REPORT

ACRS Thermalhydraulic Phenomena Subcommittee Meeting
November 12-14 NRC, Washington, DC

S. Banerjee

1. Introduction

The ACRS Thermalhydraulic Phenomena Subcommittee met on Nov. 12 to discuss the NRC-RES Rod bundle Heat Transfer (RBHT) Program, and on Nov. 13 and 14 to review the Framatome-ANP SRELAP5 LBLOCA Code. The presentations made on each subject were informative, and they will now be discussed in turn.

2. RBHT Program

The aim of this program is to provide data on reflood and rewet of heater rod bundles at typical pressures and reflood rates for LBLOCA. This program is underway at Penn State University, and it has taken about 5 years since project inception to construct the facility, commission it, and take preliminary data. The relatively novel aspects compared to previous rod bundle experiments are measurements of steam temperature with a traversing probe, better droplet size distribution measurements, droplet velocities (in principle, since the measurement system still does not work), and various other quantities such as inside temperatures of the heater cladding at numerous axial and radial positions, and carryover of liquid. Attempts will also be made to measure void distribution in the neighborhood of the quench front using ΔP measurements, with a closely spaced array of differential pressure transducers. The heater rod bundle contains typical spacers and viewing windows around spacer locations so

flow regimes can be visualized. In addition, facilities were incorporated to inject droplets into a single-phase superheated steam flow (without reflood) to measure the effect of droplets in dispersed-flow heat transfer. Steam cooling experiments (without droplet injection) can also be done and would serve to check heat transfer correlations for rod bundles, with spacers, at low pressures and relatively low flow rates.

The ultimate aim of the experiments is to develop a better understanding and parameterization of heat transfer in typical (PWR) rod bundles under LBLOCA reflood conditions, including the effect of spacers.

2.1 RBHT Program—Comments

1. The facility is better instrumented than other rod bundle reflood experiments and eliminates some of the shortcomings of the FLECHT/FLECHT-SEASET experiments. They also appear to be better instrumented, at least with regard to visualization and measurement of the droplet field, than theWinfreth ACHILLES experiments. In particular, the droplet size distribution far from the quench point appears to be measured quite well. However, there are several points that need further consideration and are discussed below.

2. The droplet velocity measurement system must be made operational, as simultaneous measurements of droplet velocity and size are necessary to estimate interfacial drag in the dispersed flow regime. The estimates of PCT and other important variables may be more sensitive to interfacial drag correlations than to the heat transfer correlations. Therefore, measurement of interfacial drag (and wall drag), to the extent possible, should be an important objective of the experiment—as important as the heat transfer measurement objective.

3. The void measurement technique needs assessment. It may work at the lowest reflood rates, but the frictional and accelerational pressure drops need to be carefully estimated. An independent separate-effects assessment against gamma densitometer void measurements would be valuable. Gamma densitometry in rod bundles is carried out at the Framatome Karlstein facility, so the possibility of using some of their data for such an assessment should be explored. Alternatively, a calibration of the technique in a simple geometry against a gamma densitometer, under representative conditions, would be satisfactory. (As an aside, if all existing simple, separate-effects reflood facilities have been dismantled, it is still straightforward to build a gamma densitometer (see [1]) and to apply it to a reflood experiment (see [2])).

4. The steam temperature probes also need further assessment. Though the probe outputs oscillate in temperature, and the upper bound is considered by the PI to be the steam temperature, nonetheless, there is need for further justification. One way to do this would be to incorporate some even smaller thermocouples as part of a rake and compare their performance to the thermocouples currently being used in a separate-effects experiment under similar conditions. If the steam temperatures from the two different sizes are the same, then one would have more confidence in the measurements being made. The steam temperatures are rather crucial if a mechanistic dispersed flow heat transfer model is to be developed.

5. The effect of the heater cladding material needs assessment. Roughness and the thermal conductivity of the surface layer, e.g. of the cladding (in the actual case Zircalloy and zirc-oxide) may be significant. If so, the relationship between the current Inconel heaters and typical fuel cladding with regard to rewet needs assessment.

