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AN INVESTIGATION OF TWO-PHASE FLOW REGIMES IN LOFT PIPING DURING LOSS-OF-COOLANT EXPERIMENTS

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ABSTRACT

The two-phase flow regimes present in the Loss-of-Fluid Test (LOFT) facility primary coolant piping during nonnuclear Experiments L1-1 through L1-4 have been investigated. The flow regimes were determined from density profiles calculated by a computer program using data from the five three-beam gamma densitometers employed in LOFT. The LOFT flow regime data were compared with two-phase flow transition theory data to evaluate the validity of using steady state flow maps to predict flow regimes in the LOFT primary coolant piping during a blowdown transient. The LOFT data were compared with flow regime data from the Semiscale Mod-1 facility, which is approximately 1/30 the size of LOFT, to gain insight into the effects of scale.

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SUMMARY

Two-phase flow regimes in Loss-of-Fluid Test (LOFT) facility primary coolant piping during a loss-of-coolant experiment (LOCE) were investigated. The knowledge of piping flow regimes is essential to code assessment and development. Also, this investigation of piping flow regimes provides data to improve piping heat transfer and mass flow calculations.

The LOFT facility was designed to scale the major components of a large pressurized water reactor (PWR) and to provide data from blowdown and reflood transients during LOCEs. The data are used to identify the thermal-hydraulic behavior which occurs during a LOCE and to assess analytical codes used to predict loss-of-coolant accident behavior in large PWRs.

The flow regimes in the LOFT primary coolant piping were determined from the fluid behavior (fluid velocity, chordal and average densities, void fraction, and density profiles) at each piping measurement location. The density profiles were estimated by an analytical technique which used data from five three-beam gamma densitometers installed on the LOFT piping. This technique compared densities from each densitometer beam and defined an analytical model which best describes the density profiles. The density profiles were estimated for each sampling of the densitometer data and used to calculate the piping cross-sectional average fluid density.

The flow regimes are presented for LOFT LOCE L1-4 at the five piping locations where densitometers are installed. However, flow regimes for LOCEs L1-1 through L1-3A are discussed when they differ from those for LOCE L1-4. The piping flow regimes were found to be consistent with commonly observed flow regimes and were similar between the LOFT LOCEs at the same piping locations. Some effects on flow regimes caused by experiment initial condition and system configuration were also indicated.

The flow map developed by Mandhane, Gregory, and Aziz and the flow regime transition method and flow map developed by Taitel and Dukler were compared with the indicated flow regimes in the LOFT piping. These flow maps were found not to apply to the LOFT system and transient fluid behavior during a LOCE. The differences between the LOFT LOCE data and the flow maps are considered to result because the flow maps were developed from steady state air-water data and steady state separate component assumptions.

The flow regimes in the LOFT piping were compared with results of a flow regime evaluation for the Semiscale Mod-1 facility, which is scaled approximately 1/30 the size of the LOFT facility. This comparison was performed because of the similarity in the blowdown behavior between the two facilities. The superficial phase velocities were similar for LOFT and Semiscale Mod-1, and this similarity is considered a function of the blowdown transient. However, the Semiscale Mod-1 superficial phase velocities lagged those of LOFT as the blowdown transients proceeded. A comparison of LOFT and Semiscale Mod-1 flow regimes with the Mandhane et al flow map indicated that the pipe size and blowdown transient fluid behavior were the major factors limiting the application of steady state flow maps derived from small pipe diameter data to LOCE analyses of large-scale facilities.

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FIGURES

TABLE

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AN INVESTIGATION OF TWO-PHASE FLOW REGIMES IN LOFT PIPING DURING LOSS-OF-COOLANT EXPERIMENTS

I. INTRODUCTION

This investigation provides insight into the two-phase flow regimes in the Loss-of-Fluid Test (LOFT) primary coolant piping (intact and broken loops) during a loss-of-coolant experiment (LOCE) transient. The knowledge of transient flow regimes is essential to the assessment and development of some of the more advanced analytical models and methods used for calculating loss-of-coolant accident (LOCA) response of large pressurized water reactors (PWR). This investigation also provides data which can be used to improve mass flow and piping heat transfer calculations.

