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THE LOSS-OF-FLUID TEST (LOFT) FACILITY

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ABSTRACT

The Loss-of-Fluid Test (LOFT) facility is a 50 MW(t), volumetrically scaled, pressurized water reactor (PWR) system. The LOFT facility was designed to study the engineered safety features (ESF) in commercial PWR systems as to their response to the postulated loss-of-coolant accident (LOCA). With recognition of the differences in commercial PWR designs and inherent distortions in reduced scale systems, the design objective for the LOFT facility was to produce the significant thermal-hydraulic phenomena that would occur in commercial PWR systems in the same sequence and with approximately the same time frames and magnitudes. The information acquired from loss-of-coolant experiments (LOCE) is thus used for evaluation and development of LOCA analytical methods and assessment of the quantitative margins of safety provided by the ESFs when responding to a LOCA. The design and current experience with the LOFT facility is described in relation to the Nuclear Regulatory Commission's (NRC) research program. Expectations for use of the LOFT facility with emphasis on the types of information currently of greatest importance are also described.

IN A PWR, THE ACCIDENT postulated to be the most severe is the LOCA. For a LOCA, a main coolant pipe of a nuclear reactor system is hypothesized to shear completely allowing noncommunicative flow out both sides of the break (a 200% double-ended offset shear). The worst location for such a break is between the primary coolant pump and the reactor vessel(1*). After the assumed pipe break, the system pressure would drop rapidly to the saturation pressure of the core outlet fluid and local boiling would begin. Depending on the relative depressurization rates of the reactor vessel upper and lower plenums, core flow would subside, reverse, or stagnate. This reduction in core flow would cause the fuel rods to undergo departure from nucleate boiling, after which the fuel rod cladding temperature would rise due to energy redistribution in the rod. In order to mitigate the circumstances of a LOCA, ESFs are built into all licensed nuclear power plants in the United States. The ESF most pertinent during a postulated LOCA is the emergency core coolant system (ECCS), which is designed to inject borated water into the reactor system to cool the fuel rods and remove decay heat.

To assure the safety of nuclear reactor systems, the United States NRC requires all parties wishing to operate a nuclear plant to be licensed. Before a license is granted, the candidate plant must be shown to have met the licensing criteria(2) with regard to ESF performance during a LOCA as well as other accidents. The NRC carries out various research programs to better understand the consequences of a LOCA and provide data to assess the inherent conservatisms in the computer codes used to license a nuclear plant. One such program is the LOFT Program being conducted at the Idaho National Engineering Laboratory. The LOFT facility is used to perform LOCA simulation experiments. These experiments provide the NRC with integral system data from an intermediate-size facility for code assessment and for the identification of unexpected thresholds or events that may occur during a LOCA. The term integral implies the entire system is modeled and the entire LOCA sequence is carried out as opposed to separate-effects tests in which components or single systems are tested during a particular phase of the LOCA. The NRC uses the data from LOFT, smaller integral test programs, and separate-effects tests to quantify the conservatism in its licensing process.

LOFT FACILITY DESCRIPTION

The LOFT facility(3) was scaled to generic PWRs, maintaining the system and component coolant-volume-to-total-power ratio whenever possible(4). Inherent in scaling are some compromises of geometric similarity. These scaling compromises and the LOFT reactor system and its associated experimental instrumentation are briefly described.

REACTOR SYSTEM - In the LOFT reactor system, the scaling compromises are apparent as distortions of length-to-diameter ratios and surface area-to-volume ratios. The 1.7-m-long LOFT reactor core is about one-half the length of typical reactor cores (3.7 m long) in commercial plants. The LOFT ECCSs, however, are actuated similarly to their generic counterparts and inject scaled amounts of emergency core coolant (ECC) typical of the ECC delivery behavior expected in commercial power plants. The LOFT ECCSs have the capability of injecting ECC to any of several locations including the intact loop hot or cold legs and the reactor vessel downcomer, lower plenum, or upper plenum. The LOFT facility can be operated over a range of power levels, flow rates, and maximum linear heat generation rates (MLHGR) to assure LOFT pre-LOCE operating conditions are typical of those in a generic PWR.

The LOFT primary coolant system shown in Figure 1, consists of an intact loop containing active components to simulate three unbroken loops of a four-loop PWR, a reactor vessel containing a nuclear core, and a broken loop to simulate the single broken loop of a PWR. The broken loop contains passive steam generator and pump components (simulators) and does not have appreciable flow prior to LOCE initiation. The broken loop terminates in two quick-opening blowdown valves, which simulate the pipe rupture. The pump and steam generator simulators contain orifice plates to simulate the pressure drops of their respective counterparts.

