NATURAL CIRCULATION IN A BWR

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Abstract

Natural circulation through a heated structure is a natural phenomenon that occurs when water is heated and the density decreases causing the hotter water to rise. The heated structure can be something as simple as a heated coil submerged into a tank full of water. The water adjacent to the heated coil will become hot with respect to the other fluid in the tank, and the density of water next to the heater will be less than the surrounding cooler water. The difference in density along with the vertical pressure head of the water will cause an upward movement of the heated water. As the hotter water rises, it is replace by cooler water, which eventually becomes hot and also rises. This continuous process is often called natural circulation of water through a heated structure.

At a nuclear power plant, fuel in the nuclear core is usually replaced every 18 months. To perform this replacement activity, a refueling outage is schedule to take out spent fuel and to insert new fuel. During this outage other maintenance, testing and modification activities are performed, which are crucial to the successful operation of the plant. After a nuclear power plant is shutdown, energy is continuously released from the nuclear through a process called decay heat. The decay heat energy level reduces exponentially with respect to time after shutdown of the reactor. The shutdown cooling (SDC) or residual heat removal (RHR) systems provide heat removal for the early portion of the outage. As the decay heat energy reduces with time, other systems may be used as heat removal alternatives. One of these alternatives is the use of fuel pool cooling to remove the energy generated by the reactor core. Since the heated core is more than 50 feet below the inlet and outlet of the fuel pool cooling heat exchangers, natural circulation flows and local temperatures must be established to ensure that the fuel does not over heat and technical specification limits are not exceeded.

The purpose of this paper is to describe how a boiling water reactor (BWR) and fuel pool was modeled and how he temperatures and flows in the reactor plenum, reactor core, and reactor cavity, were determined when the shutdown cooling system is taken out of service at approximately 7 days after the outage begins.

A BWR refueling outage plan included the removal of the shutdown cooling (SDC) function for the reactor at 7 days after reactor shutdown. At 7 days after

reactor shutdown, the reactor head, steam dryer, steam separators, and shroud head were removed and placed in storage. In addition, approximately 268 fuel assemblies of 724 fuel assemblies in the core were moved through the transfer canal to the spent fuel pool. For the first 7 days of the outage, SDC and normal fuel pool cooling were used to cool the fuel in the reactor cavity and spent fuel pool. After 7 days following reactor shutdown, normal shutdown cooling mode of operation was secured and the fuel pool cooling system, assisted by fuel pool cooling assist mode of the SDC system was used to remove decay heat in the reactor cavity and spent fuel pool.

A RELAP5 model was developed to ensure that the important flow paths and heat sources were accurately. In addition to the reactor, the RELAP5 natural circulation model included the reactor cavity. The flow from the spent fuel pool was simulated by adding the energy from the spent fuel rack to the flow going into the spent fuel pool, and inserting the resultant flow and energy (i.e., temperature) directly into the reactor cavity. The RELAP5 model contained the reactor cavity, which consisted of the reactor up to the reactor flange and the volume of water from the reactor flange to the pool surface. The model did not include the water volume in the transfer canal, spent fuel area, and the steam separator/dryer holding area. Acceptance criterion were established as:

1. Reactor Cavity Surface: Less than 140° F, which is the Technical Specification Limit (TSL) of the fuel pool.

2. Maximum fuel assembly exit coolant temperature: Less than 212° F.

3. To assure compliance with the TSL, the average bulk temperature of the reactor cavity shall be less than 140° F.

A nodal diagram of the BWR natural circulation RELAP5 model is presented in Figure 1. The calculated core exit and fuel pool surface temperatures are presented in Figure 2. This model demonstrated that a natural circulation path would occur through the reactor, which adequately remove decay heat.

