USS

UNDINES COMMENTS

Generally, all comments of an editorial nature were addressed.

NRR Comment 1

HTGR applicants are expected to propose that the accident source-term be based on models and methods that mechanistically predict FP release from the fuel. **[Why, Why not an upper bound]** Should this be the case, it would be different from the traditional deterministic licensing approach to source term used by LWRs, which involves a pre-determined conservative upper bound for the accident source term. As in the past, applicants will also likely propose that HTGR plants utilize a non-leak-tight "confinement" structure rather than a traditional leak-tight and pressure retaining containment structure. Accordingly, for modular HTGRs, the licensing basis, and the safety analysis will hinge, largely, on the applicant's capability to confirm, as well as the NRC's capability to confirm, fuel FP release, and address associated uncertainties. **[If applicant can not justify then it will not be approved.]**

Mechanistic prediction of FP release does not stipulate best estimate or conservative upper bound. Will depend.

ACRS COMMENTS

We consider the development of fission product release models for TRISO fuels to be the key research need for the gas-cooled reactor concepts. All the current models for fission product release in the MELCOR computer code are empirical and based on data obtained from light water reactor (LWR) fuel at burnup levels less than 45 GWd/t. To extend these models to HTGRs will require research on fission product release from highly irradiated HTGR fuel. Even the form of the empirical models (diffusive in nature) may not be appropriate to TRISO fuel for which the release of fission products is primarily related to the failure rate of the coatings,
which is not well-described by a diffusive-like correlation.

Comment 2

Additionally, it will be essential to qualitatively and quantitatively understand the design margins and safety margins to large increases in CFP failure rates and large increases in FP release. These margins will need to be known for normal operation, design-basis accidents and, potential accidents beyond the design basis. The design margin should be demonstrated by the applicant. The fuel safety margin is on top of the fuel design margin. The safety margin involves the margins to failure for conditions that exceed the fuel design conditions (e.g., fuel design specifications, fuel manufacturing specifications, fuel maximum operating temperature, fuel maximum burnup, fuel maximum fast fluence limits, fuel maximum particle power and residence time). **[Why would the later margin likely require additional NRC investigation and study]** *It is expected that safety margin aspects will be a developed by an applicant. However a complete assessment of the safety margin would likely require NRC research since HTGR designers and applicants generally oppose testing fuel to conditions that go substantially beyond the licensing basis.*

NRR Comment 3

6/10

There is a range of significant fuel design, fuel manufacture, fuel quality and fuel performance issues which will require research initiatives by the respective applicant/vendor. Exploratory and confirmatory NRC research will also be required to support safety findings and conclusions **[Define and explain why each proposed thing is needed]** *as discussed later in this section.*

NRR Comment 4

Until recently, the IAEA had a number of coordinated research programs related to the technical basis and safety performance aspects of HTGR fuels utilizing CFPs. These research programs are part of the broader International Working Group on Gas Cooled Reactors. The working group and the constituent programs, including the HTGR fuels program area, have served as fora for the international exchange of technical information. Several meetings of technical specialists working in the area of HTGR fuels research and development have taken place, beginning in the early 1980s, and continuing during the1990s. Meeting topics have included HTGR fuel development (1983), FP release and transport in HTGRs (1985), behavior of HTGR fuel during accidents (1990), response of fuel elements and HTGR cores to air and water ingress (1993), and retention of FP in CFP and transport of FP (1992–1996). The proceedings from these meetings have been published and are publically available. ~~Most recently, IAEA support for the gas reactor working group and associated coordinated research programshas substantially declinedalthough imited periodic meetings among the international experts in different HTGR techology areas including HTGR fuels may still continue for some time~~.

Comment: This does not make sense.)

