NRR

POLICY ISSUE
(Notation Vote)

January 27, 1992 SECY-92-030

For: The Commissioners

From: James M. Taylor
Executive Director for Operations

Subject: INTEGRAL SYSTEM TESTING REQUIREMENTS FOR WESTINGHOUSE'S AP600 PLANT

Purpose:

1. To give the Commission an early indication of an issue regarding the performance of AP600 passive Safety Systems that could have an adverse impact on the schedule for final design approval and design certification.

2. To inform the Commission of the staff's identification of concerns regarding the Westinghouse test program and of the need for full-height, full-pressure integral systems testing to support issuance of a final design approval leading to design certification for Westinghouse's AP600 plant.

3. To present the staff's views on ways for Westinghouse to resolve the staff's concerns regarding the need for full-height, full-pressure integral testing.

Background: In SECY-91-273, "Review of Vendors' Test Programs to Support the Design Certification of Passive Light Water Reactors," dated August 27, 1991, the staff presented the process by which it will evaluate and monitor the vendors' testing programs to support the design certification of passive advanced light water reactors (ALWRs). The staff also informed the Commission that additional thermal-hydraulic test data would be needed to validate the predicted

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performance of the AP600 reactor design. Enclosure 2 to SECY-91-273 provided an evaluation of the Westinghouse Electric Corporation's test program for the AP600. The staff identified questions regarding the potential for safety systems interactions while at high pressure, and stated that it was concerned about the lack of any high-pressure integral systems testing in the Westinghouse program, as well as identifying other potential areas of concern. The staff believes that, in the absence of (1) validated analyses that show conclusively that safety system performance is adequate or (2) design changes that provide increased assurance of high-pressure safety system performance, its concerns regarding systems behavior at high pressures should be resolved through performance of large-scale, full-height, full-pressure integral testing. The staff has concluded that such testing should be conducted by Westinghouse to address identified concerns and to demonstrate the performance of the passive safety systems, which perform the function of the active safety systems used in current plants. The integral systems testing would be needed to both confirm that the new and unique features of the passive safety systems perform as the applicant has claimed, and to uncover any adverse or unpredicted systems behavior or interactions. The staff intends to require Westinghouse to develop integral systems test data to ensure that its safety analysis models are validated adequately. Experience indicates that there is a substantial benefit to addressing integral system performance in the review process. For example, a full understanding of the integral behavior of Babcock and Wilcox plants was only developed after testing in the full-height, full-pressure MIST facility. This testing occurred only after the accident at Three Mile Island and other experience demonstrated the need for a more complete understanding of plant behavior.

Discussion: The AP600 design incorporates major changes in the design and operating philosophy for many plant safety functions. All emergency core cooling (ECC) systems and the safety-related decay heat removal system are "passive," operating by means of gravity-driven fluid flow (gravity drain and natural convection) or stored energy. These passive systems do not include pumps and the system check valves operate by means of a small pressure differential across the valve.

This approach may improve the reliability and performance of safety systems. No components except for several valves require electric power; none require an ac power source. However, the passive systems relied upon in this new approach do not have a proven performance history. Many of the passive systems rely upon small differences in temperature, pressure, or elevation for operation, the performance of which may be affected by relatively minor variations in these parameters. For example, the safety-related systems do not include any means of forcing fluid past obstructions that may occur, such as sticking check valves.

A brief description of the design and operation of the passive safety systems and some of the key active nonsafety systems is contained in Enclosure 1.

In SECY-91-273, the staff discussed how Westinghouse's test data will be used for safety system performance and code validation which must be supported as part of the AP600 design certification application. In Enclosure 2 to SECY-91-273, the staff discussed its preliminary assessment of Westinghouse's test program, and identified where additional testing appeared to be needed to provide data required for design certification.

Westinghouse's test program includes separate effects tests to study and characterize the behavior of the safety systems and their components, including automatic depressurization system (ADS) valves, check valves, and draining of the core makeup tanks (CMTs). Westinghouse will also perform small-scale, low-pressure integral systems testing at Oregon State University (OSU), principally to study the low-pressure, long-term post-ECC-injection phase of an accident. While the final design of the OSU facility has not been determined, preliminary plans call for this loop to be 1:4 linear scale (height), and approximately 1:226 volumetric scale, with the capability of operating at pressures up to about 250-300 psia. Westinghouse has not planned large-scale or high-pressure integral systems tests in its program.

