

Reactor, Boiler & Auxiliaries - Course 233

HEAT TRANSPORT SHUTDOWN COOLING

I. SYSTEM PURPOSE

There are some major design differences between stations for this system. Some stations (PNGS, DNGS) use a D₂O system and some BNGS) use an H₂O system. This lesson discusses the general principles, which are similar for both systems, and the major design differences between the two systems, but avoids discussion of specific station details.

In both types of systems the main purpose is to remove fuel decay heat after reactor shutdown. Normally the system is used to cool down the HT system for $\sim 170^{\circ}\text{C}$ to $\sim 60^{\circ}\text{C}$, following cooldown from $\sim 250^{\circ}\text{C}$ to $\sim 170^{\circ}\text{C}$ by boiler steam discharge, and to maintain cooling indefinitely at $\sim 60^{\circ}\text{C}$ during the shutdown. However, the system can be used in an emergency for a "crash cooldown" of the HT system from the hot ($\sim 250^{\circ}\text{C}$) shutdown state to the cold ($\sim 60^{\circ}\text{C}$) shutdown state.

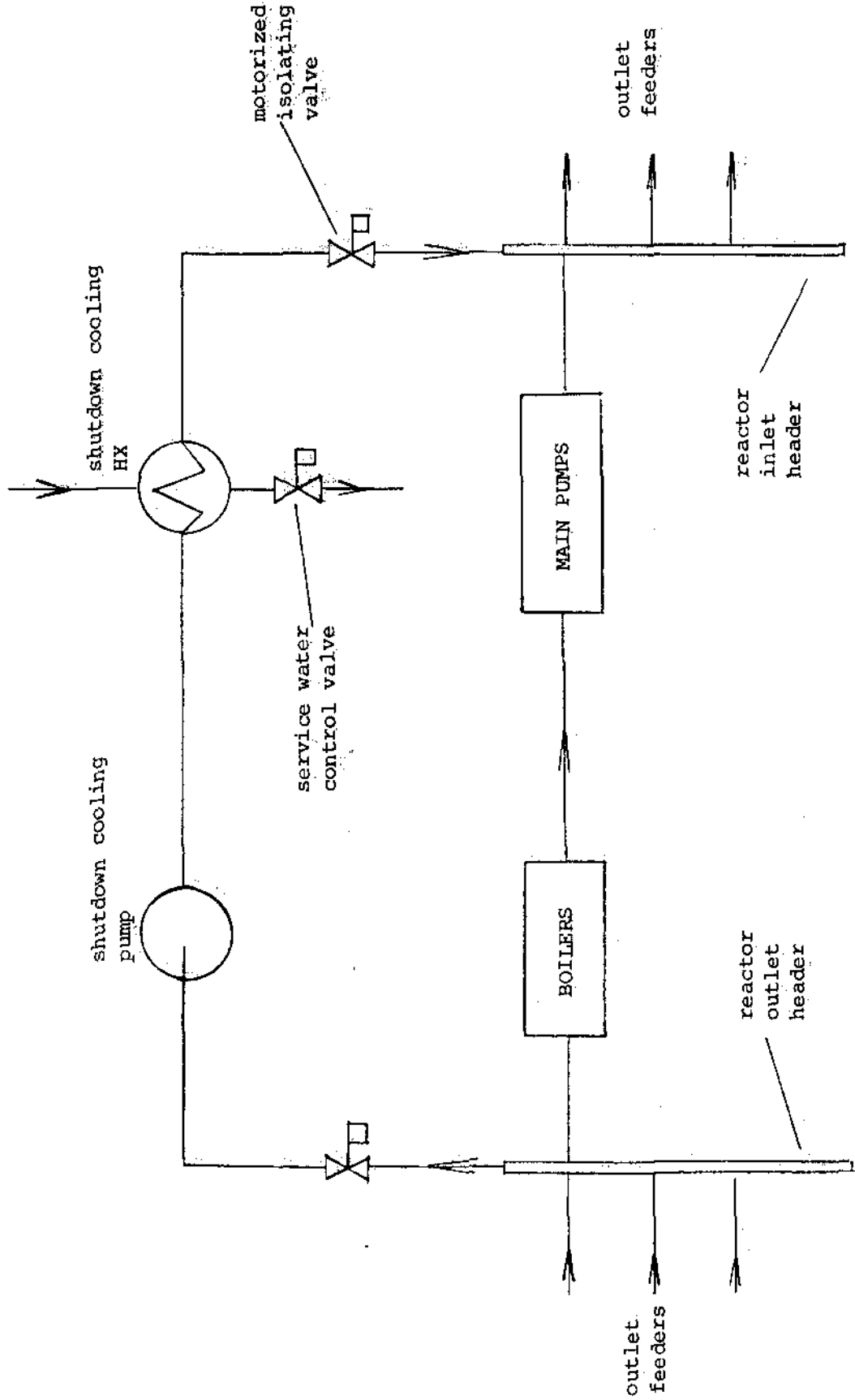
II. (a) DIRECTLY COOLED SYSTEM (PICKERING, DARLINGTON)

