ATTACHMENT 2

AECM-82/574

Flow Science, Inc.'s Evaluation
Report on Modified SOLA-VOF CODE

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EVALUATION REPORT
on
MODIFIED SOLA-VOF CODE
October 18, 1982

For: Grand Gulf Nuclear Station Humphrey Containment Concerns

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Evaluation Report
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Flow Science, Inc. has reviewed the findings presented in the G.E. Design Review Report: Effects of Local Encroachment on Pool Swell, dated 9/24/82. At the request of Mississippi Power & Light Company, we have prepared the following additional comments concerning our evaluation of the Design Review Report and of the applicability of SOLA-VOF to pool swell phenomena.

1. Basic Capability of SOLA-VOF

The SOLA-VOF code has been used for a wide variety of fluid dynamic applications. Its capability for solving incompressible flow problems with free surfaces has been demonstrated through numerous comparisons with analytic and experimental data. Documentation of these comparisons is given in the following references:

a. B.D. Nichols, C.W. Hirt, and R.S. Hotchkiss, "SOLA-VOF: A Solution Algorithm for Transient Fluid Flow with Multiple Free Boundaries," Los Alamos Scientific Laboratory report LA-8355 (1980) [see pp. 44-58 and pp. 108-117].

b. C.W. Hirt and B.D. Nichols, "A Computational Method for Free Surface Hydrodynamics," ASME Jour. Pressure Vessel Technology, 103, 136 (1981).

c. B.D. Nichols and C.W. Hirt, "Hydroelastic Phenomena in Boiling Water Reactor Suppression Pools," Proc. 5th International Conf. on Structural Mech. in Reactor Tech., Berlin, W. Germany (1980).

d. B.D. Nichols and C.W. Hirt, "Numerical Simulation of BWR Vent Clearing Hydrodynamics," Nuc. Sci. Eng., <u>73</u>, 196 (1980).

e. C.W. Hirt, B.D. Nichols, and L.R. Stein, Electric Power Research Institute report NP-1856 (1981)
Vol. 1: "Numerical Simulation of BWR Suppression Pool Dynamics,"
Vol. 2: "Multidimensional Analysis for Pressure Suppression Systems,"
Vol. 3: Studies of Bracing Influence on BWR Pool Swell Dynamics."

References c - e contain the most relevant data comparisons for pool swell phenomena.

