VALIDATION OF THE RALOC-mod.4 THERMAL-HYDRAULICS CODE ON EVAPORATION TRANSIENTS IN THE PHEBUS CONTAINMENT

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SUMMARY

IPSN and GRS are developing the ESCADRE/ASTEC systems of codes /1,3,4 & 10/, devoted to the prediction of the behavior of water-cooled reactors during a severe accident. The RALOC-mod.4 code belongs to this system and is specifically devoted to containment thermal-hydraulics studies. IPSN has designed a Thermal Hydraulic Containment Test Program in support to the Phebus Fission Product Test Program /2/. Evaporation tests have been recently performed in the Phebus containment test facility. The objective of this work is to assess against these tests the capability of the RALOC.mod4 code to capture the phenomena observed in these experiments and more particularly the evaporation heat transfer and wall heat transfers.

The Phebus 10 m^3 containment has a double-skinned structure which allows the circulation of an organic coolant liquid in charge of maintaining an homogeneous atmosphere temperature distribution.. Three condensers equip the top vault of the containment vessel. They are in charge of condensing the injected steam when present and controlling the thermal hydraulic conditions of the containment atmosphere.

Eleven tests were performed and are compared to code results for condensation/evaporation model validation. The experimental procedure is the following : from initial conditions, the sump water is heated up to a final value (ranging from 90 °C to 120 °C) which is maintained constant. The evaporation rate from the sump into the containment atmosphere increases during the water heating phase and decreases during the following phase of evaporation at a constant free surface temperature until an equilibrium value is reached. A base case was carried out with condenser temperatures equal to the vessel wall temperature. The other experiments check the influence of natural convection patterns generated by several temperature differences (ranging from 0 to 30 °C) between the condenser and the inner containment wall. Depending on the thermal hydraulic conditions, a condensation transient occurs on the condenser surfaces leading to steady states at the end of the tests for which all the steam evaporated from the sump is condensed onto the condensers.

The Raloc.mod4 code solves mass and energy balance equations in a multi-compartment geometry. A numerical simulation was run for each of the experiments. The initial and boundary conditions correspond to the experimental values. In the presence of incondensables, the condensation or evaporation rates m_s are modeled following the Stephan (or Collier) model /5, 7,8 /:

$$\frac{d}{dt} m_s = K_C \, C \, M_S \, \frac{1}{1-n} \, \text{Log} \, (Paw / Pab) \qquad (1)$$

where : Paw = incondensable pressure near condensing or evaporating surface, Pab = incondensable pressure in bulk, Kc = mass transfer coefficient (m/s), C = total molar concentration, n = gas droplet density and M_S = steam molar mass. The sign of eq. (1) is taken into account to separate condensation from evaporation. As for the Jericho code /6, 7/, the Chilton-Colburn analogy is used to model Kc :

$$Kc = Hconv \, Pr^{2/3} / \rho \, Cp \, Sc^{2/3} \qquad (2)$$

with : P_r = Prandtl number of bulk gas, S_c = Schmidt number of bulk gas, Cp = constant pressure specific heat capacity and ρ = bulk density. The convective heat transfer coefficient Hconv is based on the usual Nusselt expression valid for a turbulent convection regime :

$$Hconv = 0.15 \, \lambda \, (Gr \, Pr \, F)^{1/3} \qquad (3)$$

where F is a function of the Prandtl number.

The results of the RALOC-mod4 /8 & 9/ calculations are compared with the experimental values. In addition, two humidity probes located at two different positions in the containment give local information to be compared with the calculated average humidity ratio. We obtain a good calculation/experiment agreement on total pressures and steam pressures. The differences are about 5 to 10 % in the average and are within the experimental error band. Note that for the three tests for which sump temperatures are hotter than gas temperatures the measured and calculated steam pressures show a very good agreement during the final steady state where the condensation and evaporation rates (g/s) are equal. Calculated gas temperatures also show a very good agreement with the experimental ones validating the turbulent convective heat transfer correlation (the gas temperature is mainly monitored by heat exchange with the containment inner wall in these tests). A good calculation/experiment agreement on condenser surface temperature and sump water temperature is also obtained thus validating the heat transfer models for boundary conditions.

The Stephan model used to simulate both evaporation and condensation yields a good agreement with experimental results. The results obtained are quite comparable to those obtained with the Jericho code when the Collier condensation model is used /6/. Nevertheless, for both codes the final steady state numerically reached is often established for a calculated humidity ratio a little bit different from the experimental one. In fact, as already noticed /7/

the relative humidity ratio becomes a key parameter to correctly simulate in these experiments. This study demonstrates that RALOC-mod4 is a suitable code for predicting the containment thermal-hydraulics behavior in transients involving both condensation and evaporation.

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