External Core Catcher Cooling

Dr. Ravi L[1], Sharath R[2], Samyak Darshan C.B[3]

1- Assistant Professor Mechanical Engineering; 2, 3- B.E –Mechanical Engineering Final Year Students,
B.M.S College of Engineering, Bengaluru
1 – ravi.iisc.5@gmail.com, 9482009415
2 – sharath.r.herle@gmail.com, 9035693849
3 – samyak.darshan1998@gmail.com, 7483545503

In pool-type sodium cooled fast reactors the entire radioactive primary sodium circuit is housed in a single vessel, known as the 'main vessel' (MV). The components supported by the main vessel are core support structure (CSS), Core catcher (CC), grid plate (GP), core subassemblies, primary sodium pipes, pump header and inner vessel (Fig.1).

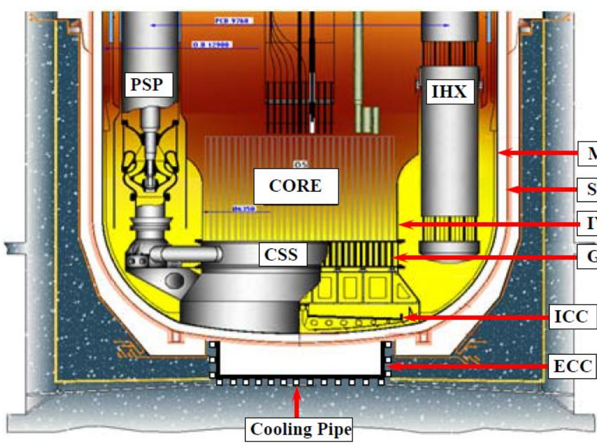

Fig.1 Reactor vessel with internal and external core catcher.

The internal core catcher is an in-vessel retention device provided at the bottom of the reactor assembly beneath the core, for accommodating, cooling and maintaining the subcritical state of the core debris generated during severe accidents, as well as to guard the reactor main vessel. PFBR in-vessel core catcher was originally intended for 7 subassemblies melt. Subsequent, thermal-hydraulic analysis of the core catcher indicated that it can accommodate 19 subassemblies melt respecting the temperature limits. Later, the dimensions of the core catcher have been increased such that it can accommodate the volume of whole core melt and the mechanical load arising out of whole core weight and CDA pressure loading. Also, the temperature limits acceptable for the core catcher has been arrived at by detailed thermo-mechanical analysis.

The enlarged section view of the internal core catcher of PFBR with construction details is depicted in Fig.2.

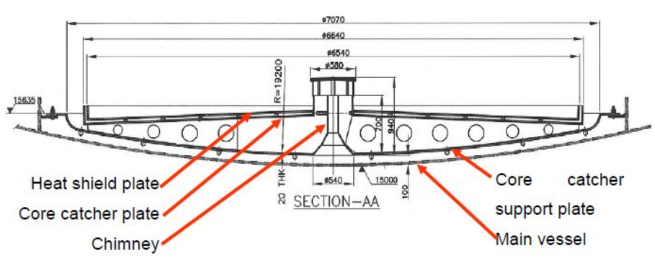

Fig.2: PFBR Core catcher.

FUNCTIONS OF THE CORE CATCHER: The core catcher is considered as an important safety component of the reactor to provide with the following safety functions: (1) To accommodate the volume of whole core inventory, mechanical load of the core melt and Core Disruptive Accident (CDA) pressure during core melting. (2) To maintain the subcritical state of core debris. (3) To cool down core debris and to guaranty the cool ability for a long duration.

CORE CATCHER CONCEPTS AND TYPES:

The primary objective of a core catcher is to bring molten core debris to rest in a cool able configuration without the escape of radioactive fission products. The core catcher can be either (a) in-vessel (i.e. within the main vessel) or (b) ex-vessel. Generally, the types of core catcher can be classified into (a) tray concept, (b) crucible concept and (c) sacrificial bed concept, as depicted in Fig.3. The in-vessel system has the advantage that the containment envelope is not enlarged. Moreover, a large quantity of sodium is present within the main vessel, which is adequate for heat rejection. The ex-vessel has the advantage that since it is not in contact with high temperature during the normal condition, the choice of potential materials is widened; for example, neutron poisons can be incorporated in the ex-vessel device.

Internal core catcher trays (b) External crucible with a conical spreader, thick liner and forced cooling (c) Cylindrical sacrificial bed with forced cooling

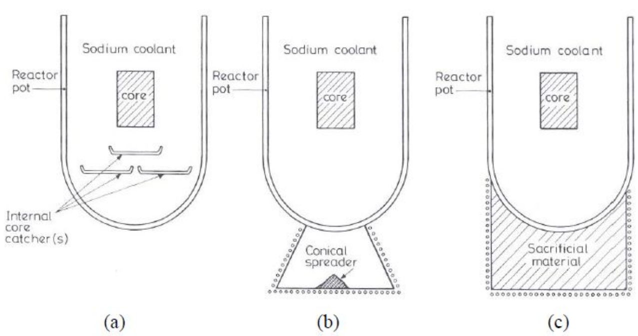

Fig.3. Various types of core catcher concepts for pool type LMFBR

CORE CATCHER COOLING: The core debris entering the core catcher during core melting is a high temperature, heat-generating material. For the safety of the core catcher and the prevention of further propagation of damage to containment, it is very essential to cool down the core debris to permissible level and retain the cooling for a longer duration to reduce their decay power density. Generally, the heat transfer from the melt to the cold wall of the core catcher takes place due to the natural convection of heat-generating fluid. The outer surface of the core catcher is cooled by circulation of cooling fluid There are various type of cooling system available for core catcher cooling, which depends upon various parameters such as reactor type, thermal load on core catcher, location of core catcher (i.e. in-vessel or ex-vessel), the geometry of the core catcher, etc.

