also, as discussed in Section 3.2.5.4, the Code does not address key requirements of the design components, such as corrosion resistance and thermal aging effects. Therefore, additional research & development effort will be required." The working group has noted this statement and would consider this during future staff evaluation of the applicable ASME Code case for endorsement with potential conditions.

e. For RAI G-13, the response states that, "The new ASME graphite design code does not currently provide guidance in selecting graphite grades for use in components with thin ligaments. Such features are, therefore, the responsibility of the respective designers. The NGNP Project will petition the ASME Subgroup on Graphite Core Components to include guidance for selection of graphite grades for core components incorporating thin ligaments."

f. For RAI G-20, the response states that, "The new ASME graphite design code does not presently address requirements for designs with thin ligaments. The evaluation of such features is, therefore, the responsibility of the respective designers. NGNP will petition the ASME Subgroup on Graphite Core Components to address requirements for thin ligaments (also see response to RAI G-13)."

g. For RAI G-40, the response states that, "In addition, the NGNP Project will petition the ASME committee to provide more guidance on the cohesive life limit, taking into account coolant chemistry and irradiation induced creep."

h. For RAI COMP-2, the response states that, "… in general, the topic of composite fatigue has been discussed within the ASME Subgroup on Graphite Core Components (SGCC). The SGCC faces a similar challenge in establishing rules and codes for these components since composites are usually fabricated/manufactured specifically to the requirements for each specific component. This makes development of a generic code for all composite components with different geometries, thermal requirements, mechanical needs, and chemical interactions particularly difficult. Specific requirements such as fatigue resistance will require a careful analysis of the component as well as the conditions the component is expected to experience. The SGCC is determining whether a general methodology can be imposed or whether this analysis should be the responsibility of the applicant."

Category IV: *The Project's response indicates that the RAI requests vendor-proprietary data or information that is stated to be beyond the scope of the materials white paper. Information are vendor specific and since the vendor is not finalized, this information cannot be disseminated now. Other headings are assigned as needed to appropriately categorize the unresolved issue.*

a. For RAI G-24, the Project's response states that "graphite manufacturing processes are controlled by and proprietary to the manufacturers. The NGNP Project does not have access to this information and therefore cannot comment on manufacturing processes and facilities. Questions regarding the graphite manufacturers' processes and facilities should be directed to the specific graphite manufacturer and issues should be addressed during the design and licensing application phase." This response is also binned in Category VI.

Category V: *The Project's response indicates that because the conceptual design of the NGNP is still evolving, the answers to the RAI are not yet available. It is expected that the NGNP Project will inform the working group of any new information that may resolve technical concerns as it becomes available. Other headings are assigned as needed to appropriately categorize the unresolved issue.*

a. In RAI GEN-2, it is stated that, "the generation of insulation-derived debris from the hot duct assembly would require a major failure of the internal liner of the hot duct assembly. For the upper plenum shroud, the generation of insulation-derived debris would require major failure of metallic cover plates." The working group comments: "Arguably, other mechanisms could potentially operate as well. For example, high-temperature atmospheric chemical reactions between the insulation and the environment, insulation and the contacting metallic alloy could potentially result in degradation products, which could be volatiles as well as solids, with an activity coefficient of unity. Unless chemical equilibrium thermodynamics calculations provide contrary information, such chemical reactions should be considered feasible for insulation degradation. See Response HTM-28 also."

Also, a major failure cannot be discounted, per se. Just because it is a major failure, that doesn't mean it can't happen (e.g., Takoma Narrows bridge). Need to look at HTM-3 to see what additional basis is provided.

b. For RAI GEN-6, the response states that, "The High Temperature Materials White Paper, as well as all of the other NGNP white papers, was written in a manner to be generic with regard to HTGR technology (i.e., independent of variations among potential reactor suppliers in design details and technology development needs). This approach is appropriate at this stage of the NGNP Project, with no decision having yet been made regarding which reactor supplier will conduct the final design of the NGNP. Accordingly, specific DDNs are not discussed in any of the NGNP white papers."

