Project No. 716

May 30, 2003

Mr. Laurence Parme, Manager
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SUBJECT: REQUESTS FOR ADDITIONAL INFORMATION ON THE GAS TURBINE MODULAR HELIUM REACTOR (GT-MHR) LOGIC FOR DERIVING FUEL QUALITY SPECIFICATIONS; DESIGN DATA NEEDS; AND FUEL PROCESS AND QUALITY CONTROL DESCRIPTION

Dear Mr. Parme:

The U.S. Nuclear Regulatory Commission's (NRC's) objectives for the Gas Turbine Modular Helium Reactor (GT-MHR) pre-application review are to obtain information from General Atomics (GA) on the GT-MHR design and its technical bases in order to identify: (1) significant technical and safety issues and (2) a path for the resolution of the issues. Achieving these objectives is expected to enhance the effectiveness and efficiency of the staff's review of an actual GT-MHR application and to provide guidance to GA that is useful in the preparation of an application.

The NRC staff is reviewing technical information provided by GA as part of the ongoing pre-application review activities for the GT-MHR. To date, the staff has focused its review on the technical documents submitted by GA in connection with the topics covered at the January 28–29, 2003, GT-MHR pre-application review meeting. The GA documents describe: the logic for deriving the fuel quality specifications; the plans for obtaining the data needed for the GT-MHR fuel performance analysis and source term calculation; and the process and quality control plans for the manufacture of the GT-MHR fuel. The NRC staff has determined that additional information is necessary to continue the review of these topics. The requests for additional information (RAIs) on each of the three topics are included in the enclosure. Additionally, the NRC staff questions related to the GA presentations on these topics at the January 28-29, 2003 meeting were transmitted to GA on February 25, 2003. It is requested that GA review the enclosed RAIs and respond as to when the requested information can be provided.

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 or comments on this request.

Sincerely,

/RA/

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

Project No. 716

Enclosure: As stated

cc w/encls: See attached list

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LETTER DATED: May 30, 2003

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Request for Additional Information (RAI)
Logic for Deriving Fuel Quality Specifications

Reference: *Logic for Deriving Fuel Quality Specifications*, PC-000498/0, March 2001

1) Summary

It is stated that the report was prepared for the 350 Mwt Modular High Temperature Gas-Cooled Reactor (MHTGR) and reflects the MHTGR design as it existed in 1988. Summarize the revisions which would need to be made to the document to address the significant differences in fission product release and transport factors, phenomena and licensing basis events to reflect the significant differences between the 1988 MHTGR steam-cycle plant design and the latest design concept for the Gas Turbine Modular Helium Reactor (GT-MHR) direct-cycle plant design.

The required fuel quality specification will also depend on the GT-MHR licensing approach. This would include such considerations as: whether a limiting conservative bounding analysis approach is used or whether a best estimate analysis approach with appropriate treatment of uncertainties is used; whether a deterministic approach is used or a probabilistic approach (or some combination) is used; how defense-in-depth is achieved; how the advanced reactor policy will be addressed; and how accident prevention and mitigation are considered in the design. Provide either a summary (or a reference description) of the GT-MHR licensing approach. In particular, it is requested that information be provided which explains:

- the basis for a vented low pressure containment, versus a low leakage high pressure containment should be accepted;

- how defense-in-depth against unacceptable radiological release to the environment is to be provided in the barrier design and safety approach (e.g., if the fraction of accident-related fuel particle failures exceeds the calculated worst case fraction);

- whether the described fission product transport and release attenuation factors are considered independent or dependent “barriers;”

- what system performance requirements will be placed on the GT-MHR safety related heat removal systems to ensure that the fraction of accident-related fuel particle failures are consistent with the accident analysis;

- how the GT-MHR design and the GT-MHR analysis approach provide for “safety margin” relative to release of fission products (accident consequences) analysis. For example, if the targets for the design data needs are met, by approximately how many orders of magnitude would it be expected that the calculated dose consequences would be less than the most constraining radionuclide control requirement at the 50% and the 95% confidence levels.

In the logic for deriving fuel quality requirements, discuss the application of 40 CFR 190, 10 CFR 50.34 (a) and EPA 400-R-92-001.