The following was also added *Recently, the IAEA has taken steps to establish a new international coordinated research project (CRP-6) on HTGR fuel. The areas identified for the CRP include: fuel performance data; fuel performance modeling and data characterization; fuel operating experience, fuel irradiation and accident condition testing, and fuel licensing issues. Fuel fabrication technology for quality and performance may also be included in CRP-6.*

NRR Comment

The U.S. DOE has established an Advanced Gas Reactor Fuel Development and Qualification Program. The program includes fabrication technology development, irradiation testing, and accident condition testing. The qualification of TRISO CFP fuel types will be based on the German fuel fabrication process. The irradiation testing program in the near-term involves German archive fuel with German manufactured TRISO CFPs. The near-term irradiations would develop performance data for the reference German fuel for test conditions exceeding those previously examined. The tests will determine TRISO particle fuel performance for the more demanding design conditions (e.g., higher operating temperatures) of modern modular HTGR designs relative to the earlier German pebble bed reactor designs. The test program will explore the failure margins of TRISO particle fuels with test conditions that are well beyond the conditions associated with the fuel design basis.

NRR Comment

In China, the Institute for Nuclear Energy and Technology (INET) is currently conducting an HTGR fuel irradiation qualification testing program for the HTR-10. This testing is being performed on both CFPs and fuel elements that were produced for use in the HTR-10. The fuel is currently being irradiated in a materials test reactor. The fuel elements will be irradiated to burnups of 30,000, 60,000 and 100,000 MWd/t. At each of these burnups, the fuel pebbles will be subject to a temperature increase to simulate design-basis accident temperature conditions. The irradiation testing is a license condition for initial power escalation and long term power operation of the HTR-10. Once the fuel qualification testing is completed, it is expected that the INET fuel testing program will enter the operational phase in which CFP fuel performance will be assessed on a large-scale as part of HTR-10 power operations. As of early CY 2002, power escalation of the HTR-10 had not yet been authorized.

Comment: This info is in section twice, consolidate it.

The two paragraphs involved were consolidated.

<u>NRR Comment Page 74</u>

Fuel vendors and applicants are expected to demonstrate that significant fuel failures do not occur even for operating and accident conditions that exceed the design basis. However, NRC research is will be needed to fully understand and quantify the margins to significant increases in TRISO particle fuel failures for normal operation, design-basis accidents and accidents beyond the design-basis. The research plan will provide the staff with the requisite level of knowledge in the areas of HTGR fuel design, manufacture, operational performance and accident performance, necessary to independently and authoritatively assess the applicant's technical and safety basis for fuel quality and safety performance. Analytical tools will be developed and validated to enable the staff to independently predict fuel performance (including CFP failure and fission product release) during normal operation, design-basis accidents and potential severe accidents. Research will provide the staff with an independent capability to calculate TRISO particle fuel source term for normal operation, design-basis accidents and potential severe accidents.

Comment: Doesn't the applicant need to provide this

Generic RES treatment of comment in front-end of SECY is applicable.

<u>NRR Comment Page 74 bottom</u>

Provide the data which explores the limits (i.e., margins) of fuel performance and fission product release for conditions that are well beyond the design basis for parameters which are important to the fuel safety margins. These conditions involve fuel operating temperature, maximum fuel accident temperature, fuel oxidizing environment, fuel burnup, energy deposition and deposition rate in the fuel (due to reactivity accidents), beyond those that are expected to be examined by the fuel vendor or applicant.

Comment: Applicant will need to provide not needed by RES

Generic RES treatment of comment in front-end of SECY is applicable.

NRR Comment Page 75 top

Independently evaluate HTGR fuel behavior, including CFP failure, fission product release and margins of safety,

Comment: Applicant needs to do this, not us.

Generic RES treatment of comment in front-end of SECY is applicable.

NRR Comment (Top/Middle page 75)

NRC fuel fabrication technology Expertise

The purpose would be to:

Provide NRC staff with in-depth knowledge of contemporary HTGR fuel fabrication, including the critical process parameters, critical product parameters and quality control measures that are vital to achieving the required fuel quality and fuel characteristics that will provide the required fuel performance over the life of the plant's fuel supply.

Comment: Define the cooperative research plan.

The following was added:

A major research element of the EU HTR-F is to re-establish know-how on TRISO coated particle fuel fabrication. The research includes both fabrication of fuel kernels and coatings.

