Pretest Analysis of Containment Studies Facility Model for Simulated Loss of Coolant Accident


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1 ABSTRACT

An experimental facility called Containment Studies Facility (CSF) has been constructed at Bhabha Atomic Research Centre (BARC) for research and development in nuclear reactor containment thermal hydraulics due to Loss of Coolant Accident (LOCA) or Main Steam Line Break (MSLB). The facility consists of volumetrically scaled down containment model and a Primary Heat Transport Model (PHTM) vessel represents the containment system and primary heat transport system of a 220 MWe Indian Pressurized Heavy Water Reactor (IPHWR). The containment model is divided into volume–V1 (dry well) and low enthalpy volume–V2 (wet well). PHTM vessel was pressurized to a predetermined pressure and then it was allowed to blowdown into volume–V1 using a rupture disk. As part of CSF project thermal hydraulic analysis, a pretest analysis was carried out for simulated LOCA conditions in containment using in-house thermal hydraulic code ‘CONTRAN’. Blow down mass and energy discharge data were obtained using RELAP/MOD3.2 code for different blow down conditions were used as inputs to the CONTRAN code. The pressure and temperature transients in the containment model were obtained for initial blow down conditions of 100bar in pressure vessel. Subsequently, a number of parametric studies were carried out to assess the influence of a large number of thermodynamic and geometrical parameters which are known to affect the transients and alter the peak pressure and temperature values.

2 INTRODUCTION

For the purpose of comprehensive research and development program towards enhancing the safety of the Indian Nuclear Power Plants, a Containment Studies Facility (CSF) has been set up at Hall-7, BARC. It is approximately 1:250 volumetrically scaled down model of the prototype 220MWe IPHWR containment system. The facility will be employed for conducting a number of containment related separate effect as well as integral experiments. The objectives of executing the project are to perform experimental studies so as to improve the capability for predicting containment thermal hydraulic behavior during accident scenarios. The experimental setup will enable the generation of a large database for the validation of existing computer codes. Besides, the experimental studies will provide a better understanding of several related complex physical/chemical phenomena, which would help in undertaking development of new theoretical models and also for the improvements of existing models.

One of the objectives of the conducting experiments on the model is to assess its behavior under simulated Loss of Coolant Accident (LOCA) or Main Steam Line Break (MSLB) conditions. As part of the CSF project analysis, it is desired to perform pretest calculations prior to the actual tests, in order to predict the peak pressure and temperature attained within the CSF containment following a simulated LOCA. The transient computations were performed using in-house thermal hydraulics code ‘CONTRAN’. For the purpose of this analysis a multi-compartment configuration of the containment model was considered. The LOCA blowdown mass and energy discharge data for a number of initial blow down conditions at a constant break size were given as input to the present code. The code evaluates the pressure and temperature transients for the above cases based on mass and energy conservation in the subdivided volumes. The containment pressure and temperature transients are influenced by a number of parameters e.g., Initial blow down conditions, integrated mass and energy discharge into the containment, heat transfer to containment structures, suppression pool, containment configuration etc to name a few. Hence, besides estimating the
pressure and temperature transients, the focus of the present study is also to assess the influence of the above parameters on the containment transients.

3  BRIEF DESCRIPTION OF THE EXPERIMENTAL FACILITY

Several areas in analysis for containment design require experimental verification. Therefore, the experimental setup called containment studies facility (CSF) is established at Hall-7, BARC. The proposed experiments will serve to improve the capability for predicting containment thermal hydraulic behavior during accident scenarios and will also help verifying the validity of the mathematical model being used for the analysis. The experimental facility consists of the pressure vessel simulating the primary heat transport system and a concrete containment model. A blow down pipe connects the pressure vessel to the containment model. The arrangement is shown schematically in Fig.1. A brief description of each of the components of the facility follows.