The Environmental Protection Agency (EPA) Protective Action Manual guidance allows state and local governments to establish protective action guides and/or dose calculation methods different from those provided in the manual. For example, many states have specified the child as the target age group for determining dose whereas the EPA manual suggests using an adult. Discuss how, if at all, potential site-specific protective action guidelines (PAGs) will be considered in establishing the fuel quality specifications.

Light-Water Reactor (LWR) licensing experience shows that the control room dose due to an accident can be more limiting than the dose for the Exclusion Area Boundary (EAB). This is due to the control room being closer to the release points and its continuous manning. Discuss how, if at all, control room dose will be considered in establishing the fuel quality specifications?

Is it expected that an occupational exposure limit of $\leq$10% of 10 CFR 20 will be realistically achievable for the GT-MHR (direct cycle) plant as it was thought to be for the MHTGR plant? What target has been established for the GT-MHR (e.g., for balance of plant maintenance activities and silver 110m plateout), regarding operational or maintenance strategies, to limit exposure?

Discuss the specific/significant elements of the existing HTGR fission product transport technology base (e.g., data) that will be used in the GT-MHR design-analysis and safety analysis. Describe elements that will require additional design-specific fuel/fission product technology development.

Will the fuel particles still use uranium oxicarbide fuel (UCO)? Will thorium also be used? If thorium is proposed for use, what regulatory criteria will be proposed by GA?

With respect to the accident dose criteria in §50.34, the staff has traditionally accepted the full value of the acceptance criteria only for the limiting design-basis accident For other, higher probability, lower consequence events, the staff has accepted designs that result in “a fraction” or “small fractions” of the acceptance criteria (e.g., see Table 6 in R.G. 1.183). The dose criteria being proposed by GA appears to be at the full value of the §50.34 acceptance criteria regardless of the event frequency. If not, discuss the numeric dose criteria and related fuel performance requirements for the (probability and consequence) spectrum of GT-MHR licensing basis events.

The document addresses the allowed radionuclide release from coated particle fuel which meet the requirements of 10 CFR Part 100 and occupational dose limits for plant inspections, maintenance and repair. These requirements relate to the plant design basis. However, these requirements do not address severe accidents, which for LWRs, comprise the largest risk contribution. How will severe accidents be considered with respect to establishing the GT-MHR fuel quality and performance specifications. What is the logic for determining the radionuclide releases for severe accident conditions?

It appears that the document does not provide a severe accident mechanistic source term for the GT-MHR that is “equivalent” to the LWR mechanistic source term described in NUREG-1465. Discuss the basis and approach to the GT-MHR severe accident term that corresponds to the source term described in NUREG-1465.

3. <u>MHTGR Radionuclide Containment System</u>

How is the effectiveness of the GT-MHR Helium Purification System (HPS) considered in the mechanistic source term analysis. To what extent is credit taken for the HPS in removing gaseous and metallic fission products from the coolant system.

Discuss whether, and to what extent, coolant pressure boundary operational leakage is considered as a source of gaseous radionuclides that must be accounted for in the GT-MHR radionuclide containment system.

For GT-MHR core temperature conditions how effective is the fuel element graphite expected to be in attenuating the release of cesium (Cs), strontium (Sr) and Silver (Ag) from the core?

Given the GT-MHR core maximum operating temperature and maximum accident temperature conditions, is the diffusion of Cs and Sr through intact silicon carbide (SiC) layers to be modeled for these conditions for purposes of calculating the core fission product transport (i.e., source term)? Is the diffusion of iodine, tellurium, xenon, and krypton through pyrolytic carbon (PyC) layers to be modeled for these conditions?

Discuss the basis for excluding the contribution of the re-mobilization of settled dust-born activity by flow transients as a source of radionuclides that must be accounted for in the GT-MHR radionuclide containment system.

Discuss the basis for excluding the contribution of oxidized activated carbon and sorbed fission products in the outer PyC, fuel matrix and graphite (caused by an air ingress event) as sources of release to be accounted for in the GT-MHR radionuclide containment system.

Discuss the basis for excluding the contribution of activated carbon and sorbed fission products in graphite (due to a local reactivity increase event) that could lead to fission product dispersal as a source of radionuclides that must be accounted for in the GT-MHR radionuclide containment system.

Discuss whether, and to what extent, credit, if any, is to be taken for the reactor building/containment structure filtration system and/or ventilation system in reducing fission product release to the environment during either normal operation, transients, or accidents in order to meet the top level regulatory requirements.

