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CORE COOLING UNDER ACCIDENT CONDITIONS AT THE HIGH FLUX BEAM REACTOR (HFBR)*

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Background

The HFBR at Brookhaven National Laboratory (BNL) is cooled and moderated by heavy water and contains U-235 in the form of narrow channel, parallel plate type fuel elements. The reactor began operation in 1965 at 40 MW operation and was upgraded to 60 MW in 1982. During normal operation the flow direction is downward through the core (Figure 1). This flow direction is maintained at a reduced flow rate during routine shutdown and on loss of commercial power by means of redundant pumps and power supplies. However in certain accident scenarios, e.g. loss of coolant accidents (LOCA) all forced flow cooling is lost. Decay heating causes a temperature increase in the core coolant and the resulting thermal buoyancy causes a reversal of the flow direction to a natural circulation mode. This reversal is facilitated by the automatic opening of spring loaded valves which provide a return path in which coolant from the reflector region enters the

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bottom of the core, flows up through the core and returns to the reflector region through the open valves. These valves are held closed during normal operation by the head developed across any one of the primary coolant pumps.

Following the transition to natural circulation, the average temperature of the water in the reactor vessel will rise to the boiling point and net steam generation will begin. Water is added to the vessel to replace escaping steam and maintain the liquid level above the core.

Although there was experimental evidence[1] during the reactor design period (1958-1963) that the heat removal capacity in the fully developed natural circulation cooling mode was relatively high, it was not possible to make a confident prediction of the heat removal capacity during the transition from downflow to natural circulation. Accordingly, a test program[2] was initiated using an electrically heated test section to simulate the fuel channel and a cooling loop to simulate the balance of the primary cooling system. These tests were simple, go, no-go tests in which the success criterion was the absence of rapid temperature excursions in the test section. The limiting heating rates obtained from the tests provided a basis for concluding that following shutdown from the design power level of 40 MW, flow reversal would occur without fuel overheating. As part of the upgrade to 60 MW operation, enhancements to the shutdown cooling system were made to reflect the heat removal limits obtained from the tests.

Reactor Shutdown (1989-1991)

In early 1989, a safety analysis performed in response to a National Academy of Science recommendation, led to a result that had not been previously recognized. In a LOCA scenario where even limited fuel damage occurs and natural circulation is established, fission product gases could be carried from the damaged fuel by steam into areas where operator access is required to maintain the core in a coolable configuration. This would force evacuation of the building and lead to extensive core damage. As a result the HFBR was shut down by the Department of Energy (DOE) and an extensive review of the HFBR was initiated. A principal focus of attention during this review was the issue of flow reversal and the prototypicality of the early tests.

In an effort to address this issue BNL developed a model[3] designed to predict the heat removal limit during flow reversal that was found to be in good agreement with the test results. The model was based on the assumption that dryout will occur when the vapor generation rate is high enough to cause a transition from slug bubble to annular flow in the coolant channel. The heat removal limit inferred from the model suggested that flow reversal would occur safely at power levels in excess of 60 MW. However, because of disagreement among the reviewers about the uncertainty in the model, a more conservative approach was adopted to establish a lower bound on the heat removal limit during flow reversal. This approach was based on the flooding limited model which assumes that liquid to cool the fuel can only enter the channels from the top and will flow counter-current to steam vapor flowing up the channel. The bottom of the channels are assumed to be blocked. The Sudo-Kaminaga correlation[4] which is based on flooding data for channel geometries similar to the HFBR, was used to generate the heat removal limit. The power level inferred from this limit is 35 MW which is the power level established for restart (30 MW nominal).

Currently a thermal-hydraulic test program is being developed to provide a more realistic and defensible estimate of the flow reversal heat removal limit so that the reactor power level can be increased.

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[4] Sudo, Y. and Kaminaga, M., "A CHF Characteristic for Downward Flow in a Narrow Vertical Rectangular Channel Heated from Both Sides," Int. J. Multiphase Flow, Vol. 15, p. 700-766, (1989).