(i) System Description

The typical system shown in Figure 1 consists of a pump and a heat exchanger in parallel with (ie, bypassing) each set of main HT pumps and boilers. Motorized isolating valves are provided between the main system and shutdown cooling system. Shutdown cooling flow through the reactor is in the same direction as with the main pumps and boilers in service. (Redundant shutdown cooling pumps are not provided in each loop as sufficient flow is available from the remaining shutdown cooling pumps even if one becomes unavailable. Total flow with all pumps is typically $\sim 12\%$ main system flow rate). This lesson refers to the system as a "directly cooled system" as the HT D₂O is cooled directly by the service water supplied to the shutdown cooling heat exchangers.

Because the maximum shutdown cooling requirement is only $\sim 6\%$ of full reactor power (on a crash cooldown), and ~ 1 to 3% for normal operation (on a controlled cooldown) of the system, the equipment is considerably smaller than the main system pumps and boilers. The heat exchangers are usually cooled by service water.

Figure 1 Simplified "Directly Cooled" HT Shutdown Cooling System
(One Loop Only Shown)



(ii) System Operation

Reactor at Power, Shutdown Cooling Out of Service

With the reactor at power, the shutdown cooling inlet and outlet isolating valves are closed. The shutdown cooling loops are filled with cold, pressurized D₂O via small lines from the reactor outlet headers.

Reactor Shutdown, Shutdown Cooling In Service

During a cooldown of the HT system, following a reactor shutdown, the shutdown cooling system is used to cool the HT system for ~170°C to ~60°C. (Cooldown of the HT system from hot shutdown (~250°C) to ~170°C is achieved by boiler steam discharge via steam relief valves to atmosphere). To avoid thermal shock to the heat exchanger, the shutdown cooling loops are warmed up close to the main circuit temperature before being valved into service by slowly admitting some HT D₂O from the main circuit via a small warm up line (not shown in Figure 1).

Temperature control of the HT D₂O is achieved by the shutdown cooling system with a temperature control loop employing a control valve on the service water side of the heat exchanger. The shutdown cooling system can be depressurized if required by opening a depressurizing valve connecting the shutdown cooling loops to the bleed cooler inlet.

Emergency (Crash) Cooling Using Shutdown Cooling

The preferred method of crash cooling is by releasing steam to the atmosphere through the SRV's until the temperature of the HT system drops to ~170°C. Subsequent cooling is then done as described above by valving in shutdown cooling in its normal operating mode. However, if the SRV's are not operable, then emergency (crash) cooling of the HT D₂O using the shutdown coolant loops may be used, by valving the system in without prior warmup. The system is designed to withstand the thermal shock of being valved in without warmup, but for a limited number of times only. After a crash cooldown, an inservice inspection of the system will be required to confirm the integrity of the system components, in particular the heat exchanger tube sheet.

II. (b) INDIRECTLY COOLED (VIA PREHEATER) SYSTEM.
BRUCE A AND B

(i) System Description

External boiler preheaters are used at Bruce NGS to supply cooler D₂O to the inner zone of the core where the channel ΔT 's are higher than in the outer annular zone. Coolant destined for the inner core channels, having already passed through the boiler tubes, is routed through the preheater tubes, where it gives up additional heat to preheat boiler feedwater on the shell side. Thus, precooling of HT D₂O for the inner zone of the core and preheating of boiler feedwater are both accomplished in the same vessel, the preheater. This same vessel is also used as part of the shutdown cooling system.

The system is more complex than the Pickering bypass design, and it is shown simplified in Figures 2 and 3. The HT D₂O (which passes through the preheater tubes, see below) is not cooled directly by service water but by H₂O feedwater circulating through the boiler feedwater preheater shells in the closed loops shutdown cooling system. Heat is rejected from this closed loop to service water via the shutdown cooling heat exchanger. The system consists typically of 2 x 100% shutdown cooling pumps and 2 x 50% heat exchangers, with isolation provided by motorized valves from the normal boiler feedwater system, as shown in Figure 3.

(ii) System Operation

Reactor at Power, Shutdown Cooling Out of Service

With the reactor at power, the shutdown cooling loop is kept cold depressurized and isolated from the preheaters. Pressurization in this case is obtained via a small line from the boiler steam drum, see Figure 2 and Figure 3.

Reactor Shutdown, Shutdown Cooling In Service

During a cooldown of the HT system following a reactor shutdown, the shutdown cooling system is used to cool the HT system from $\sim 170^{\circ}\text{C}$ to $\sim 60^{\circ}\text{C}$. (Cooldown of the HT system from hot shutdown ($\sim 250^{\circ}\text{C}$) to $\sim 170^{\circ}\text{C}$ is done by heat rejection via atmospheric steam discharge valves blowing boiler steam to the atmosphere.)

