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ISSUES AFFECTING ADVANCED PASSIVE LIGHT-WATER REACTOR SAFETY ANALYSIS

R. J. BEELMAN C. D. FLETCHER S. M. MODRO
Idaho National Engineering Laboratory
EG&G Idaho, Inc., P.O. Box 1625
Idaho Falls, Idaho 83415-2403
208-526-9703

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ABSTRACT

Next generation commercial reactor designs emphasize enhanced safety through improved safety system reliability and performance by means of system simplification and reliance on immutable natural forces for system operation. Simulating the performance of these safety systems will be central to analytical safety evaluation of advanced passive reactor designs. Yet the characteristically small driving forces of these safety systems pose challenging computational problems to current thermal-hydraulic systems analysis codes. Additionally, the safety systems generally interact closely with one another, requiring accurate, integrated simulation of the nuclear steam supply system, engineered safeguards and containment. Furthermore, numerical safety analysis of these advanced passive reactor designs will necessitate simulation of long-duration, slowly-developing transients compared with current reactor designs. The composite effects of small computational inaccuracies on induced system interactions and perturbations over long periods may well lead to predicted results which are significantly different than would otherwise be expected or might actually occur. Comparisons between the engineered safety features of competing U.S. advanced light water reactor designs and analogous present day reactor designs are examined relative to the adequacy of existing thermal-hydraulic safety codes in predicting the mechanisms of passive safety. Areas where existing codes might require modification, extension or assessment relative to passive safety designs are identified. Conclusions concerning the applicability of these codes to advanced passive light water reactor safety analysis are presented.

INTRODUCTION

The passive safety principles of the next generation of advanced U.S. light water reactor (LWR) designs include: (1) low volumetric heat generation rates with correspondingly low peak-to-average flux ratios; (2) reliance solely on immutable natural forces, such as gravity and gas pressurization, for safety system operation; and, (3) dependence on irrefutable natural phenomena, such as natural convection and condensation, for safety system performance. The engineered safety features which incorporate these passive safety principles achieve increased reliability by means of system redundancy, minimization of system components, non-reliance on external power sources, and integral passive long term decay heat removal/containment cooling. The containment itself becomes the decay heat exchanger and all safety components are integrated into it. As a result the containment and passive safety features (PSFs) of advanced passive LWR designs interact with the reactor coolant system (RCS) and each other in a more integral fashion than current LWR designs. Therefore, it becomes necessary to analyze the coupled behavior of the RCS, containment and PSFs.

The proposed Westinghouse AP600 design is basically a two-loop pressurized water reactor (PWR) arranged in a two-hot-leg, four-cold-leg (2x4) nuclear steam supply system (NSSS) configuration (see Figure 1). However, whereas current generation PWRs employ pumped emergency core coolant (ECC) systems, AP600 is equipped with passive ECC systems. The AP600 design calls for lost coolant to be replenished by RCS pressure balanced core makeup tanks (CMTs), gas-pressurized accumulators, and an elevated, gravity drain, containment-pressure-equalized, in-containment refueling water storage tank (IRWST). Once the contents of these tanks have been discharged, the resulting containment liquid level reportedly exceeds the elevation of the loops, draining back into the RCS via sump valves provided for this purpose. Vaporized coolant condensing on the containment walls is collected via gutters and returned to the IRWST. An automatic depressurization system (ADS) is provided to ensure viability of passive ECC systems. A full RCS pressure, full decay power rated, passive residual heat removal (PRHR) heat exchanger submerged in the IRWST is provided to remove decay heat by forced convection or natural circulation if necessary. Passive containment cooling is achieved by gravity-driven, external containment evaporative cooling and is reportedly sustainable during dry natural draft conditions.

The proposed General Electric (GE) Simplified Boiling Water Reactor (SBWR) design is basically a natural circulation variant of existing forced recirculation BWR designs (see Figure 2). There are no recirculation loops or recirculation pumps. The SBWR containment employs a conventional drywell with an elevated suppression pool. The SBWR design calls for lost coolant to be replenished by an elevated, drywell-pressure-equalized, gravity-driven cooling system (GDCS) reservoir via squib-actuated valves. Squib-actuated automatic depressurization valves (ADVs) reduce RCS pressure, if necessary, to ensure viability of passive ECC systems. Two sets of natural circulation driven condensers, submerged in pools of water atop containment, provide for passive decay heat removal and containment cooling. During postulated accident conditions one set of ICs condenses steam produced in the core returning condensate to the reactor vessel; the other set condenses steam from the containment environment returning condensate to the GDCS while routing non-condensable gases to the suppression pool. A gas-pressurized, highly borated, standby liquid control system (SLCS) accumulator provides for passive emergency boration via squib-actuated valves.

