Sensitivity of SBLOCA Analysis to Model Nodalization

by

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Abstract

The recent Semiscale test S-UT-8 indicates the possibility for primary liquid to hang up in the steam generators during a SBLOCA, permitting core uncovery prior to loop-seal clearance. In analysis of Small Break Loss of Coolant Accidents with RELAP5, we have found that resultant transient behavior is quite sensitive to the selection of nodalization for the steam generators. Although global parameters such as integrated mass loss, primary inventory and primary pressure are relatively insensitive to the nodalization, we find that the predicted distribution of inventory around the primary is signficantly affected by nodalization. More detailed nodalization predicts that more of the inventory tends to remain in the steam generators, resulting in less inventory in the reactor vessel and therefore causing earlier and more severe core uncovery.

Recent attention was focused (by Semiscale test S-UT-8) upon the possibility for primary liquid to hang up in the steam generators during a SBLOCA, permitting core uncovery prior to loop seal clearance. If the steam generator analytical behavior is sensitive to the choice of nodalization in the steam generator, SBLOCA analytical results will be similarly sensitive. The NRC's Division of Systems Integration has suggested[1] that vendor codes be reviewed to see if they adequately model liquid storage in the U-tubes, since computed consequences of SBLOCA might be more severe if codes do not adequately model this phenomenon.

In analysis of Small Break Loss of Coolant Accidents with RELAP5, we have found that resultant transient behavior is quite sensitive to the selection of nodalization for the steam generators. Although global parameters such as integrated mass loss, primary inventory and primary pressure are relatively insensitive to the nodalization, we find that the predicted distribution of inventory around the primary is significantly affected by nodalization. More detailed nodalization predicts that more of the inventory tends to remain in the steam generators, resulting in less inventory in the reactor vessel and therefore causing earlier and more severe core uncovery. In addition, nodalization impacts the code's prediction of which loop seal (intact or broken side) clears first -- and therefore impacts the amount and timing of recovery of the core. These results, which are strongly driven by the RELAP5 flow and heat transfer regime maps, indicate that the suggested standardized RELAP5 nodalization[2] does not yield a converged solution and in this case was also not the most conservative SBLOCA analysis. Furthermore, it is not obvious without further study that our fine noding is "converged" in the sense that putting in more nodes might show further differences. However, we believe the uncertainties in the RELAP5 flow region maps outweigh the differences which would appear in further refinement of nodalization.

The computations presented are similar to the FSAR computations of a 4-inch cold leg break in a Westinghouse four loop plant, and were performed with RELAP5/MOD1.5/Cycle 26. The code was slightly modified to employ a version of the Moody critical flow model for the break flow -- since FSAR computations use that model.

For a particular breaksize, the SBLOCA transient is most strongly influenced by the retention of water (loop seals) in the cold legs at the pump inlets. This loop seal formation tends to insulate the steam generator from the core, and therefore its formation is a dominant factor in early core uncovery and its destruction terminates that early uncovery. The rate and degree of pre-loop-seal-clearance core uncovery is controlled by how much primary inventory gets into the core region, which is in turn controlled by how much primary fluid condensation takes place in the steam generators and whether that condensed fluid gets back to the core to provide coolant. These latter two phenomena are, expectably, dominated by the computer code's models for heat transfer and flow regimes respectively. If, for example, horizontal stratified countercurrent flow is predicted to occur easily in the hot legs, then steam generated in the core can slip by the liquid, be condensed in the steam generator tubes, and run back down the hot legs toward the core. Conversely, if the flow regime maps of the code tend to prohibit countercurrent horizontal stratified flow then primary inventory tends to hang up in the steam generators aggravating core uncovery. These are expected results of the code developers' methods of implementing flow regime maps. The surprising result in our analysis was the strength of the interaction between the flow regime maps and the nodalization and its important impact upon the predicted severity of core uncovery.

We selected, as our base case, the standardized nodalization suggested by EG&G , which has four vertically stacked secondary side boiling regions in the U-tube region and the corresponding 8 nodes in the U-tubes (4 uphill and 4 downhill) (Fig. 1). For comparison we doubled the number of nodes in the steam generators, keeping the rest of the plant model identical. As mentioned earlier, the transient behaviors of the global parameters such as primary pressure and net inventory were nearly identical between the two nodalizations. Similarly, we found the secondary side behaviors to be nominally identical, i.e., similar void distributions vs time, similar pressure and temperature history. However, the similarities ended there.