6. While the planned experiments with a uniform reflood rate (and a uniform heating rate) can serve as a reference case, nonetheless the reflood rate is not steady in reality. It is known that with oscillatory reflood rates, the entrainment changes significantly (see [3]). Furthermore, oscillatory reflood rates have been seen in large-scale experiments (CCTF). Therefore, it is important that the methodology for taking such effects into account with regard to entrainment rate and heat transfer estimation be clarified.

7. Finally, the experiments appear to be proceeding in something of a vacuum. The experimentalists are using a version of COBRA/TRAC to interpret their results, but the interaction with TRAC M development is not clear. An example of how the data may be systematically analyzed in the context of multifield models is contained in [4] and [5]. This was also the case with the subcooled boiling experiments at UCLA—a situation that NRC-RES seems now to be tackling after interaction with the ACRS Thermalhydraulic Phenomena Subcommittee. A similar response in this case would be desirable.

2.2 RBHT Program—Recommendations

1. Construct a simple geometry, separate-effects facility to assess instrumentation, e.g. the void fraction and steam temperature measurements techniques. The facility could also be used to calibrate and assess other instrumentation as the program proceeds, e.g. the droplet size, distribution and velocity measurement technique.

   Ideally, the facility would be located in a separate organization to eliminate conflicts of interest in terms of such assessments.

2. Clarify the objectives and the safety impact of achieving the objectives, which are somewhat unclear in any case. For example, the SRELAP5 presentations appear to indicate a relatively small effect of the details of the dispersed-flow heat transfer correlation on PCT. If this is true, then much of the droplet size and velocity measurement experiments would have a relatively small impact—though the entrainment and carryover is clearly of first-order importance. Whatever the situation, NRC-RES should prioritize the importance of the various experiments with regard to regulatory significance, and also indicate the expectations with regard to reflood rate oscillations (e.g. from CCTF).

3. SRELAP5

Framatome-ANP has adapted a version of RELAP5 (of which there are many) to their purposes and presented some aspects on Nov. 13 and 14, viz.

- momentum formulations in the code
- a methodology for applying it to LBLOCA based on the CSAU framework.

(Ostensibly, the discussion centered on applicability to LBLOCA, but in many parts of the presentation, allusions were made to SBLOCA and to BWRs, which suggests that Framatome may return, for approval, with variants based on the same structure.)

More specifically, the purpose of the submission was to request approval for the use of SRELAP5 in assessing the safety-related behavior of Framatome fuel reloads in various Westinghouse and CE PWRs.

The overall thrust of the presentations appeared to propose that Framatome was building on an already approved basis (in fact one of the NRC's

own codes), and only the modifications made and the method of application was up for examination.

3.1 SRELAP5—Comments

1. In the several decades since RELAP5 and its various versions were developed, there have been many developments in our understanding of the thermalhydraulic phenomena involved in LBLOCA. However, few of these developments seem to have found their way into SRELAP5. As an example, consider the heat transfer correlation used for condensation that is compared with data in Figure 1, taken from a presentation made by J. Kelly [6] several years ago. It is clear that the heat transfer coefficient is wrong by several orders of magnitude (the interfacial area was measured in these experiments) and yet continues to be used. The justification appears to be that PCT is sufficiently well predicted in comparison to the various available experiments, and therefore there is no need for much change.

