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Plant Protection System Optimization Studies to Mitigate Consequences of Large Breaks in the Advanced Neutron Source Reactor

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This paper documents some of the optimization studies performed to maximize the performance of the engineered safety features and scram systems to mitigate the consequences of large breaks in the primary cooling system of the Advanced Neutron Source (ANS) Reactor.[1] ANS is a new basic and applied research facility based on a powerful steady-state research reactor that provides beams of neutrons for measurements and experiments in the field of material science and engineering, biology, chemistry, material analysis, and nuclear science. To achieve the high neutron fluxes for these state-of-the-art experiments, the ANS design has a very high power density core (330 $MW_{fission}$ with an active volume of 67.6 L) surrounded by a large heavy water reflector where most neutrons are moderated. This design maximizes the number of neutrons available for experiments, but results in a low heat capacity core that creates unique challenges to the design of the plant protection system.

The conceptual ANS plant protection system design takes advantage of many passive safety features. For example, most of the primary cooling system is submerged under light water pools that provide not only a long term heat sink for isolation events, but also convert all loss of coolant events into simple loss of pressure events. Under all postulated breaks, the core remains covered and a well-defined path exists to dissipate decay heat. Parts of the cooling system are contained in limited-volume dry cells that are passively flooded by gas-charged accumulators in case of breaks. The gas accumulators also serve the function of maintaining high pressure for a sufficient period of time following a break to allow a safe reactor scram. Analyses, however, show that the rapid depressurization caused by a large break may cause a short-time heat-transfer crisis that may result in core damage even if the long-term cooling is assured. For this reason, a fast-responding active scram system is required. Using existing well-proven technology, the ANS conceptual design incorporates a protection system that inserts one dollar worth of reactivity in 130 ms (30 ms for detection and 100 ms for actuation).

The dynamic response of the ANS cooling system under break conditions has been analyzed with three independent codes: a ANS specific version of RELAP5 and two in-house developed single-phase codes, ANSDM[2] and PRSDYN.[3] Results for these three codes have been benchamrked and agree remarkably well within their individual limitations. The results of these analyses indicated two areas critical to the plant protection system performance: (1) location of the pressure sensor, and (2) location and size of the gas accumulators. Examples of these analyses results are shown in Figs. 1 and 2 for a core-inlet double-ended guillotine break that opens exponentially in 500 ms. Figure 1 shows the PRSDYN calculated local pressure change at different points in the cooling loops, and Fig. 2 shows the margin to flow-excursion critical heat

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flux based on the Costa correlation.[4] These figures indicate that the pressure sensors need to be located as close as possible to the core outlet. As seen in Fig. 1, locating the pressure sensor close to the accumulator would result in a scram delay of as much as 400 ms and safety limits would not be maintained. This observed delay is caused by the non-equilibrium nature of the flow and pressure during this transient as the hot leg flow is decelerated by the strong accumulator back pressure. Sensitivity analyses also indicate that the accumulators need to be located close to the pump suction to minimize pump cavitation and the possibility of reversing the core flow in the case of breaks at the core inlet.