The staff has met several times with Westinghouse to discuss its concerns and possible means for their resolution, most recently in January 1992. Westinghouse has presented its view that the proposed low-pressure integral test program at OSU will be sufficient, in combination with the planned separate effects tests and analytical code development and validation, to adequately demonstrate AP600 safety system performance. However, the staff believes that its concerns cannot be addressed adequately by Westinghouse's current program because of the lack of large scale, full-height, full-pressure integral testing.

The staff views the lack of large-scale, full-height, full-pressure integral systems test data for the AP600 design as significant. The separate effects tests will provide valuable data on individual components and systems, and the low-pressure, small-scale integral test will allow Westinghouse to examine plant behavior following reactor coolant system (RCS) depressurization. However, Westinghouse has planned no tests to study systems behavior and systems interactions at high and intermediate pressures. The staff is concerned that at these pressures the passive safety-related systems in the AP600 design may interact in ways that could degrade ECC system performance. The staff has reviewed the Anticipated Operational Occurrences and Postulated Accidents normally considered in the design basis of PWRs with regard to their applicability to the AP600 design. The staff has also considered whether there are any anticipated operational occurrences or postulated accidents that would actuate the passive safety systems while the primary system pressure was still relatively high. The evaluation is preliminary and needs to be supported by thermal-hydraulic analyses, but the staff has concluded that there are at least four accidents that could actuate the passive Safety Systems: a large-break loss-of-coolant accident (LBLOCA); a small-break loss-of-coolant accident (SBLOCA); a steam generator tube rupture (SGTR); and a steam line break (SLB). Descriptions of accident scenarios for these four accidents are included in Enclosure 2.

The potential for systems interactions at elevated pressures for three of the four postulated accidents (all but the LBLOCA) are of concern to the staff, and must be carefully assessed through analysis and testing. The complex piping configuration and the numerous interconnections among safety system components, such as the CMTs and the primary system, or the multiple stages of the ADS connected to the pressurizer, provide the potential for significant flow redistribution during RCS depressurization and safety injection. The NRC's Office of Nuclear Regulatory Research has sponsored preliminary analyses of the AP600 to simulate several accidents, especially SBLOCAs. The results of these simulations must be viewed with extreme caution, since some of the component and thermal-hydraulic models have not been fully developed and validated against test data. However, these calculations have shown that there is a potential for complex systems interactions. Examples include recirculation between the cold leg and the CMTs, resulting in cessation of ECC injection and possibly leading to core uncovery; injection of noncondensible gas from the CMT accumulators to the RCS after depletion of liquid inventory, slowing depressurization and possibly stopping ECC injection, leading to core uncovery; and delayed and intermittent injection from the In-containment Refueling Water Storage Tank (IRWST) due to the inability of the fourth stage ADS valves to reduce and maintain system pressure low enough to permit continuous gravity drain, also having the potential to progress to core uncovery. As a result, there is substantial uncertainty about the ability of the safety systems to maintain core temperatures below limiting values.

Another aspect of the issue of systems interactions is the close interdependence of the various safety systems. The actuation of each ADS stage is keyed to a particular liquid level in the CMTs. The depressurization rate, therefore, depends directly upon the draining behavior of the CMTs, which depends in turn upon the break size, break location, and the pressurizer response, which is itself influenced by depressurization. There is the potential for a manometric type flow effect between the CMTs and the pressurizer, where for small breaks, the CMTs may be inhibited from draining. The high-pressure behavior of the RCS and passive safety systems can thus be important in an accident in which systems interdependencies cause interactions, such as those described above, that would delay the actuation of the early ADS stages or inhibit passive safety system performance. The operation of the instrumentation and control systems is also a vital aspect of system performance. For example, a break in a pressure balancing line between the pressurizer and a CMT could cause pressurizer level swell and erroneous pressurizer level indication. CMT discharge (keyed to pressurizer level) could thus be delayed, as could ADS actuation (keyed to CMT level). The timing of the operation of the ADS system, and the resulting actuation of the various ECC injection systems, is the key concern, and is completely sequence-dependent. Integral systems tests must be employed to study these issues; separate effects tests can provide information about the behavior of specific components, but cannot simulate dynamically varying boundary conditions during the course of an accident or transient, or account for systems interactions. Interaction effects, leading to degraded safety system performance, may be exacerbated if a train of the ECC systems is disabled, for instance by a break in a single safety injection line. In addition there is the potential for asymmetric flow behavior between the two loops because the CMTs and accumulators are located in one loop and the Passive Residual Heat Removal System (PRHR) and pressurizer are located in the other loop.