Discuss whether the release of gas-borne activities absorbed on core graphite blocks during normal operation contribute to the source term in the development of the fuel specifications.

Discuss why thorium dioxide kernels do not hydrolyze while UCO kernels can hydrolyze.

Provide a quantitative discussion of the dependence between temperature and burnup in relation to the retentivity of oxidic fuel kernels for the long-lived, volatile fission metals.

Provide a quantitative discussion of the effectiveness of the graphite as a release barrier with respect to temperature.

Discuss the time frames and temperatures for the release of the volatile metals through the SiC coating.

4. MHTGR Radionuclide Control Requirements

Licensing Basis Events (LBEs) are defined in Reference 4, and are for the standard MHTGR. Accordingly, the stated classes of events that contribute to plant risk are framed by the standard MHTGR LBEs. However, the risk significance associated these events could be significantly different for a GT-MHR. For example, water ingress events could be significantly diminished for a GT-MHR, due to the absence of steam generators and their associated large water inventory. For a GT-MHR, other classes of LBEs might replace the water ingress event as significant risk contributors such as those caused by rotating machinery. For example, it might be possible for air to be drawn into a depressurized core, relatively soon after a pipe/vessel break, by helium contracting on the relatively cool surfaces of the power conversion system water-cooled heat exchangers, or on a longer time scale, by the diffusion of air into the core region. Discuss whether GT-MHR LBEs might result in risk-significant LBE's and/or fission product transport mechanisms not included among those for an MHTGR. In particular, discuss whether the GT-MHR design might result in risk-significant LBE's (e.g., air ingress) and fission product transport mechanisms (e.g., graphite oxidation) due to either air diffusion or active mechanisms related to the direct connection of the power conversion system vessel to the reactor vessel.

For the GT-MHR, what kinds of events are considered "severe accidents." Discuss whether the fission product transport of severe accidents is covered by the same logic and fission product transport mechanisms in Section 4.0 (for deriving the fuel quality specifications) or is not covered. Discuss the significant differences, if any.

Discuss why a "high-pressure containment building" would be "inconsistent with the passively-safe design philosophy."

Discuss how LBEs involving both prompt releases (e.g., release of fission products in the helium coolant and on surfaces within the vessel system due to reapid depressurization) and delayed releases (e.g., fission products released by core heatup) are accounted for in fission product transport mechanisms and logic.

4.1 Radionuclide Retention by the Plant Site

Discuss the models and methods used for the atmospheric dispersion and transport calculation (e.g., ground level, elevated, diffuse, sector dependent 99.5% meteorology or site dependent 95% meteorology). Compare the methods to the guidance in RG 1.145 and the basis for any significant differences. How, if at all, will site-specific atmospheric dispersion and transport phenomena be accounted for in establishing the fuel quality specifications.

Discuss the dose calculation model, (e.g., finite plume, submergence, source of dose conversion factors). Compare the methods to the guidance in Section 4 of RG 1.183 and the basis for any significant differences.

4.2 Fission Product Retention by the Vented Low Pressure Containment (VLPC)

Discuss the basis for the fission product attenuation assumptions stated in this subsection.

Discuss whether the VLPC provides for radionuclide retention during a slow depressurization event without water ingress.

Discuss the assumed fission product retention characteristics of the VLPC for delayed releases.

Discuss the assumed retention characteristics of the VLPC for fission products transported in oxidized graphite.

4.3 Fission Product Retention by Reactor Vessel

Discuss the basis for each of the fission product attenuation assumptions stated in this subsection. How will these assumptions be verified or revised as needed based on further fission product transport technology development activities?

Discuss the fission product retention characteristics of the reactor vessel for releases.

Discuss the assumed retention characteristics of the reactor vessel for fission/activation products transported via oxidized graphite and graphite dust.

It is stated that liftoff of 5% of the deposited radioactivity is a conservative estimate for the design basis depressurization event. Are the effects of mechanical vibration and/or shock (that would accompany a rapid depressurization event) taken into account in calculating radionuclide liftoff (i.e., resuspension)? Explain.

Transport of certain fission products from the reactor core region will involve aerosol physics. Particles in the relative dry environment will be “chain agglomerates,” but most aerosol models are based on equations for spheres and “shape factors” are used to correct for nonspherical particles. What shape factors are appropriate for analysis of aerosol transport in the GT-MHR? Are these shape factors dependent on particle size or the electrostatic charging of the aerosols?