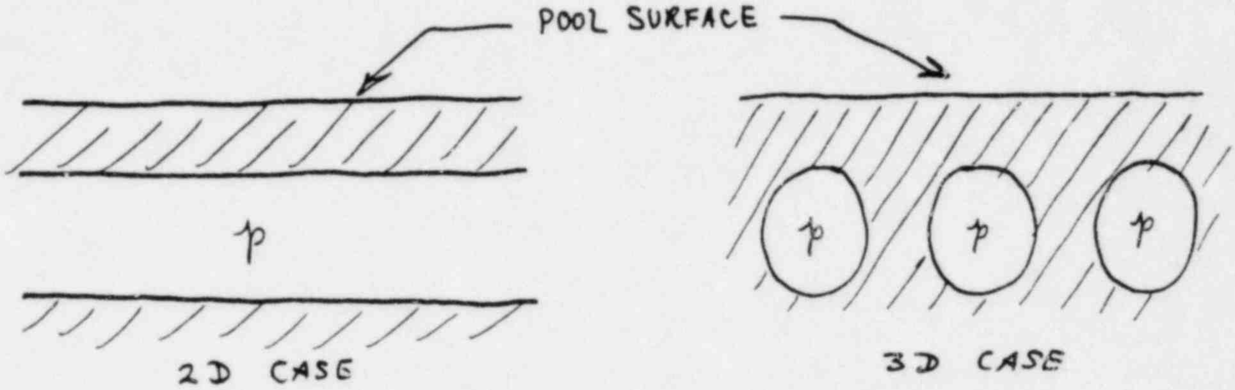
2. Assumptions in SOLA-VOF

SOLA-VOF provides a numerical solution algorithm to the Navier-Stokes equations (mass and momentum conservation equations). These equations assume incompressible water and only consider viscous stresses associated with a constant coefficient of viscosity (i.e., no turbulence is included). There should be no question of the suitability of the differential equations. The Numerical Solution algorithm is based on a well established finite-difference method that has been used and refined over a period of 17 years (J.E. Welch, F.H. Harlow, J.P. Shannon, and B.J. Daly, "The MAC Method," Los Alamos Scientific Laboratory report LA-3425, 1965).

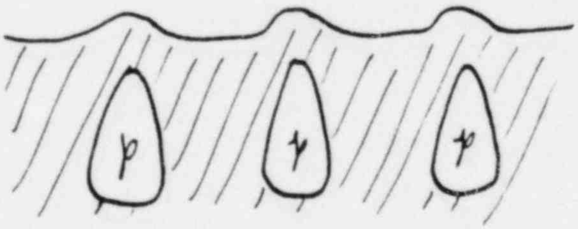
The principal limitation in SOLA-VOF solutions is that they cannot describe phenomena whose scales are less than the size of the underlying finite-difference grid. This, of course, is the basic limitation of any numerical solution method. For pool swell phenomena this limitation has an important consequence related to bubble breakthrough times. Breakthrough is known to be enhanced by small scale Taylor instabilities. For water, the dominant unstable wavelength is on the order of a centimeter, which is far smaller than the smallest mesh cell used to model the pool region. By not allowing this small scale penetration to occur, the SOLA-VOF calculations will have delayed bubble breakthrough times. Consequently, bubble pressures, which remain above the wet well pressure until breakthrough, will accelerate the pool surface to a higher velocity in the calculations than in a real case. This, therefore, is a conservatism. Some of this conservatism has been reduced in the G.E. calculations because they include a model for breakthrough which ramps the bubble pressures to the wet well pressure at a time determined from test data. It should also be noted that three-dimensional bubbles will break through sooner than two-dimensional bubbles (see below) so this too is a conservatism in the SOLA-VOF calculations.

3. Effect of 2D versus 3D Bubbles on Pool Swell

The two-dimensional, axisymmetric bubbles modeled in SOLA-VOF are slower to break through pool surfaces than spherical bubbles with the same pressure history. The reason for this is evident from a simple 2D, cross-sectional picture of the two cases:



In the 2D Case the top water layer will accelerate upward uniformly (assuming no variations normal to the page) and no breakthrough will occur! In the 3D Case fluid will be accelerated most above the top of each bubble (where the fluid layer is thinest). Fluid will also be pushed left and right above each bubble center, allowing the bubbles to deform and push through the surface as shown schematically here:



Bubble penetration accelerates in time because the amount of water to be accelerated above the bubble is continually reduced.

The net upward fluid momentum will also be less in the 3D

Case than the 2D Case because the horizontal area on which the bubble pressure acts is less in the 3D Case.

From these examples it is clear that increasing the surface curvatures of bubbles will increase their ability to penetrate the pool surface. Therefore, we see that bubbles generated in Mark III suppression pools by multiple inlet vents will more readily penetrate the pool surface than an axisymmetric bubble at the same pressure and located the same distance below the surface.

By the same argument, the distortion of an axisymmetric bubble by a limited encroachment will induce local curvatures that can lead to earlier breakthrough.

The influence of bubble pressure on pool surface velocity can also be understood from the above picture. The vertical velocity acceleration above the center of a bubble is primarily the result of the local pressure gradient and gravity accelerations. The average pressure gradient is the difference in bubble pressure and wet well pressure divided by the thickness of the water layer. Thus, higher bubble pressures (or smaller water layers) produce larger pressure gradients, hence, larger upward accelerations.