The staff also believes that the safety systems and nonsafety front-line systems can interact with one another. Since the operational philosophy of the AP600 calls for the nonsafety systems to serve as the first line of defense in transients or some accidents, nonsafety systems may be on line when safety systems are actuated, leading to untested systems interactions. For example, the operators may try to bring the normal residual heat removal system on line in an attempt to prevent actuation of the fourth stage of the ADS system. There is, therefore, a potential for interactions between the safety and nonsafety systems that could adversely affect plant safety. In addition to system performance issues, the staff is concerned about the development of and need for analytical models for system analyses. Westinghouse will utilize best-estimate models for analysis of the AP600 design. This process removes much of the conservatism inherent in previous licensing practices, and requires sufficient data over the entire operational range of the system for code validation. While separate effects tests can provide valuable data for model development, only integral testing can provide a means by which system effects can be investigated and, if necessary, incorporated into phenomenological models. Also, these detailed systems models will provide the basis for developing more simplified models for use in plant simulators for operator training. High pressure systems behavior must be modeled well and validated to assure that the simplified models can represent adequately the plant's response to transients and accidents over its entire operational range.

Westinghouse could address the staff's concerns by making changes in the AP600 design (to reduce dependence on these passive high pressure systems). In addition to addressing the thermal-hydraulic issues of high pressure, passive system performance, a design change providing reliable high pressure injection could address other issues such as ADS failure during a SBLOCA. In the absence of a high pressure injection system, an ADS failure would lead to the plant being hung up at high pressure, and the passive safety systems potentially being unable to cool the core. However, if Westinghouse proposes no design changes to deal with these issues, the staff has concluded that testing in a full-height, full-pressure integral facility would be required to assure that Westinghouse's analytical safety methods are adequately verified, and to demonstrate that safety system functional performance criteria are met.

Proper test facility design is key to resolving staff concerns. An AP600 integral test facility would need to be large-scale, full-pressure, and full-height. "Large-scale" is a relative term, but in general means that the facility is large enough to minimize distortions in important phenomena and the behavior of key systems. The phenomena to be studied determine the type of scaling criteria that can be applied to determine the minimum size of the test loop that will not introduce unacceptable distortions that would make correspondence between test data and actual plant behavior difficult to determine. Some distortions in systems response, however, are unavoidable because of the reduction in component sizes. For example, a recent study performed by the Office of Research indicated that test facility piping should be about 2½ to 3 inches to minimize distortions due to surface tension effect.

"Full-height" means that the differences in elevation between system components are the same as in the actual plant. While it is possible to relate data from less-than-full-height tests to plant behavior, data from such a facility is subject to additional distortion, particularly in natural circulation systems, since it is the difference in elevation between system components that provides the main driving force for fluid flow.

Data from these tests would be used to validate computer codes and to investigate the manner in which the safety and nonsafety systems could interact. In view of the requirements for design certification, stated in Section 52.47(b)(2)(i)(A) of Title 10 of the Code of Federal Regulations, that the applicant must adequately demonstrate the performance of safety features through tests, analyses, or experience; evaluate interdependent effects among safety features and find them acceptable; and show that a sufficient database exists to establish the capability of the analytical tools to perform requisite analyses, the staff believes that Westinghouse should develop a program to acquire data from large-scale, full-pressure, full-height integral test loop, or be able to demonstrate that their current testing program resolves staff concerns. The program should address specifically the types of issues identified in this paper with respect to safety systems interactions and passive safety/active nonsafety systems interactions. The control systems that will actuate the passive safety systems should also be adequately represented.

