CONF-911107--14

DE91 015636

LOCA MITIGATION STUDIES FOR THE ADVANCED NEUTRON SOURCE: THE INERTIAL FLOW DIODE CONCEPT

M. I. Khayat
The University of Tennessee

José March-Leuba
Oak Ridge National Laboratory*

R. B. Perez
The University of Tennessee

MASTER

Abstract submitted to the American Nuclear Society Winter Meeting, San Francisco, California, November 1991.

* Managed by Martin Marietta Energy Systems, Inc., for the U. S. Department of Energy under Contract No. DE-AC05-84OR21400

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This paper documents a study of the consequences of loss of coolant (LOCA) accidents in the Advanced Neutron Source (ANS) reactor,[1] and it introduces the concept of an inertial flow diode (IFD) to mitigate the effect of large cold leg breaks. The ANS is primarily a neutron scattering facility, but it is also being designed for isotope production and irradiation experiments. To accomplish these goals, the ANS design is based on a high power ($\approx$350 MW_{fis}) D_2O-cooled compact core (67 L) surrounded by a large (1.75 m radius) D_2O reflector where most of the neutrons generated in the core by fission are moderated and available for scattering experiments.

To reduce the consequences of a large pipe break, the ANS design includes the following safety features: (1) The whole primary loop is submerged under light water so that pipe breaks result in loss of pressure, but not loss of coolant. To protect the D_2O inventory investment, small pipes (such as instrument lines) and other components that are likely to leak at least once during the reactor life are located in limited volume air cells. (2) Three redundant and passive gas accumulators provide sufficient D_2O inventory to flood the limited volume cells, to maintain pressure above the net positive suction head while pumps coast down, and to maintain high enough pressure during anticipated events such as pressurizer pump or letdown valve malfunctions. (3) Three independent cooling loops have pumps located at least five meters under the light water pool level to assure net positive suction head with reduced flow under depressurized conditions. (4) The bulk coolant temperature is maintained under saturation even under depressurized conditions. (5) A fast scram system shuts down the core fission power quickly and reliably upon loss of pressure.

Preliminary analyses using a simplified dynamic model[2] have shown that the reference ANS reactor design should survive all pipe breaks, regardless of size, downstream of the core, but that some fuel damage may occur for breaks upstream of the core if the effective break diameter is larger than 0.15 m (6"). Our study suggested that the failure mechanism was due to inertial effects: If a break occurs in one of the three independent cold legs, then the inlet core flow is instantly reduced to at least 66%, while the core outlet flow remains at about 100% due to the inertia of all the fluid in the hot leg. This flow mismatch results in a core outlet depressurization while the hot leg flow slows down. Once the flow reaches equilibrium, the pressure recovers and the depressurization continues at a slower rate as the accumulators empty. This effect can be observed in Fig. 1.

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Three solutions to the above problem were studied: (1) Assume that the break is not instantaneous so that inertial effects are not as relevant; our study showed that if the break takes more than 250 ms to develop, then the core will survive. (2) Reduce the hot leg inertia (to avoid the inertial depressurization) by increasing its flow area; our study showed that the hot leg diameter should be increased from a reference 0.6 m (24") to 1.2 m (48"), but this increase would be costly in D_2O inventory and may cause natural circulation problems. (3) Increase the inertia of the cold leg by introducing a suitable passive device between the break and the core inlet.

An inertial flow diode is a flow restriction with a 45° angle of attack at the inlet and a 10° angle at the outlet; a long small-diameter pipe connects the two restrictions. These angles of attack result in a friction three times larger under reverse flow conditions. The long small diameter pipe supplies sufficient inertia to maintain high diode-outlet pressure while the hot leg flow slows down during a cold leg break. In our design, the cold leg contracts from a 0.35 m (14") diameter to 0.2 m (8"), and the required IFD length is of the order of 4 m; the effect of this IFD is shown in Fig. 1. To minimize the probability of breaks in the unprotected region, the short length of piping between the IFD outlet and the core inlet is double walled and monitored .

In summary, preliminary safety analyses have shown that the ANS reactor design should survive all likely pressure boundary breaks if inertial flow diodes are placed at the outlet of all three active cold legs.