3.1  Containment model

The containment model is a cylindrical structure with an ellipsoidal dome, made out of reinforced cement concrete (RCC) and inside wall surface is coated with epoxy painting. The outer diameter of the model is 6.9 m and its height is 10.95 m. This facility is approximately 1:250 volumetrically scaled down model of the prototype IPHWR. The scaled down model simulates geometrically all the major compartments viz. fuelling machine vaults, pump room vaults, boiler room, dome region, vent annulus, suppression pool etc. The containment model consists of two floors and a basement. The two floors constitute the volume–V1 that contains 6 rooms in total and the basement forms the volume–V2. The suppression pool is also a part of the basement. Volumes–V1 & V2 are connected by vent system having vent pipes or downcomers submerged in the suppression pool.

3.2  Primary Heat Transport Model system (PHTM)

The function of PHTM system is to simulate the LOCA/MSLB by discharging the mass and energy into the containment model. This result in pressure and temperature rise in the containment model. The PHTM system consists of a pressure vessel, feed and bleed system, heater unit, blowdown line and other associated equipments to generate steam at prescribed conditions. The pressure vessel is made of carbon steel with 40mm thick and designed to withstand pressure and temperature up to 128.5bar and 604K respectively. The pressure vessel is equipped with safety systems such as rupture disk, safety relief valves etc. for safe operation. The volume of pressure vessel is about 1 m³ and it is evaluated based on cumulative mass and energy discharge required to simulate LOCA in 220 MWe IPHWR. The pressure vessel has 24 number of submerged U type heater pins and heating rate of each pin is 6kW. The feed and bleed system performs the function of supplying and removing process water from the vessel depending on operating conditions.

3.3  Blow down piping system

The pressure vessel is connected to the containment model by a discharge pipe of 50mmNB (SCH 80) size. A double rupture disc (DRD) with suitable operating mechanism is mounted on this pipe. The blow down could be initiated by causing rupture of these rupture discs. The discharge occurs either in R1 or R2 compartments of the containment model.

3.4  Instrumentation

The containment model and the PHTM system are provided with extensive instrumentation for monitoring pressure, temperature, level, humidity, gas concentrations etc in a number of volumes and required control systems for actuating the DRD, feed and bleed valves etc. A dedicated data acquisition system (DAS) is available to record relevant transient data during the controlled LOCA/MSLB experiments in this facility.
4 ANALYTICAL STUDIES

The pretest analysis was carried out using the in-house code ‘CONTRAN’. The aim of analysis are (i) to estimate the pressure and temperature transients in the containment model with blow down discharge at maximum operating pressure and temperature conditions, (ii) to estimate the peak pressure and temperature together with their time of occurrence and (iii) to study the influence of condensation models, initial conditions, suppression pool and geometrical parameters on containment pressure-temperature transients.

4.1 Computer code CONTRAN

In general, computer codes for containment analysis are developed based on one of the following two approaches; (i) Discretization of the entire containment geometry into a 3-D mesh and solving the relevant governing differential equations and (ii) Dividing the containment geometry into a network of volumes (representing various compartments) which are interconnected by junctions (representing the inter-compartmental openings) and then solving the conservation equations of mass and energy for all the prevailing gas/liquid species in all the volumes of the network. The former approach would require enormous computer storage space and large computational time. The latter approach is more widely used because of its obvious advantages. The in-house computer code CONTRAN (CONtainment TRansient ANalysis) used for the present analysis adopts the second approach. It uses a generalized compartment model consisting of a liquid and a vapour region. The vapour region consists of homogeneous mixture of steam, liquid water droplets and non condensable gases. The prediction of pressure and temperature transients in the containment following a LOCA involves the solution of mass and energy conservation equations formulated suitably. The thermodynamic state of the mixture in any compartment is calculated at the end of each time step based on compartment mass and energy inventories. The inputs to the program are geometrical details, structural materials, heat transfer parameters, initial conditions, blowdown mass and energy discharge data for any break size etc. Prior to initiating the computations, proper initialization of compartment pressure, temperature, humidity etc is a prerequisite (Haware,S.K et al, 2005).

