NRR

From: Amy Cubbage
To: Lu, Shanlai; Shoop, Undine
Date: Tue, May 7, 2002 9:21 AM
Subject: Fwd: RAIs

I received the attached fuel qualification RAIs from Yuri. Please add your input, if any, and provide one combined set of RAIs that I can send to RES today.

Thanks,
Amy

CC: Caruso, Ralph; Orechwa, Yuri

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From: Yuri Orechwa
To: Amy Cubbage
Date: Mon, May 6, 2002 8:16 AM
Subject: RAIs

RAI - Fuel Fabrication Quality Control Measures and Performance Monitoring Plans for PBMR Fuel

Fuel Fabrication

1. It is implied that by reproducing the NUKEM process and fuel specifications for AVR 21-2 will result in acceptable fuel performance.

a) The specification for the manufacture of fuel for the PBMR will be based on the NUKEM specification used to manufacture the AVR 21-2 reload batch for the AVR reactor in Germany. What is the sensitivity of the performance of the fuel to variation in design specification about the NUKEM specification for AVR 21-2 fuel. In particular, quantify the variation with regard to those design specification that differ from the PBMR specifications.

b) Quantify the sensitivity of the performance of the AVR 21-2 fuel to the key parameters in manufacturing process. Why are these deemed the key parameters in the manufacturing process?

2. Is the fuel manufacturing process with respect to quality checks a batch or a continuous process?
What statistical methodology and limits are employed at each quality control point in Fig. 1?

3. It is stated that "The first check is performed as needed on the incoming feed materials." What decision rule is used for "as needed"?

4. How does the optical particle size analyzer reject particles? The traditional vibrating surface does it on a particle basis. What is the error in the optical particle size analyzer?

5. In the coating process steps what is the batch size and the sample size. What sampling strategy is employed?

6. How much variation is expected in the number of particles per fuel sphere? How many fuel spheres are in a batch?

Fuel Performance

1. You state "The PBMR is provided with instrumentation for monitoring the critical parameters necessary for determining the core operating conditions." You point to neutron flux measurements via ex-core detectors and helium coolant temperature measurements at both the vessel inlet and outlet pipe locations. These give integral or core averaged values. Fuel performance is a function of point values. How do you plan to estimate the probability of fuel failure and noble gas fission product levels based on these integral measurements?

2. How do you plan to predict the fraction of fission product plate-out, which is relevant to accident analysis?

3. Since "Fuel integrity is directly monitored by measurement of the noble gas fission product levels in the coolant.", how do you plan to distinguish the failure mode (i.e. failure of a few particles or leakage from many particles resulting in the same release) from an integral value such as the noble gas fission product level in the coolant?

4. What is meant by "remedial measures" to be taken when the failure fraction in the core shows signs of increasing beyond expected levels?

5. The fuel burnup is measured for each element at discharge. Since in the last pass of an element through the core results in a distribution (as do previous passes), how do you determine this distribution so as to define the decision rule of whether or not to allow a fuel element to pass through the core one last time?

6. The Burnup Measurement System performs extensive self -diagnostics. Please elaborate on this statement with regard to how this is done, at what time intervals and what are the alarm level and detection limits.

RAI - Fuel Qualification Test Program for PBMR

I. Relationship of Fuel Qualification Test Data to the PBMR Licensing Process in the US

1) It is stated that "the release of fission product gases from the coated fuel particles under normal operation can be used as an indicator of the state of the fuel and its ability to withstand accident conditions".

a) How do you estimate from a core integrated number such as the release of fission product gases whether there are a few failed particles that have released all their fission gases, or that there are many leakers that have released a small fraction of their fission product gases? The consequences in an accident are likely to be very different. How can you differentiate whether the leakers reflect manufacturing defects or fuel degradation resulting in a significant fraction of weak fuel which may fail en masse during an accident?

b) Over the life of the reactor does the purported relation between measurement of fission gas in the coolant and the state of the fuel remain constant?

c) What are the key design parameters that affect fuel performance in the range 1600 -1700°C? What is the sensitivity of fuel performance to these design parameters at these temperatures?