The NRC is seeking to enter into a cooperative agreement with the HTR-F. The project includes fuel fabrication element aimed at re-establishing expertise in the fabrication of fuel kernels and particle coatings. It is expected that the HTR-F project will identify the critical process and product attributes and the necessary quality controls to fabricate HTGR fuels with the required quality and characteristics needed to maintain consistently good fuel performance over the life of the plant. An NRC cooperative agreement with the HTR-F would be expected to provide the NRC with access to the information on fuel fabrication technology developed by the HTR-F project. The NRC should also endeavor to utilize technical information exchanges with foreign organizations having expertise in TRISO particle fuel fabrication (e.g., China, Japan) to obtain information and to develop expertise on the fabrication of TRISO particle fuels.

NRR Comment Top/Middle of Page 76:

Virtually all of the accident simulation tests for TRISO CFPs involved so called "ramp and hold" temperature increases. These typically consist of increasing fuel temperature at about 50°C/hr up to a set temperature (e.g., 1600°C, 1700°C or 1800°C) and then holding the fuel at the set temperature for several hundred hours while fission product release measurements are taken. The results of ramp-and-hold tests up to 1600°C, for qualified fuel, show that no additional CFP failures occur. However, in the Federal Republic of Germany, there was at least one test in which the temperature was controlled to closely simulate the predicted accident heat-up curve to 1600°C for a design basis reactor coolant pressure boundary failure. For this test, CFP failures were observed to occur. **Additional post-irradiation accident simulation tests that closely simulate the predicted temperature curve for a design basis reactor coolant pressure boundary failure would be required to determine if the traditional ramp and hold test accident simulation approach is conservative with respect to establishing CFP failure rates for postulated accidents.**

Comment: Why wouldn't applicant do this?

Generic RES treatment of comment in front-end of SECY is applicable.

NRR Comment Middle of Page 76

Among the most limiting events that could challenge HTGR CFP integrity are those involving large scale chemical attack such as air intrusion following a pipe large break in the reactor coolant pressure boundary (RCPB) and moisture intrusion for a postulated heat exchanger tube failure with the reactor helium pressure falling below the heat exchanger tube pressure. While there have been experiments on oxidation of unirradiated HTGR fuel in air and water at HTGR accident temperatures and measurements of HTGR fuel oxidation due to air or moisture impurities in helium during fuel experimental irradiations, there few experiments have been conducted on fully irradiated HTGR fuels that simulate the effects of large air or water ingress events. **Additional post-irradiation accident simulation tests that closely simulate air or water intrusion events and take the fuel to the onset of CPF failures would be needed to fully assess the adverse effects of air and water corrosion on HTGR fuels and the margins to failure for such events.**

Comment: And applicant should do these tests.

Generic RES treatment of comment in front-end of SECY is applicable.

NRR Comment Bottom/Middle of Page 76

Very limited testing has been conducted on fuels with TRISO CFPs to assess the capabilities and the margins to CFP failure for reactivity events involving a large energy deposition in the fuel over a very short time interval (<< 1 second). Some limited testing was conducted in Japan for a postulated control rod ejection accident in support of the HTTR licensing and was one of the limiting licensing basis events. The staff has been told that the PBMR design does not have a potential for such large rapid reactivity events. Further, the GT-MHR control rods, which located in the central core (fueled) region, are expected to incorporate engineered safety features to prevent a failed drive housing from rapidly and fully ejecting a control rod from the core. For these reasons PBMR and GT-MHR applicants are expected to claim that large and rapid reactivity insertion events are not within the licensing basis and that design specific fuel testing is not needed. Accordingly, **in order to fully understand the margins to failure for reactivity events, fuel irradiation experiments involving such reactivity insertion events would need to be conducted by the NRC.**

Comment: And should be done by applicant.

Generic RES treatment of comment in front-end of SECY is applicable.

NRR Comment Middle of Page 77.

It is important that the NRC staff and contractors have expertise on the proper conduct of HTGR fuel irradiation experiments, including a thorough understanding of sound testing practices as well as testing limitations and potential opportunities for oversights and omissions. Such knowledge and experience will provide the staff with a sound basis for judging the acceptability of the applicant's HTGR fuel irradiation and accident simulation program methods, quality assurance practices, etc.