   For RAI GEN-6, the response states that, "the NGNP Project is referring to a future risk informed and performance based regulatory infrastructure." It is not clear that the RIPB framework is comprehensive with regard to engineering requirements for structural integrity. The DID white paper provides only a limited discussion of ASME requirements, for example, with much of the substantial discussion given in a footnote on page 19 of that paper. That footnote states that ISI requirements for the helium pressure boundary are expected to be based on component reliability targets. Given that the Project's NGNP proposal is predicated on very high retention of fission products within the fuel particles, it is not clear how the HPB reliability targets will be conservatively established. At the extreme, one could argue that no ISI is required at all if there is no chance fission products will be released from the fuel.

c. For RAI HTM-4, the response states that, "Quantification of erosion/corrosion effects will be determined later after further design details become known."

d. For RAI G-15, the response states that, "The conceptual design of the HTGR is still underway, and a final decision regarding the HTGR design has not yet been made. Accordingly, the requested comparison cannot be made at this time. The reactor designer will use the key requirements in a design specification to select a graphite grade, considering manufacturability, grain size, and graphite costs, to achieve compliance with the ASME graphite design rules."

e. For RAI INS-3, the response states that, "However, in general, the location of these components (i.e., outside of the core) will result in minimal radiation dose levels to the material. It is anticipated that minimal property changes will result from this low neutron dose. However, this assumption will be verified through neutron analysis once the core design specifications have been drafted, and appropriate thermal analysis will be conducted."

f. For RAI INS-6, the Project's response includes: "…The various operating conditions, the specific materials to be used, and properties required to assure expected design performance cannot be provided at this time because they will be determined by the final design." This response is also included in Category VI.

Category VI: *The Project's response indicates that the technical concern contained in the RAI will/should be addressed during the actual design of the NGNP reactor. It is expected that the NGNP Project will inform the working group of any new information related to the technical concerns as it becomes available. Other headings are assigned as needed to appropriately categorize the unresolved issue.*

a. For RAI GEN-3, the response states that, "Aging management will be addressed as a part of the future license application process."

b. For RAI GEN-5, the Project's response does not clearly address the question. The reference to the DID methodology describes the role of the pressure boundary only in terms of a radiological boundary, as opposed to the need for structural integrity.

c. For RAI HTM-2, the response states that, "The actual temperature of the vessel would be still lower by some 25–50°C, depending upon the details of the design." The working group assessment notes this expectation. If a different temperature range were to be in the actual design, this could potentially affect working group assessment or feedback.

d. For RAI HTM-3, the working group has noted the Project's response: "…the thickness selected for the inner liner of the hot gas duct will include an allowance for corrosion and erosion that has not yet been established." This response has also been included under Category I.

e. For RAI HTM-3, the response states that, "The potential for flow induced vibration and its effects on the hot gas duct liner will be addressed by analysis. The effects of vibration on the insulating properties of the hot gas duct will be characterized by testing." The working group considers these as open items which need to be addressed in a licensing submittal. As written, the working group cannot endorse a vague proposal for future analysis and testing.

f. For RAI HTM-4, the response states that, "Quantification of erosion/corrosion effects will be determined later after further design details become known." This response is also noted under Category II.

g. For RAI HTM-25, the response states that, "The tenacity of this oxide may require experimental verification in either thermal cycling or flow testing if further design information suggests conditions that are significantly outside the base of experience (not expected)." The working group has noted this as a potential follow-up item for the future when the design is finalized.

h. For RAI HTM-28, the response states that, “The compatibility of the liner and insulation material will be addressed by testing where data are not presently available. Testing of the insulating characteristics of the liner, including vibration testing and cyclic thermal testing are needed to confirm the expected performance of the insulation system and to identify any potential for insulation degradation resulting from the plant design duty cycle. Details regarding the above will be addressed during detailed design efforts and the future license application process.”

i. For RAI G-24, the Project’s response states that “graphite manufacturing processes are controlled by and proprietary to the manufacturers. The NGNP Project does not have access to this information and therefore cannot comment on manufacturing processes and facilities. Questions regarding the graphite manufacturers’ processes and facilities should be directed to the specific graphite manufacturer and issues should be addressed during the design and licensing application phase.” This response is also noted under Category IV.