Some salient features of this code are (i) CONTRAN is a multicompartent containment transient analysis code and has been extensively validated against experimental data (Haware,S.K et al, 1994, 1989), (ii) the code can accommodate any number of compartment and at present each compartment can have six junctions.
which may act as inlet or outlet depending on the pressure gradient, (iii) each compartment can have up to three heat slabs of different materials which act as heat sink, (iv) a number of condensation heat transfer coefficient models are available to evaluate heat transfer to containment structures, (v) transient one-dimensional conduction heat transfer model with option of using uniform as well as non-uniform grid sizes is available, (vi) contains a model to evaluate vent clearing transients in the suppression pool (Ghosh, A.K. et al, 1984) and (vii) option of using variable time step for computation.

4.2 Assumptions for the analytical Studies

Steam condensation efficiency of Suppression pool is 100% and air cooling efficiency of Suppression pool is 50%. Tagami, Uchida and Diffusion models were employed for condensation heat transfer coefficient calculation.

4.3 Condensation models

A brief description of all the models used in the present analysis follows:

4.3.1 Tagami correlation

Tagami correlation (Carbajo, 1981) is based on the experiments performed in a small steel cylinder and the results have been extrapolated for large containments. The correlation is applicable to turbulent atmosphere, during blowdown phase only and is good for single compartment modeling. The Tagami correlation for condensation heat transfer coefficient \( h \) is

\[
h = h_{\text{max}} \left( \frac{t_p}{t_p} \right)^5 \tag{1}
\]

\[
h_{\text{max}} = C \left( \frac{Q}{V t_p} \right)^{62} \tag{2}
\]

where \( Q, V \) and \( t_p \) are total energy blowdown (kJ), total free volume of the containment (m³) and blowdown time (sec). The Constant ‘C’ is 45.0 for steel and paint and 18.0 for concrete in SI units (Kansal et al. 2002). This correlation is not applicable beyond blowdown phase.

4.3.2 Uchida correlation

This correlation was developed by injecting steam into a small volume of 1m³ (Almenas, 1982). The heat transfer coefficient \( h \) given by this correlation depends on steam weight ratio as given below:

\[
h = 380.0 \left( \frac{M_a}{M_s} \right)^{0.7} \tag{3}
\]

Where, \( h \) is the heat transfer coefficient (W/m²-K), \( M_a \) and \( M_s \) are mass of air and steam (kg) respectively.

4.3.3 Diffusion correlation

The model utilizes the heat and mass transfer analogy based on diffusion, in which, the condensing vapors diffuse through accumulated non-condensables near condensing surface and gets condensed on the condensing surface. The model assumes that the diffusion boundary layer thickness is larger than film boundary layer thickness because of presence of large amount of non-condensables. Hence the condensate film resistance is negligible in comparison to diffusion layer resistance. The condensation rate \( m \) can be evaluated based on Fick’s law of diffusion when the vapor pressure is more than the saturation pressure corresponding to the wall temperature.

\[
m = \left( D_A \Delta P \right) \left( R \delta T_{\text{wall}} \right) \tag{4}
\]

\[
D_A = \frac{2.0 \times 10^4 P_{\text{cont}}}{[T_{\text{wall}} / 373]} \tag{5}
\]

where, \( A \) is the surface area, \( \Delta P \) is the difference between the partial pressure of steam and steam saturation pressure corresponding to wall surface temperature, \( R \) is gas constant of steam air mixture and \( \delta \) is the boundary layer thickness taken as 1mm. \( D \) is the diffusion coefficient taken as 1.9 x 10⁻⁵ m²/s and \( T_{\text{wall}} \) is the wall surface temperature. The condensation heat transfer \( Q \) is estimated by using mass transfer rate and the difference of the specific enthalpy of the steam and the liquid phase.

\[
Q = m (h_g - h_L) \tag{6}
\]

\[
Q = m (h_g - h_L) \tag{6}
\]
\[ h = \frac{Q}{(\Delta T \cdot A)} \]  

(7)

Where \( h_g \) is the enthalpy of steam and \( h_L \) is the enthalpy of liquid. The condensation heat transfer coefficient \( h \) can be evaluated from the rate of heat transfer \( Q \), available surface area \( A \) and the difference between the containment ambient temperature and wall temperature \( T \).