4.4 Fission Product Retention by Fuel Elements

Discuss the basis for each of the fission product attenuation assumptions stated in this subsection. How will these assumptions be verified or revised as needed based on further fission product transport technology development, activities, etc.?

Discuss the fission product retention characteristics of the fuel elements for delayed releases.

Discuss the potential for changes on the stated limits for Cs and Ag release as it relates to plateout gamma dose rate activities for end-of-cycle maintenance and inservice inspection/inservice test on GT-MHR direct cycle power system components (e.g., turbines) near the end of the plant life time.

Discuss the effects of transport of fission/activation products in graphite dust on occupational dose.

Discuss the basis for the stated uncertainty factors (design margin numerical values) of 4 on the release of fission gases from the core and 10 on the release of fission metals from the core so as to account for the difference between the "Maximum Expected" and "Design" criteria. How will these factors be verified or revised, as needed, based on further fission product transport technology development activities?

How will the actual circulating activities during normal operation be determined to confirm analytical results? How will the actual plateout activities during normal operation be determined to confirm analytical results?

4.5 Fission Product Retention by Particle Coatings

Discuss how the diffusion of volatile metals (Cs, Ag, Sr) through intact tri-isotropic (TRISO) particles during normal operation and later at high temperature over an extended time (i.e., many hours after initiation of a core heatup accident) are considered in the GT-MHR source term analysis and thus in the analysis of the allowed heavy metal contamination and allowed fraction of failed TRISO particles.

Neither the SURVEY nor the SORS (i.e., core-wide space and time-dependent fission product release) computer codes have been reviewed by the staff. Do these codes cover the full range of GT-MHR accident and transient conditions? How will these computer codes be validated?

How will the GT-MHR technical specification limits on primary circuit contamination be established? How will the actual contamination in the primary circuit be determined during normal operation and following events having a significant potential for fuel damage?

Provide additional information on the controlling assumption in defining Goal 2.

Discuss the integrity of the coated particle, and in particular the SiC layer for conditions associated with GT-MHR severe accidents.

Discuss the experimental basis and the analytical approach to be used for calculating the extent of partially failed particles (i.e., particles with failed SiC coatings but with intact inner and/or outer PyC coatings) in the core.

When calculating particle coating failures due to core environmental conditions during normal operation and LBEs, are local “hot spots” modeled, such as might occur due to the effects of a mal-distribution of fuel particles in a compact or thermal gradients? Explain.

4.6 Fission Product Retention by Fuel Kernels

Discuss the interpretation of the attenuation factors provided by the kernels cited in the table as it relates to prompt and delayed releases from the kernel. Discuss any differences.

Experimental data for “designed-to-fail” particles would indicate that fission product diffusion rates in kernels depend on kernel microstructure which changes (uncontrollably) with burnup.

How will fission product retention in the UCO kernel be “specified,” and how will the specification be met?

Is it expected that fissile and fertile UCO kernels will have different burnup-dependent retention/diffusion characteristics? If so, how will these differences be considered in the kernel fission product retention/release analysis for normal operation and LBEs? It is stated that retention limits for fission metals are not specified for normal operation. Does this mean that it is assumed that during normal operation all fission metals (except Ag-110m) are completely released from failed particles? Explain.

How are “long-term LBEs and “short-term LBEs” defined? Explain their significance in relation to the transport of fission products during accidents (i.e., the basis for stating that for long-term LBEs, credit for kernel retention in failed particles need not be taken, but for short-term LBEs, credit for kernel retention in failed particles must be taken).

5. Resulting Fuel Design Requirements

It is stated that each of the barriers in the radionuclide containment system is necessary under certain circumstances to meet top-level, radionuclide control requirements. Explain how the GT-MHR design addresses the “defense-in-depth” philosophy with respect to meeting radionuclide release limits. Given the reliance on each barrier, discuss how the concept of “safety margins” is applied to the GT-MHR design.

5.1 Fuel Performance Requirements

The eight identified potential fuel failure mechanisms used in the fuel performance models appear to be based on the results of fuel performance and post-irradiation examinations of fuel fabricated using a process, specifications, QA techniques, etc. which may, or may not, be applicable to GT-MHR fuel to be made, in the future. Discuss GA’s plans and expectations for validating the completeness and applicability of the identified fuel failure mechanisms and performance models for UCO fuel that will be manufactured for the GT-MHR, including the potential to modify the mechanisms and models in the GA computer codes.

