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**AP600 LARGE-BREAK LOSS-OF-COOLANT-
ACCIDENT DEVELOPMENTAL ASSESSMENT
PLAN FOR TRAC-PF1/MOD2**

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**AP600 LARGE-BREAK LOSS-OF-COOLANT-ACCIDENT
DEVELOPMENTAL ASSESSMENT PLAN FOR
TRAC-PF1/MOD2**

by

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July 1996

CONTENTS

	Page
ACRONYMS	iv
ABSTRACT	1
EXECUTIVE SUMMARY	1
I. INTRODUCTION	4
II. AP600 SAFETY SYSTEMS AND THE LBLOCA TRANSIENT	5
III. AP600 PIRT AND MODEL IDENTIFICATION	12
IV. DEVELOPMENTAL ASSESSMENT REQUIREMENTS	19
A. Separate-Effects Tests	32
B. Integral Tests	34
C. Insights to Code Models	37
V. AP600 DEVELOPMENTAL ASSESSMENT MATRIX	40
VI. SUMMARY OBSERVATIONS	40
VII. CONCLUSIONS	41
REFERENCE	43
APPENDIX - FACILITY AND TEST DESCRIPTIONS	44
REFERENCE	44
INEL Post-CHF Data	45
Winfrith Steady-State Post-CHF Data	47
THETIS Boildown Test	49
GE Level-Swell Tests	51
T-Junction Test Facility	53
Upper-Plenum Test Facility (UPTF)	55
Lehigh	59
FLECHT-SEASET	61
Cylindrical Core Test Facility (CCTF)	63
Slab Core Test Facility (SCTF)	65
Loss-of-Fluid Test Facility (LOFT)	67
Semiscale Test S-06-3	70

FIGURES

	Page
1. Containment pressure from the AP600 SAR	10
2. Calculated instantaneous flooding rate	11
3. Centered 20-s average calculated flooding rate, expanded scale	12

TABLES

I. TYPICAL LBLOCA SEQUENCE OF EVENTS	7
II. THERMAL-HYDRAULIC CONDITIONS DURING AN LBLOCA	8
III. PIRT SUMMARY RESULTS	14
IV. PROCESSES AND PHENOMENA	20
V. SEPARATE-EFFECTS DEVELOPMENTAL ASSESSMENT REQUIREMENTS FOR AP600 LBLOCA	25
VI. LOGIC OF ASSESSMENT PRIORITIES FOR SEPARATE-EFFECTS TESTS	31
VII. SEPARATE-EFFECTS TESTS	33
VIII. INTEGRAL-EFFECTS TESTS	35
IX. AP600 LBLOCA DEVELOPMENTAL ASSESSMENT MATRIX	42

ACRONYMS

3D	Three-dimensional
ACRS	Advisory Committee, Reactor Safeguards
ADS	Automatic Depressurization System
AHP	Analytical hierarchical process
AP600	Advanced Passive 600 MWe reactor design
CCF	Countercurrent flow
CCFL	Countercurrent flow limitation
CCTF	Cylindrical Core Test Facility
CHF	Critical heat flux
CMT	Core Makeup Tank
CSAU	Code scaling, applicability, and uncertainty
DNB	Departure from nucleate boiling
DVI	Direct-vessel-injection
ECC	Emergency core cooling or coolant
FLECHT-SEASET	Full-Length Emergency Cooling Heat Transfer, Separate-Effects and System-Effects Test
FZK	Forschungszentrum
GE	General Electric
HPI	High-pressure injection
INEL	Idaho National Engineering Laboratory
IRWST	In-Containment Refueling Water Storage Tank
LBLOCA	Large-break LOCA
LOCA	Loss-of-cooling accident
LOFT	Loss-of-Fluid Test
NA	Not Applicable
NR	Not Ranked
NRC	Nuclear Regulatory Commission
PCCS	Passive Containment Cooling System
PCT	Peak cladding temperature
PIRT	Phenomena identification and ranking tabulation
PRHRS	Passive Residual Heat Removal System
PSIS	Passive Safety Injection System
PWR	Pressurized water reactor
SCTF	Slab Core Test Facility
SAR	Safety Analysis Report
SB	Small-break
SCTF	Slab Core Test Facility
THETIS	A British heat-transfer rig
TRAC	Transient Reactor Analysis Code
UPTF	Upper Plenum Test Facility
W 4 Loop	Westinghouse current-generation four-loop PWR

AP600 LARGE-BREAK LOSS-OF-COOLANT-ACCIDENT DEVELOPMENTAL ASSESSMENT PLAN FOR TRAC-PF1/MOD2

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ABSTRACT

The Westinghouse AP600 reactor is an advanced pressurized water reactor with passive safety systems to protect the plant against possible accidents and transients. Westinghouse has submitted the design to the United States Nuclear Regulatory Commission (NRC) for design certification. The NRC has selected the Transient Reactor Analysis Code (TRAC)-PF1/MOD2 for performing large-break loss-of-coolant-accident (LBLOCA) analyses to support the design-certification effort. To enhance certain capabilities of TRAC for these analyses, the NRC is funding a limited code development effort. The code development effort includes developmental assessment to demonstrate the adequacy of the code.

This document defines the tests to be used in the current phase of developmental assessment related to AP600 LBLOCA. The selection process is based on the phenomena identification and ranking tabulation (PIRT) developed previously for the AP600 LBLOCA transient. The PIRT results, together with a judgment on the quality of the TRAC models, identify those processes and phenomena requiring assessment. The PIRT results generally lead to the selection of separate-effects tests. We have supplemented the selection of separate-effects tests with integral tests to assess the overall calculational capability of the code and to support efforts to improve the robust nature of the code (the ability to calculate transients without code failures).

EXECUTIVE SUMMARY

The Westinghouse AP600 reactor is an advanced pressurized water reactor (PWR) with passive safety systems to protect the plant against possible accidents and transients. Westinghouse has submitted Nuclear Regulatory Commission (NRC) for design certification. The NRC has selected the Transient Reactor Analysis Code (TRAC), specifically version PF1/MOD2, for performing large-break loss-of-coolant-accident (LBLOCA) analyses in support of the design-certification effort. To enhance certain capabilities of TRAC for these analyses, the NRC is funding a limited code development effort. The code development effort includes developmental assessment to demonstrate the adequacy of the code.

This report documents the effort to define a developmental assessment plan for TRAC-PF1/MOD2 to support its application to the AP600 LBLOCA transient. As part of this effort, we reviewed the AP600 and its safety systems, testing done in support of the design certification, and a calculation of an AP600 LBLOCA transient. This review led to the conclusion that the new testing was limited to investigating small-break (SB) LOCA and non-LOCA transients and would not support the LBLOCA analyses. The effort then turns to the AP600 LBLOCA phenomena identification and ranking tabulation (PIRT), which rates the importance of processes and phenomena to the LBLOCA transient. We identified the code models corresponding to the processes and phenomena in the PIRT and combined the PIRT priorities with the adequacy of the code models to generate the developmental assessment priorities. Based on these assessment priorities and on the fluid conditions existing during the various phases of the transient, we identified separate-effects tests that can be used for developmental assessment. The nature of the PIRT leads to a concentration on separate-effects tests, and these tests seldom lead to comprehensive testing of the overall code performance. Therefore, we also identified integral tests for inclusion in the developmental assessment plan to check the overall quality of the code and to support enhancements to the robust nature of the code (the ability of the code to perform calculations without code failures).

The process of combining the PIRT priorities with the adequacy of the code models resulted in assessment priorities of high, medium, and low. For those code models with high or medium assessment priority, we identified appropriate experiments for use during developmental assessment. Some items identified for assessment against separate-effects data included downcomer phenomena (flow regimes, interfacial drag, entrainment and deentrainment, and flashing) during blowdown and refill, the rewets in the core during blowdown, and flow splits and asymmetries in the piping loops; however, the readily available separate-effects data for testing the code against these phenomena do not cover adequately the range of pressures, velocities, and void fractions for blowdown and refill. Therefore, we will rely on the selected integral tests for further assessment of the code capabilities in these areas. All three of the integral tests shown in the accompanying table exhibit data pertinent to the downcomer phenomena just listed, and both of the Loss-of-Fluid Test (LOFT) tests exhibit the blowdown rewet to varying degrees. Because of the configuration of the facilities, neither LOFT nor Semiscale will exhibit flow splits and asymmetries quite like those in AP600. This lack of fidelity in the experiments results from the piping split in AP600 at the exit from the steam generator into two cold legs.

The assessment plan is driven exclusively by the results of the PIRT and a judgment regarding the code quality. The plan makes no attempt to update the PIRT results. If the PIRT did not include a particular process or phenomenon, such as grid spacer effects, then the plan does not include an assessment activity for that process or phenomenon. If the PIRT identifies a process or phenomenon as high or medium priority, and if the judgment on the pertinent code model quality warrants it, an assessment activity is identified, such as the use of the Idaho National Engineering Laboratory and Winfrith data to assess core heat transfer during refill. If the code

developers believe that the code model is of sufficient quality, then phenomena with high or medium PIRT rankings, such as critical flow at the break or countercurrent flow limitation in the upper plenum, will not have assessment activities.

The following table shows the tests selected for assessment of the first three phases of the LBLOCA transient: blowdown, refill, and reflood. We did not select tests for assessing the code during the long-term cooling phase of the transient because the code seldom is applied to that phase and because we expect the conditions to be reasonably steady with the core temperatures maintained near saturation for long periods of time. The nature of the phenomena occurring during blowdown and refill and the limited types of separate-effects tests leads to substantial overlap between the assessments identified for blowdown and refill.

AP600 LBLOCA DEVELOPMENTAL ASSESSMENT MATRIX

LBLOCA Phase	Separate-Effects Tests	Integral Tests
Blowdown	GE Level Swell 1004-3 5801-15 INEL post-CHF data T-Junction Test Facility THETIS Boildown test T2L095 Winfrith steady-state post-CHF data	LOFT LP-02-6 LOFT L2-3 Semiscale S-06-3
Refill	GE Level Swell 1004-3 5801-15 INEL post-CHF data THETIS Boildown test T2L095 UPTF 5B, 6, 21A, 21B, 25B, 21D, and 27A Winfrith steady-state post-CHF data	LOFT LP-02-6 LOFT L2-3 Semiscale S-06-3
Reflood	CCTF Runs 14, 54, ... FLECHT-SEASET 31504 31701 33436 INEL post-CHF data Lehigh SCTF (total of 8 tests between CCTF and SCTF) Winfrith steady-state post-CHF data	LOFT LP-02-6 LOFT L2-3 Semiscale S-06-3

I. INTRODUCTION

The NRC is currently using TRAC, specifically version PF1/MOD2, for analyses of the LBLOCA in the Advanced Passive 600 MWe reactor design (AP600). In support of this effort, the NRC has funded several code development tasks to enhance TRAC-PF1/MOD2 for these analyses. A normal function of code development is to perform developmental assessment of the code as the code development tasks near completion. In support of code development and as a part of NRC Job Code L2592, "AP600 Plant Analysis with TRAC-P," the NRC funded a task to generate a developmental assessment plan for this version of TRAC-PF1/MOD2. The task description¹ follows:

Task 6.4. Developmental Assessment Plan

Based on the results of the PIRT effort in Task 5, and results of the findings in Tasks 6.1, 6.2 and 6.3, Los Alamos will technically justify the selection of all developmental assessment problems and prepare a letter report on the developmental assessment plan. A description of the assessment program of the blowdown and refill periods is presented in Tasks 6.5 and 6.6. A tentative list of facilities is indicated in Tasks 6.5 and 6.6 for the blowdown and refill phases. Los Alamos will select appropriate tests from those facilities and make a presentation of the complete plan (including reflood) to review groups and ACRS if requested by the NRC. Based on review group comments and further NRC review, the plan may be changed. The estimated completion date is July 1995.

Task 5 in the above task description is to develop a PIRT for the AP600 LBLOCA transient; Ref. 2 documents this PIRT. Tasks 6.1, 6.2, and 6.3 respectively define a method for quantifying the AP600 LBLOCA uncertainty, identify the significant code modifications that distinguish TRAC-PF1/MOD2 from TRAC-PF1/MOD1, and document the technical justification, applicability, accuracy, and scale-up capability of the pertinent TRAC-PF1/MOD2 closure relationships. References 3 and 4 document the results of Tasks 6.2 and 6.3.

The next section provides a review of the AP600 and its safety systems, the testing in support of design certification, and a calculation of the AP600 LBLOCA transient. Then in Section III, we introduce a summary of the AP600 LBLOCA PIRT and identify in general terms the TRAC models that are most important in calculating the processes and phenomena identified in the PIRT. It is important to note the AP600 PIRT defined the following phases for the LBLOCA transient:

- Blowdown—the transient period beginning at the initiation of the break and ending with the beginning of accumulator injection.
- Refill—the transient period extending from the beginning of accumulator injection to lower plenum refill.
- Reflood—the time from lower plenum refill to the final quenching of core.

- Long-term cooling—the indefinite time period after the core has quenched and during which the passive systems maintain core cooling.

For transients other than LBLOCA, the beginning of long-term cooling normally coincides with the beginning of injection from the In-containment Refueling Water Storage Tank (IRWST); the difference between these two definitions appears to involve only a short period of time over which accumulator injection ends.

Section IV sorts the information from Section III by code models to identify clearly where each model is used in the LBLOCA transient. The PIRT priorities combine with the model qualities to produce the assessment priorities. For high and medium assessment priorities, we have identified tests for use in the developmental assessment. The nature of the PIRT leads to a concentration on separate-effects tests. Separate-effects data seldom lead to comprehensive testing of the overall code performance; therefore, we identified integral tests for inclusion in the developmental assessment plan. The process of identifying code models that dominate the calculation of the various processes and phenomena requires at least a cursory review of the code models and calculational results. The more significant findings from this review are also included in Section IV.

Section V pulls together all of the selected tests, both separate effects and integral, into a developmental assessment matrix that clearly identifies which tests are to be used for assessing the code during the blowdown, refill, and reflood phases of the LBLOCA transient. Section VI is a summary of the observations made in earlier sections of the report, and Section VII provides the conclusions from the task.

II. AP600 SAFETY SYSTEMS AND THE LBLOCA TRANSIENT

The basic design configuration² of the AP600 has two hot legs and four cold legs (2 x 4), in which the loop seals have been eliminated to minimize pressure differences between the hot and cold legs during SBLOCA transients. The following are the major safety-related design features associated with AP600:

- Passive Safety Injection System (PSIS)—two trains, each consisting of a Core Makeup Tank (CMT) and an accumulator that inject directly into the downcomer via the direct-vessel-injection (DVI) nozzles.
- Core Makeup Tank—as a part of the PSIS, the CMT is a large liquid volume that does not circulate at normal operating conditions but does ride on the primary system pressure; during transients it can circulate or drain into the downcomer in response to primary system depressurization and voiding.

- Automatic Depressurization System (ADS)—two trains, each a four-stage system for depressurizing the reactor primary (initial three stages from the pressurizer and the fourth and final stage from the hot legs).
- In-containment Refueling Water Storage Tank—a large tank with sufficient liquid volume to supply water to the reactor primary through the DVI nozzles for several days after the accumulators and CMTs empty.
- Passive Residual Heat Removal System (PRHRS)—a natural circulation system to reject decay heat from the reactor to the IRWST.
- Passive Containment Cooling System (PCCS)—a system for cooling the containment in support of long-term cooling.
- Upper head, guide tubes, and drain holes—the guide tubes and drain holes allow the liquid inventory in the upper head to drain completely (the drain holes appear to be the significant change relative to earlier Westinghouse designs).

Activation of most of the passive safety features requires receipt of the S-signal to open isolation valves in the piping system. The S-signal is generated by several logic paths, but for the LBLOCA, the earliest signal is from a 5-psi over pressure in the containment. Once the S-signal has been generated during the LBLOCA transient, the CMTs can drain a little, but when the accumulators begin injection (at ~700 psi), check valves prevent any additional CMT injection until after the accumulators empty. The ADS requires that the CMTs drain to at least 2/3 of their initial inventory; this requirement results in no ADS action until after the end of reflood. Also, the IRWST cannot drain during accumulator injection because of check valves and hence does not play a part in the LBLOCA until after the end of reflood. The PRHRS interacts with the reactor primary during the LBLOCA after the S-signal, but because of the rapid voiding of the system, the PRHRS represents only a small source of water as it drains and does not reject significant heat from the primary. The PCCS does affect the containment pressure during the LBLOCA, but its effect on the primary system in code analyses is usually specified by the user through input (back pressure on the break).