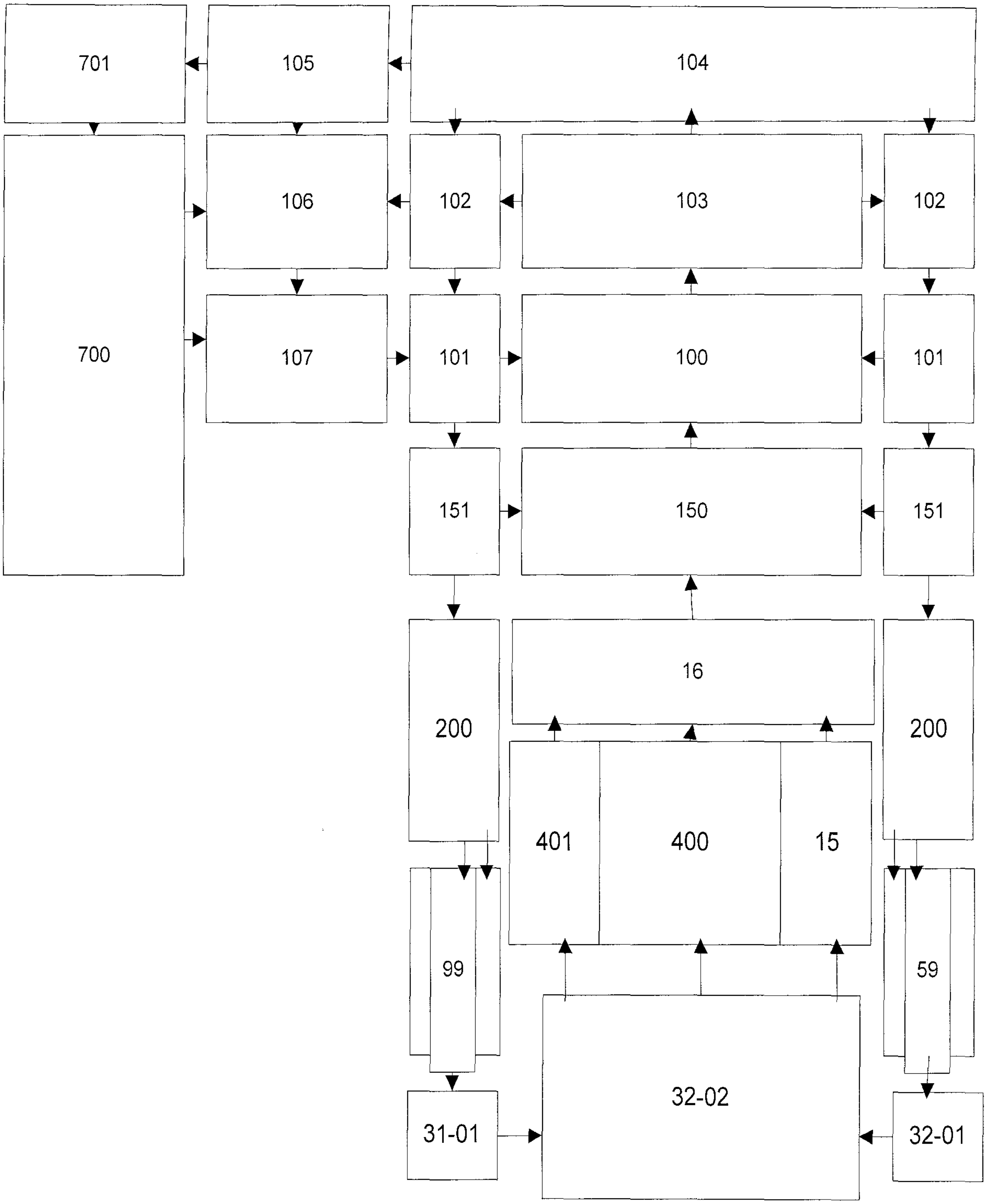

FIGURE 1 NATURAL CIRCULATION MODEL

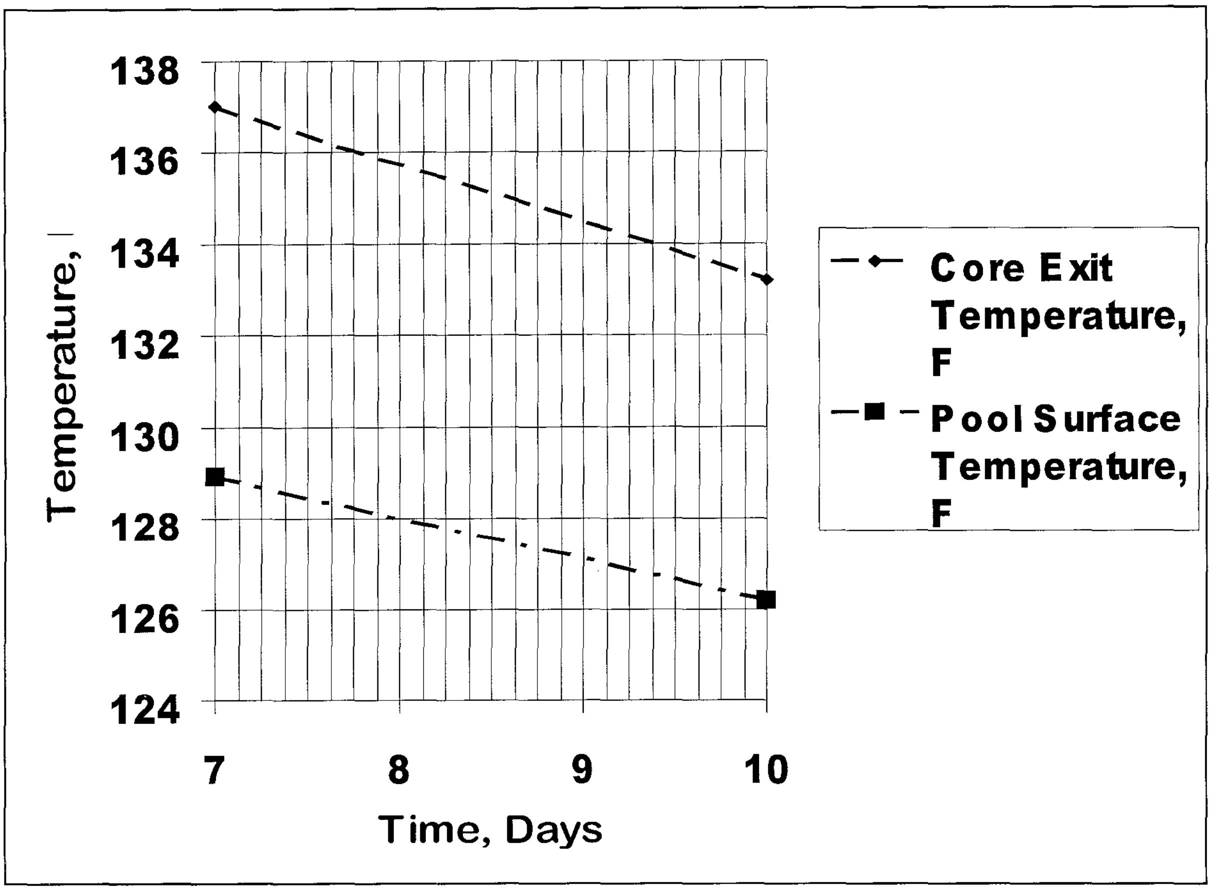

FIGURE 2 NATURAL CIRCULATION TEMPERATURES