Special Effects Investigations and Verification of the Advanced Code COBRA-NC in Conjunction with HDR Containment Experiments

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Abstract

The transient flow and pressure distribution during the blowdown experiment T 31.3 of the HDR test facility has been modeled by a three-dimensional computer model of the blowdown compartment by using the 3-field, 2-fluid containment code COBRA-NC. The pressure distribution in the compartment is strongly influenced by the primary and deflected blowdown jet as well as by crossflow openings to the adjacent compartments. Pressure distributions on the walls show variations up to 0.7 bar in the calculated example.

1. Introduction

Current blowdown-experiments at the HDR test facility are performed to investigate pressure differentials between subcompartments in a nuclear reactor containment building during the first few seconds after blowdown initiation /1/. Experience with pressure differential predictions by lumped-parameter codes has shown that the physical interactions leading to the observed presssure distribution are poorly understood and simulated. The series of experiments T 31.1-3 was conducted to study the effect of changes in the impingement plate inclination angle, while all other conditions were held constant. A three-dimensional transient model calculation of the blowdown compartment was performed in order to verify the computer code COBRA-NC and to enhance the understanding of flow and pressure distribution details.

Figure 1 shows the arrangement of the blowdown pipe and the impingement plate in the experiment. In the present study the experiment T 31.3 with jet deflection away from the main crossflow openings was selected for the numerical model. Some experimental conditions were:

RPV initial pressure	110 bar
Blowdown pipe diameter	0.45 m
Blowdown initial quality	1.0 (pure steam)
Blowdown compartment height	7.75 m
Blowdown compartment volume	280 m^3

2. Computer Code

The COBRA-NC computer code has been developed by the Battelle Pacific Northwest Laboratory for the U.S. Nuclear Regulatory Commission. It provides a two-component, two-fluid, three-field representation to allow the modelling of water and its vapor as well as a noncondensable gas mixture. The two-fluid capability is needed to account for condensation of steam in the containment atmosphere and on structural surfaces, containment sprays, pressure suppression pools etc. The three fields represent the vapor-gas mixture, the continous-liquid phase and the liquid-drop phase. The continous-liquid phase is used to model liquid films on containment structures, pools on containment floors and film built-up in vents, whereas the liquid-drop phase is used to model the two-phase blowdown jet, containment sprays as well as drop entrainment and de-entrainment between subcompartments. COBRA-NC features an extremely flexible noding scheme that allows the code to be run in a traditional lumped-parameter mode, one-dimensional, two-dimensional, three-dimensional mode or mixture thereof, i.e. 3-D breakroom, 1-D vents, lumped-parameter for neighbouring rooms. The code has a finite-difference slab conduction model for structural heat conduction which allows to use any number of materials in each slab. A mixing-length turbulence model has been incorporated to model turbulent shear flows and turbulent diffusion of gas species due to concentration gradients.

3. Numerical Model

The numerical grid for the blowdown compartment is shown in figure 2. The grid spacing ranges from 0.225 m to 1.0 m. In the upper section the locations of the blowdown pipe and the impingement plate are indicated as they are represented by the computational grid. The model consists of 898 spatial control volumes and 81 heat slabs representing structural heat transfer surfaces.

Mass and enthalpy discharge rates of the blowdown pipe were specified as measured in the experiment. The pressure boundary conditions at the vent flow openings were obtained from a separate model calculation of the entire containment, which was performed also using COBRA-NC in a lumped-parameter mode.

The three-dimensional model calculation was carried out up to a point in time of 100 ms with about 3000 s of CRAY-1 computer time. About this time, the mass discharge rate has reached its first maximum.

4. Results

Steam velocity distributions in the neighbourhood of the main vent flow opening are shown in figure 3. Maximum velocities reach 120 m/s close to the vent. The velocity distribution around the vent is highly unsymmetric; velocities are more than 60 m/s throughout the lower section, while in the upper section mostly stagnant conditions exist. Direct comparison with experimental data /2/ (velocities at a single location in the blowdown compartment) is not possible because the selected data are not yet evaluated; however, data from experiment T 31.1 show the same order of magnitude for velocity and direction in the lower section.