4.4 Input data

The initial conditions in the containment assumed for the analysis are pressure \( 101.3 \text{kPa} \), temperature \( 305.5 \text{K} \) and relative humidity (RH) in volume–V1 and V2 is 0% and 60%, respectively. Geometrical data such as volume and surface area of each room present in volume–V1 and V2 of containment, flow area between two rooms/compartment and the thermo physical properties of concrete such as density, specific heat capacity and thermal conductivity were some of the inputs. Blowdown mass and energy discharge rate from pressure vessel to containment model is evaluated separately using RELAP 5/Mod3.2 thermal hydraulic code for six different vessel initial conditions (i.e. operating pressure) such as 10, 20, 30, 50, 75 and 100 bar. These blowdown mass and energy discharge data for six different vessel operating pressure is shown in fig.2 and 3 and they were used as inputs to CONTRAN code.

![Figure 2. Blow down discharge rate Vs time](image2)

![Figure 3. Specific enthalpy Vs time](image3)

![Figure 4. Two volume configuration](image4)

![Figure 5. Seven volume configuration](image5)
4.5 Compartmental connectivity of containment model

The number of compartments and the configuration considered for analysis also influences the containment pressure and temperature transients. Therefore the containment mode was divided into several nodal compartments/rooms. Analysis was carried out for three different cases which are as follows:

i) Case-1 (2-Volume case): The containment model is divided into two nodal volumes which are shown in fig. 6. The Volume V1 is the sum of volumes of room 1 through 6 and V2 is the room 7. V1 represents the break compartment and it is connected to volume V2 by vent junction represents the vent pipes to suppression pool.

ii) Case-2 (7-Volume: door closed): The room R1 and R6 is connected by a door (refer fig. 1) of area 2.4m² apart from other small connections. In this case the door is assumed to be closed to see the flow between the compartments and its effects on pressure and temperature.

iii) Case-3 (7-Volume: door open): The door between room R1 and R6 is assumed to see the flow between the compartments and its effects on pressure and temperature.

5 RESULTS AND DISCUSSION

Based on the blow down mass and energy discharge data given by Fig. 2 and 3, the integrated mass and energy discharged into the containment is evaluated for all the cases and are shown in Table 1. The blow down duration for all the cases is different and the integrated mass and energy discharged increases with the blowdown pressure.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Blowdown pressure (bar)</th>
<th>Duration of blow down (s)</th>
<th>Integrated mass discharge (kg)</th>
<th>Integrated energy discharge (million kJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>351</td>
<td>162.6</td>
<td>0.279</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>320</td>
<td>215.4</td>
<td>0.380</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>358</td>
<td>251.4</td>
<td>0.449</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>287</td>
<td>303.4</td>
<td>0.558</td>
</tr>
<tr>
<td>5</td>
<td>75</td>
<td>263</td>
<td>353.5</td>
<td>0.658</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>225</td>
<td>398.2</td>
<td>0.780</td>
</tr>
</tbody>
</table>

5.1 Effects of condensation models

One of the most important factors influencing the containment pressure-temperature transients following an accident is the heat transfer to the structure. Among the various modes of heat transfer, the one involving the condensation of steam on the containment structure plays an important role. The effect of using different models for condensation of steam has been studied and the results are presented. Comparison of peak pressure obtained for 10bar and 100bar blowdown pressures using various condensation models is shown in table 2. From the table 2 it can be observed that the Tagami correlation gives the highest pressure for all the cases and Diffusion gives the lowest. Therefore the condensation heat transfer calculated using different models plays the vital role in determining the containment peak pressure and temperature.