Therefore, the main safety systems active during the initial three phases of the LBLOCA transient are the two accumulators. The upper head will drain during the transient through the guide tubes and drain holes. The LBLOCA scenario for AP600 through reflood is very similar to that in a current generation Westinghouse PWR, and the new AP600 features generally do not impact the LBLOCA. This observation is consistent with the decision by Westinghouse and the NRC not to pursue additional LBLOCA testing in support of the AP600 design certification. To date, Westinghouse- and NRC-

funded tests in three facilities have investigated the performance of the overall AP600 safety system in response to SBLOCA and non-LOCA transients. Because there has been no LBLOCA testing in support of AP600 (and because the AP600 LBLOCA transient should be similar to that in current generation Westinghouse PWRs), our selection of tests for developmental assessment will not include any of the new testing in support of the AP600. Also, very few separate-effects tests cover the range of pressures existing during blowdown and the early part of refill.

We have analyzed the AP600 LBLOCA previously with TRAC.⁵ This calculation considers an 80% double-ended guillotine break in one cold leg. (Westinghouse had previously indicated that this break size and location constituted the worst case.) The calculation resulted in the sequence of events shown in Table I. By our definition of the LBLOCA phases, the blowdown phase ends at 12 s; refill, at 43 s; and reflood, at 243 s. In this calculation, the end of reflood (final quenching of the core) and the end of accumulator injection occur at approximately the same time. Table II shows some of the thermal-hydraulic conditions existing at the beginning and end of blowdown, refill, and reflood. Although TRAC did not calculate very far into the long-term cooling phase, we do not expect the conditions to vary much from the conditions at the end of reflood. Tables I and II together give an indication of the duration and range of conditions that need to be covered in tests for developmental assessment during the various LBLOCA phases.

TABLE I
TYPICAL LBLOCA SEQUENCE OF EVENTS

Time (s)	Event
0	Break occurs.
0.35	"S" signal occurs from containment 5-psi overpressure signal.
0.86	Reactor trip from "S" signal, steam generators isolated.
2.1	CMT and PRHRS isolation valves start to open. A very small amount of CMT flow occurs but ceases when accumulator flow starts.
7.0	Blowdown peak cladding temperature occurs (~1021 K or 1378°F).
8	Pressurizer empties.
12	Accumulators start to inject.
17.1	Reactor coolant pumps tripped.
22	Peak accumulator flow (~408 kg/s or 900 lb _m /s) occurs; accumulator flow is limited by choking at the DVI nozzle venturi.
30	Lower plenum starts to refill.
43	Core reflood begins.
58	Reflood peak cladding temperature occurs (~1197 K or 1695°F).
243	Reflood ends with the final quenching of the core.
270	IRWST injection begins.

TABLE II
THERMAL-HYDRAULIC CONDITIONS DURING AN LBLOCA

Steady -State Operation

Primary:

Pressure	15.51 MPa	2250 psia	(pressurizer pressure)
Hot-leg temperature	587.4 K	597.7°F	
Cold-leg temperature	551.3 K	532.7°F	
Flow (total)	9930 kg/s	21,892 lb _m /s	(sum over all cold legs)
Void fraction	0.0		
Power (core)	1971.7 MW _t	102%	(Westinghouse-specified value for LBLOCA)

Secondary:

Pressure	5.36 MPa	777 psia	(steam exit pressure)
Feedwater flow	531 kg/s	1170 lb _m /s	(per steam generator)
Steam flow	531 kg/s	1170 lb _m /s	(per steam generator)
Feedwater temperature	497 K	435°F	
Steam temperature	541.5 K	515°F	(steam line)
Level	12.32 m	485 in	(downcomer level)

End of Blowdown Phase (beginning of accumulator injection)

Transient time 12 s

Primary:

Pressure	5.06 MPa	734 psia	(pressurizer pressure)
Hot-leg temperature	537.2 K	507.3°F	
Cold-leg temperature	537.2 K	507.3°F	
Flow (total)	943 kg/s	2079 lb _m /s	(sum over intact cold legs)
Break flow (total)	5359 kg/s	11,815 lb _m /s	(maximum is 20,000 kg/s at 1 s into transient)
Void fraction	≤ 1.0		
Power (core)	124.2 MW _t	6.4%	
Emergency core coolant (ECC) flow	160 kg/s	353 lb _m /s	(from CMT)

Secondary:

Pressure	5.6 MPa	812 psia	(steam exit pressure)
Feedwater flow	0 kg/s	0 lb _m /s	(per steam generator)
Steam flow	0 kg/s	0 lb _m /s	(per steam generator)
Feedwater temperature	497.0 K	435°F	
Steam temperature	545.0 K	521.3°F	(steam line)
Level	11.61 m	457 in	(downcomer level)

TABLE II (Cont)
THERMAL-HYDRAULIC CONDITIONS DURING AN LBLOCA

End of Refill Phase (time of lower-plenum refill)

Transient time 43 s

Primary:

Pressure	126.5 kPa	18.3 psia	(pressurizer pressure)
Hot-leg temperature	380.0 K	224.3°F	
Cold-leg temperature	374.0 K	213.5°F	
Flow (total)	112 kg/s	247 lb _m /s	(sum over intact cold legs)
Break flow (total)	21 kg/s	46 lb _m /s	(fluctuates due to bypass)
Void fraction	≤ 1.0		
Power (core)	88.1 MW _t	4.6%	
ECC flow	816 kg/s	1800 lb _m /s	(maximum flow occurred at 22 s)

Secondary:

Pressure	5.4 MPa	783 psia	(steam exit pressure)
Feedwater flow	0 kg/s	0 lb _m /s	(per steam generator)
Steam flow	0 kg/s	0 lb _m /s	(per steam generator)
Feedwater temperature	497.0 K	435°F	
Steam temperature	541.6 K	515.2°F	(steam line)
Level	10.29 m	405 in	(downcomer level)

End of Reflood Phase and Beginning of Long-Term Cooling (core quenched)

Transient time ~243 s (end of reflood)
 ~270 s (beginning of IRWST injection)

Primary:

Pressure	161.4 kPa	23.4 psia	(pressurizer pressure)
Hot-leg temperature	386.0 K	235.1°F	
Cold-leg temperature	384.0 K	231.5°F	
Flow (total)	18.5 kg/s	40.8 lb _m /s	(sum over intact cold legs)
Break flow (total)	173 kg/s	381 lb _m /s	
Void fraction	≤ 1.0		
Power (core)	52.9 MW _t	2.7%	
ECC flow	11.5 kg/s	25.4 lb _m /s	(accumulators empty; CMT injection commencing)

Secondary:

Pressure	5.3 MPa	769 psia	(steam exit pressure)
Feedwater flow	0 kg/s	0 lb _m /s	(per steam generator)
Steam flow	0 kg/s	0 lb _m /s	(per steam generator)
Feedwater temperature	497.0 K	435°F	
Steam temperature	540.2 K	512.7°F	(steam line)
Level	10.29 m	405 in	(downcomer level)

Figure 1 shows the containment pressure that is presented in Fig. 6.2.1.1-3 (page 6.2-107) of the AP600 Safety Analysis Report (SAR).⁶ We have developed the figure by digitizing the curve from the SAR and then plotting the time period of interest in a LBLOCA transient. Because reflood begins at 43 s, the containment pressure during reflood, or the back pressure for the reflood process, ranges between 315 and 336 kPa (45.7–48.7 psia). Westinghouse calculated this curve with the WGOTHIC code. Westinghouse makes the argument that this curve is conservative from a containment performance perspective, that is, it represents an upper bound for the expected containment pressure. This containment pressure curve has an initial value of 108.25 kPa (15.7 psia) and is consistent with the timing of the S-signal on 5-psi overpressure in the containment. However, we ran our LBLOCA calculation with a back pressure of 101.3 kPa (14.7 psia), which was consistent with the Westinghouse calculation of the LBLOCA for the reactor system. A specification of a low containment pressure for the LBLOCA calculation has been considered as conservative for the reactor system in the past. Table II shows that the TRAC-calculated pressurizer pressure increases from 126.5 to 161.4 kPa (18.3 to 23.4 psia) during the reflood period of the transient.

Fig. 1. Containment pressure from the AP600 SAR.

Figures 2 and 3 show the flooding rate for the TRAC calculation⁵ described in Section II. The information in the figures is based on the core-inlet liquid volumetric flow, which has been divided by the axial flow area in the core. Figure 2 shows the instantaneous flooding rates every 0.5 s, and Fig. 3 shows the average flooding rate to remove the effect of the oscillations that are inherent in a gravity-driven reflood situation. Because of the large oscillations in the instantaneous reflood rate, the two figures have significantly different scales for the ordinate. [The average is taken over a 20-s interval (41 points) centered on the time point of interest, and the average is simply the arithmetic average of the 41 points.] The steady-state flow through the core, or the initial condition for the transient, is $11.86 \text{ m}^3/\text{s}$, which corresponds to an average velocity of 3.31 m/s . As indicated above, the reflood phase of the transient starts at 43 s, and the average flooding rate varied between $\sim 0.04 \text{ m/s}$ ($\sim 1.6 \text{ in/s}$) and $\sim 0.12 \text{ m/s}$ ($\sim 4.7 \text{ in/s}$). The peak flooding rate occurs at $\sim 180 \text{ s}$.

Fig. 2. Calculated instantaneous flooding rate.

Fig. 3. Centered 20-s average calculated flooding rate, expanded scale.

III. AP600 PIRT AND MODEL IDENTIFICATION

Los Alamos has produced a PIRT² to evaluate the relative importance of various processes and phenomena in the systems and components that comprise the AP600 reactor. This PIRT evaluated all four phases of the LBLOCA transient; however, the code analyses of the LBLOCA transient generally stop with the end of reflood and the beginning of long-term cooling. Reference 2 produced a detailed table of the PIRT results for all four phases, but then produced a summary table that only covered the PIRT results for blowdown, refill, and reflood. This summary table (Table 2 of Ref. 2) reflected a collapsing of the PIRT results into more general categories of systems and components, with a listing of the processes and phenomena under each system or component. This summary allowed for a comparison with the earlier code scaling, applicability, and uncertainty (CSAU) PIRT results for the current generation Westinghouse four-loop PWR. It also turns out that this summary form of the PIRT is a

more convenient form to work with in defining the developmental assessment requirements for TRAC-PF1/MOD2.

Table III replicates the summary table from Ref. 2. All of the footnotes for the table are listed at the end of the table to conserve space. The first three columns contain essentially all of the information from the summary table including the system or component, process or phenomenon, the AP600 PIRT priorities, and the Westinghouse four-loop PWR (W 4 Loop) PIRT priorities. For each process or phenomenon, we have listed the PIRT priorities as a series of three letters (XXX) corresponding to the blowdown, refill, and reflood phases. The priorities defined below agree with the priorities from Ref. 2:

- High (H)—the process or phenomenon controls or dominates the course of the transient as indicated by the (PCT),
- Medium (M)—the process or phenomenon has a moderate influence on the transient as indicated by the PCT, and
- Low (L)—the process or phenomenon has a small or insignificant effect on the transient as indicated by the PCT.

The only change is that if Ref. 2 listed the priority as not rated (NR), not applicable (NA), or null (—), it is listed here as null (—) for simplicity. While our efforts will ultimately concentrate only on the AP600 PIRT priorities, we have carried forward the W 4 Loop priorities to relate the new AP600 design to the current generation PWR. The fourth column, similarity in behavior, reflects our judgment as to the similarity in performance between AP600 and W 4 Loop. The last column, code model, is our judgment as to which generic code models primarily control the code calculation for that particular process or phenomenon.

Table III introduces the following acronyms, which we define here to conserve space in the table:

Critical heat flux (CHF)
Countercurrent flow (CCF)
Countercurrent flow limitation (CCFL)
High-pressure injection (HPI)

TABLE III
PIRT SUMMARY RESULTS

<u>System/Component</u> <u>Process/Phenomenon</u>	<u>LBLOCA PIRT^a</u> <u>AP600</u>	<u>W 4 Loop^b</u>	<u>Similarity in</u> <u>behavior^c</u>	<u>Code Model</u>
Fuel rod				
Stored energy	HLL	HLL	H	Rod conduction and material properties
Oxidation	---	-LH	H	Metal-water reaction
Decay heat	MHH	LLH	H	Reactor kinetics and/or user input
Gas (gap) conductance	HMM	LLM	H	Gap conductance
Core				
CHF	MLL	MLL	H	Heat transfer, critical heat flux and dryout criteria
Post-CHF	HHH	MHM	H	Heat transfer, transition and film boiling
Rewet	MMM	HML	H	Heat transfer, transition and film boiling
Reflood heat transfer	--H	--H	H	Heat transfer, reflood
Nucleate boiling	LLM	MLL	H	Heat transfer, nucleate boiling
1-phase gas natural circulation	---	-MM	H	Momentum closure
3D flow	MMH	LLH	H	Vessel closure
Void generation and distribution	HHH	MMH	H	Interphase heat and mass transfer; interfacial drag
Entrainment and deentrainment	MMH	LLM	H	Flow-regime map; interfacial drag; entrainment fraction
Flow reversal or stagnation	MLL	LLL	H	Momentum closure
Radiation heat transfer	---	--L	-	Heat transfer, film-boiling; no model for wall-to-wall radiation heat transfer
Upper head				
Guide tube flow ^d	MLL	---	None	Momentum closure
Drain hole flow ^d	MLL	---	None	Momentum closure

TABLE III (Cont)
PIRT SUMMARY RESULTS

<u>System/Component</u> <u>Process/Phenomenon</u>	<u>LBLOCA</u>	<u>PIRT^a</u> <u>W 4 Loop^b</u>	<u>Similarity in</u> <u>behavior^c</u>	<u>Code Model</u>
Upper plenum				
Entrainment and deentrainment ^d	MLM	LLH	H	Flow-regime map; interfacial drag; entrainment fraction
Phase separation	LLL	LLL	H	Momentum closure
CCF drain/feedback	MMM	LLM	H	CCFL and momentum closure
2-phase convection	---	LLM	H	Momentum closure
3D flow	MLM	---	H	Vessel closure
Hot leg				
Entrainment and deentrainment	LLM	LLH	H	Flow-regime map; interfacial drag; entrainment fraction
Flow reversal	LLL	LL-	H	Momentum closure
Void distribution	LLM	LLM	H	Momentum closure
2-phase convection	LLM	LLL	H	Momentum closure
Pressurizer				
Early quench	---	H--	H	See hot leg, upper plenum, and core above
Critical flow in surge line	L--	H--	H	Critical flow
Flashing	MLL	HLL	H	Interphase heat and mass transfer
Steam generator				
Steam binding	LLM	-LH	H	Heat transfer, wall, and momentum closure
ΔP and form losses	LLL	LLL	H	Momentum closure and user input
Pump				
2-phase performance	HLL	HM-	H	Pump curves, built-in or user input
ΔP and form losses	LLM	LLH	H	Pump model
Cold leg and accumulator				
Condensation	LLL	LHM	L	Interphase heat and mass transfer
Noncondensable gas	---	-LH	None	Momentum closure and interphase heat transfer
HPI mixing	---	-LL	None	Momentum and energy closure
Accumulator discharge	-HH	---	None	Momentum closure

TABLE III (Cont)
PIRT SUMMARY RESULTS

<u>System/Component</u> <u>Process/Phenomenon</u>	<u>LBLOCA PIRT^a</u> <u>AP600</u>	<u>W 4 Loop^b</u>	<u>Similarity in</u> <u>behavior^c</u>	<u>Code Model</u>
Downcomer				
Entrainment and deentrainment	MHL	LHL	H	Flow-regime map; interfacial drag; entrainment fraction
Condensation	LML	-HL	H	Interphase heat and mass transfer
Flow regime ^e — counter-current flow, slug flow, and nonequilibrium flow	LHL	LHL	H	Flow-regime map; interfacial heat and mass transfer and drag
Hot wall	LMM	-ML	H	Heat transfer, wall, and conduction closure
2-phase convection and bypass	MML	LLL	H	Momentum closure
Saturated nucleate boiling	---	LLL	H	Heat transfer, nucleate boiling
3D effects	MHL	LHL	H	Vessel closure
Flashing	MLL	L--	H	Interphase heat and mass transfer
Liquid level oscillations	LMH	-LH	H	Momentum closure
Lower plenum				
Sweep out	MLL	LMM	H	Momentum closure and user input
Hot wall	LLL	LHM	H	Heat transfer, wall, and conduction closure
3D effects	LLL	LLH	H	Vessel closure
Break				
Flow, choked and unchoked	HHM	HHL	H	Critical flow and momentum closure
Flashing	LLL	LLL	H	Interphase heat and mass transfer
Containment pressure	LLM	LML	H	User input
Piping loops				
2-phase ΔP	MMM	HHM	H	Interfacial and wall drag
Oscillations	---	-HH	-	Momentum closure
Flow splits (asymmetries)	MLL	HHL	M	Momentum closure for Tee, Plenum, and Vessel closure

TABLE III (Cont)
PIRT SUMMARY RESULTS

- ^a The PIRT priorities are given as a three-letter sequence, with each letter in order corresponding to the blowdown, refill, and reflood phases of the LBLOCA. The PIRT priorities are high (H), medium (M), low (L), or null (-). A null (-) PIRT priority means that the Process or Phenomenon in the original PIRT summary was listed as Not Ranked (NR), Not Applicable (NA), or blank (-). Also, a process or phenomenon in either PIRT exercise that was not listed or that was not given an explicit ranking is indicated with "-" in this table.
- ^b Analytical hierarchical process (AHP) ranks 7-9 in the original CSAU study have been translated to High (H) ranking; AHP ranks 4-6, to Medium (M) ranking; and AHP ranks 1-3, to Low (L) ranking.
- ^c Similarity in behavior is subjectively judged as High (H), Medium (M), or Low (L) independent of the PIRT rankings. However, if no ranking is given in either the AP600 column or the W 4 Loop column, then no judgment is made regarding similarity. If the visualization of the process or phenomenon is expected to be basically identical between AP600 and W 4 Loop, the similarity is described as High; if the visualization is significantly different, the similarity is described as Low. If there is no corresponding process or phenomenon in both designs, the similarity is described as None.
- ^d The AP600 LBLOCA PIRT priorities shown here were based on the Los Alamos TRAC analyses⁵ and the Westinghouse WCOBRA/TRAC analyses as presented in the SAR.⁶ In July 1995, Westinghouse issued revised analysis results, which exhibited an extensive core rewet during blowdown due to the draining of the upper head. If we had considered these new results in the PIRT process, the medium priority for the blowdown phase might have changed to high. A change to high priorities for guide-tube flow and drain-hole flow would not have changed the subsequent determination of assessment priorities in later tables. A change to high priority for upper-plenum entrainment and deentrainment would have increased the assessment priority from low to medium; the phenomena involved should be addressed by upper plenum test facility (UPTF) tests that have been defined for other situations.
- ^e In the original PIRT summary, this item was listed simply as "countercurrent, slug, noeq," which is now listed primarily as Flow Regime.