Pressure distributions at several walls are shown in figures 4 and 5. The deflected jet causes a pressure maximum when hitting the wall; this maximum exceeds the surrounding pressure by about 0.35 bar. Pressure differences at the wall containing the main vent flow opening are around 0.2 bar. Experimental pressure values of 1.5 bar were measured at several locations /3/. This is about 0.2 bar less than the computed mean pressure in the blowdown room. Local pressure deviations cannot be recognized in the experimental data because there are too few transducer records (3) available. Therefore, a detailed comparison with experimental data should be extended to include the other experiments in the series, i.e. T 31.1-3.

Finally, figure 6 shows the steam/air distribution close to the impingement plate. High steam concentrations in the upper section are caused by the upward deflected jet. Temperature transducers in the upper section show temperatures around 120 °C, while in the lower section 106-114 °C were measured, thus verifying the calculated steam stratification.

5. Conclusions

First comparisons of calculated and measured flow and pressure data in the HDR blowdown compartment show a good qualitative comparison. Further calculations for tests T 31.1-2 should be performed for to make a more detailed comparison between experiment and model calculation possible.

6. References

/1/ HDR-Sicherheitsprogramm - Gesamtprogramm - Phase II. Kernforschungs-Zentrum Karlsruhe, PHDR Arbeitsbericht 05.19/84, Januar 1984.

/2/ HDR Sicherheitsprogramm. Ergänzungsbericht Versuchsprotokolle T 31.1, T 31.2 und T 31.3. Kernforschungszentrum Karlsruhe, PHDR-Arbeitsbericht 3.442/84, Oktober 1984.

/3/ HDR-Sicherheitsprogramm. Versuchsprotokoll Versuch T 31.3. Kernforschungszentrum Karlsruhe, PHDR-Arbeitsbericht 3.428/84, Juli 1985.

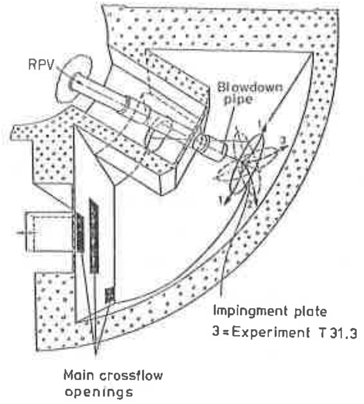
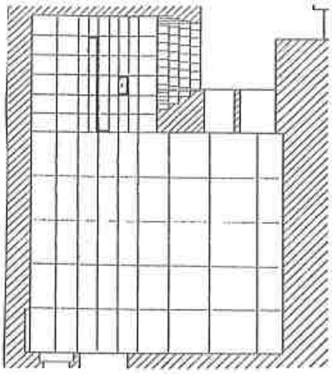


Fig. 1: Blowdown compartment

a)



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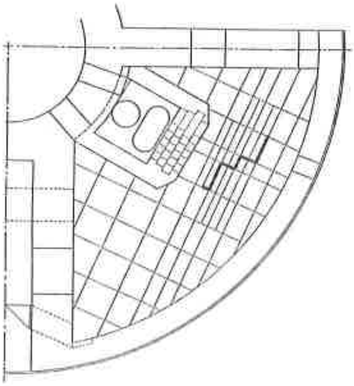
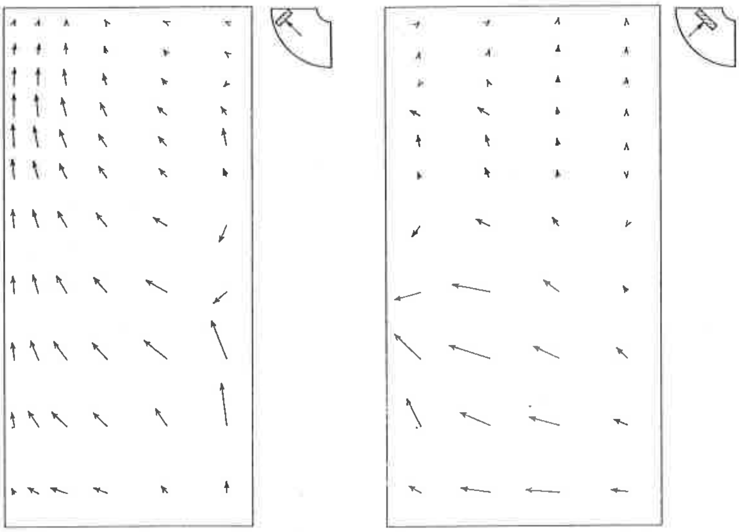