j. For RAI G-33, the Project’s response is: “Since the 3-dimensional temperature and dose profiles within the graphite components are design specific, the cumulative effect this has on graphite response will be addressed for all material properties once the design has been established. Once the proper conditions have been understood from the design, the variation in stress relief response (i.e., creep) as a function of this 3-dimensional temperature and dose variation can be effectively modeled based upon the results from the graphite irradiation program. The irradiation program will provide irradiation material property changes over a range of dose (0.5 – 7 displacements per atom (dpa)) at three nominal temperature levels (600, 900, and 1200°C) and three different stress levels (7 megapascals (MPa), 14 MPa, and 21 MPa). Using these empirically determined values and an appropriate analytical creep model (currently being developed by the NGNP Graphite Program), the material response over a range of dose, stress, and temperature can be calculated for all positions within the graphite core. As the dose (or temperature) evolves over time the material response can be calculated up to a dose level of 7 dpa. Operation times or doses over an accumulated dose of 7 dpa will require additional data to verify the model and calculations.” This response is also noted under Category II.

k. For RAI G-41, the response is: “…. If the reactor design requires graphite components to receive doses exceeding 7dpa, additional tensile loaded irradiation experiments will be required to measure the creep rate of the major grades of graphite for dose levels past turnaround.” This response is also noted under Category II.

l. For RAI G-46, the response states that, “The replacement of fuel elements will be governed by the fuel cycle. The replacement of reflector blocks will be guided by the data from the AGC program, supplemented by examination of replaced blocks. Also, see the response to RAI G-29 for projected fluences at replacement.” This response has also been noted under Category II.

m. For RAI COMP-1, the response states that, “Once a reference design for the NGNP core components have been established quantitative measurements/attributes will be presented in support of the composite components. These measured properties will be compared to the specification requirements established within the reference design criteria."

n. For RAI INS-6, the response states, "The comment is correct. The intended value is 1018 n/cm2 EDN (Equivalent DIDO Nickel). This dose corresponds to approximately 0.0013 dpa and illustrates that the fast neutron dose is very small for these components. This formatting error will be corrected, and the conversion will be added to Section 3.4.4 in the next revision of the white paper. The various operating conditions, the specific materials to be used, and properties required to assure expected design performance cannot be provided at this time because they will be determined by the final design." This response has also been included in Category VII.

o. For RAI INS-8, the Project's response is: "However, in general, there are ASTM standards, that specify the maximum boron content levels and how to determine the equivalent boron contents of nuclear materials. It is anticipated that these ASTM standards may be used when the NGNP reference design has been established or a designated designer identifies the specifications for ceramic insulating components. These standards include:

   - ASTM D 7219, Standard Specification for Isotropic and Near-isotropic Nuclear Graphite
   - ASTM C 1233, Practice for Determining Equivalent Boron Contents of Nuclear Materials

   Furthermore, the response states that, "As noted in the response to RAI G-36, the PBMR Program has been terminated. The PBMR procedure for determining equivalent boron content is not presently available to the NGNP Project."

p. For RAI INS-9, the response states that, "The issue of bypass flows associated with fractures is essentially the same as stated for structural graphite components. The designer must demonstrate that coolant flows associated with credible fractures will not result in significant (i.e., sufficient to result in overheating of the metallic components) radial overheating from the active core, where heating is taking place, to the core periphery, where the core barrel or core support structure are located. Since heated coolant flows tend to involve cooler inlet helium (which is at higher pressure), it is not likely that this mechanism will pose a significant issue."

<u>Category VII</u>: *The Project's response indicates that it will be revising, as stated in the response, the contents of the white paper pertaining to the RAI. Based on the RAI, the white paper will be modified to reflect adequate response to RAIs. It is expected that the NGNP Project will inform the working group of any revisions to the white paper as a result of the technical concerns. Other headings are assigned as needed to appropriately categorize the unresolved issue.*

a. For high temperature materials issues related to code, the Project's response states, "….specific Code Cases will be modified to acknowledge the anticipated evolution from the present Code Cases to the new Division 5 rules. In the RAI responses below, references to Code Cases N-201-5 and N-499-2 should be understood in the above context. The modification to the white paper will be completed upon resolution of the issues raised in the RAIs."

b. For RAI HTM-13, HTM-15, and HTM-16, the response states that, "At this time, the NGNP Project is not considering the use of Alloy X/XR at the current core outlet temperatures. Section 3.2.3 will be deleted from the whitepaper, as will other areas of the whitepaper that address Alloy X/XR."

