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# REPORT OF S. BANERJEE, ACRS CONSULTANT

## ACRS Thermal-Hydraulic Phenomena Subcommittee Meeting, June 26, 2002

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1. Introduction

This report contains comments related to the following topics:

- ATLATS phase separation tests
- Entrainment onset model
- Entrainment rate model
- TRAC-M development and documentation
- Rod bundle heat transfer program
- Recriticality control for PWR SBLOCAs.

In overall terms, the June 26th meeting was very useful and the presentation, in particular by Dr. D. Diamond of BNL, was exceptionally illuminating. My specific comments on each topic covered follow.

2. Specific Comments

2.1 ATLATS phase separation tests

The air-water test facility (ATLATS) at Oregon State University is being used to study entrainment rates into ADS4 lines from hot legs with geometries that are of interest to AP600 and AP1000. This involves studies of entrainment rate into a vertical uptake at the top of a hot leg with an upward oriented line connected to a steam generator plenum.

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The upward oriented line apparently leads to oscillating slugs that periodically pass the offtake, causing considerable liquid to be entrained when this happens. Such phenomena were also observed in the ROSA tests for AP600.

The experiments were performed by fixing the input air and water flow rates and measuring the various parameters until their mean values reached steady state. The outflow through the ADS4 offtake then equaled the inflow. The void fractions (liquid levels) were measured on each side of the ADS4 offtake and there averages were used subsequently for correlating the entrainment rate.

My comments are:

a) No attempt was made to measure the instantaneous outflow of air and water through the ADS4 offtake. Thus, the periodic slugging in the ADS4 line observed in ROSA was not measured. Similarly, the time-varying void fraction in the ADS4 offtake was not measured, again eliminating a possibility for observation of the effect of slugging. Clearly, much of the liquid entrainment occurs when the liquid slug passes the offtake.

b) The slugging characteristics may be expected to be a function of system parameters, e.g. compliance of the vessel head and SG volumes, compliance of the ADS4 line, etc. Thus, it is necessary to vary the compliance of some of these components and observe their effect on slugging.

c) A plot was presented of the standard deviation of the fluctuating hot leg "levels" vs. the hot leg level itself and showed considerable scatter. It was not clear whether this scatter actually came about due to differences between the experimental conditions, or because the averaging time was too short. In any case, this point needs further clarification.

d) The range of thermophysical properties that would characterize the steam-water system under conditions when ADS4 operates should be made available and compared with

ATLATS conditions. In particular, the range of surface tension, viscosities, vapor and liquid densities calculated for the full-scale nuclear plants and the ATLATS facility require comparison. Whether the correct scaling laws are being used should be tested by varying the important scales, i.e., those that appear to affect entrainment onset and rates.

Overall, I had the sense that the experiments were addressing too narrow a parameter range, both in thermophysical properties and in geometry.

## 2.2 Entrainment Onset Model

The model appears to be a variant of one proposed by Bharathan et al. for entrainment from a stagnant pool. The variation from the original model relates to the length of the waves initiated on the pool surface due to suction through the offtake. If the offtake is large and close to the pool surface, then wavelength is taken to be the offtake diameter, whereas, for a small offtake far from the surface, the flow is treated as a point sink. All this has been phased into a potential flow model for the velocity field and a modified of Bharathan's model derived. Arguments are "hand wavy" and should be checked with a straightforward CFD calculation, particularly to see whether viscous effects play a role.

The correlation itself performs reasonably well with ATLATS data, but there are some systematic deviations of low $h_p/D$ compared to KfK data. (This is masked to some extent by the "scrunched up" plot at low values). Also, the CEA data are not shown—perhaps because they were difficult to unravel. Every attempt should be made, however, to obtain the CEA data and compare it with the proposed correlation. Furthermore, the ATLATS data already taken with a different hot leg geometry should also be compared to the correlation. The slug frequencies may be expected to be different in this case, and they could be a good test for the correlation.

2.3 Entrainment Rate Model

The basis for development of this model is not clear. The argument appears to be that the energy in the inflowing gas stream is used to move liquid through the offtake and to raising the liquid level in the hot leg through a gravitational term. The kinetic energy in the gas flow in the offtake appears to be neglected. The arguments leading to the correlation are difficult to defend and appear to ignore an important mechanism for entrainment, i.e. periodic passage of a plug past the offtake when liquid gets sucked upwards. Perhaps the model works, in some average sense, as a correlation, though even here there are systematic deviations at low h/D ratios where slugging occurs. The whole thing needs to be put on a firmer footing, with ATLATS data from other tests and CEA data being incorporated.

