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RESPONSE OF A TWO-COMPARTMENT CONTAINMENT VESSEL TO A PRESSURE VESSEL BLOWDOWN

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SUMMARY A small blowdown/containment rig at Lucas Heights has been rearranged to have a two-compartment containment and experiments have been performed to provide data on containment phenomena. Measurements were made of pressure, temperature, heat transfer coefficient and intercompartment flow during a pressure vessel blowdown. These measurements are described together with modifications made to the computer code ZOCO V for calculating the transient response.

NOTATION

H	condensation heat transfer coefficient
E	rate of energy flow
M	mass
v	specific volume
W	rate of mass flow

Suffixes

a	compartment A
b	compartment B
g	air
p	peak value
u	Uchida
s	steam

1 INTRODUCTION

The containment of a water-cooled nuclear power reactor must be designed to withstand the stresses generated in the unlikely event of a major loss-of-coolant accident. If this were to occur the high pressure, high temperature fluid from the primary circuit would be released into the containment building and it is therefore necessary to be able to predict the pressure and temperature distribution throughout the containment in the subsequent period. Because the containment is a major component in the safety system for these reactors considerable effort is expended by reactor manufacturers and safety organisations in generating computer codes which can calculate conditions in postulated accidents and also in performing experiments to test and develop these codes. The OECD Nuclear Energy Agency has been coordinating exercises, Containment Analysis Standard Problems (CASPs), in which interested organisations make analyses of such an experiment. These analyses are then compared with each other and against the experimental results to give data for development of the codes.

The AAEC has for some time been studying this topic at a relatively low level of effort, has performed experiments in a small rig at Lucas Heights, and has also joined in the analysis of several of the CASPs. In 1981 the OECD/NEA requested that an experiment proposed for the Lucas Heights blowdown/containment rig should be used as an international standard problem. Although this rig is very much smaller than those used in previous problems, and is minute compared to a nuclear reactor, it was thought that some features of it could be of use in code development. This request was agreed to and the CASP has now been completed with full participation by eight countries (Marshall 1983). This paper describes the experiment and an analysis made at Lucas Heights using a German containment response code ZOCO V, with various modifications.

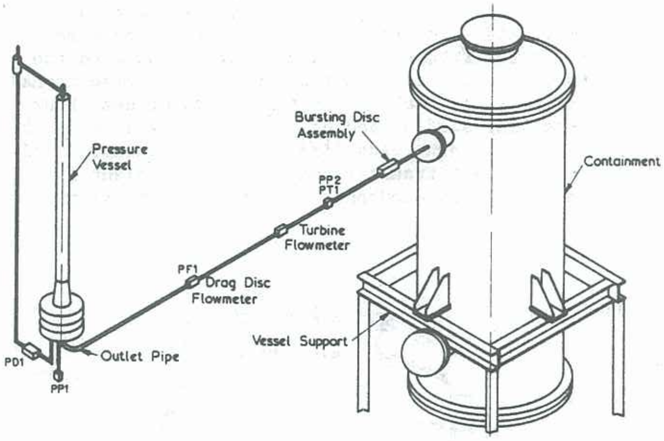

Figure 1 Blowdown/containment rig

2 EXPERIMENTS

The general rig arrangement is shown in Figure 1 and some summarised dimensional values are given in Table 1. The pressure vessel is insulated and contains an electric heater. The outlet pipe is heated by an electric heater tape and contains an orifice plate within the bursting disc assembly. This assembly also contains a copper disc which blocks off the pipe and is ruptured to start the blowdown. Mass flowrate from the pressure vessel is measured by a drag-disc flowmeter in conjunction with a differential-pressure pressure-vessel-contents measurement and fluid temperature and pressure measurements to gain information on the steam quality.

The overall containment vessel is about 3 m high and about 0.9 m diameter. The internal arrangement is shown in Figure 2, which shows the partition dividing the vessel into two compartments and also indicates the positions of the various transducers. The transducers feed into a data logging system consisting of a high speed computer-based data logger which records most of the channels, and an ultra-violet recorder which records some of the thermocouple signals. All the temperature measurements are made by stainless steel clad thermocouples and the pressure measurements by strain gauge/diaphragm transducers. In the containment vessel pressure is measured in both compartments and thermocouples are arranged to measure the temperature distribution. The flow between the two compartments is measured by a drag-disc flowmeter (BF1). There are devices for measurement of condensation heat transfer coefficient in both compartments (AH1 and BH1). These consist of a short metal rod fitted internally with a

TABLE 1

RIG DIMENSIONS

Item	Enclosed Volume m^3	Wall Area m^2	Wall Thickness mm	Material
Pressure vessel	0.0136	0.57	8.5	s.s.
Compartment A	0.369			
External walls		1.34	6.4	m.s.
Partition wall		0.77	12.0	m.s.
Compartment B	1.438			
External walls		6.94	6.4	m.s.

thermocouple near to a free surface. The rest of the rod other than this surface is insulated. A second thermocouple is positioned in the atmosphere in front of the free surface. An analytical method has been devised (Marshall 1979) involving transformation of the measured metal-temperature transient from the time domain to the frequency domain, convolution with the response function for the rod, and then inverse transformation. This enables the transients of heat flux into the free surface and of surface temperature to be derived which then leads directly to determination of the surface heat transfer coefficient transient from the measured bulk atmosphere temperature transient.

