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Temperature limit in the RHR system when aligned to the ECCS

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ABSTRACT

A thermal hydraulic analysis was performed for the Residual Heat Removal (RHR) system shortly after a transition from the shutdown cooling mode to the standby Emergency Core Cooling System (ECCS) injection mode when a Loss-of-Coolant Accident (LOCA) was postulated to occur. This condition causes the potential of hot fluid to be trapped in the isolated hot leg suction piping when the RHR system is aligned to the Reactor Coolant System (RCS). Subsequently, the RHR system can be realigned to the ECCS, which is at a low pressure, if the system is needed in response to the LOCA. As a result, the hot fluid can flash to steam, so the system may fail to provide the RCS cooling due to the potential of the steam ingestion into the RHR pump. Westinghouse issued two Nuclear Safety Advisory Letters (NSALs), NSAL-93-004 and NSAL-09-8, to ensure that the affected facilities establish the temperature limits to appropriately address the concerns in regard to the RHR pump operability. In this analysis, a detailed calculation of the temperature limits was performed using the RELAP5/MOD3.3 (Patch 03) computer code. The temperature limits were calculated by considering no steam ingestion into the RHR pump.

1. Introduction

In 1993, Westinghouse issued the Nuclear Safety Advisory Letter (NSAL), NSAL-93-004 (Westinghouse, 1993) to identify a potential concern associated with steam flashing of hot water in the isolated hot leg suction piping during the transition from mode 3 (hot standby mode) to mode 4 (hot shutdown mode) when the RHR system is aligned to the Reactor Coolant System (RCS). In mode 3, the reactor is subcritical with an average reactor coolant temperature equal to or greater than 350 °F (177 °C), and the temperature is between 200 °F (93 °C) and 350 °F (177 °C) while in mode 4 as presented in (U.S. NRC, 2012). In mode 4, one train of the standby Emergency Core Cooling System (ECCS) is required to be operable in order to provide core cooling in the event of LOCA. The RHR system is realigned to the Refueling Water Storage Tank (RWST) which is at relatively low pressure.

In 2009, Westinghouse issued an additional letter, NSAL-09-8 (Westinghouse, 2009) to clarify the previous guidance, which was identified in NSAL-93-004 (Westinghouse, 1993), and to ensure the consideration of the reduced hydrostatic head when the RHR system water source is transferred from the RWST to the containment sump during the recirculation mode. Consequently, the temperature limit, which is sufficient when aligned to the RWST, should be reduced to eliminate the potential for flashing of the hot water due to the reduced hydrostatic head.

Fig. 1 shows the schematic diagram of the Westinghouse three-loop Pressurized Water Reactor (PWR) RHR system. The RHR pumps are normally fed from the RWST until the ECCS suction switchover to the containment sump is initiated based on the RWST water level. The RWST injection line is 16-inches (0.406 m) in diameter and is reduced to a 14-inch (0.356 m) diameter. Each RHR pump suction line is fed by a 14-inch (0.356 m) header through an isolation valve and a check valve.

The other normal supply path for the RHR pump is from the containment sump. Each RHR pump has a suction header leading from a sump compartment through the isolation valves with or without a check valve. This header is 14 inches (0.356 m) in diameter and continues down to the pump suction inlet. A 12-inch (0.305 m) diameter hot leg suction line is connected to this header downstream of the isolation valves of the RWST and the sump to provide the shutdown cooling suction path. A 3-inch (0.076 m) diameter mini-flow return line is connected to the hot leg suction line above this header.

2. Phenomena of concern and screening evaluation

2.1. Phenomena of concern

The issues associated with trapped fluid at an elevated temperature in the isolated hot leg suction line when a postulated ECCS injection occurs are:

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Nomenclature

ECCS	Emergency Core Cooling System
HX	Heat Exchanger
LOCA	Loss-of-Coolant Accident
LTOP	Low Temperature Overpressure Protection
NSAL	Nuclear Safety Advisory Letter
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
RELAP	Reactor Excursion and Leakage Analysis Program
RHR	Residual Heat Removal
RWST	Refueling Water Storage Tank
SI	International System of Units
TDV	Time Dependent Volume
U.S. NRC	United States Nuclear Regulatory Commission

