Omaha Public Power District

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October 12, 2007
LIC-07-0054

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555-0001

Reference: Docket No. 50-285

SUBJECT: Fort Calhoun Station Unit No. 1, License Amendment Request (LAR), "Uprate of Shutdown Cooling (SDC) System Entry Conditions"

Pursuant to 10 CFR 50.90, the Omaha Public Power District (OPPD) hereby transmits an application for amendment to the Fort Calhoun Station (FCS), Unit No. 1, Renewed Operating License No. DPR-40. The proposed amendment modifies the plant design and licensing basis to increase the shutdown cooling (SDC) system entry temperature from 300°F to 350°F (cold leg), and the SDC entry pressure from 250 psia to 300 psia (indicated at the pressurizer). Additionally, OPPD requests a change to the Updated Safety Analysis Report (USAR) described design methodology applied to the SDC heat exchangers.

One purpose of the proposed amendment is to increase the SDC system entry conditions to be more consistent with other Combustion Engineering (CE) and Westinghouse nuclear steam supply system (NSSS) plants. Implementation of the proposed change will also increase the operating margin between the auto-closure interlock pressure setpoint for the SDC suction isolation valves (HCV-347/348) and the reactor coolant pump (RCP) net positive suction head (NPSH) requirements. Currently, as the reactor coolant system (RCS) is transitioned to or from SDC entry conditions (300°F and 250 psia), the RCS pressure approaches the minimum RCP NPSH required. The current lack of operating margin was a contributing cause of the loss of SDC event that occurred during startup from the 2006 refueling outage (RFO).

In addition, the proposed increase in the maximum temperature limitation from 300°F to 350°F will improve plant operation. Currently, during a cooldown, the steam generators (SGs) must remain in service to remove decay heat until RCS temperature is reduced to 300°F. As the temperature approaches this value, the primary-to-secondary side temperature differential, and corresponding heat removal rate, is significantly reduced, which extends the duration of the cooldown. The increased maximum temperature limit for SDC entry would provide an improvement in plant performance by permitting an earlier transition from SG heat removal to a faster cooldown using the SDC system. The existing TS RCS cooldown rate limitations are unaffected by the proposed change.

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The proposed modification will change the existing TS requirements for plant conditions at which the SDC system is to be operable to support decay heat removal. TS 2.1, *Reactor Coolant System*, Sections 2.1.1(2), 2.1.1(3), and 2.1.1(11) are revised to permit operation of the SDC system at RCS cold leg temperatures above 300°F, up to and including 350°F. This change will allow plant operators to initiate SDC operation at 350°F during a plant cooldown. The TS 2.1 Basis and the FCS Technical Data Book (TDB) are also being revised. The TS Basis changes will be processed in accordance with the TS Basis Change Control program.

In addition, a change is proposed to surveillance requirement TS 3.16, *Residual Heat Removal System Integrity Testing*, to increase the system leakage test pressure from 250 psig to 300 psig. The proposed increase in test pressure is associated with the increase in SDC entry pressure. A typographical correction is also being made to TS 3.16(1)d to change the spelling of the word "frequence" to "frequency."

To support the proposed change, the SDC system will be rerated to increase the maximum operating temperature and pressure. The SDC heat exchangers are currently classified as American Society of Mechanical Engineers (ASME) Code, Section III, Class C; however, they were originally designed to Class A and Class C requirements, as described in the Updated Safety Analysis Report (USAR). For the rerate, OPPD proposes to apply only the ASME Class C requirements, consistent with the component classification. This represents a change to a USAR-described evaluation methodology that is used in establishing the design bases. OPPD requests approval of the change to the USAR described methodology applied to the SDC heat exchangers. The SDC system rerate activity will be performed by OPPD under the 10 CFR 50.59 process.

The enclosure provides OPPD's evaluation of the proposed amendment including a description of the proposed changes, the associated technical basis, and Significant Hazards Evaluation. Attachments 1 and 2 contain the marked-up and clean-typed TS pages, respectively. Attachment 3 is the revised low temperature overpressure protection (LTOP) analysis that supports the proposed change. Attachment 4 provides changes to the FCS Technical Data Book for information purposes.

In order for the plant modification needed to support the proposed SDC entry condition uprate to be completed during the 2008 RFO, OPPD requests approval of the proposed amendment by April 4, 2008, with implementation prior to startup from the 2008 RFO.

This license amendment request (LAR) is limited in scope in an effort to expedite NRC review and approval prior to the 2008 RFO. However, OPPD plans to process a future LAR to revise the remaining 300°F temperatures located throughout the TS to promote consistency within the TS.

There are no regulatory commitments in this letter.

In accordance with 10 CFR 50.91, a copy of this application, with the enclosure/attachments, is being provided to the designated State of Nebraska official.

If you should have any questions regarding this license amendment request submittal or require additional information, please contact Mr. Thomas C. Matthews at 402-533-6938.

I declare under penalty of perjury that the foregoing is true and correct. Executed on October 12, 2007.

D. J. Bannister
Acting Site Director

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Enclosure: OPPD's Evaluation of the Proposed Change

c: E. E. Collins, NRC Regional Administrator, Region IV
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Omaha Public Power District's Evaluation of the Proposed Change

Uprate of Shutdown Cooling System Entry Conditions

ATTACHMENTS:

1. Technical Specification Pages Markups
2. Retyped ("Clean") Technical Specifications
3. OPPD Report FC07187, Revision 0, "Low Temperature Overpressure Protection Analysis in Support of Shutdown Cooling System Initiation Temperature Change"
4. FCS Technical Data Book Pages

1.0 SUMMARY DESCRIPTION

This letter is a request to amend Renewed Operating License No. DPR-40 for Fort Calhoun Station (FCS), Unit No. 1, to uprate the shutdown cooling (SDC) entry conditions.

The proposed amendment modifies the plant design and licensing basis to increase the SDC system entry temperature from 300°F to 350°F (cold leg), and the SDC entry pressure from 250 pounds-per-square-inch absolute (psia) to 300 psia (indicated at the pressurizer). This will increase the SDC entry conditions to be more consistent with other Combustion Engineering (CE) and Westinghouse nuclear steam supply system (NSSS) plants. This proposed change increases the operating margin between the auto-closure interlock pressure setpoint for the SDC suction isolation valves (HCV-347/348) and the reactor coolant pump (RCP) net positive section head (NPSH) requirements. In addition, the change to the SDC entry conditions will improve plant operations by enabling a more rapid cooldown of the RCS.

The proposed modification will change the current Technical Specification (TS) requirements for plant conditions at which the SDC system is to be operable to support decay heat removal. TS 2.1, *Reactor Coolant System*, Sections 2.1.1(2), 2.1.1(3), and 2.1.1(11), will be revised to permit operation of the SDC system at RCS cold leg temperatures above 300°F, up to and including 350°F. This change will allow plant operators to initiate SDC operation at 350°F during a plant cooldown. The TS 2.1 Basis and the FCS Technical Data Book (TDB) will also be revised. The TS Basis changes will be processed via the TS Basis Change Control program.

In addition, a change is proposed to TS 3.16, *Residual Heat Removal System Integrity Testing*, to increase the system leakage test pressure from 250 pounds-per-square-inch gauge (psig) to 300 psig. The proposed increase in test pressure is associated with the increase in SDC entry pressure. A typographical correction is being made to TS 3.16(1)d to change the spelling of the word "frequence" to "frequency."

To support the proposed change, the SDC system will be rerated in accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI, to increase the maximum operating temperature and pressure. For the rerate, the Omaha Public Power District (OPPD) proposes to apply only the ASME, Section III, Class C requirements for the SDC heat exchangers in lieu of the existing USAR requirements (i.e., Class A and Class C). This represents a change to a USAR-described evaluation methodology that is used in establishing the design basis, and as such, requires NRC approval.

2.0 DETAILED DESCRIPTION

The proposed changes to the FCS TS are as follows:

2.1 Revise TS 2.1.1(2) for the limiting conditions for operation (LCO) temperature range for the reactor coolant loops, to increase the lower temperature limit from 300°F to 350°F, and to read as follows:

Hot Shutdown or ***350°F*** $\leq T_{cold} \leq$ *515°F*

2.2 Revise TS 2.1.1(3) for the LCO temperature range for the decay heat removal loops, to increase the upper temperature limit from 300°F to 350°F, and to read as follows:

*210°F ≤ T_{cold} ≤ **350°F** or T_{cold} < 210°F with fuel in the reactor and all reactor vessel head closure bolts fully tensioned.*

2.3 Revise TS 2.1.1(11)(b), for Low Temperature Overpressure Protection (LTOP), to increase the SDC entry temperature from 300°F to 350°F, and to read as follows:

*The unit cannot be placed on shutdown cooling until the RCS has cooled to an indicated RCS temperature of less than or equal to **350°F**.*

2.4 Revise TS 3.16(1)a., for Residual Heat Removal System Integrity Testing, to increase the system test pressure from 250 psig to 300 psig, and to read as follows:

*a. The portion of the shutdown cooling system that is outside the containment, and the piping between the containment spray pump suction and discharge isolation valves, shall be examined for leakage at a pressure no less than **300** psig. This shall be performed on a refueling frequency.*

2.5 Revise TS 3.16(1)d. to correct a typographical error by replacing the misspelled word "frequence" with "frequency" and to read, in part, as follows:

d. An internal leakage test shall be performed on a refueling frequency.

The proposed amendment will increase the SDC system entry conditions to be more consistent with other CE and Westinghouse NSSS plants. The proposed increase in the maximum temperature limitation from 300°F to 350°F will improve plant operation. Currently, during a cooldown, the steam generators (SGs) must remain in service to remove decay heat until RCS temperature is reduced to 300°F. As the temperature approaches this value, the primary-to-secondary side temperature differential, and corresponding heat removal rate, is significantly reduced, which extends the duration of the cooldown. The increased maximum temperature limit for SDC entry would provide an improvement in plant performance by permitting an earlier transition from SG heat removal to a faster cooldown using the SDC system. The existing TS RCS cooldown rate limitations are unaffected by the proposed change.

In addition, implementation of the proposed change will increase the operating margin between the auto-closure interlock pressure setpoint for the SDC suction isolation valves (HCV-347/348) and the RCP NPSH requirements. Currently, as the RCS is transitioned to or from SDC entry conditions (300°F and 250 psia), the RCS pressure approaches the minimum RCP NPSH required. The lowest RCS pressure for RCP operation is 225 psia (indicated at the pressurizer), as specified in the FCS TDB. The current lack of operating margin was a contributing cause of the loss of SDC event that occurred during startup from the 2006 refueling outage (RFO). This change increases the available operating margin from 25 psia, for SDC initiation at 250 psia, to 75 psia, with SDC initiation at 300 psia.

To support the proposed change, the SDC system will be rerated in accordance with the ASME Boiler and Pressure Vessel Code, Section XI, to increase the maximum operating temperature from 300°F to 350°F (cold leg) and pressure from 250 psia (235 psig) to 300 psia (285 psig), indicated at the pressurizer. The SDC heat exchangers are currently classified as ASME Code, Section III, Class C; however, they were originally designed to Class A and Class C requirements, as described in the Updated Safety Analysis Report (USAR). For the rerate, OPPD proposes to apply only the ASME Class C requirements. This represents a change to a USAR-described evaluation methodology that is used in establishing the design bases. OPPD requests approval of the change to the USAR-described methodology applied to the SDC heat exchangers. The SDC system rerate activity will be performed by OPPD under the 10 CFR 50.59 process.

3.0 TECHNICAL EVALUATION

3.1 Shutdown Cooling (SDC) System Description

The SDC system is shown in USAR Figure 9.3-1 and described in USAR Sections 6.2 and 9.3. The SDC system is designed to reduce the temperature of the reactor coolant at a controlled rate from 300°F to normal refueling temperature. The system also functions to maintain the proper reactor coolant temperature during refueling and it can be used for reactor coolant purification purposes. While the plant is shutdown, the SDC system provides an emergency backup for the spent fuel pool cooling system in case of failure of that system.

In addition, the SDC system provides flow to the reactor during the long term core cooling mode following a large break loss-of-coolant accident (LOCA) for the purpose of simultaneous hot and cold leg injection. The SDC heat exchangers can also be made available to supply cooled containment sump water to the high pressure safety injection (HPSI) pumps for long term core cooling. The SDC system interfaces with the RCS, the low pressure safety injection (LPSI) system, and the component cooling water (CCW) system. The RCS, LPSI system and the CCW system are described in USAR Section 4.0, USAR Section 6.2, and USAR Section 9.7, respectively.

During plant operation, two valves in series isolate the suction of both LPSI pumps from the RCS. In addition, a relief valve in this piping, vented to the waste disposal system, protects the system from overpressure. These isolation valves are opened after the RCS temperature has been decreased to 300°F and the RCS pressure has been reduced to below 250 psia (235 psig), indicated at the pressurizer, by bypassing steam to the condenser or by another appropriate steam path (e.g., atmospheric dump valves). The system utilizes the LPSI pumps to circulate the reactor coolant from the SDC nozzle through the two SDC heat exchangers, returning it to the RCS through the LPSI header. The cooldown rate is controlled by adjusting the flow rate through the heat exchangers. Either heat exchanger can achieve cooldown at the design rate. Cooling water for the SDC heat exchangers is normally supplied by the CCW system, although the raw water system may be used as a backup.

SDC initiation is controlled by the procedural limits of 300°F and 250 psia (235 psig), as noted above, and also by the SDC suction valve interlock, set at 235 psig (250 psia at pressurizer). The TS, through the RCS Pressure-Temperature Limits Report (PTLR), establish limits for plant operation for protection of the 10 CFR 50, Appendix G, brittle fracture limits. Low temperature overpressure protection (LTOP) requirements establish maximum pressure limits during low temperature RCS operation. The bounding limitation is the pressurizer power-operated relief valve (PORV) variable setpoint. Operational limitations, in accordance with the PTLR, are required below the LTOP enable temperature of 350°F.

3.2 Rerate of SDC System

To support the proposed change, the SDC system will be rerated as required to have higher design and operating pressures and temperatures. The SDC system components are subject to ASME Boiler and Pressure Vessel Code, Section XI, *Rules for Inservice Inspection of Nuclear Power Plant Components*, and the requirements of ASME, Section XI, paragraph IWA-4330, *Rerating*, apply. The rerating task and the associated plant physical modifications and changes to approved plant procedures will be performed in accordance with the FCS modification process and 10 CFR 50.59 review process. Therefore, NRC approval of the rerate activity is not requested in this license amendment request (LAR). The topics addressed in the rerate activity are summarized below for information:

3.2.1 Changes to SDC Design Pressure and Temperature

The revised design pressures and temperatures for the SDC system piping and components are summarized in the following SDC Design Pressures and Temperatures Table:

Table 1 - SDC Design Pressures and Temperatures

Component	Current Design Pressure [psig]	New Design Pressure [psig]	Current Design Temperature [°F]	New Design Temperature [°F]
SDC pumps suction piping	300	350	300	350
SDC (LPSI) pumps discharge piping	500	550	350	350
SDC (LPSI) pumps	500	550	350	350
SDC heat exchangers	500	550	350	350

In addition, the SDC suction-to-RCS valves (HCV-347 and HCV-348) interlock setpoint will be changed from 235 psig (250 psia at pressurizer) to 285 psig (300 psia at pressurizer).

3.2.2 SDC Heat Exchanger Design Capability

Heat Transfer Capability

During normal plant shutdown cooling, the SDC heat exchangers are designed to remove RCS decay heat, primary pump work heat and LPSI pump work heat to gradually cool the RCS. The heat removed from the RCS is transferred to the CCW system. The CCW design operating range at the CCW heat exchanger outlet is 55°F to 110°F. Decay heat is a function of the time after shutdown. By increasing the SDC system initiation point from an RCS temperature of 300°F to an RCS temperature of 350°F, the SDC initiation time after shutdown is potentially decreased and the decay heat load is potentially increased. Conservatively assuming an RCS cooldown rate equal to the maximum allowable cooldown rate of 100°F/hour, the minimum SDC initiation time after shutdown is decreased. This results in an increase in the decay heat load of about 8% to 12% at the time of SDC initiation (assuming a conservative 2-hour cooldown at 100°F/hour from 550°F to 350°F). However, the initial temperature differential between the RCS fluid and CCW fluid will also increase. Based on a CCW inlet temperature to the SDC heat exchanger of 110°F, the initial temperature difference will increase by approximately 26%. As the heat transfer capacity of heat exchangers is a function of differential temperature, the increased heat transfer capacity as a result of the increase in SDC initiation temperature will exceed the increase in the decay heat load. A calculation was performed that verifies that the SDC/CCW system has the capability to cool down from the new initiation reactor coolant temperature of 350°F to 130°F at nominal full power of 1500 MWt and nominal service fouling level in the original design basis time of 24 hours. Therefore, the heat transfer capacity of the SDC heat exchangers will remain adequate.

Thermal Transient Evaluation

The SDC heat exchangers are designed to withstand an instantaneous increase in tube side inlet flow temperature from 70°F to 300°F. The 300°F temperature is consistent with the current maximum RCS temperature for the initiation of the SDC system for the normal operating mode. It is also consistent with current limitations on SDC system initiation under accident operating modes in which the SDC system takes suction from the RCS. For accident operating modes in which the SDC system takes suction from alternative sources (e.g., the safety injection and refueling water tank (SIRWT) or the containment recirculation sump), the peak operating temperature of the SDC system is based on the temperature of the alternate suction source and is independent of the RCS temperature.

For the rerate, it is proposed that the RCS temperature limitation for initiation of the SDC system be raised to 350°F for both the normal operating mode and accident operating modes in which the SDC system takes suction from the RCS.

Initiation of the SDC system in the normal operating mode requires operator action. It is not an automatic action (e.g., like automatic initiation of safety injection upon receipt of a safety injection actuation signal (SIAS)). For the normal SDC operating mode, plant procedures require a gradual warm-up of the SDC system to the RCS temperature. The maximum warm-up rate is specified as 20°F/min and the procedure states that the SDC warm-up should take at least 10 minutes. Warm-up is accomplished by using a warm-up recirculation line and by limiting flow to/from the RCS during SDC initiation. These procedural requirements will be maintained for the proposed change. Therefore, the normal SDC initiation procedure will not subject the heat exchangers to a rapid thermal transient. Hence, testing of the SDC heat exchangers for a rapid thermal transient to the proposed new SDC system initiation temperature of 350°F is not required to qualify the normal operating mode.

Similar to the normal operating mode, the initiation of the SDC system in any of the accident operating modes in which the SDC system does not take suction from the RCS, requires operator action. For these accident SDC operating modes, the governing procedures require a gradual warm-up of the SDC system to the RCS temperature. The maximum warm-up rate is specified as 20°F/min and the procedures state that the SDC warm-up should take at least 10 minutes. Warm-up is accomplished by using a warm-up recirculation line and by limiting flow to/from the RCS during SDC initiation. These procedural requirements will be maintained for the proposed change. Therefore, these accident SDC initiation procedures will not subject the heat exchangers to a rapid thermal transient. Hence, testing the SDC heat exchangers for a rapid thermal transient to the proposed new peak SDC system initiation temperature of 350°F is not required to qualify these accident operating modes.

SDC (LPSI) Pumps Design

The SDC pumps, SI-1A and SI-1B, also referred to as the LPSI pumps, have been analyzed for the new design pressure and temperature of 550 psig and 350°F from a Code stress standpoint. In order to meet Code allowable stress limits, the existing pump hold-down bolting must be replaced with bolting composed of a stronger material.

The NPSH margin for the pumps has been shown to be acceptable at the rerate design conditions. The LPSI pumps were designed for thermal transients which exceed those expected during operation. Testing for one LPSI pump included a suction temperature increase from 50°F to 303°F (ΔT=253°F) in 12 seconds and a suction temperature decrease from 308°F to 60°F (ΔT=248°F) in 12 seconds (USAR Section 6.2.3.2). During normal plant cooldown, the SDC system is warmed up before initiation as described above. During plant startup and SDC shutdown, no cold water is introduced during the plant start up process. Additionally the effect of thermal shock for a transient of 40°F to 350°F (ΔT=290°F) in 5 to 10 seconds was reviewed as part of the pump rerate evaluation. The loading caused by the induced thermal stress on the casing ring was found to be acceptable with significant margin.

Based on the procedurally controlled manner in which the SDC system is warmed to RCS temperature after system initiation, it is concluded that no re-analysis or additional testing for rapid thermal transients is required.

In accordance with ASME Code Section XI, Paragraph IWA-4331(d), a Form NIS-2 must be completed to document the pump rerating. Also, Paragraph IWA-4331(e) requires that a new nameplate be added with the revised ratings and reference to the rerating documentation must be attached to the LPSI pumps as close as possible to the existing nameplates.

The design pressure and temperature of the LPSI pump coolers (5140 psig and 800°F, respectively) bound the rerate design conditions. Additionally, the impact of the rerate on the pump cooling loop has been evaluated. In order to ensure adequate pump seal and bearing cooling, the CCW inlet temperature at the seal cooler must not exceed the design value of 100°F when the reactor coolant temperature is between 300°F and 350°F. The SDC system operating procedures will be revised (under EC 35639) to ensure that this requirement is imposed during SDC system operation. CCW temperature can be controlled by removing non-essential heat loads and/or throttling CCW flow.

3.2.3 Other SDC Component Evaluations

Although the LPSI pumps (and pump coolers) and the SDC heat exchangers are the major components requiring evaluation, other components in the SDC system were evaluated for adequacy of temperature and pressure ratings, and setpoints. The evaluations included assessment of: relief valve setpoints and discharge capacity; valve actuator thrust capability; control valve cavitation (due to higher operating temperature); MOV torque/thrust requirements; MOV pressure locking and thermal binding; SDC isolation valve interlocks; and instrumentation setpoints and ranges. Physical plant changes will be implemented, as required to ensure the design is adequate for the uprated SDC conditions, via the modification/engineering change process for EC 35639.

3.2.4 SDC Piping Analysis

The SDC piping system has been re-analyzed as part of EC 35639 to ensure that the piping/support configuration meets the ASME Boiler and Pressure Vessel Code, Section III, USAR commitments, and OPPD piping analysis and modeling criteria. This included evaluation of support loads, valve accelerations, pump and heat exchanger nozzle loads, and pipe movements at wall penetration bellows.

3.2.5 Impact on CCW System

As discussed in Section 3.2.2, the proposed 50°F increase in SDC initiation temperature could result in an approximately 8% to 12% relative increase in the SDC heat load on the component cooling water system from decay heat. Therefore, this increase in SDC initiation temperature to 350°F can also result in an increase in CCW temperature until the temperature of the RCS decreases below 300°F. The CCW system is designed for the design basis post accident heat loads which bound the SDC loads. The SDC system rerate has no impact on the Chapter 14 design basis post- accident cooling requirements. As discussed below, the post-accident cooling loads on the CCW system still bound the loads during SDC system operation by a significant margin.

The maximum CCW system return temperature to the CCW heat exchanger is 160°F based on post accident conditions. The CCW design operating range at the CCW heat exchanger outlet is 55°F to 110°F. The current design heat load of each SDC heat exchanger on the CCW system during shutdown cooling operation is 37.1 MBtu/hr. The post-accident heat load of each heat exchanger on the CCW system is 58.9 MBtu/hr (117.8 MBtu/hr for two heat exchangers). Additionally, the total CCW system heat load during shutdown cooling operation (61.1 MBtu/hr) is significantly lower than the total CCW system heat load during the injection phase of a LOCA (352.2 MBtu/hr).

Therefore, considering the maximum expected increase in SDC heat exchanger heat load of approximately 8% to 12%, the design basis post-accident SDC heat exchanger loads on the CCW system bound the SDC heat exchanger loads on the CCW system. A calculation was performed that verifies that the SDC/CCW system has the capability to cool down from the proposed new SDC entry temperature of 350°F to 130°F in 24 hours, assuming the reactor has operated at nominal full power of 1500 MWt and the SDC heat exchangers have nominal service fouling. The 24-hour time is consistent with the original design basis for the SDC system.

Hence, the design basis post-accident CCW return temperature from the SDC heat exchangers will also bound the CCW return temperature from the SDC heat exchangers during shutdown cooling.

3.3 SDC Heat Exchangers USAR Design Methodology Change

The current licensing basis evaluation methodology applicable to the SDC heat exchangers is described in USAR Section 6.2.3.4. This section states that the units were designed and constructed to the standards of ASME Boiler and Pressure Vessel Code, Section III, Classes A and C, and Tubular Exchanger Manufacturers Association (TEMA) Class R requirements. In addition to the requirements of the code, a fatigue analysis was performed which considered all specified transient conditions. The heat exchanger tube side was conservatively analyzed as Class A and Class C, as shown in Table 6.2-3. However, as also stated in the USAR, the classification of the tube side was subsequently changed to ASME Section III, Class C.

For the SDC system rerate activity described in Section 3.2, it was determined that the SDC heat exchanger tube side should be evaluated to ASME Section III, Class C, consistent with the current component classification in the USAR. However, this analytical method differs from the original design method described in the USAR (i.e., Class A and C). Therefore, the proposed activity involves a change to a USAR-described evaluation methodology that is used in establishing the design bases. Following the NRC's review and approval of this amendment request, the USAR will be revised to indicate that the heat exchanger tube side meets ASME Code, Section III, Class C design requirements.

3.4 LTOP Analysis

Attachment 3 provides the revised LTOP analysis supporting the proposed change. The LTOP system at FCS provides peak pressure protection for transients that may occur while the RCS temperature is at the LTOP enable temperature of 350°F, (indicated T-cold). These transients are bounded by mass injection events such as a spurious safety injection (SI) signal, and by heat addition events such as the startup of an RCP while the SGs contain hot secondary fluid. In the first case, the added water pressurizes the RCS. In the second case, cool RCS fluid is introduced into the SGs causing the RCS fluid to expand, also pressurizing the RCS.

LTOP protection is provided by one of two means depending on the transient. For mass addition cases, the pressurizer PORVs open relieving sufficient water flow to offset the injected fluid. The PORV control system compares the pressurizer pressure to a function of pressure versus cold leg temperature. If the pressurizer pressure exceeds this pressure vs. temperature curve (termed the LTOP curve), then the PORVs open. (Note: the mass addition cases conservatively also include a loss of SDC, so that heat is also added from the RCPs, the core decay heat, and the pressurizer heaters. Thus, the mass addition case also bounds all anticipated spurious heat addition sources that might occur simultaneous to mass injection.)

The limiting heat addition case involves the startup of an RCP. The mitigation of the heat addition transient is by the TS 2.1.1(11)(c) requirement for a minimum steam void in the pressurizer prior to RCP start. The steam void maintains pressure as it collapses, since the steam is at saturated conditions and sees only a modest temperature rise as it is condensed. The time required for the void collapse allows the RCS to heat up and equilibrate with the secondary fluid temperature. Once this occurs, the transient has been effectively mitigated, although there is still a small net heat input due to the methodology's conservative assumptions. Specifically, it is assumed that SDC is not available while heat is added from the RCP, a high assumed decay heat, and a failed pressurizer heater control system.

The revised analysis uses a RELAP5 Mod 3.2d model, consistent with the current analysis. The only mass addition transient from the current design basis analysis that required reanalysis is Case 9, which is the mass addition case when first aligned to shutdown cooling. Previously, this case was run assuming that the RCS was at 314°F (300°F nominal plus 14°F uncertainty in indicated temperature). For the proposed change, Case 9 is run assuming that the RCS is at 364°F (350°F nominal plus 14°F uncertainty).

The same heat addition transients that were previously evaluated are re-analyzed for the proposed change. The results are more limiting, since the initial RCS-SG temperature differential is increased, and therefore more heat is added into the RCS. Even so, with an assumed pressurizer steam void of 40% actual (at least 50% indicated), all cases demonstrate that a sizable steam void remains in the pressurizer after ten minutes, and that the event at this time is limited to normal heat sources (decay heat, pressurizer heaters, and RCP heat). Steady state is not quite achieved because the conservative methodology specifies a net heat input due to a hypothesized loss of shutdown cooling. In all heat addition cases, it is expected that no PORV will open; however, one case is also provided that intentionally opens a PORV to demonstrate that the PORV capacity is sufficient to offset the transient.

The results of the revised LTOP analysis provided in Attachment 3 show that the existing FCS LTOP setpoint curve provided in FCS TDB-III.7.a, *RCS Pressure and Temperature Limits*, will continue to be acceptable for use after implementation of the proposed change. In addition, the operational restrictions listed in Table 2 of Attachment 3 are unchanged, except for the requirement that the SDC system cannot be placed in operation until the RCS has been cooled to 350°F.

Other TDB sections that will be affected by implementation of the proposed change include TDB-IX, *RCS Pressure and Temperature Limits Report* and TDB-III.7.d, *RCS Pressure and Temperature Limits*. The markup to TDB-III.7.d is provided for information in Attachment 4 to show the change to the P-T limit curve for the proposed modified SDC conditions.

3.5 SDC System Leakage Testing

As discussed in USAR Section 14.15, *Loss-of Coolant Accident*, the combined engineered safety feature (ESF) and safety injection/refueling water tank (SIRWT) recirculation leakage outside containment is limited by the TS to 3800 cubic centimeters (cc)/hr. The USAR analysis used 7600 cc/hr as the ESF/SIRWT leakage rate (includes factor of 2). The 3800 cc/hr leakage limit is currently verified in accordance with TS 3.16. Per the TS, the portion of the SDC system that is outside the containment, and the piping between the containment spray pump suction and discharge isolation valves, are tested for leakage at each RFO at a pressure no less than 250 psig. For the proposed change, the test pressure is to be increased to 300 psig. This represents a 50 psi increase over the existing test pressure, and is consistent with the increase in the operating pressure limit and the design pressure. However, the leakage limit of 3800 cc/hr will not be increased.

3.6 Use of RCS T_{cold} vs. T_{hot} in the Technical Specifications

Reference 6.3 provided FCS TS Amendment No. 212, which revised TS 2.5, "Steam and Feedwater Systems." The changes were made to bring the FCS auxiliary feedwater (AFW) TS into closer alignment with the Standard Technical Specifications (STS) (Reference 6.2). As discussed in the NRC safety evaluation for the amendment and related correspondence, OPPD was requested to justify use of T_{cold} rather than T_{hot} as the reference temperature for TS 2.5. The NRC noted that T_{hot} is the most direct indication of RCS temperature for determination of the need for the AFW system. However, OPPD stated that when the RCS temperature approaches 300°F during plant shutdown and startup, the difference between RCS T_{hot} and T_{cold} is less than 2°F. This difference is close to the accuracy of the temperature instrument, thus, the TS reference temperature, T_{cold}, is essentially equivalent to T_{hot} or T_{avg}. This conclusion was supported by data taken during the shutdown and startup of the plant for the Spring 2002 RFO.

For the proposed change, the justification for using T_{cold} has been reviewed to confirm its validity for the increased SDC entry temperature of 350°F. Based on plant operating data for RCS temperature, the difference between RCS T_{hot} and T_{cold} at the increased SDC entry temperature is less than 2°F. It is concluded that continued use of T_{cold} as a reference temperature in the TS is acceptable.

3.7 Impact on USAR Accident Analysis

Applicable accidents previously analyzed in the USAR are summarized in Section 4.1.2. The effects of the proposed change are discussed below.

Boron Dilution Incident

The proposed change to increase the SDC entry temperature to 350°F affects the analysis of the Boron Dilution Incident analyzed in USAR Section 14.3. Boron dilution is a manual operation that uses the chemical and volume control system (CVCS), conducted under strict procedural controls, which specify permissible limits on the rate and magnitude of any required change in boron concentration. Boron concentration in the RCS can be decreased either by controlled addition of unborated makeup water with a corresponding removal of reactor coolant (feed and bleed) or by using the deborating ion exchangers. The deborating ion exchangers are used for boron removal when the boron concentration is low, and the feed and bleed method becomes inefficient.

An inadvertent boron dilution occurs through the introduction of unborated water into the RCS via the CVCS. The unborated water increases the core reactivity and reduces the shutdown margin. An inadvertent boron dilution can occur only if there is a combination of operator error and a CVCS malfunction occurring at the same time. The most limiting inadvertent boron dilution transient is typically a malfunction that causes pure water to be delivered to the RCS by all available charging pumps.

Although the possibility is remote, a boron dilution incident could occur either with the reactor shutdown or operating. The purpose of the boron dilution analysis is to ensure that there is a large enough time interval for the operator to manually terminate a boron dilution event for any mode of operation before specified acceptable fuel design limits are violated.

The USAR boron dilution analysis employs two dilution models, depending on whether the RCPs are operating or the SDC system is in service. The dilution rate in the SDC mode is slower than when the RCPs are operating. The current analysis evaluates a case where the RCS temperature is between the cold shutdown temperature (> 210°F) and 300°F. The proposed change to increase the SDC entry temperature to 350°F requires re-evaluation of this case. The boron dilution analysis is performed each operating cycle to incorporate cycle-specific core physics data. The final boron dilution analysis for the next cycle (Cycle 25) will be completed prior to shutdown for the 2008 RFO. However, a preliminary re-analysis has been performed with the revised SDC conditions. The acceptance criterion is that a minimum time interval of 15 minutes must be available for operator action to terminate the event. The current analysis indicates that 17.78 minutes are available (USAR Table 14.3-2). Although the preliminary re-analysis for the proposed change shows that the available time is reduced by 0.55 minutes, the acceptance criterion is still met.

Main Steam Line Break (MSLB)

As discussed in Section 4.1.2, the MSLB analysis evaluates steam release from the secondary system through the main steam safety valves and the atmospheric dump valves for radiological impacts. The release occurs until SDC entry conditions are reached at 295°F. Although the proposed change would enable an earlier SDC entry (at 350°F), it is more conservative to assume an 8-hour steam release and SDC entry at 295°F. Therefore, these analyses are not being revised for the proposed change.

Large Break LOCA

As discussed in Section 3.5, the SDC leakage test pressure will be increased by the proposed change, however, the test acceptance criteria of 3800 cc/hr will not be changed. Therefore, the USAR Section 14.15.8 radiological analysis of the LOCA will not be affected.

LOCA during Shutdown

USAR Section 14.15.7.1 discusses a LOCA during plant shutdown. The USAR explains that, although the event is unlikely due to the reduced pressure conditions, there is a period of about 25 hours during a cooldown during which automatic initiation of the emergency core cooling system (ECCS) is not available. The pressurizer pressure low signal (PPLS) is bypassed below 1700 psia, and the safety injection tanks will be valved out when the system temperature and pressure reach 400°F and 400 psia, respectively. This 25-hour period considers a cooldown to SDC entry conditions (300°F and 250 psia), followed by a temperature reduction from 300°F to 140°F in about 24 hours. For the proposed change, the higher entry temperature will allow for faster cooldown from 350°F using the SDC system as compared to the current method, which requires use of the SGs from 350°F to 300°F. A calculation was performed that verifies that the SDC/CCW system has the capability to cool down from the proposed new SDC entry temperature of 350°F to 130°F in 24 hours, assuming the reactor has operated at nominal full power of 1500 MWt and the SDC heat exchangers have nominal service fouling. The 24-hour time is consistent with the original design basis for the SDC system. Therefore, the period during which automatic initiation of the ECCS is not available during a shutdown is bounded by the current analysis.

Other Accidents

As summarized in Section 4.1.2, previously analyzed accidents in the USAR, other than the boron dilution incident, credit the safety functions of the SDC system for accident mitigation. The proposed change does not affect the safety functions or any setpoints associated with the accident mitigation functions of the SDC system.

3.8 Risk Information

The proposed change is based on the calculations and analyses performed in conjunction with modification/engineering change (EC) 35639, "Shutdown Cooling Entry Conditions." The ASME Section XI, Class 2 pressure retaining components were rerated in accordance with the requirements of ASME Section XI, paragraph IWA-4330, "RERATING."

In addition, implementation of the proposed change will increase the operating margin between the auto-closure interlock pressure setpoint for the SDC suction isolation valves (HCV-347/348) and the RCP NPSH requirements. The current lack of operating margin was a contributing cause of the loss of SDC event that occurred during startup from the 2006 RFO.

The new SDC entry conditions result in the initiation of SDC approximately 1/2 hour earlier in the shutdown process (at a maximum cooldown rate of 100°F/hr) and, similarly, 1/2 hour later in the start up process where decay heat is low. This results in a small increase in the time that the plant is susceptible to an intersystem LOCA, in which the SDC suction isolation valves HCV-347 and HCV-348 are open.

The SG availability for decay heat removal is maintained by the current LCOs in TS 2.1.1(6), *Reactor Coolant System*, and 2.5, *Steam and Feedwater Systems*, that require the SGs and AFW system to be operable with the RCS temperature above 300°F. This will ensure that the SGs are available to remove decay heat, if required, during periods when the RCS is operating in the increased SDC operating temperature range (i.e., 300°F to 350°F).

The primary benefit of the proposed change to the SDC entry conditions is that the operating margin for the SDC suction valve auto-closure interlock setpoint is increased. This reduces the probability of inadvertently isolating the SDC system. The proposed change does not alter the independence and/or redundancy of the systems being modified and the single failure provisions as described in the USAR are not affected. The proposed change does not increase the potential for operator error. No new operator system interactions are introduced. Setpoints associated with RCS pressure are changed, however, the operator response remains the same.

In addition, OPPD's evaluation of Generic Letter 98-02, *Loss of Reactor Coolant Inventory and Associated Potential for Loss of Mitigation Functions While in a Shutdown Condition* (Reference 6.4), is not affected by the proposed change. This evaluation determined that FCS is not susceptible to common-mode failure similar to events described in the generic letter.

3.9 Summary

The proposed uprate of the SDC entry conditions in the TS is supported by a rerate of the SDC system design temperature and pressure, and the maximum operating temperature and pressure, performed in accordance with Section XI of the ASME Code. A change is proposed to the SDC heat exchangers USAR design methodology to be consistent with the current USAR classification of these components. The LTOP analysis has been revised to address the uprated conditions and no changes to the LTOP setpoints are required. The proposed increase in the SDC system leakage test pressure in the TS is consistent with the rerate of the system and will not affect the leakage test acceptance criteria. The affect of the proposed change on the USAR Boron Dilution Incident has been evaluated and the results remain within the USAR acceptance criteria. The proposed change will increase FCS SDC entry conditions to be more consistent with other CE plants, improve plant operation, and provide increased operating margin between the auto-close interlock pressure setpoint for the SDC suction isolation valves and the RCP NPSH requirements.

4.0 REGULATORY EVALUATION

4.1 Applicable Regulatory Requirements/Criteria

4.1.1 Regulations

General Design Criteria

FCS was licensed for construction prior to May 21, 1971, and at that time committed to the draft General Design Criteria (GDC). These draft general design criteria are contained in the FCS Updated Safety Analysis Report (USAR) Appendix G. The preliminary design criteria which relate to this LAR are:

Criterion 1 – *Quality Standards*. The proposed amendment complies with this criterion. FCS Criterion 1 states that those systems and components of reactor facilities which are essential to the prevention of accidents which could affect the public health and safety or to mitigation of their consequences shall be identified and then designed, fabricated, and erected to quality standards that reflect the importance of the safety function to be performed. Where generally recognized codes or standards on design, materials, fabrication, and inspection are used, they shall be identified. Where adherence to such codes or standards does not suffice to assure a quality product in keeping with the safety function, they shall be supplemented or modified as necessary. Quality assurance programs, test procedures, and inspection acceptance levels to be used shall be identified. A showing of sufficiency and applicability of codes, standards, quality assurance programs, test procedures, and inspection acceptance levels used is required.