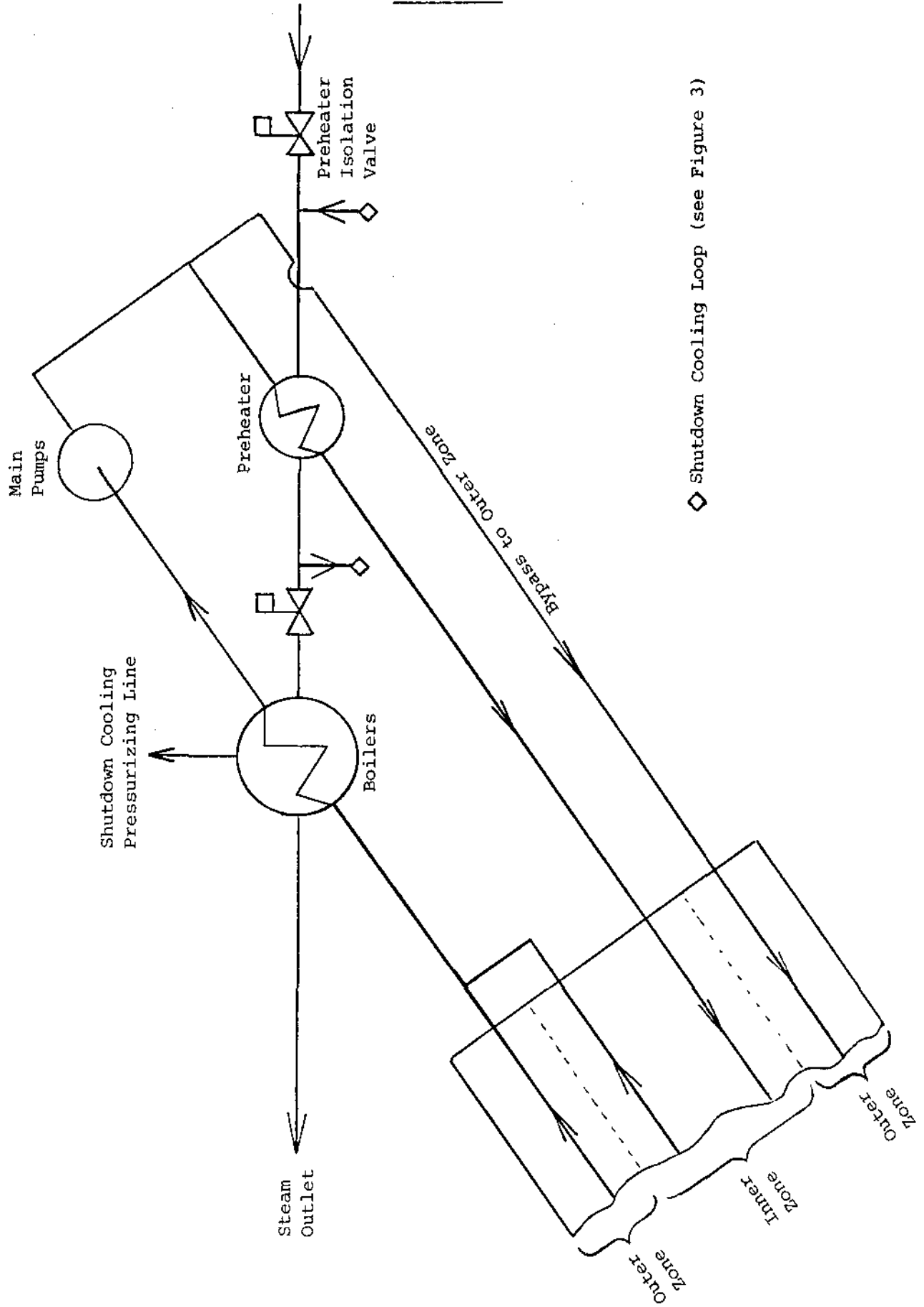
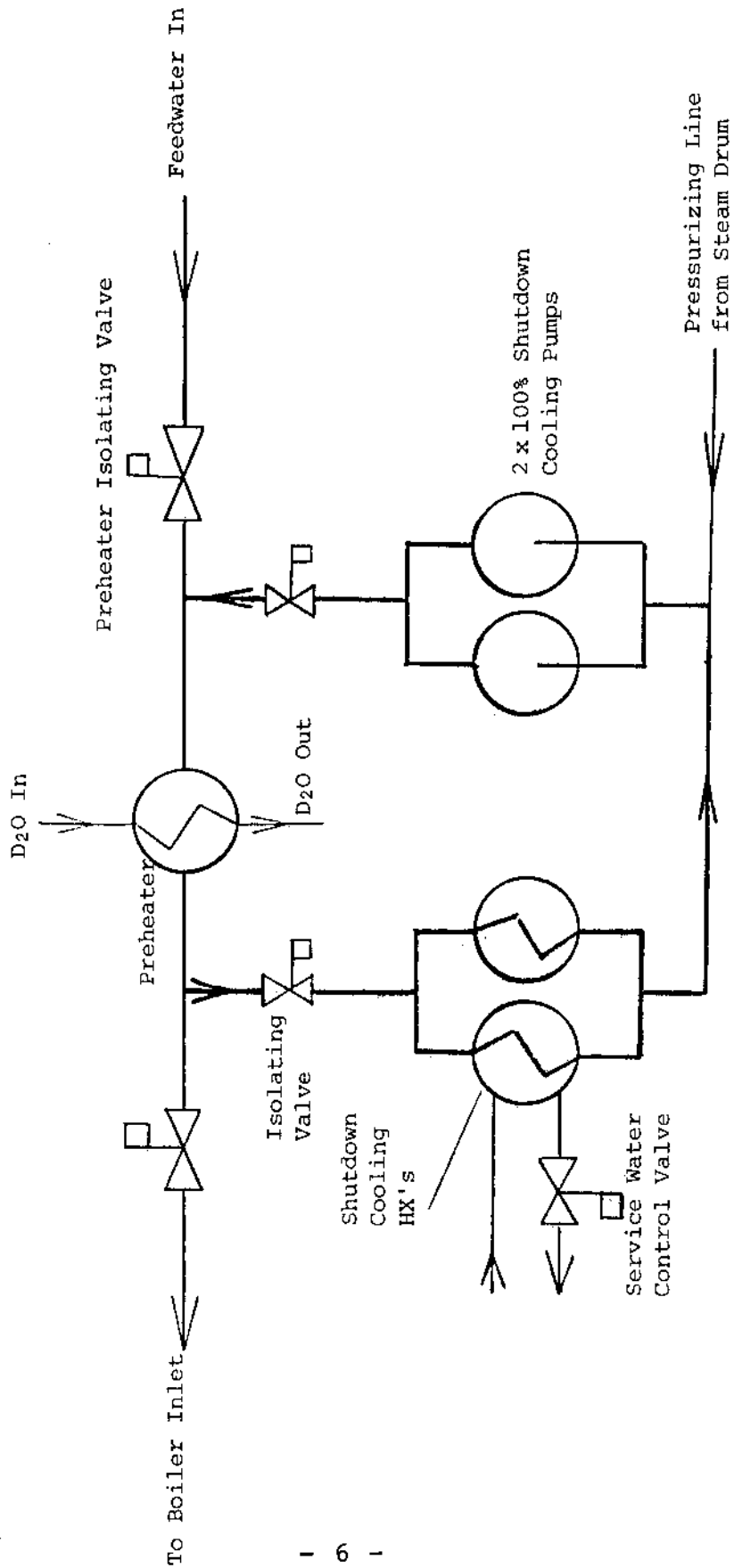


