Extreme Pressure and Thermal Loads on 500 MWe PHWR Containment Following Steam Line Break

M. Das, R. N. Bhawal, P. Prakash
Nuclear Power Corporation of India, Ltd., Bombay, India

INTRODUCTION

Indian PHWRs adopt vapour suppression type of containment system. The vapour suppression type of containment calls for containment to be divided into two accident based volumes, drywell (volume V1) and wetwell (volume V2), separated by leaktight walls and floors. Drywell encompasses all enclosures housing the high enthalpy Primary Heat Transport (PHT) system and part of the secondary system. The rest of the containment building constitutes wetwell and includes all those areas of the building that are accessible during reactor operation. The design of the containment system requires evaluation of pressure and temperature transients in the containment following postulated rupture in pressure boundary of primary and secondary coolant systems. Reactor building containment structure is designed to withstand extreme load conditions following these postulated accidents. In this paper methodology adopted for calculation of R.B. peak pressure and temperature have been discussed and results of pressure and temperature transients following a steam line break within the containment have been reported.

ACCIDENT SCENARIO

In the postulated event of steam line break high enthalpy steam flashes into the containment from the Steam Generators (SG) through the break. While steam generator water boils at low pressure, it rapidly removes the heat stored in primary and secondary system hardware, primary coolant, fuel and decay heat. As the high enthalpy steam discharges into the drywell the consequent rapid pressure build up forces the air steam mixture into the suppression pool via the vent shaft and distribution header system. The steam condenses in the pool water and the air is vented to the wetwell.

METHODOLOGY

To assess the mass and energy discharge into the containment following steam line break, the primary heat transport and the secondary circuits have been modelled in number of control volumes with lumped parameter assumption. One dimensional heat flow for heat transfer between different components of the system and critical flow for blow down calculation have been considered. Colburn correlation has been used for film heat transfer co-efficients on primary side and natural convection equation for calculating the same in the secondary side. Figure 1 shows the schematic of primary and secondary circuit as modelled for steam mass and energy discharge rate calculation. The four SGs have been grouped into two banks each having two SGs. Two isolation valves in series have been provided on the interconnecting line joining these two banks to limit the discharge of steam into the containment from two SGs only, incase of steam line break. Normally these valves are kept closed and opened only during testing of turbine stop valves. The present analysis postulates a steam line break at the time of testing assuming a delay of 5 seconds for the closure of these valves.

The mass and energy discharge rates thus obtained are used as input for containment pressure and temperature transient analysis. For this analysis a computer code PACSR (Post Accident Containment System Response) has been used for pressure suppression type of containment system. In this code the containment is modelled in two volumes (i.e. drywell and wetwell) which are connected through vent shaft, distribution header and suppression pool. Each volume is treated as having two regions, liquid and vapour. The liquid region consists of water on the floor either condensed steam or suppression pool water. Above the liquid region in each volume the vapour region exists which comprises of air, steam and liquid droplets (if present). These two regions may have different temperatures. Other features like air coolers, structural walls/floors which serve as heat sinks, leak path between volume V1 & volume V2 (i.e. by passing of suppression pool system) have also been modelled. A variable finite time step method is used for transient calculation. In each time interval, the amount of flashed steam mass and energy added to the containment atmosphere is assumed to mix uniformly with the drywell vapour region. The resulting pressure build up causes clearing of vents in the suppression pool and subsequently steam and air mixture flows into the pool water.

Pressure Suppression System

Suppression pool system has been modelled in two parts. Vent clearing transient and steam air flow transient. Vent clearing transient is modelled by one dimensional incompressible flow momentum equation to find water expulsion rate and time at which vent clearing transient is over.

For steam-air flow, incompressible homogeneous flow model is used for simplicity. This assumption is reasonable owing to the fact that pressure drop along the flow path of vent shaft is not large compared to absolute pressure in drywell. An overall loss factor and inertia of flow path for the vent system are fed as input data. While passing through suppression pool water steam gets condensed in the water and air gets released into the wetwell volume after partial cooling inside water. The analysis considers 100% condensation of steam passing in the suppression pool. However, the air emerging from the pool into the wetwell volume is assumed to be saturated with water.

Building coolers

The energy removal rate for the air coolers is assumed to be temperature dependent and is represented as a function of drywell vapour region temperature.

Structural walls/floors

Structural walls/floors have been simulated as consisting of several heat conducting elements where thermal behaviour is described by one dimensional heat conduction equation for slab geometry. For convective heat transfer at surface of these elements Tagami model for concrete structures has been used.

Leak path

Leak path between drywell and wetwell has been simulated by providing an opening area (equivalent to leak area) and considering homogeneous compressible fluid, orifice flow model. No steam condensation is allowed for these steam and air mixtures flow which is by passing the suppression pool.