As discussed in the USAR, Appendix G, the low pressure injection pumps were hydrostatically tested per the ASME Code, Section VIII, and the SDC heat exchangers were hydrostatically tested in accordance with the ASME Code, Section III. For the proposed uprate amendment, system leakage testing will be performed for the new service condition in accordance with ASME Section XI, paragraph IWA-4334.

In addition, USAR Appendix G states that the pressure containing materials of the heat exchangers were tested and examined per ASME Code, Section III, Class A (on tube side) and Class C (on shell side). As a clarification, the design classification for the tube and shell side is Class C (per USAR 6.2.3.4) and the proposed rerate activity will be performed in accordance with ASME Section XI, IWA-4330. After receipt of the NRC's approval of the proposed change, the USAR response to Criterion 1 will be updated to reflect the rerate of the SDC system as part of the LAR implementation process.

Criterion 2 – *Performance Standards*. The proposed amendment complies with this criterion. FCS Criterion 2 states that those systems and components of reactor facilities which are essential to the prevention of accidents which could affect public health and safety or to mitigation of their consequences shall be designed, fabricated, and erected to performance standards that will enable the facility to withstand, without loss of the capability to protect the public, the additional forces that might be imposed by natural phenomena such as earthquakes, tornadoes, flooding conditions, winds, ice and other local site effects. The design bases so established shall reflect: (a) Appropriate consideration for the most severe of these natural phenomena that have been recorded for the site and the surrounding area and (b) an appropriate margin for withstanding forces greater than those recorded to reflect uncertainties about the historical data and their suitability as a basis for design.

Criterion 9 – *Reactor Coolant Pressure Boundary*. The proposed amendment complies with this criterion. FCS Criterion 9 states that the reactor coolant pressure boundary shall be designed and constructed so as to have an exceedingly low probability of gross rupture or significant leakage throughout its design lifetime.

Criterion 33 – *Reactor Coolant Pressure Boundary Capability*. The proposed amendment complies with this criterion. FCS Criterion 33 states that the reactor coolant pressure boundary shall be capable of accommodating without rupture, and with only limited allowance for energy absorption through plastic deformation, the static and dynamic loads imposed on any boundary component as a result of any inadvertent and sudden release of energy to the coolant. As a design reference, this sudden release shall be taken as that which would result from a sudden reactivity insertion such as rod ejection (unless prevented by positive mechanical means), rod dropout, or cold water addition.

Criterion 34 – *Reactor Coolant Pressure Boundary Rapid Propagation Failure Prevention*. The proposed amendment complies with this criterion. FCS Criterion 34 states that the reactor coolant pressure boundary shall be designed to minimize the probability of rapidly propagating type failures. Consideration shall be given (a) to the notch-toughness properties of materials extending to the upper shelf of the Charpy transition curve, (b) to the state of stress of materials under static and transient loadings, (c) to the quality control specified for materials and component fabrication to limit flaw sizes, and (d) to the provisions for control over service temperature and irradiation effects which may require operational restrictions.

Criterion 35 – *Reactor Coolant Pressure Boundary Brittle Fracture Prevention*. The proposed amendment complies with this criterion. FCS Criterion 35 states that under conditions where reactor coolant pressure boundary system components constructed of ferritic materials may be subjected to potential loadings, such as a reactivity-induced loading, service temperatures shall be at least 120°F above the nil ductility transition (NDT) temperature of the component material if the resulting energy release is expected to be absorbed by plastic deformation or 60°F above the NDT temperature of the component material if the resulting energy release is expected to be absorbed within the elastic strain energy range.

Criterion 36 – *Reactor Coolant Pressure Boundary Surveillance*. The proposed amendment complies with this criterion. FCS Criterion 36 states that Reactor coolant pressure boundary components shall have provisions for inspection, testing, and surveillance by appropriate means to assess the structural and leaktight integrity of the boundary components during their service lifetime.

Criterion 37 – *Engineered Safety Features Basis for Design*. The proposed amendment complies with this criterion. FCS Criterion 37 states that engineered safety features shall be provided in the facility to back up the safety provided by the core design, the reactor coolant pressure boundary, and their protection systems. As a minimum, such engineered safety features shall be designed to cope with any size reactor coolant pressure boundary break up to and including the circumferential rupture of any pipe in that boundary assuming unobstructed discharge from both ends.

Criterion 38 – *Reliability and Testability of Engineered Safety Features*. The proposed amendment complies with this criterion. FCS Criterion 38 states that all engineered safety features shall be designed to provide high functional reliability and ready testability. In determining the suitability of a facility for a proposed site, the degree of reliance upon and acceptance of the inherent and engineered safety afforded by the systems, including engineered safety features, will be influenced by the known and the demonstrated performance capability and reliability of the systems, and by the extent to which the operability of such systems can be tested and inspected where appropriate during the life of the plant.

Criterion 41 – *Engineered Safety Features Performance Capability*. The proposed amendment complies with this criterion. FCS Criterion 41 states that engineered safety features such as emergency core cooling and containment heat removal systems shall provide sufficient performance capability to accommodate partial loss of installed capacity and still fulfill the required safety function. As a minimum, each engineered safety feature shall provide this required safety function assuming a failure of a single active component.

Criterion 42 – *Engineered Safety Features Components Capability*. The proposed amendment complies with this criterion. FCS Criterion 42 states that engineered safety features shall be designed so that the capability of each component and system to perform its required function is not impaired by the effects of a loss-of-coolant accident.

Criterion 43 – *Accident Aggravation Prevention*. The proposed amendment complies with this criterion. FCS Criterion 43 states that engineered safety features shall be designed so that any action of the engineered safety features which might accentuate the adverse after-effects of the loss of normal cooling is avoided.

Criterion 44 – *Emergency Core Cooling Systems Capability*. The proposed amendment complies with this criterion. FCS Criterion 44 states that at least two emergency core cooling systems, preferably of different design principles, each with a capability for accomplishing abundant emergency core cooling, shall be provided. Each emergency core cooling system and the core shall be designed to prevent fuel and clad damage that would interfere with the emergency core cooling function and to limit the clad metal-water reaction to negligible amounts for all sizes of breaks in the reactor coolant pressure boundary, including the double-ended rupture of the largest pipe. The performance of each emergency core cooling system shall be evaluated conservatively in each area of uncertainty. The systems shall not share active components and shall not share other features or components unless it can be demonstrated that (a) the capability of the shared feature or component to perform its required function can be readily ascertained during reactor operation, (b) failure of the shared feature or component does not initiate a loss-of-coolant accident, and (c) capability of the shared feature or component to perform its required function is not impaired by the effects of a loss-of-coolant accident and is not lost during the entire period this function is required following the accident.

Criterion 45 – *Inspection of Emergency Core Cooling Systems*. The proposed amendment complies with this criterion. FCS Criterion 45 states that design provisions shall be made to facilitate physical inspection of all critical parts of the emergency core cooling system, including reactor vessel internals and water injection nozzles.

Criterion 46 – *Testing of Emergency Core Cooling Systems Components*. The proposed amendment complies with this criterion. FCS Criterion 46 states that design provisions shall be made so that active components of the emergency core cooling systems, such as pumps and valves, can be tested periodically for operability and required functional performance.

Criterion 47 – *Testing of Emergency Core Cooling Systems*. The proposed amendment complies with this criterion. FCS Criterion 47 states that a capability shall be provided to test periodically the delivery capability of the emergency core cooling systems at a location as close to the core as practical.

Criterion 51 – *Reactor Coolant Pressure Boundary Outside Containment*. The proposed amendment complies with this criterion. FCS Criterion 51 states that if part of the reactor coolant pressure boundary is outside the containment, appropriate features as necessary shall be provided to protect the health and safety of the public in case of an accidental rupture in that part. Determination of the appropriateness of features such as isolation valves and additional containment shall include consideration of the environmental and population conditions surrounding the site.

Criterion 53 – *Containment Isolation Valves*. The proposed amendment complies with this criterion. FCS Criterion 53 states that penetrations that require closure for the containment function shall be protected by redundant valving and associated apparatus.

Criterion 57 – *Provision for Testing of Isolation Valves*. The proposed amendment complies with this criterion. FCS Criterion 57 states that capability shall be provided for testing functional operability of valves and associated apparatus essential to the containment function for establishing that no failure has occurred and for determining that valve leakage does not exceed acceptable limits.

Criterion 67 – *Fuel and Waste Storage Decay Heat*. The proposed amendment complies with this criterion. FCS Criterion 67 states that reliable decay heat removal systems shall be designed to prevent damage to the fuel in storage facilities that could result in radioactivity release to plant operating areas or the public environs.

10 CFR 50:

10 CFR 50.36 – *Technical Specifications*. 10 CFR 50.36(c)(2)(ii) describes the requirements for TS Limiting Conditions for Operation (LCOs) and is applicable to the proposed amendment. The proposed amendment retains the LCOs related to shutdown cooling system operation.

10 CFR 50.55a – *Codes and Standards*. 10CFR50.55a mandates use of ASME Boiler and Pressure Vessel Code, Section XI, for plant inservice inspection, with limitations and modifications. The proposed amendment will be in accordance with ASME Section XI (Reference 6.1), paragraph IWA-4330, “Rerating.”

10 CFR 50, Appendix G – *Fracture Toughness Requirements*. The revised LTOP analysis ensures that the P-T limits required per Appendix G are not exceeded during limiting LTOP events.

4.1.2 Design Basis (USAR)

The applicable FCS USAR accidents analyzed for this LAR are discussed below:

Boron Dilution Incident (USAR Section 14.3): An inadvertent boron dilution occurs through the introduction of unborated water into the RCS via the CVCS. The unborated water increases the core reactivity and reduces the shutdown margin. An inadvertent boron dilution can occur only if there is a combination of operator error and a CVCS malfunction occurring at the same time. The most limiting inadvertent boron dilution transient is typically a malfunction that causes pure water to be delivered to the RCS by all available charging pumps.

The USAR analysis of this accident is affected by the proposed change. The USAR evaluation for dilution considers a dilution case for RCS temperatures between the cold shutdown temperature (above 210°F) and 300°F. The maximum temperature corresponds to SDC entry conditions. For the proposed change, this case has been re-analyzed with an SDC entry temperature of 350°F. (Refer to Section 3.7 for further discussion.)

Main Steam Line Break (MSLB) Accident (USAR Section 14.12): In the event of a large pipe break in the main steam system, rapid depletion of the SG inventory causes an increased rate of heat extraction from the primary coolant. The resultant cooldown of the primary coolant, in the presence of a negative moderator temperature coefficient of reactivity, will cause an increase in nuclear power prior to a reactor trip and an erosion of shutdown margin after reactor trip. If the most reactive control element assembly (CEA) is assumed stuck in its fully withdrawn position after reactor trip, there is an increased possibility that the core will return to power and criticality.

The accident assessment addresses steam releases from the atmospheric dump valves (ADVs) from the intact SG. The iodine activity in the intact SG liquid is released to the environment in proportion to the steaming rate and the partition factor. The intact SG steam releases terminate when SDC conditions are reached. For the analysis, a SDC entry temperature of 295°F was assumed. The proposed change increases the SDC entry temperature from 300°F to 350°F, which would enable an earlier SDC entry. However, for the MSLB, it is more conservative to assume a steam release until SDC entry at 295°F. Therefore, this analysis will not be revised by the proposed amendment.

LOCA during shutdown (Section 14.15.7.1): The USAR explains that at any time after the Safety Injection Tanks (SITs) are isolated, the RCS pressure is 400 psia or less, and the total stress in any component will be less than the total stress at the design pressure. Therefore, the possibility of a LOCA during SDC becomes even more remote than while at power. Although the event is unlikely due to the reduced pressure conditions, there is a period of about 25 hours during a cooldown during which automatic initiation of the emergency core cooling system (ECCS) is not available. The PPLS is bypassed below 1700 psia, and the safety injection tanks will be valved out when the system temperature and pressure reach 400°F and 400 psia, respectively. This 25-hour period considers a cooldown to SDC entry conditions (300°F and 250 psia), followed by a temperature reduction from 300°F to 140°F in about 24 hours. A calculation was performed that verifies that the SDC/CCW system has the capability to cool down from the proposed new SDC entry temperature of 350°F to 130°F in 24 hours, assuming the reactor has operated at nominal full power of 1500 MWt and the SDC heat exchangers have nominal service fouling. The 24-hour time is consistent with the original design basis for the SDC system. (Refer to Section 3.7 for further discussion.)

The SDC system safety function is credited in the accident analyses for several other events, as described in the USAR, although the initiation temperature is not specifically discussed: Loss of Coolant Flow Incident (Section 14.6); Control Element Assembly (CEA) Ejection Accident (Section 14.13); Steam Generator Tube Rupture (SGTR) Accident (Section 14.14); and, Loss of Coolant Accident (large break) (Section 14.15). The proposed change will not affect the SDC accident-mitigation function and will not affect these analyses.

4.1.3 Approved Methodologies

The SDC heat exchangers are analyzed in accordance with ASME Code, Section III, Class C design requirements. Use of this code is authorized by 10 CFR 50.55a.

OPPD's LTOP methodology for FCS, which uses RELAP5 Mod 3.2d, is an NRC-approved methodology.

4.1.4 Analysis

The design analysis of the SDC heat exchangers for the proposed change will comply with the ASME Code, Section III, 1968 Edition. The revised LTOP analysis ensures that the P-T limits required per Appendix G are not exceeded during limiting LTOP events. The revised analysis (Attachment 3) determined that no changes to the LTOP setpoints are required for the proposed change.

4.2 Precedent

No specific precedent has been identified for uprating the SDC system entry conditions. OPPD's review indicates that many pressurized water reactors (PWRs) have SDC entry conditions that are above 300°F and 250 psia (235 psig) as many PWRs were originally designed with entry temperatures above 300°F and pressures above 250 psia (235 psig). In the case of Palo Verde, it was identified that, during Unit No. 1 construction, the SDC system pressure was increased from 350 psig to 400 psig.

However, precedent for uprating conditions via a license amendment was not identified. The proposed amendment raises the SDC entry conditions to be more consistent with other PWRs. Examples of SDC entry conditions for several CE NSSS plants are:

Arkansas Nuclear One Unit 2	275° F / 300 psia
Palisades	300° F / 270 psia
San Onofre Units 2 and 3	350° F / 376 psia
St. Lucie Unit 1:	350 °F / 350 psig
Waterford Unit 3:	350 °F / 377 psig
Palo Verde Units 1, 2, 3:	350 °F / 400 psig

With regard to LTOP protection, of the six plants listed above, St. Lucie Unit 1 and Palisades provide LTOP protection using pressurizer PORVs, which is the same method used at FCS. However, ANO-2, San Onofre, Waterford, and Palo Verde do not have pressurizer PORVs and provide different means of LTOP protection.

4.3 Significant Hazards Consideration

The proposed amendment revises Technical Specification (TS) 2.1, *Reactor Coolant System*, Sections 2.1.1(2), 2.1.1(3), and 2.1.1(11), to permit operation of the shutdown cooling (SDC) system at reactor coolant system (RCS) cold leg temperatures above 300°F, up to and including 350°F; and revises TS 3.16, *Residual Heat Removal System Integrity Testing*, to increase the system leakage test pressure from 250 psig to 300 psig. These changes will improve plant operations by enabling a more rapid cooldown of the RCS while maintaining current cooldown rate limits. The proposed change will also provide increased operating margin between the auto-close interlock pressure setpoint for the SDC suction isolation valves and the reactor coolant pump (RCP) net positive suction head (NPSH). The proposed increase in test pressure is associated with the increase in SDC entry pressure. A change is also proposed to the SDC heat exchangers Updated Safety Analysis Report (USAR) described design methodology to be consistent with the current USAR classification of these components.

The Omaha Public Power District (OPPD) has evaluated whether or not a significant hazards consideration is involved with the proposed amendment(s) by focusing on the three standards set forth in 10 CFR 50.92, "Issuance of Amendment," as discussed below:

1. **Does the proposed amendment involve a significant increase in the probability or consequences of an accident previously evaluated?**

   Response: No.

   The shutdown cooling (SDC) system provides flow to the reactor during long term cooling mode following a large break loss-of-coolant accident (LOCA). In addition, the SDC system can supply cooled sump water to the high pressure safety injection (HPSI) pumps for long term core cooling. The SDC system is also designed to reduce the temperature of the reactor coolant system (RCS) from 300°F to refueling temperature within 24 hours and to maintain the proper RCS temperature during refueling. As such, the SDC system is not an initiator for any accident previously evaluated.

   The proposed change to increase the SDC entry temperature from 300°F to 350°F affects the inputs to the analysis of the Boron Dilution Incident. However, re-analysis of this accident with the increased temperature does not result in an increase in the probability of the accident. The proposed increase in SDC system design and operating temperature and pressure has been evaluated for affects on system piping and components using appropriate codes and standards. The proposed changes do not introduce any failure mechanisms that would initiate a previously analyzed accident. Therefore, the proposed change to uprate the SDC system entry conditions does not result in a significant increase in the probability of a previously evaluated accident.

The potential effect of the proposed change on the consequences of a previously evaluated accident has been considered. Re-analysis of the Boron Dilution Incident with the proposed increased SDC entry temperature does not result in an increase in the consequences of the accident.

In addition, although an increase in the SDC system leakage test pressure is proposed, the leakage test acceptance criteria (i.e., maximum permitted leakage per hour) will not be affected. Therefore, the limit on post-accident leakage to atmosphere from the SDC system is unchanged. The proposed increase in SDC system design and operating temperature and pressure does not affect the redundancy or availability of the SDC system. The design functions of the system are not affected by the proposed change. Therefore, the SDC system will still be capable of performing the safety functions needed to mitigate the consequences of an accident previously evaluated.

Therefore, the proposed change does not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. **Does the proposed amendment create the possibility of a new or different kind of accident from any accident previously evaluated?**

Response: No.

The proposed change alters the SDC system entry conditions and increases the system leakage test pressure. In the current design, the SDC system has been excluded from consideration as a pipe rupture initiator since it is not normally in operation. It is used for plant shutdown and startup, and for accident mitigation. With the proposed change, the operating modes of the system will not be affected. The proposed change increases the RCS temperature and pressure at which the SDC system can be placed in service during shutdown (or removed from service during startup), but the RCS, SDC, and other plant systems are not operated in a different manner. The increased heat load on the component cooling water (CCW) system resulting from normal operation of the SDC at increased SDC temperatures has been evaluated. The increased normal operating heat load has been determined to be bounded by the post-accident CCW heat load. Any adjustments to the cooldown rate needed to accommodate the increased SDC entry temperature will be performed using approved procedures consistent with current practice and would not require operating the plant in a different manner.

The RCS cooldown rate limitations in the Technical Specifications (TS) are not affected by the proposed change. In addition, adjustments of CCW heat loads to maintain required CCW inlet temperatures for the SDC (Low Pressure Safety Injection (LPSI)) pump coolers, when operating at the increased SDC entry temperature, will be in accordance with plant procedures and within existing system capabilities. The low temperature overpressurization (LTOP) analysis has been revised for the proposed change. However, there are no effects on existing LTOP setpoints or operating limitations, other than the proposed change to TS 2.1.1(11)(b), which states that the unit cannot be placed on shutdown cooling until the RCS has been cooled to $\leq$ 350°F. The proposed change in SDC operating limitations does not introduce the possibility of new or different equipment malfunctions or accident precursors.

Therefore, the proposed change does not create the possibility of a new or different kind of accident from any previously evaluated.

3. **Does the proposed amendment involve a significant reduction in a margin of safety?**

   Response: No.

   The margins of safety are established through design parameters, operating parameters, and the setpoints at which automatic actions are initiated. The proposed change increases the SDC system entry conditions for plant shutdown, startup and following postulated accidents, and the SDC system leakage test pressure. However, the accident mitigation function and post-accident operation of the system is not affected. The operating limits on temperature and pressure will remain below the design temperature and pressure for the system. The time interval for operator action after a postulated boron dilution event with the SDC system in operation is reduced, however, the available time remains greater than the minimum required time interval of 15 minutes. The proposed change does not affect any design or operating parameter or setpoint used in the accident analyses to establish the margin of safety.

   Therefore, the proposed change does not involve a significant reduction in a margin of safety.

Based on the above, OPPD concludes that the proposed amendment presents no significant hazards consideration under the standards set forth in 10 CFR 50.92(c), and, accordingly, a finding of "no significant hazards consideration" is justified.

4.4 Conclusions

In conclusion, based on the considerations discussed above, (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

5.0 ENVIRONMENTAL CONSIDERATION

A review has determined that the proposed amendment would change a requirement with respect to installation or use of a facility component located within the restricted area, as defined in 10 CFR 20, or would change an inspection or surveillance requirement. However, the proposed amendment does not involve (i) a significant hazards consideration, (ii) a significant change in the types or significant increase in the amounts of any effluent that may be released offsite, or (iii) a significant increase in individual or cumulative occupational radiation exposure.

Accordingly, the proposed amendment meets the eligibility criterion for categorical exclusion set forth in 10 CFR 51.22(c)(9). Therefore, pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the proposed amendment.

6.0 REFERENCES

6.1 American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI, 1998 Edition, with 2000 Addenda.

6.2 NUREG-1432, Revision 3.0, *Standard Technical Specifications Combustion Engineering Plants*, dated June 2004.

6.3 Letter from NRC (A. B. Wang) to OPPD (R. T. Ridenoure), dated November 26, 2002, “Fort Calhoun Station Unit No. 1 – Issuance of Amendment [No. 212] Re: Steam and Feedwater Systems,” (NRC-02-0174) (ML022550475).

6.4 Letter from NRC (L. R. Wharton) to OPPD (S. K. Gambhir), dated February 9, 2001, Fort Calhoun Station, Unit No. 1 - Completion Of Licensing Action For Generic Letter 98-02, "Loss Fort Calhoun Station, Unit No. 1 - "Loss Of Reactor Coolant Inventory and Associated Potential for Loss of Emergency Mitigation Function While in a Shutdown Condition" (TAC No. MA4771) (ML010400237).

Technical Specifications Page Markups

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2.0 **LIMITING CONDITIONS FOR OPERATION**

2.1 Reactor Coolant System

2.1.1 Operable Components

Applicability

Applies to the operable status of the reactor coolant system components.

Objective

To specify certain conditions of the reactor coolant system components.

Specifications

Limiting conditions for operation are as follows:

(1) Reactor Critical

All four (4) reactor coolant pumps shall be in operation.

Exceptions

The limitations of this specification may be suspended during the performance of physics tests provided the power level is $\leq 10^{-1}$ % of rated power and the flow requirements of Table 1.1 No. 2 are met.

(2) Hot Shutdown or ~~300~~ 350°F $\leq T_{cold} \leq$ 515°F

(a) The reactor coolant loops listed below shall be operable:

(i) Reactor coolant loop 1 and at least one associated reactor coolant pump.

(ii) Reactor coolant loop 2 and at least one associated reactor coolant pump.

(b) At least one of the above reactor coolant loops shall be in operation.

Exceptions

All reactor coolant pumps may be de-energized for up to one hour provided (1) no operations are permitted that would cause dilution of the reactor coolant system boron concentration, and (2) core outlet temperature is maintained at least 10°F below saturation temperature.

2.0 **LIMITING CONDITIONS FOR OPERATION**
2.1 Reactor Coolant System (Continued)
2.1.1 Operable Components (Continued)

(c) If fewer than the above required reactor coolant loops are OPERABLE, the required loops shall be restored to OPERABLE status within 72 hours or the reactor shall be placed in COLD SHUTDOWN within the next 12 hours.

(3) 210°F ≤ T_{cold} ≤ ~~300~~ 350°F or T_{cold} < 210°F with fuel in the reactor and all reactor vessel head closure bolts fully tensioned.

(a) At least two (2) of the decay heat removal loops listed below shall be OPERABLE:

(i) Reactor coolant loop 1 and its associated steam generator and at least one associated reactor coolant pump.

(ii) Reactor coolant loop 2 and its associated steam generator and at least one associated reactor coolant pump.

(iii) One shutdown cooling pump, one shutdown cooling heat exchanger, and associated shutdown cooling piping.

(iv) One shutdown cooling pump, in addition to that in (iii) above, one shutdown cooling heat exchanger, in addition to that in (iii) above, and associated shutdown cooling piping.

(b) At least one (1) of the decay heat removal loops listed above shall be IN OPERATION.

(c) With no coolant loop IN OPERATION, suspend all operations involving a reduction in boron concentration of the Reactor Coolant System and initiate corrective action to return the required coolant loop to operation in 8 hours.

(d) For the purposes of items a(iii) and a(iv) above, the containment spray pumps can be considered as available shutdown cooling pumps only if both of the following conditions are met:

(i) Reactor Coolant System temperature is less than 120°F.

(ii) The Reactor Coolant System is vented with a vent area greater than or equal to 47 in^2.

(4) DELETED

2.0 **LIMITING CONDITIONS FOR OPERATION**
2.1 Reactor Coolant System (Continued)
2.1.1 Operable Components (Continued)

(5) DELETED

(6) Both steam generators shall be filled above the low steam generator water level trip set point and available to remove decay heat whenever the average temperature of the reactor coolant is above 300°F.

(7) Maximum reactor coolant system hydrostatic test pressure shall be 3125 psia. A maximum of 10 cycles of 3125 psia hydrostatic tests are allowed.

(8) Reactor coolant system leak and hydrostatic test shall be conducted within the limitations of the pressure and temperature limit Figure(s) shown in the PTLR.

(9) Maximum secondary hydrostatic test pressure shall not exceed 1250 psia. A minimum measured temperature of 73°F is required. Only 10 cycles are permitted.

(10) Maximum steam generator steam side leak test pressure shall not exceed 1000 psia. A minimum measured temperature of 73°F is required.

(11) Low Temperature Overpressure Protection (LTOP)

(a) The LTOP enable temperature and RCP operations shall be maintained in accordance with the PTLR.

(b) The unit can not be placed on shutdown cooling until the RCS has cooled to an indicated RCS temperature of less than or equal to ~~300~~ 350°F.

(c) If no reactor coolant pumps are operating, a non-operating reactor coolant pump shall not be started while T_c is below the LTOP enable temperature stated in the PTLR unless there is a minimum indicated pressurizer steam space of at least 50% by volume.

2.0 **LIMITING CONDITIONS FOR OPERATION**
2.1 Reactor Coolant System (Continued)
2.1.1 Operable Components (Continued)

Basis (Continued)

When Specification 2.1.1(3) is applicable, a single reactor coolant loop or shutdown cooling loop provides sufficient heat removal capability for removing decay heat, but single failure considerations require that at least two loops be operable. Thus, if the reactor coolant loops are not OPERABLE, this specification requires two shutdown cooling pumps to be OPERABLE.

One of the conditions for which Specification 2.1.1(3) is applicable is when the RCS temperature (T_{cold}) is less than 210°F, fuel is in the reactor and all reactor vessel closure bolts are fully tensioned. As soon as a reactor vessel head closure bolt is loosened, Specification 2.1.1(3) no longer applies, and Specification 2.8 is applicable. Specification 2.8 also requires two shutdown cooling loops to be operable if there is less than 23 feet of water above the top of the core.

The restrictions on availability of the containment spray pumps for shutdown cooling service ensure that the SI/CS pumps' suction header piping is not subjected to an unanalyzed condition in this mode. Analysis has determined that the minimum required RCS vent area is 47 in^2. This requirement may be met by removal of the pressurizer manway which has a cross-sectional area greater than 47 in^2.

When reactor coolant boron concentration is being changed, the process must be uniform throughout the reactor coolant system volume to prevent stratification of reactor coolant at lower boron concentration which could result in a reactivity insertion. Sufficient mixing of the reactor coolant is assured if one low pressure safety injection pump or one reactor coolant pump is in operation. The low pressure safety injection pump will circulate the reactor coolant system volume in less than 35 minutes when operated at rated capacity. The pressurizer volume is relatively inactive; therefore, it will tend to have a boron concentration higher than the rest of the reactor coolant system during a dilution operation. Administrative procedures will provide for use of pressurizer sprays to maintain a nominal spread between the boron concentration in the pressurizer and the reactor coolant system during the addition of boron.[1]

Both steam generators are required to be filled above the low steam generator water level trip set point whenever the temperature of the reactor coolant is greater than ~~the design temperature of the shutdown cooling system to assure a redundant heat removal system for the reactor.~~ **300°F to assure a reactor heat removal system that is redundant to the shutdown cooling system.**

The basis for the LTOP system requirements are documented in the PTLR.

3.0 **SURVEILLANCE REQUIREMENTS**

3.16 Residual Heat Removal System Integrity Testing

Applicability

Applies to determination of the integrity of the residual heat removal (RHR) systems and associated components.

Objective

To verify that the leakage from the residual heat removal system components is within acceptable limits.

Specifications

(1) a. The portion of the shutdown cooling system that is outside the containment, and the piping between the containment spray pump suction and discharge isolation valves, shall be examined for leakage at a pressure no less than ~~250~~ 300 psig. This shall be performed on a refueling frequency.

b. Piping from valves HCV-383-3 and HCV-383-4 to the suction isolation valves of the low pressure safety injection pumps and containment spray pumps and to the high pressure safety injection pumps shall be examined for leakage at a pressure no less that 82 psig. This shall be performed at the testing frequency specified in (1)a. above.

c. The portion of the high pressure safety injection (HPSI) system that is located outside the containment and downstream of the HPSI pumps shall be examined for leakage when subjected to the discharge pressure of a HPSI pump operating in the minimum recirculation mode. This test shall be performed at the frequency specified in (1)a. above. The leakage contribution from this section shall be the observed leakage from this piping at the test pressure multiplied by the square root of the ratio 1500/P, where P is the test discharge pressure (in psig) of the operating HPSI pump.

d. An internal leakage test shall be performed on a refueling ~~frequence~~ frequency. The test shall measure and quantify the leakage to the safety injection refueling water tank (SIRWT) from applicable water leakage paths.

e. Visual inspection of the system's components shall be performed at the frequency specified in (1)a. above to uncover any significant external leakage to atmosphere (including leakage from valve stems, flanges, and pump seals). The leakage shall be measured by collection and weighing or by any other equivalent method.

(2) a. The sum of leakages from section (1)a, (1)b, (1)c, and (1)d above shall not exceed 3800 cc/hour.

b. Repairs shall be made as required to maintain leakage within the acceptable limits.

Retyped ("Clean") Technical Specification Pages

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The limitations of this specification may be suspended during the performance of physics tests provided the power level is $\leq 10^{-1}\%$ of rated power and the flow requirements of Table 1.1 No. 2 are met.

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(ii) Reactor coolant loop 2 and at least one associated reactor coolant pump.

(b) At least one of the above reactor coolant loops shall be in operation.

Exceptions

All reactor coolant pumps may be de-energized for up to one hour provided (1) no operations are permitted that would cause dilution of the reactor coolant system boron concentration, and (2) core outlet temperature is maintained at least 10°F below saturation temperature.

2.0 **LIMITING CONDITIONS FOR OPERATION**
2.1 Reactor Coolant System (Continued)
2.1.1 Operable Components (Continued)

(c) If fewer than the above required reactor coolant loops are OPERABLE, the required loops shall be restored to OPERABLE status within 72 hours or the reactor shall be placed in COLD SHUTDOWN within the next 12 hours.

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(iii) One shutdown cooling pump, one shutdown cooling heat exchanger, and associated shutdown cooling piping.

(iv) One shutdown cooling pump, in addition to that in (iii) above, one shutdown cooling heat exchanger, in addition to that in (iii) above, and associated shutdown cooling piping.

(b) At least one (1) of the decay heat removal loops listed above shall be IN OPERATION.

(c) With no coolant loop IN OPERATION, suspend all operations involving a reduction in boron concentration of the Reactor Coolant System and initiate corrective action to return the required coolant loop to operation in 8 hours.

(d) For the purposes of items a(iii) and a(iv) above, the containment spray pumps can be considered as available shutdown cooling pumps only if both of the following conditions are met:

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(4) DELETED

2.0 **LIMITING CONDITIONS FOR OPERATION**
2.1 Reactor Coolant System (Continued)
2.1.1 Operable Components (Continued)

(5) DELETED

(6) Both steam generators shall be filled above the low steam generator water level trip set point and available to remove decay heat whenever the average temperature of the reactor coolant is above 300°F.

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(a) The LTOP enable temperature and RCP operations shall be maintained in accordance with the PTLR.

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(c) If no reactor coolant pumps are operating, a non-operating reactor coolant pump shall not be started while T_c is below the LTOP enable temperature stated in the PTLR unless there is a minimum indicated pressurizer steam space of at least 50% by volume.

2.0 **LIMITING CONDITIONS FOR OPERATION**
2.1 Reactor Coolant System (Continued)
2.1.1 Operable Components (Continued)

Basis (Continued)

When Specification 2.1.1(3) is applicable, a single reactor coolant loop or shutdown cooling loop provides sufficient heat removal capability for removing decay heat, but single failure considerations require that at least two loops be operable. Thus, if the reactor coolant loops are not OPERABLE, this specification requires two shutdown cooling pumps to be OPERABLE.

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Both steam generators are required to be filled above the low steam generator water level trip set point whenever the temperature of the reactor coolant is greater than 300°F to assure a reactor heat removal system that is redundant to the shutdown cooling system.

The basis for the LTOP system requirements are documented in the PTLR.

3.0 SURVEILLANCE REQUIREMENTS

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Applies to determination of the integrity of the residual heat removal (RHR) systems and associated components.

Objective

To verify that the leakage from the residual heat removal system components is within acceptable limits.

Specifications

(1) a. The portion of the shutdown cooling system that is outside the containment, and the piping between the containment spray pump suction and discharge isolation valves, shall be examined for leakage at a pressure no less than 300 psig. This shall be performed on a refueling frequency.

b. Piping from valves HCV-383-3 and HCV-383-4 to the suction isolation valves of the low pressure safety injection pumps and containment spray pumps and to the high pressure safety injection pumps shall be examined for leakage at a pressure no less that 82 psig. This shall be performed at the testing frequency specified in (1)a. above.

c. The portion of the high pressure safety injection (HPSI) system that is located outside the containment and downstream of the HPSI pumps shall be examined for leakage when subjected to the discharge pressure of a HPSI pump operating in the minimum recirculation mode. This test shall be performed at the frequency specified in (1)a. above. The leakage contribution from this section shall be the observed leakage from this piping at the test pressure multiplied by the square root of the ratio 1500/P, where P is the test discharge pressure (in psig) of the operating HPSI pump.

d. An internal leakage test shall be performed on a refueling frequency. The test shall measure and quantify the leakage to the safety injection refueling water tank (SIRWT) from applicable water leakage paths.

e. Visual inspection of the system's components shall be performed at the frequency specified in (1)a. above to uncover any significant external leakage to atmosphere (including leakage from valve stems, flanges, and pump seals). The leakage shall be measured by collection and weighing or by any other equivalent method.

(2) a. The sum of leakages from section (1)a, (1)b, (1)c, and (1)d above shall not exceed 3800 cc/hour.

b. Repairs shall be made as required to maintain leakage within the acceptable limits.

OPPD Calculation FC07187, Revision 0

Low Temperature Overpressure Protection Analysis in
Support of Shutdown Cooling System Initiation Temperature Change

CALCULATION COVER SHEET

Calculation Number: FC07187	Page No.: 1
QA Category: [X] CQE [ ] Non-CQE [ ] LCQE	Total Pages: 105
Calculation Title: Low Temperature Overpressure Protection (LTOP) Analysis in Support of Shutdown Cooling System Initiation Temperature Change	Short Term Calc: [ ] Yes [X] No Vendor Calc. No.: OPPD024-REPT-001 Associated Project:: EC 35639
Software Tracking No.: (from PED-MEI-23, if applicable)	Responsible NED Dept No.: 356

Owner Assignment (by Dept Head):
(Required only if there are affected documents to be changed)

OPPD Engineer Assignment (by Dept Head):
(Required only for verification of vendor/contractor calculations)

Verification of Vendor/Contractor Calc. assumptions, inputs and conclusions complete:

OPPD Engineer: Doug Molzer Date: 09/07/07

APPROVALS - SIGNATURE AND DATE (Multiple preparers shall identify section prepared per PED-QP-3, Section 4.3.)				Supersedes Calc No.	Confirmation Required?	
Rev. No.	Preparer(s)	Reviewer(s)	Required for CQE Independent Reviewer(s)		Yes	No
0	See Attached Vendor Signoff Sheet	See Attached Vendor Signoff Sheet	See Attached Vendor Signoff Sheet	NA		X

CALCULATION COVER SHEET

Calculation Number: FC07187	Page No.: 2

Applicable System(s) / Tag Number(s)

Reactor Coolant / PCV-102-1, PCV-102-2

EA's and/or Calculations Used as input in this Calculation

External Organization Distribution (Groups affected by this calculation)

Name and Location	Copy Sent (✓)	Name and Location	Copy Sent (✓)

CALCULATION REVISION SHEET

Calculation No.: FC07187	Page No.: 3
Rev. #	**Description/Reason for Change**
0	Initial Issue

PROJECT REPORT

For

OMAHA PUBLIC POWER DISTRICT

FORT CALHOUN

LOW TEMPERATURE OVERPRESSURE PROTECTION ANALYSIS

IN SUPPORT OF

SHUTDOWN COOLING SYSTEM INITIATION TEMPERATURE CHANGE

Independent Review Required: (Yes) No

Prepared by: Ralph Burger Date: 5/25/2007

Reviewed by: Simon Li Date: 5/25/2007

Independent Reviewer

Approved by: [signature] Date: 5/25/2007

Project Manager or Designee

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FIGURES AND TABLES

I. INTRODUCTION AND PURPOSE

The Low Temperature Overpressure Protection (LTOP) System at Fort Calhoun provides peak pressure protection for transients that may occur while the Reactor Coolant System (RCS) temperature is at the LTOP enable temperature of 350°F, indicated. These transients are bounded by mass injection events such as a spurious Safety Injection (SI) signal, and by heat addition events such as the startup of a Reactor Coolant Pump (RCP) while the Steam Generators (SGs) contain hot secondary fluid. In the first case, the added water pressurizes the RCS. In the second case, cool RCS fluid is introduced into the SGs causing the RCS fluid to expand, also pressurizing the RCS.

LTOP protection is provided by one of two means depending on the transient. For mass injection cases, the Pressurizer Power Operated Relief Valves (PORVs) open relieving sufficient water flow to offset the injected fluid. The PORV control system compares the Pressurizer pressure to a function of pressure versus cold leg temperature. If the Pressurizer pressure exceeds this pressure vs. temperature curve (termed the LTOP curve), the PORVs open. (Note: the mass addition cases conservatively also include a loss of shutdown cooling, so that heat is also added from the RCPs, the core decay heat, and the Pressurizer heaters. Thus the mass addition case also bounds all anticipated spurious heat addition sources that might occur simultaneous to mass injection.)

The limiting heat addition case involves the startup of a RCP. The mitigation of the heat addition transient is by a Technical Specification (TS) requirement for a minimum steam void in the Pressurizer prior to RCP start. The steam void maintains pressure as it collapses, since the steam is at saturated conditions and sees only a modest temperature rise as it is condensed. The time required for the void collapse allows the RCS to heat up and equilibrate with the secondary fluid temperature. Once this occurs, the transient has been effectively mitigated, although there is still a small net heat input due to the methodology's conservative assumptions. Specifically, it is assumed that shutdown cooling is not available while heat is added from the RCP, a high assumed decay heat, and a failed Pressurizer heater control system.