EXPERIMENTAL INSTRUMENTATION - The LOFT system is extensively instrumented to allow data acquisition for parameters of interest for computer code assessment and phenomena determination.

The reactor vessel instrumentation includes core inlet and outlet coolant temperature; fuel rod cladding and guide tube temperature; core outlet and downcomer momentum flux and velocity; downcomer, lower plenum, core, and upper plenum liquid level; and in-core neutron flux measurements. The basic philosophy for in-core instrumentation was to instrument the center fuel assembly and about one-half of the peripheral fuel assemblies and to leave the

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* Numbers in parentheses designate References at end of paper.

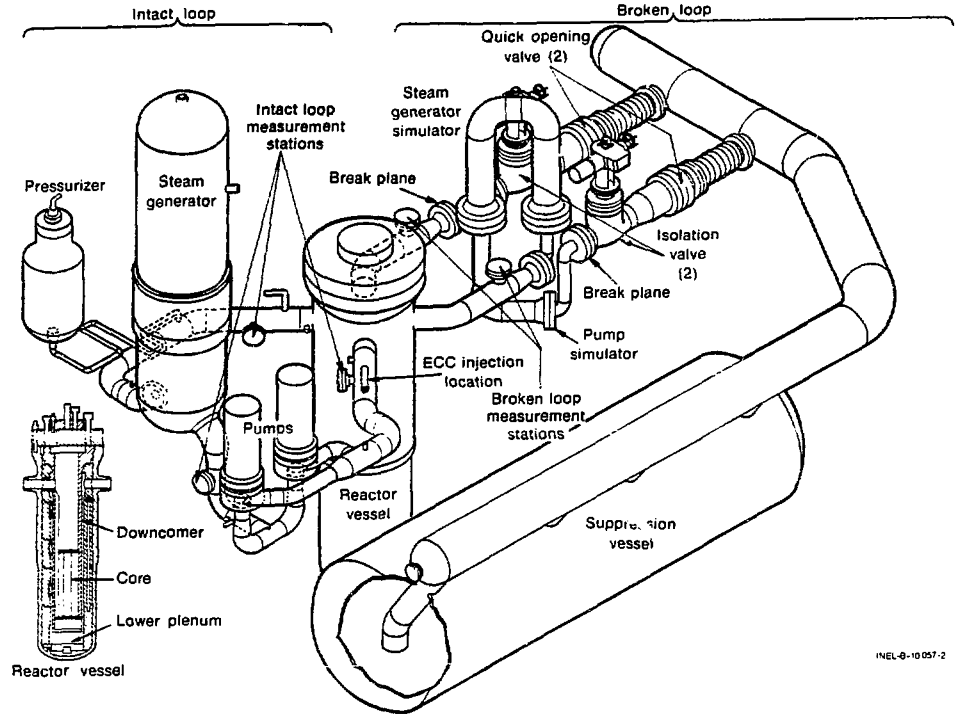

Fig. 1. - LOFT major components in cold leg break configuration

remainder of the core uninstrumented. This philosophy is intended to allow postirradiation examination of the fuel to assess the effects of instrumentation on fuel rod behavior. The location and type of instrumentation in the LOFT core is shown in Figure 2.

The primary coolant system and ECCS are also extensively instrumented for experimental purposes. There are five measurement stations located in the primary coolant piping (see Figure 1); one near each of the four reactor vessel nozzles and one in the intact loop pump suction piping. The fluid conditions at the pump suction station are very turbulent during a LOCE. This turbulence has caused occasional instrument failures, which resulted in unreported measurements during some experiments. Each station consists of a density measurement; three velocity, momentum flux, and temperature measurements; and a single pressure measurement. These measurements allow determination of the thermodynamic state of the fluid and provide a state-of-the-art measurement of the two-phase flow phenomena during a LOCE.

The remainder of the primary coolant system is instrumented to measure pressures and temperatures and to provide differential pressure closure around the intact loop and to the break. The ECCS is instrumented to provide flow rates and temperatures of the injected ECC.

In general, the measurement uncertainties for the measured principal variables have been determined as:

(1) Temperature - $\pm$ 3 K
(2) Pressure - $\pm$ 0.03 MPa
(3) Differential pressure - $\pm$ 0.01 MPa
(4) Density - $\pm$ 0.03 Mg/m^3
(5) Momentum flux - $\pm$ 12.0 Mg/(m - s^2)
(6) Velocity - $\pm$ 2.7 m/s.