In general, we have rated the similarity in behavior between the two reactors as high, which is consistent with the assumption that existing experimental data base in support of LBLOCA is applicable to the AP600. We did not rate the similarity in fuel rod radiation heat transfer primarily because the phenomenon was not rated in the AP600 PIRT. The upper-head guide tube and drain-hole flows were listed as not having any

similarity, because in AP600 the guide tubes and drain holes are designed specifically to drain the upper-head inventory early in the transient.

The early quench phenomenon in Table III under the pressurizer component should be the same between the two designs, if it occurs. This phenomenon requires other related processes, including the draining of the pressurizer into the hot leg and the convection of the liquid from the hot leg through the upper plenum to the core. What may be more important to the pressurizer-driven early quench is the blowdown of steam in the pressurizer after the liquid has drained and the resulting brief pressurization event in the hot leg. This brief pressurization in the hot leg has the potential to move liquid inventories toward the core. Also under pressurizer, critical flow in the pressurizer surge line rates high in terms of similarity, but it is not obvious how important it is or if it occurs at all. Our experience with the code indicates that the flow is primarily friction limited, and if choking occurs, it is only for a very short time period.

Under cold leg and accumulator, condensation rates low in similarity, and noncondensable gas, HPI mixing, and accumulator discharge rate no similarity. These ratings reflect significant differences between the two reactors. In AP600, the accumulators inject directly into the downcomer over a much longer period of time. Noncondensable gas injection does not begin until almost the end of reflood. Because of the injection location, AP600 should not experience the same condensation driven oscillations in the cold leg that the W 4 Loop does. Finally, AP600 does not have the equivalent of an HPI system.

For the piping loops, we rated oscillations as null (-) in similarity because AP600 should not experience the same condensation-induced oscillations as W 4 Loop because of the change in the injection location. The flow splits (asymmetries) should exhibit only a medium similarity because of the 2 x 4 loop design in AP600 and the 4 x 4 loop design in W 4 Loop. AP600 has a flow split at the exit from the steam generator that does not exist in the other reactor.

We have attempted to list the most controlling code model(s) for the given phenomenon. "Heat transfer, reflood" indicates the entire set of heat-transfer correlations used in the reflood model, and "heat transfer, wall" also indicates the entire boiling curve. Momentum closure is listed to indicate that several terms in the momentum equation control the phenomenon. Vessel closure is listed in the same vein as momentum closure but requires specifically the three-dimensional (3D) momentum equation of the Vessel component. Vessel closure usually appears when the phenomenon explicitly indicates 3D; however, there are instances in which the momentum closure is identified even though the context of the location indicates that only the 3D momentum closure is the concern. Also, the indentation used in listing models in Table III and subsequent tables does not indicate subordination of items appearing in the second and following lines, but rather is used only to separate clearly one set of models from another.

We have listed "user input" under code model for several entries in Table III. Under "fuel rod, decay heat," the user frequently specifies the decay heat as a function of time after scram. Even if he specifies the point reactor kinetics model in the code, there are still many user-input parameters that must be specified to describe adequately the reactivity-feedback effects and the buildup of fission products in the fuel. Under "steam generator, ΔP and form losses," the user must either input his own estimate of the required form losses, or alternatively correctly flag the built-in code model for abrupt area changes. Under "pump, 2-phase performance," the code has built-in pump curves to describe the Semiscale and LOFT pumps, but these models are not necessarily applicable to the reactor pumps. The user must judge if the required geometric similarity is sufficient to use one of the built-in sets of curves or if he must supply through input the homologous curves for the pumps in his particular application. Under "lower plenum, sweep out," the user-prescribed nodalization of the lower-plenum region must follow the user guidelines carefully because generally the nodalization in this region is too coarse and affects the magnitude of the sweep out. Under "break, containment pressure," almost invariably the user specifies through input the back pressure on the break; using the code to calculate directly the containment pressure represents a significant extension in the application of the code beyond the development goals.

One of the first things that result from the form of Table III is that by sorting processes and phenomena by system or component, we allow a given process and phenomenon to show up possibly more than once. This repetition also results in repeating various code models. To identify clearly the processes or phenomena that may require assessment, we have sorted Table III into Table IV, which lists the processes and phenomena in the first column in alphabetical order. The location by component or system now shows up in the second column. The rest of the information is the same as in Table III.

IV. DEVELOPMENTAL ASSESSMENT REQUIREMENTS

Table V shows the developmental assessment requirements for separate-effects tests. We have based this table on Table IV, which included the summarized PIRT results and the definition of the controlling code models for various processes and phenomena. We have restructured the table to list the code models in the first column and then sorted on the code models to place them in alphabetical order. This arrangement of the table allows one to see directly all of the assessment requirements for a given model. As before, the term momentum closure, when used to describe code models, means that most of the terms on the right-hand side of the equation are important. In particular, the terms for wall and interfacial drag (which includes the flow regime map), form loss, and gravity head appear to be of comparable importance. In this context of code models, the term Vessel closure indicates specifically the 3D momentum equation.

The second and third columns list the process or phenomenon and the system or component as defined in Table III, PIRT Summary Results. We have included these two columns from the PIRT table to indicate clearly the conditions and locations under which the PIRT process determined importance.

TABLE IV
PROCESSES AND PHENOMENA

<u>Process/Phenomenon</u>	<u>System or Component</u>	<u>AP600 PIRT</u>	<u>W 4 Loop PIRT</u>	<u>Code Model</u>
1-phase gas natural circulation	Core	---	- MM	Momentum closure
2-phase convection	Upper plenum	---	LLM	Momentum closure
2-phase convection	Hot leg	LLM	LLL	Momentum closure
2-phase convection and bypass	Downcomer	MML	LLL	Momentum closure
2-phase performance	Pump	HLL	HM-	Pump curves, built-in or user input
2-phase ΔP	Piping loops	MMM	HHM	Interfacial and wall drag
3D effects	Downcomer	MHL	LHL	Vessel closure
3D effects	Lower plenum	LLL	LLH	Vessel closure
3D flow	Core	MMH	LLH	Vessel closure
3D flow	Upper plenum	MLM	---	Vessel closure
Accumulator discharge	Cold leg and accumulator	-HH	---	Momentum closure
CCF drain/feedback	Upper plenum	MMM	LLM	CCFL and momentum closure
Condensation	Cold leg and accumulator	LLL	LHM	Interphase heat and mass transfer
Condensation	Downcomer	LML	-HL	Interphase heat and mass transfer
Containment pressure	Break	LLM	LML	User input
Critical flow in surge line	Pressurizer	L--	H--	Critical flow
Decay heat	Fuel rod	MHH	LLH	Reactor kinetics and/or user input
CHF	Core	MLL	MLL	Heat transfer, DNB and dryout criteria
Drain hole flow	Upper head	MLL	---	Momentum closure
Early quench	Pressurizer	---	H--	See hot leg, upper plenum, and core in the System or Component column

TABLE IV (Cont)
PROCESSES AND PHENOMENA

<u>Process/Phenomenon</u>	<u>System or Component</u>	<u>AP600 PIRT</u>	<u>W 4 Loop PIRT</u>	<u>Code Model</u>
Entrainment and deentrainment	Core	MMH	LLM	Flow-regime map; interfacial drag; entrainment fraction
Entrainment and deentrainment	Upper plenum	MLM	LLH	Flow-regime map; interfacial drag; entrainment fraction
Entrainment and deentrainment	Hot leg	LLM	LLH	Flow-regime map; interfacial drag; entrainment fraction
Entrainment and deentrainment	Downcomer	MHL	LHL	Flow-regime map; interfacial drag; entrainment fraction
Flashing	Pressurizer	MLL	HLL	Interphase heat and mass transfer
Flashing	Downcomer	MLL	L--	Interphase heat and mass transfer
Flashing	Break	LLL	LLL	Interphase heat and mass transfer
Flow regime (countercurrent flow, slug flow, and nonequilibrium flow)	Downcomer	LHL	LHL	Flow-regime map; interfacial heat and mass transfer and drag
Flow reversal	Hot leg	LLL	LL-	Momentum closure
Flow reversal or stagnation	Core	MLL	LLL	Momentum closure
Flow splits (asymmetries)	Piping loops	MLL	HHL	Momentum closure for Tee, Plenum, and Vessel
Flow, choked and unchoked	Break	HHM	HHL	Critical flow and momentum closure
Gas (gap) conductance	Fuel rod	HMM	LLM	Gap conductance
Guide tube flow	Upper head	MLL	---	Momentum closure
Hot wall	Downcomer	LMM	-ML	Heat transfer, wall, and conduction equation
Hot wall	Lower plenum	LLL	LHM	Heat transfer, wall, and conduction equation
HPI mixing	Cold leg and accumulator	---	-LL	Momentum and energy closure

TABLE IV (Cont)
PROCESSES AND PHENOMENA

<u>Process/Phenomenon</u>	<u>System or Component</u>	<u>AP600 PIRT</u>	<u>W 4 Loop PIRT</u>	<u>Code Model</u>
Liquid level oscillations	Downcomer	LMH	-LH	Momentum closure
Noncondensable gas	Cold leg and accumulator	---	-LH	Momentum closure and interphase heat transfer
Nucleate boiling	Core	LLM	MLL	Heat transfer, nucleate boiling
Oscillations	Piping loops	---	-HH	Momentum closure
Oxidation	Fuel rod	---	-LH	Metal-water reaction
Phase separation	Upper plenum	LLL	LLL	Momentum closure
Post-CHF	Core	HHH	MHM	Heat transfer, transition and film boiling
Radiation heat transfer	Core	---	--L	Heat transfer, film-boiling; no model for wall-to-wall radiation heat transfer
Reflood heat transfer	Core	--H	--H	Heat transfer, reflood
Rewet	Core	MMM	HML	Heat transfer, transition and film boiling
Saturated nucleate boiling	Downcomer	---	LLL	Heat transfer, nucleate boiling
Steam binding	Steam generator	LLM	-LH	Heat transfer, wall, and momentum closure
Stored energy	Fuel rod	HLL	HLL	Rod conduction and material properties
Sweep out	Lower plenum	MLL	LMM	Momentum closure and user input
Void distribution	Hot leg	LLM	LLM	Momentum closure
Void generation and distribution	Core	HHH	MMH	Interphase heat and mass transfer; interfacial drag
ΔP and form losses	Steam generator	LLL	LLL	Momentum closure and user input
ΔP and form losses	Pump	LLM	LLH	Pump model

To carry forward as much information as possible, the column labeled PIRT Priority lists the PIRT priorities in the form XXX/YYY. The XXX values are the importances from the AP600 PIRT for the blowdown, refill, and reflood phases of the transient. The YYY values are the same importances from the original Westinghouse 4-loop PWR PIRT that was part of the CSAU. As stated previously, the AP600 PIRT and the Westinghouse 4-loop PIRT yielded similar results, and we will work only with the AP600 PIRT priorities in determining the assessment priorities. PIRT priorities relate to the impact of a given process or phenomenon on the peak cladding temperature (PCT) and are as follows:

- High (H)—the process or phenomenon controls or dominates the course of the transient as indicated by the PCT.
- Medium (M)—the process or phenomenon has a moderate influence on the transient as indicated by the PCT.
- Low (L)—the process or phenomenon has a small or insignificant effect on the transient as indicated by the PCT.
- Null (—)—the process or phenomenon was not ranked in the summary table of PIRT results.

Table V introduces the following acronyms, which we define here to conserve space in the table:

Cylindrical Core Test Facility (CCTF)
 Departure from nucleate boiling (DNB)
 Full-Length Emergency Cooling Heat Transfer, Separate-Effects and System-Effects Test (FLECHT-SEASET)
 General Electric (GE)
 Idaho National Engineering Laboratory (INEL)
 Slab Core Test Facility (SCTF)
 THETIS (a British heat-transfer rig)
 Upper Plenum Test Facility (UPTF)

The Current Code Capability represents a subjective judgment of the quality of the various code models. This judgment should be consistent with the code theory manual,⁷ the document³ describing the differences between TRAC-PF1/MOD1 and TRAC-PF1/MOD2, and the document⁴ describing the technical justification, applicability, accuracy, and scale-up capability of each TRAC-PF1/MOD2 correlation that is needed to model each process or phenomenon rated as high or medium in importance in the AP600 PIRT. We have described the current code capability with the following terms:

- Good—to the best of the knowledge of the code developers, the model meets the needs of the AP600 LBLOCA calculations.
- Adequate—the code developers are aware of minor deficiencies in the model, but the model works acceptably well in most cases.
- Marginal—the model has limitations that adversely impact the current calculations.
- Inadequate—the model does not represent the physics correctly.
- Improved—the model has been the subject of recent code development efforts.

The first four terms above reflect graded judgments of the capabilities that have existed in TRAC-PF1/MOD2 (defined by version number 5.4 and an earlier developmental assessment manual⁸). These capabilities have undergone some assessment previously and have been used in various applications of the code. The last term, improved, indicates new improvements for which we do not yet have enough experience with assessment and applications to grade the model.

The Assessment Priority is a combination of the AP600 PIRT Priority and the Current Code Capability; at this point, we no longer consider the priorities from the Westinghouse 4-Loop PWR PIRT. As with the PIRT priorities, the Assessment Priority is by transient phase: blowdown, refill, and reflood. Table VI provides the logic for combining the PIRT priority and the code capability into an Assessment Priority. The logic in this table is somewhat arbitrary and subject to review by experts. Note that the logic for determining the assessment priority requires that if the code model is described as improved, indicating recent code development work, the assessment priority is high regardless of PIRT priority. Otherwise, if the PIRT priority is not ranked (–), the assessment priority is low regardless of the code capability. For a low PIRT priority, an inadequate code capability has only a medium assessment priority. And as the PIRT priority increases, the assessment priority for the lower rated code capabilities increases.

The final column in Table V is Assessment Facility. In this column, we identify facilities and potential tests that will be useful in the assessment of the code; we will expand on the definition of tests in subsequent sections and in the appendix. Note that for each code model and situation (process or phenomenon, system or component) with a high or medium assessment priority, we have identified separate-effects tests for assessment. Combinations of code models and situations that resulted in low assessment priorities are listed as not requiring assessment. We have treated all of the 2D/3D facilities (CCTF, SCTF, and UPTF) as separate-effects tests. We made this distinction primarily for convenience and define a separate-effects test as one that looks at either a single phenomenon or limited group of phenomena or a single phase of the transient. UPTF stretches this definition the most, but it is convenient to use Table V to identify how the UPTF tests will be used in developmental assessment. Certainly UPTF is more limited in several ways in its coverage of the integral LBLOCA transient than the integral tests to be discussed later. UPTF offers unique instrumentation coverage of downcomer and upper plenum.