<table>
<thead>
<tr>
<th>Condensation models</th>
<th>Blowdown pressure (bar)</th>
<th>Peak Containment Pressure (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 volume</td>
<td>7 volume open door</td>
</tr>
<tr>
<td></td>
<td>V1</td>
<td>V2</td>
</tr>
<tr>
<td>Tagami Model</td>
<td>10</td>
<td>152.7</td>
</tr>
<tr>
<td>Uchida Model</td>
<td>132.3</td>
<td>120.3</td>
</tr>
<tr>
<td>Diffusion model</td>
<td>123.0</td>
<td>111.0</td>
</tr>
<tr>
<td>Tagami Model</td>
<td>100</td>
<td>259.1</td>
</tr>
<tr>
<td>Uchida Model</td>
<td>217.3</td>
<td>205.4</td>
</tr>
<tr>
<td>Diffusion model</td>
<td>207.2</td>
<td>195.2</td>
</tr>
</tbody>
</table>
Fig. 6 and 7 show the containment pressure and temperature transient (2-volume case) for 100 bar blowdown pressure. Containment pressure transients calculated using Uchida model is lies between Tagami and Diffusion model predictions and in the same way the containment temperature transients are also varying. The containment pressure starts rising till the blowdown rate is higher than the condensation rate and starts decreasing when the condensation rate is predominant. Blowdown takes place in V1 volume and the blowdown steam purges steam air mixture from V1 to V2 volume through suppression pool and steam get condensed in the pool (100% condensation is assumed) and air escapes into V2 volume. Therefore the partial
...pressure of air in V1 volume starts decreasing and steam partial pressure starts rising. In V2 volume partial pressure of air starts rising and it loses heat but convective heat transfer. Since the steam present in V1 volume gets condensed, the V1 pressure falls below V2 pressure after some time. Peak pressure obtained using different condensation models are different; therefore the upcoming experimental facility would be helpful in selecting the appropriate condensation model. Since Uchida model is extensively used for calculating the containment condensation heat transfer coefficient, it is used in present analysis for studying the effects of various parameters.

5.2 Pressure and temperature transients for maximum rate of discharge

From fig.2 and 3 we can see that the maximum rate of discharge occurs when initial blow down condition in pressure vessel is 100 bar and 311.1°C. Cumulative blowdown mass and energy that are shown in table 1 is high for 100bar blowdown pressure. Therefore pressure and temperature transients in containment model are evaluated for all the three cases (i.e. 2-volume, 7 volume: closed door and 7 volume: open door) with the mass and energy discharge data obtained for 100bar blowdown pressure. Fig.8 shows the pressure transients obtained for all the three cases. Fig.9 to 11 show the temperature transients for case-1 (2-volume), case-2 (7 volume: closed door) and case-3 (7 volume: open door) respectively. The peak pressure in volume V1 and V2 reaches 217.3 kPa and 205.4 kPa and peak temperature reaches 394.1K and 369.1K for Case-1 (2-Volume case) using Uchida Model.

5.3 Effects of blowdown mass and energy discharge

Two-volume configuration (fig.4) was considered for carrying out the parametric studies. Based on the blow down mass and energy discharge data given by fig.2 and 3, the pressure and temperature transients were obtained in the containment for all the blowdown pressures. Table-1 shows that higher the operating pressure and temperature in pressure vessel prior to initiation of blowdown would result in higher integrated mass and energy discharge into the containment and this result in higher containment pressure and temperature. Fig.12 shows the V1 volume pressure transients for different blowdown pressure.

Figure 12. Containment pressure transient for all blowdown pressures for 2 volume case.

5.4 Effects of initial conditions

5.4.1 Initial containment temperature

The initial containment ambient temperature in a prototype nuclear power plant could vary depending on the seasonal variation and the heat dissipation from the high enthalpy systems inside containment. Therefore in this study the initial containment ambient temperature was changed to see the effect on pressure and temperature transients. It was observed that, with the increase in the initial temperature, the containment peak pressure also increases in both V1 and V2 volume. Like wise the containment peak temperature also increases with the containment initial temperature. Higher the initial containment temperature in the containment results in low initial mass of air inside the containment on account of lower density. However the initial wall surface temperature also high due to attaining of thermal equilibrium with the initial containment temperature and it largely affects the containment condensation. Wall condensation will not

![Figure 12](image-url)
occur till the steam partial pressure exceeds the saturation pressure corresponding to wall surface temperature. Therefore, lower the wall surface temperature (due to low initial containment ambient temperature) earlier the wall condensation and more mass and energy transfer takes place and results in reduced peak pressure and temperature for low initial containment temperature. Effect of variation of the initial temperature on containment pressure and temperature transients in V1 and V2 volume using Uchida model for 100bar blowdown pressures (for case-1: 2 volume) is shown in fig.13 and 14. The containment peak pressure and peak temperature increases by 3% and 4% respectively when the initial containment temperature increased from 20°C to 45°C.