The first four variables listed have been measured with a high degree of accuracy during the LOFT LOCEs completed to date. Techniques and instrument design are well developed for measurement of these variables. The last two variables, momentum flux and velocity, are difficult to measure in two-phase transient flow conditions. The uncertainties stated for these variables reflect this difficulty and represent the largest uncertainties, which occur during low quality fluid conditions.

LOFT EXPERIMENTAL PHILOSOPHY

In line with the NRC position of providing additional quantification of the safety margins in nuclear power plants during a LOCA(5), the primary objective of the LOFT experimental program is to conduct the full-power LOCE as soon as possible consistent with an orderly approach to that experiment. After the full-power LOCE, other important experiments less potentially damaging to the fuel rod cladding will be performed. To carry out this testing sequence, several experiment series were planned including nonnuclear and nuclear experiments. The nonnuclear experiments are defined as those with isothermal conditions existing in the primary coolant system. The nuclear experiments are those in which the nuclear core is producing power and a temperature gradient exists across the core. The nonnuclear experiments were designed to allow assessment of system response and instrumentation performance prior to the more demanding nuclear experiment series. The experiment series are listed

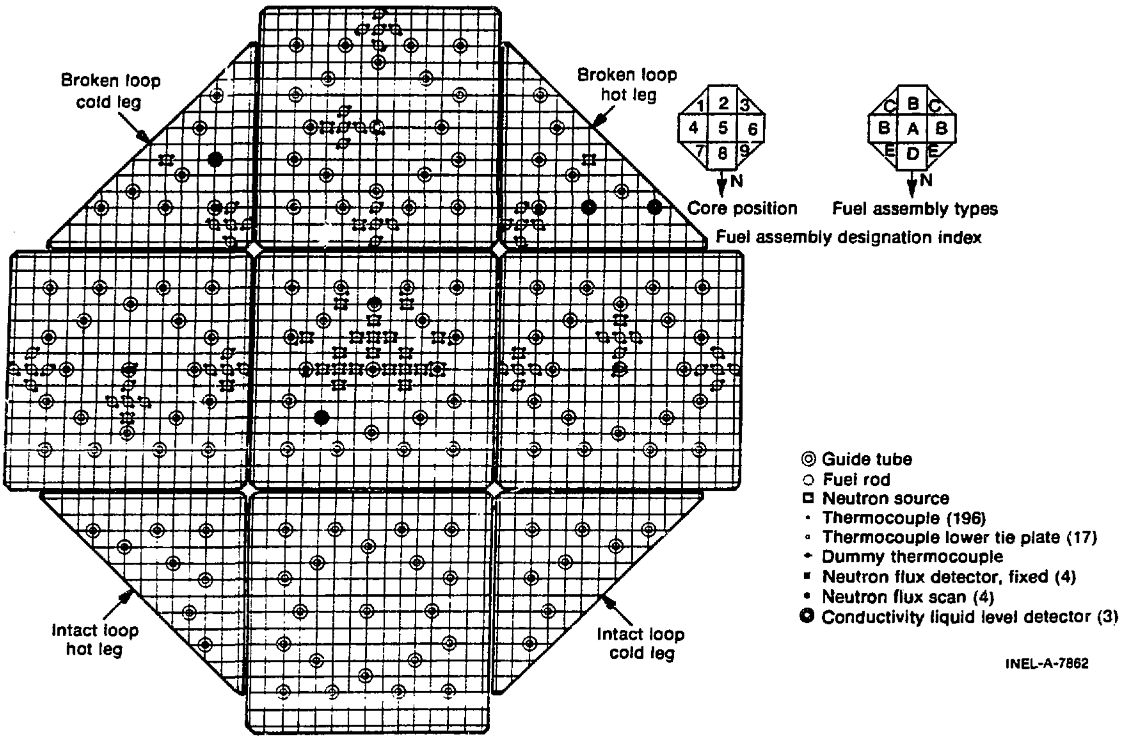

Fig. 2. - LOFT core configuration and instrumentation

in Table 1. Following L2, the chronological order of the series will depend on plant turnaround time, data requirements, and NRC priorities.

LOFT EXPERIENCE

Nonnuclear Experiment Series L1 was completed April 25, 1978. These experiments have provided useful information on LOFT operating characteristics and system response during a LOCE, in assessment of some conservatisms in the licensing procedure, and for several advances in best-estimate modeling of reactor systems in the areas of the reactor vessel downcomer and the pressurizer. Evaluation of the magnitude of the hot wall delay deterrent to ECC penetration of the downcomer in LOFT was performed with data from nonnuclear Experiment Series L1(6). Also, data for evaluation of the LOFT scaling techniques(7) were obtained from Experiment Series L1. Table 2 summarizes the system configurations and Table 3 summarizes initial conditions for Experiment Series L1.

