SAN097-1611C
SAND--97-1611C

Development and Assessment of the CONTAIN Hybrid Flow Solver*

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CONF-971125--6

June 20, 1997

1. Introduction

A new gravitational head formulation for the treatment of stratified flows has been developed for CONTAIN, a lumped-parameter code used primarily for the analysis of postulated accidents in nuclear power plants. This new "hybrid" formulation is discussed and compared in this paper with the old, average-density CONTAIN formulation. In addition, these formulations are assessed against experimental data from three large-scale experiments in which stratified conditions were observed. These are the NUPEC M-8-1[1], Surtsey ST-3[2], and the HDR E11.2[3] experiments.

2. Description of Work

The hybrid formulation was developed specifically to address the tendency of lumped-parameter codes to overmix stable stratifications formed by buoyant sources. The old CONTAIN

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*This work was supported by the United States Nuclear Regulatory Commission and was performed at Sandia National Laboratories, which is operated by Lockheed Martin for the U. S. Department of Energy under Contract DE-AC04-94AL-85000.

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formulation calculates the gravitational head between cells on the assumption that the gas density in a flow path is the average of the cell densities connected by the flow path. While it gives the proper behavior in the well-mixed asymptotic limit, this formulation is shown to be unstable with respect to recirculating flows. The donor-based hybrid formulation, however, is shown to be consistent with the momentum equation, to give the correct behavior in the well-mixed asymptotic limit, and to treat properly the stability of stratifications, within the usual lumped-parameter assumption that momentum convection can be neglected. A more complete discussion of the hybrid formulation is given by Murata and Stamps[4].

Other modeling limitations besides the neglect of momentum convection could enter into the discrepancy between the code predictions and experiments. These other limitations are discussed and include the lack of proper plume or jet entrainment models and the lack of modeling of diffusion processes across gas-gas interfaces. The impact of these limitations on the predicted results for each experiment is discussed.

An important class of stratifications for containment analysis is the fully developed stratification. These are stratifications that are formed by plumes or stable buoyant jets, that satisfy the one-dimensional criteria given by Peterson[5] and that have had time to mix down to the injection elevation of the plume or jet. Such stratifications may be treated zero-dimensionally, without need for a proper plume or jet entrainment model.

3. Results

The NUPEC M-8-1 experiment provides a classic example of a fully developed stratification. Good agreement between the predicted degree of stratification and the experiment is obtained with the hybrid formulation, in contrast to the old formulation, despite the fact that a proper plume entrainment model is not used in the comparison. Figure 1 illustrates the improvement in the prediction of the helium stratification in this experiment with the hybrid formulation.

The Surtsey ST-3 experiment used a high-velocity hydrogen jet that resulted in a marginally unstable stratification, as a consequence of the momentum convection carried by the jet. It therefore provides an opportunity to assess the hybrid formulation in such a regime. The observed stratification was somewhat unstable, with mixing observed below the injection elevation. For the 16-cell nodalization studied, the old formulation produces somewhat better agreement with the observed stratification than the hybrid formulation. This somewhat better agreement arises from the fact that the hybrid formulation treats the stratification as stable, whereas the old formulation treats it as unstable. However, this somewhat better agreement is clearly fortuitous because momentum convection, the mechanism causing the mixing below the source, is not modeled in CONTAIN.

The HDR E11.2 experiment exhibited the most complex stratification behavior of the three experiments. The most important modeling uncertainty appears to be the buoyancy heads developed by the mid-elevation sources. When the effective elevation of these sources is taken to be approximately the injection elevation, good agreement is found with respect to the location of the stratification boundaries with the hybrid formulation, up to the time of decreasing light-gas concentrations during the dome spray period. As expected, poor agreement is found with the old formulation. Predictions of the light-gas concentration in the dome are too low initially with the hybrid formulation, in spite of good agreement with respect to the location of the stratification boundaries. This is to be expected from the fact that the predicted steam concentrations in the dome are initially too high. However, the agreement in the concentration improves dramatically as the steam condenses out, up to the time of decreasing light gas concentrations in the dome.

In conclusion, when significant stratification is present, the hybrid formulation appears to treat the stability of the stratification in a robust fashion and also gives good agreement with the measured degree of stratification in those cases in which the key phenomenological processes are either modeled or can be simulated through input.

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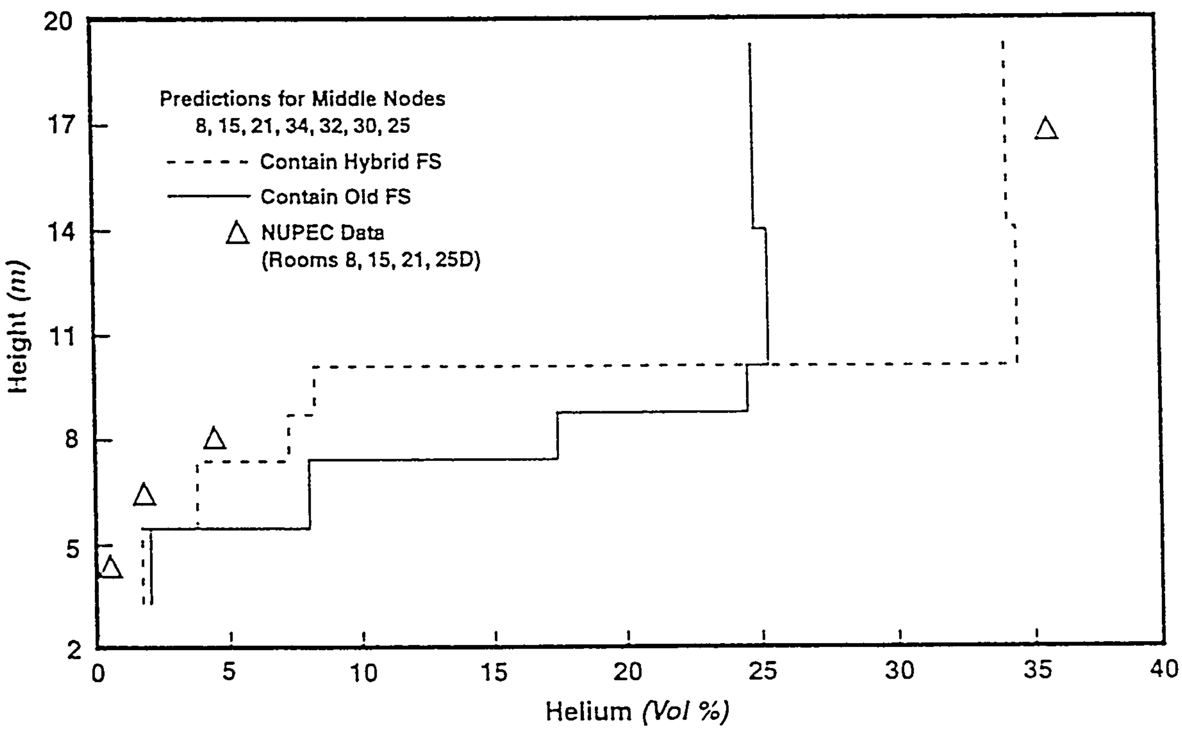

Figure 1. The Helium Concentration Profiles Predicted in the NUPEC M-8-1 Experiment at the End of the Injection Period, Compared to the Experimental Data.