Once the primary loop flows slowed to the natural circulation flowrates (by ~300 seconds), substantial differences began to appear in the predicted hot leg flowrates between the two nodalizations. In the coarse (standardized) noding a substantial flowrate of condensed liquid back toward the core was predicted to occur for a period of more than 200 seconds, while this phenomena was only predicted to occur for roughly 40 seconds in the fine noding. This difference was eventually traced to the computed behavior of the flow in the uphill legs of the U-tubes. The fine noding predicted more resistance to countercurrent flow and therefore greater retention of liquid, resulting in less condensed fluid returning to the core. This resulted in earlier and more extensive pre-loop-seal-clearance core uncovery. These results are shown in Figure 2 which compares the fuel cladding temperatures at various core elevations for the two nodalization. We note the striking difference between the results of the two computations which differed only in selection of steam generator nodalization.

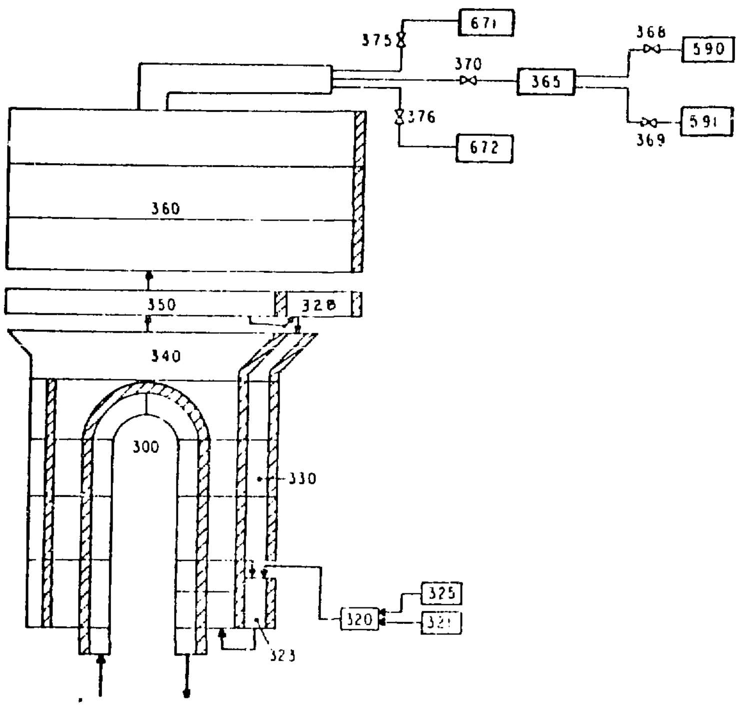
In conclusion we observe that SBLOCA analyses is very sensitive to steam generator nodalization, and that the standardized analysis nodalization recommended by EG&G does not provide a converged solution (from a nodalization perspective). Although these results are obviously driven by the RELAP5 flow regime maps, they probably represent a generic effect which can only be avoided by very careful implementation by the code developers. Finally, we recommend that analysts perform careful and complete parametric studies with their computer code, since they may otherwise be subject to criticism for not identifying the most severe accident conditions.

References

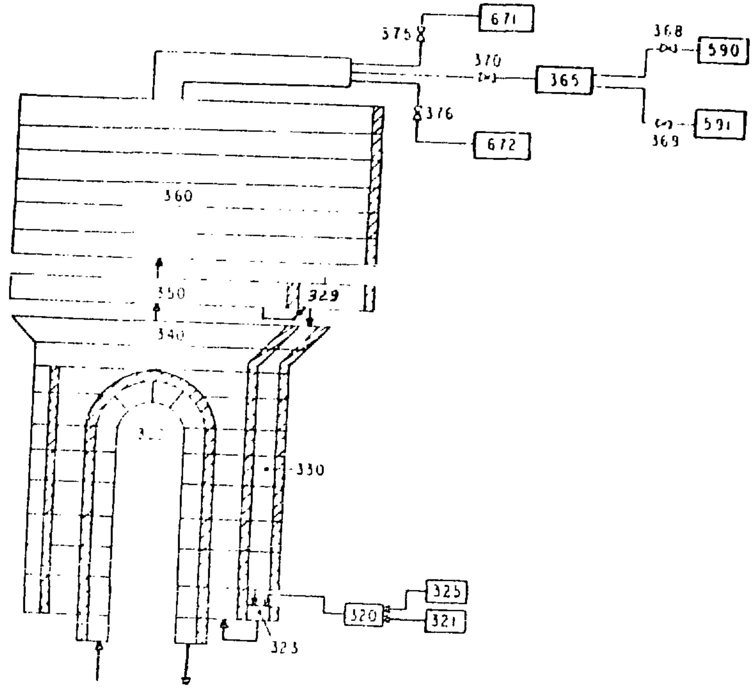
1. NRC Letter, Mattson to Eisenhut, "Board Notification Regarding Semiscale S-UT-8 Test Results," November 28, 1982.