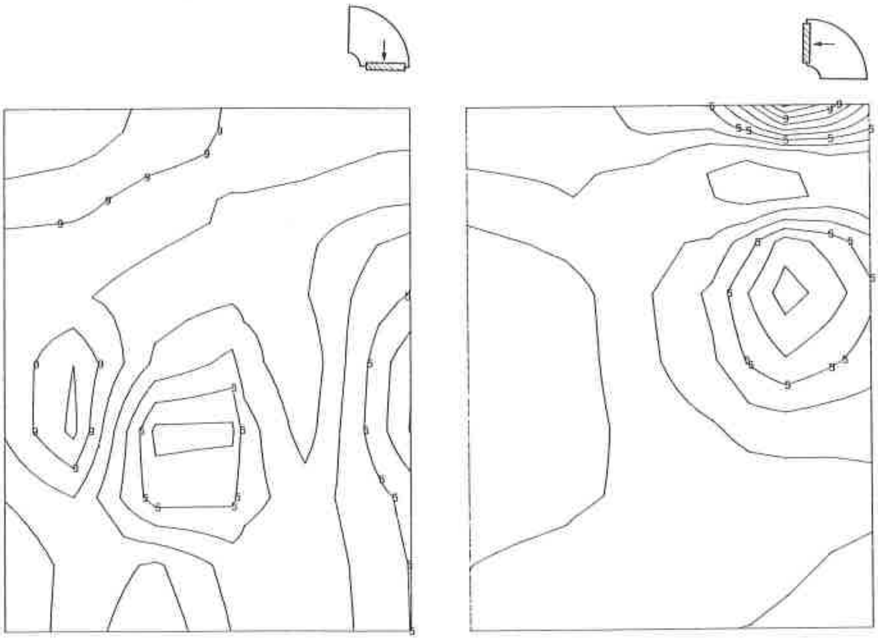
Fig. 2: Vertical (a) and horizontal (b) plane of numerical model



Maximum velocity 76.4 m/s

Maximum velocity 116.8 m/s

<u>Fig. 3:</u> Velocity distributions close to main vent flow opening



3: 1.66 bar

10: 1.87 bar

2: 1.78 bar

11: 2.50 bar

<u>Fig. 4:</u> Pressure distributions at various walls

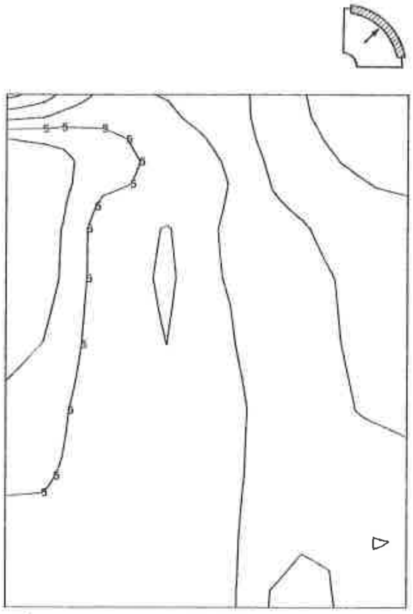


Fig. 5: Pressure distribution at outer wall

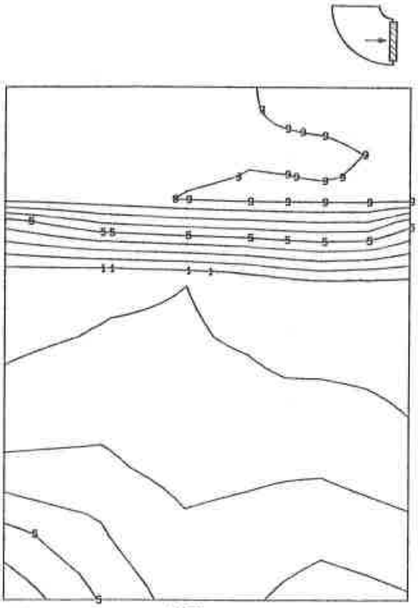


Fig. 6: Distribution of steam volume fraction