The design of a large-scale, full-pressure, full height integral test facility and the development of a test program to address the staff's concerns are the responsibility of Westinghouse. The staff will review the facility design and test program, and will monitor the test program. It may be possible for Westinghouse to employ existing integral test facilities, appropriately modified, to address the staff's concerns and to minimize schedular impacts. An integrated test program, employing data from a large-scale, full-pressure facility, the OSU low-pressure and separate effects tests, and analytical calculations using validated models and supported by an in-depth scaling analysis, would satisfy regulatory requirements. Absent an acceptable integrated test program, or design changes to reduce dependencies on the passive high pressure systems, the staff believes it will be difficult to certify the AP600 design as currently proposed, because of uncertainties in passive safety system performance.

Recommendation: That the Commission approve the staff's position on the need for Westinghouse to perform large-scale, full-pressure, full-height integral testing to support AP600 design certification or make changes to design.

Coordination: The ACRS has been briefed on this plan, and the Office of the General Counsel has no legal objection.

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for Operations

Enclosures:
1. Design and Operation of AP600 Passive Safety Systems and Key Active Nonsafety Systems
2. Description of Accident Scenarios for the AP600 Design

This paper is tentatively scheduled for discussion at an Open Meeting on Wednesday, February 12, 1992.

Commissioners' comments or consent should be provided directly to the Office of the Secretary by COB Wednesday, February 19, 1992.

Commission Staff Office comments, if any, should be submitted to the Commissioners NLT Thursday, February 6, 1992, with an information copy to the Office of the Secretary. If the paper is of such a nature that it requires additional review and comment, the Commissioners and the Secretariat should be apprised of when comments may be expected.

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ENCLOSURE 1

DESIGN AND OPERATION OF AP600 PASSIVE SAFETY SYSTEMS AND KEY ACTIVE NONSAFETY SYSTEMS

The design of the AP600 plant includes safety-related systems to respond to accidents and transients, including high-, intermediate-, and low-pressure emergency core cooling (ECC); residual heat removal from both the reactor and the containment; and automatic depressurization. All of the safety-related systems are passive, relying either on gravity-driven flow (natural convection or gravity drain) or stored energy, such as gas-pressurized accumulators. Valves in the safety-related systems are either check valves, which open and close in response to differential pressure, or dc-powered valves, which draw energy from a safety-related, redundant battery system. In addition, the plant has nonsafety systems that serve as the first line of defense in the event of accidents or transients. In many cases, these systems are similar to safety-related systems in conventional plant designs, such as diesel generators, startup (auxiliary) feedwater, and normal (pumped) residual heat removal. However, the AP600 design has removed the diesel generators from the "safety-related" classification, as well as any system that relies upon diesel generator-supplied ac power supply or includes continuously operating machinery.

Although they are no longer designated "safety-related," the active systems are still important in that they are the first line of defense in the event of a transient and will likely be initiated in response to an accident, and are intended to reduce the challenges to the passive safety systems. The traditional approach of "defense-in-depth" for these designs, therefore, relies heavily on the reliable operation of nonsafety systems as well as safety-related systems.

A brief description of each of the major passive safety systems is given below.

The passive emergency core cooling (ECC) injection systems include one high-pressure, one intermediate pressure, and one low-pressure system. The high-pressure system uses two core makeup tanks (CMTs) which are connected by pressure balancing lines to both the pressurizer and the reactor coolant system (RCS) cold legs. Upon receiving a "low-low" level or low pressure signal from the pressurizer, dc-operated valves open, allowing borated water from the CMTs to drain into the RCS, driven by the difference in static pressure between the cold CMTs and the pressurizer. At a later stage in an accident, when the coolant level in the RCS falls below the elevation of the cold legs, the pressure balancing function shifts to the cold leg lines. The intermediate pressure system employs two gas-pressurized accumulators, which begin to inject borated water to the RCS when the RCS pressure falls below the gas pressure of 700 psia. The low-pressure system comprises gravity-driven injection of water from the in-containment refueling water storage tank (IRWST), which is elevated with reference to the RCS, into the reactor vessel. When the RCS pressure drops to a point where the static head of the water in the IRWST is greater than the difference between the RCS and containment pressures, water flows from the IRWST into the RCS. All of the ECC water is injected through two direct vessel injection (DVI) lines into the downcomer, where flow deflectors steer the fluid streams toward the bottom of the vessel.