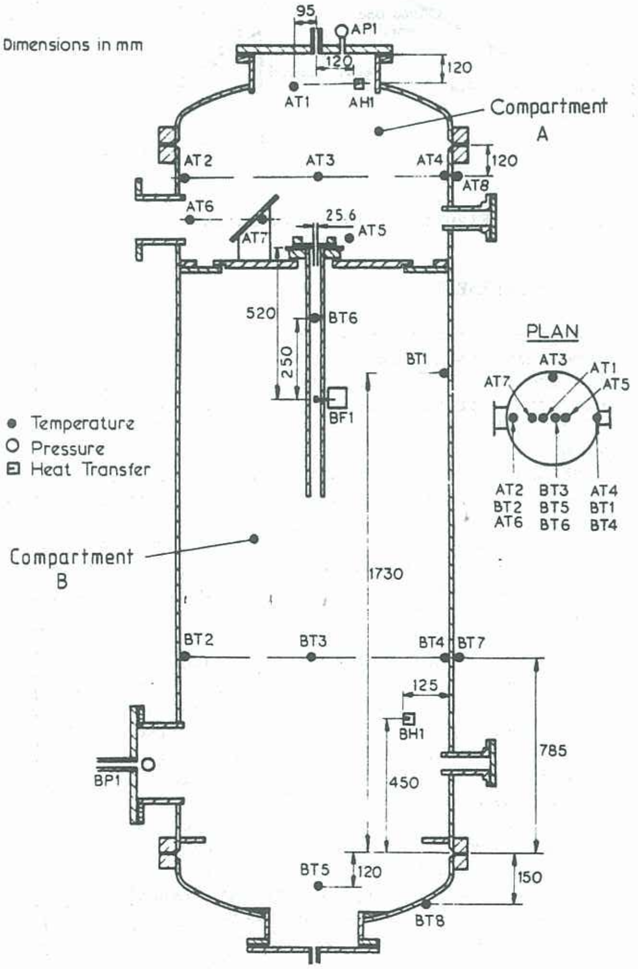

Figure 2 Containment compartments

For this experiment 8.5 kg of water was put into the pressure vessel and heat was applied until the pressure rose to 10.4 MPa. When conditions were steady the blocking copper disc was ruptured and the various measurements recorded.

3 ANALYSIS

The computer code ZOCO V (Brosche 1972) had been used on previous CASPs with reasonable success and was used again for analysis of this problem. This code solves the thermohydraulic conservation equations for mass, energy and volume in either equilibrium or non-equilibrium conditions. It is specifically designed to deal with systems of interconnected chambers, with both fluid and heat transport between chambers. Conditions within each chamber are calculated by one set of equations. In order to obtain satisfactory results on this particular experiment, however, it was necessary to modify the condensation heat transfer calculation used in the code. The original code used data which was essentially for steady state conditions of condensation by natural convection in a steam/air mixture. The scheme used here for analysis of conditions in the inlet compartment A was based on previous work with this rig when used in a single compartment configuration (Marshall 1979). The heat transfer algorithm was

$$H_a = \max[7 \cdot E(t)/E_p \cdot H_u;\ H_u]\ \mathrm{W\,m^{-2}\,K^{-1}} \qquad (1)$$

where $H_u = 450\ (M_s/M_g)^{0.8}$ and $300 < H_u < 3000$.

The term H_u is a correlation of the Uchida et al. (1964) data for steady state condensation in a steam/air atmosphere. It is then multiplied by a factor which depends on the power of the blowdown fluid. In the high-flow blowdown period the compartment atmosphere is being considerably disturbed and therefore in this period the heat transfer coefficient is increased. The values taken for the lower compartment B were calculated directly from the Uchida correlation but in practice this meant that the coefficient was held constant at the lower limit value because of the low steam/air mass ratio in this compartment.