Pressure & temperature calculation at the end of each time step of iteration

Considering all the above air and steam mixture flows, heat input and heat removal the mass and energy of drywell and wetwell are updated. The new pressure and temperature are calculated from mass and energy balance using Newton-Rapson method.

RESULTS

While calculating steam discharge rates from the break into the containment the steam which is released through relief valves (electromatic relief valves), atmospheric discharge valves (ASDVs) & condenser steam dump valves (CSDVs) has also been calculated as shown in figure 2 & 3. It is seen that after 5 seconds when two banks of SG get isolated by closure of the isolation valves (ref. figure-1), almost 50% of the total steam discharged from steam generators finds its way through the relief valves/SDVs. Remaining 50% comes into the containment thus substantially reducing the load on the containment.

With the mass and energy discharge rate of steam as input, the containment pressure and temperature transient calculations show (figures 4 & 5)that maximum pressure in the R.B is about 1.44 kg/sq.cm(g) at about 325 secs. after the break. Whereas peak temperature is about 136 °C at the initial period of blow down at about 50 secs. This peak in temperature is due to unsaturated R.B atmosphere at the initial stage when high enthalpy steam is coming. After it becomes saturated and R.B emergency coolers also start operating (a delay of 60 secs. is assumed), the temperature falls rapidly. After that there is, a near balance between heat loss and heat gain due to temperature gradient until at the end when temperature starts falling.

R.B. structural floors and walls also absorb heat and gradually average temperature rises. Figures 6 & 7 show the temperature profiles for across the walls of drywell and wetwell at different time intervals. The results of these calculations have been produced for longer time to show how the profile changes with time.

CONCLUSION

Steam line break within containment is an important accident that needs proper consideration for containment structural design. It is noted that this accident results in higher temperature than that of LOCA. However, for containment design the worst combination of pressure and temperature at different time and for different accidents has to be considered as extreme design loads. The methodology of analysis as described in the paper can also be used for other types of accidents viz. LOCA to arrive at containment pressure and temperature.