TABLE V
SEPARATE-EFFECTS DEVELOPMENTAL ASSESSMENT REQUIREMENTS FOR AP600 LBLOCA

Code Model	Process/Phenomenon	System or Component	PIRT Priority AP600/W 4 Loop	Current Code Capability	Assessment Priority	Assessment Facility
CCFL and momentum closure	CCF drain/feedback	Upper plenum	MMM/LLM	Good	LLL	Not required; we assessed this model in the earlier MOD2 version.
Critical flow	Critical flow in surge line	Pressurizer	L--/H--	Good	LLL	Not required; we believe that this phenomenon is of limited duration and that current models are adequate.
Critical flow and momentum closure	Flow, choked and unchoked	Break	HHM/HHL	Good	LLL	Not required; we assessed this model in the earlier MOD2 version.
Flow-regime map; interfacial drag; entrainment fraction	Entrainment and deentrainment	Core	MMH/LLM	Improved	HHH	For blowdown and refill, THETIS Boildown Test T2L095, GE Level Swell Tests 1004-3 and 5801-15. For reflood phase, Lehigh or equivalent tests, FLECHT-SEASET, and CCTF and/or SCTF tests.
Flow-regime map; interfacial drag; entrainment fraction	Entrainment and deentrainment	Downcomer	MHL/LHL	Marginal	MHL	GE Level Swell Tests 1004-3 and 5801-15, UPTF tests.
Flow-regime map; interfacial drag; entrainment fraction	Entrainment and deentrainment	Upper plenum	MLM/LLH	Adequate	LLL	Not required, but UPTF should address this issue.
Flow-regime map; interfacial drag; entrainment fraction	Entrainment and deentrainment	Hot leg	LLM/LLH	Good	LLL	Not required.

TABLE V (Cont)
SEPARATE-EFFECTS DEVELOPMENTAL ASSESSMENT REQUIREMENTS FOR AP600 LBLOCA

Code Model	Process/Phenomenon	System or Component	PIRT Priority AP600/W 4 Loop	Current Code Capability	Assessment Priority	Assessment Facility
Flow-regime map; interfacial heat and mass transfer and drag	Flow regime (counter-current flow, slug flow, and nonequilibrium flow)	Downcomer	LHL/LHL	Marginal	LHL	GE Level Swell Tests 1004-3 and 5801-15, UPTF tests.
Gap conductance	Gas (gap) conductance	Fuel rod	HMM/LLM	Good	LLL	Not required.
Heat transfer, critical heat flux and dryout criteria	DNB	Core	MLL/MLL	Good	LLL	Not required.
Heat transfer, film boiling; no model for wall-to-wall radiation heat transfer	Radiation heat transfer	Core	---/-L	Adequate with respect to radiation	LLL	Not required.
Heat transfer, nucleate boiling	Nucleate boiling	Core	LLM/MLL	Good	LLL	Not required.
Heat transfer, nucleate boiling	Saturated nucleate boiling	Downcomer	---/LLL	Good	LLL	Not required.
Heat transfer, reflood	Reflood heat transfer	Core	--H/--H	Improved	--H	Lehigh, FLECHT-SEASET, SCTF, CCTF.
Heat transfer, transition and film boiling	Post-CHF	Core	HHH/MHM	Marginal	HHH	INEL post-CHF data, Winfrith steady-state post-CHF data.
Heat transfer, transition and film boiling	Rewet	Core	MMM/HML	Inadequate	HHH	INEL post-CHF data, Winfrith steady-state post-CHF data.
Heat transfer, wall, and conduction equation	Hot wall	Downcomer	LMM/-ML	Good	LLL	Not required.

TABLE V (Cont)
SEPARATE-EFFECTS DEVELOPMENTAL ASSESSMENT REQUIREMENTS FOR AP600 LBLOCA

Code Model	Process/Phenomenon	System or Component	PIRT Priority AP600/W 4 Loop	Current Code Capability	Assessment Priority	Assessment Facility
Heat transfer, wall, and conduction equation	Hot wall	Lower plenum	LLL/LHM	Good	LLL	Not required.
Heat transfer, wall, and momentum closure	Steam binding	Steam generator	LLM/-LH	Good	LLL	Not required.
Interfacial and wall drag	2-phase ΔP	Piping loops	MMM/HHM	Adequate	LLL	Not required.
Interphase heat and mass transfer	Condensation	Downcomer	LML/-HL	Marginal	LML	UPTF.
Interphase heat and mass transfer	Flashing	Pressurizer	MLL/HLL	Good	LLL	Not required.
Interphase heat and mass transfer	Flashing	Downcomer	MLL/L--	Marginal	MLL	LOFT and Semiscale integral LBLOCA tests (only integral data appear to cover this phenomenon during blowdown).
Interphase heat and mass transfer	Condensation	Cold leg and accumulator	LLL/LHM	Marginal	LLL	Not required, but UPTF should address this issue.
Interphase heat and mass transfer	Flashing	Break	LLL/LLL	Good	LLL	Not required.
Interphase heat and mass transfer; interfacial drag	Void generation and distribution	Core	HHH/MMH	Marginal	HHH	For blowdown and refill, THETIS Boildown Test T2L095, GE Level Swell Tests 1004-3 and 5801-15. For reflood phase, Lehigh or equivalent tests, FLECHT-SEASET, CCTF and/or SCTF tests.
Metal-water reaction	Oxidation	Fuel rod	--/-LH	Good	LLL	Not required.

TABLE V (Cont)
SEPARATE-EFFECTS DEVELOPMENTAL ASSESSMENT REQUIREMENTS FOR AP600 LBLOCA

Code Model	Process/Phenomenon	System or Component	PIRT Priority AP600/W 4 Loop	Current Code Capability	Assessment Priority	Assessment Facility
Momentum and energy closure	HPI mixing	Cold leg and accumulator	---/-LL	Good	LLL	Not required.
Momentum closure	Accumulator discharge	Cold leg and accumulator	-HH/--	Good	-LL	Not required.
Momentum closure	Liquid level oscillations	Downcomer	LMH/-LH	Good	LLL	Not required.
Momentum closure	2-phase convection	Hot leg	LLM/LLL	Good	LLL	Not required.
Momentum closure	2-phase convection and bypass	Downcomer	MML/LLL	Adequate	LLL	Not required, but UPTF should address this issue.
Momentum closure	Drain hole flow	Upper head	MLL/--	Good	LLL	Not required.
Momentum closure	Flow reversal or stagnation	Core	MLL/LLL	Good	LLL	Not required.
Momentum closure	Guide tube flow	Upper head	MLL/--	Good	LLL	Not required.
Momentum closure	Void distribution	Hot leg	LLM/LLM	Good	LLL	Not required.
Momentum closure	Flow reversal	Hot leg	LLL/LL-	Good	LLL	Not required.
Momentum closure	Phase separation	Upper plenum	LLL/LLL	Adequate	LLL	Not required, but UPTF should address this issue.
Momentum closure	1-phase gas natural circulation	Core	---/-MM	Good	LLL	Not required.
Momentum closure	2-phase convection	Upper plenum	---/LLM	Adequate	LLL	Not required, but UPTF should address this issue.
Momentum closure	Oscillations	Piping loops	---/-HH	Adequate	LLL	Not required.

TABLE V (Cont)
SEPARATE-EFFECTS DEVELOPMENTAL ASSESSMENT REQUIREMENTS FOR AP600 LBLOCA

Code Model	Process/Phenomenon	System or Component	PIRT Priority AP600/W 4 Loop	Current Code Capability	Assessment Priority	Assessment Facility
Momentum closure and interphase heat transfer	Noncondensable gas	Cold leg and accumulator	---/-LH	Adequate	LLL	Not required.
Momentum closure and user input	Sweep out	Lower plenum	MLL/LMM	Adequate	LLL	Not required.
Momentum closure and user input	ΔP and form losses	Steam generator	LLL/LLL	Good	LLL	Not required.
Momentum closure for Tee, Plenum, and Vessel	Flow splits (asymmetries)	Piping loops	MLL/HHL	Marginal	MLL	T-Junction Test Facility (Germany)
Pump curves, built-in or user input	2-phase performance	Pump	HLL/HM-	Good	LLL	Not required.
Pump model	ΔP and form losses	Pump	LLM/LLH	Good	LLL	Not required.
Reactor kinetics and/or user input	Decay heat	Fuel rod	MHH/LLH	Good	LLL	Not required.
Rod conduction and material properties	Stored energy	Fuel rod	HLL/HLL	Good	LLL	Not required; we assessed rod conduction in the earlier MOD2 version.
User input	Containment pressure	Break	LLM/LML	Adequate	LLL	Not required.
Vessel closure	3D effects	Downcomer	MHL/LHL	Adequate	LML	UPTF.
Vessel closure	3D flow	Core	MMH/LLH	Improved	HHH	For blowdown and refill, THETIS Boildown Test T2L095, GE Level Swell Tests 1004-3 and 5801-15. For reflood phase, CCTF, SCTF.

TABLE V (Cont)
SEPARATE-EFFECTS DEVELOPMENTAL ASSESSMENT REQUIREMENTS FOR AP600 LBLOCA

Code Model	Process/Phenomenon	System or Component	PIRT Priority AP600/W 4 Loop	Current Code Capability	Assessment Priority	Assessment Facility
Vessel closure	3D flow	Upper plenum	MLM/---	Adequate	LLL	Not required, but UPTF should address this issue.
Vessel closure	3D effects	Lower plenum	LLL/LLH	Adequate	LLL	Not required, but UPTF should address this issue.
[See transition and film boiling (core); flow regime map, interfacial drag, and entrainment fraction (upper plenum and hot leg); momentum closure and CCFL (upper plenum); and momentum closure (hot leg)]	Early quench	Pressurizer	---/H---	Adequate	LLL	Not required.

TABLE VI
LOGIC OF ASSESSMENT PRIORITIES FOR SEPARATE-EFFECTS TESTS

<u>AP600 PIRT Priority</u>	<u>Code Capability</u>	<u>Assessment Priority</u>
High	Good	Low
High	Adequate	Medium
High	Marginal	High
High	Inadequate	High
High	Improved	High
Medium	Good	Low
Medium	Adequate	Low
Medium	Marginal	Medium
Medium	Inadequate	High
Medium	Improved	High
Low	Good	Low
Low	Adequate	Low
Low	Marginal	Low
Low	Inadequate	Medium
Low	Improved	High
—	Good	Low
—	Adequate	Low
—	Marginal	Low
—	Inadequate	Low
—	Improved	High

The assessment plan is driven exclusively by the results of the PIRT and a judgment regarding the code quality. The plan makes no attempt to update the PIRT results. If the PIRT did not include a particular process or phenomenon, such as grid spacer effects, then the plan does not include an assessment activity for that process or phenomenon. If the PIRT identifies a process or phenomenon as high or medium priority, and if the judgment on the pertinent code model quality warrants it, an assessment activity is identified, such as the use of the INEL and Winfrith data to assess core heat transfer during refill. If the code developers believe that the code model is of sufficient quality, then phenomena with high or medium PIRT rankings, such as critical flow at the break or CCFL in the upper plenum, will not have assessment activities.

In general, we have not listed integral tests in Table V even though we plan to assess the code against several integral tests. The reasons for not listing integral tests in the table are as follows:

- Integral tests in general do not provide sufficient data to assess adequately the performance of a given model, and

- Integral tests by their very nature exercise most of the models in the code and therefore would show up in the last column of Table V for almost every code model.

We will have more to say about the need for assessment against integral test data later.

A. Separate-Effects Tests

Table V identified the separate-effects facilities and/or tests for the developmental assessment of TRAC-PF1/MOD2. Table VII consolidates the listing of facilities and expands on the definition of the tests. The appendix supplies summary descriptions for the selected facilities and tests.

In the context of Tables V and VII, one should note that downcomer phenomena (flow regimes, entrainment and deentrainment, and flashing) received high and medium PIRT priorities for blowdown and refill, which led to high and medium assessment priorities when combined with the code capability. However, the available separate-effects tests generally do not extend to high enough pressures and temperatures that apply during blowdown and the early stages of refill. The GE Level Swell experiments do not cover the entire range of parameters expected during the transient phases for which the test was specified for assessment. In particular, these experiments are generally low pressure and low flow, whereas the transient phase includes pressures as high as the normal plant operating pressure, and flows start high, accelerate during blowdown and refill, and then decrease as refill ends. UPTF also attempts to pick up the transient in the later stages of refill, and its scale is too large to allow good judgments regarding interfacial heat and mass transfer, and interphase drag. There appears to be a lack of data that addresses interphase heat and mass transfer (flashing) and interfacial drag (including flow regimes) at conditions when the downcomer begins to flash during a LBLOCA, and during the early period of accumulator injection when ECC bypass is most likely.

Another significant issue relates to transient rewets observed in LOFT LBLOCA experiments before the beginning of reflood. These rewets are driven by liquid carried into and through the core from above (top-down rewets) or below (bottom-up rewets). How much liquid is involved, the distribution of that liquid, and the duration of its stay in the core, together with the resulting film- and transition-boiling heat transfer, impact the magnitude of core cooling and the extent of any rewets. There is potentially a lack of separate-effects test data on which to assess the code models that would produce these rewets. These tests should investigate film- and transition-boiling heat transfer on a rod (or rod bundle) with high initial surface temperatures with the abrupt introduction of liquid with varying duration times.

Flow splits are another area for which separate-effects data are lacking. Because of the 2 x 4 loop geometry in AP600, the reactor should undergo important, asymmetric flow splits during a LBLOCA. One place these flow splits occur is in the upper plenum as the flow exits to the hot legs. There should be significant asymmetries in the

**TABLE VII
SEPARATE-EFFECTS TESTS**

Facility	Tests	Transient Phase	Code Models
CCTF	Select a total of 8 tests combined from CCTF and SCTF. Run 14—base case Run 54—low power	Reflood	Entrainment fraction Flow regime map Heat transfer, reflood Interfacial drag Interphase heat and mass transfer Vessel (3D momentum)
FLECHT-SEASET	31504—forced reflood at 2.46 cm/s 31701—forced reflood at 16 cm/s 33436—gravity reflood	Reflood	Entrainment fraction Flow regime map Heat transfer, reflood Interfacial drag Interphase heat and mass transfer
GE Level Swell	1004-3, 5801-15	Blowdown Refill	Entrainment fraction Flow regime map Interfacial drag Interphase heat and mass transfer
INEL post-CHF data		Blowdown Refill Reflood	Heat transfer, transition and film boiling
Lehigh		Reflood	Entrainment fraction Flow regime map Heat transfer, reflood Interfacial drag
SCTF	Select a total of 8 tests combined from CCTF and SCTF.	Reflood	Entrainment fraction Flow regime map Heat transfer, reflood Interfacial drag Interphase heat and mass transfer Vessel (3D momentum)
T-Junction Test Facility	Questions about the type of test and availability of data.	Blowdown	Momentum equation for Tee and Plenum
THETIS	Boildown Test T2L095	Blowdown Refill	Entrainment fraction Flow regime map Interfacial drag Interphase heat and mass transfer

TABLE VII (Cont)
SEPARATE-EFFECTS TESTS

Facility	Tests	Transient Phase	Code Models
UPTF	Select tests as necessary: Downcomer CCFL and ECC bypass tests— 5B (cold-leg injection), 6 (cold-leg injection), 21A and B (downcomer injection) Downcomer entrainment tests— 25B (cold-leg injection) 21D (downcomer injection) Cold leg injection integral test— 27A (BE refill and reflood)	Refill	Entrainment fraction Flow-regime map Interfacial drag Interphase heat and mass transfer Momentum closure Vessel (3D momentum)
Winfrith steady-state post-CHF data	Selected tests AEEW-R 2267 AEEW-R 2486 AEEW-R 2503	Blowdown Refill Reflood	Heat transfer, transition and film boiling

downcomer flow, with two cold legs associated with the intact loop, and one intact and one broken cold leg associated with the broken loop. Then there is the flow split in each loop at the exit from the steam generator into the two cold legs; this flow split in the broken loop may be very important in determining break flow. All of these flow splits affect the way in which fluid is fed to the break because of asymmetric distortions resulting from the break in an otherwise symmetric piping loop. In the realm of transients other than LBLOCA, such as intermediate and small break and non-LOCA transients, mixing of warm and cool flows in the vessel may have a significant impact on the course of the transients. Test data are needed to assess the code capability to model these important flow splits and mixing processes. We have identified the T-Junction Test Facility in Germany as a potential source of useful data; however, it is not clear when and how the facility was operated or if the data are available to us. Also, INEL has conducted Tee tests in the past, but we believe that these were directed towards investigating critical flow in geometries important to SBLOCAs.

