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Dr. Thomas E. Murley
9106 McDonald Drive
Bethesda, MD 20817

SUBJECT: RESPONSE TO YOUR LETTER TO MR. THOMAS KING, DATED NOVEMBER 12, 2001

Dear Dr. Tom Murley:

Thank you for your participation in and written comments on the High-Temperature Gas-Cooled Reactor (HTGR) Safety and Research Issues Workshop that was held at NRC on October 10-12, 2001. In your letter of November 12, 2001, you raised concerns regarding the migration of fuel pebbles into the non-fuel inner zone of the pebble-bed modular reactor (PBMR) and the potential for sudden increases in reactivity caused by pebble-bed compaction.

Unfortunately, recent events and their impact on our mail system significantly delayed our receipt of your letter and, therefore, this response. As you may know, Tom King retired from the NRC at the end of December, and I have taken his place as Director of the Division of Systems Analysis and Regulatory Effectiveness. In response to your concerns, we recognize that fuel-pebble migration and pebble-bed compaction are issues that need to be considered and are including the specific issues you raise as topics for investigation in our preapplication activities and forthcoming NRC Advanced Reactors Research Plan.

Our PBMR research efforts to date have included preliminary in-house scoping calculations to evaluate the reactivity insertions caused by postulated compactions of the pebble bed core. Donald Carlson, of my staff, performed these calculations immediately after the October workshop in response to your questions. His initial results are consistent with the published compaction analysis results for similar pebble-bed designs.

In following up on the compaction issue, we intend to (1) identify credible scenarios that could lead to global or localized compaction of the pebble bed core (e.g., seismic events, local pebble bridging), (2) use available test data and modeling results to help bound the maximum rates and extent of compaction to be considered, and (3) employ coupled reactor kinetics and thermal feedback models in evaluating the resulting reactivity and power excursions under various initial and boundary conditions (e.g., initial core at zero power, equilibrium core at full power, scram failure, and rod withdrawal).

Credible power transients resulting from pebble-bed compaction and other HTGR reactivity insertion events will be considered in determining the accident testing requirements for HTGR fuels.

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In closing, I would like to thank you again for your insightful comments. Please feel free to contact me (fxe@nrc.gov, 301-415-7499) or Dr. Carlson (dec1@nrc.gov, 301-415-0109) if you would like to further pursue any comments or questions in this area.

Sincerely,

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

cc:
W. Travers, EDO
S. Collins, NRR
A. Thadani/R. Zimmerman, RES
J. Larkins, ACRS

To: Thadani, RES

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THOMAS E. MURLEY

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November 12, 2001

Mr. Thomas King
Director, DSARE
Office of Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. King:

This letter is to report my comments on the HTGCR Safety and Research Issues Workshop held by NRC on October 10-12.

There are several inherent positive safety characteristics of HTGCRs that are well known and have been demonstrated in prototype reactors. These include a low core power density, high heat capacity of core and structures, relatively low stored energy in the coolant, large margins to fuel failure and low worker doses during normal operation. Still, there are a significant number of safety research needs documented by Mr. Boyak and Mr. Meyer during the workshop, and I subscribe to those research needs.

There is a design feature of the Pebble Bed Modular Reactor that raises significant safety questions which appear not to have been thoroughly studied. The reactor core is nominally a right circular cylinder and consists of two zones. The inner zone contains approximately 110,000 inert graphite spheres, and the annular outer zone contains approximately 330,000 fuel spheres. The two zones are not separated by a physical barrier and the inert spheres and fuel spheres can intermix. Thus, the internal geometry of the PBMR core cannot be known precisely during operation.

It is possible that fuel spheres may migrate well into the inner core zone where the neutron density is highest. This would result in a higher power density and higher fuel temperatures for those fuel spheres. The assessment of peak fuel temperatures thus becomes a complicated statistical calculation.

We were told that the nominal packing fraction of the spheres during operation is 0.61 and that the theoretical maximum packing fraction is 0.74. Further, we were told that there was the possibility of "bridging" of the spheres, thereby producing regions of lower packing fraction in the core. It is possible to contemplate, therefore, that a shaking of the reactor vessel and core (from seismic motion, for example) could lead to a sudden increase in core density of 10-20%.

It was noted in the workshop that pebble bed compaction (increase in core density) would increase the core reactivity through reduced neutron leakage. But there is another phenomenon that might be more important than reduced neutron leakage. In an undermoderated core such as PBMR an increase in core density of 10-20% would lead to a softer neutron energy spectrum and a consequent increase in fission rate relative to neutron capture rate. One would have to do careful neutron physics calculations to assess the magnitude of the positive reactivity effects of a core compaction event, but my judgment is that it would be well over a dollar of reactivity. If that proves to be the case, and if as it appears the only significant prompt negative reactivity feedback effect is the Doppler effect from U-238 heatup, the PBMR core and fuel spheres could be subjected to a severe power excursion in a core compaction event.

There are several obvious questions for research that arise from a postulated core compaction event (which does not seem to me to be a highly unlikely event.)

- What is the magnitude of positive reactivity increase due to a 10-20% increase in core density?
- What is the magnitude of the Doppler feedback coefficient?
- Are there other prompt negative feedback effects?
- What is the resultant power excursion from a core compaction event?
- What is the response of individual fuel spheres to the power excursions?
- What is the response of the pebble bed core to the power excursions?

I believe the latter two questions have to be addressed through experiments in a test reactor.

A related issue that would have to be addressed in the safety review of PBMR is that a seismic event could cause simultaneous power excursions in all the reactors of a multiple module facility. This raises obvious questions of control room staffing as well as consequence calculations.

If you have any questions concerning these comments, please call me at (301)469-7573.

Best regards,

Thomas E. Murley

Cc: Mr. William Travers, EDO
Mr. Samuel Collins, NRR
Mr. Ashok Thadani, RES
Mr. John Larkins, ACRS