The investigation included a study of flow regime data from LOFT nonnuclear experiments. The results of this study were then compared (a) with steady state flow maps to examine their applicability for evaluating flow regimes in a PWR during a loss-of-coolant transient and (b) with results from an investigation of flow regimes in the Semiscale Mod-1 facility, which is scaled approximately 1/30 the size of LOFT, to gain insight into the effects of scale.

The piping flow regime data used in this investigation were from the first five nonnuclear experiments performed in the LOFT facility. The flow regimes were determined from fluid density profiles calculated using an analytical technique developed by the LOFT Experimental Program Division. The data used for calculating the fluid density profiles in LOFT were from five three-beam gamma densitometers installed on the intact and broken loop piping.

The LOFT facility is a 50-MW (thermal) PWR designed to provide large scale integrated plant data for blowdown and reflood from LOCEs. One of the primary objectives of the LOFT experimental program is to provide data to evaluate the adequacy and improve the analytical methods currently used to predict the LOCA response of large PWRs.

The LOFT system and experiments from which data for this investigation were taken are briefly described in Section II of this report. The analytical technique used to calculate the LOFT fluid density profiles and the procedure used to determine the piping two-phase flow regimes are discussed in Section III. Section IV presents a detailed discussion of the calculated density profiles and piping flow regimes in LOFT during the nonnuclear LOCEs. The LOFT flow regime data are compared with steady state flow maps and with Semiscale Mod-1 flow regime data in Section V. Conclusions reached from the investigation of piping flow regimes are presented in Section VI. Section VII contains references. Support material for the flow map descriptions is presented in Appendixes. Appendix A describes the flow regime transition method used in this report, and Appendix B describes the method used to calculate the superficial phase velocities from LOFT experimental data.

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II. LOFT SYSTEM AND EXPERIMENT DESCRIPTIONS

The LOFT Integral[a] Test facility was designed to simulate the major components of a large PWR. Several series of experiments have been planned for performance in LOFT to produce data on combined thermal, hydraulic, nuclear, and structural processes expected to occur in a PWR during a postulated LOCA. The first series of experiments (designated as Test Series L1) is a nonnuclear test series and has been completed. Data for this investigation of flow regimes in the LOFT primary coolant piping were taken from the first five experiments in the nonnuclear test series. Brief descriptions of the LOFT system and nonnuclear test series are presented in the following sections.

1. LOFT SYSTEM DESCRIPTION

The LOFT test assembly comprises five major subsystems which have been instrumented such that desirable system variables can be measured and recorded during a LOCE. The subsystems include: (a) the reactor vessel, (b) the intact loop, (c) the broken loop, (d) the blowdown suppression system, and (e) the emergency core coolant system (ECCS). An isometric of the LOFT major components is shown in Figure 1. A detailed description of the subsystems, components, and instrumentation is given in Reference 1.

The fluid density measurements in LOFT which are of primary interest to this investigation were taken from five three-beam gamma densitometers installed on the LOFT piping at the following locations, which are shown in Figure 1: (a) the intact loop cold leg, (b) the intact loop hot leg, (c) the intact loop steam generator outlet, (d) the broken loop cold leg, and (e) the broken loop hot leg. The four gamma densitometers located on the intact and broken loops hot and cold legs are installed on horizontal piping. The gamma densitometer located on the intact loop steam generator outlet is installed on a vertical pipe. All piping on which the densitometers are installed is 14-inch Schedule 160 with an inside diameter of 28.42 cm.

The three-beam gamma densitometers consist of a 30-curie Cesium-137 source and three sodium-iodine crystal scintillation detectors. The source is collimated to allow a beam in the direction of each detector located around the pipe as shown in Figure 2. Each beam-detector pair gives the average fluid density of the beam chord crossing the pipe. The orientation of the source and detectors at each location is also shown in Figure 2. A more detailed discussion of the gamma densitometers is given in Reference 2.

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[a] The term "integral" is used to describe an experiment combining the nuclear, thermal-hydraulic, and structural processes expected to occur during a LOCA and as distinguished from "separate effects", which describe experiments performed to study a single effect or system.

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