B. Integral Tests

Developmental assessment should include integral tests to verify the ability of the code to calculate the entire LBLOCA scenario. Integral assessments compliment the separate-effects assessments, and vice versa. Neither integral assessments nor separate-effects assessments by themselves are sufficient. The integral assessments may reveal weaknesses in the numerical solution algorithm (robustness issue) and examine the transitions between models as the transient progresses through blowdown, refill, and

reflood. The integral assessment tests the code against all processes and phenomena that occur during a LBLOCA transient (to the extent that the experiment captures them), whereas the separate-effects assessment by necessity looks only at a limited subset of the processes and phenomena. Assessment against integral experiments also provides a unique test of the ability of the code to capture scaling effects. We have identified the integral tests listed in Table VIII for use in developmental assessment in support of the AP600 LBLOCA analyses.

LOFT LP-02-6 is commonly referred to as test L2-6. This test simulates a conventional LBLOCA at near maximum power (~ 15 kW/ft at the center of the core) with an early pump trip. This test exhibited a partial rewet of the core during blowdown. The initial and boundary conditions are more typical of LBLOCA scenarios in PWRs than the other LOFT tests. Because LOFT has a nuclear core, it provides a test of the code modeling of a nuclear fuel rod. This test is our first choice for integral assessment.

There are certainly scaling issues with the LOFT facility. These include (1) a short core (1.68 m in LOFT vs 3.66 m in the plant), (2) external thermocouples on the cladding of selected rods to measure cladding surface temperatures, and (3) the general facility distortions associated with a short overall height and one active, intact loop and one passive, broken loop. We have identified full-length separate-effects reflood tests (FLECHT-SEASET, CCTF, and SCTF) to balance the scaling issue associated with the core length. INEL⁹ has studied the external thermocouple issue at length and concluded that the external thermocouples do not compromise the LOFT data for the blowdown peak cladding temperatures. The other facility distortions have been acceptable in the past for performing code assessment.

LOFT L2-3 is another LBLOCA test with the same facility configuration as test LP-02-6. However, the initial power is only about 75% of that for LP-02-6, and the pumps run at nearly constant speed throughout the test. Test L2-3 exhibits a more extensive rewet (nearly complete) of the core during blowdown than LP-02-6.

TABLE VIII
INTEGRAL-EFFECTS TESTS

<u>Facility</u>	<u>Tests</u>	<u>Transient Phase</u>	<u>Test Characteristics</u>
LOFT	LP-02-6 L2-3	Blowdown	Largest scale fully integral tests available.
		Refill	LP-02-6 is near maximum power.
		Reflood	Two tests exhibit different extents of blowdown rewet.
Semiscale	S-06-3	Blowdown	Scaled to LOFT.
		Refill	Significantly smaller scale than LOFT.
		Reflood	Counterpart test to LOFT L2-3.

The two LOFT tests provide an opportunity to demonstrate that we have not removed from the code real sensitivities in significant parameters or made compensating errors to capture a desired behavior in a particular test. These two LOFT tests are very much the same in terms of the facility configuration and in the initial and boundary conditions; the only major differences are the core power and pump operation.

The third selected test is Semiscale test S-06-3, which is the Semiscale counterpart test to LOFT L2-3. The Semiscale facility for this test was scaled (power-to-volume scaling while maintaining full height) to the LOFT facility. However, in Semiscale the facility scale is much smaller than in LOFT, and the core is electrically heated as opposed to nuclear. The S-06-3 transient is significantly different from L2-3 in that there is almost no blowdown rewet, ECC bypass is much more extensive (the LOFT LBLOCA tests exhibited very little ECC bypass), and the time to final quench during reflood is later.

LOFT L2-3 and Semiscale test S-06-3 represent a unique pair of LBLOCA tests in facilities of significantly different scales ($\sim 1/60$ and $\sim 1/2000$, respectively) that were defined with very similar scaling methodologies, both for the facilities and for the test conditions. Also, the two facilities preserve heights relative to each other. Although both facilities used the same scaling methodologies, there are significant differences in the facilities: large differences in the structural mass and surface area (heat transfer) relative to the fluid volume—Semiscale has too much mass and surface area; the Semiscale downcomer (and other vertically oriented components) have a much larger length-to-diameter ratio than LOFT; Semiscale uses electrical heater rods to simulate the nuclear core in LOFT; and except in the core and the steam generators, velocities are not preserved well. These types of differences did lead to significant differences in the responses from the tests. Relative to LOFT, Semiscale does not exhibit the early blowdown quench, and the time to the beginning of reflood is longer (more ECC bypass); these two changes in the early behavior result in differences in the reflood performance. The point to running both tests with the code is to provide a demonstration that the code, including both field equations and closure models, is sensitive to these facility differences and can predict the differences in response.

By themselves, tests S-06-3 and L2-3 do not demonstrate conclusively that the code can scale to the power plant. They can be viewed as a necessary, but not sufficient, condition to support scaling arguments for the code and application of the code to the full-scale plant.

Therefore, the three tests—LP-02-6, L2-3, and S-02-3—offer a stern test to support code scaling arguments and to demonstrate a lack of tuning to specific tests and the absence of obvious compensating errors.

Another candidate test that we did not select is LOFT L2-5. This test was planned to minimize the early blowdown rewet that LOFT had exhibited in test L2-2 and L2-3. A result of the changes to the test operation was a limited top-down rewet of the core due to liquid draining from the upper plenum and the intact hot leg. However, this result was achieved by a very early trip of the primary coolant pumps and a subsequent early

decoupling of the pumps from the motor generators to force the most rapid pump coast down possible. We believe this L2-5 behavior is significantly different from the draining of the upper head in the AP600 LBLOCA. Because of this atypical pump operation and resulting coast down, we did not select test L2-5 for use in the developmental assessment.

C. Insights to Code Models

In the process of developing Table V, certain information regarding various code models may be important to the assessment process and to understanding some of the material in Table V. This information is presented below in the same model order that is listed in Table V. The following information is not intended to be a complete description of the models in the code nor a justification of the models; the information simply represents concerns about the models and technical issues that arose during the development of the assessment plan and that should be considered during the developmental assessment.

Flow-regime map—general: There are separate flow regime maps in TRAC to identify the interfacial drag, interfacial heat (and mass) transfer, and wall drag. These flow regime maps are not identical but rather are tailored to the set of correlations used to represent the various phenomena and the regimes to which the correlations apply. Therefore, it is difficult to assess the flow regime map by itself. This issue argues for the need for an integrated closure package.

Flow-regime map, interfacial drag, and entrainment fraction—upper plenum: This set of models in this location rated as a low assessment priority for all three phases of the LBLOCA transient. However, we will run several UPTF tests that will afford an evaluation of the model in the upper plenum. We have noted that in addition to the standard TRAC interfacial drag package in the Vessel component, the Wilson interfacial drag model has been added to the upper plenum at some point in the past; the Wilson model does not appear to be a recent improvement. The assessment effort with UPTF should look at the effect of the Wilson model on the behavior of the upper plenum.

Gap conductance—core: The gap-conductance model has been in the code for a long time and appears to work correctly. However, the user needs to be aware that the results are sensitive to the input. In particular, the initial specification of the gap dimension through the code input has a large effect on the stored energy in the fuel rods. In general, unless there is information available to indicate otherwise, the user should input a small gap relative to the as-built dimensions of the fuel rod because only a few thermal cycles of the fuel are required to crack the fuel pellets and produce a significant closing of the gap.

Heat transfer, DNB, and dryout criteria—core: Our experience indicates that for LBLOCA, the CHF is almost always driven by dryout considerations rather than exceeding DNB, particularly during the blowdown and refill phases of the transient. Therefore, the DNB correlation is not that important to LBLOCA.

Heat transfer, film boiling—radiation heat transfer in the core. The film-boiling model in TRAC includes a term for radiation heat transfer from the surface to the fluid. There are other terms in the film-boiling model to represent nonradiative heat transfer (boiling and convection) from the wall to the liquid and from the wall to the gas. However, at this time, there is no model to represent wall-to-wall radiation heat transfer.

Heat transfer, nucleate boiling—core. We believe that the nucleate boiling heat-transfer model, both saturated and subcooled, is good from a heat-transfer perspective. However, there appears to be a problem with the production of voids by subcooled nucleate boiling. Specifically, too much voiding is produced in certain cases, and these voids may not collapse fast enough in unheated, highly subcooled liquid regions. This observation is based on a steady-state calculation for LOFT LP-02-6. The subcooled voiding is a phenomenon that is addressed by interfacial heat and mass transfer within the code; the PIRT did not produce an appropriate category for this phenomenon when associated with subcooled nucleate boiling.

Heat transfer, reflood vs transition, and film boiling—core. At first glance, the breakout of the heat-transfer model into reflood or transition and film boiling appears to be redundant. However, within TRAC there are two separate heat-transfer packages, one for general use (which has included reflood in TRAC-PF1/MOD1 and earlier versions) and the other specifically for reflood heat transfer in the core. Both packages should be assessed.

Heat transfer, reflood—core. Table V lists the current code capability for this model as improved; however, even with the improvements, the model remains marginal in the current code version. The current model is based on single tube experiments. We plan additional work to extend the model to rod bundles before performing the developmental assessment for reflood.

Heat transfer, transition and film boiling—core. The current model for transition boiling produces results that are nodalization dependent.

Heat transfer, wall, and momentum closure—steam binding in the steam generator. The integral experiments and the LBLOCA calculations to date for plants appear to indicate that steam binding for the standard LBLOCA scenario is not a significant participant in the transient outcome. In particular, there is little evidence that significant quantities of liquid are convected to the steam-generator tubes to cause either blockage or pressurization that would retard the reflood process.

Interfacial and wall drag—two-phase ΔP in piping loops. We rated the assessment priority as low for these two models for this phenomenon and location.; however, based on the LOFT LP-02-6 calculation, there may be a problem with a transition in the interfacial drag at ~75% void fraction. This transition problem is evident only in the pressurizer surge line as the pressurizer drains and produces a significant reduction in the rate at which the last of the liquid in the pressurizer drains into the hot leg. The wall

drag is based on the Churchill correlation, which is a very good representation of the Moody diagram with variable surface roughness. For two-phase conditions, the code evaluates the Churchill correlation with a Reynolds number based on the mixture density and viscosity, and the resulting friction factor is applied to both the liquid and gas phases.

Interphase heat and mass transfer—all locations. Interphase heat and mass transfer generally received low assessment priority (downcomer was rated medium); however, these models usually are the most significant in terms of code robustness. That is to say, code failures and poor run time are generally traced back to calculated conditions that are the direct result of interphase heat and mass transfer.

Interphase heat and mass transfer; interfacial drag—void generation and distribution in the core. We selected the GE Level Swell Tests and THETIS to assess this capability in the code; however, a significant issue for void generation and distribution in the core concerns early rewets before reflood begins. These rewets can be driven by liquid carried into and through the core from above (top-down rewets) or below (bottom-up rewets). How much liquid is involved, the distribution of that liquid, and the duration of its stay in the core impact the magnitude of core cooling and the extent of any rewets. The selected tests do not really address this phenomenon of transient rewets because they traverse the void fraction range in the opposite direction of a rewet and because the fluid conditions do not match up well. (This issue also relates to heat transfer, transition, and film boiling for the rewet phenomenon for which case we have selected Winfrith and INEL post-CHF tests for assessment.)

Interphase heat and mass transfer; interfacial drag—void generation and distribution in the core. As indicated in this section (heat transfer, nucleate boiling: core), there is a potential deficiency in the code relating to the voiding produced by subcooled nucleate boiling and to the collapse of subcooled voids when the heat source is removed or the bubbles flow out of the core.

Momentum closure—upper plenum. See "flow-regime map, interfacial drag, and entrainment fraction: upper plenum" above for a discussion of the Wilson interfacial drag model in the upper plenum.

Momentum closure—sweep out in the lower plenum. Lower-plenum sweep out during blowdown and refill may be nodalization dependent because of the tendency to prescribe a coarse axial nodalization.

Pump curves, built-in or user input; and pump model: The code contains homologous curves to describe both the Semiscale and LOFT pumps. Neither of these pumps is a good geometrical representation of the reactor-coolant pumps used in PWRs, and therefore neither built-in set of homologous curves is necessarily applicable to PWR analyses. The user is allowed to input plant-specific information, including homologous curves, to describe pump performance. Also, because of the way the homologous curves are defined, we assume that the pump homologous curves account

for any form loss and wall drag associated directly with the pump. We require the user to specify, through input, the elevation change through the pump to ensure there are no unbalanced gravity heads under natural-circulation conditions.

User input—containment pressure. The code user normally specifies through input the containment pressure or back pressure on the break. The specified back pressure generally is the result of a calculation with a code designed specifically for containment analysis.

Vessel—3D flow in the upper plenum. See "flow-regime map, interfacial drag, and entrainment fraction: upper plenum" above for a discussion of the Wilson interfacial drag model in the upper plenum.

V. AP600 DEVELOPMENTAL ASSESSMENT MATRIX

The previous section detailed the selection of tests for the developmental assessment of TRAC-PF1/MOD2 in support of AP600 LBLOCA analyses. The results of the selection process were presented in Tables V, VII, and VIII. We have consolidated the selected tests into Table IX to provide a concise presentation of the AP600 developmental assessment matrix.

VI. SUMMARY OBSERVATIONS

We have reviewed the AP600 LBLOCA PIRT and the AP600 design in preparation for creating a developmental assessment plan for TRAC-PF1/MOD2. The review of the AP600 design included supporting experiments and indicated that to date there has been no AP600-specific test with regard to LBLOCA. Furthermore, the testing in support of AP600 design certification has been directed toward investigating the performance of the new AP600 safety systems, but these safety systems, other than the accumulators, do not play a significant part in the LBLOCA transient until after the end of reflood. Therefore, we have not selected any of the new experiments for use in the developmental assessment.

We took the AP600 LBLOCA PIRT results and defined the controlling models in TRAC-PF1/MOD2. Based on information from the code developers and from Ref. 3, 4, and 7, we graded subjectively the quality of the models. We then defined a logic, shown in Table VI, for combining the AP600 PIRT priorities and the model qualities into assessment priorities of high, medium, and low. Assessment priorities of high and medium resulted in the specification of separate-effects tests for use in developmental assessment to support AP600 LBLOCA analyses. An additional step defined three integral tests (LOFT LP-02-6 and L2-3 and Semiscale test S-06-3) to provide a stringent test of the code's overall quality, to support improvements in the numerical robustness of the code, and to demonstrate that the code correctly calculates scaling differences in the selected tests.

Table IX summarizes the developmental assessment matrix for TRAC-PF1/MOD2. The table shows the selected tests by LBLOCA phase—blowdown, refill, and reflood. Because TRAC is not normally used to calculate reactor behavior after the end of reflood, we have not considered the long-term cooling phase in defining the developmental assessment. The table does include UPTF downcomer injection tests (21A, 21B, and 21D), although these tests did not direct the accumulator flow downward as AP600 does. In addition to supporting the application of TRAC-PF1/MOD2 to the AP600 LBLOCA, the identified assessment tests also support the application of the code to existing PWRs because of the similarity in the PIRTs for the two reactor designs.

Some of the higher rated items for assessment against separate-effects tests included downcomer phenomena (flow regimes, interfacial drag, entrainment and deentrainment, and flashing) in blowdown and refill, the rewets in the core during blowdown, and flow splits and asymmetries in the piping loops. There are no separate-effects data readily available for completely testing these phenomena during assessment. With respect to the downcomer phenomena, there are some data that are applicable at lower pressures and flows, but not at the higher pressures and higher flows during blowdown and the early part of refill when sweep out and ECC bypass are most important. The rewet phenomenon during blowdown occurs at relatively high pressures. The core is completely voided, and the cladding temperatures are generally well elevated before the introduction of liquid. The available tests, however, are generally at lower pressures and progress from cool temperatures to high temperatures (the wrong direction). The flow splits and asymmetries affect conditions upstream of the break and the rate at which inventory is depleted from the primary system.

