Experimental and Analytical Results of Recent HDR Containment Blowdown Experiments (Steam and Water Line Break Simulation)

T.F. Kanzleiter
Battelle-Institut e.V., Am Römerhof 35, D-6000 Frankfurt/Main 90, Germany
K.-H. Scholl
Kernforschungszentrum Karlsruhe GmbH, Projekt HDR, Postfach 3640, D-7500 Karlsruhe 1, Germany

Abstract

In the HDR test facility, the loads acting on an LWR full-pressure containment during a LOCA are being investigated on an approximated full-size scale. The measured data are used to verify and further develop the currently applied computer codes.

The present paper compares pre-calculated and measured results of short-term containment loads. It concludes that the existing lumped-parameter codes are not able to model all relevant processes correctly in terms of a best-estimate calculation and that further verification work is necessary to ensure reliable extrapolation from the present experiments to other conditions.

1. Introduction

Reactor containments are designed to withstand a loss-of-coolant accident during which the water inventory of the reactor escapes into the containment with intense steam generation, exerting three types of loads on the containment structures:

(1) jet impingement forces,
(2) differential pressures acting on the partition walls inside the containment during a short term,
(3) overpressure within the containment shell and temperature-dependent strains during a long term.

The present paper is focused on the second load type and deals with the results of recent HDR containment experiments and accompanying model calculations.

2. Experimental Facility, Experimental Program and Model Calculations

The HDR is a German decommissioned prototype light-water reactor which is now being used for a large variety of reactor safety investigations. These include experiments dealing with LOCA loads on a full-pressure containment which have been performed for the first time in an approximated full-scale facility.

The HDR containment (11,300 m^3 volume) consists of a steel shell 60 m in height and 20 m in diameter, which is subdivided into 62 compartments by concrete partition walls (Fig.1). These compartments are interconnected by some hundred vent flow openings. For all HDR containment experiments performed so far, the primary system break for LOCA simulation was located in compartment R1603 (Figs. 1 and 2). The free areas of its vent flow openings were reduced to such an extent that all the relevant pressure differential loads within the containment are acting on the walls of the break compartment or its neighboring compartments and only negligible pressure differentials exist between most of the other compartments. This design permits compartments located far from the break to be combined in compartment groups for modeling. A highly simplified modeling scheme for a specific HDR experiment is depicted in Fig. 3.

The HDR containment test instrumentation consists of about 230 thermal-hydraulic and 80 structural measuring channels for both short-term and long-term measurements. It also includes special measuring systems for heat transfer, steam/air composition and vent flow.

In 1982, a first test series of three steam blowdown experiments (Nos. V42 to V44; variation of break mass flow histories and vent flow areas) was performed. In 1983, a second test series was carried out, which consisted of two water and one steam blowdown experiment (Nos. V21.1, V21.2 and V45; variation of vent flow areas). As a result of deviations observed between the experimental results and model calculations, a third test series of another three experiments (Nos. T31.1 to T31.3; variation of flow patterns within the break compartment) was performed in 1984. Two further containment experiments are scheduled for the end of 1986.

For all experiments, pre-test and post-test model calculations were and are being made by various German and foreign institutions using the following multi-node codes for containment short-term behavior simulation: COBRA-NC (Battelle), COFLOW (GRS), CONTEMPT-4 (US NRC), DDIFF (KWU) and GRUYER (CEA), COBRA-NC being used also for 3-D calculations.

3. Experimental Results and Analytical Simulation

Fig. 4 illustrates how the inflowing two-phase mixture affects the pressurization of the individual containment compartments and the formation of differential pressures during the short term.

For analytical simulation of these processes, multi-node lumped-parameter codes are available. In these codes each node represents averaged values for one compartment or a group of compartments. The flow velocities and the composition of the two-phase mixtures flowing between the nodes are calculated by rather simple models (e.g. the orifice flow equation), crucial simulation problems concerning, e. g. vent opening shapes or water deposition effects, being by-passed by dialing correction coefficients. These codes and the models and coefficients involved had been verified by the results of the RS 50 model containment experiments performed at Battelle Frankfurt during

1974 to 1979.

Based on this knowledge, best-estimate pre-test calculations for the first HDR containment test series were made by various institutions using predicted mass flow curves. A typical example of calculated and measured results is given in Fig. 5. Calculations Nos. 2 and 2a differ only in the mass flow input and indicate its strong influence on the Δp results. Considering the deviation between the mass flow input and the measured values, a substantial underestimation of the actual pressure differential pressures must be stated for most of the so-called best-estimate predictions depicted in Fig. 5. More recent analyses suggest that the flow resistances of the vent flow openings between the compartments and the influence of the flow patterns within the break compartment were not considered in an adequate manner.

