Design and Modelling of Hydraulic Control Rod Driven Mechanism(CRDM) for Passive In-core Cooling System (PINCs) for Small Modular Reactor(SMR) 220

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Abstract Proposal

Safety has always been a prime concern for a Nuclear Reactor after Fukushima Daiichi accident of Japan on March 11, 2011. Therefore several research in the development of passive systems to mitigate the damage caused after situation like Station Blackout (SBO) are constantly being proposed and developed. A SBO refers to the complete loss of off-site power at a nuclear power plant.The loss of power means that the reactor’s cooling systems may be unable to operate, potentially leading to overheating of the reactor core. In this situation PINCs provides safety and reaction control feature by using hydraulic CRDM. Hydraulic CRDM serves two function, namely controls the nuclear reaction using hydraulic Control Rods (CRs) and removal of decay heat using heat pipe.

Hydraulic CRDM doesn't require any mechanical pumps to establish the flow however CRs are driven by hydraulic pressure of working fluid. The research project will carried out theoretically by formulating mathematical models and computationally in-case it is required. The mathematical equations will be derived from first principles and will be used to evaluate bulk coolant temperature, clad temperature and fuel centre-line temperature of reactor core. The maximum fuel temperature has to be within the allowable limit set by the materials engineer typically this is metal softening temperature.Similarly, the clad temperature shall be within its applicable safety limit. Therefore axial temperature distribution will be plotted with an appropriate constraints.

In PINCs, the decay heat will be automatically removed from the active core without AC supply. The inserted hybrid control rods in PINCs can perform dual functions, namely to serve as the reactor scram, and to transfer heat. The CR is present inside the Guide Tube(GT) The working fluid flows from bottom to top inside the GT due to pressure difference. Under SBO scenarios, the coolant flow rate sharply decreases and thus the hydraulic pressure is insufficient to lift the CRs and therefore it comes at the bottom of reactor core and helps to stop the nuclear reaction by absorbing neutrons. Similarly heat pipe arrangement in PINCs throws the decay heat out into a natural circulation loop to cool the reactor core. The force balance will be performed on the CR to obtain the solution for required flow rate of working fluid, hydraulic pressure and drop time of CR.

The flow pass the CRs will also be closely observed through commercially available Ansys Fluent software. This will help to better conclude on the movement of CR with time. Also to perform computational analysis of CRDM inside the GT, dynamic meshing has to be properly implemented with proper numerical solver with optimum number of grid points specially close to the surface of CR where working fluid interacts with CR surface. The variation of fluid mechanic parameters including fluid friction, velocity of CR, position of CR with time is therefore plotted to draw important conclusion related to flow pattern such as velocity vectors and streamlines in the region of interest. The mass of CRs will create difference in flow pattern since all fluid mechanics variables depends on mass of CR, therefore CR will be loaded with different sets of weight and thus a parametric analysis will be carried out to conclude the best and optimal weight of CR for efficient performance of reactor.

During decay heat removal, say decay heat is 1% (constant) of total operating power of SMR, an outer circuit is established with Natural Circulation for removal of heat from the Reactor Pressure Vessel(RPV). Ultimately the scenario of Containment Vessel (CNV) design during Small Break Loss of Coolant Accident (LOCA) will be proposed using concept of 2 phase flow and first principle to obtain a crude idea of CNV pressurization and CNV wall temperature with it’s optimum surface area required for safer operation under RPV depressurization.