The results of the new production (NP)-MHTGR fuel development program irradiations which were conducted in the early-1990's do not support the stated view that as-manufactured, heavy metal contamination and the failure of particles with manufacturing defects are the dominant sources of radionuclide releases or that defective or missing SiC coatings are the second most important source for releases. Discuss the relationship of the GT-MHR fuel technology development, qualification and proof test programs to the validation, or the need for revision of the statements on the relative sources of fission product release from the GT-MHR fuel.

It is stated that fuel performance models are based on an international database. Discuss the applicability of the these models and the information used to derive these models, to the range of GT-MHR conditions and applicable fuel fabrication.

5.2 As-Manufactured Fuel Attributes

5.2.2 As-Manufactured Quality Requirements

Discuss the relationships of the GT-MHR fuel technology development, qualification and proof test programs, and the GT-MHR core safety performance analysis, to the validation, or the need for revision, of the allowable defects in fuel compacts shown in the table for GT-MHR fuel. Describe the techniques used to assess missing buffers, defective inner pyrolytic carbons (IPyCs) and defective outer pyrolytic carbons (OPyCs) from manufacture.

What are GA's plans/expectations for revising and validating, as needed, the fuel failure and fission product transport models used in the SURVEY and SORS codes based on the GT-MHR fuel technology development and qualification program?

Compare the technical rigor of the GT-MHR mechanisitic source term analysis approach to the technical rigor used to establish the LWR source term identified in NUREG-1465.

Discuss how the GT-MHR safety analysis codes and methods for fission product transport utilize the as-manufactured statistical fuel quality requirements to calculate the number of fuel particle failures during operation and accidents.

Request for Additional Information (RAI)
Gas Turbine-Modular Helium Reactor Design Data Needs

Reference: *600 MW(t) Gas Turbine-Modular Helium Reactor Design Data Needs*, DOE-GT-MHR-100217(draft), July 1994

DDN Scope

Discuss the plans, if any, to develop Gas Turbine Modular Helium Reactor (GT-MHR) design-specific data that would be needed to assess the radiological consequences of air ingress, water ingress, and reactivity insertion events. If existing data associated with other historical fuels are to be used to assess the consequences of such events for a GT-MHR, discuss the source of these data and the basis for the applicability of the data to the GT-MHR design.

DDN C.07.01.01

What is meant by the statement that the quality was not completely demonstrated for UCO material? How was it demonstrated? To what level?

Provide or reference additional information on the NP-MHTGR program, including it's objectives and test methods.

Explain what is meant by uniform structure.

DDN C.07.01.02

Explain why the identified process parameters were chosen as the "key process parameters."

DDN C.07.01.03

Explain why the identified process parameters were chosen as the "key process parameters."

DDN C.07.02.01

Discuss the plans for obtaining unirradiated and irradiated thermophysical properties (e.g., thermal expansion, thermal conductivity, heat capacity) of reference GT-MHR TRISO fuel kernels and coatings.

Discuss the plans for obtaining the GT-MHR reference TRISO fuel irradiated-induced creep and dimensional change properties of the PyC layers and the irradiation-induced cracking properties of the OPyC layer.

Discuss why the identified process parameters are considered the "key process parameters."

Is it expected that some test conditions would exceed the maximum design conditions for the GT-MHR so as to experimentally quantify the expected margins to failure (for the most limiting particles in the core) from the identified failure mechanisms? Explain.

DDN C.07.02.02

Discuss the technical basis for the acceptability of conducting these irradiation tests at pressures which are not prototypical of a GT-MHR at full reactor pressure in terms of the effects of external pressure on the thermal-mechanical behavior of TRISO fuel particle coatings.

Provide (or cite) a reference with additional information on the reduced-scale tests, including how they are conducted, how they are reduced, and how the scaling is done.

DDN C.07.02.03

For “accelerated” fuel testing, reduced time effects are convoluted with increased temperature and increased temperature gradient effects. For kernel migration, discuss how the conditions of the accelerated irradiations, and the data that results, will be “extrapolated” to the temperature and temperature gradient versus time conditions expected for the GT-MHR. Are any “less accelerated” or “real-time” irradiations planned to develop the rates of kernel migration? Explain.