The predictions made for the water-line break experiments of the second HDR containment test series agreed better with the measurements. Typical results are depicted in Fig. 6 (please observe that the mass flow input was unterestimated for most containment calculations). This better agreement was partly due to improvements in the vent flow modeling but in some cases also to the conservative assumptions made for the influence of the water portion of the two-phase vent flow in these specific experiments. The first point is illustrated by the calculations Nos. 4 and 4a in Fig. 6: Calculation No. 4 is based on the same assumptions and parameters as the corresponding calculation in Fig. 5, whereas calculation No. 4a uses improved flow coefficients as derived from the REBECA separate-effect tests. On the other hand, calculation No. 3 is an example of the second effect: Based on the flow models and parameters which led to a small Δp underestimation for steam-line break experiments (cf. Fig. 5), but using very conservative assumptions for the water carry-over through the vent openings, this prediction of a water-line break experiment overestimates the actual Δps by a factor of two.

The main aim of the third test series was to investigate the influence of various flow patterns inside the break compartment on the resulting pressure differentials. It was assumed that this effect, which is not being considered in the lumped-parameter codes, may lead to the substantial deviations between model calculations and measurements observed in the first test series. In the experiments, variation of the flow pattern in the break compartment was achieved by varying the inclination of the baffle plate at the break side, as indicated in Fig. 2. Vent flow openings and break mass flow history were not changed during the three experiments (Nos. T31.1 to T31.3). As indicated in the upper plot of Fig. 7 (curve No. 1), the break mass flow starts with quasi-steady steam flow and switches over to two-phase flow after 0.55 s.

Fig. 8 depicts the results of absolute pressure measurements from two experiments made at different locations within the break compartment. Measuring points at locations with low flow velocity indicate a rather uniform pressure history which is close to that of the stagnation pressure. On the other hand, the static pressure measured in zones with high flow velocities is significantly lower, as can be seen from curve No. 3 in the upper plot and curves Nos. 4 and 5 in the lower plot of Fig. 8.

Results of pressure measurements in a low-velocity zone and of typical differential pressure measurements from all three experiments are compared in Fig. 9. The pressures measured at location CP6302 in experiments Nos. T31.1 and T31.2 show only minor differences, while in the two-phase flow period the pressure measured in experiment T 31.3 is about 0.05 bar lower. This effect is assumed to be the result of the different break compartment flow patterns. As the pressure build-up in the neighboring compartments is identical in all experiments, also the differential pressure measurement CP6301 shows that the values measured in experiment T31.1 are 0.05 bar lower.

Multi-node lumped-parameter codes neglect the influence of flow patterns within one node. Therefore, only one set of model calculations was made for all three T31 experiments. Fig. 7 compares two typical predictions with measurements of T 31.1. In the steam flow period (t = 0 to 0.55 s), the mass flow input corresponds to the actual values. The resulting Δps, however, are significantly overestimated by both predictions. The result differs substantially from the findings after the first test series (cf. Fig. 5). The reason is a modification of the vent flow models and the assumption of flow coefficients between the first and the third test series. On the other hand, a comparison of the predictions in Figs. 5 and 7 also reveals the large sensitivity of the calculational results from the models and assumptions chosen by different individuals and at different times.

4. Conclusions

The evaluation of the HDR containment experiments is still under way. In a first step of evaluation, comparison of the results of pre-test best-estimate calculations with the results of measurements revealed that the existing calculation methods for containment short-term behavior are not as accurate and reliable as expected. The reasons include the inadequately rough modeling of some phenomena in the available lumped-parameter codes and the lack of experience and knowledge on how to bridge these deficiencies by suitable code improvements. Therefore, a second step of evaluation is being started, which is aimed at better understanding the processes involved by deeper analysis of the test data and by application of more sophisticated models (including 3 D codes) to crucial problems.

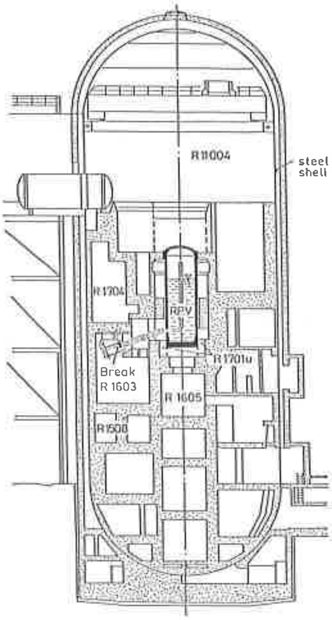

Fig. 1: HDR containment

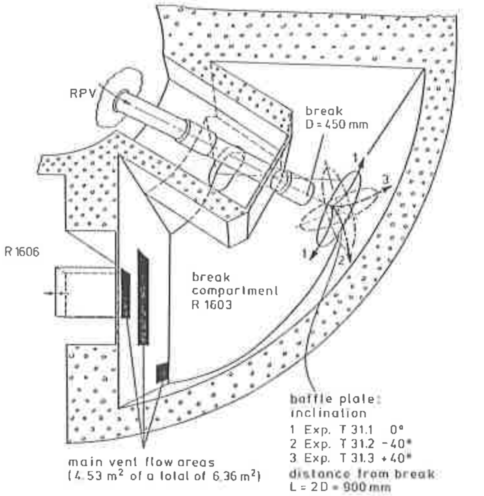

Fig. 2: Break compartment R1603 in HDR experiments T31.1 to T31.3, with variation of baffle plate inclination (variation of flow pattern in break compartment)