Simulating the performance of these safety features will be central to analytical safety evaluation required for the licensing of next generation reactors. Yet the physical mechanisms driving these safety features pose several analysis issues that go beyond the scope of development of thermal-hydraulic analysis systems codes intended for current reactor designs. PSFs operate

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FIGURE 1. AP600

Figure 2. SBWR

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by means of comparatively quite small driving forces. As a result, simulated PSF performance may be unduly affected, whether favorably or unfavorably, by relatively small perturbations. Safety simulations of advanced passive LWRs are also expected to be of significantly longer duration due to their more slowly developing transient response and the longer time required to achieve steady state long term cooling. The composite effect of computational inaccuracies and calculationally induced perturbations over long periods may well lead to predicted results which are significantly different than would otherwise be expected or might actually occur.

Finally, heretofore, traditional thermal-hydraulic systems analysis codes have been applied solely to the simulation of NSSS transients in LWRs equipped with pumped ECC systems whose function did not depend on containment pressure equalization. The high degree of communication exhibited between the RCS, containment and PSFs raises concerns about the validity and applicability of the simulation codes' closure relations under these circumstances. Particularly, existing code models simulating wall and interphase heat and mass transfer by condensation in the presence of noncondensable gases are weak or unassessed. Additionally, existing experimental data bases for these processes are often not of appropriate scale or representative conditions; therefore, determining the adequacy of these models is problematic. Clearly, the application of these codes to containment simulation breaks new ground.

Comparisons between the engineered safety features (ESFs) of competing U.S. advanced passive LWR (APLWR) designs and analogous present day reactor designs are examined relative to fulfilling generic safety functions. The adequacy of existing thermal-hydraulic (T-H) safety code simulation capabilities is broadly addressed from the standpoint of their ability to predict the underlying mechanisms of passive safety. Areas where existing codes may require modification, extension or assessment relative to passive safety designs are identified. Conclusions concerning the applicability of these codes to advanced passive LWR safety analysis are presented.

AP600 ESF COMPARISONS

The AP600 PSFs are first compared to the ESFs of current generation PWRs relative to satisfying three generic safety functions: RCS inventory control, long term decay heat removal, and containment cooling. The contrasting mechanisms of safety are then examined relative to the applicability of current T-H safety codes to the analytical safety evaluation of AP600. Finally, a preliminary AP600 small break loss-of-coolant accident (SBLOCA) scoping calculation is used to illustrate the functioning of the AP600 PSFs.

RCS Inventory Control

In order to maintain adequate RCS inventory during postulated loss-of-coolant accidents (LOCAs), current PWRs are equipped with three distinct ECC systems: three trains of pumped high pressure injection (HPI), with shutoff heads nominally ranging from 1250-2700 psig, for SBLOCA inventory control; two to four gas-pressurized accumulators, nominally pressurized from 200-600 psig, for large break LOCA (LBLOCA) core refill and intermediate LOCA inventory control; and, two trains of pumped low pressure injection (LPI), with shut-off heads nominally ranging from 200-250 psig, for LBLOCA inventory control. AP600 is equipped with two RCS

pressure balanced CMTs with approximately 20 feet of static head, two 700 psig gas-pressurized accumulators and a gravity drain IRWST, with approximately 28 feet of static head, to achieve the same purposes, respectively. An ADS is provided to ensure the viability of these systems in maintaining adequate RCS inventory in keeping the core covered and cooled. During a hypothetical LOCA, RCS pressure would be expected to stabilize at the saturation pressure for the prevailing hot leg temperature for break energies roughly equal to core decay heat minus other available heat sinks (i.e., ECC, secondary, structural, etc.); the RCS would be expected to repressurize for net positive RCS heat addition rates and to depressurize for net negative RCS heat addition rates. For break sizes and locations which maximize coolant loss and minimize energy loss, RCS inventory depletion would continue at elevated pressures after CMT emptying. To ensure depressurization and sustained core cooling, four stages of ADS are provided contingent on decreasing, preset, CMT levels. Key to calculating the correct RCS transient inventory is the ability to correctly calculate: the critical break flow accounting for break orientation and location; the proper CMT and IRWST static driving potentials; the transient accumulator pressure; ADS flow rates and RCS depressurization rate; RCP degraded head and flow performance; RCS flow coastdown and forced/natural convective heat transfer to available heat sinks.