![Figure 13](image1.png)  
**Figure 13.** Containment pressure transient for 100bar blowdown pressure for different containment initial temperatures.

![Figure 14](image2.png)  
**Figure 14.** Containment temperature transient for 100bar blowdown pressure for different containment initial temperatures.

![Figure 15](image3.png)  
**Figure 15.** Containment pressure transient for 100bar blowdown pressure for different Relative Humidity values.

![Figure 16](image4.png)  
**Figure 16.** Containment temperature transient for 100bar blowdown pressure for different Relative Humidity values.

5.4.2 Initial relative humidity (R.H) of containment atmosphere

The other seasonal varying parameter is initial relative humidity present in containment atmosphere. To understand the influence of this parameter on the containment transients a case study was carried out. It was observed that, the containment peak pressure decreases in both V1 and V2 volume with the increase in the initial R.H. This is due to the fact that, a higher initial R.H results in increased energy absorption by the containment atmosphere. Water vapor contains more energy, due to latent heat, than air. High R.H means more quantity of water vapor in the containment atmosphere and, therefore, it increases the amount of energy it can absorb. It was found that variation of R.H from 0% to 90% causes a reduction in containment peak pressure by about 2%. Thus assuming 0% initial R.H in containment will result in a conservative estimate of the containment peak pressure. Influence of initial R.H on containment pressure and temperature transients
in V1 and V2 volume using Uchida model for 100bar blowdown pressures (for case-1: volume) is shown in Fig.15 and 16.

5.5 Effects of geometrical parameters

5.5.1 Effect of multi compartment configuration

The number of compartments and the configuration considered for analysis also influences the containment pressure and temperature transients. In this study, two configurations were considered; one is two-volume configuration and other is seven-volume configuration. For the two-volume case (see fig.4) the blow down injection is in volume V1 taken as a whole. For the seven-volume case (see fig.5), the injection is in room 1 of volume V1.

Fig.17 and 18 show the pressure transients for various cases (1, 2 and 3) for 100bar blowdown pressure using Tagami and Uchida model respectively. From these plots it is observed that the peak pressure is high for case-2 (7 volumes: closed door) when Tagami condensation model is used and peak pressure is high for case-1 (2 volumes) when Uchida model is used. This is because of variation of condensation heat transfer coefficient in all the cases is identical when Tagami model is used. In Uchida model the heat transfer coefficient is function of ratio of mass air and steam present in a room/compartment, therefore the heat transfer coefficients in various rooms in all the cases are different.

For case-1 (2-volume), the variation of partial pressure of air and mass of air in volume V1 and V2 are shown in fig.19 and 20, respectively for 100bar blowdown pressure using Uchida model. Similarly the partial pressure of steam and mass of steam variation is shown in fig.21 and 22 respectively for the same case. It is observed that partial pressure of air (fig.19) in volume–V2 rises faster and higher than the volume V1. During blowdown steam-air mixture is flowing from V1 to V2, therefore mass of air in volume in V1 starts reducing and in V2 it is rising. Temperature in V1 and V2 volume also rises but in V2 volume the peak temperature obtained is less than V1 volume. It is also to be noted that volume (m³) of V1 is higher than the volume of V2. The partial pressure of steam (fig.21) in volume–V1 starts rising due to blow down and in volume–V2 it is not rising due to condensation of steam in suppression pool and the mass of steam variation in volume–V1 and V2 is similar to partial pressure variation.