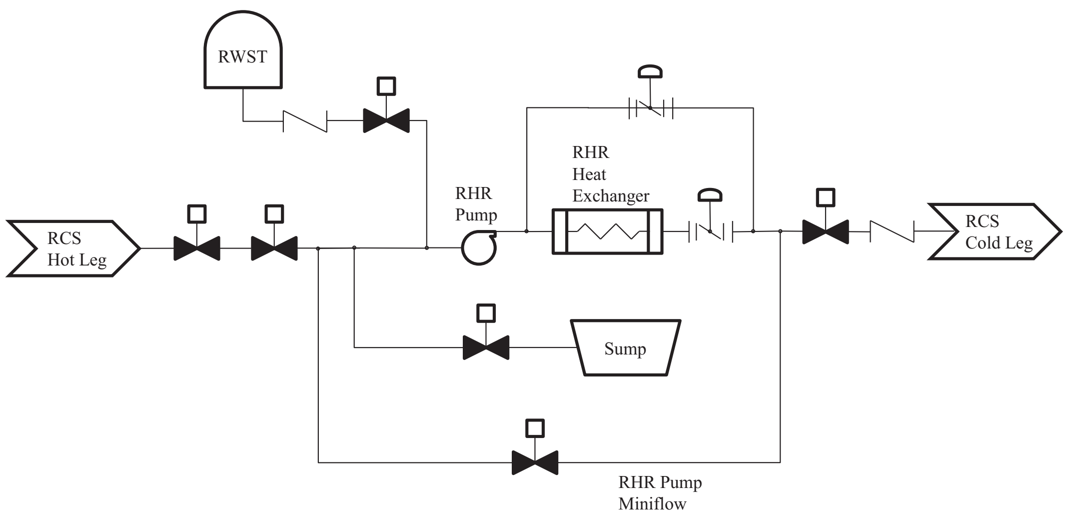

Fig. 1. Westinghouse Three-loop PWR RHR System.

1) The fluid can flash and a steam-water mixture will preferentially feed the RHR pump suction as long as the saturation pressure remains above the source pressures from the RWST or the containment sump. This condition can lead to steam binding and postulated failure of the RHR pump.
2) If voiding occurs and the pressure drops below to initiate the injection from the RWST or the containment sump, conditions favorable to condensation induced water hammer may be created that can challenge the piping and its supports.
3) If drainage in the RHR pump discharge line occurs during the recirculation from the containment sump, a liquid column separation and rejoining of the water hammer may be expected in the RHR pump discharge line, including the RHR Heat Exchanger (HX) tubes when the RHR pump restarts.

Therefore, it becomes important to identify a primary system temperature at which the RHR system can be isolated and avoid these issues. It is desirable to maximize this temperature for the following reasons:

1) During the startup, it is desirable to establish the pressure in the steam generators to allow steam dump operations in order to control the primary system heat up prior to isolating the RHR system.
2) The RHR system needs to remain in operation to support the Low Temperature Overpressure Protection (LTOP) pressure relief until a bubble is drawn in the pressurizer.

2.2. Screening evaluation

The first step to address the concerns was to conduct an investigation into the geometry of the RHR system and understand the effects of the geometry.

A review of the operating procedures indicates that the RHR pumps would be shut down before the switchover from the RWST injection to the recirculation from the containment sump. The RHR HXs and the highpoints of the pump discharge line are horizontally located below the containment sump water surface. Therefore, there should be no drainage in the pump discharge line during the manual switchover to the containment sump. Particularly, a liquid column separation and rejoining water hammer is not expected in the pump discharge line and the RHR HX tubes when the RHR pumps restart.

The mini-flow return is relatively close to the RHR pump suction downcomer, near where the RWST supply header ties in. This means that forced circulation cooling of the RHR system will not provide cooling of the bulk of the hot leg suction piping.

The static pressures and their corresponding saturation temperatures define the maximum temperature that can be supported without flashing in the isolated hot leg suction line. These were calculated including the effects of the pressure drop through the RWST supply line and the containment sump suction line. In particular, total sump suction line losses were calculated by adding the sump suction pipe losses and the strainer head loss. The RWST vortex suppression level was assumed as a minimum water level conservatively, with no instrument uncertainty or additional margin. The vortex suppression level is a minimum submergence from