REFERENCES

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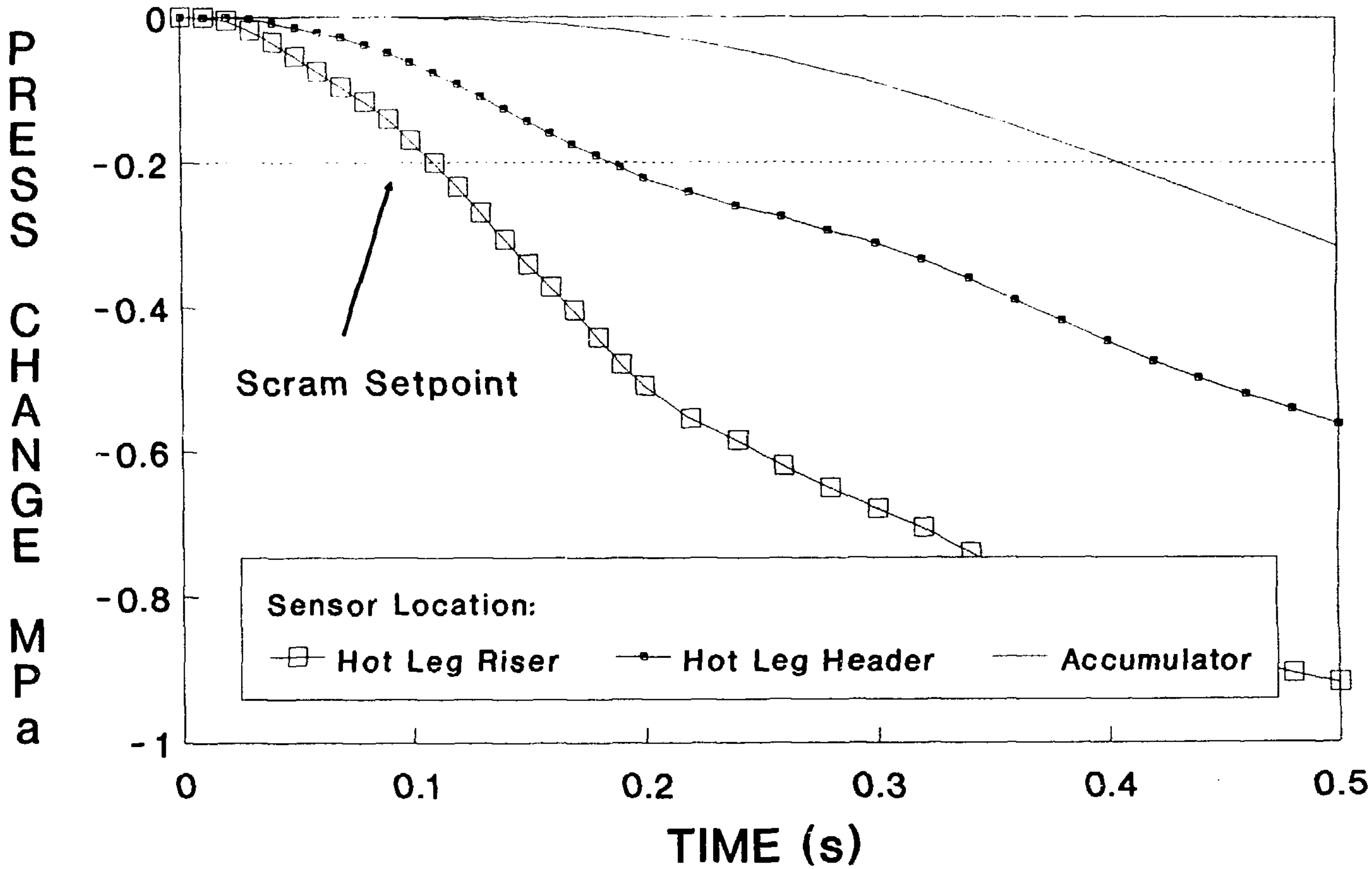
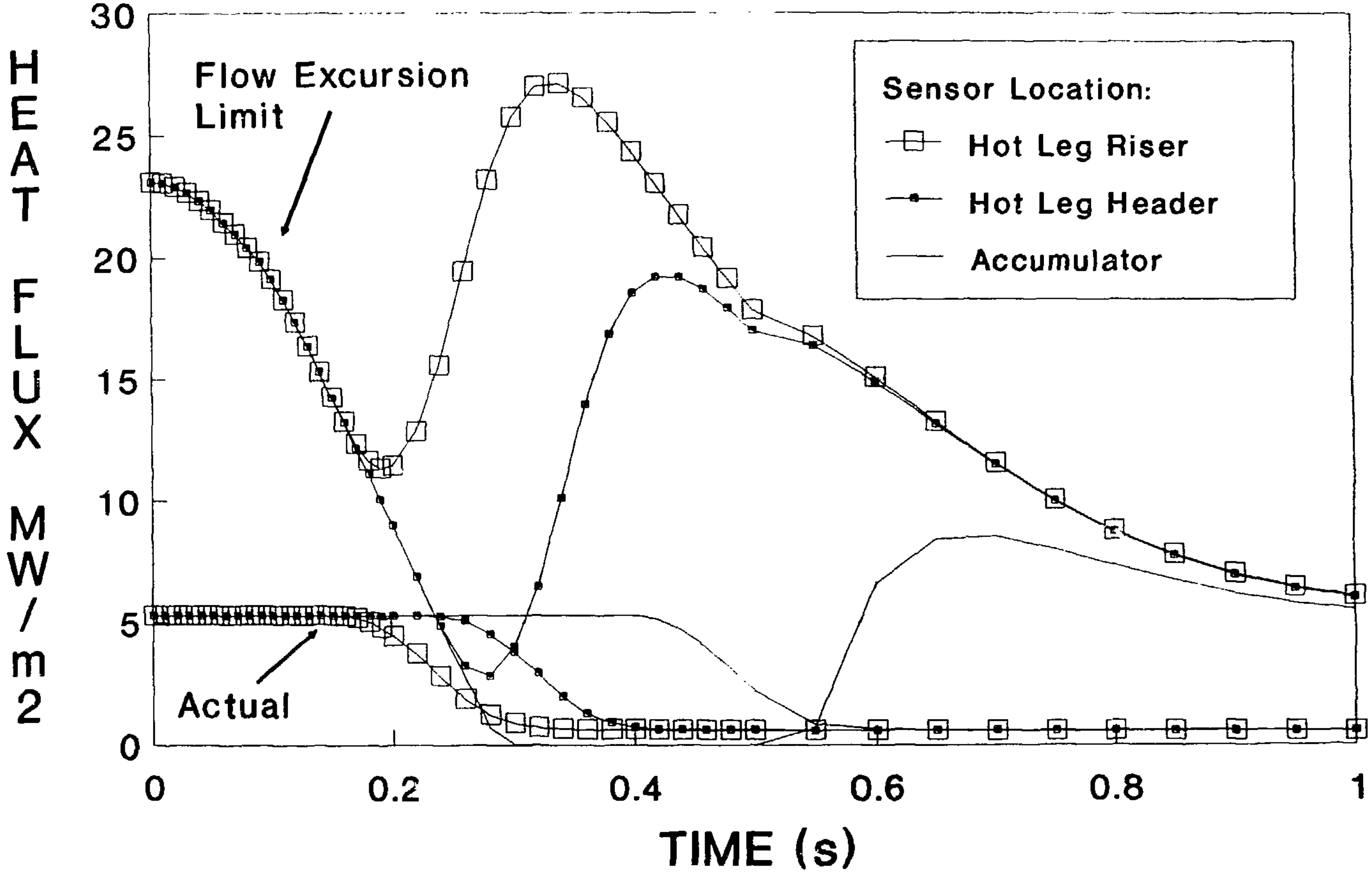
Figure 1. Change in pressure at different locations following a large core-inlet break (1 s opening time) showing the scram time delay if the pressure sensor is located close to the gas accumulator.

Figure 2. Heat fluxes for large core-inlet break showing the flow-excursion limit is not satisfied unless pressure sensor is located close to the core in the hot leg riser.



PRESS CHANGE MPa
0
-0.2
-0.4
-0.6
-0.8
-1
0
0.1
0.2
0.3
0.4
0.5
TIME (s)
Scram Setpoint
Sensor Location:
Hot Leg Riser
Hot Leg Header
Accumulator



HEAT FLUX MW/m2
30
25
20
15
10
5
0
Flow Excursion Limit
Actual
Sensor Location:
Hot Leg Riser
Hot Leg Header
Accumulator
0
0.2
0.4
0.6
0.8
1
TIME (s)