THERMAL LOAD ON CORE CATCHER

The thermal load on the core catcher depends on the number of subassemblies that have melted down during core meltdown accidents. The total heat generation rate (Q_{cc}) of the molten pool in the core catcher is calculated as:

$$Q_{cc} = q'''.\ V_{pool}\ .\rho_{melt}\ .W$$

Where q''' is volumetric heat generation of melt in W/m^3, V_{pool} is the volume of molten pool in m^3, and ρ_{melt} is the density of melt in kg/m^3.

The PFBR core catcher was originally intended for seven subassemblies melt. Subsequent, thermal-hydraulic analysis of the core catcher indicated that it can accommodate nineteen subassemblies melt respecting the temperature limits. Later, the dimensions of the core catcher have been increased such that it can accommodate the volume of whole core melt PFBR internal core catcher was originally intended for seven subassemblies melt. Subsequent, thermal-hydraulic analysis of the core catcher indicated that it can accommodate nineteen subassemblies melt respecting the temperature limits. Later, the dimensions of the core catcher have been increased such that it can accommodate the volume of a whole core melt.

OBJECTIVES OF THE PRESENT WORK

The objective of the present work is to develop a conceptual design of an external core catcher for PFBR by carrying out the detailed thermal-hydraulics study for cooling of ex-vessel core catcher under the condition of a whole core meltdown. The focus of this study is fluid flow and heat transfer in heat-generating fluid with special concern on the maximum temperature on the walls of the core catcher. The study needs to identify the various possible configurations of the external cooling circuit and cooling area at the bottom as well as the vertical wall of the core catcher to prevent the damage to the core catcher.

MATHEMATICAL MODEL :

GOVERNING EQUATIONS:

The geometry considered for turbulent natural convection is a 2D axis-symmetric enclosure as depicted in Fig.1. The heat-generating fluid in the molten pool is assumed to be incompressible.

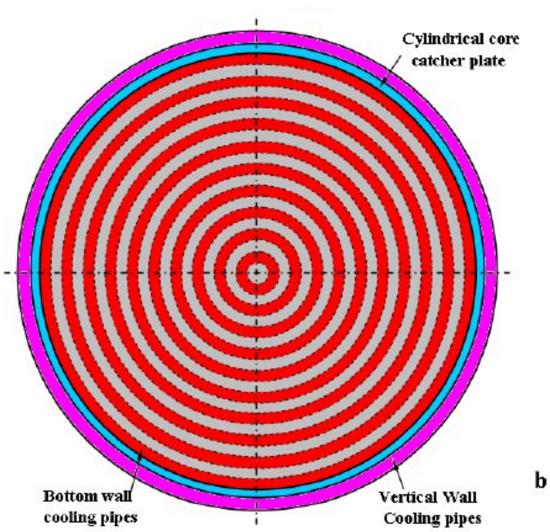

Fig. 4. Physical model of core catcher (a) Sectional front view (b) Top view

The Boussineque approximation is used to account for the buoyancy force in the vertical momentum equation. The turbulent flow is described mathematically by the Reynolds Averaged Stokes (RANS) equations, including the time-averaged energy equation for the mean temperature field that drives the flow by buoyancy force. The turbulence is modeled by the standard k-ε turbulence closure.

The transient form of RANS equations for mass, momentum and energy conservation along with the equation for turbulent kinetic energy (k) and its dissipation rate (ε) in the heat generating molten fluid are:

1. **Continuity Equation**
2. **Momentum Equations**
   a. **Radial momentum equation**
   b. **Vertical momentum equation**
3. **Energy Equation**

Corium composition:

The composition depends on the design type of the reactor, and also materials used in the control rods, coolant, and vessel's structural materials.

During a meltdown, the temperature of the fuel rods increases and they can deform above 700 degrees Celcius. If the reactor pressure is low, the pressure inside the fuel rods ruptures the control rod cladding. High-pressure conditions push the cladding onto the fuel pellets, promoting the formation of uranium dioxide zirconium eutectic. An exothermic reaction occurs between steam and zirconium, which may produce enough heat to be self-sustaining without the contribution of decay heat from radioactivity.

. A large amount of heat can be released by the reaction of metals (Zr) in corium with water. Flooding of the corium mass with water, or the drop of molten corium mass into a water pool, may result in a temperature spike and production of large amounts of hydrogen, which can result in a pressure spike in the containment vessel. The steam explosion resulting from such sudden corium-water contact can disperse the materials and form projectiles that may damage the containment vessel by the impact. Subsequent pressure spikes can be caused by the combustion of the released hydrogen.