2) It is stated that "It is expected that the combined data from the US, Russia and South African test programs will be used t satisfy the fuel performance requirements."

a) What specifically are "the data" and how will they be "combined"? What statistical criteria will be applied to assure that they are combinable?

b) It is well established that fuel particle performance is very sensitive to fuel particle manufacturing process parameters. (IAEA-TECDOC-978) How will the manufacturing differences between US, Russian and South African fuels be taken into account in the combination of the data?

II. Relationship of PBMR Licensing and Fuel Qualification Testing Schedules

1) You state that " PBMR fuel qualification testing will be confirmatory in mature". Specifically and quantitatively what figures of merit will be confirmed? What are the statistical tests and their power that will be employed?

2) You state that "It is expected that the first PBMR core loading will be manufactured before completion of the entire fuel qualification test program." Is the sought after operating license for initial core loading and power ascension only? What burnup limitation do you expect on the first core?

III. PBMR Fuel

1) You state that: i) "The PBMR fuel manufacturing and quality control processes and methods have been specified to be comparable to those that were used in the German fuel fabrication plant." and ii) "expected irradiation conditions for PBMR fuel fall within the envelope of German fuel qualification tests, and that it can be proved that PBMR fuel is comparable to German fuel."

The operative word in both these statements is "comparable". What are the quantitative measures and the sensitivity levels that determine "comparable" with regard to

a) Manufacturing specifications

b) Input raw materials

c) Important fuel manufacturing process and equipment parameters

d) The working parts used for critical processes

e) QA procedures and tests

IV. Production of PBMR Fuel

1) Are the measurements at the quality control check points in the manufacturing process made by batch or continuous sampling? Please specify and give the batch size, where appropriate, and the number of measurements, together with instrument and sampling errors.

2) What are the detection probability and "false alarm" limits for the acceptance levels of the measured QC characteristics for the UO_2 kernels and the coated particles?

V. Supporting International Fuel Data

1) It appears to be well established that fuel particle performance is strongly dependent on the fuel manufacturing process even for fuel with identical design parameters. (IAEA-TECDOC-978) The specifics of the processes in the various countries with coated particle technologies appear to differ, so, although the general success rate demonstrates proof of principle, how do you plan to quantitatively incorporate these international data into the results of the PBMR test results?

VI. Fuel Performance in Normal Operation

1) You state that "the irradiation program for PBMR fuel is directed toward qualification for service under PBMR design conditions, with the understanding that results of this limited test program are supported by a large body of data from similar fuels tested under PBMR relevant conditions."

a) In specific quantitative and statistical terms what is meant by "supported"?

b) As mentioned before, how do you plan to treat the variation in the manufacturing processes in that "large body of data"?

VII. Fuel Performance Under Accident Conditions

Heatup Testing

1) Since irradiation history of the fuel prior to heatup is an important factor determining fuel performance, both burnup and fluence are important parameters. You mention that samples used in heatup test have spanned burnups exceeding discharge burnup. What were the related fluences and how do the burnup-to-fluence ratios compare to that of PBMR?

2) What is the estimated probability density function for the fission gas pressure at the peak discharge burnup? What is the assumed fission gas release fraction?

Oxidation Testing

1) You state that intact coated particles are not affected by water. Under what conditions does this cease to be true?

2) Tests with regard to oxidation on failed particles are not the only issue. For these results to be meaningful requires tests for the conditions under which the probability of irradiated particle failure becomes significant. What relevant tests exist or are proposed to address the issue of what are these conditions with regard to moisture ingress and air ingress as a function of irradiation?

3) In particular, what are the oxidizing conditions for the failure of the silicon carbide coating as a function of fluence and internal gas pressure?

Reactivity Transient Testing

1) In the pulse tests that you describe what was the incremental increase in particle failure? What trends, if any, of failure rate as a function of energy deposition and energy deposition rate applicable to PBMR can be derived from these data?

VIII PBMR Fuel Qualification Testing

A. Fuel Failure Mechanisms, Key Variables and Their Impact on the Test Program

Over-pressure

1) What are the tensile strengths of unirradiated and irradiated PyC and SiC as a function of temperature.

2) From theoretical considerations at what burnup and temperature combinations would the onset of fuel-coating mechanical interaction be expected?