The Reference 1 report analyzes the transient scenarios just described for the Fort Calhoun Power Plant with Replacement Steam Generators and Replacement Pressurizer. Additionally, the model core decay heat was increased above current nominal to accommodate a potential future uprate. Use of this higher decay heat is conservative for the current plant licensed power. Reference 1, however, assumed that the highest temperature for initiating shutdown cooling (SDC) was 300°F indicated RCS temperature, and Fort Calhoun is seeking a plant change to allow SDC at 350°F indicated RCS temperature. The higher temperature means that heat addition cases will see greater energy flow into the RCS, and that the previous maximum-RCS-temperature mass addition Case 9 will no longer meet the highest possible RCS LTOP temperature transient.

The purpose of this report is to demonstrate that with the existing LTOP curve, the TS Pressure/Temperature limits (termed the P/T curve) is not exceeded by any of the LTOP transients impacted by the higher SDC system initiation temperature. Thus of the Reference 1 transients, all the heat addition cases and the one mass addition Case 9 are re-analyzed. This report also justifies that the control logic setpoints for the LTOP system, and the TS requirements for Pressurizer voids at the time of the first potential RCP start, High Pressure Safety Injection pump and Coolant Charging Pump (HPSI and CCP) limitations, shutdown cooling, and RCP operation requirements, remain appropriate for the proposed plant modifications.

II. OVERVIEW

A conservative RELAP5 Mod 3.2d model was developed for LTOP system adequacy demonstration in Reference 1. The conservatisms in this model are significant and provide comfortable assurance of the quality of the conclusions. In this report, the model is updated to reflect the proposed plant operation change.

The only mass addition transient from Reference 1 that is re-analyzed here is Case 9, which is the mass addition case when first aligned to shutdown cooling. In Reference 1 this case was run assuming that the RCS was at 314°F (300°F nominal plus 14°F uncertainty in indicated temperature). In this report, Case 9 is run assuming that the RCS is at 364°F (350°F nominal plus 14°F uncertainty).

The same heat addition transients that were evaluated in Reference 1 are re-analyzed for the modified plant. The results are more limiting, since the initial RCS-SG temperature differential is increased, and therefore more heat is added into the RCS. Even so, with an assumed Pressurizer steam void of 40% actual (at least 50% indicated), all cases demonstrate that a sizable steam void remains in the Pressurizer after ten minutes, and that the event at this time is limited to normal heat sources (decay heat, Pressurizer heaters, and RCP heat). Steady state is not quite achieved because the conservative methodology specifies a net heat input due to a hypothesized loss of shutdown cooling. In all heat addition cases, it is expected that no PORV will open; however, one case is also provided that intentionally opens a PORV to demonstrate that the PORV capacity is sufficient to offset the transient. Note, though, that plant procedures, as discussed in Section IX, should prevent any PORV opening during actual RCP starts.

The LTOP setpoint curve from Reference 13 is given in Table 1. (Note: Reference 13 presents this data in graphic form, but the spreadsheet used to draw the Reference 13 curve was located and is reproduced in Table 1 with the only modification being that the temperatures are rounded off to the nearest degree. Maximum round off was 0.02°F.)

Figure 1 presents the P/T limits and LTOP setpoint curve. Table 2 contains other operational restrictions assumed in the analysis that are implemented at Fort Calhoun.

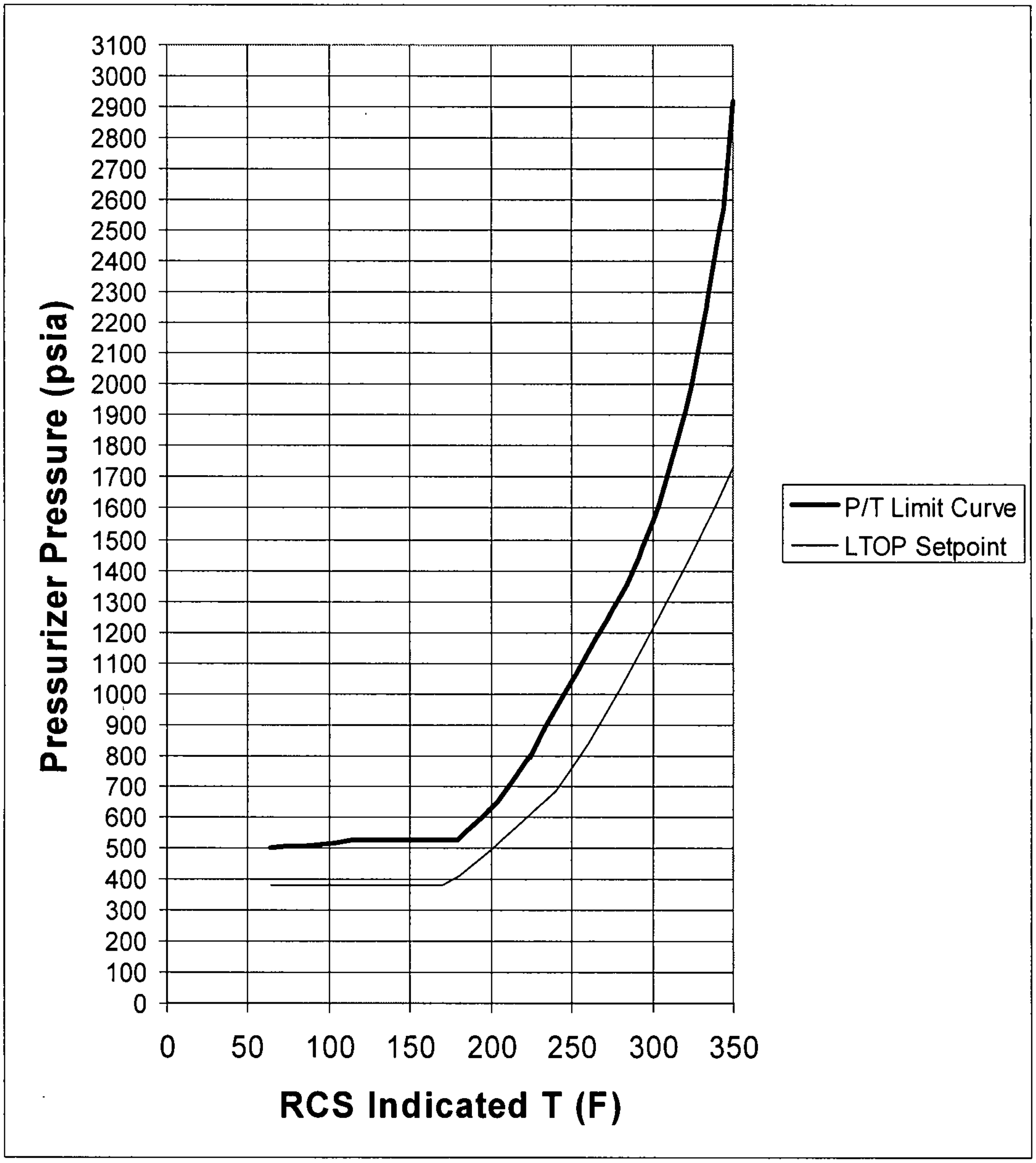
Table 1: LTOP Setpoint Curve from TDB III.7.a (Reference 13)

RCS Indicated Temperature (°F)	LTOP Setpoint Curve TDB III.7.a (psia)
64	379.5
170	379.5
180	409.25
200	494.5
220	587.75
240	684.5
260	837
280	1017
300	1210.75
320	1410.75
340	1621.8
350	1729.8

Table 2. Operational Restrictions

Components	Restrictions
RCPs	Only 3 or fewer RCPs are allowed to be operating once LTOP is enabled; only 2 are allowed below 224°F indicated RCS temperature (based on factors used to develop the P/T curve)
HPSIs	Only the equivalent of 2 HPSIs and 3 CCPs can be operational once LTOP is enabled; only the equivalent of 1 HPSI and 3 CCPs are enabled below 320°F indicated RCS temperature; and only the equivalent of 3 CCPs are enabled below 270°F indicated RCS temperature
Shutdown Cooling	The unit cannot be put on Shutdown Cooling until the RCS has cooled to 350°F indicated RCS temperature
Pressurizer Steam Void	When starting the first RCP, there must be an indicated steam void of 50% in the Pressurizer
RCS pressure	When starting the first RCP, the RCS pressure should be at least 61 psi below the LTOP setpoint pressure at the given RCS temperature, in order to prevent a PORV lift

Figure 1: P/T Limit and LTOP setpoint curve.
Data for the P/T limit curve are in Table 6, and data for the LTOP curves are in Table 1.
Note: These curves are identical to the P-T curve and PORV Trip Setpoint curve in TDB III-7.a (Reference 13)



III. ANALYSIS CRITERIA

The purpose of the LTOP system is to limit pressure transients to below the pressure-temperature limits (P/T curve) in order to protect RCS integrity from any risk associated with neutron embrittlement. The P/T curves show the maximum pressure in the Pressurizer based on the temperature at the cold legs. Figure 1 above shows the P/T curve and Table 6 contains the data that was used to draw this figure. The source of this data is originally EA-FC-01-022 (Reference 10), but it is also seen graphically in EA-FC-02-025 (Reference 11) and the Pressure and Temperature Limits Report (PTLR) in TDB-IX (Reference 12). The exact numbers in Table 6 were taken from the Excel spreadsheet that produced the curve in TDB-III.7.a (Reference 13).

The horizontal axis of Figure 1 is labeled "Indicated T", meaning that the RCS pressure should never exceed the given value at the indicated temperature. The curve has been shifted 14 degrees to the right from the actual P/T limit based on embrittlement concerns to account for uncertainty errors in indicated RCS temperature. For example, if the embrittlement concern arises if the pressure reaches 1600 psia while the RCS is at 286°F, the P/T limit curve is conservatively set to 1600 psia at 300°F. So long as the indicated temperature is at least 300°F, the operators are assured that the real temperature is greater than 286°F, and therefore acceptable. By the same method, the P/T limit at an indicated 286°F is reduced to 1450 psia.

The setpoint curve is also based on indicated temperature. That is, when the indicated temperature is 300°F, a PORV-open signal is generated when indicated pressure reaches 1200 psia. However, this involves errors in both the P and T instrumentation. The actual conditions might be 286°F and 1250 psia. To address this, the analysis uses an analysis LTOP setpoint curve that is shifted to the left and upwards.

Note that using the analysis LTOP setpoint curve and the conservative P/T limit is double counting the instrument error. For example, if the temperature is actually 286°F yet indicated 300°F, one conservatism comes from assuming that the PORV open signal is the pressure value associated with 300°F, and the second count would be assuming the conservative pressure limit associated with 286°F that is in fact shifted over from 272°F.

This confusion is dealt with in the analysis by assuming all pressures and temperatures are correct without error. Thus the analysis P/T limit is based on the actual embrittlement limits (in the above example, 286°F and 1600 psia). All uncertainty is added to the analysis LTOP setpoint curve, which is shifted to the left and up as described in Section IX of Reference 1. This assures that when the real temperature and pressure meet the conditions described by the analysis LTOP curve, the PORV open signal will be generated, and the pressure will be kept below the real P/T limit. Figure 2 attempts to show this conceptually.

Note also that while the RCS indicated temperature uncertainty is 14°F, the PORV actuation temperature uncertainty is 16.3°F. This larger uncertainty was accounted for when developing the LTOP setpoints for use in the plant instrumentation.

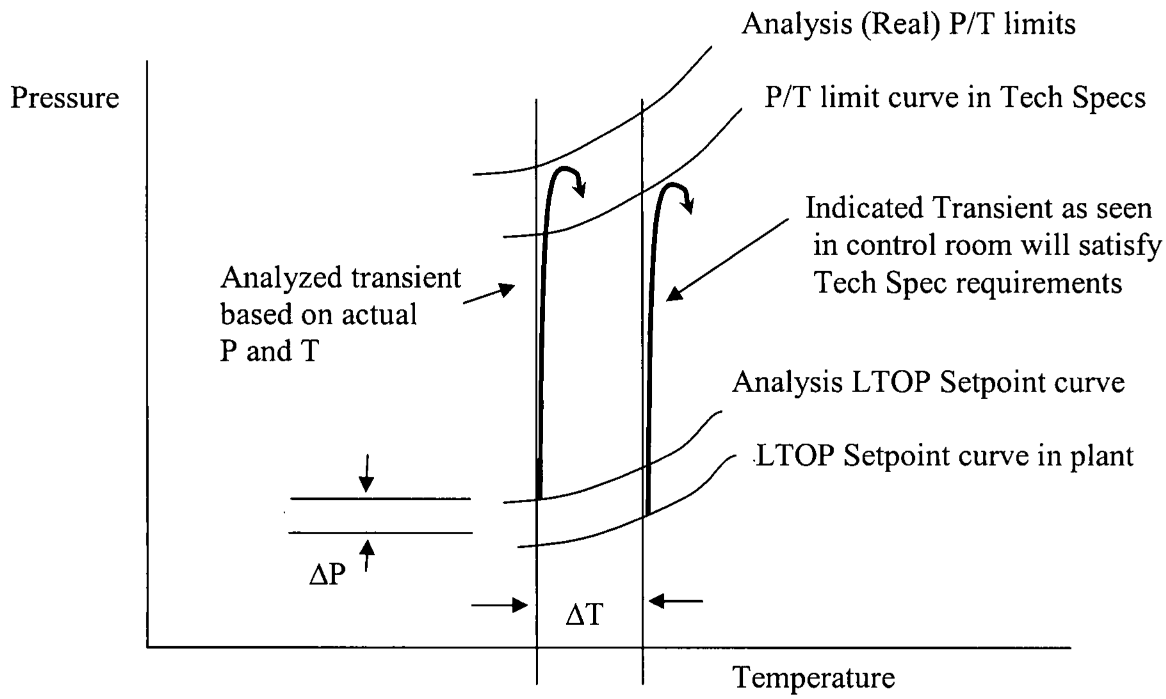


Figure 2: Conceptual Representation of Uncertainty Treatment. The PORV open signal is generated at a conservative offset of ΔT and ΔP, but the criteria are based on the real P/T limitations rather than the conservative P/T curve of technical specifications.

The pressure axis in Figure 1 is the Pressurizer pressure. The curve has been shifted downward from the calculated Reactor Vessel beltline limiting pressure to account for the fact that the beltline pressure will be higher than the Pressurizer pressure due to elevation and flow effects. The Pressure Correction Factor (PCF) shift in the LTOP enable temperature range is 61 psi below 210°F, and 67 psi above 210°F (these temperatures are the real values and not the indicated temperature; the values change at 210° because below this value only 2 RCPs are assumed to be running, and above this value 3 RCPs are assumed). The PCFs are conservative because:

- The PCFs include the pressure drop from the inlet nozzle and downcomer, yet these do not contribute to the pressure difference from the beltline to the Pressurizer.
- They are conservative for heat addition events, since only one RCP is running at that time.
- They are based on cold water density, but many transients involve warmer temperatures.

The PCFs were originally developed by Combustion Engineering, which has since become part of Westinghouse Electric Company (WEC). They have been verified to remain conservative for the new Steam Generators and Pressurizer in Framatome ANP document 32-5038452-01, 8/17/04 (Reference 8). They can also be seen on page 33 of Reference 10.

The RELAP program produces the actual Reactor Vessel peak pressures; however, to be conservative and to be consistent with the PTLR, the RELAP peak Pressurizer pressure is compared to the P/T curve. (Reference 1 results show that if the RELAP peak Reactor Vessel pressure is compared to the P/T limit for beltline pressure, an additional margin of about 30 psi results for most transients.)

Figure 3 compares the analysis LTOP curve (conservatively higher than the plant LTOP curve) and the analysis P/T limits (offset by 14°F to the left based on the assumption of the real RCS temperature) to the curves of Figure 1. Note that since this calculation involves RCS temperatures as high as 364°F (350°F indicated plus 14°F uncertainty), the P/T curve is extrapolated out to 364°F in a conservative horizontal extension. In point of fact, the extension does not matter since the P/T curve in this region is higher than the more restrictive operating pressure limit of 2750 psia described in USAR accident analyses (Reference 9).

The LTOP curve is also extended in a horizontal line at 1809.1 psia as is seen in Table 6. This is justified because the highest possible LTOP setting will be 1729.8 psia indicated per Table 1, and therefore the highest possible actual pressure to lift the PORV will be 1729.8 psia plus 66.7 psi uncertainty, or 1796.5 psia. Use of the value of 1809.1 psia therefore adds additional conservatism. (The historic reason for 1809.1 is that it was based on the LTOP setpoint curve of Reference 1, whereas when actually assigning the LTOP setpoint in Reference 11, Fort Calhoun used values that were approximately 12 psi lower and more conservative.)

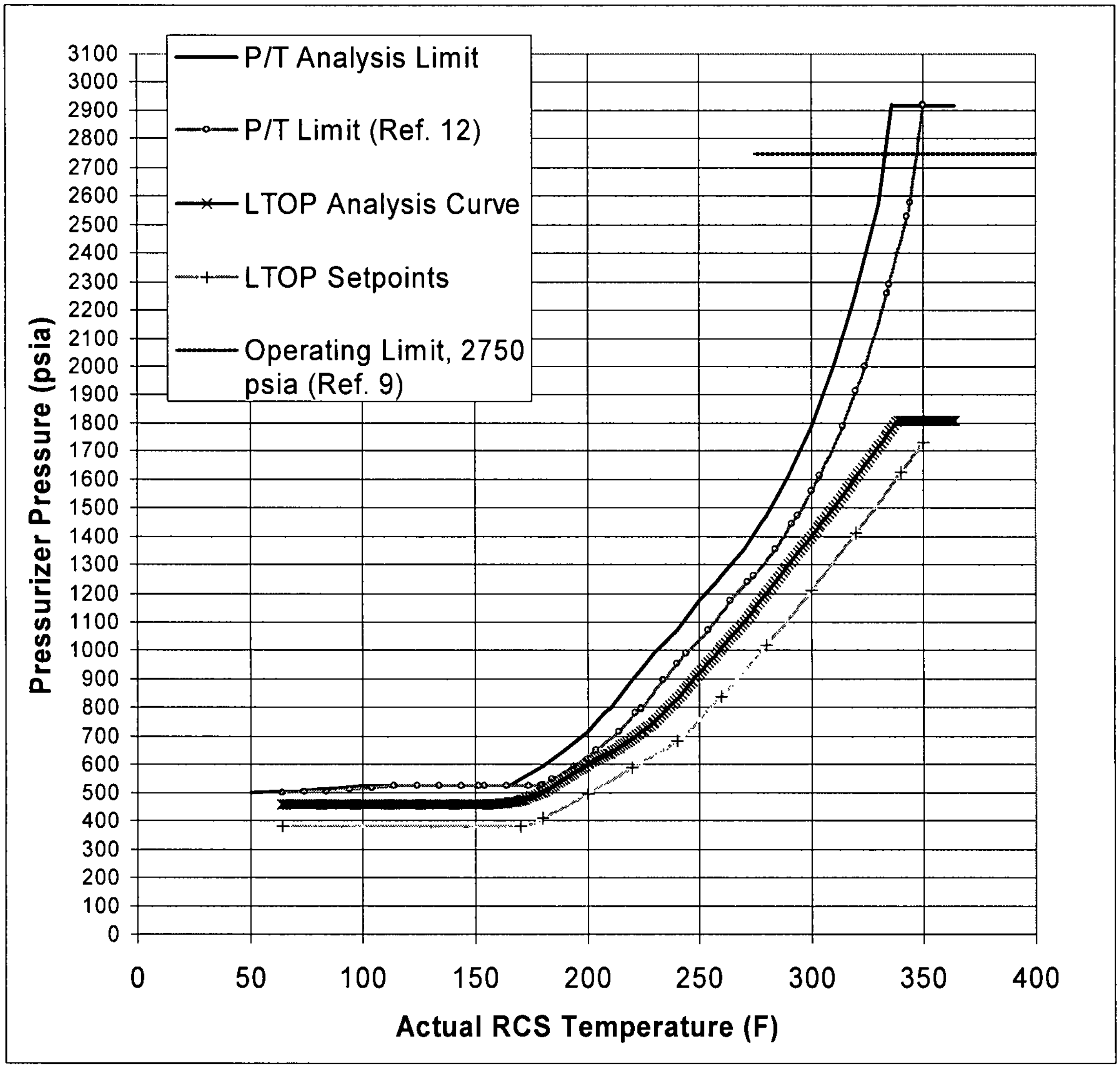


Figure 3: Analysis curves versus Plant curves (see Figure 2)

IV. INPUT DATA

Analysis input data are provided in a series of tables below. In most cases, the data is taken from Reference 1, where there is additional discussion about the data choices. A schematic of the RELAP model is shown in Attachment 1, along with additional piping information such as lengths, diameters, elevation changes and flow coefficients. Changes between the values assumed for this report and the original values contained in Reference 1 are highlighted and in bold font.

Table 3: Inputs Assumed for the LTOP Analysis

Name	Value	Direction of conservatism	Source
Energy Sources			
Plant Thermal Power	1765 MWt	Use 102% * 1765 for conservatism	Conservatively bounds current value of 1500 MWt, and allows for future uprate
Decay Heat	30.3 MWt	Value includes conservatism to maximize heat	Based on previous LTOP value of 25.7 increased by 1765/1500
RCP Heat Input	1.4 MWt per pump	Use maximum	Reference 1
SG Heat Transfer Surface Area	48,980 ft^2	Use maximum	Reference 1
SG number of tubes	5200, or 4680 at 10% plugged	Use maximum for heat addition, min for mass addition	Reference 1
SG tube volumes	662 ft^3 hot 654 ft^3 cold	Use maximum for heat addition (662 ft^3), min – 10% (588.6 ft^3) for mass addition	Reference 1
SG tube ID	0.664"	NA	Reference 1
SG tube OD	0.75"	NA	Reference 1
SG Material	Inconel 690	NA	Reference 1
SG tube heat capacity (Btu/Fft^3)	32F = 53.6 70F = 54.4 100F = 55.0 200F = 56.9 300F = 58.5 400F = 59.9 500F = 61.2 600F = 62.1	NA	Reference 1

Name	Value	Direction of conservatism	Source
SG tube conductivity	^{0}F Btu/sFft 32 1.82E-03 70 1.89E-03 100 1.94E-03 150 2.03E-03 200 2.11E-03 250 2.19E-03 300 2.28E-03 350 2.36E-03 400 2.44E-03	NA	Reference 1
SG Secondary Side Volume	4722 ft^3	Use Maximum	Reference 1 Conservatism in terms of maximizing heat source is assured by assuming the full volume applies to water volume
Pressurizer Heaters	900 kWt	Use maximum (actual is 892 kWt)	Reference 1
Mass Addition Sources			
Charging Flow (3 Pumps)	132 gpm	Use maximum	Reference 1
HPSI (1 Pump)	Data Table 4	Use maximum	Reference 1
HPSI (2 Pumps)	Data Table 5	Use maximum	Reference 1
Success Criteria			
P/T Curve	Table 6	Use minimum	Reference 1
LTOP Setpoint	Table 7	NA	Reference 1
Volumes, Lengths, Areas, Flow Resistances, and Elevations			
All Piping and Vessel Sections		See Table 4	Reference 1
PORV Data			
PORV	Dresser 2.5" 31533VX-30: 0.94 in^2 orifice, 110,220 #/hr capacity, 2385 psia Set Pressure, 0.95 flow coefficient	NA	Reference 1
PORV Opening Time	1.5 seconds	Use maximum	Reference 1
Uncertainty in Temperature Measurement	14 F° indicated	Use maximum	Reference 1

Name	Value	Direction of conservatism	Source
PORV actuation system uncertainty	16.245 F 66.896 psi	Use maximum	Reference 1
Location of Measured Temperature	Cold Legs	Analysis will conservatively use warmer Cold Leg to determine PORV lift setpoint	Reference 1
Uncertainty in Pressure Measurement	50 psi indicated	Use maximum	Reference 1
Miscellaneous Data			
SG Temperature during RCS cooldown by SDC	**364 °F**	**Use maximum expected**	**Subject of this analysis**
Quench Tank Maximum Backpressure for PORV	90 psia	Use maximum of 90 psia based on safety relief valve at 70 psig plus an additional 5 psi to address pipe losses	Reference 1
SI injection Temperature, Pressure and Density	250° F 90 psia 62.42 lbm/ft^3	Use maximum T, maximum P, minimum density	Reference 1
RCP performance	See Tables 9 and 10	See Tables 9 and 10	Reference 1
RCP rated head and flow	47,500 gpm 225 ft	Use maximum (analysis conservatively increases head to 290 ft)	Reference 1
RCP anti-rotation device	Modeled	NA	Reference 1
Pressurizer Level Indication Uncertainty	10%	Use maximum	Reference 1

Table 4: Maximum HPSI Injection Flow Rate, 1 Pump, from Reference 1

RCS Pressure (psia)	CESEC (Ref. 2), Minimum 1 HPSI Pump (gpm)	RELAP Model Maximum 1 HPSI Pump (gpm)
0	400	440
100	386	425
200	375	413
300	360	396
400	348	383
500	330	363
600	316	348
700	299	330
800	275	303
900	250	275
1000	223	245
1100	186	205
1200	151	166
1300	100	110
1385	0	0

Table 5: Maximum HPSI Injection Flow Rate, 2 Pumps
It is conservative to double the single pump maximum flow rate from Table 4.

RCS Pressure (psia)	RELAP Model Maximum 1 HPSI Pump (gpm)
0	880
100	850
200	826
300	792
400	766
500	726
600	696
700	660
800	606
900	550
1000	490
1100	410
1200	332
1300	220
1385	0

Table 6: P/T Curve. These values are to be compared to the Pressurizer pressure. The indicated RCS temperature is 14°F greater than true to account for instrument error. The 1st and 3rd columns come from the spreadsheet used to draw the P-T Curve in TDB-III.7.a (Reference 13). The analysis uses the 2nd and 3rd columns.

RCS Indicated Temperature (°F)	RCS Actual Temperature (°F)	Composite P/T Limit (psia)
64	50	498
74	60	502
84	70	505
94	80	510
104	90	515
114	100	522
118	104	525
124	110	525
134	120	525
144	130	525
154	140	525
164	150	525
174	160	525
178	164	525
184	170	548
194	180	593
204	190	649
214	200	717
224	210	794
234	220	895
244	230	990
254	240	1072
264	250	1172
274	260	1259
284	270	1355
294	280	1471
304	290	1613
314	300	1786
324	310	1998
334	320	2258
344	330	2575
354	340	2918
	364	2918 (conserv. extrapolation)

Table 7: LTOP Analysis Curve.

The first two columns are the analytical curve that do not account for measurement uncertainty. For comparison, the LTOP curve of Table 1 is repeated in the third and fourth columns. By comparing similar RCS temperature points, it is seen that the analytical curve assumes a much higher PORV open pressure at comparable temperatures. This higher open pressure is conservative and is designed to account for a PORV actuation temperature error of 16.3°F and a PORV actuation pressure error of 66.9 psi, as discussed in Reference 1.

RCS Actual Temperature (°F)	LTOP analysis curve actual pressure (psia)	RCS Indicated Temperature (°F)	LTOP Setpoint Curve TDB III.7.a (psia)
50	459	64	379.5
160	459	160	
170	470	170	379.5
180	500	180	409.25
190	550	190	
200	600	200	494.5
210	640	210	
220	690	220	587.75
230	750	230	
240	830	240	684.5
250	920	250	
260	1010	260	837
270	1100	270	
280	1200	280	1017
290	1300	290	
300	1400	300	1210.75
310	1500	310	
320	1608	320	1410.75
340	1809.1	340	1621.8
364	1809.1	350	1729.8

Table 8: RCP Homologous Curves, from Reference 1

α/γ or γ/α	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
HAN	1.826	1.644	1.524	1.417	1.321	1.374	1.323	1.259	1.187	1.085	1.0
HVN	-1.42	-1.25	-1.09	-0.92	-0.73	-0.51	0.00	0.30	0.541	0.6887	1.0
BAN	1.417	1.262	1.156	1.041	1.0	0.961	0.965	0.980	1.00	1.002	1.0
BVN	-1.45	-1.1	-0.85	-0.64	-0.43	-0.113	0.241	0.406	0.610	0.797	1.0
HAD	1.826	1.984	2.228	2.44	2.60	2.87	3.078	3.37	3.69	4.0	4.34
HVD	1.42	1.56	1.64	1.777	1.93	2.16	2.52	2.973	3.31	3.69	4.34
BAD	1.417	1.56	1.73	1.93	2.16	2.37	2.69	2.92	3.19	3.56	4.0
BVD	1.49	1.64	1.777	1.93	2.1	2.37	2.60	2.92	3.19	3.56	4.0
HAT	0.20	0.26	0.30	0.31	0.35	0.38	0.40	0.430	0.496	0.610	0.769
HVT	1.42	1.23	1.04	0.907	0.842	0.826	0.812	0.812	0.797	0.769	0.769
BAT	-1.32	-0.89	-0.61	-0.40	-0.24	-0.118	0.0	0.12	0.251	0.391	0.503
BVT	1.49	1.42	1.35	1.23	1.13	1.02	0.916	0.826	0.718	0.620	0.503
HAR	0.20	0.12	0.0	-0.246	-0.513	-0.83	-1.035	-1.60	-2.05	-2.55	-3.10
HVR	-1.42	-1.715	-1.96	-2.15	-2.34	-2.52	-2.69	-2.81	-2.93	-3.01	-3.10
BAR	-1.32	-1.66	-1.91	-2.19	-2.49	-2.83	-3.24	-3.60	-4.05	-4.54	-5.03
BVR	-1.45	-1.85	-2.20	-2.52	-2.85	-3.15	-3.49	-3.84	-4.23	-4.61	-5.03

Table 9: Interpretation of Homologous Curves. By examining the relative magnitude of α and γ, the user can select the correct independent variable and apply it to Table 8. This table is from the RELAP manual NUREG/CR-5535-V2 p. 2-38 (Ref. 5)

Regime Number	Regime Mode ID Name	α	γ	γ/α	Independent Variable	Head (Dependent Variable)	Torque (Dependent Variable)
1	HAN & BAN Normal	>0	≥0	≤1	γ/α	H/α^2	β/α^2
2	HVN & BVN Normal	>0	>0	>1	α/γ	H/γ^2	β/γ^2
3	HAD & BAD Dissipation	>0	<0	≥-1	γ/α	H/α^2	β/α^2
4	HVD & BVD Dissipation	>0	<0	<-1	α/γ	H/γ^2	β/γ^2
5	HAT & BAT Turbine	≤0	≤0	≤1	γ/α	H/α^2	β/α^2
6	HVT&BVT Turbine	≤0	≤0	>1	α/γ	H/γ^2	β/γ^2
7	HAR & BAR Reverse	≤0	>0	≥-1	γ/α	H/α^2	β/α^2
8	HVR & BVR Reverse	≤0	>0	<-1	α/γ	H/γ^2	β/γ^2

V. NRC LTOP ANALYSIS REQUIREMENTS

The Combustion Engineering Owners Group (CEOG) produced Report CE NPSD-683-A, Rev. 6 (Reference 3), which defined the methodology to be used in LTOP analyses such as this. The NRC's review and approval of this document is a letter dated 3/16/2001 entitled "Safety Evaluation of Topical Report CE NPSD-683-A, Rev. 6, Development of a RCS Pressure and Temperature Limits Report for the Removal of P/T Limits and LTOP Requirements from the Technical Specifications" (TAC No. MA9561) (Reference 4). The NRC document stipulates the following requirements for LTOP analyses performed in accordance with the CEOG Report:

1. Initial conditions are the most limiting allowed by Technical Specifications.
2. Only one (1) PORV is credited with opening.
3. No credit is taken for letdown, RCS metal volume expansion, or RCS metal thermal inertia.
4. Water-solid conditions in the PZR are assumed unless TSs exist to require a steam or other gas volume.
5. Full PZR heater capacity must be assumed.
6. Decay heat must be accounted for, with the maximum specified cooldown rate used to determine the time after shutdown. (Note: this analysis uses a conservatively minimal time to calculate decay heat, and then increases the value by 20% for all but Case 9, which uses a 5% margin. See decay heat discussion in Section VI.)
7. PORV setpoint uncertainty must be treated consistent with RG 1.105 and ISA Standard S67.04-1994. (Note: in this case, the LTOP analysis is performed without uncertainty. The resulting LTOP curve is protected by biasing the field setpoints to account for measurement uncertainty as described in Section IX.)
8. The heat addition methodology to evaluate one (1) RCP starting with a hot Steam Generator must be evaluated on a submittal-specific basis.
9. The mass-addition event is based on the maximum combined flow rate from HPSI pumps and charging pumps, where the flow rates are either the design flows plus 10% or flows based on IST with uncertainty or Safety Analysis limits.
10. The peak pressure for these transients is described as being based on the larger of either the maximum pressurization rate times the time to open the PORV, or the pressure when the mass addition flow rate equals the PORV flow rate. (This is not a necessary statement with the use of RELAP, since RELAP will simulate the transient completely and provide the maximum pressure directly.)
11. PORV discharge curves must be provided using appropriate correlations, applying a conservative back pressure, considering flow reduction due to flashing, relating the valve flow rate with either valve inlet pressure or Pressurizer pressure, covering the full range of expected pressures, accounting for the inlet piping pressure drop, and cover pressures regardless of setpoint. (ENERCON utilizes the RELAP5 code to calculate the PORV flow rates based on orifice area, upstream conditions, and a conservative backpressure based on the Quench Tank Safety Valve setpoint plus 5 psi to account for line losses. See Section VI for discussion.)

12. There is also a reference made to the Safety Injection Tank (SIT), but this is not applicable to Fort Calhoun since SITs are pressurized to less than the lowest PORV setpoint or valved out.

VI. ANALYSIS DISCUSSIONS

This section will present all assumptions and conservatisms. In addition, discussion is provided for various aspects of the transients and how they have been conservatively addressed.

ASSUMPTIONS/CONSERVATISMS

1. The P/T limit curve is based on conservative PCFs that protect the maximum beltline pressure. This analysis compares the resulting Pressurizer pressure to the P/T limit. This is a conservatism, because the RELAP delta-P between the Pressurizer and Reactor Vessel is much less than the PCF. The difference is typically around 30 psi.
2. The RELAP-based LTOP model uses, for Pressurizer pressure, the pressure at the midpoint of the top element in the pressurizer (typically the pressure at 2.03 ft below the top of the Pressurizer), which is generally within 1 psi of the lowest pressure existing in the Pressurizer.
3. The RELAP-based LTOP model uses, for RCS temperature, the cold leg segment directly downstream of the Steam Generator, to select an analytical PORV opening pressure from the first two columns of Table 7. This is the warmest location in the cold leg. The use of minimum Pressurizer pressure and maximum RCS temperature maximizes the PORV setpoint as read off the pressure vs. temperature LTOP curve.
4. The Fort Calhoun PORV is fully opened after 1.5 seconds after an open signal is generated. The RELAP code models the PORVs as starting to open after 1.5 seconds, and ramping to full open in an additional 0.5s. This avoids the need to model accurate flow characteristics while the valve is stroking open (expected to occur between 0.9s and 1.5s after signal generation). The ramp rate is used to avoid pressure oscillations that result when the PORV is modeled as opening instantaneously.
5. All the identified conservative assumptions from the NRC Safety Evaluation (Reference 4) were applied. These are:
    a. Initial conditions are the most limiting allowed by TSs.
    b. Only one (1) PORV is credited for relief.
    c. No credit is taken for letdown, RCS volume expansion, or RCS metal thermal inertia.
    d. Water-solid conditions in the PZR are assumed for mass injection events (the heat addition events, a RCP start, have an associated TS requiring a minimum steam volume).
    e. Full PZR heater capacity is assumed (backup and proportional).
    f. Decay heat is accounted for.
    g. PORV setpoint uncertainty is addressed.

h. Mass injection flow rates are conservatively bounded based on the combined flow from all available CCPs and HPSIs. The 1 HPSI cases use a 10% greater than design pump curve. The 2 HPSI cases use twice this flow rate.

7. The decay heat was particularly conservative, since a bounding value was used based on 20% greater than the value that would exist at the fastest possible cooldown to 314°F RCS temperature. This value was applied to all transients, even those initiated at 50°F. Note that one transient, Case 9, was run with an RCS temperature of 364°F. The decay heat is not as conservative for that case, but it still retains 5% conservatism. Case 9 has a very large margin to the P/T limit compared to other mass addition cases, so it is not as critical to model this case with as much conservatism.
8. The model requires certain operational restrictions identified in Table 2. Only 3 RCPs are assumed to operate while the LTOP system is enabled. Only 2 RCPs are assumed to be operating below 210°F actual temperature based on the Reference 8 PCFs (however, it is conservative for this analysis to assume that 3 RCPs are on, to maximize reactor vessel beltline pressure, so all mass addition cases assume 3 RCPS regardless of the initial temperature). Only 2 HPSI pumps are modeled as capable of operating once the LTOP system is enabled, and only 1 HPSI pump modeled below 320°F indicated RCS temperature, and no HPSI pumps are modeled below 270°F indicated. Shutdown cooling is not initiated until 350°F indicated. A minimum actual Pressurizer steam void of 40% is required prior to the start of the first RCP (indicated void must be 40% plus level uncertainty). The RCPs should only be started at pressures at least 61 psi below the LTOP setpoint in order to assure that the subsequent pressure rise will not cause a PORV lift.
9. The PORV flow rate was based on default RELAP flow equations. This is a best estimate flow, rather than a conservative flow, but it is not important to the final conclusions. The reason is that in all scenarios, at the moment that the PORV opens, the flow rate is well above that required to reduce the peak pressure (the pressure trace shows an immediate fall in pressure). Hence even large errors in the PORV flow rate would not change the peak pressure.
10. The PORV flow rate was based on a reduced area. Instead of the 0.94 inch^2 listed in Table 3, 0.77 inch^2 was used. This was done based on sensitivity runs that showed this area generated the rated flow of 110,220 lbm/hr at the rated pressure of 2385 psia. In addition, the PORV flow rates were made more conservative for non-choking cases by assuming a conservatively high backpressure equal to the quench tank relief valve setpoint plus 5 psi. This is especially conservative given that the initial PORV flow rate is the one that determines the peak pressure, and during the initial PORV operation the quench tank is not pressurized.
11. The RCS pressure drop loss coefficients were developed using design basis documents, and then a larger pressure drop across the Reactor Vessel outlet nozzles was added for additional conservatism. This increased pressure drop is greater than the CESEC (Reference 2) and MVCDL (Reference 6) models, but is consistent with a parallel RELAP model discussed in Reference 3. The RCPs' head was conservatively increased to generate the same design flow rate with this additional head loss.

12. For the start of a RCP, the conservative assumption was that the speed of the pump goes from 0 to full in 1 second (instead of the typical 30 seconds or so). The flow rate than increases according to pump homologous curves.
13. The volumes used in the RCS model were conservatively applied. Notably, a minimum volume primary side for the SGs was applied when conservative for mass injection cases, and a maximum volume primary side was applied when conservative for heat addition. The minimum volume was based on the design limit of 10% SG tube plugging, and the maximum volume was based on the unplugged SG volume.
14. The surface area of SGs was modeled as the area associated with zero tube plugging for the heat addition case. For the mass addition case, heat loss to the secondary side was conservatively neglected.
15. Mass addition cases include no credit for a steam volume that may exist in the Pressurizer. This is more realistic than conservative in that sensitivity runs show that the steam volume did not provide a benefit. The transient was delayed as the steam volume decreased to zero, and then continued as if the steam bubble had not been there.
16. Heat addition cases were run with extreme primary to secondary temperature differences that are not considered credible (the limiting case was a 314°F difference). This was done to avoid any operational restrictions based on primary to secondary temperature differences.
17. Heat addition cases were run with the conservative assumption of isothermal conditions in the SG secondary side. In reality, stratification on the SG shell side would cause only a portion of the SG water heat to be transmitted to the RCS.
18. Heat addition cases were run with conservative SG water masses. Although the majority of the secondary side of the SG will be steam, the model assumes the entire secondary side of the steam generator (4722 ft^3 as stated in Reference 1) is filled with hot water. Since such a large SG water mass is assumed, the heat energy stored in the SG metal mass other than the tube metal, that is, the exterior surface of the SG and non-modeled SG internals, is neglected for simplicity.
19. The safety injection water was conservatively treated. The density assumed is based on water that is just above freezing at 90 psia, but the enthalpy is based on 250°F water at 90 psia per Reference 2. This maximizes the energy and mass added to the RCS bounding all possible SI water conditions.