For fission product/SiC interactions, discuss how the accelerated irradiation conditions, and the data that results, will be “extrapolated” to the temperature and temperature gradient versus time conditions expected for the GT-MHR. Is it expected that the interaction data will reflect localized SiC interactions or “average” interactions with the SiC (since the latter might not be conservative for purposes of modeling SiC failure)?

Is it expected that some test conditions would exceed the maximum design conditions for the GT-MHR so as to experimentally quantify the expected margins to failure (for the most limiting particles in the core) from the identified failure mechanisms? Explain.

Will data be collected to determine the effects of enhanced diffusion through intact SiC layers at very high temperatures?

Discuss the technical basis for the acceptability of conducting these irradiation tests at pressures which are not prototypical of a GT-MHR at full reactor pressure in terms of the effects of external pressure on the thermal-mechanical behavior of TRISO fuel particle coatings.

The radionuclide transport test data for the DDNs of this section and subsequent sections cover a relatively small (albeit important) set of the radionuclides needed for the source term analysis. The staff found no description or reference to how the various chemical and physical forms of the radionuclides will be treated. Since such considerations are important to fission product transport, describe how the full range of radionuclides and the chemical or physical forms of the radionuclides will be developed for the source term analysis.

Provide (or cite) a reference that discusses what is meant by the statement that “no significant UCO kernel migration has ever been observed.” How many kernels were examined and for what irradiation conditions?

Describe the “reduced scale tests” that may be planned by the technology organization.

DDN C.07.02.04

Describe how the information from simulated fuel compacts will be correlated with actual fuel compacts, and how the irradiation effects on these parameters will be quantified.

DDN C.07.02.05

It is noted that the current fuel performance models are based to a large extent on previous experience with fuel having from 10 to 100 times greater coated particle failures than will be allowed by the fuel specifications for the GT-MHR. Improving the fuel to meet the new more restrictive GT-MHR fuel failure rate might result in previous significant failure mechanisms being eliminated or becoming less prevalent/important with new/different failure mechanisms emerging as dominating or controlling the improved performance. How would any important new/different failure mechanisms (e.g., IPyC cracking induced SiC failures), that might be identified from validation testing and associated postirradiation examinations (PIEs) (i.e., which might be observed in DDN C.07.02.07), but which are not modeled in the fuel performance codes, be considered in the fuel performance code development and validation process? How would failure mechanisms modeled in the fuel performance codes (e.g., missing particle coatings) but are also not observed in the validation testing (i.e., DDN C.07.02.07) and associated PIEs, be considered in the fuel performance code development and validation process?

Is it expected that some test conditions would exceed the maximum design conditions for the GT-MHR so as to validate that the design methods do not become significantly inaccurate (e.g., significantly more than a factor of 4) for conditions somewhat beyond the design basis?

DDN C.07.02.06

Same question as the first question in DDN C.07.02.05 above.

Will the accident heat up tests be isothermal? If so, what is the technical justification for such tests when a GT-MHR core heatup accident would involve the effects of temperature gradients across the kernel, particle layers, and compact? Are there any plans to compare isothermal tests with heatup simulation conducted in a test reactor where the early effects of decay heat on temperature profiles across the kernel, layers, and compact matrix could more closely simulate those of an actual core heatup event? Explain.

It is stated that the fission product release data will be used to validate the fuel performance (i.e., failure) models. It will also be used to characterize the fission product retention effects from matrix sorption and matrix particle interaction. Other than these two fission product transport mechanisms, will the fission product release data obtained by this DDN be used for validating any other fuel fission product transport models? If so, explain.

It is stated that the tests in this DDN will generate data that will be used to validate the models that are used to predict the rate of oxidation in the compact matrix for an air ingress event. Do these models and tests include the effects of air flow velocity and oxygen partial pressure as well as fuel burnup/fluence? Will these test data be used to validate models used to predict particle failure due to the effects of particle layer oxidation? Explain.

Discuss the TRISO particle test data that will be used to validate the models that will be used to predict the effects on particle performance due to reactivity insertion events.

<u>DDN C.07.02.07</u>

Under “Data Needed” there is no provision for PIEs to confirm that particle performance (e.g., failure mechanisms for any observed particle failures) are in accordance with those in the fuel performance models. Explain why PIE data is not needed.
Explain why at least some confirmatory proof tests need not be conducted using close to real-time (versus accelerated) fuel irradiations.