Comment: Doesn't Yuri already have this. All we need to tech transfer from Yuri to others.

Not true. HTGR fuel irradiation experiments are much different than LWR fuel experiments.

NRR Comment Middle of Page 77

The proposed NRC HTGR fuel irradiation testing program plan has three elements. These are testing of unirradiated German archive pebble fuel fabricated for the AVR, testing of HTGR production fuel for demonstration or prototype HTGR plants that may be built in the U.S. Table 1 at the end of this section summarizes a proposed irradiation testing plan for German archive pebble fuel, Table 2 summarizes a proposed testing plan for PBMR production fuel, and Table 3 summarizes a proposed testing plan for GT-MHR production fuel compacts. Testing of the German archive fuel will provide information on the acceptability of traditional testing methods, insights into adequacy of vendor testing programs and information on operational and accident condition safety margins for reference TRISO particle fuel types. These test plans could be implemented in connection with the following cooperative agreements, and any proposed testing would not duplicate but will capitalize on testing performed by DOE.

Comment: Need to state what hope to get out of these tests

Add: Testing of German archive pebble fuel fabricated for the AVR will provide benchmark TRISO fuel performance data for TRISO coated particle fuel that is considered to be among the best quality and highest performing HTGR fuel that has been manufactured. These test results will provide a basis for comparison with GT-MHR and PBMR production fuel irradiation and accident condition performance. Testing of HTGR production fuel for demonstration or prototype HTGR plants that may be built in the U.S.

NRR Comment Bottom of Page 77

This plan also assumes NRC will participate in the European Commission (EC) research HTGR program project on HTGR fuel technology. The NRC will provide support for the irradiation experiments on German Archive fuel and GA compacts fabricated using a new manufacturing procure as well as the accident heat up simulations with fission product release measurements and post irradiation examinations. The NRC will also support the retrieval of data from past HTGR experiments with the aim of constructing a searchable fuel database.

Comment: What will participation provide the U.S.? Spell out as well as if this testing (NRC providing support) is part of the above paragraph testing or if it is new testing.

The benefits to the NRC are provided in the paragraphs that follow.

NRR Comment Bottom of Page 77

This plan assumes NRC participation in a cooperative HTGR fuel test program with the Department of Energy (DOE). **The NRC emphasis for this cooperative fuel testing program will be on understanding the safety margins,** by exploring conditions that are well beyond the fuel design-basis conditions associated with normal operations and postulated accidents. It is expected that participation in the program will also provide: test data which can be used for developing and validating fuel performance analysis models and **data that can be used to confirm an applicant's fuel performance analysis.** Further, staff knowledge of fuel testing will be increased for later use in the review of an applicant's fuel qualification program documents.

Comment: Applicant should find margins.

Generic RES treatment of comment in front-end of SECY is applicable.

Comment: For RES to get into which would provide information to check applicable data would imply that RES is proposing to do operating condition test not just margin tests which would be inappropriate.

RES operating condition testing will be well beyond the design conditions. RES accident condition testing would also be beyond the design basis accident conditions. DOE testing would be at the licensing limits and NRC would obtain the data for these and can be used for developing and validating fuel performance analysis models.

YURI COMMENTS

NRR Comment

A. HTGR Fuel Irradiation Testing Plan

It is stated that "It is assumed that PBMR and GT-MHR license applicants/vendors will conduct all fuel testing necessary to support licensing". The review of the applicants' submitals will be made by NRR in light of the submitted material. A priori this material cannot be superceded by separate testing under RES auspices. Given that so far basically nothing of consequence has been submitted, it is difficult at this time to identify research efforts outside of those to be performed by the applicant in due time which will be needed to support NRR's licensing of HTGRs.