Long Term Decay Heat Removal

Current PWRs are equipped with dual, forced circulation, decay heat exchangers, normally plumbed with the LPI system, to achieve long term decay heat removal. Since AP600 has no pumped ECC, it has no decay heat exchangers per se. Although it is equipped with a PRHR heat exchanger (PRHX), this PRHX is intended to obviate the need for pumped, safety grade, auxiliary feedwater in the event of a loss of secondary heat sink. During hypothetical LOCAs the utility of this PRHX in the decay heat removal mode would be negated as IRWST liquid level recedes exposing the PRHX. The AP600 containment itself is intended to provide long term decay heat removal. Once the contents of the CMTs, accumulators and IRWST have been discharged the resulting containment liquid level presumably exceeds the elevation of the loops, passively draining back into the RCS via sump valves provided for this purpose. Steam condensing on the interior containment walls rejects decay heat to the environment via passive external containment cooling. Condensate running down the interior containment walls is collected via gutters and returned to the IRWST for re-introduction into the RCS. Aside from the obvious concern for simulating the operation of the sump valves and quantifying the return ECC flow rate, the need for a more mechanistic approach to the simulation of wall condensation heat transfer in the presence of noncondensable gases is apparent. The mechanisms of heat transfer to the containment wall need to be physically modeled more accurately. A model to track the steadily thickening film of condensate running down the containment walls and account for interfacial effects is needed. Assessment of existing flow regime maps and mass transfer models for wall and interphase condensation in the presence of noncondensibles must be undertaken. New flow regime maps probably need to be developed to account for rainout and dropwise condensation on the underside of the containment interior dome.

Containment Cooling

Current PWR containments are equipped with two trains of fans, coolers and sprays to control containment environmental

conditions. AP600 is equipped with two gas-pressurized accumulator spray trains but relies on an external passive containment cooling system (PCCS) for decay heat removal. A three day supply of water stored in a tank situated atop the containment building is allowed to gravity flow over the steel containment shell exterior wall. Air is allowed to enter near the bottom of the steel shell thereby setting up natural convection currents which evaporatively cool containment and exhaust decay heat through a chimney at the top of the containment building. Upon depleting containment cooling water supplies, decay heat levels are such that containment cooling can reportedly be sustained by dry natural draft conditions. This evaporative cooling technology is original in terms of its application to containment cooling. Evaporative cooling models will need to be implemented. Correlations will need to be developed to account for the effects of wind, humidity, chimney recirculation and variable surface wetting on containment cooling. Clearly, these effects will have a pronounced effect on the natural circulation flow patterns within containment and the effectiveness of long term decay heat removal.

Demonstration AP600 SBLOCA Response

A preliminary AP600 SBLOCA scoping calculation using RELAP5 is presented to illustrate the expected functioning of the PSFs and the simulated overall system response. The initiating event chosen for the AP600 demonstration calculation was a 3-inch diameter small break in the vertical portion of one of the CMT cold leg pressure balance lines. The piping at this location is 8-inch Schedule 160 (6.8-inch ID). This break location and size were chosen for three reasons. First, this break size would require ADS actuation to achieve effective, timely passive ECC injection. Second, it was expected to result in asymmetric CMT behavior thereby disadvantaging passive ECC. Third, Westinghouse had performed a similar calculation with which the results could be compared. Because of the preliminary, evolving nature of the AP600 design, conclusions concerning the adequacy of the design and the efficacy of the PSFs were considered premature and were therefore avoided. The main purposes of this work were to demonstrate the general applicability of RELAP5 to AP600 transient simulation, improve understanding of AP600 transient response, and identify areas where modification or extension of RELAP5 might be required to characterize AP600 transient performance [1,2].

The calculated chronological sequence of events and simulated system response are indicated by the calculated pressurizer pressure shown in Figure 3. The transient was initiated at To by instantaneously opening a junction connecting to the containment. The system depressurized rapidly to the pressurizer low pressure scram setpoint. The turbine throttle valves close and main feedwater flow is terminated upon reactor scram. Feedwater isolation at scram was necessitated because no data regarding AP600 balance of plant or steam generator level control was available. An automatic RCP trip signal is generated at To+25 seconds on a pressurizer low-low level signal. The pressure continues to decrease until the pressurizer empties and the RCS saturates. The pressure then stabilizes for a period and then begins to decrease, indicative of net RCS energy loss through the break, after transitioning to a higher quality break flow. The system pressure response looks very similar to that of conventional PWR SBLOCA simulations until ADS actuation. ADS staged actuation proceeds progressively at preset CMT levels as CMT inventory decreases. ADS stages 1, 2 and 3 are sparged in the IRWST. Fourth stage ADS blows down directly to the con-

tainment. First stage ADS actuation occurs at To+738 seconds, causing a rapid decline in system pressure resulting in accumulator injection at 700 psia. Accumulator injection begins at To+738 seconds and continues until To+1083 seconds. The CMTs empty at To+2640 seconds. IRWST injection begins at To+3036 seconds.