c. For RAI HTM-17, the response states that, "Section 3.2.4.2 should have listed fatigue as an important consideration for designing components made from modified 9Cr-1Mo alloy. During the next revision, the white paper will be corrected to include fatigue in Section 3.2.4.2."

d. For RAI HTM-21, the response states that, "In the next update of the High Temperature Materials White Paper, the sentence in the second paragraph of Section 3.2.4.3 will be deleted to provide clarification."

e. For RAI HTM-27, the Project's response states that, "A discussion of the potential effect of fatigue should have been provided in Section 3.2.6.2. Therefore, during the next revision of the white paper, Section 3.2.6.2 (page 25) will be revised"

f. For RAI HTM-30, the response states that, "In the next revision of the White Paper, Section 5.1 will be further updated to make it clear that the ASME Code is not proposed as the exclusive basis for qualification. This will be done in conjunction with the changes noted in NGNP's General Response for Metals RAIs at the beginning of the Metals RAI section."

g. For RAI G-6, the response states that, "During the next revision of the white paper, Section 3.3.1 (page 29) will be revised as shown in the response to RAI G-5 to provide clarification regarding the ASME design process."

h. For RAI G-10, the response states that, "During the next revision of the white paper, Section 3.3.2 (page 29) will be revised to provide clarification regarding the graphite grade selection process…"

i. For RAI G-13, the response states that, "During the next revision of the white paper, Section 3.3.3 (pages 30-31) will be revised to provide clarification regarding the ASME design process…"

j. For RAI G-17, the response states that "In the next revision of the white paper, Section 3.3.4 (page 32) will be revised to provide clarification regarding the ASTM standards…"

k. For RAI G-19, the response states that, "Currently, the NGNP Project is developing a document to further elucidate the ASME graphite design rules. The document will provide the background theories used in the ASME design rules and their application in code assessments (e.g., compressive strength requirements, use of tensile strength for determination of probability of failure requirements for various structural reliability classes, how the graphite component lifetime is determined using the design code). The plan is for this document to be an addendum to the updated white paper in the future. If the document becomes available prior to the update to the white paper, it will be provided as a reference material."

l. For RAI G-21, the response states that, "In addition, "volatile carbon artifacts" will be replaced with "volatile components" in Section 3.3.4.2."

m. For RAI G-25, the response states that, "Currently, the NGNP Project is developing a document to further elucidate the ASME graphite design rules. The document will provide the background theories used in the ASME design rules and their application in code assessments (e.g., compressive strength requirements, use of tensile strength for determination of probability of failure requirements for various structural reliability classes, how the graphite component lifetime is determined using the design code). The plan is for this document to be an addendum to the updated white paper in the future. If the document becomes available prior to the update to the white paper, it will be provided as a reference material." The response also states that, "In addition, Table 4, Maximum probability of failure for each safety class, will be revised to clarify the maximum probability of failure for the respective structural reliability classes."

n. For RAI G-26, the Project's response states that, "During the next revision of the white paper, Section 3.3.5.2 (page 36) will be revised to provide clarification regarding the ASME Code…"

o. For RAI G-28, the response provided includes the statement, "During the next revision of the white paper, Section 3.3.5.2 (page 36) will be revised to provide clarification regarding the ASME Code."

p. For RAI G-29, the response states that, "In the next revision of the white paper, Section 3.3.6.1 (page 36) will be revised to provide clarification regarding the service conditions…"

q. For RAI G-32, the Project's response is: "Currently, the NGNP Project is developing a document to further elucidate the ASME graphite design rules. The document will provide the background theories used in the ASME design rules and their application in code assessments (e.g., compressive strength requirements, use of tensile strength for determination of probability of failure requirements for various structural reliability classes, how the graphite component lifetime is determined using the design code). The plan is for this document to be an addendum to the updated white paper in the future. If the document becomes available prior to the update to the white paper, it will be provided as a reference material. During the next revision of the white paper, Section 3.3.6.3 (page 39) will be revised to provide clarification regarding the ASME code rules…"

r. For RAI G-36, the Project's response is: "In the next revision of the white paper, Section 3.3.6.4 (page 40) will be modified …. to clarify the status of the PBMR program."

s. For RAI G-37, the Project's response has been stated as: "During the next revision of the white paper, NGNP Section 3.3.3 will be revised to clarify the statement…" The response also states that, "Also, to clarify this section, the statement that iso-molded graphites need to be used for prismatic designs will be deleted."