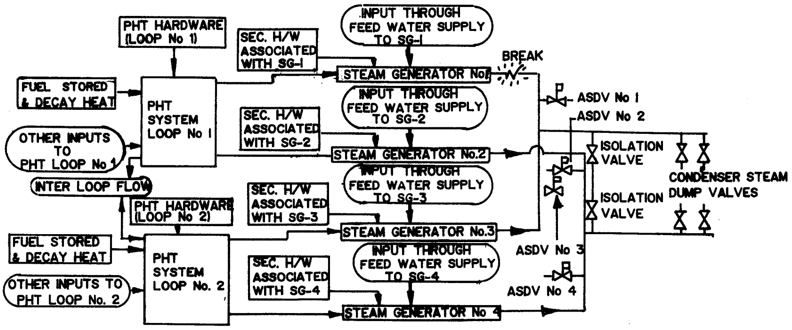

FIG. 1: HEAT FLOW SCHEMATIC FOR THE MAIN STEAM LINE BREAK ANALYSIS

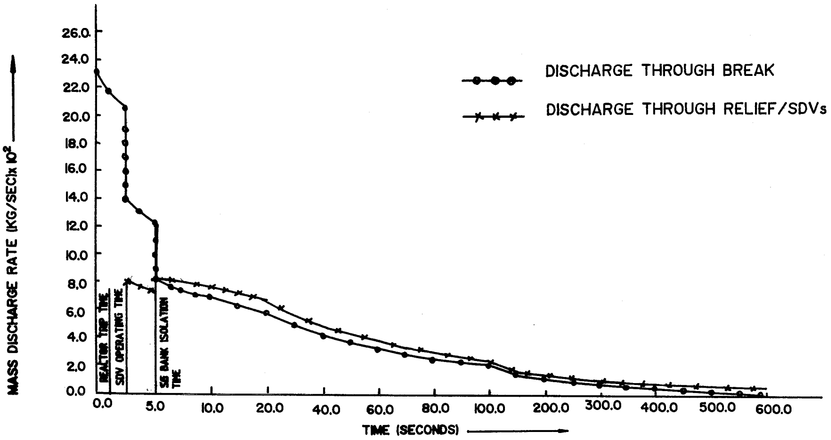

FIG. 2: MASS DISCHARGE RATES FROM BREAK & SDVs FOLLOWING MAIN STEAM LINE BREAK

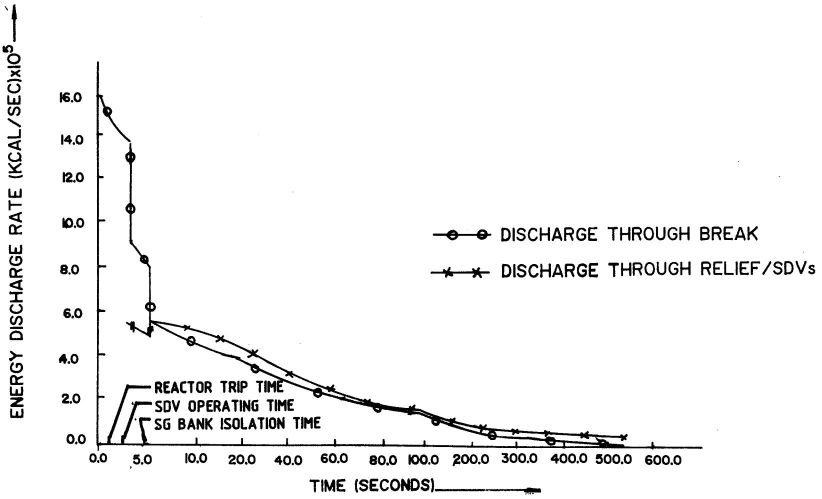

FIG. 3: ENERGY DISCHARGE RATES FROM BREAK & SDVs FOLLOWING MAIN STEAM LINE BREAK

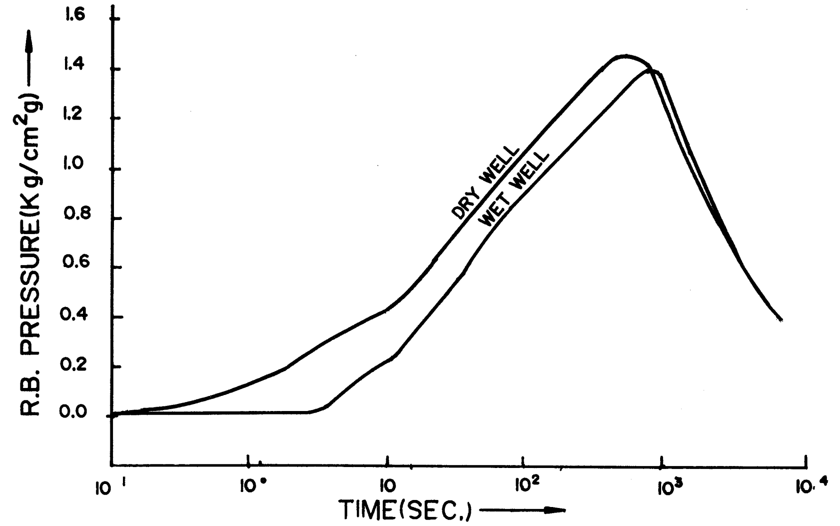