For case-2 (7-volume: closed door), the variation of partial pressure of air and mass of air in all the rooms/compartments of volume V1 and V2 are shown in fig.23 and 24 respectively and the partial pressure of steam and mass of steam variation in all rooms are shown in fig.25 and 26 respectively for the same case. The partial pressure of air (fig.23) in rooms 1, 2 and 3 starts reducing right from the initiation of blowdown and in rooms 4 and 5 first it starts rising and then it starts decreasing. In rooms 6 and 7 the partial pressure of air starts rising and reduces at a lower rate. The variation of mass of air (fig.24) in all the rooms/compartments is similar to the variation of partial pressure of air. The peak partial pressure of steam (fig.25) in rooms 1, 2 and 3 is around 200kPa and in rooms 4 and 5 is around 100kPa and in room 6 it is 45kPa. The mass of steam is high in room 5 because it is volume is larger than other volumes (fig.26). From the fig.23 to 26, it is observed that the steam flows from room 1 to 3 and from room 3 to 5 and from 5 to 6 and from room 6 to volume–V2 (i.e. room7) through suppression pool. The steam takes longer path before reaching volume–V2 through suppression pool. Therefore it purges the more air to volume–V2 and less steam flow through suppression pool and results in more steam held up in volume–V1 thereby high partial pressure of steam.

For case-3 (7-volume: open door), the variation of partial pressure of air and mass of air in all the rooms/compartments of volume V1 and V2 are shown in fig.27 and 28 respectively and the partial pressure of steam and mass of steam variation in all rooms are shown in fig.29 and 30 respectively for the same case. The door between room 1 and 6 is assumed to be open in this case. Therefore the partial pressure of air (fig.27) in rooms 1, 6, 3 and 2 are starts reducing initially and then gradually rising. But in rooms 4, 5 and 7 the partial pressure of air starts rising initially and decreases at a slower rate. The variation of mass of air in all the rooms is varying in respect to the partial pressure variation. The peak partial pressure of steam (fig.29) occurs in room 1 and next occurs in room 6, 3 and 4 respectively and lowest peak partial pressure of steam is obtained in room 4 and 5. Since the volume of room 6 is second largest among the rooms in volume–V1, the mass of steam present in this room is also high (fig.30). From the fig.27 to 30, it is observed
Figure 17. Containment pressure transients for various configurations for 100 bar blowdown pressure using Tagami model

Figure 18. Containment pressure transients for various configurations for 100 bar blowdown pressure using Uchida model

Figure 19. Variation of partial pressure of air in volume V1 and V2 for (case-1: 2-volume) using Uchida model

Figure 20. Variation of mass of air in volume V1 and V2 for (case-1: 2-volume) using Uchida model

Figure 21. Variation of partial pressure of steam in volume V1 and V2 for (case-1: 2-volume) using Uchida model

Figure 22. Variation of mass of steam in volume V1 and V2 for (case-1: 2-volume) using Uchida model
Figure 23. Variation of partial pressure of air in different rooms for (case-2: 7-volume closed door ) using Uchida model

Figure 24. Variation of mass of air in different rooms for (case-2: 7-volume closed door ) using Uchida model

Figure 25. Variation of partial pressure of steam in different rooms for (case-2: 7-volume closed door ) using Uchida model

Figure 26. Variation of mass of steam in different rooms for (case-2: 7-volume closed door ) using Uchida model

Figure 27. Variation of partial pressure of air in different rooms for (case-3: 7-volume open door ) using Uchida model

Figure 28. Variation of mass of air in different rooms for (case-3: 7-volume open door ) using Uchida model
5.5.2 Effect of down comer submergence depth

The volume–V1 is connected to volume–V2 through vent pipes and suppression pool. The one end of vent pipe is in volume V1 and the other end is submerged into suppression pool (fig.1). The height from the suppression pool water surface to the bottom end of vent pipe is called submergence depth. It was observed that with the increase in depth of downcomer submergence, the peak pressure in the volume V1 rises. The time-integrated pressure (area under the pressure curve) also increases. This behavior can be explained by the act that as the depth increases, the pressure require to clear the suppression pool water in vent pipes also increases and the flow through vent pipes also reduces due to increased resistance. Subsequently, this results
in higher V1 volume containment peak pressure. This phenomenon also explains the delay in vent opening time following an accident. Effect of downcomer submergence depth on containment pressure transients in V1 and V2 volume for 100bar blowdown pressures (case-1:2-volume) is shown in fig.31.