t. For RAI G-47, the response states that, "In the next revision of the white paper, Section 3.3.6.4 (page 43) will be modified to clarify that the Petten experiments were not irradiated to greater than 20 dpa. The NGNP AGC program will be producing irradiation data on both fine and medium grained-graphite in the future." This response is also noted in category 2.

u. For RAI G-48, the Project's response is: "During the next revision of the white paper, Section 3.3.6.4 (page 43) will be modified to clarify the graphite irradiation program…"

v. For RAI G-53, the Project's response is: "The NGNP Project uses foreign reactor high temperature reactor program data only as background material and will not use this data for final design or licensing. The NGNP Project cannot comment on technical aspects of other foreign governments' or foreign countries' high temperature gas reactor programs, since these programs and reactors are not under NGNP Project control, nor will they be used to support licensing of the NGNP.

In the next revision of the white paper, Section 4.2.1.1 (page 63) will be modified to clarify ASME code for graphite structures."

w. For RAI INS-1 through 10, the Project has stated in its response thus: "The NGNP Project plans to update Section 3.4, Ceramic Insulation Materials, during the next revision of the white paper. The update will clarify the purpose of the information being provided for this section. The information provided in this section is presented as background information providing a historical summary of nuclear ceramic insulation material development and manufacturing used in previous reactor designs including foreign reactor programs. The introduction of these foreign high temperature gas-cooled reactors is not intended to represent them as a basis for NGNP core component qualification."

"In addition, the NGNP Project plans to update Section 5.2, Outcome Objectives for Nonmetallic Materials, based on…"

x. For RAI INS-6, the response states, "The comment is correct. The intended value is 1018 n/cm2 EDN (Equivalent DIDO Nickel). This dose corresponds to approximately 0.0013 dpa and illustrates that the fast neutron dose is very small for these components. This formatting error will be corrected, and the conversion will be added to Section 3.4.4 in the next revision of the white paper. The various operating conditions, the specific materials to be used, and properties required to assure expected design performance cannot be provided at this time because they will be determined by the final design.” This response is also captured in Category VI.

<u>Category VIII:</u> *The Project’s response indicates that it will withdraw portions of the original white paper text, based on the RAI concern. It is expected that the NGNP Project will inform the working group of any subsequent revisions to the white paper as a result of the technical concerns.*

a. In response to RAI G-18, the Project has stated that, ““End-product” specimens will be used in the irradiation program. This paragraph repeats the behavior of isotropic materials previously discussed. It will therefore be deleted in the next revision to the white paper.

The following paragraph in Section 3.3.4 will be deleted to provide clarity to this section.

“It is important to recognize that the degree of isotropy only serves as an initial indicator of the graphite behavior under irradiation. End-product isotropy is influenced by raw material, grain size, forming method, and heat treatment. Graphite billets can be fabricated by extrusion, isostatic molding, or vibration molding. Extrusion tends to yield graphite that are less isotropic and less dimensionally stable under irradiation than molded graphite, although isotropy can be improved remarkably through careful control of raw material and processing. Isostatic-molded graphite is commonly available in smaller sizes than extruded grades, while vibration molding is available for larger block sizes.”

b. Regarding RAI G-19, the response states that, “The term “strength reserves” is not a concept used in the ASME code. Therefore, during next revision of the white paper, the use of this term will be deleted.”

c. In response to RAI G-50, the response states that, “Section 3.3.7.2, “Reliability and Integrity Management (RIM) Program and the Outcome Objective for RIM Program,” as discussed in Section 5.2 Non-Metallic Materials, will be deleted from the white paper. The plant operational considerations presently discussed in Section 3.3.7.2 will be defined during the final design and licensing application phases.

The term “inherent fault tolerance” is not used in the ASME graphite design rules and, therefore, does not represent any concept of design safety. Its inclusion in the white paper was based on the judgment that the basic characteristics of the design make it tolerant to failures.”

d. For RAI G-51, the response states that, “As stated in the response to RAI G-50, Section 3.3.7.2, “RIM Program” and the corresponding Outcome Objective, Item 3 in Section 5.2, “Non-Metallic Materials,” will be deleted from the white paper.”

e. For RAI G-52, the response states that: “There is operational experience with initial placement of permanent reflectors; however, there is no operational experience with replacement of permanent reflectors in HTGRs.