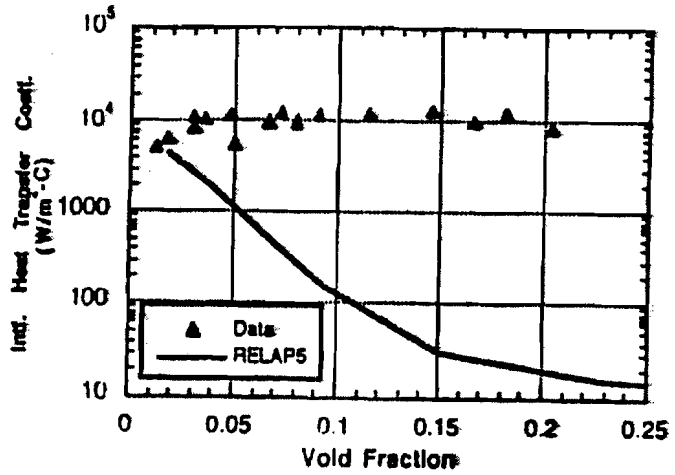

FIGURE 1: Comparison of RELAP5 predicted values for interfacial Heat transfercoefficient in subcolled boiling vs. the McMasters University data (from Kelly, 1997).

This argument would be more convincing if there were truly representative integral experiments at various scales. Unfortunately, the only large-scale integral experiments were those in LOFT, which had many significant scaling problems, such as with regard to core height and steam generator configuration. In view of this, a code should capture not only the PCT in LOFT and the smaller-scale experiments (such as Semiscale), but also the behavior of some of the other variables. For example, it would be desirable to predict the time

at which PCT occurred (as well as the value of the PCT)—amongst other variables. This would enhance confidence in the capabilities of a code and suggest that it had predictive capability, rather than the current situation where one suspects many skeletons are buried in the closets of "nodalization", "correlations", and "hidden internal switches".

To reiterate, the issue is whether codes should predict several important variables in experiments of various scales to be considered validated, or is PCT enough. In view of the very few experiments at markedly different scales, the substantial distortions in scaling between these experiments, and the enormous scale-up needed to get to operating PWRs, good prediction of several important variables seems a more technologically and publicly defensible position.

2. SRELAP5 appears to use a momentum equation, which in some situations appears to be an underived, and unsupported, form of the mechanical energy equation and, in some situations, is the momentum equation. As forces on structures are not required, a form of the mechanical energy equation could be used everywhere and should be derived (and used consistently). If no one else does, I will derive such an equation and send it on in a separate note.

3. The sensitivity of the results to nodalization remains an issue. For example, the results change dramatically if the nodalization of the lower plenum is changed. Ideally, nodalization should be such that the results with regard to several important variables are insensitive to changes over a reasonable range. This problem needs further study by the NRC.

4. Part of the problem with regard to more extensive sensitivity testing of correlations and nodalization lies in Appendix B, which apparently

serves as an impediment to running SRELAP5 on modern computers. The code cannot be run, at present, on LINUX boxes or clusters, and has to run, in some cases, in VAXs! This is an instance where some change is needed to ensure that the lack of sensitivity studies, and demonstration of convergence, is not attributed to antediluvian regulations regarding computational platforms.

5. There were many other issues that need to be addressed, e.g., the critical flow model, the heat transfer package—particularly for subcooled boiling and dispersed-flow boiling—and various others like the inclusion of break size in the statistical methodology for uncertainty assessment. As others will address these, I will not.

3.2 SRELAP5—Recommendations

1. A systematic and comprehensive nodalization study should be performed under the NRC supervision to clarify nodalization impact on several important variables—not just PCT. Perhaps time at which PCT occurred, reflood rate and break flow should also be checked (see also Point 2 below).

2. PCT is not the only significant variable for assessment of code capabilities. It would be worth compiling a list of the other important variables that a code should predict. This should be done by the NRC before the nodalization study in 1 (above) is carried out.

3. The current qualification process for codes to operate on various platforms has to be modernized. The price of distributed memory clusters is decreasing rapidly and CFD codes routinely run calculations with 10^6 nodes, whereas SRELAP5 uses a few hundred nodes. The excuse that computational resources do not permit more extensive studies of convergence, the effect of nodalization, and incorporation of multidimensional components, is very weak.

Its only support appears to be that the codes are restricted to use ancient and inefficient computational platforms for which they have been "qualified", and that re-qualification for more efficient platforms is (apparently) expensive. This excuse should be eliminated. NRC should require that codes be maintained in a qualified state for at least one contemporary computational system and compiler.

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