MODELING DISCUSSIONS

The Shutdown Cooling System, Decay Heat and Pressurizer Heaters

The NRC identified that the decay heat should be added to the analysis as an additional conservatism. The decay heat for all but the highest temperature scenarios is conservatively bounded by 25.7 MWt (for both cooldown and heat up) as described in Table 3 of Reference 1. This is conservatively 20% greater than the 1.4% value shown in CESEC (Reference 2), p. 28, for the most conservative model at 7,848 seconds after shutdown (.014*1530=21.4 MWt, 21.4*1.2=25.7 MW). The cooldown time is based on a cooldown from 532 °F at 100°F/hr, e.g., (532-314)/100 = 2.18 hours = 7848 seconds. The maximum assumed initial RCS temperature for all cases except Case 9 is less than 314°F so this is bounding. For example, a cooldown to 200°F would take 11,952 seconds.

Case 9 is not a limiting case, so less conservatism in the decay heat is acceptable, but analysis shows that the 25.7 MW value is conservative for Case 9 as well. Cooldown to 364°F would require (532-364)/100 = 1.68 hours = 6048 seconds. Page 28 of Reference 2 shows that the worst case decay heat model gives a power fraction of 1.6% at this time. That would be a decay heat of .016*1530MW = 24.5 MW, which is 5% below the value of 25.7 MW. Therefore, the use of 25.7 MW of decay heat is acceptable for all transients.

In order to envelope a potential future uprate from 1500 MWt to 1765 MWt core power, the decay heat of 25.7 was multiplied by the ratio 1765/1500 and rounded up to 30.3 MWt. This preserves all the conservatism discussed in the paragraph above.

The Pressurizer heat of 0.9 MW is added to the Pressurizer continuously after the event initiates to conservatively model the Pressurizer heaters as failed on full power.

<u>PORV Flow Rate</u>

The flow rate through the PORV is conservatively assumed to be zero until the time at which the PORV is fully opened per plant data (1.5 seconds after signal generation). Then the valve is modeled as though linearly ramped open from zero flow area to full flow area in 0.5 seconds. This additional time to ramp open the valve avoids a sudden pressure wave that results when the valve opening is modeled as instantaneous. Since the flow predicted during the ramping period is less than the full flow rate, this approach is conservative.

RELAP contains its own flow equations for flashing flow through a valve based on the flow data of Table 3. The flow equations are explained in the RELAP manual (Reference 5), Volume IV, Section 7.2. In general, the RELAP flow rates are more accurate but less conservative than typical relief valve sizing equations. A sensitivity analysis was run (mporv.txt) to discover that a flow area of 0.77 inch^2 (0.00535 ft^2) provides the flow rate of 110,220 lbm/hr at 2385 psia. This is slightly smaller than the Table 3 value of 0.94 inch^2. This area of 0.00535 ft^2 is used in the analysis.

The exact flow rate through the PORV is not critical to the analysis if the flow is sufficient to halt the pressure rise. That is, if as soon as the PORV is full open, the flow out of the PORV is greater than the RCS volumetric increase (due either to mass addition or heat expansion), then the pressure will fall. Small errors in the PORV flow rate will affect the rate of depressurization, but not the peak pressure. This analysis is only concerned with peak pressure.

For transients where the pressure is not immediately relieved at PORV lift, the RCS pressure will continue to rise until an equilibrium condition exists. Should this scenario occur, the accuracy of the PORV equation is important to the peak pressure. Conservatism is assured in this analysis by the use of a high backpressure of 90 psia as described in Table 3. As demonstrated in the Results section, all PORV lifts immediately reduce the transient pressure; hence modest changes in the PORV flow rates would not affect the peak pressures.

Reactor Coolant Pumps

Having RCPs running is conservative for the mass addition cases because they increase the pressure difference from the base of the Reactor Vessel to the top of the Pressurizer where the LTOP system gets its pressure input.

The RCP homologous curves are taken from CESEC (Reference 2), pp. 544 through 546. Homologous data is dimensionless pump data developed through the normalization of pump head, flow, torque and speed data by the pump rated head, flow, torque and speed. The normalized variables are flow ratio $\gamma = Q/Q_R$, speed ratio $\alpha = N/N_R$, head ratio $\eta = H/H_R$, and torque ratio $\beta = T/T_R$. These are mapped over four quadrants, where the normal quadrant is when the pump drives the flow (γ & $\alpha > 0$); dissipation is when the flow is going backwards against the spinning pump ($\gamma < 0$; $\alpha > 0$); turbine is when a reverse flow spins a pump backwards (γ & $\alpha < 0$); and reverse is reverse spinning of the pump against a forward flow rate ($\gamma > 0$; $\alpha < 0$). In point of fact, Fort Calhoun has an anti-reverse rotation lock (Reference 7, Section 2.2.3, pg. 3 of 10) and, in these scenarios, the flow never opposes a running pump, so only the normal quadrant applies to this analysis. Nevertheless, all four quadrants were entered into RELAP. The data is presented in Tables 9 and 10. Note: here the four quadrants are further divided into 8 regimes depending on whether the flow ratio or speed ratio is numerically larger. HAN is head H over speed α ratio in the Normal quadrant; BVR is torque ratio β over flow ratio γ in the Reverse quadrant; and so on. A negative HAN value indicates that the pump is spinning so slowly relative to flow that there is actually a head loss through the pump.

Pump rated head and rated flow were taken as the design values for the RCPs, which corresponds to the maximum efficiency of the RCP. An additional 10% was added to the rated flow (and head) values in order to provide an additional conservative margin to the modeling of RCS flow. The addition of this margin would tend to increase the pressurization rate during the heat addition transient. However, it was determined through sensitivity studies that minor changes in RCS flow rate have negligible effect upon the results of the heat addition analysis.

For pump start up, the pump speed ramp rate is conservatively bounded by a zero-to-full speed acceleration in just 1 second (typical times are on the order of 30 seconds). This manual acceleration means that the pump inertia entered in the RELAP deck is arbitrary. Although the pump reaches full rpm speed in 1 second, the system's inertia will make the RCS flow rate take an additional time period. This is conservative due to the 10% higher head and fast rpm acceleration. Since the pump model imposes a linear acceleration from zero to full rpm in 1 second, all the model inputs for pump rpm, rotational inertia, and torque are not used, and the data supplied to the model is arbitrary. That is, the model requires inputs for pump rpm, torque and moment of inertia, but the values are not used and are not based on Fort Calhoun RCPs.

As noted above, Fort Calhoun RCPs have anti-reverse-rotation devices, so all the secured RCPs (which will all have reverse flow) are modeled with a loss coefficient.

The heat input from each pump is modeled with a 1.4 MWt heat slab that is on whenever the pump is running.

Flow Resistances and further RCP Conservatism

Attachment 2 of Reference 1 presented the development of flow resistances based primarily on CESEC (Reference 2) and MVCDL (Reference 6) pressure drops. Benchmarking indicated good agreement between the RELAP model and these sources; however, an additional independent RELAP model described in Reference 1 predicted a larger pressure drop across the hot leg nozzle. It was conservative to model this larger pressure drop, because it increases the beltline pressure in the reactor vessel relative to the Pressurizer pressure. Therefore the reactor vessel hot leg nozzle resistance was made greater to match the referenced pressure drop.

When the higher flow losses were included in this LTOP model, the calculated flow rate was less than the 198,000 gpm flow desired. It was necessary to increase the rated RCP head again (from 273.02 to 290.0 ft) to generate a benchmark full flow case MFULFLO.TXT at 198,000 gpm. (Note: the value of 198,000 gpm is based on enveloping the MVCDL (Reference 6) item 11g flow rate of 196,000 gpm, and is slightly different from the model of reference 2 which used 198,584 gpm.) At that point, the Reference 1 model was judged to be in sufficient agreement with other Fort Calhoun flow models.

Mass Addition Cases – Initial Pressure

Exploratory runs demonstrate that the initial pressure does not have a significant impact on the peak pressure of a mass addition transient so long as the Pressurizer is water-solid at the time of PORV lift. This is because the mass addition inlet flow rate is a function of RCS pressure (or a constant if just the CCPs) and is not a function of time. Whether the system is initially just below the PORV setpoint pressure, or whether the system ramps up to the PORV setpoint from some lower initial value, does not affect the pressure rise rate during the period between reaching the PORV setpoint and the 1.5 second delay time of the PORV opening.

Mass Addition Cases – Initial Pressurizer Bubble

Exploratory runs demonstrate that it is difficult to credit a steam bubble in the Pressurizer with assisting mass addition event mitigation. The RELAP model shows that when a bubble is present, the pressure starts to rise immediately following the start of mass injection. However, when the pressure rises sufficiently, the Pressurizer bubble collapses at a rate that offsets the mass addition, and pressure is constant. Pressure does not continue to rise until after the bubble is completely gone. Hence if the initial pressure is sufficiently below the PORV lift pressure, the bubble vanishes and the peak pressure is the same as if the initial condition was water solid.

This phenomenon is particularly true for LTOP events because of the low density of the steam in the Pressurizer (relative to the steam density at 2100 psia). This low mass bubble is easier to condense than when the plant is operating at power. The condition of a water-solid lift is also specified in the NRC SER (Reference 4).

Mass Addition Events – SI Injection Temperature

It is difficult to identify the worst case temperature for SI injection. The volumetric flow rate is constant, which means the mass flow rate is greater for colder temperatures. However, the injection water enthalpy is greater for higher temperatures. In order to assure a conservative choice, the model uses a mass flow rate appropriate to water that is just a few degrees above freezing (62.42 lbm/ft^3 based on 32.02°F, 90 psia water), and an enthalpy associated with 250°F, 90 psia water (Reference 2). This is done by using the greater density when calculating the mass injection flow rate in lbm/s, but specifying 250°F, 90 psia water in the RELAP components for SI injection.

Heat Addition Events -- Effect of Temperature Rise on PORV Opening Setpoint

The effect of temperature rise during heat addition events can have a critical impact on the LTOP curve requirements if the PORV is relied upon for transient mitigation. The effect can best be explained by reviewing a typical heat addition analysis scenario, Case hp509s36. In this scenario, the initial conditions are a Reactor Vessel at 50°F, a Steam Generator at 364°F, and no RCS flow. The P/T limit at 50°F is 498 psia. A RCP is suddenly started, causing an extreme reverse heat transfer. The RCS rapidly heats up to over 200°F by just 40 seconds. Since the LTOP system sets the PORV lift setpoint as a function of RCS temperature, the PORV will not lift until the setpoint associated with 200°F. Meanwhile, the Reactor Vessel temperature at 1/4th thickness (the depth of a hypothesized crack) will still be close to 50°F. This means, in effect, if pressure rises to the LTOP setpoint for this scenario, the LTOP setpoint at 200°F, which is seen to be 600 psia in Table 7 (accounting for uncertainties), will be insufficient to protect against the 50°F P/T limit of 498 psia in Table 6.

The situation can be made even worse by selection of a "worst size bubble." A larger bubble will slow down the transient. Due to very conservative assumptions about decay heat, the RCS warms up rapidly while the bubble is collapsing. It is possible to postulate a bubble size for the above scenario that does not collapse until the RCS reaches 300°F.

In order to avoid a significant restriction on the LTOP curve, the heat addition transients must be mitigated before the Pressurizer steam void is lost. This keeps the RCS pressure very close to the initial pressure, and does not stress the reactor vessel. This is done by requiring a large void prior to the first RCP start via a TS requirement, and determining that the void will not entirely collapse by the time that the Steam Generator and RCS temperatures equilibrate. After equilibration, the transient is effectively mitigated, with very little pressure rise.

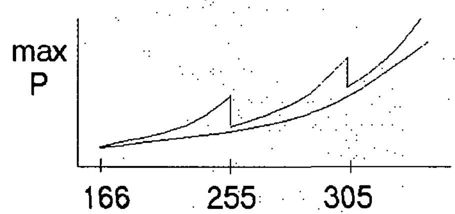
Heat Addition Cases – Initial Conditions

Heat addition cases are primarily associated with cooldown transients. A conservative bounding assumption is that once the plant is placed on shutdown cooling, the Steam

Generators maintain the previous temperature (364°F) while the Reactor Vessel, Hot Leg, and Cold Leg are cooled. Should a RCP suddenly start up, the hot Steam Generator serves as a heat source and rapidly expands the RCS water as specific volume increases. In accordance with NRC guidance, the pump heat, Pressurizer heaters, and decay heat are all additional heat sources. In this model, the secondary side is conservatively modeled as isothermal water filling the full volume of the Steam Generator to maximize the latent heat delivered to the RCS.

Setpoint Curve Shape

There are distinct temperatures where the mass addition case can suddenly become more limiting due to additional mass injection. Specifically, at 255°F actual RCS T, the injected flow rate increases from that associated with 3 CCPs to that associated with 3 CCPs and 1 HPSI. At 305°F, the flow rate again increases, this time to that associated with 3 CCPs and 2 HPSIs. A jagged LTOP curve could have been used in response to these sudden jumps in mass addition, but it would have made the circuitry function more complicated. Instead, the LTOP setpoint curve was developed as a conservatively lower smooth curve. The curve at right shows conceptually the "tightest" LTOP setpoint curve allowed by analysis compared to the lower smooth curve used. Since the margin is smallest between the curves at 166°F, 255°F, and 305°F, these will be critical temperatures at which to simulate mass addition events.



VII. CASE RUN MATRIX

For all cases

A bounding decay heat of 30.3 MWt is used per Table 3 (no credit is taken for the SDC system). This is especially conservative for heat up cases, but it allows the below scenarios to bound both heat up and cooldown. The Pressurizer heaters are assumed on (0.9 MWt to Pressurizer water). Each running RCP contributes a heat input of 1.4 MWt.

The initial pressure is assigned to all components. During the first 2 seconds of analysis, the Pressurizer pressure decreases and the Reactor Vessel pressure increases to a new steady state based on elevation changes and RCP flow. Hence the transients typically start with a Pressurizer pressure that is a few psi below the tabular value.

For all Mass Addition Cases (1 through 9)

SI flow and charging flow are conservatively assumed to be at 250°F, yet the mass flow rate in lbm/s is that associated with 32.02°F water. This conservatively bounds any injection temperature and avoids the need to run repeated cases at different injection temperatures to find a worst-case combination of energy and density. Three RCPs are assumed to be running to maximize the pressure differential from the Reactor Vessel bottom and the Pressurizer (where the LTOP pressure input is located). Since 3 RCPs are running and the unit is at zero power, the Steam Generators would be at the same temperature as the RCS. Modeling the SG secondary side would tend to reduce any temperature increase associated with decay heat or warm SI injection, therefore the SG tubes are conservatively modeled as insulated, i.e., there is no model of the secondary side water. The minimum SG volume is used to maximize the mass addition rate as a percentage of total RCS volume. No credit is taken for Pressurizer bubbles, because sensitivity analyses show that the bubbles collapse before the pressure rises to the PORV setpoint. Other assumptions are as in Section VI., including no credit for RCS expansion, letdown, or heat absorption in metal.

A full deck for Case 9 is included in Attachment 2.

For all Heat Addition Cases (10 through 14)
The heat addition cases include the secondary side of the Steam Generator and the SG tubes. This involves more cards to be added to each input deck.

A full deck for Case 10 is included in Attachment 2.

Table 10: Case Run Matrix. Cases 1 through 8 are not changed from Reference 1, and are therefore not re-run as part of this effort.

Case, File	Tinitial actual (°F)	Pinitial actual (psia)	SI Flow	RCPs	SG T (°F)	Pressurizer Bubble	SG Volume
1 M80BASR	80	200	132 gpm	3		0	Min
2 M50P2R	50	200	132 gpm	3		0	Min
3 M50P4R	50	400	132 gpm	3		0	Min
4 M50BR	50	200	132 gpm	3		6%	Min
5 M166P2R	166	200	132 gpm	3		0	Min
6 M210P2R	210	200	132 gpm	3		0	Min
7 M255P2R	255	200	132 gpm +1 HPSI	3		0	Min
8 M305P2R	305	200	132 gpm +2 HPSI	3		0	Min
9 M364P2R	364	200	132 gpm + 2 HPSI	3		0	Min
10 HP509S36	50	170	0	1 starts	364	40%	Max
11 HP503S36	50	390	0	1 starts	364	40%	Max
11a HP535S36*	50	350	0	1 starts	364	40%	Max
12 HP504S36**	50	390	0	1 starts	364	40%	Max
13 HP166S36.	166	170	0	1 starts	364	40%	Max
14 HP290S36	290	390	0	1 starts	364	40%	Max

* Differs from Case 11 by using a more realistic initial pressure
** Differs from Case 11 by forcing the PORV to open

VIII. RESULTS

Since Reference 1 provided a detailed description of each case, and this report only adjusts the model without substantially altering the outcome, the results are summarized briefly. The conclusions section discusses the impact of the new SG temperature relative to the Reference 1 results.

Case 1: Mass addition, $T_i = 80^oF$, $P_i = 200$ psia (M80BASR.TXT of Reference 1)
Case 1 of Reference 1 was a benchmarking case. It is not discussed here because it is not impacted by changes in the SG temperature, and Case 1 is not one of the limiting cases for LTOP setpoint development.

Case 2: Mass addition, $T_i = 50^oF$, $P_i = 200$ psia (M50P2R, Figure 5)
This case differs from Case 1 in the use of stronger RCPs that resulted from a Reference 1 model modification to match other Fort Calhoun flow models. Case 2 also uses a lower temperature, which has a lower associated P/T limit of 498 psia making it more conservative. Although it is not impacted by the change in Steam Generator temperature at LTOP initiation, it is summarized briefly here since it is one of the cases that determines that the setpoint curve of Table 1 and the flow capacity of a PORV are acceptable to mitigate LTOP transients.

The model predicts a peak Pressurizer pressure of 482.74 psia, which is below the P/T limit of 498 psia at the Pressurizer.

The peak mass flow rate out of the PORV is shown in the output file to be 50.14 lbm/s. At 50^oF, the density of water is about 62.5 lbm/ft^3. Therefore the flow rate is:

$$50.14 \text{ lbm/s}*1/62.5 \text{ lbm/ft}^3*7.481 \text{gal/ft}^3*60 \text{ s/min} = 360 \text{ gpm}$$

This is well above the injection flow rate of 132 gpm. As noted in Reference 1, modest errors in PORV flow rate may affect the depressurization rate, but they have no impact on the peak pressure. Note also that this flow is water rather than steam, so the mass flow rate in lbm/hr is greater than the reference steam mass flow rate of Assumption 10.

Case 3: Mass addition, $T_i = 50^oF$, $P_i = 400$ psia (M50P4R, Figure 6)
This case differs from Case 2 in the initial pressure only. It was run to demonstrate that the peak pressure is independent of initial pressure. The results verify this expectation. The peak Pressurizer pressure is 482.09 psia (compared to Case 2 result of 482.74 psia). The difference in the peak pressure is insignificant. It can be explained by the conservative analysis assumption of pressurizer heaters and decay heat providing energy to the RCS. The higher initial pressure results in a faster PORV lift, so there is less time for this energy addition in Case 3.

Case 4: Mass addition, $T_i = 50^oF$, $P_i = 200$ psia, 6% Steam Void (M50BR, Figure 7)
This case differs from Case 2 in that a bubble exists at the start time. It was run to demonstrate that the pressure is near constant while any existing bubble collapses, and

thereafter the pressure rise and peak pressure are nearly the same as the water solid case. A small bubble of 6% was specified simply to speed up the run. A larger bubble would have taken longer to collapse without changing the peak pressure significantly.

As in Reference 1, the results show that the Pressurizer pressure rises only modestly before the bubble collapse offsets the mass injection. For the next few minutes, the pressure is constant while the bubble collapses. When the bubble vanishes and the RCS goes water solid, the pressure rises at nearly the same linear rate as in Cases 2 and 3. The PORV opens at just about the identical pressure. The peak pressure is 485.85 psia, which is not notably different from the Case 2 value of 482.74 or the Case 3 value of 482.09 psia.

Case 5: Mass addition, T_i = 166°F, P_i = 200 psia (M166P2R, Figure 8)
This case differs from Case 2 in having a higher initial temperature. The value of 166°F is slightly more conservative than using the value of 164°F where the P/T limit starts to increase. The peak Pressurizer pressure is compared to the P/T criteria of 525 psia, which is the high end of the flat portion of the P/T curve at 164°F.

The results show a peak Pressurizer pressure of 507.96 psia. Compared to Case 2 (peak pressure of 482.74 psia), this is 25 psi higher for 116°F warmer conditions. There are two reasons for this increase in overshoot.

The first is that the change in volume for each Btu of energy addition is faster for water at 166°F than it is at 50°F. This is shown in Figure 4 at right, recognizing that the heat capacity, or dT/dh, is pretty close to constant over this temperature range. Thus the decay heat addition has a bigger impact for Case 5.

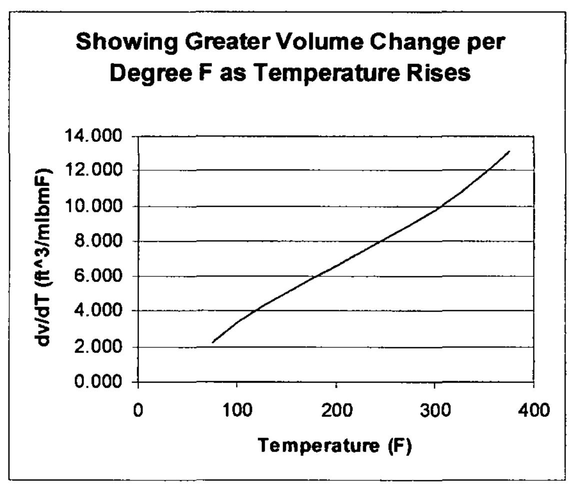


Figure 4: dV/dT versus T

The second is that as the transient continues, the RCS warms up just a little due to the assumed high decay heat. At the time of PORV lift, the RCS is at 167.2°F. The LTOP curve at this temperature is 467 psia, rather than the 459 psia for Case 2. Therefore 8 psi of the 25 psi greater overshoot is due to the LTOP curve, and 17 psi of the increased overshoot is due to the dv/dT increase for warmer water.

Case 6: Mass addition, T_i = 210°F, P_i = 200 psia (M210P2R, Figure 9)
Cases 2 and 5 bound the temperature range of up to 255°F, the lowest temperature for which a HPSI pump may be enabled. At initial temperatures over 166°F, the gap between the LTOP curve and the P-T curve increases monotonically. The overshoot will be nearly identical because the heat and injection flow are independent of RCS pressure. The small 17 psi increase in overshoot due to Case 5 being 116°F warmer than Case 2 is

insignificant compared to the growing margin between LTOP curve and P/T limit (at 160°F, the margin is 525-459 = 66 psi; at 250°F the margin is 1172-920 = 252 psi).

This Case 6 is run in the midpoint of the range 166 to 255°F to verify this reasoning. The result is a peak Pressurizer pressure of 690.91 psia while the P/T limit is 794 psia, so the margin is over 100 psi.

Case 7: Mass addition, T_i = 255°F, P_i = 200 psia (M255P2R, Figure 10)
This case differs from Cases 2 through 5 in that, at this higher initial temperature, a HPSI pump may be enabled. At t=20 seconds, the 250°F mass injection, decay heat, RCP heat, and Pressurizer heater heat begins. The injection flow rate is given by Table 4 and is initially about 413 gpm. The injection flow rate decreases as pressure rises to about 215 gpm at the PORV lift point.

The peak pressure is 1067.1 psia, which is comfortably below the P/T limit for 255°F of 1216 psia.

This is the first case since Case 2 that the PORV flow rate is significantly different because this is the first case with a different driving pressure. The computer output shows the peak PORV flow rate is 76.2 lbm/s. At 255°F, the density of water is 58.7 lbm/ft^3. The volumetric flow rate is therefore:

$$76.2 \text{ lbm/s} * 1/58.7 \text{ lbm/ft}^3 * 7.481 \text{gal/ft}^3 * 60 \text{ s/min} = 582 \text{ gpm}$$

This is well above the injection flow rate of 215 gpm at this pressure. As expected, modest errors in PORV flow rate may affect the depressurization rate, but they have no impact on the peak pressure.

Higher temperature, 1 HPSI transients will be bounded by this transient. At higher temperatures, the PORV setpoint might be higher, but so is the P/T limit. The margin between the LTOP curve and the P-T limit grows monotonically. The overshoot will be less at higher temperatures because the associated higher pressures will result in less injection flow.

Case 8: Mass addition, T_i = 305°F, P_i = 200 psia (M305P2R, Figure 11)
This case differs from Cases 2 through 6 in that, at this higher initial temperature, two HPSI pumps may be enabled. At t=20 seconds, the 250°F mass injection, decay heat, RCP heat, and Pressurizer heater heat begins.

The peak pressure is 1522.9 psia, which is comfortably below the P/T limit for 305°F of 1892 psia. The margin is 1892-1522.9 = 359 psi.

The PORV flow rate is larger than in Case 6 due to a greater driving pressure. The computer output shows the peak PORV flow rate is 97.6 lbm/s. At 305°F, the density of water is 57.2 lbm/ft^3. The volumetric flow rate is therefore:

97.6 lbm/s*1/57.2 lbm/ft^3*7.481gal/ft^3*60 s/min = 766 gpm

This is well above that needed to offset the injection and decay heat. As noted, the injection flow rate is limited to the 132 gpm CCPs since the pressure is greater than the HPSI pump shutoff.

Case 9: Mass addition, T_i = 364°F, P_i = 200 psia (M364P2R, Figure 12)
Higher temperature, 2 HPSI transients will be bounded by Case 8. The gap between the LTOP curve and the P-T limit grows monotonically. The overshoot will be less at higher temperatures because the associated higher pressures will result in less injection flow. To demonstrate this, Case 9 was run at 364°F, the highest possible RCS temperature based on initiating LTOP control at 350°F indicated, plus 14°F error in indicated temperature.

This case is the first to be changed from Reference 1 (Cases 1 through 8, although summarized here above, were not rerun because nothing had changed in their scenarios). The first change relates to the LTOP curve. Previously, in Reference 1, no RCS temperature ever exceeded 314°F, so the curve stopped at shortly above that point. Now the curve is adjusted to match the final two rows of Table 7 (the horizontal extrapolation seen in Figure 3). The change is to the following two cards. (Note: making the final card 400°F instead of 364°F just assures that the curve extends beyond any temperature that may result here; it has no impact on the PORV lift behavior up to 364°F.)

```
20220119   340.0    1809.1
20220120   400.0    1809.1
```

The second change is to make the initial temperature 364°F instead of 314°F in all the RCS and secondary side volumes. The following cards are therefore changed from the Reference 1 case 9. Previously, the values of 364 were 314.

```
* input change for m364p2
* Change initial P and T (P = 200, T = 364)
2001201 3 200. 364.0 0 0 0 2
2100200   3   200. 364.0
2201201 3 200. 364.0 0 0 0,6
2300200   3   200. 364.0
2401201 3 200. 364.0 0 0 0,2
2500200   3   200. 364.0
2601201 3 200. 364.0 0 0 0,2
3000200   3   200. 364.0
3010200   3   200. 364.0
4001201 3 200. 364.0 0 0 0,10
4101201   3   200.  364.00   0.  0 0,5
4101202   3   200.  364.00   0.  0 0,6
3020200   3   200. 364.0
3100200   3   200. 364.0
3201201 3 200. 364.0 0 0 0,6
3300200   3   200. 364.0
3401201 3 200. 364.0 0 0 0,2
3500200   3   200. 364.0
3601201 3 200. 364.0 0 0 0,2
3701201 3 200. 364.0 0 0 0,2
```

```
3800200    3    200. 364.0
3901201 3 200. 364.0 0 0 0,2
1000200    3    200. 364.0
1101201 3 200. 364.0 0 0 0,2
1200200    3    200. 364.0
1301201 3 200. 364.0 0 0 0,3
1500200    3    200. 364.0
1600200    3    200. 364.0
10200 3 200. 364.0 0 0
20200 3 200. 364.0 0 0
30200 3 200. 364.0
11000401   364.0  3
11100401   364.0  3
11200401   364.0  3
11300401   364.0  3
```

The peak pressure is 1847 psia compared to a P/T limit of 2918 psia. This is based on the P/T curve value of 2918 psia at an indicated 354°F (340°F actual after the worst case indication uncertainty of 14°F is applied). Based on this consideration, the pressure margin is over 1000 psi. A lower limit is the 110% of design pressure, or 2750 psia per the USAR section 14.9 (Reference 9). There is still a 903 psia margin to this limit. This is a larger margin than Case 8, and verifies the expectation that Case 8 would be more limiting.

Case 10: Heat addition, T_i = 50°F, T-SG = 364°F, P_i = 170 psia (HP509S36, Figure 13)
In the heat addition cases, there is initially no RCP running. A brief initial period is allowed to reach a steady state as the elevation differences cause pressures to adjust. At 10 seconds, the single RCP is started. The pressure is 170 psia primary and secondary sides to provide subcooling margin (the saturation pressure at 364°F is 161 psia).

The cards changed from Reference 1's Case 10 relate to the LTOP curve and the initial conditions. The LTOP curve is changed only at the high temperatures to make sure it extends to 364°F as in case 9. Those changes are identical to Case 9:

```
20220119   340.0    1809.1
20220120   400.0    1809.1
```

The additional changes are to set the initial steam generator temperature to 364°F instead of 314°F (this includes both primary side - volumes 220 and 320 - and secondary side - volumes 510 and 520 - and heat slabs card 12001401). In order to prevent initial boiling inside the steam generator tubes, the RCS and Pressurizer pressure had to be increased to 170 psia. The changes are as follows:

```
*initial conditions
* Ti set to 50 F, Pi set to 170 psia
2001201 3 170.0 50.0 0 0 0 2
2100200    3    170.0 50.0
2300200    3    170.0 50.0
2401201 3 170.0 50.0 0 0 0,2
```

```
2500200    3    170.0 50.0
2601201 3 170.0 50.0 0 0 0,2
3000200    3    170.0 50.0
3010200    3    170.0 50.0
4001201 3 170.0 50.0 0 0 0,10
3020200    3    170.0 50.0
3100200    3    170.0 50.0
3300200    3    170.0 50.0
3401201 3 170.0 50.0 0 0 0,2
3500200    3    170.0 50.0
3601201 3 170.0 50.0 0 0 0,2
3701201 3 170.0 50.0 0 0 0,2
3800200    3    170.0 50.0
3901201 3 170.0 50.0 0 0 0,2
1000200    3    170.0 50.0
1101201 3 170.0 50.0 0 0 0,2
1200200    3    170.0 50.0
1301201 3 170.0 50.0 0 0 0,3
1500200    3    170.0 50.0
1600200    3    170.0 50.0
10200 3 170.0 50.0
20200 3 170.0 50.0 0 0
30200 3 170.0 50.0
4101201    2    170.    0.0     0.   0 0,5
4101202    2    170.    1.0     0.   0 0,6
2201201 3 170. 364.0 0 0 0,6
3201201 3 170. 364.0 0 0 0,6
5101201 3 170. 364.0 0 0 0  3
5201201 3 170. 364.0 0 0 0  3
12001401    364.0  9
```

In the heat addition cases, the goal is not a peak pressure limit, but rather the demonstration of a minor pressure rise and a remaining steam void after the SG and RCS temperatures have equilibrated. The transients are run out to 610 seconds, or ten minutes after the RCP is started.

Case 10 is the most limiting heat addition case in terms of assuring a remaining steam bubble. This is the lowest credible temperature and pressure for a RCP start, coupled with the highest SG temperature and decay heat. With this high initial delta-T of 314°F, there is an initial energy input of 1100 MWs a few seconds after cold water starts to flow into the hot Steam Generator. Note: Figure 13 shows just the energy from the Steam Generators; an additional heat of about 33 MWs comes from the conservative decay heat (30.3 MW), the pressurizer heaters (0.9 MW), and the RCP itself (1.4MW). The RCS rapidly heats up until at near 200 seconds the RCS and SG water have equilibrated. Heat continues to be added due to the analysis conservatisms of no shut down cooling and loss of pressurizer heater control, but the heat addition rate is modest after this time.

During the RCS temperature rise, the steam bubble is collapsing. The bubble is initially 40% of 940 ft^3, or 376 ft^3. After 610 seconds, the bubble has collapsed to 75 ft^3. The transient has been mitigated, but there is still an imbalance in the heat input due to the conservative methodology. Therefore the bubble size is still slowly shrinking after the RCS and the SGs have equilibrated.

The pressure plot, as seen in Figure 13, is very stable for this transient. When the RCP is started at 10 seconds, there is an initial Pressurizer pressure decrease due to a Bernoulli effect at the surgeline branch, i.e., the velocity causes the hotleg pressure to decrease sucking in water from the surgeline. Pressure quickly rises as the heat from the SG causes the RCS to expand and flow into the Pressurizer, but after just a small pressure rise, the low-density bubble starts to collapse and maintains the pressure at a nearly constant value. The peak pressure is 189 psia, so pressure only rises 19 psi above the initial value.

<u>Case 11: Heat addition, T_i = 50°F, T-SG = 364°F, P_i = 390 psia (HP503S36, Figure 14)</u>
This case differs from Case 10 only in the initial pressure. The following cards are changed from Case 10:

```
*initial conditions
* Ti set to 50 F, Pi set to 390 psia
2001201 3 390.0 50.0 0 0 0 2
2100200   3   390.0 50.0
2300200   3   390.0 50.0
2401201 3 390.0 50.0 0 0 0,2
2500200   3   390.0 50.0
2601201 3 390.0 50.0 0 0 0,2
3000200   3   390.0 50.0
3010200   3   390.0 50.0
4001201 3 390.0 50.0 0 0 0,10
3020200   3   390.0 50.0
3100200   3   390.0 50.0
3300200   3   390.0 50.0
3401201 3 390.0 50.0 0 0 0,2
3500200   3   390.0 50.0
3601201 3 390.0 50.0 0 0 0,2
3701201 3 390.0 50.0 0 0 0,2
3800200   3   390.0 50.0
3901201 3 390.0 50.0 0 0 0,2
1000200   3   390.0 50.0
1101201 3 390.0 50.0 0 0 0,2
1200200   3   390.0 50.0
1301201 3 390.0 50.0 0 0 0,3
1500200   3   390.0 50.0
1600200   3   390.0 50.0
10200 3 390.0 50.0
20200 3 390.0 50.0 0 0
30200 3 390.0 50.0
4101201   2   390.   0.0    0.  0 0,5
4101202   2   390.   1.0    0.  0 0,6
2201201 3 390. 364.0 0 0 0,6
3201201 3 390. 364.0 0 0 0,6
5101201 3 390. 364.0 0 0 0  3
5201201 3 390. 364.0 0 0 0  3
```

Once again, with the high initial delta-T of 314°F, there is an initial energy input of around 1100 MWs as cold water flows into the hot Steam Generator. The RCS rapidly heats up and the energy input falls quickly.

During the RCS temperature rise, the steam bubble is collapsing (see Figure 16), but it collapses slightly more slowly due to the increased mass of steam resulting from higher initial density. The bubble is now 76.1 ft^3 after ten minutes compared to 75.3 ft^3 in case 10. This case demonstrates that lower initial pressures are limiting, because they imply less mass in the steam phase, and therefore bubbles are easier to collapse. However, the sensitivity is slight.

In this event, the higher density bubble pressurizes more before condensation matches the RCS expansion. In point of fact, the Pressurizer pressure rises 72 psi from 390 psia initially to 462 psia. The reason that the PORV does not open at the 459 psia setpoint is that the RCS heats up so dramatically, that when RCS pressure crosses the lift pressure of 459 psia at about 40 seconds, the RCS temperature in volume 306 is now high enough to change the lift pressure in the LTOP logic. The run output shows the RCS temperature in volume 306 is about 205°F by 40 seconds. At that temperature, the PORV lift pressure in Table 7 is over 600 psia.

This extreme case (314°F between SG and RCS) predicts a 72 psi pressure rise. Thus so long as the indicated RCS pressure is more than 72 psi below the LTOP curve, it is safe to start an RCP without lifting a PORV. This value of 72 psi is larger than the value of 61 psi developed in Reference 1, Case 11. The reason for the larger required margin is due to the possibility of a larger temperature differential.

Case 11a: Heat addition, T_i = 50°F, T-SG = 364°F, P_i = 350 psia (HP535s36, Figure 14a)
The result of Case 11 implies a maximum 72 psi increase in pressure when an RCP is started. This is not a desirable result, since the 61 psi value from Reference 1 is used in creating Curve 3 of TDB III.7.a (Reference 13). An additional case is run to justify maintaining 61 psi as a maximum overshoot. The basis for rerunning this case is that there is no need to model this transient with an initial pressure of 390 psia, as was done in Case 11. The plant is limited to a maximum pressure of 318.5 psia by Curve 3 of Reference 13 when starting an RCP at these low temperatures. Moreover, the plant is actually limited to even a lower pressure, since the plant is on shutdown cooling prior to RCP start. Startup procedure OP-2A (Reference 15) directs the operators to jog the pumps while still on shutdown cooling, and there could be no large SG to RCS temperature difference without being on shutdown cooling The maximum allowed pressure for shutdown cooling is currently 250 psia (Reference 14), but this is being revised upward to 300 psia.

At these lower initial pressures, the steam bubble is less dense and more readily condenses to hold down the pressure rise. Therefore the overshoot will be less than the 72 psi found in Case 11.

Case 11a is therefore run with initial pressure equal to the maximum indicated pressure allowed by procedure, which will be 300 psia after Reference 14 is revised, plus the 50 psi error in indicated pressure per Table 3. Thus case hp535s36 is run with conditions very similar to Case 11, but the initial pressure is 350 psia instead of 390 psia. The changes from Case 10 are as follows:

```
*initial conditions
* change for HP535s36: change Ti to 50, Pi to 350.0
2001201 3 350.0 50.0 0 0 0 2
2100200    3   350.0 50.0
2300200    3   350.0 50.0
2401201 3 350.0 50.0 0 0 0,2
2500200    3   350.0 50.0
2601201 3 350.0 50.0 0 0 0,2
3000200    3   350.0 50.0
3010200    3   350.0 50.0
4001201 3 350.0 50.0 0 0 0,10
3020200    3   350.0 50.0
3100200    3   350.0 50.0
3300200    3   350.0 50.0
3401201 3 350.0 50.0 0 0 0,2
3500200    3   350.0 50.0
3601201 3 350.0 50.0 0 0 0,2
3701201 3 350.0 50.0 0 0 0,2
3800200    3   350.0 50.0
3901201 3 350.0 50.0 0 0 0,2
1000200    3   350.0 50.0
1101201 3 350.0 50.0 0 0 0,2
1200200    3   350.0 50.0
1301201 3 350.0 50.0 0 0 0,3
1500200    3   350.0 50.0
1600200    3   350.0 50.0
10200 3 350.0 50.0
20200 3 350.0 50.0 0 0
30200 3 350.0 50.0
11000401    50.0  3
11100401    50.0  3
11200401    50.0  3
11300401    50.0  3
2201201 3 350. 364.0 0 0 0,6
3201201 3 350. 364.0 0 0 0,6
5101201 3 350. 364.0 0 0 0  3
5201201 3 350. 364.0 0 0 0  3
```

The results of the Case 11a run is a peak pressure of 411 psia, which is a pressure rise of 61 psi, just as in Reference 1. The higher SG temperature of this calculation (364°F versus 314°F) is offset by the lower initial pressure (350 psia versus 390 psia) in terms of total pressure rise. The use of 350 psia is justified by Fort Calhoun procedures.