As stated in the response to RAI G-50, Section 3.3.7.2, entitled, “RIM Program” and the corresponding Outcome Objective, Item 3 in Section 5.2, “Non-Metallic Materials,” will be deleted from the white paper.”

f. In response to RAI G-54, the Project has stated,” The following paragraphs in Section 4.2.1 (page 65) will be deleted in the next revision of the white paper, since, the PBMR program is no longer accessible by the NGNP Project, and the data will not be used by the NGNP Project for graphite qualification.

As an example, Figure 5 illustrates the relationship between the legacy German database and the PBMR Specific Materials Test Reactor Program irradiation conditions that were selected earlier for the proposed PBMR Demonstration Power Plant in South Africa. The solid blue line in the figure represents the projected temperature-fluence envelope at the end of service life for components that serve a structural function (SRC¬1, as defined in Table 4), whereas the dotted red line denotes a similar envelope for the most highly-irradiated nonstructural components adjacent to the pebble fuel (SRC-2). As shown in Figure 5, the primary and secondary MTR data are designed to both confirm the applicability of the historical data and to supplement that data where required.

Finally, the proposed service life of the graphite components in the PBMR implies the need for a relatively lengthy MTR program. On this basis, the PBMR approach is to acquire MTR data for a significant portion of the service life prior to the start of the lead reactor. The balance of the MTR data would be acquired in such a manner that it substantially leads the actual operation of the reactor.”

g. In response to RAI G-55, the Project has stated that, “The graphite behavior theories discussed in the PIRT panel will not be used for final NGNP design or NGNP licensing. The ASME graphite core design rules use empirical mechanical and thermal data collected from qualified providers with known statistical confidence levels. The relevance of these graphite behavior theories is moot, since the ASME graphite core design rules will be used.

The second paragraph in Section 4.2.1.3 will be deleted, which includes the statement: *“The PIRT panel also concluded that theories that can explain graphite behavior have been postulated and, in many cases, shown to represent experimental data well.”*

h. For RAIs related to Carbon-Carbon Composites Section of the Materials White Paper, the Project has responded thus: “The NGNP Project plans to update Sections 3.5 and 4.2.3, Composites Materials, during the next revision of the white paper. Section 4.2.3 “Composites” will be deleted and Section 3.5 will be updated to clarify the purpose of the information being provided for this section. The information provided in this section is presented as background information providing a historical summary of nuclear composite development and manufacturing used in previous U.S. reactor designs as well as foreign reactor programs. The introduction of these foreign high temperature gas-cooled reactors is not intended to represent them as a basis for NGNP core component qualification. "

"In addition, the NGNP Project plans to update Section 5.2, Outcome Objectives for Nonmetallic Materials, based on above clarification."

Category IX: *The Project's response does not adequately address the RAI concern. It is expected that the NGNP Project will inform the working group of any new information related to the technical concerns as it becomes available. Other headings are assigned as needed to appropriately categorize the unresolved issue.*

a. For RAI HTM-5, the response states, "Although the NGNP technology and development program is expecting to generate Alloy 800H crack growth data at a later date, those testing plans are not included in current NGNP Project documentation. Once these test plans have been formalized and documented, that information then can be shared with the NRC." It is not clear if the proposed test plan will address RAI concerns.

The response also states that, "Note that since the hot gas duct liner does not serve a pressure retaining function, extensive cracking would be required to result in major failure of that component." The working group has two comments on this response. (1) This will nevertheless contribute to by-pass flow and potential hot streaking in the cross "vessel", which could potentially lead to excessive creep deformation and failure or heat cracking. See Response HTM-28. (2) This may be true, but the responses also note that there is a pressure differential from the cold to the hot duct. It is unlikely that NRC would accept failure of the hot duct liner.

b. For RAI HTM-7, the response states that, "The liner is not a pressure boundary and, by design, will see minimal loads during normal operation and during other events within the duty cycle." The working group notes that, however, there is a pressure differential across it (compressive, though). It's not obvious that there will be minimal loads. It seems reasonable to anticipate that there may be thermal loads, including possible thermal striping and other transients. The response also states that, "since the main circulator includes a flow-assisted check valve that passively closes when the HTS circulator stops." The working group notes with interest that this design detail is described when so many others are not. The working group further notes that there is a need for an SSC to provide this function. The response states further that "pressurized conduction cool down events are rare events with a correspondingly low number of cycles." However, the working group opines that this is yet to be demonstrated by detailed design.