Figure 2 Arrangement of Preheater Relative to HT System Loop

Figure 3 Preheater Shutdown Cooling System



To bring the system into operation, the shutdown cooling isolating valves are opened and the normal feedwater supply to the preheaters is isolated with the preheater isolating valves shown.

HT temperature control is provided by a temperature control loop employing a control valve on the heat exchanger service water. The HT system temperature can then be taken down to $\sim 60^{\circ}\text{C}$. Note that in order to obtain HT D_2O flow in the preheater, the primary pumps must be operating. Therefore, the HT pump heat as well as decay heat must be removed by the light water shutdown cooling system. (By contrast, the D_2O bypass shutdown cooling system has to remove only decay heat.) In addition, since the HT system must remain pressurized as long as the main pumps are running, the final state of the HT will be cold pressurized, not cold depressurized, which is possible with the bypass system.

To take the HT system down to the cold depressurized state, the maintenance cooling system has to be used. The maintenance cooling system, designed for $\sim 1\%$ full power heat removal, is discussed in section 30-6. Loss of the HT pumps during shutdown cooling system operation will result in inadequate heat removal via the preheaters. Heat removal will then take place via HT thermosyphoning/boiler steam discharge until maintenance cooling is placed in service.

Emergency (Crash) Cooling Using Shutdown Cooling

In principle, the shutdown cooling system provides the heat transfer paths necessary to crash cool the HT D_2O all the way from 250°C to 60°C . In practice, the problem is one of thermal stress on the system due to the step rise of about 200°C in temperature, which would occur if the system were valved in for crash cooling.

As a result, the use of the Bruce shutdown cooling system for a crash cool is currently thought to be able to withstand fewer crash cooldowns than the equivalent system at Pickering.

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