5.5.3 Effect of number of vent pipes/down comers

Similar to submergence depth, the vent flow area (depends upon the number of vent pipes) is also influence the pressure transient in containment due to LOCA/MSLB. The vent flow area can be altered by changing the number of downcomers/vent pipes available for service. Fig.32 shows the pressure transients obtained in V1 and V2 volumes (for 100bar blowdown pressure) with all the 8 downcomers available and no downcomers available. If downcomers are not available then steam-air flow does not reach volume V2 (no flow path available) and only V1 is available (V1/V2 ratio infinity). It can be seen that as the vent flow area increases, the peak pressure and time integrated overpressure decreases. With all the downcomers/vent pipes available, the pressure in volume–V1 is reduced by 8.5% and 30% for 10bar and 100bar blowdown pressure respectively.

Figure 33. Peak pressure variation for different V1/V2 ratio for 10bar blowdown pressure.

Figure 34. Peak pressure variation for different V1/V2 ratio for 100bar blowdown pressure.

Figure 35. Containment pressure transient in V1 volume for with and without suppression pool.

Figure 36. Containment pressure transient in V2 volume for with and without suppression pool.

5.5.4 Influence of V1/V2 ratio

For a suppression pool type of containment one of the most important parameters is the V1/V2 ratio. For a given total containment volume, if this ratio is altered then the containment peak pressure may attain a different value. The volume ratio in the present study was altered by suitably opening or closing inter-compartmental opening between rooms in volume–V1 and since no compartments are available in volume–V2, the volume was reduced hypothetically for studying the effects of V1/V2 ratio. Effect of V1/V2 ratio on containment peak pressure for 10bar and 100 blowdown pressure is shown in fig.33 and 34. It may be noted
that containment peak pressure is high when the V1/V2 ratio is lowest. However, the peak pressure reduces with increasing the ratio of V1/V2 till the certain value and again shows upward trend. From this study it is observed that V1/V2 ratio is also affects the peak pressure.

5.6 Effect of Suppression pool

Effect of suppression pool on containment pressure transient is studied by assuming availability and unavailability of suppression pool. Fig.35 and 36 show the containment pressure transients in V1 and V2 volumes for different blowdown pressures when suppression pool is available and not available. At low blowdown pressure the V1 volume pressure is higher when suppression pool is available and this is due to the less pressure difference to overcome the flow resistance. In case of higher blow down pressures, the V1 volume pressure is lesser when suppression pool is available. Therefore, at higher pressures the suppression pool is effective in reducing the peak pressure.

6 CONCLUSION

The effect of various parameters on the containment pressure and temperature transients has been estimated using in-house code CONTRAN by conducting parametric studies. A large number of factors are found to influence these transients. Based on the parametric studies conducted, the following main conclusions can be drawn (i) higher initial energy content working fluid in pressure vessel prior to blowdown increases the mass and energy discharge during blow-down into containment which further results in increased peak pressure as well as time integrated over pressure, (ii) low initial RH in containment results in higher peak pressure, (iii) lower initial containment temperature results in lower peak pressure, (iv) condensation heat transfer to the structure plays an important role and therefore care needs to be exercised in selecting the appropriate condensation model, (v) compartments and its arrangement inside the containment that are considered for the analysis will also affect containment transients significantly, (vi) higher depth of submergence of vent pipes in suppression pool would result in higher peak pressure, (vii) larger vent flow area would results in more steam-air mixture flows to pool thereby resulting in lower peak pressure, (viii) appropriate V1/V2 ratio is to be selected for getting optimized peak pressure and (ix) at higher pressures the suppression pool is effective in reducing the peak pressure.

It was observed that all these parameters have varying degree of influence individually on the containment pressure transients. However, the integral effect of all the parameters would be very significant. These pretest calculations will provide prior insights to carry out the experiments related the containment thermal hydraulics.

REFERENCES