A further modification was in the calculation of intercompartment flow. The code originally assumed that the compartment atmosphere would be a uniform mixture of steam and air and that the outflow could be calculated on the basis of each component being in the proportion of the mass ratio within the compartment. For the present experiment it was considered that in the initial period the components might not be thoroughly mixed and therefore the air might be pushed ahead of the incoming steam. The flow was therefore assumed to vary from all air to the original mass weighted ratio over the first 4 seconds. The code also originally used a flow calculation depending on experimental data suitable for flow through normal containment interconnecting openings and this was used in the CASP but tended to give rather high intercompartment flow. For the present paper the flow data was changed to that for compressible flow through an orifice, with a discharge coefficient of 0.8.

In calculating the pressure response of the two compartment system to the blowdown, the input to the code was the mass and enthalpy of fluid from the pressure vessel as measured during the experiment, and the dimensions and thermal properties of the containment. The numerical constants in the heat transfer coefficient and flow algorithms were varied to give reasonable fit to the measurements.

4 DISCUSSION

The measured transients of mass flowrate and enthalpy from the pressure vessel are shown in Figure 3. This data was used in the analysis as the input to the containment.

The measured and calculated containment pressure transients are shown in Figure 4. The measured compartment A pressure rises rapidly to a peak, then falls, rising slowly up to the end of the liquid blowdown (11.7 s Figure 3), whereas compartment B pressure rises continuously, due to the flow of air and steam through the intercompartment flow passage, until the two pressures become very close together at about 12 s. Subsequently both pressures fall slowly. In calculating these transients it was found that the numerical multiplier in the heat transfer expression affected primarily the value of the initial peak in Compartment A pressure and gave reasonable results with the value shown in equation (1), i.e. seven. The value previously determined for the system with containment vessel arranged as one compartment without the partition wall, and where such a peak did not occur, was five. The heat transfer coefficient transient for Compartment A derived in the calculation is shown in Figure 5 together with the measured transient. Note that the measurement was made at a point in the compartment (AH1, Figure 2) which is exposed to almost direct impact from the incoming blowdown flow. A large proportion of the surfaces would not receive such direct impact and so the measured values would not be the same as the calculated values which are averages for the whole surface. However the general shapes of the transients are similar. In this compartment the air may be pushed out through the intercompartment flow passage by the incoming blowdown steam/water mixture. As already discussed such an effect was included in the calculation and affects the calculated pressure transient for compartment A in influencing the extent of the dip in pressure after the initial peak, presumably because the loss of air increases the steam/air ratio and thus the calculated heat transfer coefficient.

In compartment B the air content increases due to the flow from compartment A and the increase in vapour content is not high so that the heat transfer coefficient calculated directly from the H_u correlation gives very low values. These were found inappropriate and the lower limit of 300 W m^{-2} K^{-1} was applied, which became the value actually calculated for compartment B over the whole period. The calculated pressure response was not particularly sensitive to this value, it had little effect in the initial period but more effect after about 15 s when the heat transfer coefficient in the top compartment made little difference to the calculation because the walls in this compartment were nearly at the calculated fluid temperature. It was not possible to make a measurement of heat transfer coefficient in compartment B because of the very small temperature changes produced in the transducer.

The flow between compartments is shown in Figure 6 plotted as the variable W^2v, i.e. (mass flow)^2 x (specific volume), which is directly measured by the drag-disc flowmeter. The calculated transient is also shown. In the experiment the final water content in each compartment was measured by draining and by evacuation and collection of water in cold traps. The flow passage inlet had been designed to prevent flow of condensed water from compartment A to B. Only about 4% of the water was in compartment B but the calculated result was nearly 10%.

Temperature transients are shown in Figure 7; again note that the calculated transients are averages for the whole of a compartment whereas the measurements are made at particular points. However, all the fluid temperatures measured in compartment A were within about 3°C after the water blowdown period, indicating that conditions were fairly uniform throughout the chamber after that time. The temperatures calculated for this compartment were generally higher than those measured. The measured temperature AT5 shows a small delay before the initial rise, which is due to the distance of this position from the inlet. In compartment B the wall temperatures measured did not change by more than 2°C in the whole period and so are not shown. The fluid temperature measured, BT5, is remote from the intercompartment flow inlet but would tend to be higher than the computed average for the compartment because of the large dead volume in the upper region.