Case 12: Heat addition, T_i = 50°F, T-SG = 364°F, P_i = 390 psia (HP504S36, Figure 15)

Case 11 demonstrated that some pressure rise can occur prior to the bubble collapse offsetting the RCS expansion. This means there is a possibility of lifting the PORV. This Case 12 scenario is run to demonstrate that if the PORV lifts, the transient is still successfully mitigated. In order to force the PORV to open, the LTOP setpoint curve is changed to be a constant 459 psia independent of the RCS temperature. This will assure a lift at around 40 seconds when the heat input is still very large. Hence the only change from Case 11 is to change the LTOP lift pressure curve to a constant 459 psia over all temperatures.

```
* LTOP Analysis Curve - forced to 459 to make sure PORV opens
20220100    reac-t
20220101    0.0        459.0
20220102    160.0      459.0
20220103    170.0      459.0
20220104    180.0      459.0
20220105    190.0      459.0
20220106    200.0      459.0
20220107    210.0      459.0
20220108    220.0      459.0
20220109    230.0      459.0
20220110    240.0      459.0
20220111    250.0      459.0
20220112    260.0     459.0
20220113    270.0     459.0
20220114    280.0     459.0
20220115    290.0     459.0
20220116    300.0     459.0
20220117    310.0     459.0
20220118    320.0     459.0
20220119    340.0     459.1
20220120    400.0     459.1
```

Figure 15 shows that the PORV lift does not impact the heat addition significantly. The slight changes in RCS pressure do not impact any of the heat sources. Figure 15 shows that the pressure does exceed the setpoint of 459 psia but that pressurization rate is relatively low, such that the peak pressure is only 461 psia when the PORV opens. At that point, the PORV is relieving steam, which is a large volumetric advantage relative to water. The pressure drops suddenly from the peak to a stable pressure where Pressurizer fluid can now flash to steam. Figure 15 shows that the bubble does not bleed off after the PORV opens, but rather slowly increases in size due to depressurization and flashing. There is a sizable bubble of 170 ft^3 at 610 seconds when the unusual heat addition has been mitigated.

Note that the simple PORV model does not include reseat characteristics. That is because the model's purpose is to predict the ability to mitigate the LTOP event, and that can be demonstrated by the successful first lift. The expectation is that the PORV would reseat and a more constant pressure and bubble would be maintained. However, the conclusion of this report, that the LTOP system successfully prevents overpressure, is demonstrated without modeling PORV reseat.

Case 13: Heat addition, T_i = 166°F, T-SG = 364°F, P_i = 170 psia (HP166S36, Figure 16)
This case differs from the previous heat addition transients in that a higher RCS temperature is assumed. The changes from Reference 1 Case 13 are in the LTOP curve and initial conditions. The cards changed are as follows:

```
20220119    340.0     1809.1
20220120    400.0     1809.1
2201201 3 170. 364.0 0 0 0,6
3201201 3 170. 364.0 0 0 0,6
```

```
5101201 3 170. 364.0 0 0 0  3
5201201 3 170. 364.0 0 0 0  3
4101201   2   170.   0.0    0.  0 0,5
4101202   2   170.   1.0    0.  0 0,6
12001401   364.0  9
* Change for HP166S30: change Ti to 166 Pi is 170
2001201 3 170.0 166.0 0 0 0 2
2100200   3   170.0 166.0
2300200   3   170.0 166.0
2401201 3 170.0 166.0 0 0 0,2
2500200   3   170.0 166.0
2601201 3 170.0 166.0 0 0 0,2
3000200   3   170.0 166.0
3010200   3   170.0 166.0
4001201 3 170.0 166.0 0 0 0,10
3020200   3   170.0 166.0
3100200   3   170.0 166.0
3300200   3   170.0 166.0
3401201 3 170.0 166.0 0 0 0,2
3500200   3   170.0 166.0
3601201 3 170.0 166.0 0 0 0,2
3701201 3 170.0 166.0 0 0 0,2
3800200   3   170.0 166.0
3901201 3 170.0 166.0 0 0 0,2
1000200   3   170.0 166.0
1101201 3 170.0 166.0 0 0 0,2
1200200   3   170.0 166.0
1301201 3 170.0 166.0 0 0 0,3
1500200   3   170.0 166.0
1600200   3   170.0 166.0
10200 3 170.0 166.0
20200 3 170.0 166.0 0 0
30200 3 170.0 166.0
```

This is an easier transient to mitigate, because the energy inflow is less. Figure 16 shows the peak energy in is less than 700 MWt. This results in a bubble of 84 ft^3 remaining after ten minutes (as opposed to 75 ft^3 for Case 10). The pressure rise is negligible with a peak of 188 psia in the pressurizer.

This transient shows that Case 10 will limit all cases with the Steam Generator at 364°F. Any higher RCS temperature cases will involve less energy flowing into the RCS and subsequently less bubble collapse.

Case 14: Heat addition, T_i = 290°F, T-SG = 364°F, P_i = 390 psia (HP290S36, Figure 17)
This case was run simply because the plant may need to start a RCP when the RCS temperature is close to 300°F. Since the delta-T is only 74°F, this case is less limiting than Cases 10 through 12.

The change from Reference 1 Cased 14 is an increase in the Steam Generator temperature to 364°F and the same change in the LTOP curve. The cards affected are the following:

```
20220119   340.0    1809.1
20220120   400.0    1809.1
```

```
* STEAM GEN SECONDARY SIDE T CHANGE
2201201 3 170. 364.0 0 0 0,6
3201201 3 170. 364.0 0 0 0,6
5101201 3 170. 364.0 0 0 0  3
5201201 3 170. 364.0 0 0 0  3
12001401   364.0  9
```

The heat input from the SGs is limited to less than 250 MWt, and most of the steam void loss is due just to the conservative assumptions regarding the inability of shutdown cooling to offset decay heat and pump heat. The remaining void at ten minutes is 178 ft^3. The pressure rise is modest and Pressurizer pressure does not exceed 439 psia.

Figure 5: Case 2 is the limiting mass addition case in terms of minimal margin to P/T Limit (limit at this temperature is 498 psia for the Pressurizer pressure). This case is taken from Reference 1 and is not impacted by higher steam generator temperatures.

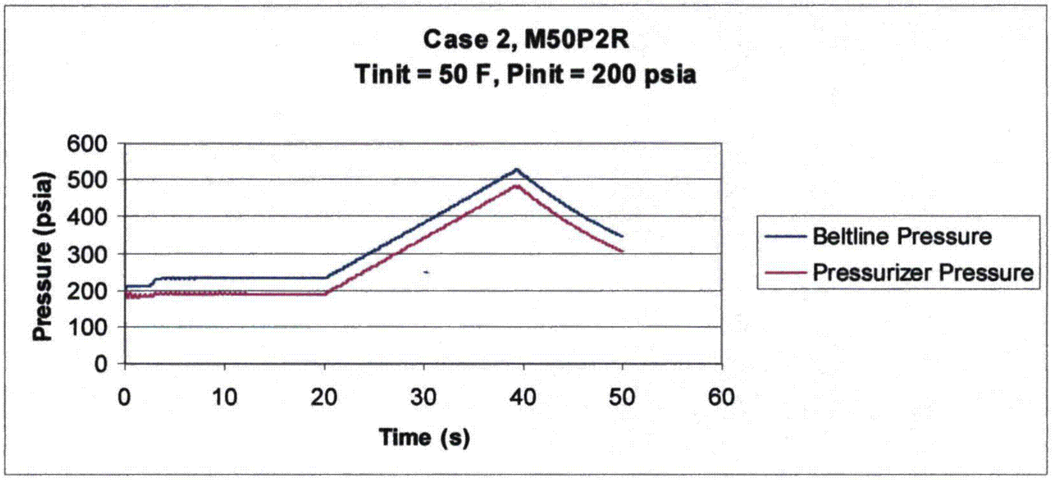


Figure 6: Case 3 examines the effect of higher initial pressure. This case is taken from Reference 1 and is not impacted by higher steam generator temperatures.

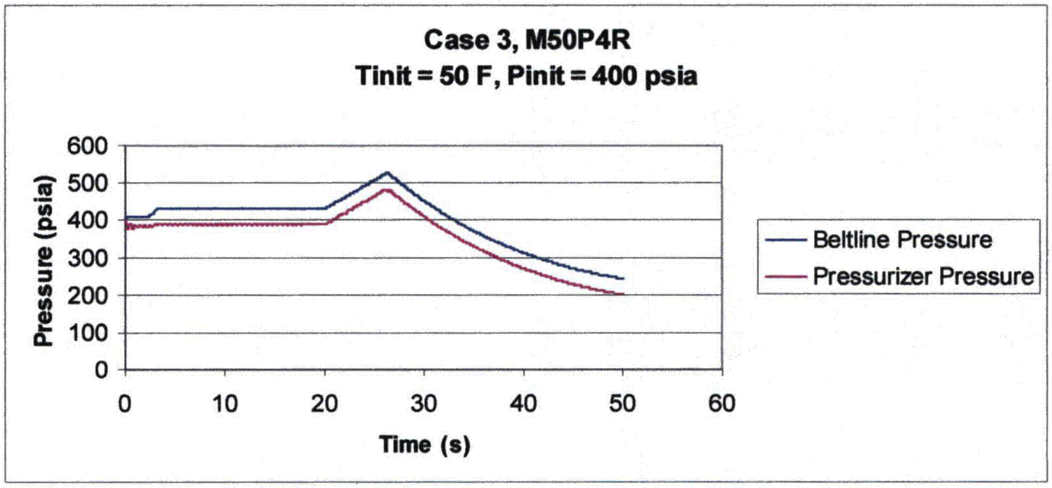
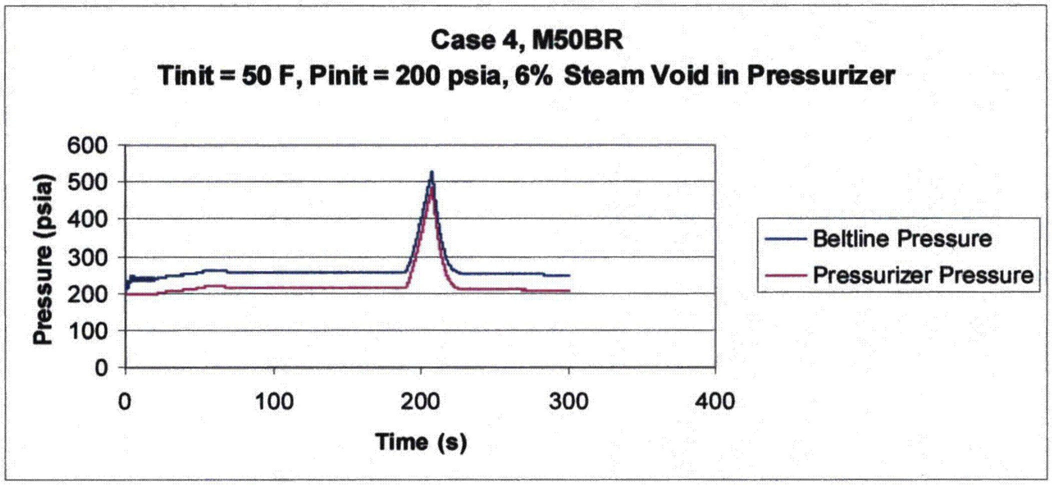


Figure 7: Case 4 shows that an initial steam void delays the pressurization until after the void collapses, but does not impact the peak pressure significantly. This case is taken from Reference 1 and is not impacted by higher steam generator temperatures.



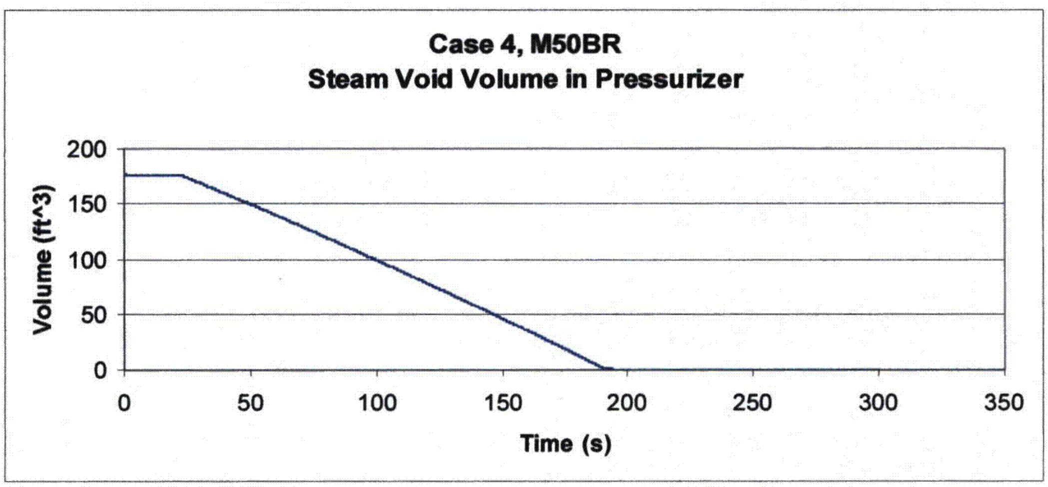


Figure 8: Case 5 shows the impact of warmer RCS temperature. This case is taken from Reference 1 and is not impacted by higher steam generator temperatures.

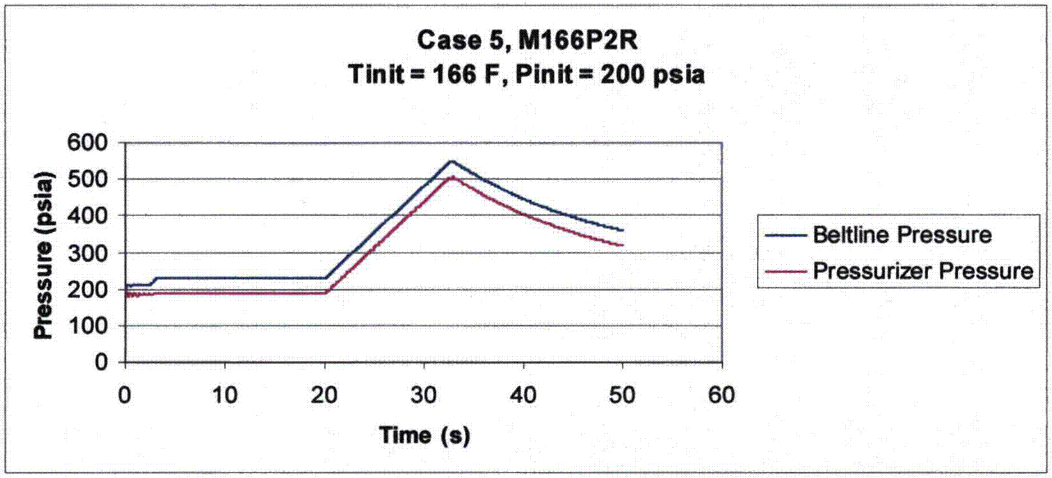


Figure 9: Case 6 is an intermediate T between Cases 5 and 7. This case is taken from Reference 1 and is not impacted by higher steam generator temperatures.

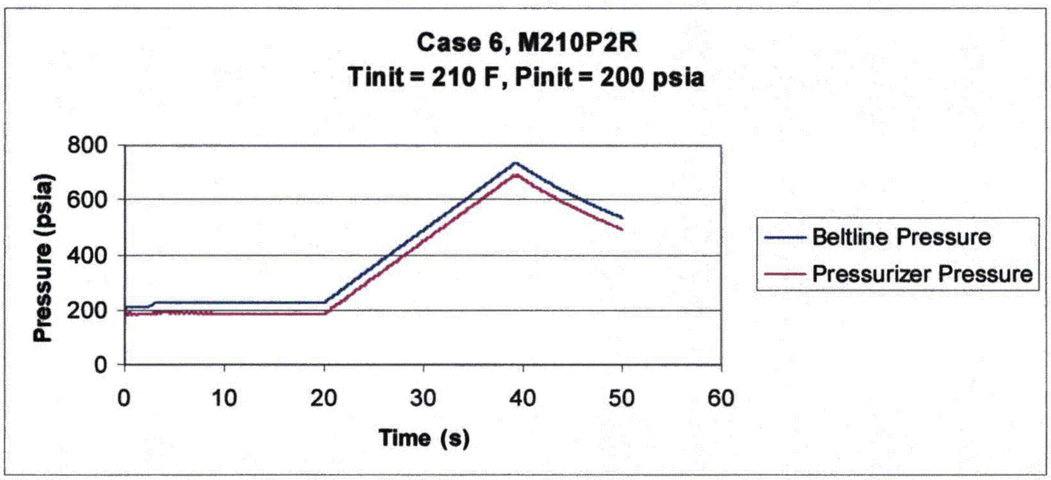


Figure 10: Case 7 is the lowest T at which an HPSI pump may be enabled. This case is taken from Reference 1 and is not impacted by higher steam generator temperatures.

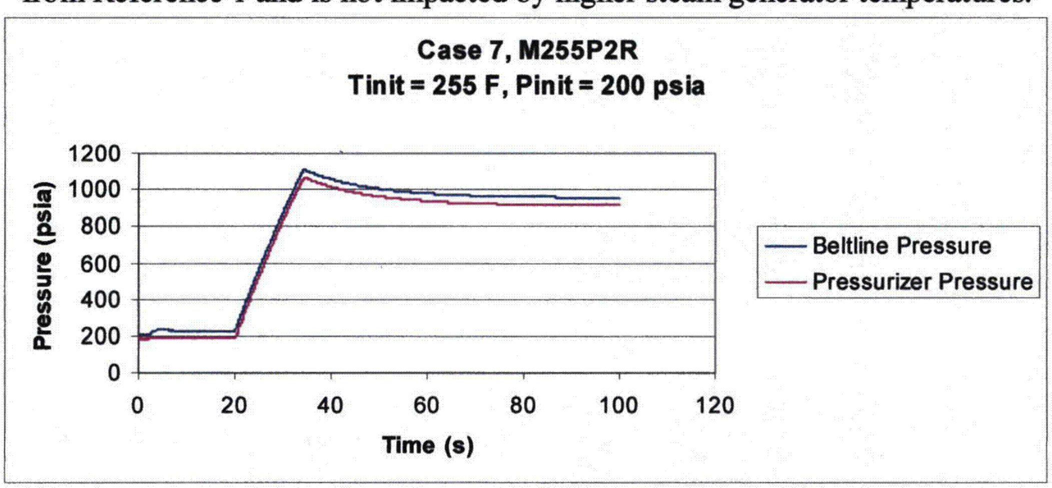


Figure 11: Case 8 is the lowest T at which two HPSI pumps may be enabled. This case is taken from Reference 1 and is not impacted by higher steam generator temperatures.

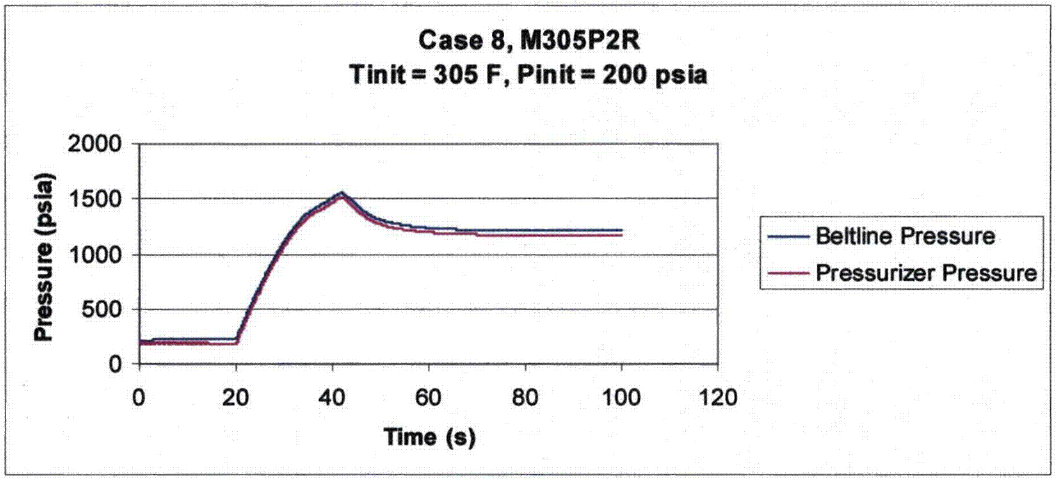


Figure 12: Case 9 demonstrates that Case 8 is limiting for high temperatures by observing the transient at the highest possible initial temperature.

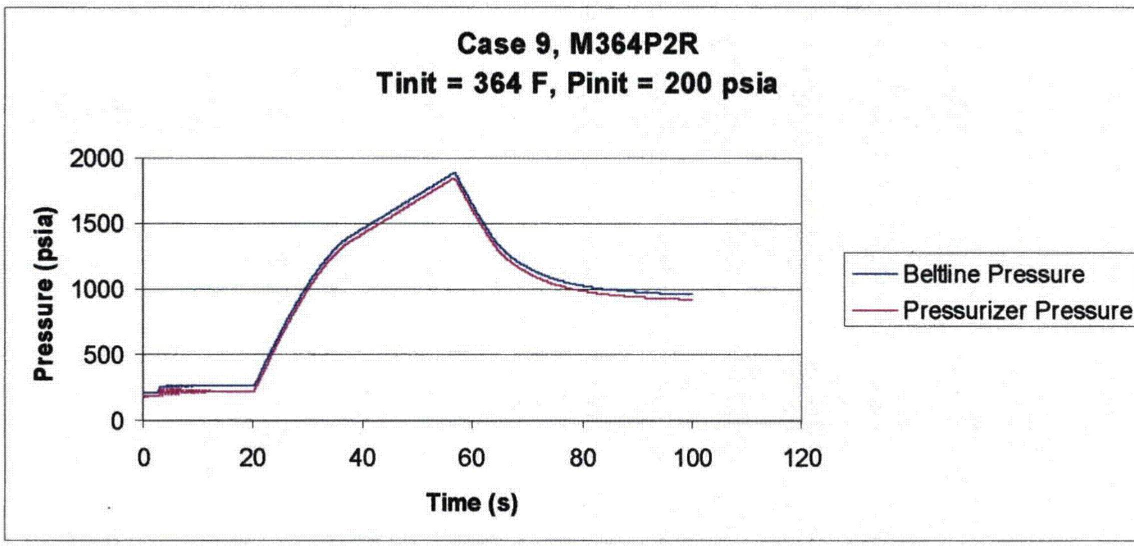
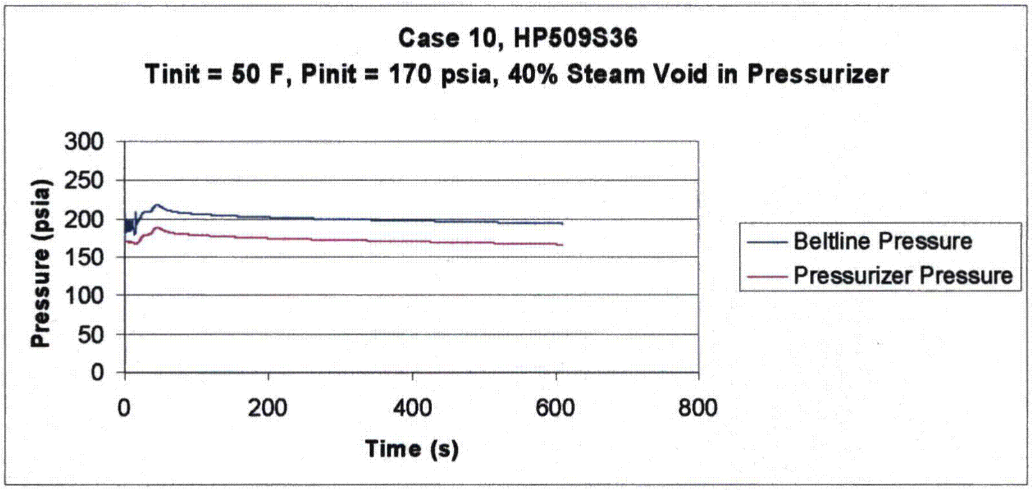
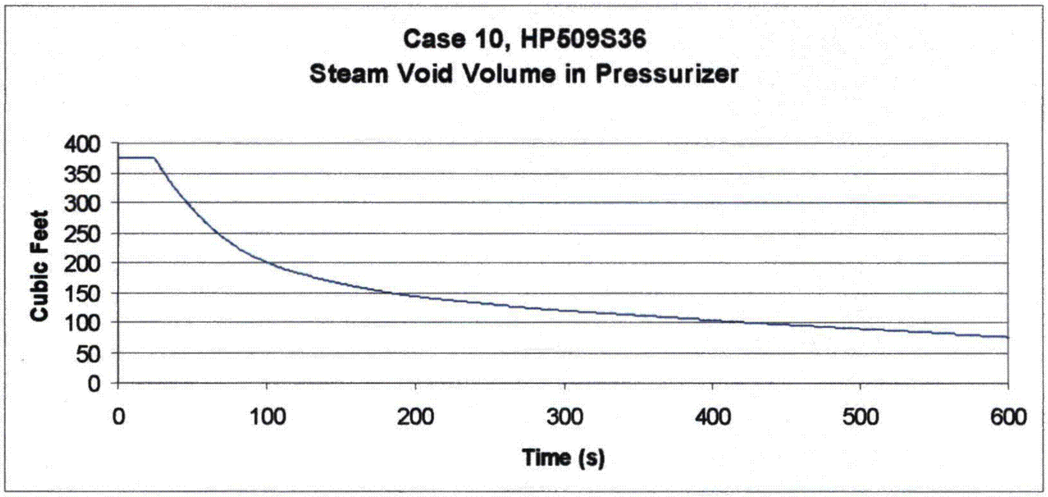


Figure 13: Heat Addition Case 10 is the limiting heat addition case in terms of approaching closest to water-solid (zero steam void in pressurizer)





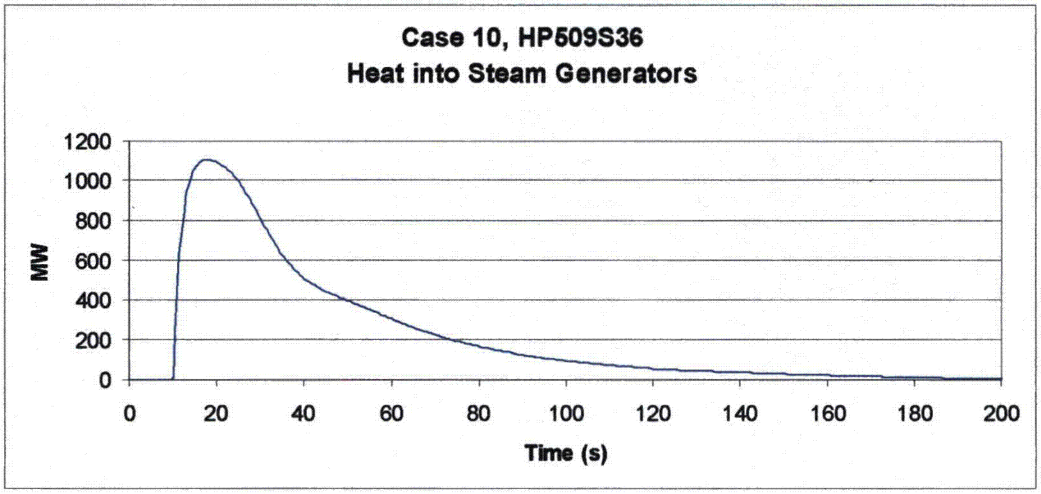
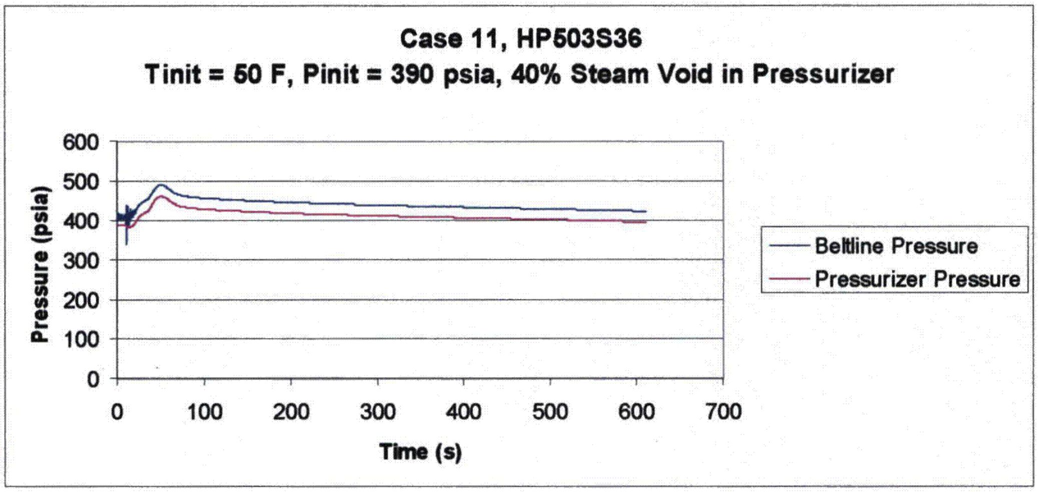
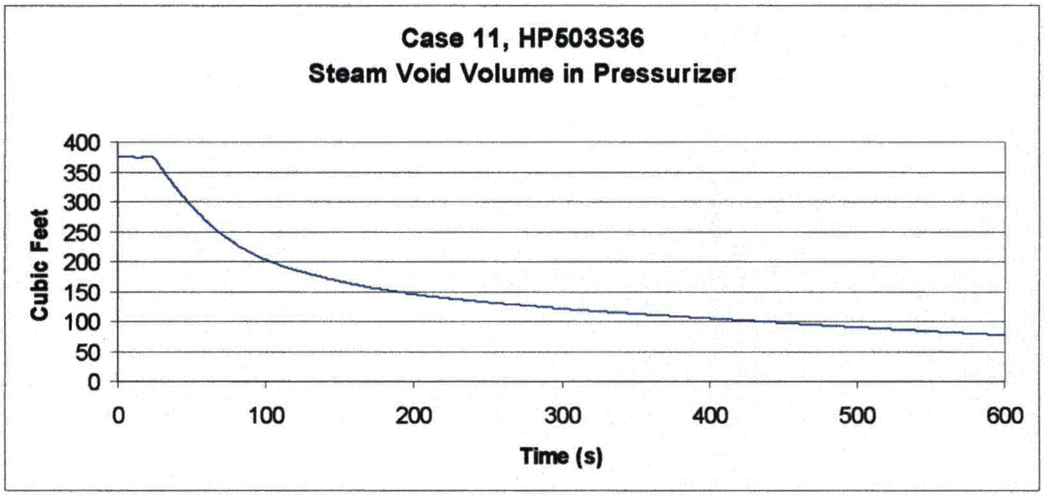


Figure 14: Case 11 Shows Higher RCS Pressure is insignificantly less limiting





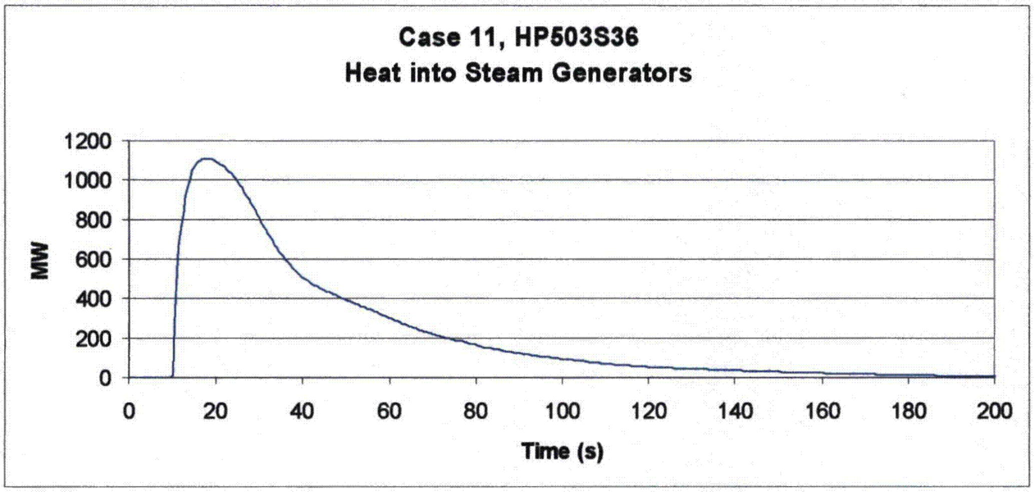


Figure 14a: Case 11a Shows that the Maximum Pressure Rise, Starting from a Conservative but Possible Initial Pressure of 350 psia, is 61 psi

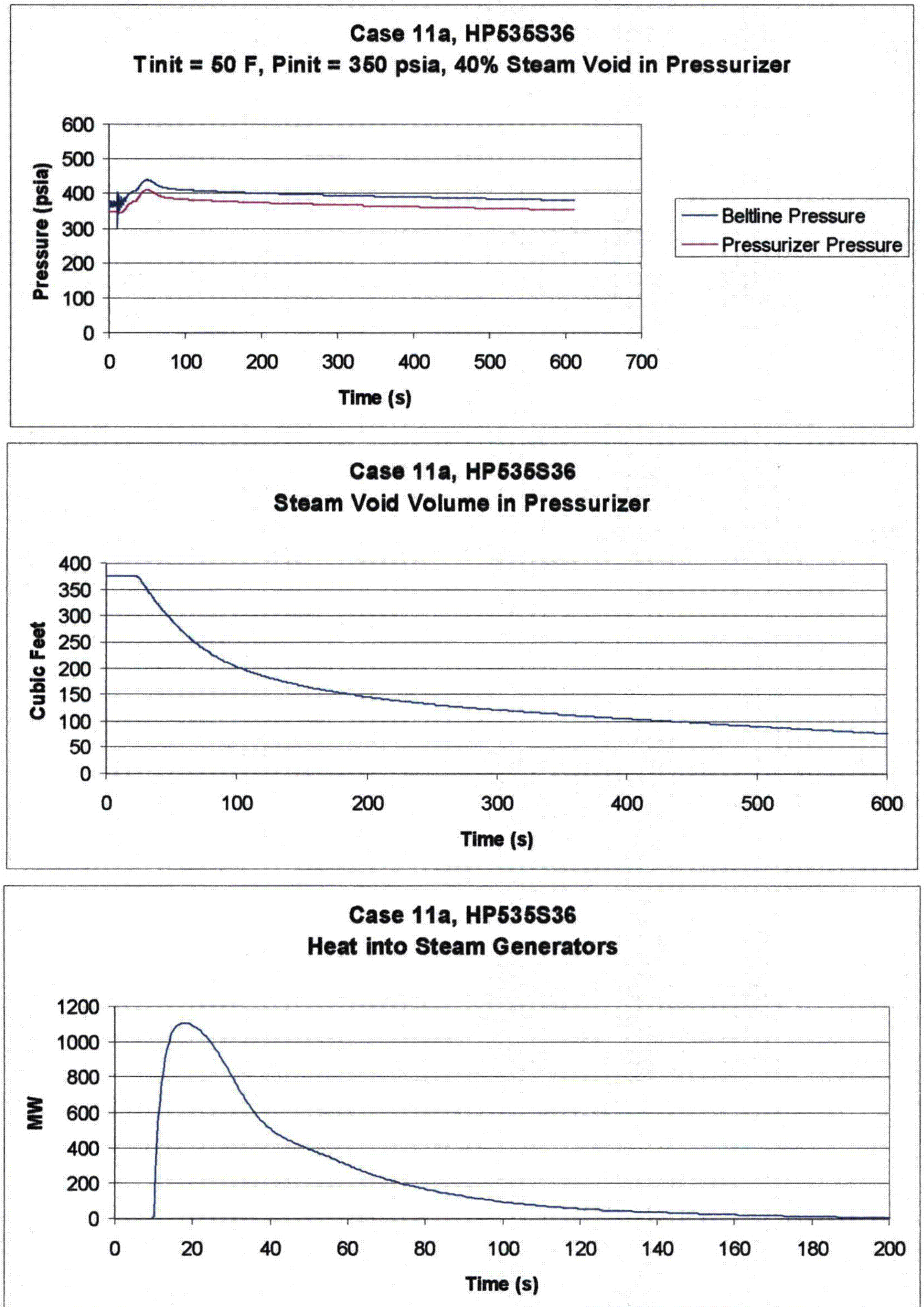
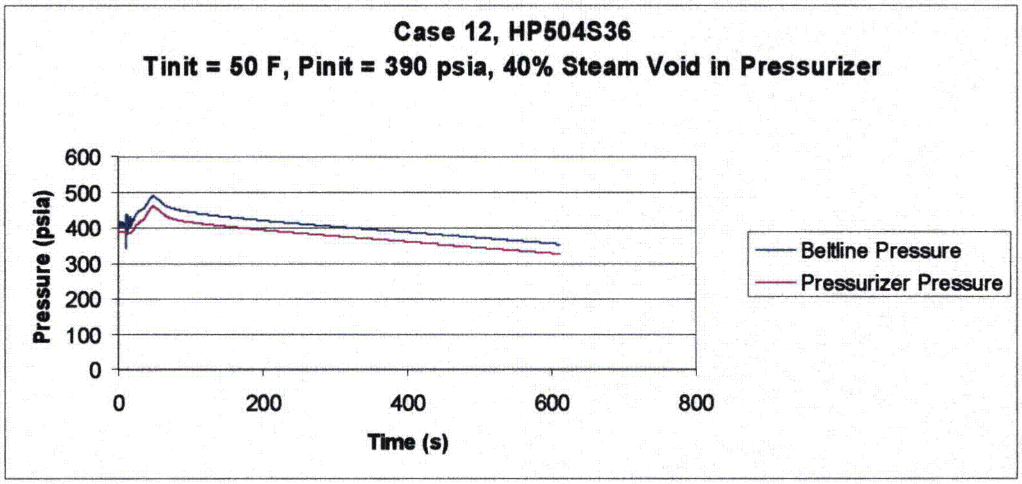
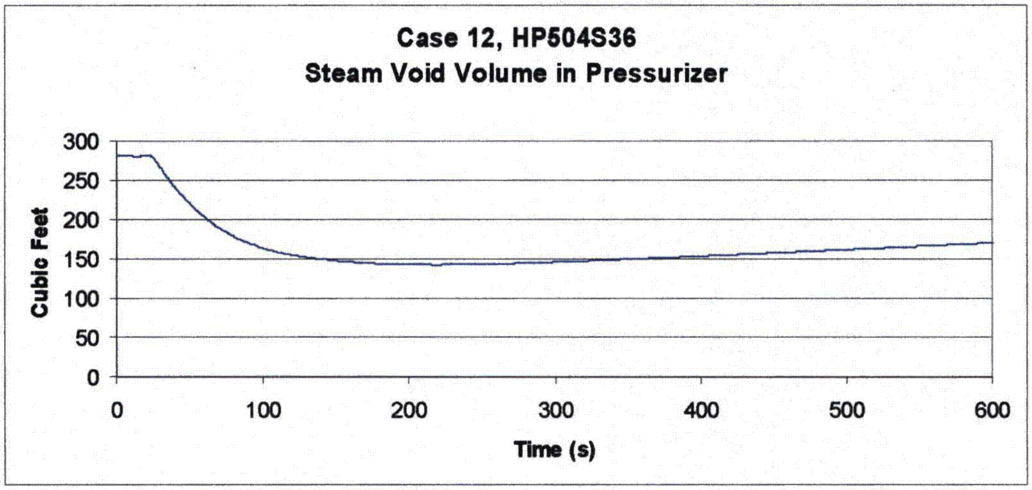