The total fluid volume of the three ECC systems is sufficient to flood the RCS and the containment to an elevation greater than that of the loop piping. Once all of the ECC water has been injected into the RCS, a long-term cooling mode is entered, in which water is boiled in the reactor (at containment temperature and pressure), and the steam released is condensed on the inside of the containment dome by the passive containment cooling system (PCCS). The condensate is then returned to the RCS either through a gutter system that empties into the IRWST, or through the containment sump.

The AP600 plant also includes an automatic depressurization system (ADS), to reduce rapidly the pressure in the RCS to that of the containment if an event occurs, such as a small-break loss of coolant accident (SBLOCA), that results in loss of inventory without complete system depressurization. The ADS consists of four stages of redundant valves that also require dc power for operation. Each stage consists of two valves in series, and there are two independent ADS trains. The first three stages of both trains are connected to lines extending from the top of the pressurizer, and the fourth stage is connected to stub lines from the RCS hot legs (one train on each hot leg). The ADS exhausts upon receiving level signals from instrumentation in the CMTs; each stage of the ADS opens at successively lower fluid levels in those tanks. The first three stages exhaust through spargers to the IRWST, where the steam from the pressurizer is condensed. However, the fourth stage exhausts from the hot legs directly to the containment. This aspect of the system is of major importance. Since the last stage of ECC injection from the IRWST is dependent upon rough equilibration between the containment and RCS pressures as described above, a communication path sufficient to establish and maintain that condition is essential.

The passive residual heat removal (PRHR) system is a full-reactor-pressure, natural circulation system that is actuated if both the main and startup feedwater systems are lost. Water circulates from the RCS through piping connected to one of the fourth-stage ADS stub lines to a series of heat exchangers submerged in the IRWST, and returns to the cold side of the lower head of the steam generator. In addition to operating upon loss of all feedwater, the PRHR system is also actuated by the control system when the first stage of the ADS is triggered. Containment heat removal is accomplished using the PCCS. Water is sprayed on the outside of the steel containment shell, and steam on the inside of the shell condenses as it transfers its energy through the shell to the cooling water. The shield building around the containment is designed to promote the natural circulation of air around the containment, which both aids in the cooling function and sweeps evaporating PCCS water away from the exterior of the shell.

ENCLOSURE 2

DESCRIPTION OF ACCIDENT SCENARIOS FOR THE AP600 DESIGN

Many of the accidents and transients that are analyzed for conventional PWRs are applicable to the AP600 plant. However, a preliminary assessment of possible accidents and transients has identified four accident sequences that could provide a serious challenge to the passive safety systems. One major reason for this challenge is the fact that each accident will produce a safety injection ("S") signal, which in turn will activate the passive safety systems. The four accidents are: large break loss-of-coolant accident (LBLOCA); small break loss-of-coolant accident (SBLOCA); steam generator tube rupture (SGTR); and steam line break (SLB). These accident scenarios provide much of the basis for the selection of tests to be performed in integral test facilities. The following discussion is not meant to provide a detailed description of the sequence of events for each of these accidents. However, it is meant to highlight key phenomena and areas of uncertainly with respect to the response and operation of the passive safety systems.

Three of the accident scenarios (LBLOCA, SBLOCA, SGTR) involve a loss of primary coolant inventory. For the LOCA events, it is important that the reactor coolant system (RCS) pressure be reduced to approximately that of the containment. This is necessary to permit the gravity-fed injection of emergency core coolant from the in-containment refueling water storage tank (IRWST) to the RCS (see Enclosure 1 for a description of the passive safety systems). The same is true for the SGTR if the affected steam generator cannot be isolated, or if the inventory loss exceeds the capacity of the nonsafety makeup systems.

The LBLOCA will very rapidly depressurize the primary system, and the accumulator injection is expected to pressurize the cold leg and downcomer sufficiently to prevent core makeup tank (CMT) discharge until accumulator discharge is complete and the primary pressure is down in the range of 250 psia. Hence, for the LBLOCA, automatic depressurization system (ADS) operation is not important, and CMT discharge will not occur until the primary system is at low pressure. The low-pressure test facility proposed by Westinghouse will probably be sufficient to provide integral systems data on passive safety system performance for the LBLOCA. It is also expected to provide sufficient integral systems data on passive safety system performance during the long-term recirculation phase of accidents and transients after the ADS has depressurized the primary system.