Response: Exelon understands that the applicant is responsible for all fuel testing necessary to support licensing. The fuel qualification test plan submitted by Exelon in a white paper, and a supplemental white paper on historical German TRISO fuels performance testing, reflects their views on the fuel irradiation testing and accident condition testing that will be necessary to support PBMR fuel licensing. We have not yet received a test plan from GA but we would expect that they would have a similar understanding

NRR Comment

The draft preapplication Safety Evaluation Report for the MHTGR (NUREG-1338) and also the presentations by Excelon and General Atomics have identified the manufacturing process of the fuel as the key to maintaining a low fission product release potential due to both fuel failure and the "tramp" uranium. The proposed plan addresses only fuel irradiation; yet the applicants argument will contain a lot about manufacturing of the fuel and acceptance sampling and testing. Moreover, the "tramp" uranium is a unique feature of this fuel and is a significant contributor with time to the source term, and as such its behavior will be an issue in any review by NRR of these advanced reactor concepts. Given a well formed Triso fuel particle its performance has been, and is likely to be in the future, well documented.

It is difficult to see how the testing of unirradiated German archive pebble fuel fabricated for the AVR can significantly enhance NRR's regulatory effort with regard to the HTR in general , or even with the PBMR in particular. The Triso particle fuel, although of the same design as PBMR, was manufactured at a facility which no longer exists and whose relation to the PBMR fuel manufacturing facility would need to be established and evaluated. Moreover, this fuel has been tested extensively and its performance has been well documented. The irradiation of a few more fuel pebbles is not statistically significant. The applicants fuel will be evaluated by NRR in light of the applicant's test results and analyses of the applicant's fuel. As such, it is difficult to say at this time what the expected value of research information would be to NRR's regulatory mission from additional irradiations under the auspices of RES.

Response

The point is well taken for fuel qualification and proof testing of specific fuel designs and manufacture for specific operating conditions and accident conditions. Testing of AVR archive fuel would be of no real value for licensing PBMR specific or GT-MHR specific fuels. This is not the focus of the RES plan nor the focus of the vendor fuel qualification plans. Both PBMR and GT-MHR have stated that they plan to manufacture their TRISO particles using a process that is equivalent to the German fuel process. Their aim is to achieve equivalent fuel quality and equivalent fuel performance during operations and during accidents. The PBMR and GA fuel irradiation and accident condition test plans will be expected to show this to themselves and to the NRC within the licensing basis conditions of operation and postulated accidents. Neither vendor is planning to test either their own fuel or the German reference fuel to conditions that explore the margins and push their fuel to conditions where significant increases in the rate of fuel particle failures occur.

The NRC test plan is focused on margin testing for conditions well beyond the licensing conditions. By testing the German archive fuel, a performance benchmark is established for such margin testing for fuel reported to be among the best ever made and the limits of integrity for such fuel can be identified. A comparison of margins between German fuel and GA and PBMR production fuel can then be made when they are available.

These German archive fuel testing will also provide

- Early data on whether core condition (coolant activity) monitoring systems are capab;le of detecting latent failures

- an important learning curve for NRC staff for fuel irradiation testing and accident condition testing of TRISO fuel elements in advance of such testing on PBMR production fuel and GT-MHR production fuel

- Timely insights into issues that are important to the staff's review of the applicant's fuel irradiation testing and accident condition testing programs (e.g., how to account for change in fuel element center (pebble) and center line (compact) temperatures due to irradiation-induced changes to matrix graphite conductivity.

- **Note: This entire issue may be moot if DOE decides to not conduct irradiation testing of the German Archive fuel pebbles for PBMR fuel qualification. If this were to be decided the NRC/DOE cooperative agreement for irradiation testing of German pebble fuel will not be go forward.**

NRR Comment

B. HTGR Fuel Analytic Model and Methods Development

Since the inception of the coated fuel particle in the fifties every HTGR research group has been developing mechanistic models to assess coated particle fuel performance. This is still going on; see, for example, the current issue of Nuclear Engineering and Design. It is clear from their presentations so far that each applicant will submit an analytic fuel performance model to support the license application. NRR will evaluate the model in the context of benchmark problems and experimental results, as is done with all other codes submitted for review for use in licensing applications. It is difficult to see how another code, which needs to be also evaluated against the same benchmarks and experiments, will add significantly to NRR's ability to evaluate the coated particle as an HTGR fuel.