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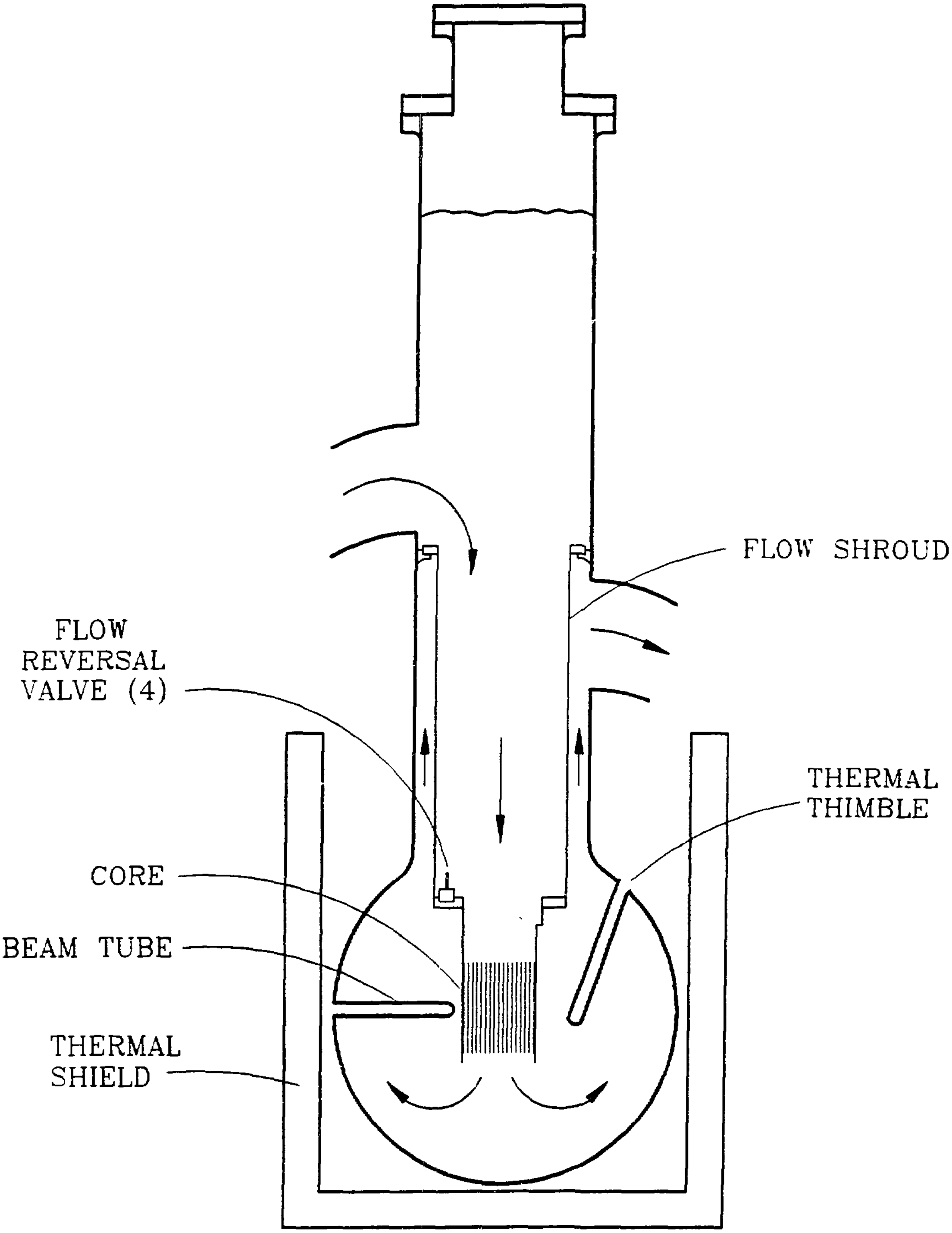

FIG. 1 SCHEMATIC OF REACTOR VESSEL
SHOWING NORMAL FLOW DIRECTION