VII. CONCLUSIONS

We have reviewed the calculated AP600 LBLOCA PIRT and the calculated events, processes, and phenomena. Based on the PIRT, the transient calculation, and the perceived quality of the code models, we have defined a set of assessment cases for blowdown, refill, and reflood to support the development and application of TRAC to the AP600 LBLOCA. Table IX summarizes the assessment matrix by the LBLOCA phase; the matrix includes both separate-effects tests and integral tests. The matrix represents a sufficient number of assessment cases to provide confidence in the application of the code.

TABLE IX
AP600 LBLOCA DEVELOPMENTAL ASSESSMENT MATRIX

<u>LBLOCA Phase</u>	<u>Separate-Effects Tests</u>	<u>Integral Tests</u>
Blowdown	GE Level Swell 1004-3 5801-15 INEL post-CHF data T-Junction Test Facility THETIS Boildown test T2L095 Winfrith steady-state post-CHF data (selected tests) AEEW-R 2267 AEEW-R 2486 AEEW-R 2503	LOFT LP-02-6 LOFT L2-3 Semiscale S-06-3
Refill	GE Level Swell 1004-3 5801-15 INEL post-CHF data THETIS Boildown test T2L095 UPTF 5B, 6, 21A, 21B, 25B, 21D, and 27A Winfrith steady-state post-CHF data (selected tests) AEEW-R 2267 AEEW-R 2486 AEEW-R 2503	LOFT LP-02-6 LOFT L2-3 Semiscale S-06-3
Reflood	CCTF Runs 14, 54, ... FLECHT-SEASET 31504 31701 33436 INEL post-CHF data Lehigh SCTF (total of 8 tests between CCTF and SCTF) Winfrith steady-state post-CHF data (selected tests) AEEW-R 2267 AEEW-R 2486 AEEW-R 2503	LOFT LP-02-6 LOFT L2-3 Semiscale S-06-3

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8. J. C. Lin, V. Martinez, and J. W. Spore, "TRAC-PF1/MOD2 Developmental Assessment Manual," Los Alamos National Laboratory draft report (August 1993).
9. V. T. Berta, R. G. Hanson, G. W. Johnsen, and R. R. Schultz, "Determination of the Bias in LOFT Fuel Peak Cladding Temperature Data from the Blowdown Phase of Large-Break LOCA Experiments," Idaho National Engineering Laboratory report NUREG/CR-6061, EGG-2610 (May 1993).

APPENDIX

FACILITY AND TEST DESCRIPTIONS

The following information describes the facilities and tests that we have selected for the TRAC-PF1/MOD2 developmental assessment in support of the AP600 LBLOCA analyses. Test selection is based in part on the type of test (how it matches up with the assessment needs outlined previously) and on the quality of the associated data sets. Additional factors in the selection process included the availability of existing input decks and the availability of the data. These additional factors do not involve a simple yes or no answer, but balance ease of availability against adequacy and represent a judgment on our part. Among tests that we considered to be essentially equal in terms of quality and appropriateness, availability became the determining factor. We have not selected tests simply because we have input decks and data already; if a test was judged to be inadequate or inappropriate even though we have the input decks and data, we did not include that test in our assessment matrix for AP600 LBLOCA applications.

It is also clear that we could have selected many more tests for inclusion in the assessment matrix; however, the selected set represents both an upper bound of assessment of cases that can be accomplished within the current schedule and budget, and further, it represents a sufficient set to demonstrate the adequacy of the code.

REFERENCE

1. N. Aksan, F. D'Auria, H. Glaeser, R. Pochard, C. Richards, and A. Sjoberg, "Facility and Experiment Characteristics for OECD/NEA-CSNI SET Validation Matrix," CSNI draft document LHT 1.1.9-C1, Ver. 1.10 (December 4, 1991).

INEL Post-CHF Data

References: Richard C. Gottula, Keith G. Condie, Ramu K. Sundaram, Sudhakar Neti, John C. Chen, and Ralph A. Nelson, "Forced Convective, Nonequilibrium, Post-CHF Heat Transfer Experiment Data and Correlation Comparison Report," EG&G Idaho, Inc., report NUREG/CR-3193, EGG-2245 (March 1985).

Listed in the OECD/NEA-CSNI SET Validation Matrix¹ as Number 11.3.

Facility Description: Reference 1 describes this facility and its data as providing "valuable information for [the] verification or development of post-CHF heat transfer and vapor generation rate correlations."

The objectives of the tests were to (1) provide additional data to support the synthesized low-flow, low-quality effect in film boiling at pressure up to 7 MPa, (2) provide nonequilibrium data, at pressures up to 7 MPa, over as wide a range of flow rates and fluid qualities as possible, and (3) measure the rate of change of vapor superheat with respect to length by measuring the vapor superheat at multiple axial locations in the test section.

The test section consisted of a vertical Inconel tube with an inside diameter of 15.39 mm and a heated length of 2.1336 m with hot patches at the inlet and outlet that were intended to prevent quench fronts from entering the test section during steady-state tests. The test section was heated electrically by passing a current through the tube and relying on the electrical resistance of the Inconel tube. Near steady-state operating conditions were provided by a system to set the back pressure on the test section and another system to provide high-temperature, high-pressure, subcooled water to the inlet of the test apparatus. The test section ran in vertical upflow.

Test Procedure: The supply loop was heated to a temperature that would provide fluid at the desired test section inlet quality when flashed across the inlet flow control valve at a desired test section pressure. The test section was initially dry and at zero flow with the pressure set with nitrogen. For the steady-state tests, the test section and the hot patches were slowly heated to the desired temperatures. When the desired conditions were achieved, flow was directed into the test section by opening the flow-control valve and allowing the upstream liquid water to flash to the lower pressure of the test section. Flow was measured upstream of the flow-control valve under conditions of subcooled liquid.

For the steady-state tests, the hot patches were maintained at 800 K (some testing was performed with the lower hot patch at 1025 K). However, at

higher pressures and flows, the hot patches were not successful in preventing a quench front from entering the test section, and therefore a series of quasi-steady tests with a slowly moving quench front were run (with the inlet hot patch maintained at near saturation temperature).

Steady-state tests were run at the following conditions:

Pressure:	0.2–0.7 MPa
Mass flux:	12–24 kg/m ² ·s
Heat flux:	7.7–27.5 kW/m ²
Inlet equilibrium quality:	38–64%

Slowly moving quench front tests were run at the following conditions:

Pressure:	0.4–7 MPa
Mass flux:	12–70 kg/m ² ·s
Heat flux:	8–225 kW/m ²
Inlet equilibrium quality:	–7 to 47%

Selected Tests: Compare to selected steady-state tests to assess the film-boiling heat transfer model in the code and extend the comparisons to the slowly moving quench front tests if possible. (It appears that the transient tests are not adequately described in the report to allow comparison—initial and boundary conditions are not complete.)

Measurements: Outside wall temperatures at 38 elevations in the test section, steam probes (vapor temperatures) at three elevations, test section inlet pressures and ΔP , fluid conditions upstream of the flow-control valve (and orifice for measuring flow), inlet mass flow, test section voltage and current.

Type of Comparisons to be Made: Establish the correct flow conditions at the inlet and the correct temperatures in the test section wall. Compare the calculated heat fluxes with the measured heat fluxes.

Reason for Selection: The film-boiling heat transfer in the core needs to be assessed during blowdown, refill, and reflood. Precursory cooling before quench occurs in the film-boiling mode. The tests were reported to cover conditions of lower flows, lower qualities, and higher pressures than available in other tests. Low flow, low quality, and high pressure characterize the blowdown cooling and quenches during blowdown and refill.

Winfrith Steady-State Post-CHF Data

References: D. Swinnerton, M. L. Hood, and G. G. Pearson, "Steady State Post-Dryout at Low Quality and Medium Pressure Data Report," UK AEA Winfrith report AEEW-R 2267 (June 1988).

D. Swinnerton, J. C. Ralph, and K. G. Pearson, "Comparison of the Results of Harwell and Winfrith Post-Dryout Experiments," UK AEA Winfrith report AEEW-M 2382 (January 1988).

Listed in the OECD/NEA-CSNI SET Validation Matrix¹ as Number 10.4.

Additional reference for test description: AEEW-R 2192, 1988.

Facility Description: Reference 1 describes this facility, through reference to the High Pressure Rig (Ref. 1, Number 10.6) as being "suitable for code validation."

The objective, as a part of the High Pressure Rig, was to obtain steady-state post-dryout data at conditions of low steady qualities using the hot patch technique.

The test section consisted of a single Nimonic-75 tube with an inside diameter of 9.75 mm and a heated length of 920 mm. Hot patches at the inlet and outlet of the test section were intended to prevent quench fronts from entering the test section. The test section was heated via electrical resistance heating of the tube. Systems were available to establish the desired back pressure on the test section and the flow through the test section.

Test Procedure: Establish the required inlet flow, pressure, and temperature to the test section and gradually bring the hot patches up to their temperature set points. Divert the inlet flow and fully close the test section inlet valve. Apply power to the tube and, if necessary, drain and purge it with nitrogen to dry it. Gradually reestablish flow through the test section while increasing power to the test section as required to prevent quenching. Make any necessary adjustments to the inlet parameters and tube power, and allow the tube temperature to settle at a value close to the maximum working temperature. When the test parameters are steady, log the data. Reduce the tube power in a series of steps, and log data at each step after temperatures stabilize.

Steady-state tests were run at the following conditions:

Pressure:	2-20 bar in upflow 2-5 bar in downflow
Mass flux:	50-2000 kg/m ² ·s
Heat flux:	1-30 W/cm ²
Subcooling:	5-25°C (upstream of inlet hot patch)

Selected Tests: The following tests have been selected:

	Pressure	Mass Flux	Heat Flux	Inlet Subcooling
Run	(bar)	(kg/m ² ·s)	(W/cm ²)	(°C)
150	2.0	48.0	3.125	4.9
136	5.0	49.0	6.8982	6.2
176	2.0	102.0	5.372	4.7
157	10.0	102.0	9.09	2.4
194	5.0	199.0	7.319	4.5
76	9.9	217.0	14.957	6.5

Measurements: Outer tube wall temperatures at 15 axial locations, pressure at the inlet and outlet, fluid temperature at the inlet and outlet, volumetric flow at the inlet, test section power (voltage and current), hot patch power, steam temperature at the outlet.

Type of Comparisons to be Made: Compare calculated results to measured wall temperatures, heat fluxes, and steam temperature.

Reason for Selection: The film-boiling heat transfer in the core needs to be assessed during blowdown, refill, and reflood. Precursory cooling prior to quench occurs in the film-boiling mode. This facility provides an independent set of data from that in the INEL post-CHF tests.

THETIS Boildown Test

References: D. Jowitt, C. A. Cooper, and K. G. Pearson, "The THETIS 80% Blocked Cluster Experiment, Part 1: Description of the THETIS Rig, the 80% Blocked Cluster Assembly and Experimental Procedures," UK AEA Winfrith report AEEW-R 1763 (September 1984).

D. Jowitt, C. A. Cooper, and K. G. Pearson, "The THETIS 80% Blocked Cluster Experiment, Part 5: Level Swell Experiments," UK AEA Winfrith report AEEW-R 1767 (September 1984).

Listed in the OECD/NEA-CSNI SET Validation Matrix¹ as Number 10.2.

Facility Description: Reference 1 describes the test results from this facility as "suitable for code validation."

The facility was intended to investigate heat transfer in a PWR core during LOCA-type transients. To this end, most of the tests were reflood heat-transfer tests to investigate the effects of local partial blockage resulting from clad ballooning. Other tests investigated single-phase heat transfer and level swell.

The facility consisted of a test section pressure vessel, an external pipe downcomer for gravity reflood simulation, and a weir vessel for constant head during certain of the level swell tests. The test section contained an 7×7 square array of electrical heat rods in a square shroud to simulate the fuel rods. The fuel simulators had a heated length of 3.66 m with a peaking factor of 1.25. A coplanar partial blockage was represented in the a 4×4 subarray near the axial midplane of the core. There were two test series, one with a 90% blockage and the other with an 80% blockage.

Two types of level-swell tests were run—boilup, in which liquid inventory was maintained in the test section, and boildown, in which the test section inventory was depleted. A steam-water separator was attached to the top of the main pressure vessel to separate the two-phase mixture flowing out of the heater assembly. The liquid phase was collected and removed from the separator while the steam was channeled through an orifice plate to measure the mass flow rate.

Test Procedure: For level swell tests with boildown, the following procedure was used for testing. The system was initially filled with water and the core power was turned on to preheat the system and to raise the system pressure. When the pressure vessel and the steam separator were heated to the saturation temperature, the specified assembly power was set. During the heat up and pressurization period, make-up water was added to the system to prevent dryout at the top of the heater assembly. When the

desired initial conditions were attained, the test was initiated by terminating the make-up water flow and starting data recording. The test was terminated when any of the following conditions were met: (1) the data logger had completed 1000 scans of all instruments, (2) the peak heater temperature exceeded 800°C, or (3) the steam separator wall temperature exceeded 300°C.

The level swell tests were conducted in the pressure range of 2–40 bar.

Selected Tests: We have selected Test T2L095 with the following conditions:

Exit pressure:	5.1 bars
Heater bundle power:	78.3 kW
Inlet liquid temperature:	347.15 K
Initial collapsed liquid level below bottom of top grid plate:	1.8 m

Measurements: Test section inlet and outlet pressure; 12 ΔP transducers located axially along the shroud tube; turbine flow meters for air, reflood flow, and separator drain; ΔP cell and orifice for steam flow; numerous thermocouples to monitor temperatures of both the fluid and structures.

Type of Comparisons to be Made: Compare with collapsed levels and swelled levels, with the height of the subcooled region, and with void distribution in the test section.

Reason for Selection: The test provides insight into the processes of entrainment, deentrainment, and void generation and distribution in the core during blowdown and refill. It is also a check for the overall package of closure relationships in the Vessel component. While the facility geometry is really not applicable to downcomer studies, the assessment will investigate some (but not all) of the closure models that are invoked in the downcomer. Finally, it provides a test of the subcooled boiling model (although assessment of the subcooled boiling model was not specifically called for in the developmental assessment plan).

GE Level-Swell Tests

References: J. A. Findlay and O. L. Sazzi, "BWR Refill-Reflood Program—Model Qualification Task Plan," EPRI report NP-1527, NUREG/CR-1899, GEAP-24898 (October 1981).

Listed in the OECD/NEA-CSNI SET Validation Matrix¹ as Number 11.44.

Facility Description: There were two versions of this facility, one with a 12-in. (0.3048-m) diameter vessel and the other with a 47-in. (1.19-m) diameter. The description in Ref. 1 appears to mix the two facilities into a single description and makes no comment about the adequacy of the data for code assessment.

The tests basically start with a vessel, filled with liquid water and steam at saturation conditions, that is allowed to blow down to atmospheric pressure through an attached pipe. Immersible heaters are used to heat the water and establish the initial conditions for the test. The vessel was mostly open without internal structures. Rupture discs were used to initiate a test.

The smaller facility consisted of a vertically-oriented vessel 14 ft high with a 12-in. diameter. A horizontal, 2-in. Schedule 80 pipe was connected near the top of the vessel to provide the blowdown path. The pipe contained an orifice to restrict the blowdown rate.

The larger facility consisted of a vertically-oriented vessel 14-ft high with a 47-in. diameter with the capability to have top or bottom blowdowns. As such, the horizontal, 10-in. diameter blowdown pipe was mounted low on the vessel and was provided with an vertical pipe internal to the vessel to represent a top blowdown. A venturi in the blowdown pipe controlled the blowdown rate.

Test Procedure: In both facilities, the initial liquid inventory is established in the vessel and heated to saturation conditions at the desired pressure. The test is initiated by blowing the rupture disks and allowing the vessel to blow down through the orifice or venturi

Selected Tests: We have selected two tests:

Test 1004-3 in the small-diameter facility:

Initial conditions

Pressure:	1000 psia
Liquid level:	~10.5 ft
Test duration:	200 s
Orifice:	0.375 in.

Test 5801-15, top blowdown in the large-diameter facility:

Initial conditions

Pressure:	1000 psia
Liquid level:	~5.5 ft.
Test duration:	20 s
Venturi size:	?

Measurements: Vessel pressure was measured at the top of the vessel, and ΔP s were measured over 2-ft increments along the height of the vessel. The ΔP s were converted to void fractions by assuming that hydrostatic conditions prevailed.

Type of Comparisons to be Made: Compare the calculated results to the pressure and void fraction histories and to the void profiles. It may be necessary to take the TRAC-calculated ΔP s and convert them to void fractions with the same assumptions as the data to produce a valid comparison.