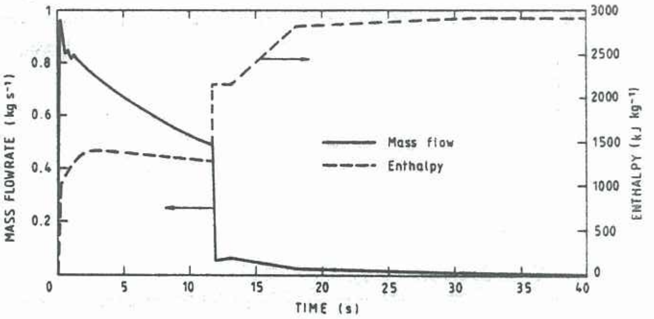

Figure 3 Pressure vessel outflow

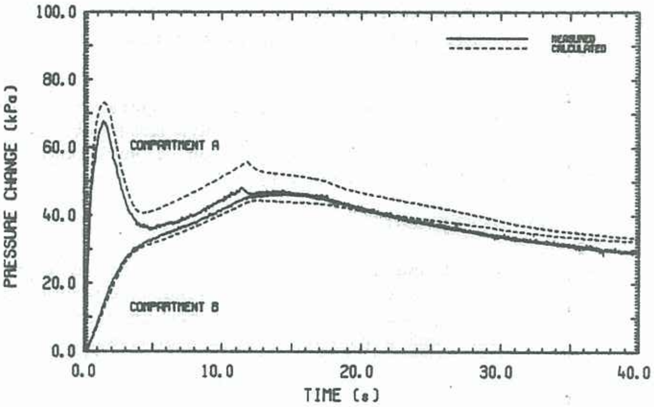

Figure 4 Pressure transients

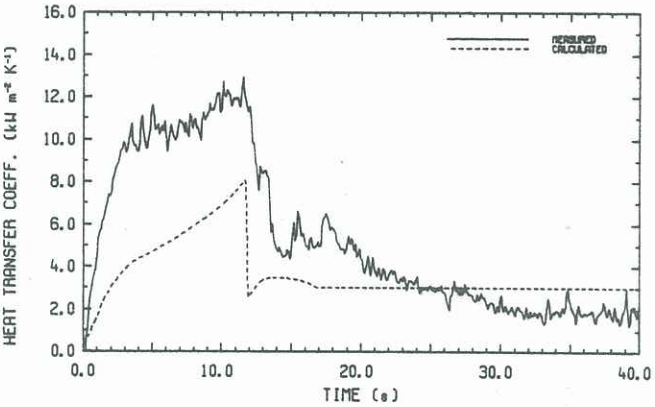

Figure 5 Heat transfer coefficient, compartment A

5 CONCLUSIONS

This experiment is one of a series carried out in different countries under OECD/NEA auspices. The others have been with much larger and more direct models of power reactor containments. The experiment has introduced new conditions of smaller volumes and steel rather than concrete walls, which have tended to increase the importance of calculation of condensation heat transfer coefficients in simulating the transients. This has therefore focussed attention on this aspect of such calculations although in real reactor containments conditions are generally rather different. Measurement of a heat transfer coefficient transient and also of intercompartment flow has been included. By some variation in the heat transfer calculations it

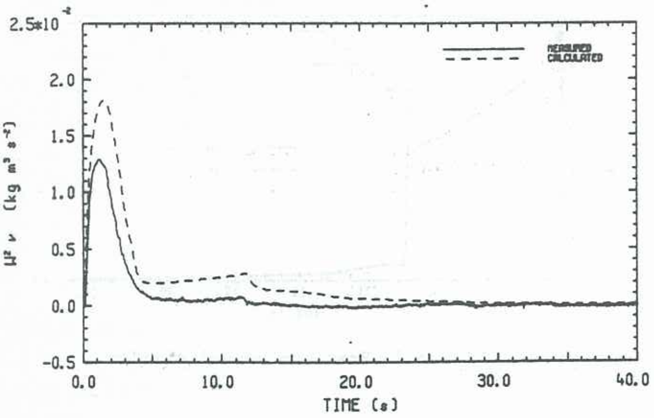

Figure 6 Intercompartment flow

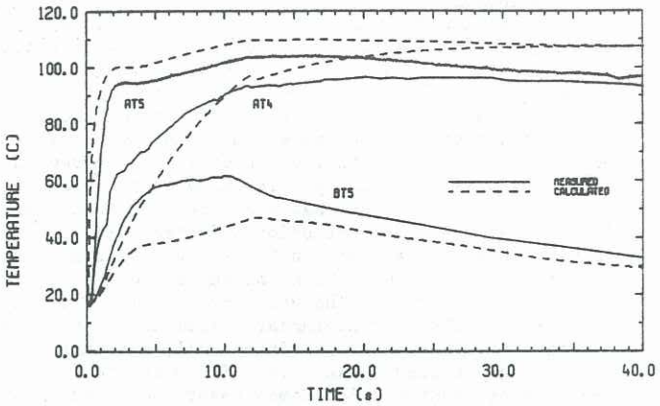

Figure 7 Temperatures

has been possible to use the reactor computer code ZOCO V to calculate the conditions although more work is needed to investigate the application of such modifications to different situations.

6 ACKNOWLEDGEMENTS

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