SBWR ESF COMPARISONS

Next, the SBWR PSFs are compared to the ESFs of current generation BWRs relative to satisfying the same three generic safety functions addressed to AP600. The contrasting safety mechanisms are then examined relative to the applicability of current T-H safety codes to the analytical safety evaluation of SBWR. Due to the state of completion of the input model, a demonstration calculation was not possible.

RCS Inventory Control

In order to maintain RCS inventory during postulated LOCAs, current BWRs are equipped with three pumped safety injection systems. The safety injection systems employ centrifugal pumps, and, therefore, the flow rate delivered to the reactor vessel varies according to the vessel pressure. At low vessel pressures the delivery is high and, as pressure increases, the delivery decreases until being shut off altogether at the shut-off pressure. The high pressure core spray (HPCS) system consists of a single pump with a shut-off head above the normal operating pressure. The low pressure core spray (LPCS) system also consists of a single pump, but with a much lower shut-off head. At low prevailing pressures the low-pressure systems are capable of injecting flow at many times that obtainable with the high-pressure system. However, at elevated vessel pressures only the high pressure system is capable of injection. Should an accident occur in which vessel inventory is declining due to a break but RPV pressure remains high because of the break location, the injection flow may not adequately replenish the break flow. In this case the RCS inventory will continue to decline. To prevent this occurrence, current BWRs employ electric motor-operated valves that provide for depressurizing the RCS and allow increased injection flow rates, thus replenishing the vessel inventory.

In the SBWR design, safety-grade coolant inventory control is accomplished using the Gravity Driven Cooling System (GDSC) in concert with automatic depressurization valves (ADV's). The GDSC consists of pools of water, located within the drywell far above the reactor vessel, plumbed to the RPV downcomer. The GDSC injection potential consists solely of the static head created by the height of the water in the pool and associated plumbing. The depressurization valves permit blowdown of the RPV into the drywell, thereby equalizing the GDSC and RPV pressures, allowing the GDSC to drain into the vessel and replenish its inventory. Inlet valves between the GDSC and the RPV, and the ADVs themselves, are opened using squibs (explosive charges) activated by the station batteries. The SBWR safety injection function is thereby accomplished passively, without the use of AC motor-operated pumps or valves. Furthermore, the diesel-electric generators, although present, are not considered safety-grade components, and, as such, are not relied upon to accomplish safety-related functions.

Proper simulation of the following parameters is necessary for a T-H systems code to correctly predict the SBWR RCS inventory: critical break flow rate (accounting for break orienta-

Preliminary AP600 Analysis Pressure Balance Line Break -- 3 in.

Pressurizer pressure

Figure 3.

tion and location), depressurization valve flow rate, RCS and drywell pressures, and the GDCS transient draining process. This last item is particularly significant because as the RCS pressure decreases, and the GDCS is drained into the RCS, the GDCS driving potential is reduced. This pressure dependency is exactly opposite that of current BWRs in which the flow rates delivered by centrifugal ECC pumps are used to decrease RCS pressure leading to higher ECC flow rates. When analyzing current BWRs, ECC flow rates are typically specified as boundary conditions, (i.e., ECC flow rate as a function of RCS pressure). However, in SBWR the ECC flow rate is a very sensitive function of the RCS and drywell pressures, and the transient GDCS liquid level. Since the GDCS driving potential is quite small, the effects of numerical instabilities and inaccuracies inherent in T-H systems codes will have a greater effect on the calculated ECC flow rates delivered in SBWR than in current BWRs. The uncertainty introduced by these effects into SBWR analyses will need to be addressed.

Long Term Decay Heat Removal

In current BWRs long term decay heat removal is accomplished via a shutdown cooling system employing two AC motor-driven pumps and associated decay heat exchangers. In SBWR this function is accomplished by means of isolation condensers (ICs) and passive containment cooling system (PCCS) condensers. If the depressurization valves are closed, only the ICs are employed; however, if the valves are open, then both condenser systems are employed. The functioning of the ICs is discussed in this section, while the PCCS is discussed in the next section.