On December 9, 1978, the first nuclear experiment, LOCE L2-2, in the LOFT Power Ascension Series (Experiment Series L2) was conducted. The results of this experiment are included in other papers in this session and are not discussed here. The initial conditions for LOCE L2-2 are shown in Table 4.

FUTURE APPLICATIONS

Currently five more experiment series and the four remaining experiments in Experiment Series L2 are scheduled to be conducted in the LOFT facility.

Table 1 - LOFT Experiment Series

Experiment Series	Type of Experiments
L1	Nonnuclear LOCE
L2	Nuclear power ascension LOCE double-ended cold leg break
L3	Nuclear LOCE with small- and intermediate-size breaks
L4	Nuclear LOCE alternate ECCS
L5	Nuclear LOCE hot leg breaks
L6	Nuclear non-LOCE
L7	Nuclear LOCE with steam generator tube rupture

These are outlined in Table 1. Experiment Series L2 through L7 are described briefly as follows.

SERIES L2 - LOFT POWER ASCENSION EXPERIMENT SERIES - Experiment Series L2, currently in progress, consists of five double-ended cold leg break (DECLB) LOCEs at increasing power levels up to 52.5 kW/m maximum linear heat generation rate (MLHGR). The series includes one experiment with 10 CFR 50.46(2) assumptions and one experiment with prepressurized

Table 2 - System Configurations and Initial Conditions for Experiment Series L1 LOCEs

Configuration	LOCE L1-1	LOCE L1-2	LOCE L1-3	LOCE L1-3A	LOCE L1-4	LOCE L1-5
Pipe break:						
Location	Hot leg	Cold leg	Cold leg	Cold leg	Cold leg	Cold leg
Size (%)	100	200	200	200	200	200
Opening time (ms)	17	17	17	18	18	19.5
Core	Simulator for ΔP	Simulator for ΔP	Simulator for ΔP	Simulator for ΔP	Simulator for ΔP	Nuclear core
Primary system pump operation	Powered to T_o + 30 s	Power terminated at T_o +< 1 s	Power terminated at T_o +< 1 s	Power terminated at T_o +< 1 s	Power terminated at T_o +< 1 s	Powered to T_o + 70 s
Broken loop pump simulator*	Locked rotor (K = 25.65)	Locked rotor (K = 20.70)	Locked rotor (K = 20.70)	Locked rotor (K = 20.70)	Locked rotor (K = 20.70)	Operating pump (K = 9.95)
Intact loop resistance	Low resistance (K = 131.7)	High resistance (K = 359.8)	Low resistance (K = 131.7)	Low resistance (K = 131.7)	Low resistance (K = 131.7)	Low resistance (K = 131.7)
ECCSs	HPIS**, LPIS***, and accumulator	HPIS, LPIS, and accumulator	HPIS and LPIS	HPIS, LPIS, and accumulator	HPIS, LPIS, and accumulator	HPIS, LPIS, and accumulator
ECC injection location	Intact loop cold leg	Intact loop cold leg	Lower plenum	Lower plenum	Intact loop cold leg	Intact loop cold leg
ECCSs actuation mode:						
Accumulator	Pressure	Time	Not actuated	Pressure	Pressure	Pressure
LPIS	Pressure	Time	Time	Time	Time	Pressure-level
HPIS	Time	Not actuated	Time	Time	Time	Pressure-level
Secondary coolant system	PCS**** saturation conditions, no flow	PCS saturation conditions, no flow	PCS saturation conditions, no flow	PCS saturation conditions, no flow	PCS saturation conditions, no flow	PCS saturation conditions, no flow

*Darcy K factor based on 0.016 m^2 flow area.

**HPIS - high-pressure injection system.

***LPIS - low-pressure injection system.

****PCS - primary coolant system.

fuel in the central fuel assembly. Experiment Series L2 initial conditions are given in Table 5.

SERIES L3 - SMALL AND INTERMEDIATE BREAK EXPERIMENT SERIES - Experiment Series L3 will consist of three LOCEs designed to bracket and include the break size causing the longest duration of core stagnation. The experiments in LOCE L3 will be conducted from initial conditions similar to LOCE L2-3 with the break size varied.

SERIES L4 - ALTERNATE ECCSs EXPERIMENT SERIES - Experiment Series L4 will consist of five DECLB LOCEs to investigate the following alternate ECC injection concepts:

(1) Lower plenum injection
(2) Hot leg injection
(3) Combined hot and cold leg injection
(4) Direct downcomer injection
(5) Cold leg injection with upper plenum/downcomer pressure equalization.

All experiments in Series L4 will be run at the LOCE L2-3 initial conditions to allow assessment of the various ECC concepts.