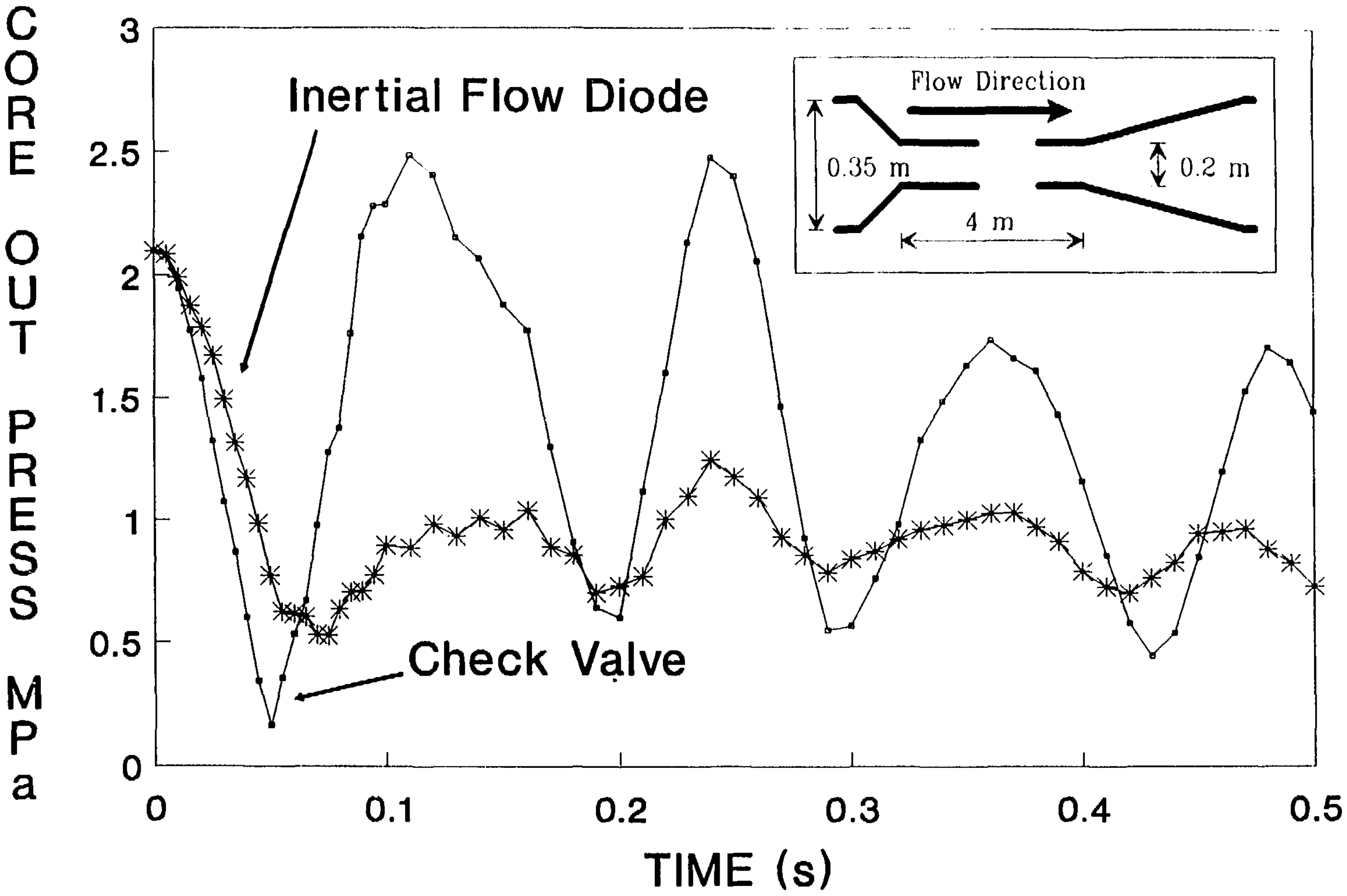
REFERENCES

1. C. D. West, "Overview of the ANS Project," Trans. Am. Nucl. Soc., 57, 288 (1988)

2. M. I. Khayat, J. March-Leuba, and H. L. Dodds, "Pressure Dynamics Modeling for the Design of the Advanced Neutron Source Reactor," Trans. Am. Nucl. Soc., 63, 459 (1991)

FIGURE CAPTIONS

Fig. 1. Core outlet pressure following a fast (50 ms) double ended guillotine break at one of three cold leg outlets, showing the effect of different design options.



CORE OUT PRESS MPa
3
2.5
2
1.5
1
0.5
0
0
0.1
0.2
0.3
0.4
0.5
TIME (s)
Inertial Flow Diode
Check Valve
Flow Direction
0.35 m
0.2 m
4 m