c. For RAI HTM-10, the response states that, "detailed histories of the heat exchanger operating conditions that would allow direct extrapolation are not presently available to the NGNP Project." The working group is still of the opinion that it is not appropriate to claim extensive HTGR operating experience. For example, adverse materials' performance took far longer to manifest itself in some cases for LWRs.

d. In response to RAI HTM-17, it is stated that "this strain range-allowable cycles curve (Fig. T-1420-1E) contains data out to 108 cycles." However, it is not clear to the working group whether the data is applicable to 60-year operating life. The working group would need additional clarification for an informed review.

e. The response for RAI HTM-20 states that "For these reasons, corrosion is not a particular concern." The working group believes that sufficient information is not available to support this conclusion. On the contrary, published information indicates that internal oxidation could be a potential technical issue. Ref: C. Cabet et al. "High temperature corrosion of two structural nickel base alloys in the primary coolant helium of a VHTR", Paper No: E00000143, Proceedings HTR2006: 3rd International Topical Meeting on High Temperature Reactor Technology, October 1-4, 2006, Johannesburg, South Africa.

f. The response to RAI HTM-21 states that, "there are currently no plans to consider the use of Modified 9Cr-1Mo for the current HTGR steam cycle concept in a pressure-retaining application. For most of the core internals and support structures where Modified 9Cr-1Mo is being considered, the fabrication would not be performed on-site. Where onsite fabrication is necessary, it would be performed to the same quality standards as shop fabrication, including heat treatments." The working group considers this as a potential commitment for some future activity under NRC's regulatory authority. The working group's current assessment of the white paper does not provide an NRC staff position on or approval of any aspect of the design, qualification of any NGNP components, materials, or their use in the plant design, or fabrication.

g. For RAI HTM-22, the response states that, "The same requirements (including the requirement to account for the effects of neutron irradiation) are judged to be applicable to the modular HTGR." However, the response does not provide an adequate description on what the requirements are or why they are appropriate. Also, the response states that, "Note also that fracture toughness improves with temperature over the operating range of interest." The working group notes that, besides fracture toughness, an important property is ductility to maintain plastic accommodation for potentially propagating crack. It is not clear whether any potential adverse change in design ductility could potentially occur,

h. For RAI HTM-26, the response states that, "There is currently no intention to utilize HTTR materials operating data to proceed with design work for the NGNP Project." If this statement is true, then, arguably, the references to HTTR operating experience should be removed altogether. (See also working group comment on response to RAI HTM-10.

i. For RAI HTM-28, the response states that, "the stresses seen by the liner are minimal by design, and the thermal structural characteristics of the liner will be addressed by analysis." Response says stresses "are minimal," but should say "will be minimal" or some similar anticipatory wording. Lacking a design, a judgment on stresses is speculative.

j. The working group considers the response to RAI HTM-29 as being vague, needing further clarification. If KTA rules are not relevant, then inclusion adds to confusion regarding its applicability to ASME design code rule.

k. For RAI G-4, the working group is satisfied with the clarification that more research is underway to address technical concerns contained in the RAI. However, the response to the RAI has generated additional need for clarification. The response states that, "The phenomena that control all three regimes are well understood and models have been developed that seamlessly account for all three regimes. These models have been verified and validated to a limited extent using data from previous experiments." However, it is not clear or apparent that the mentioned reference contains such information. The response also states that, "Oxidation of graphite components must also be considered, however, its influence on component strength and, hence, structural integrity is not expected to be significant for events within the design basis." This is due to the limited time for oxidation during one of these events (seconds to minutes for water ingress; hours to a few days for air ingress), and further mitigated by the limitations on oxidant ingress that are integral to the respective designs."