Discuss the temperature versus time profiles that will be used for the heatup tests. How does this profile compare with the temperature versus time profile expected for the GT-MHR heatup event. If there are significant differences, discuss why the tests would still be applicable as proof tests.

Discuss the technical basis for the acceptability of conducting the proof tests at pressures which are not prototypical of a GT-MHR at full reactor pressure in terms of the effects of external pressure on the thermal-mechanical behavior of TRISO fuel particle coatings.

For a postulated air ingress event, such as might occur due to a large break depressurization accident followed by air entry and flow through the core, discuss whether proof tests are planned to confirm the failed particle fraction predicted for the GT-MHR fuel.

For a postulated reactivity event, such as might occur due to the withdrawal of multiple control rods or a rod ejection accident, discuss whether proof tests are planned to confirm the failed particle fraction predicted for the GT-MHR fuel.

Will the heatup proof tests involve some irradiated fuel which has also been “preconditioned” with one or more simulated operational or anticipated transients (e.g., loss of normal heat removal)? Explain.

Considering the billions of fuel particles in a GT-MHR, discuss the basis for establishing the number of fuel particles in the proof tests to adequately demonstrate the needed low fuel failure fractions, with a 95-percent certainty.

<u>DDN C.07.02.05 to DDN .07.02.07</u>

Compacts will operate with thermal gradients and will experience thermal gradients during accidents. How will releases and fuel failures observed in furnace tests of compacts without thermal gradients be corrected to account for the effects of gradients in operations and accidents?

<u>DDN C.07.03.01</u>

Are these tests to be conducted with real-time or accelerated irradiations? Explain.

For particles that fail during heatup, discuss the applicability of fission gas release (rate) data that would be associated with a laser-failed particle with the fission gas release (rate) data that

would be associated with a particle failure mode caused by an actual failure mechanism (e.g., pressure vessel failure) of TRISO particle fuels.

For particles that fail during irradiation, discuss the applicability of fission gas release (rate) data that would be associated with a designed-to-fail particle with the fission gas release (rate) data that would be associated with a particle failure mode caused by an actual failure mechanism (e.g., pressure vessel failure) with TRISO particle fuels.

DDN C.07.03.02

Discuss whether chemical interaction between the buffer layer and the UCO kernel under severe accident conditions can lead to releases that are not diffusive in nature but are controlled by the rate of interaction.

DDN C.07.03.03

How will the effects of sorption or trapping within the coating layers, or of any preferential retention in a specific coating layer, be accounted for in the effective diffusion coefficients in terms of the additional release of the sorbed or trapped fission products which would occur under accident conditions?

DDN C.07.03.04

How will the effects of sorption or trapping within the graphite, be accounted for in the graphite diffusivities in terms of the additional release of the sorbed or trapped fission products which would occur under accident conditions?

DDN C.07.03.12

It is stated that no credit is taken for radionuclide retention in the VLPC in order to meet [10 CFR 100] dose limits while retention in the VLPC is considered to show compliance with the PAG dose limits. Discuss the VLPC radiological containment performance criteria.

DDN C.07.03.14 to DDN C.07.03.18

These DDNs are identified as integral validation testing by which the predictive performance of the accident analysis codes could be assessed. However, these validation tests are in some respects still a validation of separate effects. What, if any, test data will be used to validate the overall transport, (i.e., to ensure that there are no unexpected synergies that would not be identified in the separate effects testing) such as fission product transport data from an operating HTGR or prototype GT-MHR?

In several DDN's there are statements such as the following: *"..failure to take credit for limited fission product liftoff during rapid depressurization transients would impose more stringent requirements on the other barriers to fission product release from the PCS and increase unnecessarily the calculated doses from primary coolant leaks; ultimately, a high-pressure containment may be mandated..."* Such statements would imply that phenomena measurement uncertainties might significantly degrade fission product release safety margins. Discuss the sensitivity of offsite doses to these parameters.