Figure 15: Case 12 Shows PORV Lift Relieves Pressure





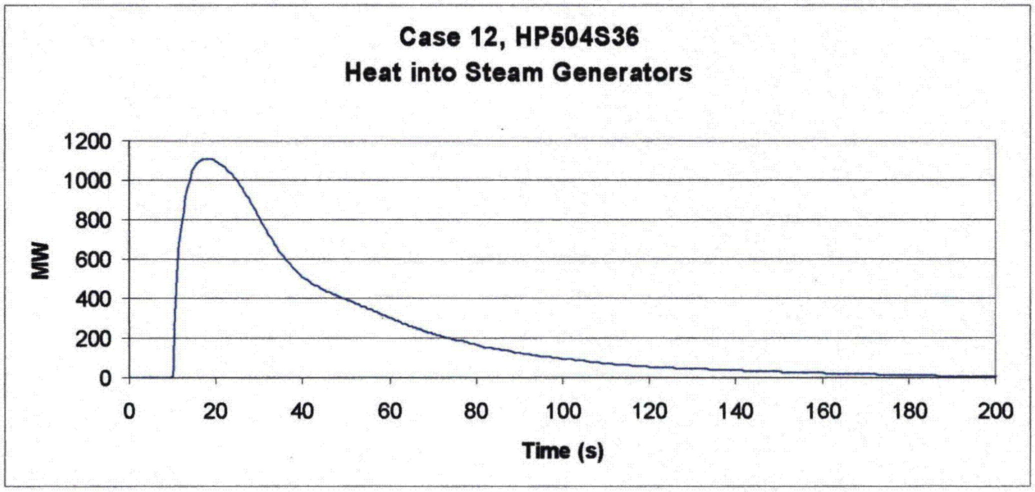
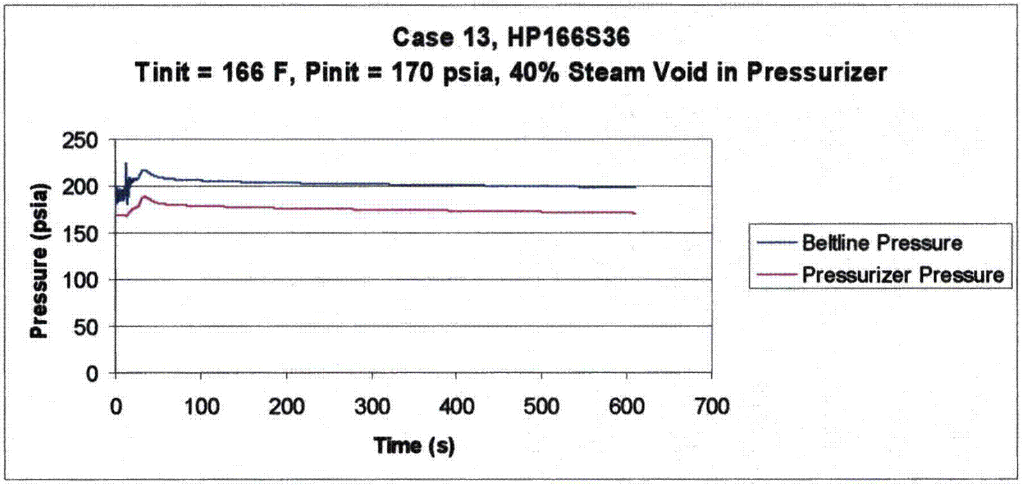
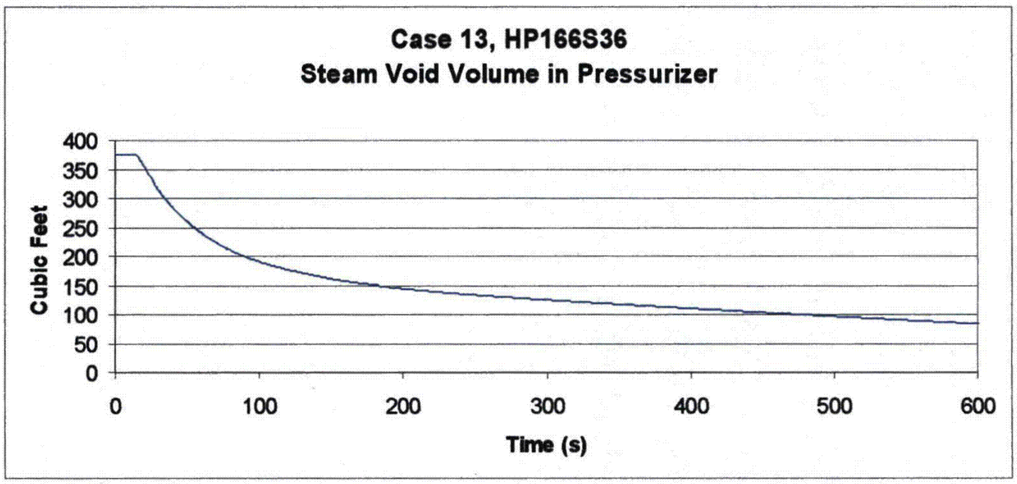


Figure 16: Case 13 Shows Higher RCS Temperature is less limiting





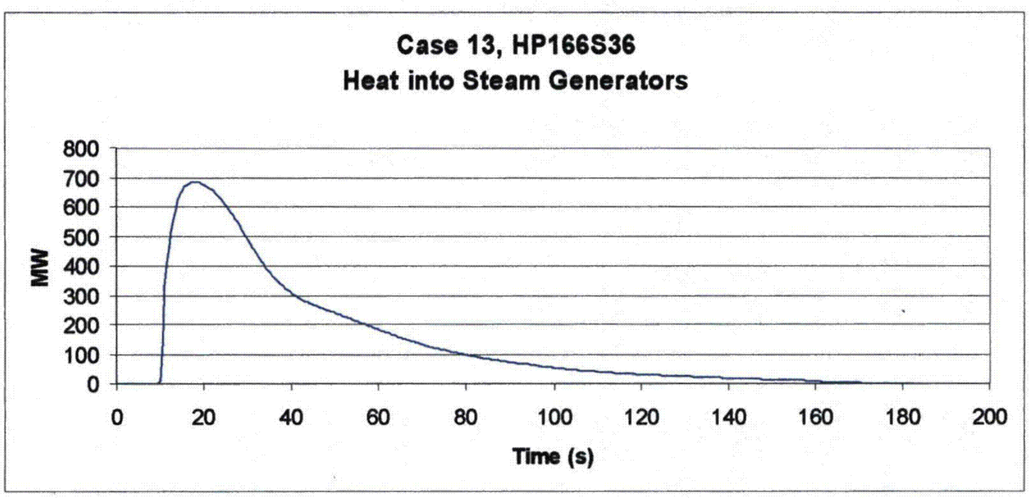
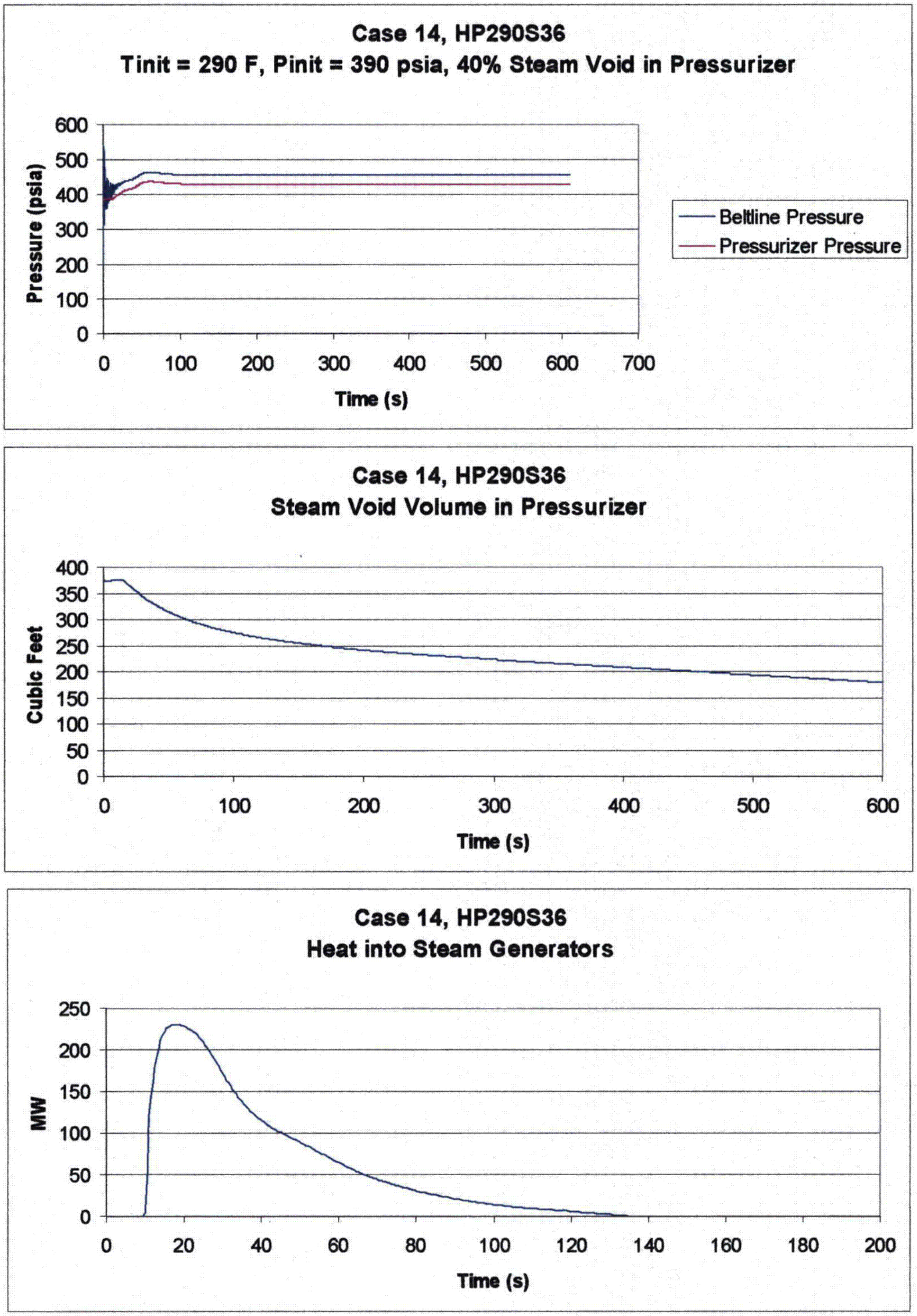


Figure 17: Case 14 Shows Lower RCS - SG Temperature differences are less limiting



Results Summary

The mass addition cases are run to demonstrate full PORV opening prior to exceeding the P/T limit curve. In every case, there is sufficient margin to demonstrate this. Case 1 is not included since it was a benchmarking case in Reference 1. Cases 2 through 8 are from Reference 1 since they are not impacted by the proposed change to allow higher steam generator temperature at the time of LTOP initiation. Case 9 differs from Case 9 of Reference 1 since it is run at 364°F instead of the previously used 314°F.

Table 11: Mass Addition Case Results

Case, File	Tinitial actual (°F)	Pinitial actual (psia)	SI Flow (gpm)*	P/T Limit (psia)	Max PZR P (psia)
2 M50P2R	50	200	132	498	482.74
3 M50P4R	50	400	132	498	482.09
4 M50BR	50	200	132	498	485.85
5 M166P2R	166	200	132	525	507.96
6 M210P2R	210	200	132	794	690.91
7 M255P2R	255	200	215 @ PORV open	1216	1067.1
8 M305P2R	305	200	132 @ PORV open	1892	1522.9
9 M364P2R	364	200	132 @ PORV open	2918	1847

* Minimum PORV flow after full open is 360 gpm, so in every case the PORV flow rate is much greater than the injection rate, assuring peak pressure mitigation.

The heat addition cases are run to show that the pressurizer steam void will absorb enough of the expansion that a PORV lift does not occur. Even in the event that a lift does occur (Case 12), the pressure rise is modest and the volumetric relief is large, so that the pressure is less limiting than the mass addition cases.

Table 12: Heat Addition Case Results

Case, File	Tinitial actual (°F)	Pinitial actual (psia)	SI Flow (gpm)	Steam Void Goal (ft^3)	Min Void (ft^3)	Maximum Pressure Rise (psia)
10 HP509S36	50	170	0	>0	75	19
11 HP503S36	50	390	0	>0	76	72
11a HP535S36	50	350	0	>0	76	61
12 HP504S36	50	390	0	*	143	71
13 HP166S36	166	170	0	>0	84	18
14 HP290S36	290	390	0	>0	178	49

* In this scenario, the initial conditions were set up to initiate a PORV lift. The goal was to limit peak pressure to 498 psia or less. The scenario peak pressure was 461 psia.

IX. FIRST RCP START PRESSURE

It is noted that Case 11 demonstrates that when a RCP is started under extremely conservative assumptions (SG temperature of 364°F, RCS temperature of 50°F, decay heat associated with approximately 1.5 hours after shutdown), the pressure rise is 72 psi. However, not only are these conditions unlikely, the Case 11 assumption of an initial pressure of 390 psia is not credible. Fort Calhoun procedures limit the pressure to 300 psia based on the shutdown cooling system maximum pressure in TDB-III.7.d (Reference 14). Note that the current limit is actually 250 psia, but the intent is to increase this to 300 psia. Therefore Case 11a was run at 300 psia plus 50 psi indication uncertainty, that is, the initial pressure was changed from 390 psia in Case 11 to 350 psia in Case 11a. With this change, the overshoot becomes 61 psi. This is the value reported in Table 2.

The indicated pressure and LTOP PORV setpoint circuitry share much of the same instrumentation. The uncertainty error in the shared instrumentation would impact both equally. Because of this, and because of the conservatism in the analysis that results in the 61 psi overshoot, there is no need to increase the pressure offset any more to account for instrument uncertainty.

Adherence to the maximum pressure to start a RCP avoids PORV lifts and reduces the number of activations of a safety system. This guidance is provided as Curve 3 in TDB-III.7a (Reference 13), which is identified in Step 21 of the startup procedure OP-2A (Reference 15).

X. CONCLUSIONS

This report describes a conservative simulation of postulated limiting LTOP transients at the Fort Calhoun Nuclear Power Plant. The analysis is consistent with NRC guidelines (Reference 3) and contains extensive conservatisms to assure adequate performance.

The previous LTOP analysis contained within Reference 1 showed that the existing LTOP curve is acceptable for plant operation. This report finds that this conclusion also applies even though increasing the shutdown cooling system initiation to 350°F decreases the bubble margin for heat addition cases. No LTOP system changes are necessary, and no new operational restrictions are required.

The LTOP setpoint curve is presented in Table 1. The necessary operational restrictions are given in Table 2. So long as the operational restrictions are satisfied and the PORV circuitry has setpoints equal to or more conservative than the values in Table 1, the LTOP system is adequate to protect against all postulated low temperature overpressure events.

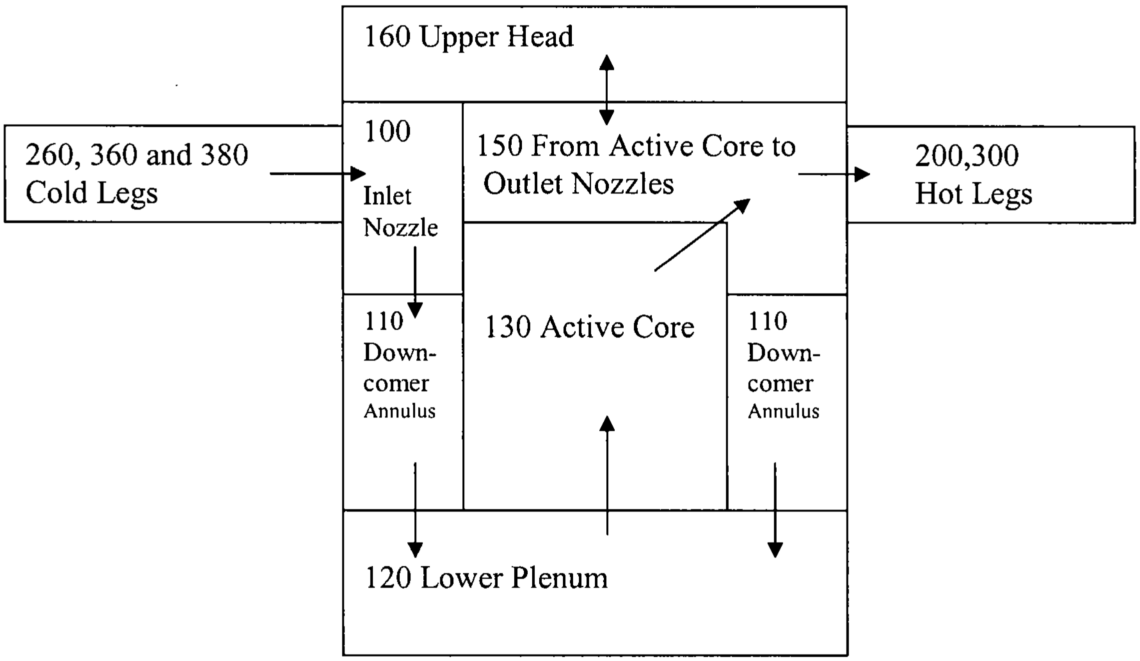
XI. REFERENCES

1. "Low Temperature Overpressure Protection (LTOP) Analysis in Support of Steam Generator Replacement, OPP006-REPT-001," 1/28/2005
2. "CESEC CODE VERIFICATION AND CYCLE 18 UPDATE," Engineering Evaluation (EA) EA-FC-97-017, Revision 0
3. Combustion Engineering Owners Group (CEOG) Report CE NPSD-683-A, Rev. 6
4. "Safety Evaluation of Topical Report CE NPSD-683, Rev. 6, Development of a RCS Pressure and Temperature Limits Report (PTLR) for the Removal of P-T Limits and LTOP Requirements from the Technical Specifications" (TAC No. MA9561)
5. RELAP5/MOD3 Code Manual Volume IV: Models and Correlations, NUREG/CR-5535, June 1995
6. "MIXEE VENDOR CORE DATA LIST FOR FORT CALHOUN UNIT 1 (MVCDL)," EA-FC-90-004, Revision 0
7. Fort Calhoun SDBD-RC-128
8. "Fort Calhoun Station RSG-RCS Hydraulics," Framatome ANP document 32-5038452-01, 8/17/04 (FC 06977)
9. Fort Calhoun USAR, Section 14.9, Loss of Load Safety Analysis
10. EA-FC-01-022, Rev. 0, "Pressure and Temperature Limit Curves for 40 EFPY," 11/15/01
11. EA-FC-02-025, Rev. 0, "Development of the RCS PTLR"
12. TDB-IX, RCS Pressure and Temperature Limits Report, 11/22/06
13. TDB-III.7.a, Pressure and Temperature Limits for 40 EFPY
14. TDB-III.7.d, RCS Pressure and Temperature Limits
15. Operating Procedure OP-2A, Plant Startup, 1/18/07

ATTACHMENT 1
Fort Calhoun LTOP RELAP Model

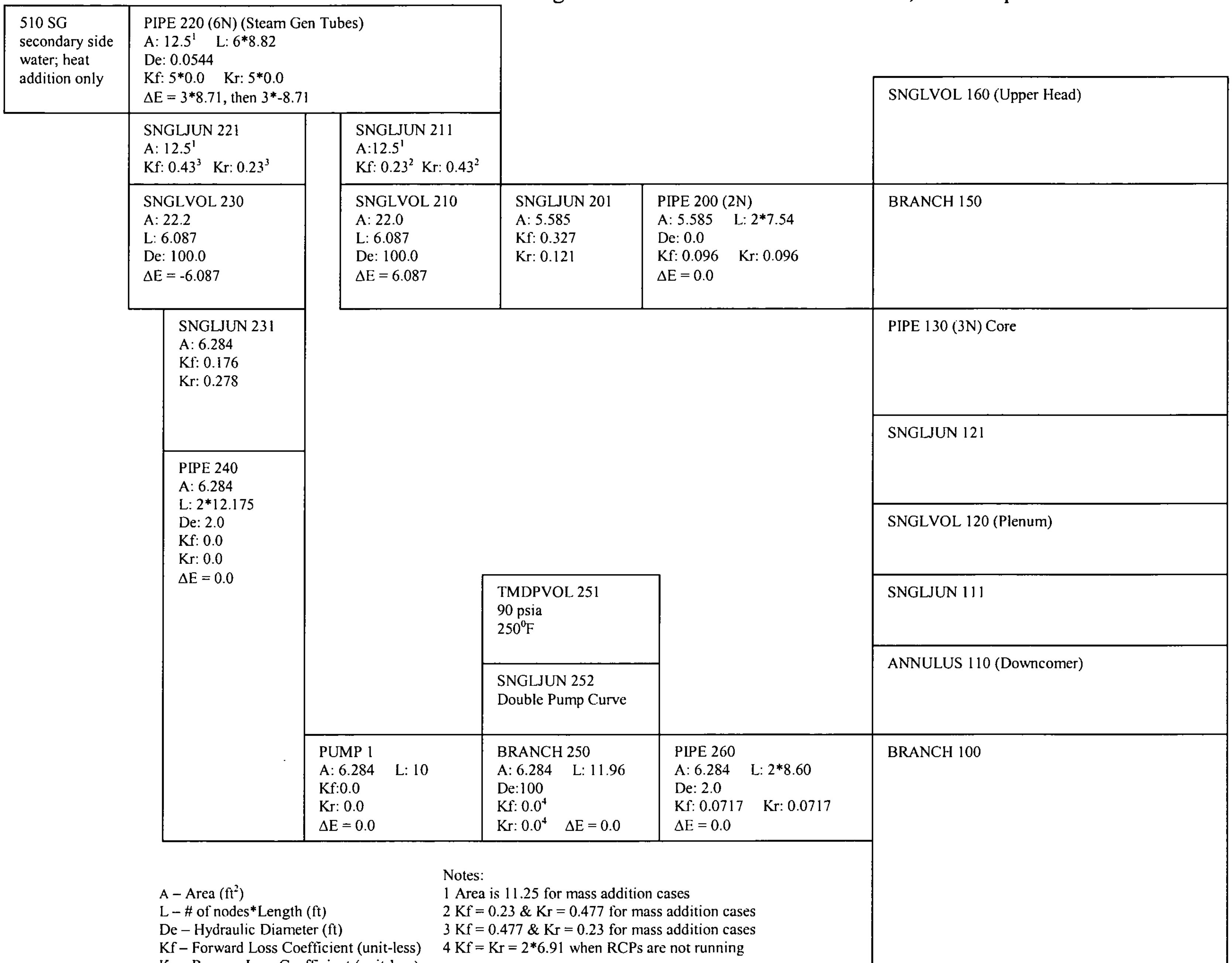
The RELAP model schematic is shown in Figures A1-2 and A1-3. Figure A1-1 represents the noding of the Reactor Vessel in a format that better demonstrates the relative elevations and is more consistent with physical drawings of the vessel.

Figure A1-1: Noding of Reactor Vessel



Details behind all RELAP values described can be found in Reference 1.

Figure A1-2: RELAP Model Schematic, Left Loop



A – Area (ft^2)
L – # of nodes*Length (ft)
De – Hydraulic Diameter (ft)
Kf – Forward Loss Coefficient (unit-less)
Kr – Reverse Loss Coefficient (unit-less)
E – Elevation Change (ft)

Notes:
1 Area is 11.25 for mass addition cases
2 Kf = 0.23 & Kr = 0.477 for mass addition cases
3 Kf = 0.477 & Kr = 0.23 for mass addition cases
4 Kf = Kr = 2*6.91 when RCPs are not running

Figure A1-3: RELAP Model Partial Schematic, Right Loop

TMDPVOL 430
(PORV backpressure)
90 psia
0.0 quality

VALVE 420 (PORV)
A: 0.00535
Kf = 0.0   Kr = 0.0

PIPE 410 6N (Pressurizer)
A: 37.06   L: 6*4.227
De: 0.0   Kf: 0.0   Kr: 0.0
ΔE: 6*4.227

SNGLJUN 401
A: 0.394   Kf: 1.0   Kr: 0.5

PIPE 400
A: 0.394   De: 0.0
L: 7.595,8*6.678,7.595
ΔE=7.595,8*0,7.595
Kf: 9*0.0
Kr: 9*0.0

520 SG
secondary side water; heat addition only

PIPE 320 (6N) (Steam Gen Tubes)
A: 12.5[1]   L: 6*8.82
De: 0.0544
Kf: 5*0.0   Kr: 5*0.0
ΔE = 3*8.71, then 3*-8.71*0.0964

SNGLJUN 311
A: 12.5[1]
Kf: 0.23[2]   Kr: 0.43[2]

BRANCH 330
A: 12.5[1]
L:6.087 ΔE=-6.087
De:10 0.0
Kf: 0.43[3]   Kr: 0.23[3]
two exit legs:
A: 3.14
Kf: 0.176
Kr: 0.278

SNGLVOL 160 (Upper Head)
A: 69.61   L: 12.08   De: 0.0
ΔE = 12.08

BRANCH 150
A: 74.65   L: 5.534   De: 0.0
Kf: 6.88   Kr: 9.86
ΔE = 5.534
To hot legs: A=5.585 Kf: 1.484   Kr: 1.551
To upper head: A=69.61 Kf: 1.0   Kr: 1.0

SNGLVOL 300
A: 5.585
L: 5.02
De: 0.0
ΔE=0.0

BRANCH 301
A: 5.585   L: 5.02
De: 0.0   Kf: 2*0.048
Kr: 2*0.048
Ab: 0.394   Kfb: 2.34
Krb: 1.95   ΔE=0.0

SNGLVOL 302
A: 5.585
L: 5.02
De: 0.0
ΔE=0.0

SNGLJUN 303
A: 5.585
Kf: 0.327
Kr: 0.121

SINGLVOL 310
A: 22.0
L: 6.087
De: 100.0
ΔE=6.087

PIPE 130 (3N) Core
A: 47.26   L: 3*3.556   De: 0.0414
Kf: 2*5.29   Kr: 2*6.27
ΔE=3*3.556

SNGLJUN 121
A: 47.26
Kf: 10.35   Kr: 27.55

SNGLVOL 120 (Plenum)
A: 61.67   L: 9.14   De: 0.0
ΔE = 9.14

SNGLJUN 111
A: 23.33
Kf: 1.27   Kr: 1.09

ANNULUS 110 (Downcomer)
A: 23.33   L: 2*12.671   De: 0.3775
Kf: 1.27   Kr: 1.09
ΔE = 2 * -12.671

BRANCH 100
A: 12.566   L: 3.5   De: 0.0
Kf: 0.074   Kr: 0.063
ΔE = 0.0
Left:
A: 6.284
Kf: 0.295
Kr: 0.252
Right (two):
A: 3.142
Kf: 0.295
Kr: 0.252

A – Area (ft^2)
L – # of nodes*Length (ft)
De – Hydraulic Diameter (ft)
Kf – Forward Loss Coefficient (unit-less)
Kr – Reverse Loss Coefficient (unit-less)
E – Elevation Change (ft)

Notes
1 Area is 11.25 for mass addition cases
2 Kf = 0.23 & Kr = 0.477 for mass addition cases
3 Kf = 0.477 & Kr = 0.23 for mass addition cases
4 Kf = Kr = 2*6.91 when RCPs are not running

TMDPVOL 351
90 psia
250°F

SNGLJUN 352
Single Pump Curve

BRANCH 350
A: 3.142   L: 11.96
De: 2.0
Kf: 0.0[4]   Kr: 0.0[4]

PUMP 2
A: 3.142   L: 10.0
Kf: 0.0
Kr: 0.0

PIPE 340
A: 3.142   L: 2*12.175
De: 2.0   Kf: 0.0
Kr: 0.0

PIPE 360
A: 3.142   L: 2*8.60   De: 2.0
Kf: 0.0717   Kr: 0.0717

TMDPVOL 381
90 psia
250°F

SNGLJUN 382
Single Pump Curve

PIPE 390
A: 3.142   L: 2*8.60   De: 2.0
Kf: 0.0717   Kr: 0.0717

BRANCH 380
A: 3.142   L: 11.96
De: 2.0   Kf: 0.0[4]
Kr: 0.0[4]

PUMP 3
A: 3.142   L: 10.0
Kf: 0.0
Kr: 0.0

PIPE 370
A: 3.142   L: 2*12.175
De: 2.0 Kf: 0.0
Kr: 0.0

ATTACHMENT 2
Listing of RELAP INPUT DECKS

Two decks are provided, the mass addition Case 9 (M364P2R.TXT) and the heat addition Case 10 (HP509S36.TXT). The other heat addition cases are defined based on Case 10 with the cards listed in the main body of the calculation.