Reason for Selection: These tests provide insight into the processes of entrainment, deentrainment, and void generation and distribution in more open regions than the core during blowdown and refill. They also provide a check for the overall package of closure relationships in the Vessel component. While the facility geometries are not fully applicable to downcomer studies (flow regimes and velocities are not typical of refill), the assessment will investigate some (but not all) of the closure models that are invoked in the downcomer.

T-Junction Test Facility

References: Listed in the OECD/NEA-CSNI SET Validation Matrix¹ as Number 4.16. The availability of data is listed as questionable. The facility apparently was operated at KFK Karlsruhe, Germany.

Facility Description: Reference 1 describes the facility as providing "a broad range and reliable set of data" and further describes it as having the "broadest experimental parameter range on two-phase flow through T-junctions existing so far."

The tests investigated pressure drop and phase redistribution in dividing Tee junctions with a horizontal inlet and outlet and different branch orientations and diameters.

Horizontal inlet pipe:	50 mm ID, 1852 mm long
Horizontal outlet pipe:	50 mm ID, 3086 mm long
Branch pipe at 90° angle:	horizontal, vertical up, vertical down 4.2, 10, 26, and 50 mm ID up length, 2120 mm down length, 760 mm horizontal length, 3115 mm

There are mixing chambers on each of the three legs, and there are gas-liquid separators, steam condensers, and air-water separators at the exits from the outlet pipe and from the branch pipe. There are the necessary pump, air compressors, and boilers to operate the facility.

Test Procedure: Not clear but probably not complex.

Selected Tests: We must see the data before we can select specific tests.

Measurements: Inlet, outlet, and branch flows; absolute and differential pressures; gas and liquid mass flows (measured as separate phases before mixing at the entrance and after separation at the exits).

Type of Comparisons to be Made: We assume that we would compare to ΔP s and the total and phasic flows.

Reason for Selection: The PIRT listed flow splits (asymmetries) in piping loops as a medium priority for blowdown and as low priority for refill and reflood. The current code capability, associated primarily with Tee and Plenum components but also with the Vessel component, was judged as marginal based on known deficiencies in the Tee component, on the prescription for momentum flux transport in the Plenum component, and on old assessments of the capability of the Vessel component to predict mixing of

single-phase liquids at different temperatures from the loops. The combination of PIRT priority and current code capability resulted in a medium assessment priority for blowdown and a low assessment priority for refill and reflood.

The main concern from the PIRT is in the piping loops, and the most significant flow splits that occur in the piping loops are at the steam-generator exit plenum, where the flow splits into the two cold legs. Downstream of these splits, each cold leg has a pump, and the pumps may dominate the flow splits. If the pumps dominate, then the value of the currently defined assessment for flow splits is reduced.

Other tests that appear to address flow splits [T-Break Test Facility in Japan (OECD/NEA-CSNI SET Validation Matrix¹ Number 6.3) and the INEL Tee Critical Flow tests (OECD/NEA-CSNI SET Validation Matrix¹ Number 11.35—description is very general and refers to Tee tests only through a reference)] are more directed toward critical flow out the branch leg of the Tee and therefore are not typical of splits addressed in AP600 LBLOCA PIRT.

Upper-Plenum Test Facility (UPTF)

References: "2D/3D Program Work Summary Report," International Agreement Report NUREG/IA-0126, GRS-100, MPR-1345 (prepared jointly by Japan Atomic Energy Research Institute; Gesellschaft fuer Anlagen-und Reaktorsicherheit; Siemens AG, UB KWU; U.S. Nuclear Regulatory Commission; Los Alamos National Laboratory; and MPR Associates, Inc.) (June 1993).

Listed in the OECD/NEA-CSNI SET Validation Matrix¹ as Number 4.1.

Facility Description: Reference 1 describes this facility as providing "reliable data on thermohydraulic processes controlled by ECC injection" and as the "only 1:1 [full-scale] test facility simulating thermohydraulic phenomena within [the] primary cooling system during late LOCA phase."

The objective for the facility was to investigate multidimensional flow phenomena and temperature distribution in the upper plenum and downcomer of a PWR in LOCA conditions [during refill and reflood ($P \leq 1.05$ MPa)] for various ECC injection sites (cold leg, combined hot and cold leg, and downcomer), for both hot- and cold-leg breaks, and for break sizes ranging from 25% to 200%. [Note that there is a terminology disconnect with UPTF. The UPTF Program describes the facility as running from near the end of blowdown through reflood, and they have apparently defined the end of blowdown as coinciding closely to the time that the primary system and containment pressures equilibrate. However, we have defined the boundary between blowdown and refill as the time accumulator injection begins because lower-plenum refill begins as the primary system continues to blow down. By our definitions, UPTF operates in the later part of refill and reflood.]

The facility is a full-scale model of the primary system of a German 1300-MWe reactor. The core was simulated with fuel assembly dummies (0.8 m long), each with 2 grid spacers, upper-end box, and a steam-water mixing device. There were 17 steam-water injection zones in the core simulator. There were two steam generator simulators with steam-water separators and steam injection controlled by a feed-back control system. There was a core feed-back control system for water break-through at the tie plate and core water level. The pumps were simulated as flow resistances. The containment was simulated by a pressure suppression system with supplementary steam injection .

Additional systems included the accumulators, water drainage from the lower plenum and the steam-generator simulators, and a nitrogen gas supply.

Depending on the specific test, the ECC injection location could be moved, and various parts of the piping loops could be valved out.

Test Procedure: The facility configuration for each test is established through the correct alignment of valves, and the facility initial conditions are established in terms of flows and inventories. The transient is initiated by opening the break simulator and starting the ECC flows as required. Depending on the test, liquid drains may be made to maintain desired levels in the facility.

The test conditions were as follows:

Test vessel and primary loop:	pressure	≤ 2 MPa
	temperature	$\leq 200^{\circ}\text{C}$
Containment simulator:	pressure	≤ 1.0 MPa
	drywell vol.	500 m ³
	wetwell vol.	1000 m ³
Core simulator:	steam injection	≤ 360 kg/s
	water injection	≤ 2000 kg/s
Steam generator simulator	steam injection	≤ 50 kg/s
Break	steam discharge	≤ 500 kg/s
	steam insurge	≤ 420 kg/s
	nitrogen discharge	≤ 300 kg/s
	valve opening	2 s
ECC injection	loop, each nozzle	30–600 kg/s
	downcomer, each nozzle	100–1000 kg/s

Selected Tests: We have selected the following tests: 5B, 6, 21A, 21B, 25B, 21D, and 27A. (For other possibilities, see Table 4.1-1 on pages 4.1-7 through 4.1-10 in the reference cited above.)

Test 5B:	Test Group:	Downcomer behavior during end of blowdown.
	Test Objective:	Downcomer CCFL and ECC bypass.
	Run number:	062
	Description:	Quasi-steady test with cold-leg injection, core-simulator steam injection, and loops blocked.
Test 6:	Test Group:	Downcomer behavior during end of blowdown.
	Test Objective:	Downcomer CCFL and ECC bypass.
	Run numbers:	131, 132, 133, 135, and 136
	Description:	The series of runs essentially trace a flooding curve for the downcomer.

Quasi-steady tests with cold-leg injection, saturated ECC, core-simulator steam injection, and loops blocked.

Test 21A:	Test Group:	Downcomer behavior during end of blowdown.
	Test Objective:	Downcomer CCFL and ECC bypass.
	Run number:	272
	Description:	Quasi-steady test with downcomer injection, subcooled ECC, core-simulator steam injection, and loops blocked. This test can be viewed as a counter part test to Tests 5B, 6, and 21B.
Test 21B:	Test Group:	Downcomer behavior during end of blowdown.
	Test Objective:	Downcomer CCFL and ECC bypass.
	Run number:	274
	Description:	Quasi-steady test with downcomer injection, saturated ECC, core-simulator steam injection, and loops blocked. This test can be viewed as a counter part test to Tests 5B, 6, and 21A.
Test 25B:	Test Group:	Downcomer behavior during reflood.
	Test Objective:	Downcomer entrainment.
	Run number:	241
	Description:	Quasi-steady test with cold-leg injection, saturated downcomer wall, steam-generator-simulator steam injection, and loops open. Test looks at entrainment out of the downcomer during the reflood stage of the transient.
Test 21D:	Test Group:	Downcomer behavior during reflood.
	Test Objective:	Downcomer entrainment.
	Run number:	171
	Description:	Quasi-steady test with downcomer injection, saturated downcomer wall, steam-generator-simulator steam injection, and loops open. Test looks at entrainment out of the downcomer

during the reflood stage of the transient. Test is similar to 25B except for injection location.

Test 27A:	Test Group:	Cold-leg ECC injection integral test.
	Test Objective:	System behavior during a simulated LOCA transient.
	Run number:	256
	Description:	Cold-leg injection with best-estimate refill/reflood simulation, and nitrogen discharge from the accumulators.
	Note:	There is not a downcomer-injection-only integral test. For AP600, this assessment does not need to be carried out through nitrogen injection.

Measurements: There was a very large number of instruments, including fluid temperatures, loop flows and densities, single-phase mass flows, water levels, absolute pressures, and differential pressures.

Type of Comparisons to be Made: We will make the appropriate comparisons to temperatures, flows, densities, levels, pressures, differential pressures, and flooding data.

Reason for Selection: The combination of the PIRT results and the current code capability indicates the need to assess the code against the following downcomer processes and phenomena: entrainment and deentrainment, condensation, and 3D effects. Additionally, the AP600 injects ECC directly into the downcomer, and while the UPTF downcomer injection is not fully typical of the AP600 downcomer injection, the UPTF does provide full-scale downcomer injection tests and investigates parametric variations to which the code should be sensitive. The selected tests look at entrainment and deentrainment in the downcomer as functions of condensation (subcooled and saturated ECC), injection location, and the phase of the transient. Additionally, we have selected one test that provides a more integral test of code by running a simulated LOCA transient.

Lehigh

References: K. Tuzla, C. Unal, O. Badr, S. Neti, and J. C. Chen, "Thermodynamic Nonequilibrium in Post-Critical-Heat-Flux Boiling in a Rod Bundle," Los Alamos National Laboratory report NUREG/CR-5095, Vols. 1-4 (July 1987).

List in the OECD/NEA-CSNI SET Validation Matrix¹ as Number 11.42.

Facility Description: Reference 1 describes this facility and its data as being "suitable for code development and assessment" and as providing "reliable data basis for non-equilibrium post-CHF boiling in bundle geometry."

The facility was designed to provide post-CHF data in a 3 x 3 rod bundle at low mass fluxes, low-to-moderate vapor qualities, and near atmospheric pressures. The experiments were carried out in a closed, two-phase loop with a vertical rod bundle test section. Upstream of the test section, subcooled water was pumped into a 3.66-m-long vertical boiler tube with a 14.3-mm inside diameter. Direct resistive heating of the Inconel 600 alloy tube was used to heat and partially vaporize the inlet water, and the two-phase mixture then flowed vertically upwards into the test section. The two-phase mixture exiting from the test section was throttled to the condenser pressure of one atmosphere. A separation tank was used upstream of the throttling valve to minimize two-phase flow oscillations during throttling. The condensate flowed into a surge tank and then returned to the pump.

The 1.22-m long test section consisted of a heated shroud containing a 3 x 3 rod bundle assembly. Dimensions of the rods and the shroud were selected to provide equal hydraulic diameters in all subchannels. The shroud was 2-mm-thick Inconel 625 alloy. The shroud was heated on the outside by radiation heat transfer with three independent control zones. The rods were 9.5-mm in diameter and were heated internally with electric resistance ribbons. The bundle had one spacer located 0.762 m from the inlet. A hot patch (a copper block and 9 short hot pins) at the bottom of the test section was available to condition the thermal state of the inlet two-phase flow and to stabilize the quench front for those tests where a fixed CHF point was desired.

Test Procedure: Post-CHF experiments were conducted in three different modes: steady-state tests with a fixed CHF location, reflood experiments with slowly advancing CHF locations (propagating quench front), and boil-off tests with retreating CHF locations. Tests were conducted for the following ranges of conditions:

Coolant mass flux	0.1–26 kg/m ² ·s
Inlet quality	40°C subcooled to 0.4
Pressure	105–120 kPa
Heat flux	5–43 kW/m ²

For a typical reflood run, the test section was preheated to a selected post-CHF state with the shroud and rods at substantial superheats. A steady two-phase flow, with desired flow rate, pressure, and inlet mixture enthalpy, was established in a bypass loop while the test section was cooled with steam flow during the preheating stage. For quenching runs, the inlet hot patches were maintained as adiabatic sections at the fluid saturation temperature. When the desired initial conditions were achieved, the test was initiated by powering the test section at the specified heat flux, closing the cooling steam line, switching the flow from bypass into the test section, and starting the data acquisition.

Selected Tests: Reflood Test 02/24/86–6 with 25.13 kg/m²·s mass flux, 15°C inlet subcooling, and atmospheric pressure.

Measurements: 12 external thermocouples on the shroud, 12 internal thermocouples in each rod, 2 vapor temperature probes, 2 ΔP s.

Type of Comparisons to be Made: Compare the calculated results to measured wall temperatures, ΔP , and steam temperatures.

Reason for Selection: The combination of the PIRT results and the current code capability indicates the need to assess the code for the following processes and phenomena in the core during reflood: reflood heat transfer, entrainment and deentrainment, void generation and distribution, and 3D flow. The Lehigh small bundle reflood test represents a test of the reflood modeling in a facility that is reasonably simple and mostly one dimensional that will benchmark the code capability close to its development roots and provides a stepping stone to more complex reflood tests from other facilities.

FLECHT-SEASET

References: M. J. Loftus, et al., "PWR FLECHT-SEASET Unblocked Bundle, Forced and Gravity Reflood Task—Data Report," Volumes 1 and 2, Westinghouse report NUREG/CR-1532, EPRI NP-1459, WCAP-9699 (June 1980).

N. Lee, et al., "PWR FLECHT-SEASET Unblocked Bundle, Forced and Gravity Reflood Task—Data Evaluation and Analysis Report," NRC report NUREG/CR-2256 (February 1982).

Listed in the OECD/NEA-CSNI SET Validation Matrix¹ as Number 11.23.

Facility Description: Reference 1 describes these tests as "suitable for model development and code assessment."

The facility investigated thermal-hydraulic behavior during reflood in a 161-rod bundle scaled to represent a reactor core based on a 17 x 17 fuel-rod bundle. The facility could simulate either a once-through or gravity-flow reflood. The rod bundle simulated a full-length core with a uniform radial power profile and a modified-cosine axial power profile. The peak-to-average power ratio was 1.66. The rods were heated internally by electrical resistance. The bundle was contained in a low-mass housing with upper and lower plenums. The lower plenum served to straighten the inlet flow and to provide a connection for the external pipe downcomer for the gravity reflood tests. The upper plenum served as a steam-water separator to facilitate measuring the phasic flows.

Test Procedure: The facility was preheated to the desired temperatures, and the test was initiated by starting the inlet flow, core power, and data recording. The range of test conditions were as follows:

Initial cladding temperature:	135–1079°C
Peak power:	0.87–3.1 kW/m
Upper plenum pressure:	1.4–4.1 bar
Flooding rates (constant):	1.0–15.2 cm/s
Flooding rates (variable):	15.2–1.5 cm/s in steps
inlet subcooling:	3–78°C

Selected Tests: We have selected the following three tests:

Test 31504: Forced reflood

Flooding rate = 2.46 cm/s (low)

Outlet pressure = 2.8 bar

Inlet temperature = 52°C (maximum subcooling)

Test 31701: Forced reflood
Flooding rate = 16 cm/s (high)
Outlet pressure = 2.8 bar
Inlet temperature = 52°C (maximum subcooling)

Test 33436: Gravity reflood
Inlet flow = 5.80 kg/s for 15 s; then 0.785 kg/s
Implied flooding rate = 38 cm/s for 15 s; then 5.1 cm/s
Outlet pressure = 2.7 bar
Inlet temperature = 52°C (maximum subcooling)

Measurements: The instrumentation on the unblocked bundle facility was designed to measure temperature, pressure, flow, liquid level, and power. There were aspirating steam probes to measure steam temperature inside the bundle and at the bundle outlet.

Type of Comparisons to be Made: Compare calculated results to measured heater rod temperatures, pressures, flows, steam temperatures, ΔP s, and liquid level.

Reason for Selection: The combination of the PIRT results and the current code capability indicates the need to assess the code for the following processes and phenomena in the core during reflood: reflood heat transfer, entrainment and deentrainment, void generation and distribution, and 3D flow. These three FLECHT-SEASET tests represent a step up in complexity from the Lehigh test and offer both forced and gravity reflood tests. The flooding rates are reasonable relative to the average flooding rates calculated for the AP600 LBLOCA.