3) You account for oxidation of the particle coating in estimating the time to rupture of the particle coating? If so how is that taken into account?

4) Is there any evidence of fuel cracking so that local fuel-coating mechanical interaction can develop?

Irradiation-Induced IPyC Cracking

1) What is the sensitivity of the density of shrinkage cracks to degree of anisotropy as a function of irradiation and temperature?

2) What is the relation between shrinkage crack density and tensile strength of the IPyC layer?

Kernel Migration

1) How much do the AVR and THTR thermal gradients differ from PBMR? Do you expect some failures due to the ameba effect in PBMR?

Fission Product Attack

1) What is the experimental evidence that the level of Pd attack is benign in particle fuel at PBMR conditions? How were the measurements made and how many particles were examined?

SiC Thermal Decomposition

1) Is there a temperature threshold for the onset of thermal decomposition of SiC? What is the rate of decomposition as a function of irradiation and temperature?

Enhanced SiC Permeability

1) Is this a threshold effect?

2) What fraction of the release is attributed to this effect in the range of PBMR operating conditions?

As Manufactured Defects

1) PBMR will have ~15,000 particles per pebble as opposed to ~9,600 for the AVR21-2 fuel what effect, if any, is that expected to have on the initial failed particle rate per pebble from the formation of the particles into pebbles?

Relevant Statistical Issues

1) For modeling purposes and failure prediction with a significant statistical power at different operating and accident conditions requires knowledge of the contributions from the different modes of failure as discussed in the previous material. Your estimate of ~200,000 particles to

achieve the needed statistical power is associated with the integral value of total failure fraction. This does not distinguish between failure modes. Such a distinction in the failure modes to the power that you propose would require far mode data. The arguments as presented in this white paper that "none of the fuel failure mechanisms are expected to be significant" is heuristic at best.

B. Fuel Performance Testing Under Normal Conditions

1) In general, many aspects of fuel performance are correlated to the rate of irradiation. All irradiations in the test matrix are 1.5 and 3 times real time. Please give your rational that this accelerated testing does not affect your conclusions, or how you will take the effect into account.

2) The test matrix contains three fuels of different origin: Pre-production fuel, Archived German fuel and production fuel. Given the sensitivity of fuel performance to the manufacturing processes, how do you assure that the performance implied by these tests as a whole is valid for prediction of fuel performance in PBMR? What are the key parameters and their sensitivity limits that you feel are sufficient to assure this?

3) Your statement "Demonstration (i.e. confirmatory) testing is at best misleading. Demonstration testing and confirmatory testing are not an equivalent statistical inference. Please formulate your argument in the form of a statistical hypothesis test.

4) You state in the last paragraph on page 34 that "These 12 pebbles constitute the statistical demonstration test for the fuel.". Precisely what is being demonstrated? Is it on the particle or the pebble level?

5) What is meant by statistical database for these tests? That is what are the figures of merit? What are the independent variables? What are the fixed and random effects parameters? What are the statistical models? Has any effort been made to apply experimental design techniques?

C Fuel Performance Testing under Accident Conditions

Technical Rationale

1) Given that the chosen 1600 °C fuel temperature constrains the maximum design power level, what is the sensitivity of PBMR power level to this temperature? What is your estimate and its uncertainty of the coolant bypass flow, and what are the consequences on the chose 1600 °C fuel temperature for a fixed core power level?

2) Since "sufficient data are already available" with regard to UO_2 coated particle fuel performance under oxidizing conditions, a quantitative assessment, rather than a qualitative assessment, of residual risk associated with each event category should be given.

3) Please specify where "Data are available with general applicability to the PBMR demonstrating very large margins for transient over power events.".

Test Matrix

1) The test matrix contains three fuels of different origin: Pre-production fuel, Archived German fuel and production fuel. Given the sensitivity of fuel performance to the manufacturing processes, how do you assure that the performance implied by these tests as a whole is valid for prediction of fuel performance in PBMR? What are the key parameters and their sensitivity limits that you feel are sufficient to assure this?

D Post Irradiation Examinations

1) Are the metallographic results included in the statistical database? If so, how? That is, what variables are included and how are they quantified? How are they related to fuel performance models and their predictions?