Conservation of Fluid Mass and Energy by RELAP5-3D during a SBLOCA

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Introduction

- RELAP5-3D was developed to simulate the thermal-hydraulic behavior of reactor systems, including two phase conditions such as a SBLOCA
- Users frequently perform mass and energy balances to provide confidence in the calculated results
  - Previous balances were generally limited to the total fluid, which does not fully test the two-fluid model
- This analysis also includes mass and energy balances for the gas phase
- The primary coolant system of a typical PWR was selected for analysis

Introduction (cont'd)

- Total mass and energy in the primary coolant system were calculated using two methods
  - Total values obtained by summing the mass and energy of each control volume in the primary coolant system
  - Integrating the mass and energy conservation equations
- Control variables were used to calculate the terms needed for both methods

Mass balance equations for the combined fluid

$$M = \sum_k M_k = \sum_k (\alpha_f \rho_f V)_k + \sum_k (\alpha_g \rho_g V)_k$$

$$M = M_0 + \int_0^t (\dot{m}_{in} - \dot{m}_{out})dt$$

Mass balance equations for the gas

$$M_g = \sum_k M_{g\text{-}k} = \sum_k (\alpha_g \rho_g V)_k$$

$$M_g = M_{g\text{-}0} + \int_0^t (\dot{m}_{g\text{-in}} - \dot{m}_{g\text{-out}})dt + \int_0^t \left(\sum_k (\Gamma V)_k \right) dt$$

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Energy balance equations for the combined fluid

$$U = \sum_k U_k = \sum_k (\alpha_f \rho_f u_f V)_k + \sum_k (\alpha_g \rho_g u_g V)_k$$

$$U = U_0 + \int_0^t (\dot{m}_{in} h_{in} - \dot{m}_{out} h_{out}) dt + \int_0^t \left(\sum_k Q_{w\text{-}k} \right) dt - \int_0^t \left(\sum_k \omega_k \tau_k \right) dt$$

The latter equation neglects kinetic and potential energy and viscous dissipation and is therefore approximate

Energy balance equations for the gas

$$U_g = \sum_k U_{g\text{-}k} = \sum_k (\alpha_g \rho_g u_g V)_k$$

$$U_g = U_{g\text{-}0} + \int_0^t (\dot{m}_{in\text{-}g} h_{in\text{-}g} - \dot{m}_{out\text{-}g} h_{out\text{-}g}) dt + \int_0^t \left(\sum_k \left(Q_{w\text{-}g} \right)_k \right) dt - \int_0^t \left(\sum_k \alpha_k \omega_k \tau_k \right) dt$$
$$- \int_0^t \left(\sum_k \left(P d\alpha_g / dt \right)_k \right) dt + \int_0^t \left(\sum_k \left(H_{ig} (T_s - T_g) V \right)_k \right) dt + \int_0^t \left(\sum_k \left(h_g \Gamma_i + h_g \Gamma_w + h_f \Gamma_c \right)_k \right) dt$$

- The latter equation neglects viscous dissipation and interfacial heat transfer in the presence of noncondensables
- The phasic enthalpies are evaluated at either bulk or saturation conditions by the code, but evaluated at bulk conditions in the analysis

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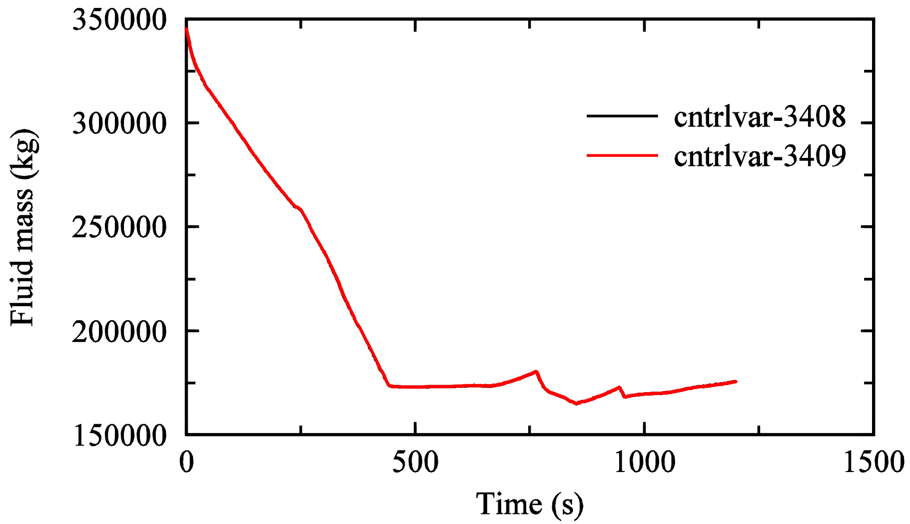
The reactor model is based on typ12002.i