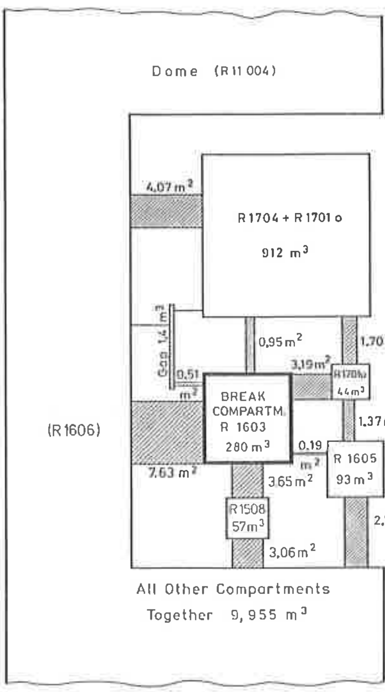

Fig. 3: Simplified modeling scheme (zones and vent flow paths) of the HDR containment in experiment V21.1

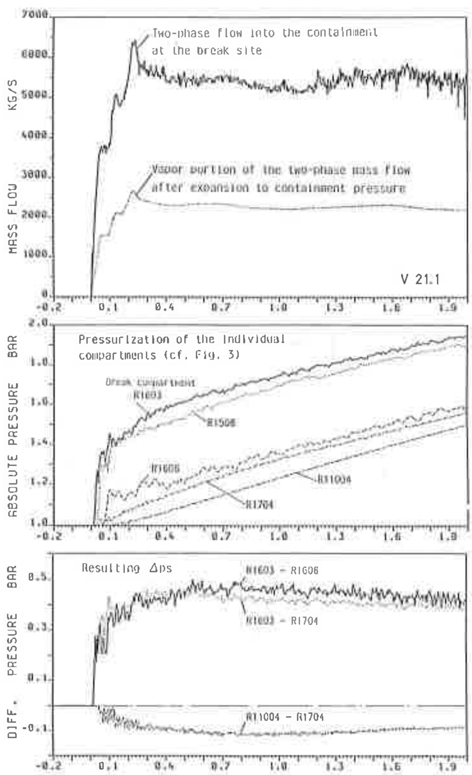

Fig. 4: Short-term pressurization of the containment in water-line break experiment V21.1

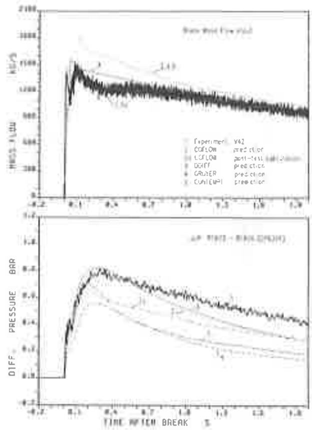

Fig. 5: Steam-line break experiment V42 (first test series): Calculated and measured Δp results

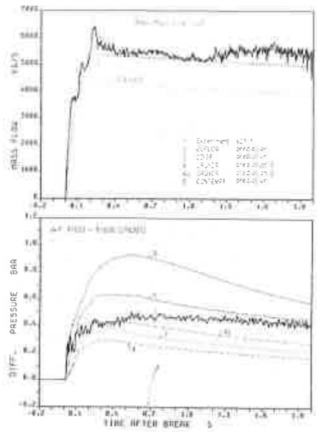

Fig. 6: Water-line break experiment V21.1 (second test series): Calculated and measured Δp results

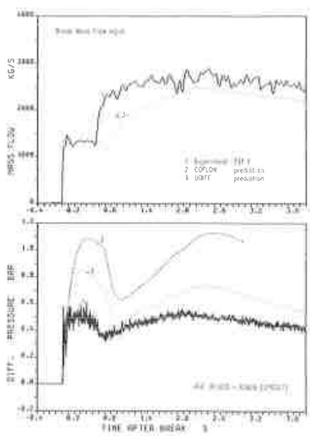

Fig. 7: Steam-line break experiment T31.1 (third test series): Calculated and measured Δp results

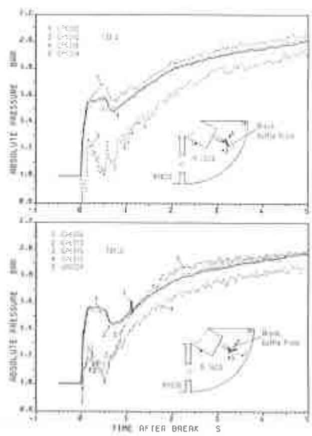

Fig. 8: Pressure distribution in break compartment R1603 (variation of break flow direction; see Fig. 2)

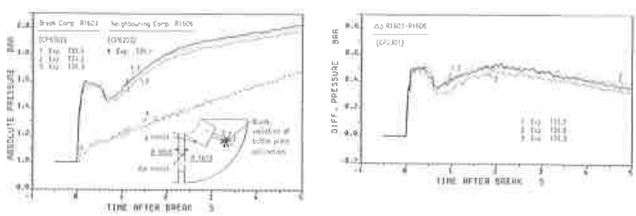

Fig. 9: Influence of the break flow direction on absolute and differential pressures