M364P2R.TXT

```
=Fort Calhoun LTOP Model for Steam Gen Replacement
* Case 9 mass addition, Tinit = 364 F, Pinit = 200 psia
*
100 new transnt
102 british british
105
*****
*  time step control
*
201  2.0  1.0-6 0.010 5 10 250    1000
202  20.0  1.0-6 0.001 5 100 5000 10000
203  1000.0  1.0-6 0.0005 5 40 20000 100000
*
* Output control
*
301 p 120010000
302 p 410060000
303 p 301010000
304 p 200020000
305 voidg 410060000
306 tempf  410060000
307 tempf  360010000
311 mflowj 401000000
312 mflowj 311000000
313 mflowj 330020000
314 mflowj 330030000
315 mflowj 252000000
316 mflowj 352000000
317 mflowj 382000000
318 mflowj 420000000
319 mflowj 211000000
321 cntrlvar   1
322 cntrlvar   2
323 cntrlvar   3
324 cntrlvar   4
325 cntrlvar   201
326 cntrlvar   106
327 cntrlvar   101
328 cntrlvar   102
329 cntrlvar   103
330 cntrlvar   104
331 pmphead  1
332 pmphead  2
333 cntrlvar   306
**********************
*  trip cards
*  501 run stop time
```

```
*   502  si and charging start time
*   503  porv set point
*   504  porv delay time
*   505  rcp 1 stop time
*   506  rcp 2 stop time
*   507  rcp 3 stop time
*   508  rcp 1 start time
*   509  rcp 2 start time
*   510  porv close trip (intentionally gt end time)
*   520  heat to pressurizer
*   521  decay heat control
*   522  sg secondary side temp control
*   600 run stop
*   601 rcp 1 run control
*   602 rcp 2 run control
*   603 rcp 3 run control
*********************
501  time    0           ge   null     0      50.0       l
502  time    0           ge   null     0      20.0       l
503  cntrlvar   106      ge   cntrlvar  201  0.0         l
504  time    0           ge  timeof   503    1.5         l
505  time    0           ge   null     0      0.0        l
506  time    0           ge   null     0      0.0        l
508  time    0           ge   null     0      2.0        l
509  time    0           ge   null     0      2.0        l
510  time    0           ge  timeof   503    5000.0      l
600  501
601  505  and  -508  n
602  506  and  -509  n
* Non-Pressurizer Loop
*
* LEFT HOT LEG
* first pipe has explanatory notes
2000000 hleg1 pipe
* number of nodes
2000001 2
* area of nodes, then interior junctions
2000101 5.585,2
2000201 5.585,1
* node lengths
2000301 7.54,2
* vertical angle
2000601 0.0,2
* Elevation change = either length*angle or use a card 701
* Pipe friction, hydraulic dia, node#
2000801 0.00015  0.0  2
* forward K, reverse K, junc#
2000901 .096  .096  1
* required volume flags, in 1101 use 0100 if an abrupt area change
2001001 0   2
2001101 0   1
* with 3, init-P, init-T, init-T, three 0, node#
2001201 3 200. 80.0 0 0 0 2
* liq vel ft/s, vapor vel, interface=0 junc#
2001301 0.0 0.0 0.0,1
*
*
* LEFT HOT LEG TO SG JUNCTION
```

```
2010000   Lhl-Lsg    sngljun
* from, to, minimum area, forwrd-K, reverse-K,0100=abrupt area change(0000
else)
2010101   200010000   210000000   5.585   0.317   0.156   0000
* 0=velocities, liq vel ft/s, vapor vel, interface=0
2010201   0   0.0   0.0   0.0
*
* LEFT SG HOT PLENUM
2100000   Lsgip    snglvol
* area,length,vol(=0 to calc),az angle=0, vert angle,elev
change,rough,HD,flags
2100101   20.4   6.087  0.0   0.0   90.0  6.087   0.00015  100.0 0010
2100200   3   200. 80.0
*
* LEFT SG HOT PLENUM TO SG TUBES
2110000   Lhp-tub    sngljun
2110101   210010000   220000000   8.651   0.76  0.38   0000
2110201   0   0.0   0.0   0.0
*
* LEFT STEAM GENERATOR TUBES
2200000 lsg pipe
2200001 6
2200101 8.651,6
2200201 8.651,5
2200301 8.71,6
2200601 90.0,3
2200602 -90.0,6
2200701   8.71   3
2200702  -8.71   6
2200801 0.0  0.0544   6
2200901 0.066  0.066  5
2201001 0,6
2201101 0,5
2201201 3 200. 80.0 0 0 0,6
2201301 0.0 0.0 0.0,5
*
* LEFT STEAM GEN TUBES TO COLD PLENUM
2210000   tub-Lcp    sngljun
2210101   220010000   230000000   8.561   1.53   1.12   0000
2210201   0   0.0   0.0   0.0
*
* LEFT SG COLD PLENUM
2300000   Lsgcp    snglvol
2300101   20.0  6.087  0.0   0.0  -90.0  -6.087  0.00015  100.0  0010
2300200   3   200. 80.0
*
* LEFT SG COLD PLENUM TO CROSSOVER LEG
2310000   Lcp-Lxo    sngljun
2310101   230010000   240000000   6.284  .41   .41   0000
2310201   0   0.0   0.0   0.0
*
* LEFT CROSSOVER
2400000 Lxover pipe
2400001 2
2400101 6.284,2
2400201 6.284,1
2400301 12.175,2
2400601 0.0,2
```

```
2400801 0.00015,2.0,2
2400901 0.0   0.0   1
2401001 0,2
2401101 0,1
2401201 3 200. 80.0 0 0 0,2
2401301 0.0 0.0 0.0,1
*
* LEFT SI/CHARGING BRANCH
2500000   Lsi   branch
2500001   1   0
2500101   6.284  11.96   0.0   0.0   0.0   0.0   0.0   100.0   0010
2500200   3   200. 80.0
2501101   250010000  260000000   6.284  0.0  0.0   0000
2501201   0.0  0.0   0.0
*
* DOUBLE COLD LEG SI TIME DEPENDENT VOLUME
2510000        si2       tmdpvol
* flow area, length, volume, horiz angle, vert angle
2510101       50.0   10.0        0.0      0.0      0.0
* elev change, roughness, hydraulic diameter, flags
2510102        0.0       0.0        0.0     00
* 3 makes 201 card P&T, trip number
2510200         3
2510201        0.0      90.0       250.0
2510202      1000.0     90.0       250.0
*
* DOUBLE COLD LEG SI TIME DEPENDENT JUNCTION

2520000        si2flow tmdpjun
* from, to, area
2520101        251000000      250000000      1.0
* 1 means mass flows/0=velocity, trip number, table var & location
2520200        1             502          p       250010000
* pressure, liq lbm/s, vapor velocity, interface (=0) 1 Pump Curve
2520201          0.0          0.0            0.0         0.0
2520202         10.0          9.178          0.0         0.0
2520203       2000.0          9.178          0.0         0.0
*
* LEFT COLD LEG
2600000 cleg1 pipe
2600001 2
2600101 6.284,2
2600201 6.284,1
2600301 8.60,2
2600601 0.0,2
2600801 0.00015,2.0,2
2600901 .0717 .0717,1
2601001 0,2
2601101 0,1
2601201 3 200. 80.0 0 0 0,2
2601301 0.0 0.0 0.0,1
*
* Pressurizer Loop
*
* RIGHT HOT LEG TO PRESSURIZER BRANCH
3000000   Rhl1    snglvol
3000101   5.585   5.02 0.0   0.0   0.0 0.0   0.00015   0.0  00
3000200   3   200. 80.0
```

```
*
* RIGHT HOT LEG-PRESSURIZER BRANCH
3010000   hlegprz   branch
* Number paths described, 0 means velocities are input on 201 cards
3010001   3   0
* Area, length, volume, horz angle, inclination, elev change,rough,HD,flags
3010101   5.585   5.02   0.0   0.0   0.0   0.0   0.00015   0.0   00
* Initial P and T
3010200   3   200. 80.0
* from, to, area, K-forward, K-reverse, flags (=100 for sudden area change)
3011101   300010000  301000000   5.585   0.048   0.048   0000
3012101   301010000  302000000   5.585   0.048   0.048   0000
3013101   301010000  400000000   0.394   2.34     1.95   0000
* liq vel, steam vel, interface(=0)
3011201   0.0  0.0   0.0
3012201   0.0   0.0   0.0
3013201   0.0     0.0   0.0
*
* SURGELINE
4000000 surgline pipe
4000001 10
4000101 0.394,10
4000201 0.394,9
4000301 8.021,1
4000302 6.678,9
4000303 8.021,10
4000601 90.0,1
4000602 0.0,9
4000603 90.0,10
4000701 8.021,1
4000702 0.0,9
4000703 8.021,10
4000801 0.00015,0.0,10
4000901 0.0  0.0   9
4001001 0,10
4001101 0,9
4001201 3 200. 80.0 0 0 0,10
4001301 0.0,0.0,0.0,9
*
* SURGELINE JUNCTION TO PRESSURIZER
4010000   sl-p    sngljun
4010101   400010000   410000000   0.394   1.0   0.5   0000
4010201   0   0.0   0.0   0.0
*
* PRESSURIZER
4100000   pres   pipe
4100001   6
4100101   36.94,6
4100201   36.94,5
4100301   4.06,6
4100601   90.   6
4100801   0.00015  0.0  6
4100901   0.0    0.0   5
4101001   0,6
4101101   0,5
*Manually set Przr pressure and water level
4101201   3   200.  80.00   0.  0 0,5
4101202   3   200.  80.00   0.  0 0,6
```

```
4101300   1
4101301   0.0   0.0   0.0,5
*
* PORV
4200000   porv   valve
4200101   410010000   430000000   0.00535   0.0   0.0   0100
4200201   0   0.0   0.0   0.0
4200300   mtrvlv
4200302   504  510  2.0  0.0
*
* PORV BACKPRESSURE
4300000   cont tmdpvol
4300101   50. 10.0   0.0   0.0   0.0   0.0   0.0   0.0   00
4300200   3
4300201   0.0   90.0   50.0
4300202   1000.0   90.0   50.0
*
* RIGHT HOT LEG, PRZR TO STEAM GEN
3020000   Rhl2    snglvol
3020101   5.585   5.02 0.0   0.0   0.0 0.0   0.00015   0.0  00
3020200   3   200. 80.0
*
* RIGHT HOT LEG TO SG JUNCTION
3030000   Rhl-Rsg    sngljun
3030101   302010000   310000000   5.585   0.317   0.156   0000
3030201   0   0.0   0.0   0.0
*
* RIGHT SG HOT PLENUM
3100000   Rsgip    snglvol
3100101   20.4   6.087  0.0   0.0   90.0  6.087   0.00015   100.0   0010
3100200   3   200. 80.0
*
* RIGHT SG HOT PLENUM TO SG TUBES
3110000   Rhp-tub    sngljun
3110101   310010000   320000000   8.651   0.76   0.38   0000
3110201   0   0.0   0.0   0.0
*
* RIGHT STEAM GENERATOR TUBES
3200000 Rsg pipe
3200001 6
3200101 8.651,6
3200201 8.651,5
3200301 8.71,6
3200601 90.0,3
3200602 -90.0,6
3200701   8.71   3
3200702  -8.71   6
3200801 0.0  0.0544   6
3200901 0.066 0.066  5
3201001 0,6
3201101 0,5
3201201 3 200. 80.0 0 0 0,6
3201301 0.0 0.0 0.0,5
*
* RIGHT COLD PLENUM BRANCH
3300000   Rsgcp   branch
3300001   3   0
3300101   20.0  6.087  0.0  0.0   -90.0   -6.087   0.00015  100.0   0010
```

```
3300200   3   200. 80.0
3301101   320010000  330000000   8.651   1.53   1.12   0000
3302101   330010000  340000000   3.142   0.41   0.41   0000
3303101   330010000  370000000   3.142   0.41   0.41   0000
3301201   0.0   0.0   0.0
3302201   0.0   0.0   0.0
3303201   0.0   0.0   0.0
*
* RIGHT CROSSOVER, RCP LINE
3400000 Rxover1 pipe
3400001 2
3400101 3.142,2
3400201 3.142,1
3400301 12.175,2
3400601 0.0,2
3400801 0.00015,2.0,2
3400901 0.0  0.0   1
3401001 0,2
3401101 0,1
3401201 3 200. 80.0 0 0 0,2
3401301 0.0 0.0 0.0,1
*
*
* RIGHT SI/CHARGING BRANCH
3500000   Rsi1   branch
3500001   1   0
3500101   3.142  11.96   0.0   0.0   0.0   0.0   0.00015   2.0     00
3500200   3   200. 80.0
3501101   350010000  360000000   3.142   0.0  0.0   0000
* liq vel, steam vel, interface(=0)
3501201   0.0  0.0   0.0
*
*
* SINGLE COLD LEG SI TIME DEPENDENT VOLUME
3510000       si1a      tmdpvol
* flow area, length, volume, horiz angle, vert angle
3510101      50.0   10.0      0.0     0.0     0.0
* elev change, roughness, hydraulic diameter, flags
3510102       0.0       0.0       0.0    00
* 3 makes 201 card P&T, trip number
3510200        3
3510201       0.0     90.0      250.0
3510202     1000.0    90.0      250.0
*
* SINGLE COLD LEG SI TIME DEPENDENT JUNCTION
3520000       si1aflow tmdpjun
* from, to, area
3520101       351000000     350000000     1.0
* 1 means mass flows/0=velocity, trip number, table var & location
3520200       1            502        p      350010000
* pressure, liq velocity, vapor velocity, interface (=0) 1 Pump
3520201         0.0        0.0           0.0        0.0
3520202        10.0        9.178         0.0        0.0
3520203      2000.0        9.178         0.0        0.0
*
*
* RIGHT COLD LEG, RCP LINE
3600000 cleg1 pipe
```

```
3600001 2
3600101 3.142,2
3600201 3.142,1
3600301 8.60,2
3600601 0.0,2
3600801 0.00015,2.0,2
3600901 .0717 .0717,1
3601001 0,2
3601101 0,1
3601201 3 200. 80.0 0 0 0,2
3601301 0.0 0.0 0.0,1
*
*
* RIGHT CROSSOVER, NO RCP LINE
3700000 Rxover2 pipe
3700001 2
3700101 3.142,2
3700201 3.142,1
3700301 12.175,2
3700601 0.0,2
3700801 0.00015,2.0,2
3700901 0.0  0.0   1
3701001 0,2
3701101 0,1
3701201 3 200. 80.0 0 0 0,2
3701301 0.0 0.0 0.0,1
*
* comment out 380, 381, 382 to use pump3
* RIGHT SI/CHARGING BRANCH
3800000   Rsi2   branch
3800001   1   0
3800101   3.142   11.96   0.0   0.0   0.0   0.0   0.00015   2.0   00
3800200   3   200. 80.0
3801101   380010000  390000000   3.142   0.0  0.0   0000
* liq vel, steam vel, interface(=0)
3801201   0.0  0.0   0.0
*
*
* SINGLE COLD LEG SI TIME DEPENDENT VOLUME
3810000       si1b      tmdpvol
* flow area, length, volume, horiz angle, vert angle
3810101       50.0   10.0     0.0     0.0     0.0
* elev change, roughness, hydraulic diameter, flags
3810102       0.0      0.0       0.0    00
* 3 makes 201 card P&T, trip number
3810200        3
3810201       0.0     90.0      250.0
3810202     1000.0    90.0      250.0
*
* DOUBLE COLD LEG SI TIME DEPENDENT JUNCTION
3820000       si1bflow tmdpjun
* from, to, area
3820101       381000000     380000000     1.0
* 1 means mass flows/0=velocity, trip number, table var & location
3820200       1             502         p      380010000
* pressure, liq velocity, vapor velocity, interface (=0) 1 Pump
3820201         0.0        0.0           0.0        0.0
3820202        10.0        9.178         0.0        0.0
```

```
3820203      2000.0        9.178         0.0         0.0
*
* RIGHT COLD LEG, NO RCP LINE
3900000 cleg1 pipe
3900001 2
3900101 3.142,2
3900201 3.142,1
3900301 8.60,2
3900601 0.0,2
3900801 0.00015,2.0,2
3900901 .0717 .0717,1
3901001 0,2
3901101 0,1
3901201 3 200. 80.0 0 0 0,2
3901301 0.0 0.0 0.0,1
*
* Reactor Core
*
* CORE INLET BRANCH
1000000   inlet   branch
1000001   4   0
1000101   12.566   3.5   0.0   0.0   0.0   0.0   0.00015   0.0   00
1000200   3   200. 80.0
1001101   260010000  100000000   6.284    0.295   0.252   0000
1002101   360010000  100000000   3.142    0.295   0.252   0000
1003101   390010000  100000000   3.142    0.295   0.252   0000
1004101   100010000  110000000   12.566   0.074   0.063   0000
1001201   0.0   0.0   0.0
1002201   0.0   0.0   0.0
1003201   0.0   0.0   0.0
1004201   0.0   0.0   0.0
*
* DOWNCOMER
1100000 downcmr annulus
1100001 2
1100101 23.33,2
1100201 23.33,1
1100301 12.671,2
1100601 -90.0,2
1100701 -12.671,2
1100801 0.00015,0.3775,2
1100901 1.27  1.08  1
1101001 0,2
1101101 0,1
1101201 3 200. 80.0 0 0 0,2
1101301 0.0 0.0 0.0,1
*
* DOWNCOMER TO LOWER CORE PLENUM
1110000   dwn-plen    sngljun
1110101   110010000   120000000   23.33   1.27   1.08   0000
1110201   0   0.0   0.0   0.0
*
* LOWER CORE PLENUM
1200000   plenum    snglvol
1200101   61.67   9.14  0.0   0.0   90.0  9.14   0.00015   0.0 00
1200200   3   200. 80.0
*
* LOWER CORE PLENUM TO CORE
```

```
1210000   pln-core    sngljun
1210101   120010000   130000000   47.26   10.35   27.55   0000
1210201   0   0.0   0.0   0.0
*
* REACTOR CORE
1300000 core pipe
1300001 3
1300101 47.26,3
1300201 47.26,2
1300301 3.556,3
1300601 90.0,3
1300701 3.556,3
1300801 0.00015,0.0414,3
1300901 5.29  6.27  2
1301001 0,3
1301101 0,2
1301201 3 200. 80.0 0 0 0,3
1301301 0.0 0.0 0.0,2
*
* REACTOR OUTLET BRANCH
1500000   outlet   branch
1500001   4   0
1500101   74.65   5.534  0.0   0.0   90.0  5.534  0.00015   0.0   00
1500200   3   200. 80.0
1501101   130010000  150000000   47.26   6.88   9.86   0000
1502101   150010000  200000000   5.585   0.384  0.551  0000
1503101   150010000  300000000   5.585   0.384  0.551  0000
1504101   150010000  160000000   69.61   1.0    1.0    0000
1501201   0.0   0.0   0.0
1502201   0.0   0.0   0.0
1503201   0.0   0.0   0.0
1504201   0.0   0.0   0.0
*
* REACTOR UPPER HEAD
1600000   upperhd    snglvol
1600101   69.61   12.08   0.0   0.0   90.0  12.08   0.00015   0.0 00
1600200   3   200. 80.0
*
* pump# 1
10000 loop1 pump
10101 6.284  10.0 0 0 0 0 0
10108 240010000 6.284 0.0 0.0 0
10109 250000000 6.284 0.0 0.0 0
10200 3 200. 80.0 0 0
10201 0 0.0 0 0
10202 0 0 0 0
10301 2 -1 -3 -1 0  601 1
* pump vel, init vel ratio, flow gpm, head ft, torq lbft,I,
* dens,init torq 0=calc, frict: CHANGE init vel rat to 0 for no pump
* add 10% pump head and higher rate pump flow
10302 3560.0 0.0 95000.0 273.02 3400.8 380.3 62.3 3240.0 6.7 0 0 0
*
* pump#2
*
20000 loop2 pump
20101 3.142 10.0 0 0 0 0 0
20108 340010000 3.142 0.0 0.0 0
20109 350000000 3.142 0.0 0.0 0
```

```
20200 3 200. 80.0 0 0
20201 0 0 0 0
20202 0 0 0 0
20301 0 -1 -3 -1 0 602 1
* pump vel, init vel ratio, flow gpm, head ft, torq lbft,I,
* dens,init torq 0=calc, frict
* add 10% pump head and rated pump flow
20302 3560.0 0.0 47500.0 273.02 3400.8 380.3 62.3 3240.0 6.7 0 0 0
21100 1  1  0.0  1.826
21101 0.1  1.644
21102 0.2  1.524
21103 0.3  1.417
21104 0.4  1.321
21105 0.5  1.374
21106 0.6  1.323
21107 0.7  1.259
21108 0.8  1.187
21109 0.9  1.085
21110 1.0  1.0
21200 1  2  0.0  -1.42
21201 0.1 -1.254
21202 0.2 -1.094
21203 0.3 -0.927
21204 0.4 -0.73
21205 0.5 -0.51
21206 0.6  0.0
21207 0.7  0.3
21208 0.8  0.54
21209 0.9  0.6887
21210 1.0  1.0
21300 1  3  0.0  1.826
21301 -0.1  1.984
21302 -0.2  2.228
21303 -0.3  2.44
21304 -0.4  2.60
21305 -0.5  2.87
21306 -0.6  3.078
21307 -0.7  3.37
21308 -0.8  3.69
21309 -0.9  4.0
21310 -1.0  4.34
21400 1  4  0.0  1.42
21401 -0.1  1.56
21402 -0.2  1.64
21403 -0.3  1.777
21404 -0.4  1.93
21405 -0.5  2.16
21406 -0.6  2.52
21407 -0.7  2.973
21408 -0.8  3.31
21409 -0.9  3.69
21410 -1.0  4.34
21500 1  5  0.0  0.2
21501 0.1  0.26
21502 0.2  0.30
21503 0.3  0.31
21504 0.4  0.35
21505 0.5  0.38
```

```
21506 0.6  0.4
21507 0.7  0.43
21508 0.8  0.496
21509 0.9  0.610
21510 1.0  0.769
21600 1  6  0.0   1.42
21601 0.1  1.23
21602 0.2  1.04
21603 0.3  0.907
21604 0.4  0.842
21605 0.5  0.826
21606 0.6  0.812
21607 0.7  0.812
21608 0.8  0.797
21609 0.9  0.769
21610 1.0  0.769
21700 1  7  0.0   0.20
21701 -0.1  0.12
21702 -0.2  0.0
21703 -0.3 -0.246
21704 -0.4 -0.513
21705 -0.5 -0.83
21706 -0.6 -1.035
21707 -0.7 -1.60
21708 -0.8 -2.05
21709 -0.9 -2.55
21710 -1.0 -3.10
21800 1  8  0.0  -1.42
21801 -0.1 -1.715
21802 -0.2 -1.96
21803 -0.3 -2.15
21804 -0.4 -2.34
21805 -0.5 -2.52
21806 -0.6 -2.69
21807 -0.7 -2.81
21808 -0.8 -2.93
21809 -0.9 -3.01
21810 -1.0 -3.10
21900 2  1  0.0  1.417
21901 0.1  1.262
21902 0.2  1.156
21903 0.3  1.041
21904 0.4  1.0
21905 0.5  0.961
21906 0.6  0.965
21907 0.7  0.980
21908 0.8  1.0
21909 0.9  1.002
21910 1.0  1.0
22000 2  2  0.0  -1.45
22001 0.1 -1.1
22002 0.2 -0.85
22003 0.3 -0.64
22004 0.4 -0.43
22005 0.5 -0.113
22006 0.6  0.241
22007 0.7  0.406
22008 0.8  0.610
```

```
22009 0.9  0.797
22010 1.0  1.0
22100 2  3  0.0  1.417
22101 -0.1  1.56
22102 -0.2  1.73
22103 -0.3  1.93
22104 -0.4  2.16
22105 -0.5  2.37
22106 -0.6  2.69
22107 -0.7  2.92
22108 -0.8  3.19
22109 -0.9  3.56
22110 -1.0  4.0
22200 2  4  0.0  1.49
22201 -0.1  1.64
22202 -0.2  1.777
22203 -0.3  1.93
22204 -0.4  2.1
22205 -0.5  2.37
22206 -0.6  2.60
22207 -0.7  2.92
22208 -0.8  3.19
22209 -0.9  3.56
22210 -1.0  4.0
22300 2  5  0.0  -1.32
22301 0.1  -0.89
22302 0.2  -0.61
22303 0.3  -0.40
22304 0.4  -0.24
22205 0.5  -0.118
22306 0.6  0.0
22307 0.7  0.12
22308 0.8  0.251
22309 0.9  0.391
22310 1.0  0.503
22400 2  6  0.0   1.49
22401 0.1  1.42
22402 0.2  1.35
22403 0.3  1.23
22404 0.4  1.13
22405 0.5  01.02
22406 0.6  0.916
22407 0.7  0.826
22408 0.8  0.718
22409 0.9  0.620
22410 1.0  0.503
22500 2  7  0.0   -1.32
22501 -0.1  -1.66
22502 -0.2  -1.91
22503 -0.3 -2.19
22504 -0.4 -2.49
22505 -0.5 -2.83
22506 -0.6 -3.42
22507 -0.7 -3.60
22508 -0.8 -4.05
22509 -0.9 -4.54
22510 -1.0 -5.03
22600 2  8  0.0  -1.45
```

```
22601 -0.1 -1.85
22602 -0.2 -2.20
22603 -0.3 -2.52
22604 -0.4 -2.85
22605 -0.5 -3.15
22606 -0.6 -3.49
22607 -0.7 -3.84
22608 -0.8 -4.23
22609 -0.9 -4.61
22610 -1.0 -5.03
*
* pump#3 modeled as a volume
30000 pump3   branch
30001 2   1
30101 3.142 10.0 0.0 0.0 0.0 0.0 0.00015  100.0  0010
30200 3 200. 80.0
31101 370010000 3000000  3.142  6.91  6.91  0
31201 0.0  0.0  0.0
32101 3010000 380000000  3.142  6.91  6.91  0
32201 0.0  0.0  0.0
*
*
20500100 tr503 tripdlay  1.0  -1.0  0
20500101  503
20500200 tr504 tripdlay  1.0  -1.0  0
20500201  504
20500300 tr601 tripdlay  1.0  -1.0  0
20500301  601
20500400 tr602 tripdlay  1.0  -1.0  0
20500401  602
*
16100  508
16101  0.0    0.0
16102  1.0   3560.0
26100  509
26101  0.0    0.0
26102  1.0   3560.0
*
*
*  heat slab for pressurizer
*
11000000   2  3  2  1  3.5
11000100   0  2
11000101   0.005  2
11000201   1  2
11000301   0.0  2
11000401   80.0  3
11000501   410010000  10000  1  1  4.06  2
11000601   0  0  0  1  4.06  2
11000701   101  0.0  0.5  0.0  2
11000801   0.0  3.0  3.0  0.0  0.0  0.0  0.0  1.0  2
*
*  heat slab for reactor vessel
*
11100000   3  3  2  1  3.5
11100100   0  2
11100101   0.005  2
11100201   1  2
```

```
11100301   0.0  2
11100401   80.0  3
11100501   130010000  10000  1  1  3.556  3
11100601   0  0  0  1  3.556  3
11100701   102  0.0  0.33333  0.0  3
11100801   0.0  3.0  3.0  0.0  0.0  0.0  0.0  1.0  3
*
*  heat slab for pump1
*
11200000   1  3  2  1  1.0
11200100   0  2
11200101   0.005  2
11200201   1  2
11200301   0.0  2
11200401   80.0  3
11200501   250010000  0  1  1  11.96 1
11200601   0  0  0  1  11.96   1
11200701   103  0.0  1.0  0.0  1
11200801   0.0  3.0  3.0  0.0  0.0  0.0  0.0  1.0  1
*
*
*  heat slab for pump2
*
11300000   1  3  2  1  1.0
11300100   0  2
11300101   0.005  2
11300201   1  2
11300301   0.0  2
11300401   80.0  3
11300501   350010000  0  1  1  11.96 1
11300601   0  0  0  1  11.96   1
11300701   104  0.0  1.0  0.0  1
11300801   0.0  3.0  3.0  0.0  0.0  0.0  0.0  1.0  1
*
*  heat structure property
*
20100100   c-steel
*
*   general table
*
20210100   power
20210101   0.0  0.0
20210102   19.999  0.0
20210103   20.0  0.9
20210104   1000.0  0.9
20210200   power
20210201   0.0  0.0
20210202   19.999  0.0
20210203   20.0  25.7
20210204   1000.0  25.7
20210300   power
20210301   0.0  0.0
20210302   19.999  0.0
20210303   20.0  2.8
20210304   1000.0  2.8
20210400   power
20210401   0.0  0.0
20210402   19.999  0.0
```

```
20210403   20.0  1.4
20210404   1000.0  1.4
*
20510100  qpzre  sum  1.0e-6  0.0  1
20510101  0.0  1.0  q  410010000  1.0  q  410020000
20510200  qcore  sum  1.0e-6  0.0  1
20510201  0.0  1.0  q  130010000  1.0  q  130020000
20510202  1.0  q  130030000
20510300  qpmp1  sum  1.0e-6  0.0  1
20510301  0.0  1.0  q  250010000
20510400  qpmp2  sum  1.0e-6  0.0  1
20510401  0.0  1.0  q  350010000
*********
20510500   tcleg  sum   1.0  0.0  1
20510501   -459.67  1.8  tempf  360010000
20510600   ppzr   sum   1.0  0.0  1
20510601   0.0  1.4504e-4  p   410060000
* LTOP Analysis Curve
20220100   reac-t
20220101   0.0        459.0
20220102   160.0      459.0
20220103   170.0      470.0
20220104   180.0      500.0
20220105   190.0      540.0
20220106   200.0      590.0
20220107   210.0      640.0
20220108   220.0      690.0
20220109   230.0      750.0
20220110   240.0      830.0
20220111   250.0      920.0
20220112   260.0     1010.0
20220113   270.0     1100.0
20220114   280.0     1200.0
20220115   290.0     1300.0
20220116   300.0     1400.0
20220117   310.0     1500.0
20220118   320.0     1608.0
20220119   340.0     1809.1
20220120   400.0     1809.1
*
20520100   porvst   function  1.0  0.0  1
20520101   cntrlvar   105     201
*
* Capture peak pressure
20530100   oldp delay 1.0 0.0 0
20530101   cntrlvar 302 1.0e-6 1
20530200   maxp stdfnctn 1.0 0.0 0
20530201   max p 410060000 cntrlvar 301
20530600   pmax   sum   1.0  0.0  1
20530601   0.0  1.4504e-4  cntrlvar 302
* input change for m364p2
* Change initial P and T (P = 200, T = 364)
2001201 3 200. 364.0 0 0 0 2
2100200   3   200. 364.0
2201201 3 200. 364.0 0 0 0,6
2300200   3   200. 364.0
2401201 3 200. 364.0 0 0 0,2
2500200   3   200. 364.0
```

```
2601201 3 200. 364.0 0 0 0,2
3000200   3   200. 364.0
3010200   3   200. 364.0
4001201 3 200. 364.0 0 0 0,10
4101201   3   200.  364.00   0.  0 0,5
4101202   3   200.  364.00   0.  0 0,6
3020200   3   200. 364.0
3100200   3   200. 364.0
3201201 3 200. 364.0 0 0 0,6
3300200   3   200. 364.0
3401201 3 200. 364.0 0 0 0,2
3500200   3   200. 364.0
3601201 3 200. 364.0 0 0 0,2
3701201 3 200. 364.0 0 0 0,2
3800200   3   200. 364.0
3901201 3 200. 364.0 0 0 0,2
1000200   3   200. 364.0
1101201 3 200. 364.0 0 0 0,2
1200200   3   200. 364.0
1301201 3 200. 364.0 0 0 0,3
1500200   3   200. 364.0
1600200   3   200. 364.0
10200 3 200. 364.0 0 0
20200 3 200. 364.0 0 0
30200 3 200. 364.0
11000401   364.0  3
11100401   364.0  3
11200401   364.0  3
11300401   364.0  3
2520201          0.0          0.0         0.0        0.0
2520202         10.0       70.366         0.0        0.0
2520203        100.0       68.280         0.0        0.0
2520204        200.0       66.611         0.0        0.0
2520205        300.0       64.247         0.0        0.0
2520206        400.0       62.439         0.0        0.0
2520207        500.0       59.658         0.0        0.0
2520208        600.0       57.572         0.0        0.0
2520209        700.0       55.069         0.0        0.0
2520210        800.0       51.314         0.0        0.0
2520211        900.0       47.421         0.0        0.0
2520212       1000.0       43.249         0.0        0.0
2520213       1100.0       37.686         0.0        0.0
2520214       1200.0       32.263         0.0        0.0
2520215       1300.0       24.475         0.0        0.0
2520216       1400.0        9.178         0.0        0.0
3520201          0.0        0.0           0.0        0.0
3520202         10.0       35.183         0.0        0.0
3520203        100.0       34.140         0.0        0.0
3520204        200.0       33.306         0.0        0.0
3520205        300.0       32.124         0.0        0.0
3520206        400.0       31.220         0.0        0.0
3520207        500.0       29.829         0.0        0.0
3520208        600.0       28.786         0.0        0.0
3520209        700.0       27.535         0.0        0.0
3520210        800.0       25.657         0.0        0.0
3520211        900.0       23.710         0.0        0.0
3520212       1000.0       21.624         0.0        0.0
3520213       1100.0       18.843         0.0        0.0
```

```
3520214      1200.0       16.131        0.0        0.0
3520215      1300.0       12.238        0.0        0.0
3520216      1400.0        4.589        0.0        0.0
3820201         0.0        0.0          0.0        0.0
3820202        10.0       35.183        0.0        0.0
3820203       100.0       34.140        0.0        0.0
3820204       200.0       33.306        0.0        0.0
3820205       300.0       32.124        0.0        0.0
3820206       400.0       31.220        0.0        0.0
3820207       500.0       29.829        0.0        0.0
3820208       600.0       28.786        0.0        0.0
3820209       700.0       27.535        0.0        0.0
3820210       800.0       25.657        0.0        0.0
3820211       900.0       23.710        0.0        0.0
3820212      1000.0       21.624        0.0        0.0
3820213      1100.0       18.843        0.0        0.0
3820214      1200.0       16.131        0.0        0.0
3820215      1300.0       12.238        0.0        0.0
3820216      1400.0        4.589        0.0        0.0
* Add extra dP to nozzles
1502101   150010000  200000000   5.585   1.484  1.651  0000
1503101   150010000  300000000   5.585   1.484  1.651  0000
* Add stronger pump to offset extra dP
10302 3560.0 0.0 95000.0 290.0 3400.8 380.3 62.3 3240.0 6.7 0 0 0
20302 3560.0 0.0 47500.0 290.0 3400.8 380.3 62.3 3240.0 6.7 0 0 0
* Change end time
501  time   0            ge   null    0    100.0       1
*
* changes for RSG/RPZR
* new RSG inlet nozzle flow resistance
2010101   200010000   210000000   5.585   0.327   0.121   0000
3030101   302010000   310000000   5.585   0.327   0.121   0000
* RSG has larger inlet plenum
2100101   22.0   6.087  0.0   0.0   90.0  6.087   0.00015  100.0 0010
3100101   22.0   6.087  0.0   0.0   90.0  6.087   0.00015   100.0   0010
* RSG has larger tube area, less flow resistance
2110101   210010000   220000000   11.25   0.23   0.477   0000
3110101   310010000   320000000   11.25   0.23   0.477   0000
* RSG has larger tube area
2200101 11.25,6
2200201 11.25,5
3200101 11.25,6
3200201 11.25,5
* RSG has longer tubes
2200301 8.72,6
2200701   8.72   3
2200702  -8.72   6
3200301 8.72,6
3200701   8.72   3
3200702  -8.72   6
* RSG tube hydraulic diameter is larger, add friction
2200801 0.00000  0.0553   6
3200801 0.00000  0.0553   6
* Let RELAP calc friction, so Kf & Kr of RSG tubes are zero
2200901 0.0  0.0,  5
3200901 0.0  0.0   5
* new RSG tube area, Kf and Kr
2210101   220010000   230000000   11.25   0.477   0.23   0000
```

```
3301101   320010000   330000000   11.25   0.477   0.23  0000
* larger RSG outlet plenum
2300101   22.2  6.087  0.0   0.0  -90.0  -6.087  0.00015  100.0  0010
* new RSG exit nozzle losses
2310101   230010000   240000000   6.284   0.176   0.278   0000
3302101   330010000  340000000    3.142   0.176   0.278   0000
3303101   330010000  370000000    3.142   0.176   0.278   0000
* Changes in Surgeline Length and delta-E
4000301 7.595,1
4000303 7.595,10
4000701 7.595,1
4000703 7.595,10
* Slight Pressurizer area change to keep total volume correct
4100101   37.06,6
4100201   37.06,5
* RPZR is longer
4100301   4.227,6
* RPSR is longer, so heat slab elongated
11000501   410010000  10000  1  1  4.227  2
11000601   0  0  0  1  4.227  2
* Decay heat is uprated 117.5%  to 30.3 MW
20210203   20.0  30.3
20210204   1000.0  30.3
* Revised time steps to simplify output (no major edits)
201  2.0  1.0-6 0.010 5 10      100000    100000
202  20.0  1.0-6 0.001 5 100    100000    100000
203  1000.0  1.0-6 0.0005 5 40  100000    100000
*end of cases
.
```