FIG. 4 : REACTOR BUILDING PRESSURE TRANSIENT FOLLOWING MAIN STEAM LINE BREAK

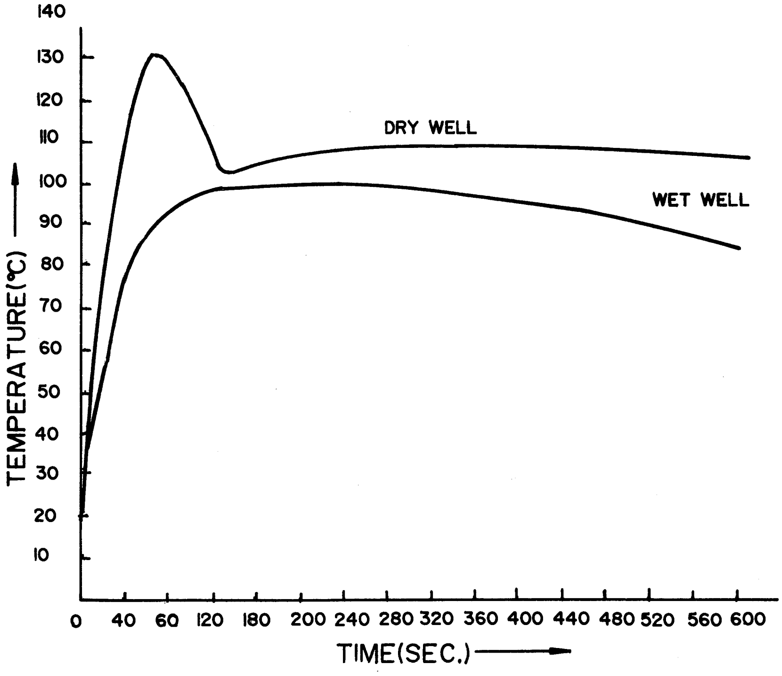

FIG. 5 : REACTOR BUILDING PRESSURE TRANSIENT FOLLOWING MAIN STEAM LINE BREAK

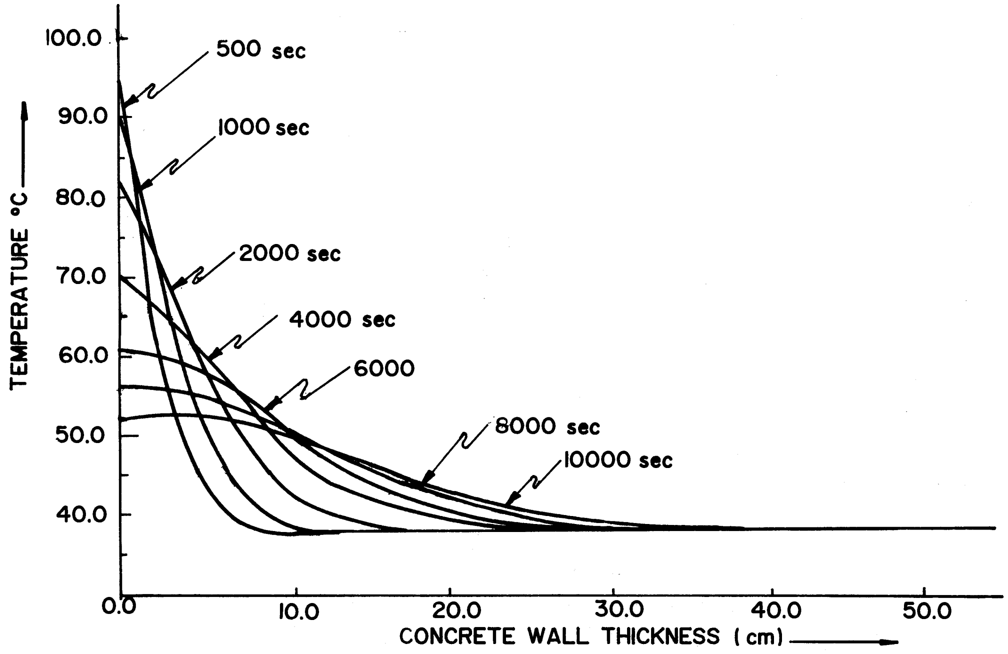

FIG. 6 : TEMPERATURE PROFILE ACROSS THE PERIMETER WALL OF DRY WELL

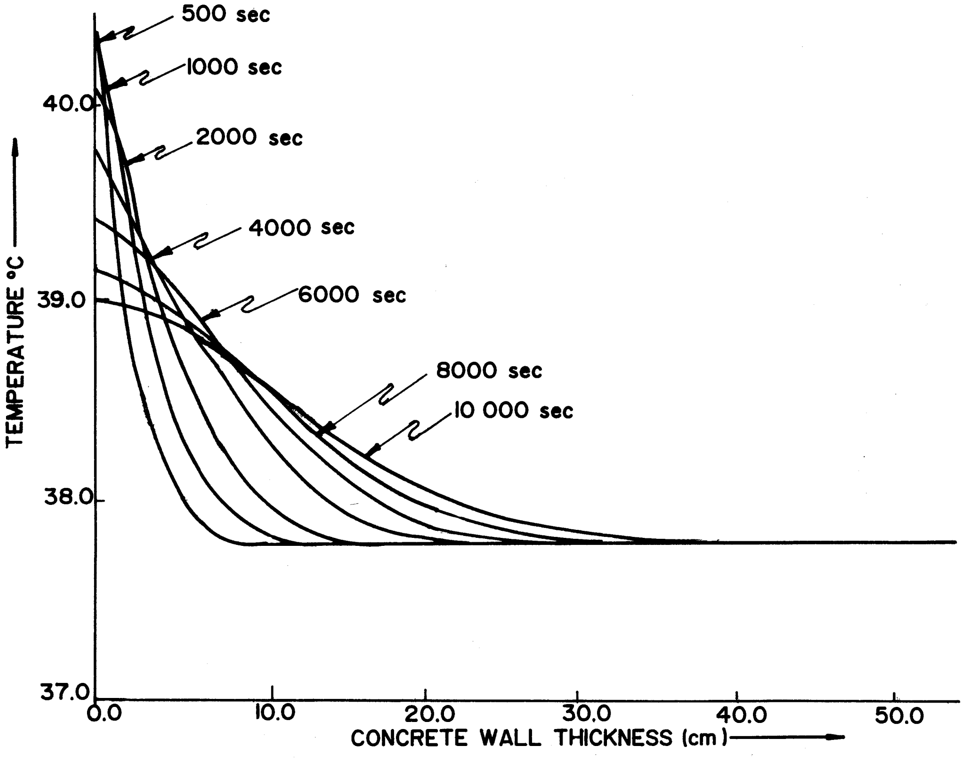

FIG. 7 : TEMPERATURE PROFILE ACROSS THE PERIMETER WALL OF WET WELL