The SBLOCA scenarios are substantially more complex than those of the large break accident. In general, an SBLOCA is characterized by a relatively small breach in the RCS that allows a loss of inventory without the rapid depressurization associated with the LBLOCA. For the AP600, the sequence of events would lead to a reduction in pressurizer level or pressure that would initiate an "S" signal. This would cause the CMT discharge valves to open, and begin passive injection from the CMTs, driven by the difference in static head between the CMTs and the pressurizer. If the leak is not or cannot be isolated, CMT injection would continue until the CMT tank level was reduced to the setpoint for actuation of the first stage of the ADS. Continued reduction in the CMT level would actuate successive stages of the ADS, ending when the fourth stage opened, which would reduce the RCS pressure to approximately that of the containment. The accumulators would also have injected during this period, when the RCS pressure dropped below that of the gas in the accumulators. When the RCS is fully depressurized, gravity-fed ECC injection from the IRWST would fill the RCS, and the long-term recirculatory cooling mode would be entered, with fluid flowing from the containment sump and the IRWST to the RCS, steaming from the RCS, and condensation of the steam by the passive containment cooling system (PCCS), with condensate returning from the interior of the containment shell to the IRWST through a system of gutters.

There are a number of questions and uncertainties related to the SBLOCA scenarios. Since the CMT, accumulators, and the IRWST all inject fluid into the same direct vessel injection (DVI) line, injection from one source may cause injection from another source to stop temporarily. For example, if the CMTs still contain water when the accumulator pressure is reached, the accumulators may begin to inject and thereby cause injection from the CMTs to slow or stop. Since the ADS is actuated based on CMT level, this will affect the rate at which the system depressurizes. Nitrogen gas from the accumulators will also be injected into the RCS when the accumulator liquid inventory is depleted. The effects of the gas as it expands in the RCS on system response is not known, and analytical models for predicting its behavior have proven to be very poor. In addition, actuation of the fourth stage of ADS is essential to allow IRWST injection, and steam from the RCS must continue to be relieved so that pressure does not build up again and cut off the gravity-fed injection. The location of the break in the RCS may also have a major impact on the course of such an accident. If the break occurs in one of the DVI lines, for instance, one of the CMTs and one of the accumulators will effectively be disabled. The system must be adequately cooled with only one CMT and one accumulator injecting; also, since the water from the CMT will flow from the break into the containment sump, the CMT level will drop, and may in fact actuate the ADS before the CMT injecting to the RCS does so, depending upon the rate of inventory loss. Timing of ADS actuation is again a key question.

The passive nature of CMT injection also requires that the reactor coolant pumps be tripped if CMTs are actuated. The pumps are therefore tripped on receipt of an "S" signal. Failure or delay in the pump trip could result in inhibiting CMT injection, at the same time accelerating the loss of inventory through the break.

The SGTR event is the last that involves loss of inventory. The AP600 is designed such that a failure of a single steam generator tube should not actuate the ADS. However, a multiple SGTR could result in sufficient inventory loss to cause CMT injection and subsequent RCS depressurization. If the faulted steam generator is not isolated and the RCS is depressurized, the secondary system could begin to inject unborated water into the primary system, with a possible increase in reactivity as the boron concentration of the primary system decreases. While Westinghouse asserts that the borated water from the CMTs will provide adequate shutdown margin to overcome any such reactivity insertion, leakage of secondary coolant to the primary system could cause flashing that would pressurize the primary system and inhibit CMT injection.

The final event noted above is the steam line break. While there is no inventory loss from the primary system, the SLB is the most severe overcooling event for current PWRs, and must be evaluated for the AP600. The rapid cooldown of the RCS in the SLB event causes a level shrinkage that could cause the pressurizer level or pressure to fall to a value that generates an "S" signal. Core cooling would not be jeopardized in this event, but overall system behavior and control system response are unknown.

Much of the behavior described above, especially with regard to the SBLOCA, about which there is substantial uncertainty, occurs at elevated pressure, and it would appear that the planned Westinghouse integral test loop will not be able to simulate many aspects of such an accident. It is far too early in the evaluation process to determine which accident is the most challenging to the passive safety systems; however, the complexity of the system's response to accidents involving inventory loss at elevated system pressures requires high-pressure, full-height integral testing to adequately represent critical system behavior and phenomenology, and to provide data for validation of analytical systems models.