The SBWR ICs provide for decay heat removal when the RCS is near normal operating pressure. The ICs are situated far above the RPV, submerged in a pool of water atop the containment. When necessary, steam from the RPV is admitted at the upper end of the vertically oriented IC tubes. Steam condensation inside the tubes rejects heat to the IC pools which are open to the atmosphere. Condensate is returned to the RPV downcomer by gravity flow. Proper simulation of wall condensation and gravity transport is required to correctly predict the SBWR IC performance. Assessment of code models pertaining to these processes will be necessary for analyzing SBWR long term decay heat removal.

Containment Cooling

During a hypothetical loss-of-coolant accident, the drywell will be heated and pressurized. Early containment cooling is provided by relieving the drywell atmosphere to the suppression pool through the horizontal vents. The SBWR PCCS condensers provide for both long-term, safety-grade, containment cooling and decay heat removal when the RCS is depressurized. Like the isolation condensers, the PCCS condensers are also elevated far above the RPV, submerged in pools of water atop the containment. The inlet to the PCCS condensers is located in the upper region of the drywell where the atmosphere will consist of a mixture of steam and air. This mixture is admitted at the upper ends of the vertically oriented PCCS condenser tubes. Steam condensation inside the tubes rejects heat to the PCCS condenser pools, which are also open to the atmosphere. Condensate is returned to the GDCS pools by gravity flow; noncondensable gases collected as the steam condenses are separated by gravity from the condensate and returned to the suppression pool. Proper simulation of the wall condensation (in the presence of

noncondensable gases), noncondensable phase separation and gravity drain processes are required for T-H codes to correctly predict the SBWR PCCS condenser operation. Assessment of code models affecting these processes will be necessary for SBWR analysis.

ISSUES AFFECTING APLWR SAFETY ANALYSIS

Safety simulations of next generation LWRs are expected to be of significantly longer duration than current LWRs. The cumulative effect of computational inaccuracies and induced perturbations during the course of the simulation factors prominently into the composite calculational uncertainty. Of paramount importance will be the ability to accurately calculate the ECC flow rates as liquid levels recede and the already initially small static driving potentials further diminish. Unlike pumped ECC systems whose delivery increases with decreasing RCS pressure, passive ECC delivery decreases with decreasing static head or decreasing accumulator pressure. Anything which diminishes the already limited static driving head greatly affects the ECC delivery. Numerical instabilities and inaccuracies, discontinuities in constitutive packages, and other numerical hiccups which perturb the problem may unduly affect the calculated RCS inventory and increase the uncertainty in calculated overall safety margin. For current LWRs the relative margin for error increases as RCS pressure decreases; for APLWRs the margin for error decreases as RCS pressure decreases and hydrostatic heads diminish. In current LWRs increasing ECC delivery at decreasing pressure overwhelms the break mass flow rate and rectifies the RCS net inventory loss at higher prevailing RCS inventory levels; just the opposite is true, for example, in AP600. Significant periods without any ECC flow are expected in the interim between the emptying of the accumulators and initiation of IRWST flow. As a result the RCS net inventory loss rate is turned around at significantly lower prevailing RCS inventories. Clearly, the margin for error in APLWR safety analysis is lessened by the inherently smaller, but more reliable, margin of safety. The composite effects of small computational inaccuracies on induced system interactions and perturbations over long periods may well lead to predicted results which are significantly different than would otherwise be expected or might actually occur. Because of these uncertainties bounding calculations will assume an expanded role in the analytical safety evaluation of APLWRs.

Furthermore, the physical mechanisms driving these safety features pose several analysis issues that go beyond the scope of development of thermal-hydraulic analysis systems codes intended for current reactor designs. Areas where existing codes may require modification, extension or assessment relative to passive safety designs are summarized in Tables 1 & 2.