SERIES L5 - HOT LEG BREAK EXPERIMENT SERIES - Experiment Series L5 will consist of two experiments with a double-ended offset shear of the reactor vessel outlet piping. One experiment will be run at the LOCE L2-3 initial conditions, and the other at LOCE L2-5 initial conditions. The experiment at LOCE L2-5 initial conditions may be omitted if data from Series L2 and analysis indicate only minor differences are expected due to 10 CFR 50.46 assumptions.

SERIES L6 - NON-LOCE TRANSIENTS EXPERIMENT SERIES - Experiment Series L6 will consist of an undetermined number of non-LOCE transients. These will include anticipated transients without scram and other operational transients. The specific transients have not been established; however, loss of feedwater flow is considered a likely candidate for the first experiment in Series L6. The experiments in Series L6 are planned to be initiated with the system operating at or near the LOCE L2-3

Table 3 - Initial Conditions for Experiment Series L1 LOCEs

Initial Conditions	LOCE L1-1	LOCE L1-2	LOCE L1-3	LOCE L1-3A	LOCE L1-4	LOCE-L1-5
Primary system:						
Pressure (MPa)	9.11	15.55	15.55	15.46	15.65	15.45
Temperature (K)	555.4	555.4	555.2	556.5	552.15	555
Mass flow (kg/s)	301.13	284.76	294.84	280.98	268.4	176.1
Boration (ppm)	0	0	0	0	1494	3087
ECCS Accumulator:						
Pressure (MPa)	4.07	3.87	Not actuated	4.05	4.14	4.17
Temperature (K)	312.04	308.99		311.48	305.15	304
Boration (ppm)	0	0		0	3307	3155
Injected volume (m^3)	2.08	2.28		2.54	2.05	1.73
Gas volume (m^3)	1.35	1.28		1.13	1.16	0.97

initial conditions. These transient experiments will be interspersed between LOCEs to maximize utilization of the LOFT facility.

SERIES L7 - STEAM GENERATOR TUBE RUPTURE EXPERIMENT SERIES - Experiment Series L7 will consist of two DECLB LOCEs with the assumption of concurrent steam generator tube ruptures. One experiment will be run at LOCE L2-3 initial conditions, and the other at LOCE L2-5 initial conditions. The second experiment may be omitted if data from Experiment Series L2 and L5 and analyses indicate only minor changes would be induced by inclusion of 10 CFR 50.46 assumptions.

CONCLUSIONS

The LOFT facility is an important part of the NRC's overall water reactor safety research program. The data obtained from the LOFT experiments have and will continue to provide the NRC and the international nuclear community with a large data base of integral system data for computer code assessment and better understanding of LOCA and non-LOCA thermal-hydraulic phenomena.

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Table 4 - System Configuration and Initial Conditions for Nuclear LOCE L2-2

Parameter	Value
Pipe break:	
Location	Cold leg
Size	200%
Opening time (ms)	17
Primary system pump operation	Powered to T_o + 200 s
Broken loop pump simulator*	Operating pump (K = 9.95)
Intact loop resistance	Low resistance (K = 131.7)
ECCSs	HPIS, LPIS, and accumulator
ECC injection location	Intact loop cold leg
ECCSs actuation mode:	
Accumulator	Pressure
LPIS	Pressure-level
HPIS	Pressure-level
Steam generator secondary:	
Pressure (MPa)	6.35
Flow rate (kg/s)	12.67
Primary system:	
Pressure (MPa)	15.64
Temperature (K):	
Hot leg	580.4
Cold leg	557.7
Core power (MW)	24.88
MLHGR (kW/m)	26.4
Mass flow (kg/s)	194.2
Boration (ppm)	838

Table 4 - (continued)

Parameter	Value
ECCS accumulator:	
Pressure (MPa)	4.11
Temperature (K)	300.8
Boration (ppm)	3301
Injected volume (m^3)	1.68
Gas volume (m^3)	1.05

*Darcy K factor based on 0.016 m^2 flow area.

Table 5 - Experiment Series L2 Initial Conditions

LOCE	Power Level (MW)	MLHGR (kW/m)	Core ΔT (K)	Flow Rate/System Volume (kg/s-m^3)	Cold Leg Temperature (K)
L2-2*	24.9	26.4	23	26.7	558
L2-3	37.2	39.4	35.8	23.9	562
L2-5**	37.2	39.4	35.8	23.9	562
L2-4	49.6	52.5	35.8	31.8	562
L2-6	37.2	39.4	35.8	23.9	562

* LOCE L2-2 was completed on December 9, 1978.

** 10 CFR 50.46 assumptions.