4. Influence of Steam Condensation

By the last argument, any steam condensation that would reduce bubble pressures would also reduce the upward accelerations, resulting in smaller pool swell velocity. Therefore, assuming equal mass flow rates through the vents, flow with some steam versus a pure air flow will result in lower bubble pressures and lower pool swell velocities.

5. Deflection of Pool Surface by Encroachment

In calculations with a 360° encroachment the pool surface is significantly tilted from the horizontal with its outer edge (i.e., at maximum radius) much higher. This feature is a direct consequence of the deflection of the flow by the bottom of the encroachment. Fluid trapped between the bubble and the encroachment is forced to move radially outward as the bubble grows. This radial momentum persists as the fluid rises and causes the pool surface to tilt as observed.

6. General Electric Modifications to SOLA-VOF

A basic assumption used in G.E.'s modification of SOLA-VOF is that bubble pressures are uniform within the bubble. This assumption is acceptable when the fluid interfaces are moving at speeds which are slow compared to the speed of sound in air. Because water/air interface speeds in these problems are at worst a few tens of feet per second, this condition is satisfied by a fair margin.

Not having to compute gas flows within bubbles is a great simplification, for then it is only necessary to follow the time dependence of global bubble properties such as total gas mass and total volume. G.E.'s implementation of these global properties is based on standard gas dynamic relations connecting different gas states. Their formulation based on pressure drop, stagnation conditions, computed volume changes, and standard ideal gas relations is logically correct. We have not reviewed the actual programming of these relations into the SOLA-VOF code. Also, we have not reviewed the prescribed dry well pressure history nor the flow loss used at the vents.

The G.E. staff has performed extensive comparisons between their modified code, SOLAV01, and test data from 1/9, 1/3, and full-area-scale test facilities. These data comparisons provided an operational procedure for the scaling of code results with data. That is, the code had to be run in rectangular geometry to properly model vent clearing, and bubble volume corrections were based on pool area ratios. There is no way to rigorously justify these procedures, but the data comparisons are quite good and provide confidence in the method for the type of problems considered.

7. Summary

The weakest point in the G.E. study is still the point at which bubbles are assumed to coalesce so that bubble pressures can be ramped from the 360° encroached case to the case with no encroachment. This was the one Open Item reported in the Design Review Report. Bubble growth and coalescence is a strictly three-dimensional phenomena, which cannot be directly modeled with SOLAV01. It is this feature that has required the introduction of volume correction factors and other model approximations. Under the two-dimensional limitations of the SOLA-VOF code, the G.E. analysis has been well done. Extensive data comparisons have been made with tests having no encroachments that provide an operational procedure for how to run and interpret SOLAV01 calculations. By combining the 360° encroached and unencroached cases into a composite model G.E. has constructed an approximation of pool swell behavior under actual plant conditions. Bubble pressures are computed using the 3D corrected bubble volumes (smaller volumes), but these pressures are applied in the 2D bubbles. Both effects should enhance pool swell velocities (i.e., higher bubble pressures and a more coherent water layer over the bubbles). Thus, these model approximations give conservative estimates for pool swell.

It's somewhat harder to judge whether the bubble pressure ramping procedure is conservative or not. Using the 360° encroached case pressure out to t = 1.0s is conservative because a higher pressure generated under a limited encroachment will tend to be relieved through azimuthal expansion. On the other hand, the selection of 1.0s as the time to start ramping down the pressure and the total ramp time of approximately 0.05s is an engineering judgement for these parameters. The assumption is that bubbles generated at different vents will coalesce at 1.0s and thereafter have the same pressure. Near the encroachment, however, higher pressures may slow bubble growth and coalescence. Unfortunately, this flow region is strongly three-dimensional and a priori estimates are difficult to make.

To go beyond the present model would necessitate fully three-dimensional calculations. Such calculations would eliminate the need to introduce 3L bubble volume corrections and the need to select a time for ramping bubble pressures between the full and unencroached cases.