2. Private communication, C. B. Davis and T. R. Charlton, EG&G, December 16, 1980.

Fig. 1. Steam Generator Nodalizations

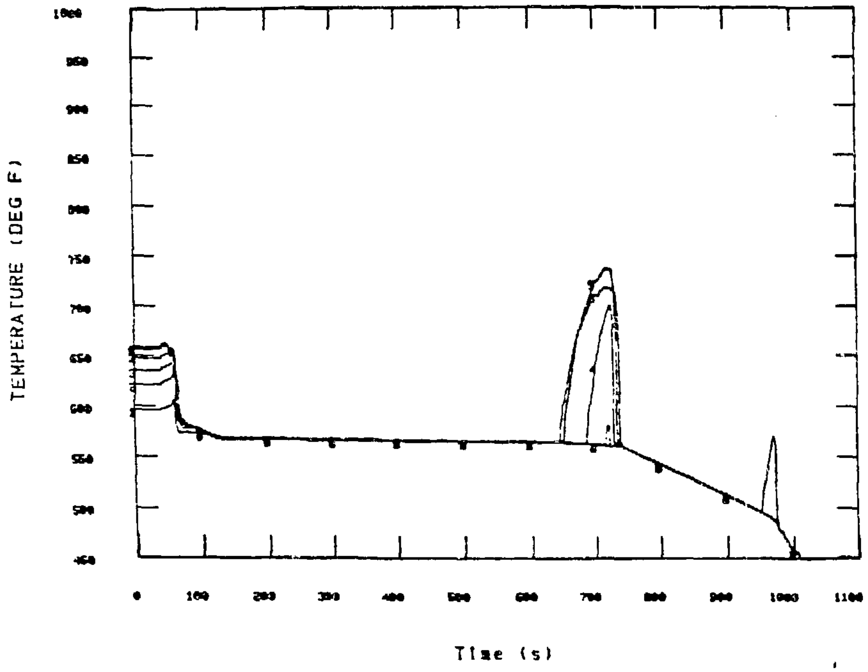


COARSE (STANDARDIZED) NODING



FINE NODING

Fig. 2. Clad Temperatures at Various Axial Locations.



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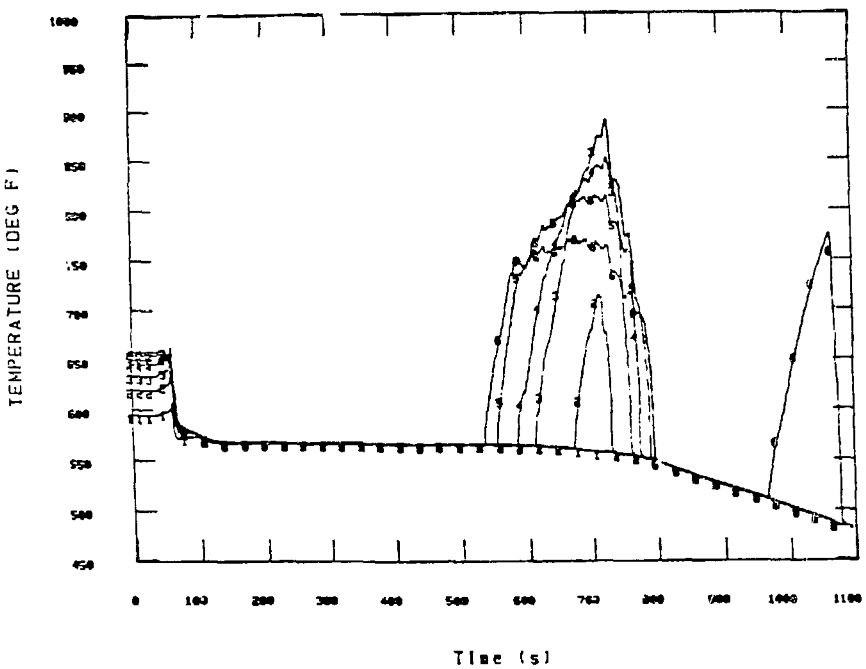

FINE NODING

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