2.4 TRAC-M Development and Documentation

The presentation reported on progress in development and validation of TRAC-M. Nothing substantive in the way of detail was presented, so it is hard to comment. The development and consolidation process has taken considerable time and still requires improved interfacial transport and reflood models. It was mentioned that the Peach Bottom turbine trip had been successfully simulated, but only after an interfacial transport model from a BWR version had been incorporated. While this is reassuring, it would be more so if such modifications were not necessary—almost every time some new test is tackled. Furthermore, it was stated that the documentation is in "TRACese" and therefore difficult to review for the uninitiated. Peer review is essential for the theory and models.

2.5 Rod Bundle Heat Transfer

Some results of instrumentation performance in the Penn State facility were presented. In particular, the steam temperature probes, and droplet size measurements are an advance over what was available for previous work of this type. However, their performance at higher reflood rates will need to be verified. In the mean time, I will wait to make detailed comments until I visit Penn State, where the experiments are being conducted.

### 2.6 Recriticality Control for PWR SBLOCAs

This issue arises for a particular range of break sizes for postulated SBLOCAs, where the coolant inventory has been depleted at relatively high pressures. Heat is then removed, to a significant extent, by steam generator condensation of steam boiled off in the core. Deborated water (condensate) then accumulates in the steam generators and eventually gets into the cold legs and up to the pumps. Eventually, the system refills and can start to naturally circulate. This could cause the slug of deborated water resident in the steam generators and cold leg piping to pass through the core, causing a rapid reactivity increase and recriticality—particularly at the beginning-of-life for a fuel charge. If the primary coolant pumps are turned on, the deborated slug passes through the core even more rapidly, and the reacitivity incident could be more severe.

The problem is of greatest significance for B&W once-through steam generator systems. The B&W Owners Group therefore addressed this issue by calculating the reactivity incident that would occur when a slug of deborated water passed through the core. They used a point kinetics reactor model, postulated an initial concentration profile for the deborated water and calculated a concentration profile for the deborated water passing through the core once natural circulation was re-established. The energy deposition in the fuel in these calculations was ~90 cal/g which was significant enough to require further study—especially in view of some of the approximations made in the estimates of boron concentration profiles.

The reactor physics calculations were repeated by BNL using a spatial reactor model (nodal) that accounted for individual fuel assemblies, and subdivided these axially. Without going into details, the work appeared to be carefully done, and the results were convincing. The BNL studies indicated a substantial lowering of the energy deposition in the fuel compared to that of the BWOG calculations. The energy deposition of significance did not occur in the primary power pulse that was very short due to the Doppler and temperature coefficients. However, much of it came from a second power pulse, and the combined spatial neutronics (PARCS)/RELAP model was effective in taking voiding and local heat transfer into account.

A little work remains to be done to put this issue to bed – as a non-issue.

a) The initial boron concentration profile used by the BWOG should be made more easily defendable or explained more clearly. This profile was used to generate the so-called "Di Marzo" profile.

b) The mixing and smearing of the profile should be done as conservatively as possible on restart of natural circulation. The "Di Marzo" version may not be bounding.

c) Further runs should be done with the more realistic smeared profile as input for the PARCS/RELAP runs.

Maldistribution of deborated water at the reactor inlet is the only other issue that may need to be addressed, but it is difficult to see how to do this except in some "bounding" sense. If this can be done without major problems in setting up the PARCS/RELAP once again, then it should also be done.

## 3. Recommendations

1. The ATLATS entrainment experiments should explore a wider range of conditions, particularly to clarify the importance of slugging—which can be expected to depend on system compliance.

2. Some CFD calculations should be done to supplement the experiments on the onset of entrainment. In particular, the behavior of the stratified liquid surface is of interest. Standard codes like FLUENT or CFX can perform such calculations easily.

3. The entrainment rate correlation should be compared to a wider set of data, both ATLATS and CEA, and the region where slugging occurs should be more carefully examined. Also, the approach needs to be put on a firmer footing.

4. Instrumentation results from the Penn State facility at higher reflood rates should be presented.

5. For TRAC-M, peer review of models and theory are essential. The rationale for use of various closure models should be carefully documented.

6. The recriticality issue should be closed as soon as possible by considering a few more PARCS/RELAP calculations with more conservative boron concentration profiles passing through the core on restart of circulation. Also, the initial profile used (before restart of circulation) for the boron concentration should be carefully justified.