Response:

With respect o NRC fuel analytical model and methods development, The purpose would be to:

- Independently evaluate HTGR fuel behavior, including CFP failure, fission product release and margins of safety, and
- Evaluate the effects of variations in irradiation service conditions, and uncertainties (i.e., sensitivity studies such as the effectiveness of online core condition monitoring systems to detect latent failures).
- Serve as benchmarks for simplified fission product release models utilized for source term assessment in HTGR system level accident analysis codes (e.g., HOTCOR)

NRR Comment

NRC Interactions and Cooperative Research

Certainly cognizance of ongoing activities and results with regard to coated fuel particle research and activities is valuable for NRR's regulatory mission with regard to HTGRs. It is not possible to currently, that is without an application in hand, to identify specific research which would be necessary to support NRR's efforts in the evaluation of HTGR license applications.

Response:

Infrastructure development in advance of an actual application

ACRS COMMENT

"Consideration should be given to research to determine whether the buildup and characteristics of radioactivity in the coolant system during the operating phase of the HTGRs could be used to infer whether the as- installed quality fuel meets the required (licensing basis) quality."

Addition Made to the HTGR Fuels Research Plan

(5) HTGR Fuel Condition Monitoring Effectiveness Assessment

Because of the importance of fuel integrity to the HTGR safety case, defense-in-depth against loss of fuel integrity is very important. Fuel manufacturing specifications and quality controls, fuel irradiation testing, fuel accident condition testing and fuel performance code analysis all play a role in assuring defense against unexpected elevated fuel particle failure rates during either plant operation or licensing basis events. An additional important defense against loss of fuel integrity is also provided by HTGR core condition monitoring systems. These systems are intended to detect elevated fuel particle failure rates during plant operations. Core condition monitoring systems are also be relied upon to monitor the condition and capability of the fuel in the core, to maintain the expected level of integrity during licensing basis events.

HTGR core condition monitoring systems typically detect manufacturing-related particle defects or irradiation-related particle failures by monitoring noble gas activity in the circulating helium coolant. Fission gas release measurements from fuel irradiation testing are used to correlate the magnitude of fission gas release due to all causes of fuel particle failure, diffusion and release mechanisms. These systems must be effective so that remedial actions can be taken where core wide failure fractions show signs of increasing above the expected levels.

An important research issue is whether HTGR core condition monitoring systems have the capability to detect significant "latent" fuel particle failure conditions (i.e., "weak fuel" or "weakened fuel") which have not yet been manifested as elevated fuel particle operational failure rates. Latent failure conditions might occur due to systematic undetected errors in either the manufactured fuel quality (e.g., incorrect particle layer coating rate) or operating conditions that are significantly outside the fuel design envelop (e.g., elevated fuel operating temperature). Such latent failures may or may not be detected and actions may or may not be taken prior to an event resulting in a core-wide failure fraction above the predicted level.

The planned research will investigate the capability to detect weak fuel caused by out-of-specification manufacture and fuel weakened by operating conditions well-above the design. The research will assess whether such fuel would generally be detectable during operations as a result of elevated (higher than expected) coolant activity caused by elevated (higher than expected) particle failure rates. The research will also seek or assess whether fuel that was weak or weakened due to specific manufacturing or operating conditions might not result in elevated particles (and coolant activity) during operations but would be sufficiently degraded to cause higher than expected fuel failure rates during heat-up accidents. The research will involve a combination of irradiation testing, accident simulation testing and sensitivity studies using fuel performance analytical tools.

Weakened fuel performance from operations will be assessed by fuel irradiation tests conducted at significantly higher than design-operating conditions followed by accident condition heat-up testing. Fission gas release measurement data for both tests will be the principle basis to assess the potential for inducing and detecting weakened fuel which would fail during an accident.

Sensitivity studies with analytical codes will used to assess whether fuel that was weak (in various ways) due to manufacturing errors would result in detectable increases in fuel failure rates or whether there are conditions of weakness due to manufacture that would not be evident as increased failures until the accident condition
Available historical irradiation test data, operational data and accident simulation test data will also be studied for any evidence on the capability of core condition monitoring systems to detect weak or weakened fuel.