Cylindrical Core Test Facility (CCTF)

References: "2D/3D Program Work Summary Report," International Agreement Report NUREG/IA-0126, GRS-100, MPR-1345 (prepared jointly by Japan Atomic Energy Research Institute; Gesellschaft fuer Anlagen-und Reaktorsicherheit; Siemens AG, UB KWU; U.S. Nuclear Regulatory Commission; Los Alamos National Laboratory; and MPR Associates, Inc.) (June 1993).

Listed in the OECD/NEA-CSNI SET Validation Matrix¹ as Number 6.15.

Facility Description: The facility was designed to study the thermal-hydraulic effects of reflood in a large-scale facility simulating a PWR vessel and piping loops. The core consists of 32 simulated electrically heated bundles in an 8 x 8 array that represented the PWR 15 x 15 fuel assemblies. The 8 x 8 bundles allowed a more cylindrical configurations that would 15 x 15 bundles for the same number of rods.

CCTF was a full-height, 1/21-scale representation of an 1100-MWe four-loop PWR. The facility simulated the overall primary system response, as well as the in-core behavior, from late in refill through reflood, for a large cold-leg break. The facility included the pressure vessel with the core and an annular downcomer, four primary piping loops (three intact and one broken), two steam generators, four pump simulators, and two tanks attached to the ends of the broken loop to simulate the containment. Each of the two steam generator vessels was shared by two loops; vertical plates divided each steam generator in half. Vertical dimensions and locations of system components were as close as practicable to the corresponding dimensions and locations in the reference reactor. The facility had the capability to model the ECCS with cold-leg injection, combined injection, downcomer injection, and upper-plenum injection.

Test Procedure: The facility configuration was set and the accumulator tank, low-pressure-coolant-injection tank, and secondary sides of the steam generators were filled with water to the prescribed levels. Then the initial conditions throughout the facility were established. Electric power was supplied to the heaters on the pressure vessel to attain and maintain a prescribed temperature of the vessel wall. A specified level of saturated water was established in the lower plenum. After the initial conditions stabilized, the rod heatup was initiated by supplying constant electrical power to the heater rods. Accumulator injection was initiated when the maximum cladding temperature reached the prescribed value. When the water was estimated to have reached the bottom of the core (reflood initiation), a programmed decay of the core power was initiated to simulate the reactor power decay.

In the core-II tests, reflood tests with either cold-leg or downcomer injection were initiated with ECC injection first into the lower plenum "to avoid atypical condensation oscillations which could occur if subcooled ECC injection flow were injected into the primary piping or downcomer at a time when the facility was stagnant and no steam was being generated in the core."

Selected Tests: We have initially selected CCTF runs 14 and 54, with a commitment to select a total of 8 tests between CCTF and SCTF. The selection of the additional tests will be made later as the assessment needs of the reflood modeling become clear and in light of any refinement in the AP600 LBLOCA calculations. The general philosophy of selecting tests will be to provide a range of reflood conditions that look at the effect of injection location (downcomer and cold leg) and bound the reflood conditions observed in the AP600 LBLOCA calculation.

Run 14 is the baseline test for core-I in CCTF and represents cold-leg injection.

Run 54 is a test similar to Run 14 but is conducted with core-II at a reduced power of 7.9 MW.

Select up to 6 additional tests from CCTF and SCTF.

Measurements: Over 1600 instruments measured cladding temperatures in the core; fluid temperatures, densities, pressures, and flows; and ΔP s in the core, plenums, downcomer, and other locations.

Type of Comparisons to be Made: Compare calculated results to measured heater rod temperatures, pressures, flows, densities, ΔP s, and liquid levels.

Reason for Selection: The combination of the PIRT results and the current code capability indicates the need to assess the code for the following processes and phenomena in the core during reflood: reflood heat transfer, entrainment and deentrainment, void generation and distribution, and 3D flow. These CCTF tests represent a significant step up in complexity and scale from the Lehigh and FLECHT-SEASET tests.

Slab Core Test Facility (SCTF)

References: "2D/3D Program Work Summary Report," International Agreement Report NUREG/IA-0126, GRS-100, MPR-1345 (prepared jointly by Japan Atomic Energy Research Institute; Gesellschaft fuer Anlagen-und Reaktorsicherheit; Siemens AG, UB KWU; U.S. Nuclear Regulatory Commission; Los Alamos National Laboratory; and MPR Associates, Inc.) (June 1993).

Listed in the OECD/NEA-CSNI SET Validation Matrix¹ as Number 6.14.

Facility Description: The facility was designed to study the thermal-hydraulic effects of reflood in a large scale facility simulating a PWR vessel and piping loops. The core consists of 8 simulated electrically heated bundles in a 16 x 16 arrays. The 16 x 16 bundles were arranged side-by-side to represent a radial slice through the reference PWR core from the centerline to the core edge.

The SCTF was a full-height, full-radius 1/21-scale model of a sector of an 1100-MWe, four-loop PWR. The objective of the SCTF test program was to study 2D thermal-hydraulic behavior within the reactor vessel during the refill and reflood phases of a LBLOCA in a PWR. While the pressure vessel was simulated in detail, only a crude loop simulation was used. The most significant feature of SCTF was that it contained a full-height heated core with realistic rod diameters and spacing, and a core lateral extent of over 1.8 m (the core radius of the largest PWRs). This large core lateral extent provided the capability to examine multidimensional effects.

The overall facility consisted of a pressure vessel, a hot leg, a steam-water separator, an intact loop with a pump simulator, a broken cold leg, and two tanks attached to the ends of the broken loop to simulate the containment. The hot leg is not circular but rather oval shaped to represent the full height of the hot leg while preserving the scaled flow area. The pressure vessel also was not cylindrical but effectively the width of a single fuel assembly with the downcomer on the side representing the outside of the reactor vessel.

Test Procedure: The test procedure is essentially the same as for CCTF.

Selected Tests: We have initially selected CCTF runs 14 and 54, with a commitment to select a total of 8 tests between CCTF and SCTF. The selection of the additional tests will be made later as the assessment needs of the reflood modeling become clear and in light of any refinement in the AP600 LBLOCA calculations. The general philosophy of selecting tests will be to provide a range of reflood conditions that look at the effect of injection

location (downcomer and cold leg) and bound the reflood conditions observed in the AP600 LBLOCA calculation.

Up to 6 additional tests will be selected from CCTF and SCTF.

Measurements: The instrumentation and level of coverage in SCTF is similar to that for CCTF.

Type of Comparisons to be Made: Compare calculated results to measured heater rod temperatures, pressures, flows, densities, ΔP s, and liquid levels.

Reason for Selection: The combination of the PIRT results and the current code capability indicates the need to assess the code for the following processes and phenomena in the core during reflood: reflood heat transfer, entrainment and deentrainment, void generation and distribution, and 3D flow. SCTF offers a significantly different configuration from CCTF at essentially the same scale and will test the capability of the code to model facility differences. Also, this difference in configuration will allow us to investigate the importance of lateral flows in the core to reflood if necessary.

Loss-of-Fluid Test Facility (LOFT)

References: D. L. Reeder, "LOFT System and Test Description (5.5-ft Nuclear Core 1 LOCES)," EG&G Idaho, Inc., Idaho National Engineering Laboratory report TREE-1208, NUREG/CR-0247 (July 1978). Subsequently, there were two sets of error corrections distributed by letters.

E. M. Feldman, "OECD LOFT Project Experiment Specification Document Cold Leg Large Break Experiment LP-02-6," EG&G Idaho, Inc., Idaho National Engineering Laboratory report OECD LOFT-T-3402 (July 1983).

Peter G. Prassinis, Bobby M. Galusha, and Donald B. Engelman, "Experiment Data Report for LOFT Power Ascension Experiment L2-3," EG&G Idaho, Inc., Idaho National Engineering Laboratory report TREE-1326, NUREG/CR-0792 (July 1979).

Facility Description: The LOFT facility was a ~1:60 scale model of a large, four-loop PWR. Because of the design constraints for the LOFT facility and its nuclear tests, the core was short (5.5 ft) relative to the PWR, and the steam generator was also of reduced height. The facility consisted of a vessel, one intact loop representing 3 loops of the reference PWR, and one broken loop representing a single loop of the reference PWR. The vessel consisted of an nuclear core with ~1300 fuel rods, an annular downcomer, a lower plenum, and an upper plenum. The intact loop had active components for the steam generator and pump, and the broken loop simulated the steam generator and pump with a series of orifice plates.

In both LP-02-6 and L2-3, the facility was configured to represent a 200% double-ended break in the cold leg and to inject ECC into the intact-loop cold leg.

Test Procedure: The facility was aligned into the desired configuration, and the specified inventories in the steam generator secondary and accumulator were set. A series of power ascension steps were run to burn into the core a minimum specified amount of decay heat that would be necessary to run the test satisfactorily through reflood. The facility was operated at normal power for a sufficient period of time to establish the correct initial conditions for the test and to preheat the metal mass of the facility. When the correct conditions were obtained, the break was initiated by blowing a rupture-disk assemblies. As the facility blew down, first the high-pressure injection came on automatically, then the accumulator injection, and finally the low-pressure injection. The test was run through the end of reflood, defined by the complete quenching of the core.

Selected Tests: We have selected tests LP-02-6 and L2-3, both of which are 200% double-ended cold-leg breaks with ECC injection into the intact-loop cold leg.

Test LP-02-6:

Core power:	46.0 MW
Intact-loop hot-leg pressure:	15.09 MPa
Intact-loop hot-let temperature:	589 K
Intact-loop cold-let temperature:	556 K
Intact-loop mass flow:	249 kg/s
Pump speed:	trip with coast down

Test L2-3:

Core power:	36.0 MW
Intact-loop hot-leg pressure:	15.06 MPa
Intact-loop hot-let temperature:	593 K
Intact-loop cold-let temperature:	561 K
Intact-loop mass flow:	199 kg/s
Pump speed:	approximately constant

Measurements: Numerous instruments measured cladding temperatures; fluid temperatures, pressures, densities, and flows throughout the system; and significant Δ Ps. In addition, there were many nuclear instruments, and for Test LP-02-6, some of the fuel rods had centerline and pellet-surface thermocouples.

Type of Comparisons to be Made: Comparisons will be made to data for cladding temperatures; for fluid temperatures, pressures, densities, and flows throughout the system; and for appropriate Δ Ps. Also, for Test LP-02-6 we will compare to the fuel-centerline and pellet-surface temperature.

Reason for Selection: Developmental assessment should include integral tests to verify the ability of the code to calculate the entire LBLOCA scenario. Integral assessments compliment the separate-effects assessments, and vice versa. Neither integral assessments nor separate-effects assessments by themselves are sufficient. The integral assessments look for weaknesses in the numerical solution algorithm (robustness issue), at the transitions between models as the transient progresses through blowdown, refill, and reflood, and at completeness and adequacy of the separate-effects assessments. The integral assessment tests the code against all processes and phenomena that occur during a LBLOCA transient (to the extent that the experiment captures them), whereas the separate-effects assessment by necessity looks only at a limited subset of the processes and phenomena.

LOFT LP-02-6 is commonly referred to as test L2-6. This test simulates a conventional LBLOCA at near maximum power (~15 kW/ft at the center of the core) with an early pump trip. This test exhibited a partial rewet of the core during blowdown. The initial and boundary conditions are more typical of LBLOCA scenarios in PWRs than the other LOFT tests. Because

LOFT has a nuclear core, it provides a test of the code modeling of a nuclear fuel rod. This test is our first choice for integral assessment.

There are certainly scaling issues with the LOFT facility. These include a short core (1.68 m in LOFT vs 3.66 m in the plant), external thermocouples on the cladding of selected rods to measure cladding surface temperatures, and the general facility distortions associated with a short overall height and one active, intact loop and one passive, broken loop. We have identified full-length separate-effects reflood tests (FLECHT-SEASET, CCTF, and SCTF) to balance the scaling issue associated with the core length. INEL has studied the external thermocouple issue at length and concluded that the external thermocouples do not compromise the LOFT data for the blowdown peak cladding temperatures. The other facility distortions have been acceptable in the past for performing code assessment.

LOFT L2-3 is another LBLOCA test with the same facility configuration as test LP-02-6. However, the initial power is only about 75% of that for LP-02-6, and the pumps run at nearly constant speed throughout the test. Test L2-3 exhibits a more extensive rewet (nearly complete) of the core during blowdown than LP-02-6.

The two LOFT tests provide an opportunity to demonstrate that we have not removed from the code real sensitivities in significant parameters or made compensating errors to capture a desired behavior in a particular test. These two LOFT tests are very much the same in terms of the facility configuration and in the initial and boundary conditions; the only major differences are the core power and pump operation.

Semiscale Test S-06-3

References: L. J. Ball, D. J. Hanson, K. A. Dietz, and D. J. Olson, "Semiscale Program Description," Idaho National Engineering Laboratory report TREE-NUREG-1210 (May 1978).

B. L. Collins, M. L. Patton, Jr., K. E. Sackett, and K. Stanger, "Experimental Data Report for Semiscale Mod-1 Test S-06-3 (LOFT Counterpart Test)," EG&G Idaho, Inc. report NUREG/CR-0251 (July 1978).

Facility Description: The Semiscale Mod-1 facility was a ~1:2000 scale model of a large, four-loop PWR, but it was also scaled to the LOFT facility and designed to simulate the LOFT tests. Because of the scaling to the LOFT facility, the core was short (5.5 ft) relative to the PWR, and the steam generator was also of reduced height. The facility consisted of a vessel, one intact loop representing 3 loops of the reference PWR, and one broken loop representing a single loop of the reference PWR. The vessel consisted of an electrically heated core with 40 fuel-rod simulators, an annular downcomer, a lower plenum, and an upper plenum. The intact loop had active components for the steam generator and pump, and the broken loop simulated the steam generator and pump with a series of orifice plates.

In the S-06-3 test, the facility was configured to represent a 200% double-ended break in the cold leg and to inject ECC into the intact-loop cold leg.

Test Procedure: The facility was aligned into the desired configuration, and the specified inventories in the steam generator secondary and accumulator were set. The facility was operated at normal power (1.0 MW) to establish the correct initial conditions for the test and to preheat the metal mass of the facility. When the correct conditions were obtained, the break was initiated by blowing a rupture-disk assembly. As the facility blew down, first the high-pressure injection came on automatically, then the accumulator injection, and finally the low-pressure injection. The test was run through the end of reflood, defined by the complete quenching of the core.

Selected Tests: We have selected Test S-06-3, which was run at the following conditions:

Core power:	1.004 MW
Pressurizer pressure:	15.77 MPa
Intact-loop cold-leg temperature:	563 K
Hot- to cold-leg ΔT :	34.1 K
Pump mass flow:	5.02 kg/s
Pump speed:	169.5 rad/s
Pump ΔP :	80 kPa

Measurements: Numerous instruments measured cladding temperatures; fluid temperatures, pressures, densities, and flows throughout the system; and significant ΔP s.

Type of Comparisons to be Made: Comparisons will be made to data for cladding temperatures; for fluid temperatures, pressures, densities, and flows throughout the system; and for appropriate ΔP s.

Reason for Selection: LOFT L2-3 and Semiscale S-06-3 represent a pair of integral LBLOCA tests in facilities of significantly different scales ($\sim 1/60$ and $\sim 1/2000$, respectively) that were defined with very similar scaling methodologies, both for the facilities and for the test conditions. Also, the two facilities preserve heights relative to each other. Although both facilities used the same scaling methodologies, there are significant differences in the facilities: large differences in the structural mass and surface area (heat transfer) relative to the fluid volume—Semiscale has too much mass and surface area; the Semiscale downcomer (and other vertically oriented components) have a much larger length-to-diameter ratio than LOFT; Semiscale uses electrical heater rods to simulate the nuclear core in LOFT; and except in the core and the steam generators, velocities are not preserved well. These types of differences did lead to significant differences in the responses from the tests. Relative to LOFT, Semiscale does not exhibit the early blowdown quench, and the time to the beginning of reflood is longer (more ECC bypass); these two changes in the early behavior result in differences in the reflood performance. The point to running both tests with the code is to provide a demonstration that the code, including both field equations and closure models, is sensitive to these facility differences and can predict the differences in response. Thus, the two tests together provide a demonstration that we have not tuned out the sensitivities and have not made significant compensating errors.

By themselves, these two tests do not demonstrate conclusively that the code can scale to the power plant, but it is damning if you can't predict the results. Thus, tests like S-06-3 and L2-3 become necessary but not sufficient tests to support the code scaling capability.