From: Amy Cubbage > NRR
To: Shoop, Undine
Date: Wed, Mar 6, 2002 3:59 PM
Subject: RAIs

Undine, please look at the attached file which contains your graphite questions tacked onto the end of Yuri's. Please check for overlap of issues and try to combine into one RAI from SRXB.

Amy

CC: Caruso, Ralph; Orechwa, Yuri

Comments and RAIs on the PBMR White Paper - High-Temperature Materials Graphite

The subject White Paper consists mainly of sections and figures copied from the short summary report "Graphite for High-Temperature Reactors", EPRI, August 2001, prepared B. Marsden of AEA Technology in England. These sections are annotated with comments as to the relevance of the material to PBMR conditions. This material together with the handout "Pebble Bed Modular Reactor High Temperature Materials Graphite" by Mark A Davies, October 2001 will be the context of what follows. In general, the data exhibited and the statements made in the above do not indicate whether they apply to a He atmosphere or some other atmosphere such as CO_2 in the case of British data. It is well known that the type of atmosphere affects the behavior of graphite at high temperatures and irradiation. In general, for all data presented for review it should be indicated what the atmosphere was under which the data were collected, ora justification given why data collected in another atmosphere is applicable.

Nuclear Graphite Manufacture:

a) On page 37 of the handout the statement is made "Suitable Nuclear Grade Graphites can be determined by appropriate choice of manufacturing process parameters". How can you be sure that you can make such a determination, what appears to be a priori, in light of the fact that there is no data beyond "turnaround" for PBMR conditions?

b) PBMR has chosen Sigri Great Lakes as the preferred supplier for the graphite reflector. A table is show of some of physical properties of the unirradiated graphites. Does data exist for these products for irradiated conditions? In particular, if these data exist, what is their relation to the conditions of interest in PBMR?

The Damage Process:

a) It is not clear what measure of fast neutron dose is to be used in the analysis and prediction of graphite behavior at high temperatures in PBMR. If the integrated flux above 0.18 Mev is used, what is the basis for this choice? If EDND is used, what is the evidence that the Thompson-Wright damage function and the standard nickel flux in DIDO are appropriate for PBMR conditions?

b) It is stated that "It is assumed that for the type of graphite to be used in PBMR, in the temperature and fluence range of interest, the graphite behavior is consistent, i.e. the material properties, when irradiated in a similar flux, may be described by mathematical equations, which are functions of irradiation temperature and dose."

i) Do you mean that the mathematical equations for all graphites of interest to PBMR and the graphites used in existing and past reactors have the same analytic form with regard to temperature and fluence? The figure on page 19 of the handout implies that there is significant material to material variability with regard to turnaround and the fluence level at the material exhaustion limit. What are the mathematical expressions used to characterize the material behavior of the relevant graphites; and how do you plan to estimate the coefficients which distinguish the behaviors between particular graphites?

ii) In computing the predicted state at end of service life based on the mathematical models, the fluence is a monotonic function of time while the temperature is not. How will the

temperature be quantified so as to represent the correct damage contribution? How will the uncertainty in the prediction be computed? How will the distinction between fixed and random effects be made?

iii) Do you account for cyclic fatigue, such as due to thermal striping in the plenums?

c) Is the expression on page 18 of the White Paper for creep or the creep rate?

i) The expression includes primary and secondary creep terms. Is there a tertiary creep term in the case of PBMR conditions?

ii) What is the limiting creep level (irradiation and thermal) for the PMBR design? Does it vary with temperature and fluence?

iii) Under what conditions, if any, does material exhaustion supersede the creep limit?

Component Performance Assessment:

a) Since fast neutron irradiation rapidly increases the strength of graphite due to pinning of the dislocations in the basal planes for PBMR conditions which is a more limiting failure criterion, one based on unirradiated graphite properties with the standard safety factors, or one derived using the UK proposed Griffith failure criterion and taking into account irradiated graphite properties. In particular, when considered for a fixed level of confidence and in the context of a modified Weibull distribution and a probability of crack initiation of 10^{-4} as proposed in the ASME code?

b) The recommended failure criteria for PBMR graphite components give on page 22 of the White Paper is consistent with how many effective full power years of PBMR operation? Are these criteria affected by the reported premature cracking in AGRs (Nucleonics Week, January 24, 2002)?

c) If the option of replacement of the inner reflectors is pursued, are there scenarios in which a reflector brick can be dropped? If yes, what damage if any can result and how will the graphite brick be retrieved?

Additional Questions:

Page 2

1. Under the adequate cooling of the pebble bed section it is stated that "care must be taken in the design to ensure that the core barrel does exceed temperature limits due to natural circulation of hot gas from the core." Assuming that it was actually meant that the core barrel should NOT exceed the temperature limits, please provide the temperature limits for the core barrel and other critical components.

Page 3

2. It is stated that the outlet plenum is designed so that the differential temperature within the gas leaving the care is less than 60 degrees C. What type of stresses does this temperature differential produce?

3. Please explain how the geometry requirement for the RCSS has a significant impact on the

structural performance of the blocks during the lifetime of the plant.

4. Please provide additional details of the method for vertically stepping the top blocks of the bottom reflector.

Page 14
5. It is stated that PBMR will ignore the concept of equivalent temperature. Does this imply that PBMR does not intend to use the other data or will a correlation between the previous data and PBMR be supplied?

Page 15
6. Please provide additional details on what is meant by "family" characteristics and how ATR-2E and VQMB graphite relate to PBMR graphite.

7. What is the basis for assuming that in the temperature and fluence of interest, the graphite behavior is consistent? What are the uncertainties? How are they accounted for?

8. What is the temperature range for which the fluence has been extrapolated? Please provide justification for extrapolating the data.

Page 17
9. What is the basis for assuming that the Poisson's ratio is independent of material direction and irradiation when there is evidence which suggests otherwise?

Page 23
10. It is stated that the sleeves are designed to be replaceable to cater for a dropped rod. Please provide additional details on how a dropped rod will require a sleeve replacement.

11. What are the typical parameter ranges for material exhaustion to occur?

General note
12. Provide verification and validation for all the equations and relationships used to support the PBMR graphite relationships.