Request for Additional Information (RAI)
Fuel Process and Quality Control Description

Reference: *MHTGR Fuel Process and Quality Control Description*, DOE-HTGR-90257/0, September 1991

3-2 <u>Fuel Quality Requirements</u>

Discuss why the key top level requirements for fuel product specifications and performance requirements (Figure 3-1) do not include: (1) 10 CFR 100 offsite accident dose requirements and (2) safety goal risk limits (e.g., frequency of occurrence of licensing basis events) as a contributor to establishing the fuel performance requirement. For example, is residence time of the fuel in the core sufficiently short that the fuel need not be designed to perform under multiple operational transients, in combination with a design-basis accident? If the fuel is to be designed to perform for combinations of LBEs, how will performance be demonstrated?

3-3 <u>Coated Fuel Particle Design</u>

The last paragraph states "....each of the barriers contributes to the capability of the plant to meet top level requirements.." Explain how this barrier approach to fission product retention in the GT-MHR design relates to the NRC safety philosophy of safety defense-in-depth.

3-8 <u>Graphite Shim Particle Requirements</u>

Table 3-2 identifies the potential fuel failure mechanisms eliminated by design.

Not included in the table is the failure of so called "standard" particles that fall within the range of all design and manufacturing specifications. The failure of "standard" particles due to the statistical performance of particles with "adverse" properties resulting from random statistical combinations of the tails of the distributions of manufactured particles (e.g., somewhat larger kernel with thinner SiC layer) can result in non-trivial failure rate in service. This is discussed further in NUREG/CR-5810, "Evaluation of MHTGR Fuel Reliability." Will the statistical failures of "standard" GT-MHR fuel particles be included as a non-trivial failure mechanism that is not eliminated by design? Explain.

Not included in the table is the potential for fuel particle failure due to either primary circuit moisture ingress (i.e., hydrolysis effects) or air ingress (i.e., oxidations effects) on the fuel particles or the effects of rapid local reactivitity increases (i.e., effects of rapid and large energy deposition and temperature rise within the particles). Explain the basis for excluding these potential failure mechanisms.

Is kernel sphericity expected to be included as a kernel parameter? Is kernel microstructure (e.g., grain size pore structure/interconectivity) expected to be included as a kernel parameters? Explain.

3-14 What is the basis for assuming that the kinds of particle defects noted in Table 3-6 will be relevant to the manufacturing process that is yet to be developed for GT-MHR fuel?

If these mechanisms are expected to be relevant, what is the basis for not including missing or incomplete SiC layer (as shown in Slide 4-5 of the January 28, 2003, GA presentation)?

3-14 What are the definitions for "missing on incomplete buffer" and "missing or incomplete OPyC" as it will apply to the particle failure and fission product release analysis? How do the definitions relate to the minimum thicknesses "critical limit" shown in Table 3-6 for these layers? Is the specified allowable fraction of particles less than the "critical limits" for thickness equivalent to the allowable fraction of missing/incomplete buffers and OpyCs used in the safety analysis? Explain.

3-14 Will SiC stiochiometry (absence of elemental silicon) be included as a manufacturing parameter?

3-17 The graphite, pitch and filler feed materials used for fabricating the shim particles and matrix for the fuel compacts are shown in Tables 3-8 and 3-9. Feed material properties can have a significant effect on fission products transport diffusion coefficients. How will potential changes in the use of other feed sources in the future be addressed in the design data needs as it relates to the fission product transport properties of the compact matrix and shim particle constituents?

4-3 Does GA plan to continue to use sequential fluidized bed coating process or a continuous fluidized bed coating process for GT-MHR particle layer coating?

6-5 The presence of "gold spots" in the form of elemental silicon in the SiC layer is considered by some as a potentially important source of particle failures if their size and prevalence is sufficiently high. What quality controls, if any, will be implemented to ensure that gold spots are not a significant contributor to particle failure?

6-13 Proper coater operation appears to be important to the manufacture of coated fuel particles having the requisite quality. Is it expected that the manufacture of coated fuel particles will include quality control inspections, tests, and maintenance on the particle coaters, or is it anticipated that the quality control on the fuel particle product property specifications and the coating process parameters will alone be sufficient to ensure that accepted batches of coated fuel particles are of the requisite quality? For example, what are the planned provisions to ensure that excessive levels of soot in the chemical vapor deposition furnace do not negatively impact the quality of the coatings and the binding strength between coating layers? Explain.

Other Issue Areas

The documents address key fuel and fission product transport phenomena associated with in-reactor conditions and events. How are the source terms for ex-reactor events, such as fuel handling accidents, to be addressed?