SUMMARY AND CONCLUSIONS

Next generation commercial reactor designs achieve enhanced safety through reliance on immutable natural forces, such as gravity and gas pressurization, for safety system operation, and dependence on irrefutable natural phenomena, such as natural convection and condensation, for safety system performance. Simulating the performance of these passive safety systems will be central to analytical safety evaluation required for the licensing of next generation reactors. Yet the characteristically small driving forces of these safety systems pose challenging computational problems to current thermal-hydraulic sys

Table 1. RELAP5/AP600 Issues

Issue	Component	Concern	Impact
Heat transfer	Containment	Condensation inside containment	Code assessment and/or a new filmwise and/or dropwise condensation model may be required which includes the effects of noncondensibles, wettability, rainout and geometry.
		Natural convection and evaporation on steel shell exterior	New natural convection and evaporation models may be required that include effects of falling film of water. Alternatively, code assessment using an overall heat transfer coefficient based upon empirical containment data.
	PRHX	Apportioning heat transfer between phases within control volumes as mixture level changes	Code assessment and/or a new vapor/liquid partitioning heat transfer model.
	CMT pressure balance lines	Potential flow restriction due to condensation	Code assessment required to confirm hydrodynamic conditions predicted.
Mass transfer	Containment/sumps	Condensate, film and liquid level tracking	Code assessment and/or new models may be required.
	sump valves/break	Refill through break & sump valves	Code assessment and/or new models may be required.
Boron transport	RCS	Boron propagation	A new model may be required which includes effects of wavefront propagation, mixing and solubility.
Neutronics	Reactor core	Boron and thermal wavefront feedback	One-dimensional kinetics may be required.

Table 2. TRAC-B/SBWR Issues

Issue	Component	Concern	Impact
Wall heat transfer	Isolation condenser	Vertical tubes, laminar and turbulent regimes, tube length effect, possibility of dropwise behavior	New models based on vertical correlations may be needed. Assessment of existing or replacement models needed.
		Condensation in presence of noncondensibles	Existing model likely not adequate, new model needed.
	Containment	Condensation in presence of noncondensibles	Assessment of CONTEMPT-based models needed.
Interfacial shear	Isolation condenser	Cocurrent annular and bubbly regimes	Assessment of existing model with wall condensation present needed.
Interfacial heat transfer	Isolation condenser	Cocurrent annular and bubbly regimes	No data available for direct comparison with theory or correlations. Existing indirect assessments are for fluid heating, not cooling. Assessment of existing model needed.
		Effect of noncondensable gas	Existing model suspect, new model needed.
	Containment	Condensation in presence of noncondensibles	Assessment of CONTEMPT-based models needed.
Noncondensable phase	Isolation condenser	Phase separation; current models assume air/steam thermal and mechanical equilibrium	Assessment of existing model needed. Improved model may be necessary.
	Containment	Nonuniform air/steam distributions	Assessment of CONTEMPT-based models needed.
Flow regime maps	Isolation condenser	Tube rupture CCFL and critical flow at same location	Assessment of coupling between existing CCFL and critical flow models needed.

Accumulator injection	SLCS	Injection of borated fluid from pressurized tank	No accumulator model exists. Model development needed.
Boron transport	RPV	Boron wavefront propagation	A new model may be required which includes effects of wavefront propagation, mixing and solubility.
Neutronics	Reactor core	Stability; boron and thermal wavefront feedback	Adequacy of existing one-dimensional kinetics in addressing stability issues needs to be assessed. Coupling between boron wavefront tracking and 1-D kinetics needs to be implemented.

tems analysis codes. The composite effect of computational inaccuracies and calculationally induced perturbations over prolonged simulations may well lead to predicted results which are significantly different than would otherwise be expected or might actually occur. Because of these uncertainties bounding calculations will assume an expanded role in the analytical safety evaluation of APLWRs.

Furthermore, the containment and PSFs of advanced passive LWR designs interact with the RCS and each other in a more integral fashion than current LWR designs. Heretofore, traditional thermal-hydraulic systems analysis codes have been applied solely to the simulation of NSSS transients in LWRs equipped with pumped ECC systems whose function did not depend on containment pressure equalization. The high degree of communication exhibited between the RCS, containment and PSFs raises concerns about the validity and applicability of the simulation codes' closure relations under these circumstances. Particularly, existing code models simulating wall and interphase heat and mass transfer by condensation in the presence of non-condensable gases remain weak or unassessed.

Although a thorough code applicability review relative to the mechanisms of passive safety revealed no new underlying phenomena, modifications and enhancements to the current thermal-hydraulic systems analysis codes will be required to extend their range of applicability at low pressures, especially in the presence of noncondensibles. Models will be required to track thermal and boron wavefront propagation phenomena. Evaporative cooling models will need to be implemented in the

containment codes. The adequacy of existing flow regime maps will need to be examined relative to the processes evidenced in the SBWR isolation and containment condensers. Code assessment against experimental data will be required to validate the application of these codes to the licensing of advanced passive LWRs.

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