   The working group needs data at the LBE temperatures (and air velocity, for oxidation dynamics) to support this statement. The working group is aware of the limited material loss in the Windscale accident. The working group is also aware of the ambiguity of graphite loss in Chernobyl accident. Furthermore, the working group is aware of literature indicating increased oxidation due to activated metals acting as catalysts for enhanced oxidation at temperatures of interest. Thus, the working group believes that this information should be adequately evaluated to support such statement.
   Ref (1) Von E. Stolz und F. L. Werner, Mannheim, "Kohlenstofftransport in den ochtemperaturreaktoren THTR und AVR," atomwirtschaft , pp 99 – 103,Februar 1968.
   Ref (2) M-L. Pointud, W. Karcher, N. Pollitt, J. Lothe, "Catalytic Influence of Different Metals on Corrosion Rate of Graphite," Dragon Project Report, April 1965.

l. Regarding RAI G-7, the response indicates that Ft. St. Vrain fuel blocks were replaced without any problems. But, specifics are lacking, such as what was the criteria for replacement and how many were replaced and when, etc. The literature citied could not be located via typical web search, including government OSTI site, and DOE's Information bridge site. Where can the working group find this and other documents referenced in the RAI responses? Also, the working group is aware of minor structural issues encountered during refueling outage in Ft. St. Vrain. (Ref: D. A. Copinger, D. L. Moses, "Fort Saint Vrain Gas Cooled Reactor Operational Experience", NUREG/CR-6839; ORNL/TM-2003/223 (2004).

m. In response to RAI COMP-4, the Project has stated that, “The component-level tests mentioned in Section 3.5.4.2 were conducted by the PBMR Program in South Africa. As noted in the response to RAI G-36, the PBMR Program has been terminated and the specific conditions of these tests are not presently available to the NGNP Project.”

n. In response to RAI COMP-6, the Project has stated that, “The tie rods and straps are mechanically attached. The specific details of the design were developed by PBMR, (Pty) Ltd., but are not available to the NGNP Project.”

o. For RAI COMP-8, the response is: “The specific details of the design were developed by PBMR, (Pty) Ltd., but are not available to the NGNP Project.”

p. For RAI INS-5, the Project’s response is: “However, in this general example the components being described are for insulating blocks at the bottom of the reactor. As such, they require low thermal conductivity/diffusivity properties to thermally protect the adjacent metallic components and high dimensional stability, since the support columns for the entire graphite core rest upon these insulating blocks and they must provide a very stable structure to ensure physical core stability.” This response has not adequately provided the information sought in the RAI.

Summary and Conclusions

The working group noted the following challenges in conducting an informed assessment of the Project’s responses to working group RAIs related to outcome objectives of the MWP:

- The NGNP plant design is still conceptual, with no confirmation of materials used for the reactor pressure vessel and its appurtenances, core support structures, primary system boundary, connecting piping, and other components important to safety and the applicable material specifications, design stress, time and temperature and other environmental conditions. It should also be noted that MWP may still be revised, based on working group RAI and some other new related information.

- RAIs raised technical issues that are planned to be addressed by ongoing or planned research programs of DOE and/or other national or international entities.

- RAIs concerning codes and standards (C&S) for use in NGNP design are either currently being addressed by the C&S bodies or the Project will be petitioning the C&S bodies to take on the assignment.

- The white paper may be revised by the Project to address RAIs. Also, portions of the original white paper text will be withdrawn based on several RAI concerns.

- The Project also will revise some of the outcome objectives of the MWP, based on working group RAIs.

- Finally, some of the Project's responses did not adequately address the working group's RAI.

The working group understands that the objective of the white paper was not to solicit a regulatory decision but rather to scope out how the working group perceives the provided materials with regard to substantiating the safety case. However, due to lack of detail and preliminary and pre-conceptual reactor design information driving the contents of the white paper, the working group cannot comment on the completeness of requirements of technical data for design basis, modeling of properties and their specific application to reactor operation. These types of comments may only be provided in the safety evaluation of a future combined license or design certification submittal.

The working group further notes that the enclosed assessment does not constitute staff endorsement or rejection of any aspect of the ASME Code. Such endorsement is typically made using NRC's standard practice of reviewing the adequacy and sufficiency of the ASME Code rules through the rulemaking process to incorporate by reference the latest editions and addenda of the ASME Codes and Code cases.

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APPENDIX A

The body of this report refers to specific RAI questions and responses. The RAI response document referenced in the report (ADAMS accession number ML11272A067) fully documents all RAI questions and responses. This Appendix provides a copy of that RAI response document for convenient reference.

Response to NGNP
Materials White Paper

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