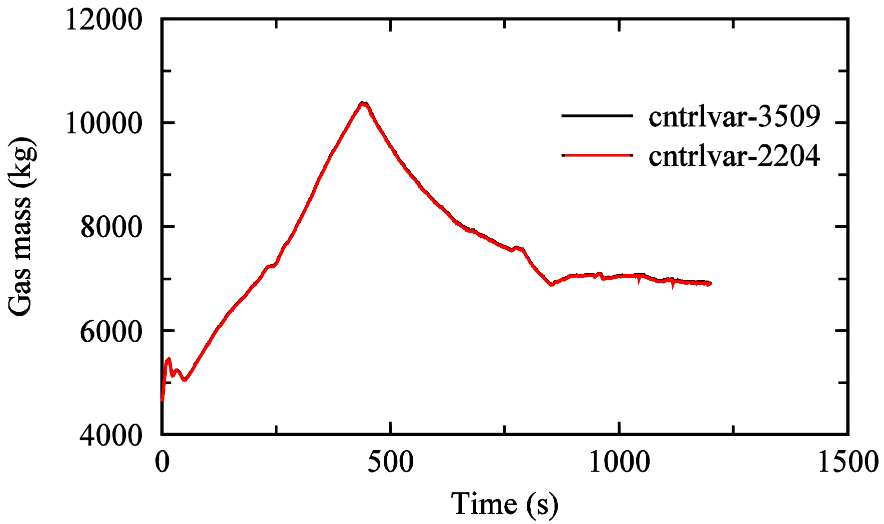
- Model simulates a SBLOCA initiated by a 4-inch diameter break in the cold leg of a typical PWR
- Inflows into the primary coolant system due to high pressure injection and charging
- Outflow at the break
- Accumulators were treated as normal control volumes within the primary coolant system
- Primary coolant system contains 107 control volumes
- Mass and energy balances used 2034 control variables, roughly 20 control variables per volume

Mass balance results

Combined fluid



Gas



Differences between the two methods were 0.04% for the combined fluid and 0.3% for the gas at 1200 s

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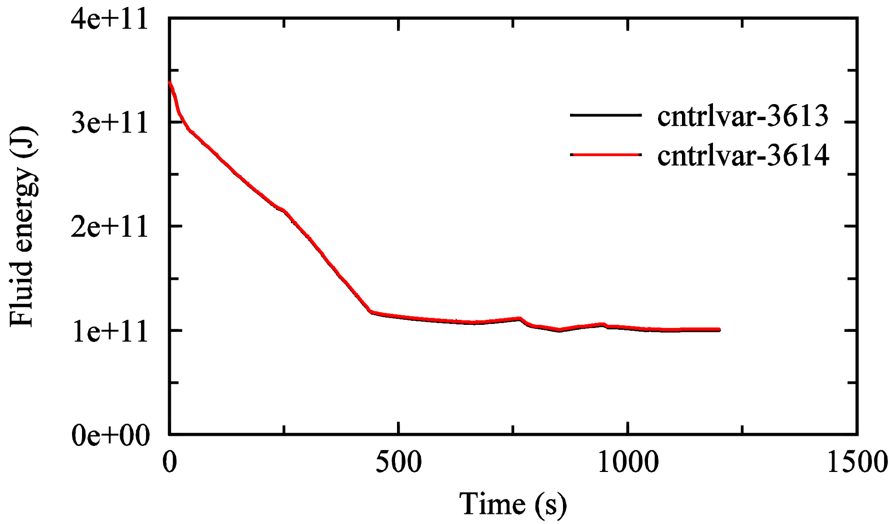
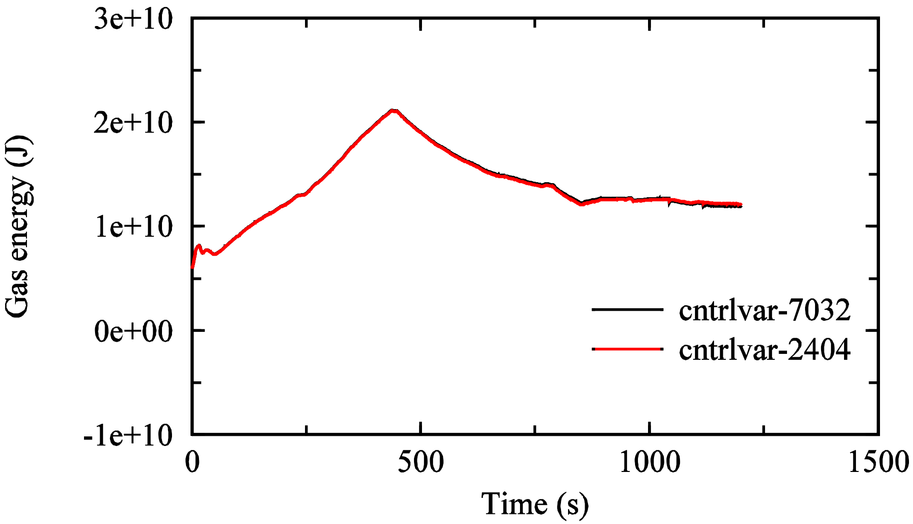
Energy balance results

Combined fluid



Gas



Differences between the two methods were 1.2% for the combined fluid and 1.0% for the gas at 1200 s

Larger differences were expected because of the simplifications made to the energy equations

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Conclusions

- **RELAP5-3D adequately conserved mass and energy during a SBLOCA in the typical PWR model for both the combined fluid and the gas phase**
- **Consequently, the code also adequately conserved the mass and energy of the liquid phase**
- **The accuracy of the solution for the gas phase was similar to that for the combined fluid**