HP509S36.TXT

```
=Fort Calhoun LTOP Model for Steam Gen Replacement
* Case 10, Tinit=50F, Pinit=170psia, SGT=364F, PZR void = 40%
*
100 new transnt
102 british british
105
*****
*  time step control
*
201  2.0  1.0-6 0.010 5 10 250    1000
202  20.0  1.0-6 0.001 5 100 5000 10000
203  1000.0  1.0-6 0.0005 5 40 20000 100000
*
* Output control
*
301 p 120010000
302 p 410060000
303 p 301010000
304 p 200020000
305 voidg 410060000
306 tempf  410060000
307 tempf  360010000
311 mflowj 401000000
312 mflowj 311000000
313 mflowj 330020000
314 mflowj 330030000
315 mflowj 252000000
316 mflowj 352000000
317 mflowj 382000000
318 mflowj 420000000
319 mflowj 211000000
321 cntrlvar   1
322 cntrlvar   2
323 cntrlvar   3
324 cntrlvar   4
325 cntrlvar   201
326 cntrlvar   106
327 cntrlvar   101
328 cntrlvar   102
329 cntrlvar   103
330 cntrlvar   104
331 pmphead  1
332 pmphead  2
333 cntrlvar   306
**********************
*  trip cards
*  501 run stop time
*  502  si and charging start time
*  503  porv set point
*  504  porv delay time
*  505  rcp 1 stop time
*  506  rcp 2 stop time
*  507  rcp 3 stop time
*  508  rcp 1 start time
*  509  rcp 2 start time
*  510  porv close trip (intentionally gt end time)
```

```
*  520  heat to pressurizer
*  521  decay heat control
*  522  sg secondary side temp control
*  600 run stop
*  601 rcp 1 run control
*  602 rcp 2 run control
*  603 rcp 3 run control
*********************
501  time   0            ge   null    0     50.0      l
502  time   0            ge   null    0     20.0      l
503  cntrlvar   106      ge   cntrlvar  201  0.0      l
504  time   0            ge  timeof   503    1.5      l
505  time   0            ge   null    0      0.0      l
506  time   0            ge   null    0      0.0      l
508  time   0            ge   null    0      2.0      l
509  time   0            ge   null    0      2.0      l
510  time   0            ge  timeof   503    5000.0   l
600  501
601  505  and  -508  n
602  506  and  -509  n
* Non-Pressurizer Loop
*
* LEFT HOT LEG
* first pipe has explanatory notes
2000000 hleg1 pipe
* number of nodes
2000001 2
* area of nodes, then interior junctions
2000101 5.585,2
2000201 5.585,1
* node lengths
2000301 7.54,2
* vertical angle
2000601 0.0,2
* Elevation change = either length*angle or use a card 701
* Pipe friction, hydraulic dia, node#
2000801 0.00015  0.0  2
* forward K, reverse K, junc#
2000901 .096  .096  1
* required volume flags, in 1101 use 0100 if an abrupt area change
2001001 0   2
2001101 0   1
* with 3, init-P, init-T, init-T, three 0, node#
2001201 3 200. 80.0 0 0 0 2
* liq vel ft/s, vapor vel, interface=0 junc#
2001301 0.0 0.0 0.0,1
*
*
* LEFT HOT LEG TO SG JUNCTION
2010000   Lhl-Lsg    sngljun
* from, to, minimum area, forwrd-K, reverse-K,0100=abrupt area change(0000
else)
2010101   200010000   210000000   5.585   0.317   0.156   0000
* 0=velocities, liq vel ft/s, vapor vel, interface=0
2010201   0   0.0   0.0   0.0
*
* LEFT SG HOT PLENUM
2100000   Lsgip    snglvol
```

```
* area,length,vol(=0 to calc),az angle=0, vert angle,elev
change,rough,HD,flags
2100101   20.4   6.087  0.0    0.0    90.0  6.087   0.00015  100.0 0010
2100200   3   200. 80.0
*
* LEFT SG HOT PLENUM TO SG TUBES
2110000   Lhp-tub    sngljun
2110101   210010000   220000000   8.651   0.76  0.38   0000
2110201   0   0.0   0.0   0.0
*
* LEFT STEAM GENERATOR TUBES
2200000 lsg pipe
2200001 6
2200101 8.651,6
2200201 8.651,5
2200301 8.71,6
2200601 90.0,3
2200602 -90.0,6
2200701   8.71   3
2200702  -8.71   6
2200801 0.0  0.0544   6
2200901 0.066  0.066  5
2201001 0,6
2201101 0,5
2201201 3 200. 80.0 0 0 0,6
2201301 0.0 0.0 0.0,5
*
* LEFT STEAM GEN TUBES TO COLD PLENUM
2210000   tub-Lcp    sngljun
2210101   220010000   230000000   8.561   1.53   1.12   0000
2210201   0   0.0   0.0   0.0
*
* LEFT SG COLD PLENUM
2300000   Lsgcp    snglvol
2300101   20.0  6.087  0.0   0.0  -90.0  -6.087  0.00015  100.0  0010
2300200   3   200. 80.0
*
* LEFT SG COLD PLENUM TO CROSSOVER LEG
2310000   Lcp-Lxo    sngljun
2310101   230010000   240000000   6.284  .41   .41   0000
2310201   0   0.0   0.0   0.0
*
* LEFT CROSSOVER
2400000 Lxover pipe
2400001 2
2400101 6.284,2
2400201 6.284,1
2400301 12.175,2
2400601 0.0,2
2400801 0.00015,2.0,2
2400901 0.0  0.0  1
2401001 0,2
2401101 0,1
2401201 3 200. 80.0 0 0 0,2
2401301 0.0 0.0 0.0,1
*
* LEFT SI/CHARGING BRANCH
2500000   Lsi   branch
```

```
2500001   1   0
2500101   6.284  11.96   0.0   0.0   0.0   0.0   0.0   100.0   0010
2500200   3   200. 80.0
2501101   250010000  260000000   6.284  0.0  0.0   0000
2501201   0.0  0.0   0.0
*
* DOUBLE COLD LEG SI TIME DEPENDENT VOLUME
2510000       si2       tmdpvol
* flow area, length, volume, horiz angle, vert angle
2510101       50.0   10.0        0.0      0.0      0.0
* elev change, roughness, hydraulic diameter, flags
2510102       0.0       0.0        0.0     00
* 3 makes 201 card P&T, trip number
2510200        3
2510201       0.0      90.0      250.0
2510202     1000.0     90.0      250.0
*
* DOUBLE COLD LEG SI TIME DEPENDENT JUNCTION

2520000       si2flow tmdpjun
* from, to, area
2520101       251000000     250000000     1.0
* 1 means mass flows/0=velocity, trip number, table var & location
2520200       1            502        p       250010000
* pressure, liq lbm/s, vapor velocity, interface (=0) 1 Pump Curve
2520201         0.0        0.0           0.0         0.0
2520202        10.0        9.178         0.0         0.0
2520203      2000.0        9.178         0.0         0.0
*
* LEFT COLD LEG
2600000 cleg1 pipe
2600001 2
2600101 6.284,2
2600201 6.284,1
2600301 8.60,2
2600601 0.0,2
2600801 0.00015,2.0,2
2600901 .0717 .0717,1
2601001 0,2
2601101 0,1
2601201 3 200. 80.0 0 0 0,2
2601301 0.0 0.0 0.0,1
*
* Pressurizer Loop
*
* RIGHT HOT LEG TO PRESSURIZER BRANCH
3000000   Rhl1    snglvol
3000101   5.585   5.02 0.0   0.0   0.0 0.0   0.00015   0.0  00
3000200   3   200. 80.0
*
* RIGHT HOT LEG-PRESSURIZER BRANCH
3010000   hlegprz   branch
* Number paths described, 0 means velocities are input on 201 cards
3010001   3   0
* Area, length, volume, horz angle, inclination, elev change,rough,HD,flags
3010101   5.585   5.02   0.0   0.0   0.0   0.0   0.00015   0.0   00
* Initial P and T
3010200   3   200. 80.0
```

```
* from, to, area, K-forward, K-reverse, flags (=100 for sudden area change)
3011101   300010000  301000000   5.585   0.048   0.048   0000
3012101   301010000  302000000   5.585   0.048   0.048   0000
3013101   301010000  400000000   0.394   2.34     1.95   0000
* liq vel, steam vel, interface(=0)
3011201   0.0  0.0   0.0
3012201   0.0   0.0   0.0
3013201   0.0     0.0   0.0
*
* SURGELINE
4000000 surgline pipe
4000001 10
4000101 0.394,10
4000201 0.394,9
4000301 8.021,1
4000302 6.678,9
4000303 8.021,10
4000601 90.0,1
4000602 0.0,9
4000603 90.0,10
4000701 8.021,1
4000702 0.0,9
4000703 8.021,10
4000801 0.00015,0.0,10
4000901 0.0  0.0   9
4001001 0,10
4001101 0,9
4001201 3 200. 80.0 0 0 0,10
4001301 0.0,0.0,0.0,9
*
* SURGELINE JUNCTION TO PRESSURIZER
4010000   sl-p    sngljun
4010101   400010000   410000000   0.394   1.0   0.5   0000
4010201   0   0.0   0.0   0.0
*
* PRESSURIZER
4100000   pres   pipe
4100001   6
4100101   36.94,6
4100201   36.94,5
4100301   4.06,6
4100601   90.   6
4100801   0.00015  0.0  6
4100901   0.0    0.0   5
4101001   0,6
4101101   0,5
*Manually set Przr pressure and water level
4101201   3   200.  80.00   0.  0 0,5
4101202   3   200.  80.00   0.  0 0,6
4101300   1
4101301   0.0    0.0    0.0,5
*
* PORV
4200000   porv   valve
4200101   410010000   430000000   0.00535   0.0   0.0   0100
4200201   0   0.0   0.0   0.0
4200300   mtrvlv
4200302   504  510  2.0  0.0
```

```
*
* PORV BACKPRESSURE
4300000   cont tmdpvol
4300101   50. 10.0   0.0   0.0   0.0   0.0   0.0   0.0   00
4300200   3
4300201   0.0   90.0   50.0
4300202   1000.0   90.0   50.0
*
* RIGHT HOT LEG, PRZR TO STEAM GEN
3020000   Rhl2    snglvol
3020101   5.585   5.02 0.0   0.0   0.0 0.0   0.00015   0.0   00
3020200   3   200. 80.0
*
* RIGHT HOT LEG TO SG JUNCTION
3030000   Rhl-Rsg    sngljun
3030101   302010000   310000000   5.585   0.317   0.156   0000
3030201   0   0.0   0.0   0.0
*
* RIGHT SG HOT PLENUM
3100000   Rsgip    snglvol
3100101   20.4   6.087  0.0   0.0   90.0  6.087   0.00015   100.0   0010
3100200   3   200. 80.0
*
* RIGHT SG HOT PLENUM TO SG TUBES
3110000   Rhp-tub    sngljun
3110101   310010000   320000000   8.651   0.76   0.38   0000
3110201   0   0.0   0.0   0.0
*
* RIGHT STEAM GENERATOR TUBES
3200000 Rsg pipe
3200001 6
3200101 8.651,6
3200201 8.651,5
3200301 8.71,6
3200601 90.0,3
3200602 -90.0,6
3200701   8.71   3
3200702  -8.71   6
3200801 0.0  0.0544   6
3200901 0.066 0.066  5
3201001 0,6
3201101 0,5
3201201 3 200. 80.0 0 0 0,6
3201301 0.0 0.0 0.0,5
*
* RIGHT COLD PLENUM BRANCH
3300000   Rsgcp   branch
3300001   3   0
3300101   20.0  6.087  0.0  0.0   -90.0   -6.087   0.00015  100.0   0010
3300200   3   200. 80.0
3301101   320010000  330000000   8.651   1.53   1.12   0000
3302101   330010000  340000000   3.142   0.41   0.41   0000
3303101   330010000  370000000   3.142   0.41   0.41   0000
3301201   0.0   0.0   0.0
3302201   0.0   0.0   0.0
3303201   0.0   0.0   0.0
*
* RIGHT CROSSOVER, RCP LINE
```

```
3400000 Rxover1 pipe
3400001 2
3400101 3.142,2
3400201 3.142,1
3400301 12.175,2
3400601 0.0,2
3400801 0.00015,2.0,2
3400901 0.0  0.0   1
3401001 0,2
3401101 0,1
3401201 3 200. 80.0 0 0 0,2
3401301 0.0 0.0 0.0,1
*
*
* RIGHT SI/CHARGING BRANCH
3500000   Rsi1   branch
3500001   1   0
3500101   3.142  11.96   0.0   0.0   0.0   0.0   0.00015   2.0     00
3500200   3   200. 80.0
3501101   350010000  360000000   3.142   0.0  0.0   0000
* liq vel, steam vel, interface(=0)
3501201   0.0  0.0   0.0
*
*
* SINGLE COLD LEG SI TIME DEPENDENT VOLUME
3510000        si1a       tmdpvol
* flow area, length, volume, horiz angle, vert angle
3510101       50.0   10.0       0.0      0.0      0.0
* elev change, roughness, hydraulic diameter, flags
3510102        0.0       0.0       0.0     00
* 3 makes 201 card P&T, trip number
3510200         3
3510201        0.0      90.0      250.0
3510202     1000.0     90.0      250.0
*
* SINGLE COLD LEG SI TIME DEPENDENT JUNCTION
3520000        si1aflow tmdpjun
* from, to, area
3520101        351000000      350000000      1.0
* 1 means mass flows/0=velocity, trip number, table var & location
3520200       1             502         p       350010000
* pressure, liq velocity, vapor velocity, interface (=0) 1 Pump
3520201          0.0        0.0           0.0         0.0
3520202         10.0        9.178         0.0         0.0
3520203       2000.0        9.178         0.0         0.0
*
*
* RIGHT COLD LEG, RCP LINE
3600000 cleg1 pipe
3600001 2
3600101 3.142,2
3600201 3.142,1
3600301 8.60,2
3600601 0.0,2
3600801 0.00015,2.0,2
3600901 .0717 .0717,1
3601001 0,2
3601101 0,1
```

```
3601201 3 200. 80.0 0 0 0,2
3601301 0.0 0.0 0.0,1
*
*
* RIGHT CROSSOVER, NO RCP LINE
3700000 Rxover2 pipe
3700001 2
3700101 3.142,2
3700201 3.142,1
3700301 12.175,2
3700601 0.0,2
3700801 0.00015,2.0,2
3700901 0.0  0.0   1
3701001 0,2
3701101 0,1
3701201 3 200. 80.0 0 0 0,2
3701301 0.0 0.0 0.0,1
*
* comment out 380, 381, 382 to use pump3
* RIGHT SI/CHARGING BRANCH
3800000   Rsi2   branch
3800001   1   0
3800101   3.142   11.96   0.0   0.0   0.0   0.0   0.00015   2.0   00
3800200   3   200. 80.0
3801101   380010000  390000000   3.142   0.0  0.0   0000
* liq vel, steam vel, interface(=0)
3801201   0.0  0.0   0.0
*
*
* SINGLE COLD LEG SI TIME DEPENDENT VOLUME
3810000       si1b      tmdpvol
* flow area, length, volume, horiz angle, vert angle
3810101       50.0   10.0     0.0     0.0     0.0
* elev change, roughness, hydraulic diameter, flags
3810102       0.0      0.0       0.0    00
* 3 makes 201 card P&T, trip number
3810200        3
3810201       0.0     90.0      250.0
3810202     1000.0    90.0      250.0
*
* DOUBLE COLD LEG SI TIME DEPENDENT JUNCTION
3820000       si1bflow tmdpjun
* from, to, area
3820101       381000000     380000000     1.0
* 1 means mass flows/0=velocity, trip number, table var & location
3820200       1             502         p       380010000
* pressure, liq velocity, vapor velocity, interface (=0) 1 Pump
3820201         0.0        0.0           0.0        0.0
3820202        10.0        9.178         0.0        0.0
3820203      2000.0        9.178         0.0        0.0
*
* RIGHT COLD LEG, NO RCP LINE
3900000 cleg1 pipe
3900001 2
3900101 3.142,2
3900201 3.142,1
3900301 8.60,2
3900601 0.0,2
```

```
3900801 0.00015,2.0,2
3900901 .0717 .0717,1
3901001 0,2
3901101 0,1
3901201 3 200. 80.0 0 0 0,2
3901301 0.0 0.0 0.0,1
*
* Reactor Core
*
* CORE INLET BRANCH
1000000   inlet   branch
1000001   4   0
1000101   12.566   3.5   0.0   0.0   0.0   0.0   0.00015   0.0   00
1000200   3   200. 80.0
1001101   260010000  100000000   6.284    0.295   0.252   0000
1002101   360010000  100000000   3.142    0.295   0.252   0000
1003101   390010000  100000000   3.142    0.295   0.252   0000
1004101   100010000  110000000   12.566   0.074   0.063   0000
1001201   0.0   0.0   0.0
1002201   0.0   0.0   0.0
1003201   0.0   0.0   0.0
1004201   0.0   0.0   0.0
*
* DOWNCOMER
1100000 downcmr annulus
1100001 2
1100101 23.33,2
1100201 23.33,1
1100301 12.671,2
1100601 -90.0,2
1100701 -12.671,2
1100801 0.00015,0.3775,2
1100901 1.27  1.08  1
1101001 0,2
1101101 0,1
1101201 3 200. 80.0 0 0 0,2
1101301 0.0 0.0 0.0,1
*
* DOWNCOMER TO LOWER CORE PLENUM
1110000   dwn-plen    sngljun
1110101   110010000   120000000   23.33   1.27   1.08   0000
1110201   0   0.0   0.0   0.0
*
* LOWER CORE PLENUM
1200000   plenum    snglvol
1200101   61.67   9.14  0.0   0.0   90.0  9.14   0.00015   0.0 00
1200200   3   200. 80.0
*
* LOWER CORE PLENUM TO CORE
1210000   pln-core    sngljun
1210101   120010000   130000000   47.26   10.35   27.55   0000
1210201   0   0.0   0.0   0.0
*
* REACTOR CORE
1300000 core pipe
1300001 3
1300101 47.26,3
1300201 47.26,2
```

```
1300301 3.556,3
1300601 90.0,3
1300701 3.556,3
1300801 0.00015,0.0414,3
1300901 5.29  6.27  2
1301001 0,3
1301101 0,2
1301201 3 200. 80.0 0 0 0,3
1301301 0.0 0.0 0.0,2
*
* REACTOR OUTLET BRANCH
1500000   outlet   branch
1500001   4   0
1500101   74.65    5.534  0.0    0.0    90.0  5.534   0.00015    0.0    00
1500200   3   200. 80.0
1501101   130010000  150000000   47.26   6.88   9.86   0000
1502101   150010000  200000000   5.585   0.384  0.551  0000
1503101   150010000  300000000   5.585   0.384  0.551  0000
1504101   150010000  160000000   69.61   1.0    1.0    0000
1501201   0.0   0.0   0.0
1502201   0.0   0.0   0.0
1503201   0.0   0.0   0.0
1504201   0.0   0.0   0.0
*
* REACTOR UPPER HEAD
1600000   upperhd    snglvol
1600101   69.61    12.08    0.0    0.0    90.0  12.08    0.00015    0.0 00
1600200   3   200. 80.0
*
* pump# 1
10000 loop1 pump
10101 6.284   10.0 0 0 0 0 0
10108 240010000 6.284 0.0 0.0 0
10109 250000000 6.284 0.0 0.0 0
10200 3 200. 80.0 0 0
10201 0 0.0 0 0
10202 0 0 0 0
10301 2 -1 -3 -1 0  601 1
* pump vel, init vel ratio, flow gpm, head ft, torq lbft,I,
* dens,init torq 0=calc, frict: CHANGE init vel rat to 0 for no pump
* add 10% pump head and higher rate pump flow
10302 3560.0 0.0 95000.0 273.02 3400.8 380.3 62.3 3240.0 6.7 0 0 0
*
* pump#2
*
20000 loop2 pump
20101 3.142 10.0 0 0 0 0 0
20108 340010000 3.142 0.0 0.0 0
20109 350000000 3.142 0.0 0.0 0
20200 3 200. 80.0 0 0
20201 0 0 0 0
20202 0 0 0 0
20301 0 -1 -3 -1 0 602 1
* pump vel, init vel ratio, flow gpm, head ft, torq lbft,I,
* dens,init torq 0=calc, frict
* add 10% pump head and rated pump flow
20302 3560.0 0.0 47500.0 273.02 3400.8 380.3 62.3 3240.0 6.7 0 0 0
21100 1  1  0.0  1.826
```

```
21101 0.1  1.644
21102 0.2  1.524
21103 0.3  1.417
21104 0.4  1.321
21105 0.5  1.374
21106 0.6  1.323
21107 0.7  1.259
21108 0.8  1.187
21109 0.9  1.085
21110 1.0  1.0
21200 1  2  0.0  -1.42
21201 0.1 -1.254
21202 0.2 -1.094
21203 0.3 -0.927
21204 0.4 -0.73
21205 0.5 -0.51
21206 0.6  0.0
21207 0.7  0.3
21208 0.8  0.54
21209 0.9  0.6887
21210 1.0  1.0
21300 1  3  0.0  1.826
21301 -0.1  1.984
21302 -0.2  2.228
21303 -0.3  2.44
21304 -0.4  2.60
21305 -0.5  2.87
21306 -0.6  3.078
21307 -0.7  3.37
21308 -0.8  3.69
21309 -0.9  4.0
21310 -1.0  4.34
21400 1  4  0.0  1.42
21401 -0.1  1.56
21402 -0.2  1.64
21403 -0.3  1.777
21404 -0.4  1.93
21405 -0.5  2.16
21406 -0.6  2.52
21407 -0.7  2.973
21408 -0.8  3.31
21409 -0.9  3.69
21410 -1.0  4.34
21500 1  5  0.0  0.2
21501 0.1  0.26
21502 0.2  0.30
21503 0.3  0.31
21504 0.4  0.35
21505 0.5  0.38
21506 0.6  0.4
21507 0.7  0.43
21508 0.8  0.496
21509 0.9  0.610
21510 1.0  0.769
21600 1  6  0.0   1.42
21601 0.1  1.23
21602 0.2  1.04
21603 0.3  0.907
```

```
21604 0.4  0.842
21605 0.5  0.826
21606 0.6  0.812
21607 0.7  0.812
21608 0.8  0.797
21609 0.9  0.769
21610 1.0  0.769
21700 1  7  0.0   0.20
21701 -0.1  0.12
21702 -0.2  0.0
21703 -0.3 -0.246
21704 -0.4 -0.513
21705 -0.5 -0.83
21706 -0.6 -1.035
21707 -0.7 -1.60
21708 -0.8 -2.05
21709 -0.9 -2.55
21710 -1.0 -3.10
21800 1  8  0.0  -1.42
21801 -0.1 -1.715
21802 -0.2 -1.96
21803 -0.3 -2.15
21804 -0.4 -2.34
21805 -0.5 -2.52
21806 -0.6 -2.69
21807 -0.7 -2.81
21808 -0.8 -2.93
21809 -0.9 -3.01
21810 -1.0 -3.10
21900 2  1  0.0  1.417
21901 0.1  1.262
21902 0.2  1.156
21903 0.3  1.041
21904 0.4  1.0
21905 0.5  0.961
21906 0.6  0.965
21907 0.7  0.980
21908 0.8  1.0
21909 0.9  1.002
21910 1.0  1.0
22000 2  2  0.0  -1.45
22001 0.1 -1.1
22002 0.2 -0.85
22003 0.3 -0.64
22004 0.4 -0.43
22005 0.5 -0.113
22006 0.6  0.241
22007 0.7  0.406
22008 0.8  0.610
22009 0.9  0.797
22010 1.0  1.0
22100 2  3  0.0  1.417
22101 -0.1  1.56
22102 -0.2  1.73
22103 -0.3  1.93
22104 -0.4  2.16
22105 -0.5  2.37
22106 -0.6  2.69
```

```
22107 -0.7  2.92
22108 -0.8  3.19
22109 -0.9  3.56
22110 -1.0  4.0
22200 2  4  0.0  1.49
22201 -0.1  1.64
22202 -0.2  1.777
22203 -0.3  1.93
22204 -0.4  2.1
22205 -0.5  2.37
22206 -0.6  2.60
22207 -0.7  2.92
22208 -0.8  3.19
22209 -0.9  3.56
22210 -1.0  4.0
22300 2  5  0.0  -1.32
22301 0.1  -0.89
22302 0.2  -0.61
22303 0.3  -0.40
22304 0.4  -0.24
22205 0.5  -0.118
22306 0.6  0.0
22307 0.7  0.12
22308 0.8  0.251
22309 0.9  0.391
22310 1.0  0.503
22400 2  6  0.0   1.49
22401 0.1  1.42
22402 0.2  1.35
22403 0.3  1.23
22404 0.4  1.13
22405 0.5  01.02
22406 0.6  0.916
22407 0.7  0.826
22408 0.8  0.718
22409 0.9  0.620
22410 1.0  0.503
22500 2  7  0.0   -1.32
22501 -0.1  -1.66
22502 -0.2  -1.91
22503 -0.3 -2.19
22504 -0.4 -2.49
22505 -0.5 -2.83
22506 -0.6 -3.42
22507 -0.7 -3.60
22508 -0.8 -4.05
22509 -0.9 -4.54
22510 -1.0 -5.03
22600 2  8  0.0  -1.45
22601 -0.1 -1.85
22602 -0.2 -2.20
22603 -0.3 -2.52
22604 -0.4 -2.85
22605 -0.5 -3.15
22606 -0.6 -3.49
22607 -0.7 -3.84
22608 -0.8 -4.23
22609 -0.9 -4.61
```

```
22610 -1.0 -5.03
*
* pump#3 modeled as a volume
30000 pump3   branch
30001 2   1
30101 3.142 10.0 0.0 0.0 0.0 0.0 0.00015  100.0  0010
30200 3 200. 80.0
31101 370010000 3000000  3.142  6.91  6.91  0
31201 0.0  0.0  0.0
32101 3010000 380000000  3.142  6.91  6.91  0
32201 0.0  0.0  0.0
*
*
20500100 tr503 tripdlay  1.0  -1.0  0
20500101  503
20500200 tr504 tripdlay  1.0  -1.0  0
20500201  504
20500300 tr601 tripdlay  1.0  -1.0  0
20500301  601
20500400 tr602 tripdlay  1.0  -1.0  0
20500401  602
*
16100  508
16101  0.0    0.0
16102  1.0   3560.0
26100  509
26101  0.0    0.0
26102  1.0   3560.0
*
*
*  heat slab for pressurizer
*
11000000   2  3  2  1  3.5
11000100   0  2
11000101   0.005  2
11000201   1  2
11000301   0.0  2
11000401   80.0  3
11000501   410010000  10000  1  1  4.06  2
11000601   0  0  0  1  4.06  2
11000701   101  0.0  0.5  0.0  2
11000801   0.0  3.0  3.0  0.0  0.0  0.0  0.0  1.0  2
*
*  heat slab for reactor vessel
*
11100000   3  3  2  1  3.5
11100100   0  2
11100101   0.005  2
11100201   1  2
11100301   0.0  2
11100401   80.0  3
11100501   130010000  10000  1  1  3.556  3
11100601   0  0  0  1  3.556  3
11100701   102  0.0  0.33333  0.0  3
11100801   0.0  3.0  3.0  0.0  0.0  0.0  0.0  1.0  3
*
*  heat slab for pump1
*
```

```
11200000   1  3  2  1  1.0
11200100   0  2
11200101   0.005  2
11200201   1  2
11200301   0.0  2
11200401   80.0  3
11200501   250010000  0  1  1  11.96 1
11200601   0  0  0  1  11.96   1
11200701   103  0.0  1.0  0.0  1
11200801   0.0  3.0  3.0  0.0  0.0  0.0  0.0  1.0  1
*
*
*  heat slab for pump2
*
11300000   1  3  2  1  1.0
11300100   0  2
11300101   0.005  2
11300201   1  2
11300301   0.0  2
11300401   80.0  3
11300501   350010000  0  1  1  11.96 1
11300601   0  0  0  1  11.96   1
11300701   104  0.0  1.0  0.0  1
11300801   0.0  3.0  3.0  0.0  0.0  0.0  0.0  1.0  1
*
*  heat structure property
*
20100100   c-steel
*
*   general table
*
20210100   power
20210101   0.0  0.0
20210102   19.999  0.0
20210103   20.0  0.9
20210104   1000.0  0.9
20210200   power
20210201   0.0  0.0
20210202   19.999  0.0
20210203   20.0  25.7
20210204   1000.0  25.7
20210300   power
20210301   0.0  0.0
20210302   19.999  0.0
20210303   20.0  2.8
20210304   1000.0  2.8
20210400   power
20210401   0.0  0.0
20210402   19.999  0.0
20210403   20.0  1.4
20210404   1000.0  1.4
*
20510100  qpzre  sum  1.0e-6  0.0  1
20510101  0.0  1.0  q  410010000  1.0  q  410020000
20510200  qcore  sum  1.0e-6  0.0  1
20510201  0.0  1.0  q  130010000  1.0  q  130020000
20510202  1.0  q  130030000
20510300  qpmp1  sum  1.0e-6  0.0  1
```

```
20510301  0.0  1.0  q  250010000
20510400  qpmp2  sum  1.0e-6  0.0  1
20510401  0.0  1.0  q  350010000
*********
20510500   tcleg  sum   1.0  0.0  1
20510501   -459.67  1.8  tempf  360010000
20510600   ppzr   sum   1.0  0.0  1
20510601   0.0  1.4504e-4  p   410060000
* LTOP Analysis Curve
20220100   reac-t
20220101   0.0        459.0
20220102   160.0      459.0
20220103   170.0      470.0
20220104   180.0      500.0
20220105   190.0      540.0
20220106   200.0      590.0
20220107   210.0      640.0
20220108   220.0      690.0
20220109   230.0      750.0
20220110   240.0      830.0
20220111   250.0      920.0
20220112   260.0     1010.0
20220113   270.0     1100.0
20220114   280.0     1200.0
20220115   290.0     1300.0
20220116   300.0     1400.0
20220117   310.0     1500.0
20220118   320.0     1608.0
20220119   340.0     1809.1
20220120   400.0     1809.1
*
20520100   porvst   function  1.0  0.0  1
20520101   cntrlvar   105     201
*
* Capture peak pressure
20530100   oldp delay 1.0 0.0 0
20530101   cntrlvar 302 1.0e-6 1
20530200   maxp stdfnctn 1.0 0.0 0
20530201   max p 410060000 cntrlvar 301
20530600   pmax   sum   1.0  0.0  1
20530601   0.0  1.4504e-4  cntrlvar 302
*
*input change for heat addition case
*
331
335 cntrlvar   107
336 cntrlvar   108
501  time   0            ge   null    0    300.0       1
502  time   0            ge   null    0   1000.0       1
509  time   0            ge   null    0     10.0       1
* pump#1 modeled as a volume
10000 pump1   branch
10001 2   1
10101 6.284 10.0 0.0 0.0 0.0 0.0 0.00015  100.0  0010
10200 3 100. 135.0
11101 240010000 1000000  6.284  6.91  6.91  0
11201 0.0  0.0  0.0
12101 1010000 250000000  6.284  6.91  6.91  0
```

```
12201 0.0  0.0  0.0
10108
10109
10201
10202
10301
10302
16100
16101
16102
*
* LEFT SG HOT PLENUM TO SG TUBES FOR MAX SG TUBE VOLUME
2110000   Lhp-tub    sngljun
2110101   210010000   220000000  10.475   1.11  0.55   0000
2110201   0   0.0   0.0   0.0
*
*
* LEFT STEAM GENERATOR TUBES FOR MAX SG TUBE VOLUME
2200000 lsg pipe
2200001 6
2200101 10.475  6
2200201 10.475  5
2200301 8.71,6
2200601 90.0,3
2200602 -90.0,6
2200701   8.71   3
2200702  -8.71   6
2200801 0.0  0.0544   6
2200901 0.097  0.097  5
2201001 0,6
2201101 0,5
2201201 3 170. 364.0 0 0 0,6
2201301 0.0 0.0 0.0,5
*
* LEFT STEAM GEN TUBES TO COLD PLENUM FOR MAX SG TUBE VOLUME
2210000   tub-Lcp    sngljun
2210101   220010000   230000000  10.475   2.24   1.65   0000
2210201   0   0.0   0.0   0.0
*
*
* RIGHT SG HOT PLENUM TO SG TUBES FOR MAX SG TUBE VOLUME
3110000   Rhp-tub    sngljun
3110101   310010000   320000000  10.475   1.11   0.55   0000
3110201   0   0.0   0.0   0.0
*
*
* RIGHT STEAM GENERATOR TUBES FOR MAX SG TUBE VOLUME
3200000 Rsg pipe
3200001 6
3200101 10.475  6
3200201 10.475  5
3200301 8.71,6
3200601 90.0,3
3200602 -90.0,6
3200701   8.71   3
3200702  -8.71   6
3200801 0.0  0.0544   6
3200901 0.097 0.097  5
```

```
3201001 0,6
3201101 0,5
3201201 3 170. 364.0 0 0 0,6
3201301 0.0 0.0 0.0,5
*
* RIGHT COLD PLENUM BRANCH FOR MAX SG TUBE VOLUME
3300000   Rsgcp   branch
3300001   3   0
3300101   20.0  6.087  0.0  0.0   -90.0   -6.087   0.00015  100.0   0010
3300200   3   200. 80.0
3301101   320010000  330000000   10.475  2.24   1.65   0000
3302101   330010000  340000000   3.142   0.41   0.41   0000
3303101   330010000  370000000   3.142   0.41   0.41   0000
3301201   0.0   0.0   0.0
3302201   0.0   0.0   0.0
3303201   0.0   0.0   0.0
*
*
* LEFT STEAM GENERATOR SHELL SIDE
5100000 lsgsh pipe
5100001 3
5100101 174.13  3
5100201 174.13  2
5100301 8.71    3
5100601 90.0,3
5100701   8.71   3
5100801 0.0  0.0   3
5100901 0.0  0.0   2
5101001 0   3
5101101 0   2
5101201 3 170. 364.0 0 0 0  3
5101301 0.0 0.0 0.0   2
*
* RIGHT STEAM GENERATOR SHELL SIDE
5200000 rsgsh pipe
5200001 3
5200101 174.13  3
5200201 174.13  2
5200301 8.71    3
5200601 90.0,3
5200701   8.71   3
5200801 0.0  0.0   3
5200901 0.0  0.0   2
5201001 0   3
5201101 0   2
5201201 3 170. 364.0 0 0 0  3
5201301 0.0 0.0 0.0   2
*
*
* PRESSURIZER STEAM BUBBLE FOR 15% PZR
4100000   pres   pipe
4100001   6
4100101   36.946,6
4100201   36.946,5
4100301   4.1412 5
4100302   3.654,6
4100601   90.   6
4100801   0.00015  0.0  6
```

```
4100901   0.0   0.0   5
4101001   0,6
4101101   0,5
*Manually set Przr pressure and water level
4101201   2   100.   0.0    0.  0 0,5
4101202   2   100.   1.0    0.  0 0,6
4101300   1
4101301   0.0   0.0   0.0,5
*
*  heat slab for sg tubes
*
12001000   12  9  2  1  0.027217
12001100   0  2
12001101   0.0005041  8
12001201   2  8
12001301   0.0  8
12001401   364.0  9
12001501   220010000  10000  1  1  40454.97  6
12001502   320010000  10000  1  1  40454.97  12
12001601   510010000  10000  1  1  40454.97  3
12001602   510030000 -10000  1  1  40454.97  6
12001603   520010000  10000  1  1  40454.97  9
12001604   520030000 -10000  1  1  40454.97  12
12001701   0  0.0  0.0  0.0  12
12001801   0.0  3.0  3.0  0.0  0.0  0.0  0.0  1.0  12
12001901   0.0  3.0  3.0  0.0  0.0  0.0  0.0  1.0  12
*
20100200   tbl/fctn  1  1
20100201   32.0  2.1167e-03
20100202   1050.0  4.0394e-03
20100251   32.0  57.18
20100252   200.0  57.114
20100253   300.0  59.118
20100254   400.0  61.122
20100255   500.0  63.126
* REB change 11/9 to delay pump start until 10 seconds
20210100   power
20210101   0.0  0.0
20210102   9.999  0.0
20210103   10.0  0.9
20210104   1000.0  0.9
20210200   power
20210201   0.0  0.0
20210202   9.999  0.0
20210203   10.0  25.7
20210204   1000.0  25.7
20210300   power
20210301   0.0  0.0
20210302   19.999  0.0
20210303   20.0  0.0
20210304   1000.0  0.0
20210400   power
20210401   0.0  0.0
20210402   9.999  0.0
20210403   10.0  1.4
20210404   1000.0  1.4
*initial conditions
* Ti set to 50 F, Pi set to 170 psia
```

```
2001201 3 170.0 50.0 0 0 0 2
2100200   3   170.0 50.0
2300200   3   170.0 50.0
2401201 3 170.0 50.0 0 0 0,2
2500200   3   170.0 50.0
2601201 3 170.0 50.0 0 0 0,2
3000200   3   170.0 50.0
3010200   3   170.0 50.0
4001201 3 170.0 50.0 0 0 0,10
3020200   3   170.0 50.0
3100200   3   170.0 50.0
3300200   3   170.0 50.0
3401201 3 170.0 50.0 0 0 0,2
3500200   3   170.0 50.0
3601201 3 170.0 50.0 0 0 0,2
3701201 3 170.0 50.0 0 0 0,2
3800200   3   170.0 50.0
3901201 3 170.0 50.0 0 0 0,2
1000200   3   170.0 50.0
1101201 3 170.0 50.0 0 0 0,2
1200200   3   170.0 50.0
1301201 3 170.0 50.0 0 0 0,3
1500200   3   170.0 50.0
1600200   3   170.0 50.0
10200 3 170.0 50.0
20200 3 170.0 50.0 0 0
30200 3 170.0 50.0
11000401   50.0  3
11100401   50.0  3
11200401   50.0  3
11300401   50.0  3
20510700  qsg1  sum  1.0e-6  0.0  1
20510701  0.0  1.0  q  220010000  1.0  q  220020000
20510702  1.0  q  220030000  1.0  q  220040000
20510703  1.0  q  220050000  1.0  q  220060000
20510800  qsg2  sum  1.0e-6  0.0  1
20510801  0.0  1.0  q  320010000  1.0  q  320020000
20510802  1.0  q  320030000  1.0  q  320040000
20510803  1.0  q  320050000  1.0  q  320060000
*
*Speed up time to calc
202  80.0  1.0-6 0.001 5 500 5000 10000
203  5000.0  1.0-6 0.002 5 500 20000 100000
* Add extra dP to nozzles
1502101   150010000  200000000   5.585   1.484  1.651  0000
1503101   150010000  300000000   5.585   1.484  1.651  0000
* Add stronger pump to offset extra dP
*10302 3560.0 0.0 95000.0 290.0 3400.8 380.3 62.3 3240.0 6.7 0 0 0
20302 3560.0 0.0 47500.0 290.0 3400.8 380.3 62.3 3240.0 6.7 0 0 0
*
* PRESSURIZER STEAM BUBBLE CHANGE TO 40% PZR
*Manually set Przr pressure and water level
4100301   2.9232, 5
4100302   9.744, 6
4101201   2   170.   0.0    0.  0 0,5
4101202   2   170.   1.0    0.  0 0,6
* Change end time
501  time   0           ge   null    0    610.0       1
```

```
*********************************************************
* new RSG inlet nozzle flow resistance
2010101   200010000   210000000   5.585   0.327   0.121   0000
3030101   302010000   310000000   5.585   0.327   0.121   0000
* RSG has larger inlet plenum
2100101   22.0   6.087  0.0   0.0   90.0  6.087   0.00015  100.0 0010
3100101   22.0   6.087  0.0   0.0   90.0  6.087   0.00015   100.0   0010
* RSG has larger tube area, less flow resistance
2110101   210010000   220000000   11.25   0.23   0.477   0000
3110101   310010000   320000000   11.25   0.23   0.477   0000
* RSG has larger tube area
2200101 11.25,6
2200201 11.25,5
3200101 11.25,6
3200201 11.25,5
* RSG has longer tubes
2200301 8.82,6
2200701   8.82   3
2200702  -8.82   6
3200301 8.82,6
3200701   8.82   3
3200702  -8.82   6
* RSG tube hydraulic diameter is larger, add friction
2200801 0.00000  0.0553   6
3200801 0.00000  0.0553   6
* Let RELAP calc friction, so Kf & Kr of RSG tubes are zero
2200901 0.0  0.0,  5
3200901 0.0  0.0   5
* new RSG tube area, Kf and Kr
2210101   220010000   230000000   11.25   0.477   0.23   0000
3301101   320010000   330000000   11.25   0.477   0.23  0000
* larger RSG outlet plenum
2300101   22.2  6.087  0.0   0.0  -90.0  -6.087  0.00015  100.0  0010
* new RSG exit nozzle losses
2310101   230010000   240000000   6.284   0.176   0.278   0000
3302101   330010000  340000000    3.142   0.176   0.278   0000
3303101   330010000  370000000    3.142   0.176   0.278   0000
* Changes in Surgeline Length and delta-E
4000301 7.595,1
4000303 7.595,10
4000701 7.595,1
4000703 7.595,10
* Slight Pressurizer area change to keep total volume correct
4100101   37.06,6
4100201   37.06,5
* RPZR is longer
4100301   4.227,6
* RPSR is longer, so heat slab elongated
11000501   410010000  10000  1  1  4.227  2
11000601   0  0  0  1  4.227  2
* Decay heat can be current 25.7, or uprated to 117%  with 30.1
20210203   20.0  30.1
20210204   1000.0  30.1
* Secondary side of RSG is larger
5100101 178.39  3
5100201 178.39  2
5200101 178.39  3
5200201 178.39  2
```

```
* RSG is longer
5100301   8.82   3
5100701   8.82   3
5200301   8.82   3
5200701   8.82   3
* New RSG Heat Slab left boundary
12001000   12  9  2  1  0.027667
* New RSG Heat Slab thickness
12001101   0.0004479  8
* New RSG Heat Slab total tube length in segment
12001501   220010000  10000  1  1  41575.52  6
12001502   320010000  10000  1  1  41575.52  12
12001601   510010000  10000  1  1  41575.52  3
12001602   510030000 -10000  1  1  41575.52  6
12001603   520010000  10000  1  1  41575.52  9
12001604   520030000 -10000  1  1  41575.52  12
* New Steel Properties associated with RSG have
* lower conductivity and lower heat capacity
20100201   32.0   1.82e-03
20100202   70.0   1.89e-03
20100203   100.0  1.94e-03
20100204   150.0  2.03e-03
20100205   200.0  2.11e-03
20100206   250.0  2.19e-03
20100207   300.0  2.28e-03
20100208   350.0  2.36e-03
20100209   400.0  2.44e-03
20100251   32.0   53.6
20100252   70.0   54.4
20100253   100.0  55.0
20100254   200.0  56.9
20100255   300.0  58.5
20100256   400.0  59.9
20100257   500.0  61.2
20100258   600.0  62.1
* New calculation of 40% bubble size
4100301   3.04368, 5
4100302   10.1456, 6
* Reduce major edits
201  2.0  1.0-6 0.010 5 10     100000  100000
202  80.0  1.0-6 0.001 5 500    100000  100000
203  5000.0  1.0-6 0.002 5 500 100000  100000
*end of cases
.
```

ATTACHMENT 3
File List

Attachment 3 Discussion

The files used to develop this report are as follows. The files were run and output created at Fort Calhoun using the OPPD UNIX-based RELAP mod3.2d program for QA control purposes.

The file naming convention is described by example for the Case 10 input file hp509s36.txt. For other input files, the name hp509s36 is replaced by the appropriate name, but the suffixes remain the same.

A script entitled runrelap executes the input file hp509s36.txt and creates the output file hp509s36.o and restart file hp509s36.r. It then executes the strip files mstrpmr.txt which pulls out the reactor beltline pressure (p 120010000, which is the pressure in volume 120 seen in Figure A1-1 of Attachment 1), the pressurizer top pressure (p 410060000 where the 6 selects the top subvolume), and the PORV mass flow rate (mflowj 420000000). This data is saved in the file hp509s36.txt.ws. A second strip file mstrpbr.txt pulls out the heat into the steam generator on the loop with the actuated RCP (control variable 108), the heat into the opposite loop (control variable 107), and the pressurizer steam bubble size (voidg 410060000). This data is saved in the file hp509s36.txt.bs.

The commands to do this manually are as follows (note: relap5.x would be replaced by relap5.exe when using a PC version of Relap5):

```
relap5.x -i hp509s36.txt -o hp509s36.o -r hp509s36.r
relap5.x -i mstrpmr.txt -o hp509s36.wso -r hp509s36.r -s hp509s36.ws
relap5.x -i mstrpbr.txt -o hp509s36.bso -r hp509s36.r -s hp509s36.bs
```

Note that the strip output files hp509s36.wso and hp509s36.bso are created, but they contain only run status information and are not utilized for this report.

The stripped data .ws files for mass injection cases are loaded into the file mplot.xls, where the plots for Cases 2 through 9 are generated. The stripped .ws and .bs files for the heat injection cases are loaded into the file hplot.xls where the figures for Cases 10 through 14 are generated.

The following files are on the Fort Calhoun UNIX system. They were created and run 5/2/2007 and 5/3/2007. Additional files exist in the directory, such as m364p2r.wso, but these are not used in this report.

Case 9, mass injection, 364°F SG, pressure of 200 psia, RSG
m364p2r.txt
m364p2r.o
m364p2r.txt.bs
m364p2r.txt.ws

Case 10, heat addition, 50°F RCS, pressure of 170 psia, SG temperature of 364°F
hp509s36.txt
hp509s36.o
hp509s36.txt.bs
hp509s36.txt.ws

Case 11, heat addition, 50°F RCS, pressure of 390 psia, SG temperature of 364°F
hp503s36.txt
hp503s36.o
hp503s36.txt.bs
hp503s36.txt.ws

Case 11a, heat addition, 50°F RCS, pressure of 350 psia, SG temperature of 364°F
hp535s36.txt
hp535s36.o
hp535s36.txt.bs
hp535s36.txt.ws

Case 12, heat addition, 50°F RCS, pressure of 390 psia, SG temperature of 364°F, PORV opens
hp504s36.txt
hp504s36.o
hp504s36.txt.bs
hp504s36.txt.ws

Case 13, heat addition, 166°F RCS, pressure of 170 psia, SG temperature of 364°F
hp166s36.txt
hp166s36.o
hp166s36.txt.bs
hp166s36.txt.ws

Case 14, heat addition, 290°F RCS, pressure of 390 psia, SG temperature of 364°F
hp290s36.txt
hp290s36.o
hp290s36.txt.bs
hp290s36.txt.ws

FCS Technical Data Book Pages

TDB-III.7.d – RCS Pressure and Temperature Limits (proposed changes)

Fort Calhoun Station
Unit 1

TDB-III.7.d

TECHNICAL DATA BOOK

RCS PRESSURE AND TEMPERATURE LIMITS

Change No.	EC ~~30302~~ 35639
Reason for Change	~~Changes made to the pressure and temperature (P-T) limit curve, Reactor Coolant Pump (RCP) net positive suction head (NPSH) curve, and the PORV trip and pretrip curves. Also, the EFPY for the applicability of this figure is being adjusted to 40 EFPY since the measurement uncertainty recapture power uprate has not occurred.~~
Requestor	L. Hautzinger
Preparer	D. Bonsall
Issue Date	11-10-06 3:00pm

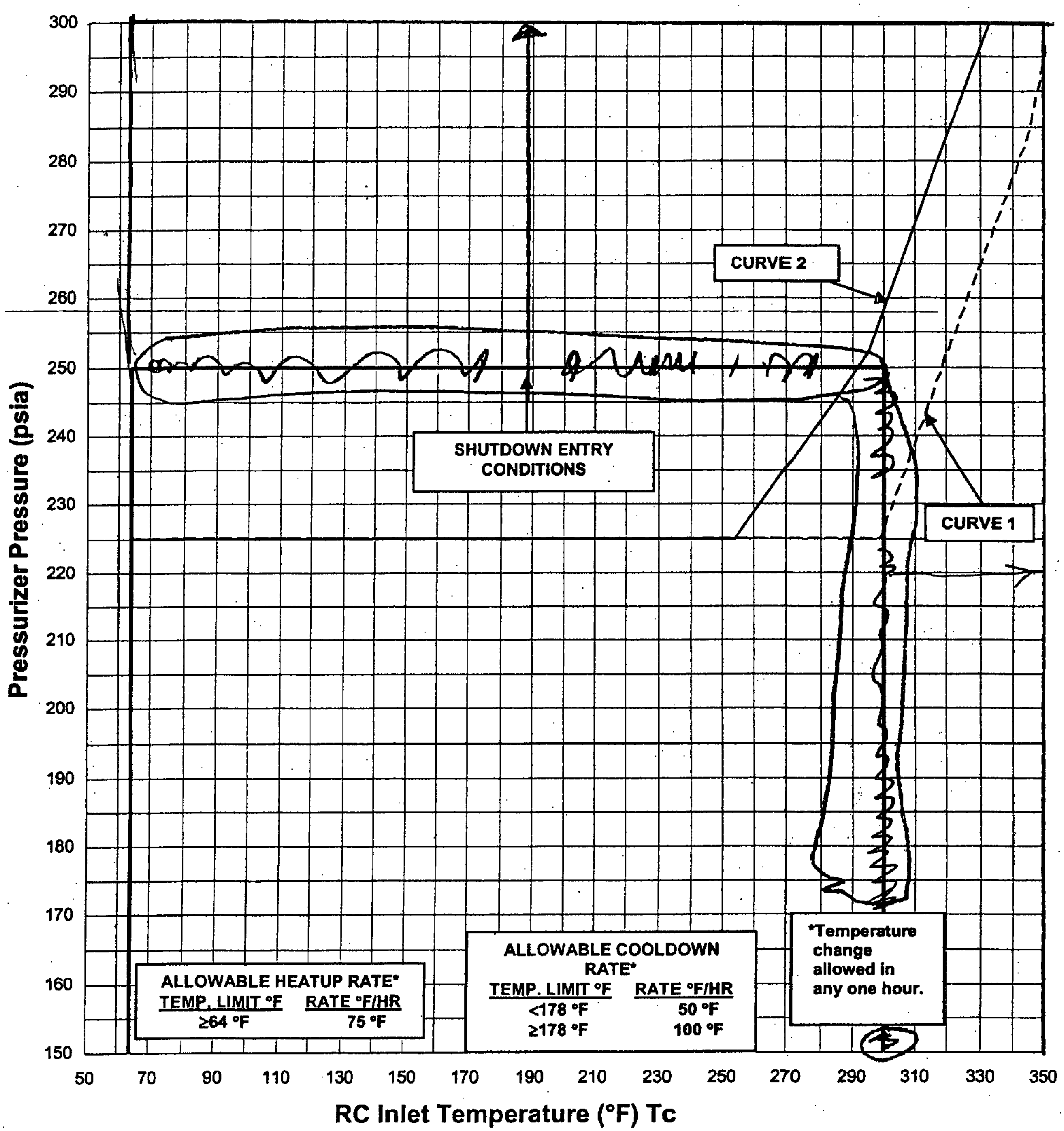
Reason for change:

Update information associated with uprate of SDC initiation conditions

INFORMATION ONLY

RCS Pressure and Temperature Limits for 40 EFPY

Reactor Not Critical



Curve 1: RCP NPSH curve for the operation of one or two RCPs.
Curve 2: RCP NPSH curve for the operation of three or four RCPs.
NOTE (1): Use only P105 or P115 Digital Display when monitoring Curve 1 or 2.
NOTE (2): RCP operation must be above and to the left of Curve 1 or 2.
NOTE (3): Pressurizer Pressure and RC Inlet Temperature are indicated values.
NOTE (4): Use only T113 or T123 when monitoring Curve 1 or 2 except for first RCP start.
Reference: EA06-036