ABSTRACT

Fast BreederReactors (FBRs) are provided with redundant and diverse plant protection systems with a very low failure probability (<10^{-6}/reactor year), thus making Core Disruptive Accident (CDA), a Beyond Design Basis Event (BDBE). Nevertheless, safety analysis is carried out even for such events in order to mitigate their consequences by providing engineered safeguards such as the in-vessel core catcher. During a CDA, a significant fraction of the hot molten fuel moves downwards and gets relocated to the core catcher. The core catcher design requires prior knowledge of core-melt relocation time which is the time taken for the molten fuel to reach the lower plenum from the active core region. This is because of the fact that the decay heat contained in the fission products of the core-melt is a strong function of time. Therefore the initial thermal load on the core catcher is primarily dictated by the core melt relocation time.

This research work aims at determining the upper and lower bounds for core-melt relocation time for postulated accident conditions of Protected Loss of Heat Sink (PLOHS) accident and Unprotected Loss of Flow Accident (ULOFA) respectively. The natural convection setting in the cold sodium plenum which can influence this time estimate is also studied with a view to prescribe proper boundary condition for the grid plate bottom following a ULOFA. Finally, a new multi layer core catcher capable of handling the debris generated from a whole core melt down accident is proposed.

In the first part of the research, natural convection of liquid sodium contained in the cold plenum below the grid plate has been investigated in detail employing a low Reynolds number k-ε turbulence model. The two dimensional axisymmetric study considers heat conduction in the thick grid plate and natural convection in liquid metal simultaneously, both in laminar and turbulent regime. Based on this study, suitable
correlations for Nusselt number in terms of Boussinesq number and other influencing parameters has been developed for various specifications of boundary conditions.

The second part of the research focuses on estimating the time taken for grid plate melt-through in case of ULOFA. Towards this, a computer code HEATRAN-1 has been developed which solves transient nonlinear heat conduction equation including phase change using a finite difference method. It is based on enthalpy formulation incorporating Voller’s improved algorithm for tracking the melt-front. To account for displacement of lighter molten steel by the heavier core-melt, a dynamic displacement procedure has been adopted. The code has been validated against standard benchmark solutions for Stefan problem. In case of PLOHS accident, molten material relocation is analyzed starting from the active core region, sequentially moving through the lower axial blanket region, lower fission gas plenum, tail piece of subassembly with flow entry nozzles and honeycomb structures for flow zoning, discriminator at the foot of the subassembly and the grid plate. Each region is approximated as a porous body with effective thermophysical properties and heat conduction analysis is performed to estimate the core-melt relocation time.

In the final part of research work, a new multi layer core catcher is conceptualized which essentially consists of a top refractory layer, a middle delay bed layer and a base load bearing structural member. The thickness of the intermediate delay bed has been optimized by analyzing the transient response of the composite structure, taking into account time varying decay heat of core debris. The purpose of this transient two dimensional heat transfer study is to limit the temperature at the base layer within design safety limits following a whole core accident.