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Brunswick Unit 2 Cycle19 Reload Safety Analysis,
dated January 2009

An AREVA and Siemens company

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AREVA NP Inc.

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Nature of Changes

Item	Page	Description and Justification
1.	All	This is the initial issue

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Nomenclature

AOO	anticipated operational occurrence
ARO	all control rods out
ASME	American Society of Mechanical Engineers
AST	alternative source term
ATWS	anticipated transient without scram
ATWS-RPT	anticipated transient without scram recirculation pump trip
BOC	beginning-of-cycle
BPWS	banked position withdrawal sequence
BSEP	Brunswick Steam Electric Plant
BSP	backup stability protection
BWROG	Boiling Water Reactor Owners Group
CFR	Code of Federal Regulations
COLR	core operating limits report
CPR	critical power ratio
CRDA	control rod drop accident
CRWE	control rod withdrawal error
EFPD	effective full-power days
EFPH	effective full-power hours
EOC	end-of-cycle
EOCLB	end-of-cycle licensing basis
EOFP	end of full power
EOOS	equipment out-of-service
FFTR	final feedwater temperature reduction
FHOOS	feedwater heaters out-of-service
FWCF	feedwater controller failure
GE	General Electric
GNF	Global Nuclear Fuels
HCOM	hot channel oscillation magnitude
HFR	heat flux ratio
ICF	increased core flow
LFWH	loss of feedwater heating
LHGR	linear heat generation rate
$LHGRFAC_f$	flow-dependent linear heat generation rate multipliers
$LHGRFAC_p$	power-dependent linear heat generation rate multipliers
LOCA	loss-of-coolant accident
LPRM	local power range monitor
LRNB	generator load rejection with no bypass

Nomenclature *(Continued)*

$MAPFAC_f$	flow-dependent maximum average planar linear heat generation rate multipliers
$MAPFAC_p$	power-dependent maximum average planar linear heat generation rate multipliers
MAPLHGR	maximum average planar linear heat generation rate
MCPR	minimum critical power ratio
$MCPR_f$	flow-dependent minimum critical power ratio
$MCPR_p$	power-dependent minimum critical power ratio
MELLLA	maximum extended load line limit analysis
MG	motor generator
MSIV	main steam isolation valve
MSIVOOS	main steam isolation valve out-of-service
NEOC	near end-of-cycle
NSS	nominal scram speed
NRC	Nuclear Regulatory Commission, U.S.
OLMCPR	operating limit minimum critical power ratio
OPRM	oscillation power range monitor
P_{bypass}	power below which direct scram on TSV/TCV closure is bypassed
PCT	peak cladding temperature
PLU	power load unbalance
PRFDS	pressure regulator failure downscale
PRFO	pressure regulator failure open
RBM	(control) rod block monitor
RHR	residual heat removal
RPT	recirculation pump trip
SLC	standby liquid control
SLMCPR	safety limit minimum critical power ratio
SLO	single-loop operation
SRV	safety/relief valve
SRVOOS	safety/relief valve out-of-service
TBVOOS	turbine bypass valves out-of-service
TCV	turbine control valve
TIP	traversing incore probe
TLO	two-loop operation
TSSS	technical specifications scram speed
TSV	turbine stop valve
TTNB	turbine trip with no bypass
UAT	unit auxiliary transformer
UFSAR	updated final safety analysis report
VFD	variable frequency drive
ΔCPR	change in critical power ratio

1.0 Introduction

This report presents the results of the reload licensing analyses performed by AREVA NP* in support of Brunswick Unit 2 Cycle 19. The analyses reported in this document were performed using methodologies previously approved for generic application to boiling water reactors. The NRC technical limitations associated with the application of the approved methodologies have been satisfied by these analyses.

The Cycle 19 core consists of a total of 560 fuel assemblies, including 238 fresh ATRIUM™-10† assemblies and 322 irradiated GE14 assemblies. The licensing analysis supports the core design presented in Reference 1.

The Cycle 19 reload licensing analysis consists of the calculation of the potentially limiting events and analyses that were identified in the disposition of events. The results of the analyses are used to establish the Technical Specifications/COLR limits and ensure that the design and licensing criteria are met. The design and safety analyses are based on the design and operational assumptions and plant parameters provided in Reference 2 and augmented by Reference 32 . The results of the reload licensing analysis support operation in the MELLLA region of the power/flow map presented in Figure 1.1 and also support operation with the equipment out-of-service (EOOS) scenarios presented in Table 1.1. A discussion of the analyses for the MELLLA+ region is presented in Appendix A.

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* AREVA NP Inc. is an AREVA and Siemens company.

† ATRIUM is a trademark of AREVA NP.

**Table 1.1 EOOS
Operating Conditions***

Single-loop operation (SLO)
Turbine bypass valves out-of-service (TBVOOS)
Feedwater heaters out-of-service (FHOOS)
One safety relief valve out-of-service (SRVOOS)
One main steam isolation valve out-of-service† (MSIVOOS)
One pressure regulator out of service‡
Up to 40% of the TIP channels out-of-service (100% available at startup)
Up to 50% of the LPRMs out-of-service

* Each EOOS condition is supported in combination with 1 SRVOOS, up to 40% of the TIP channels out-of-service, and/or up to 50% of the LPRMs out-of-service.

† Operation with one MSIVOOS is only supported at power levels less than 70% of rated.

‡ Operation with one pressure regulator out of service is only supported at power levels greater than 90% of rated and less than 50% of rated.

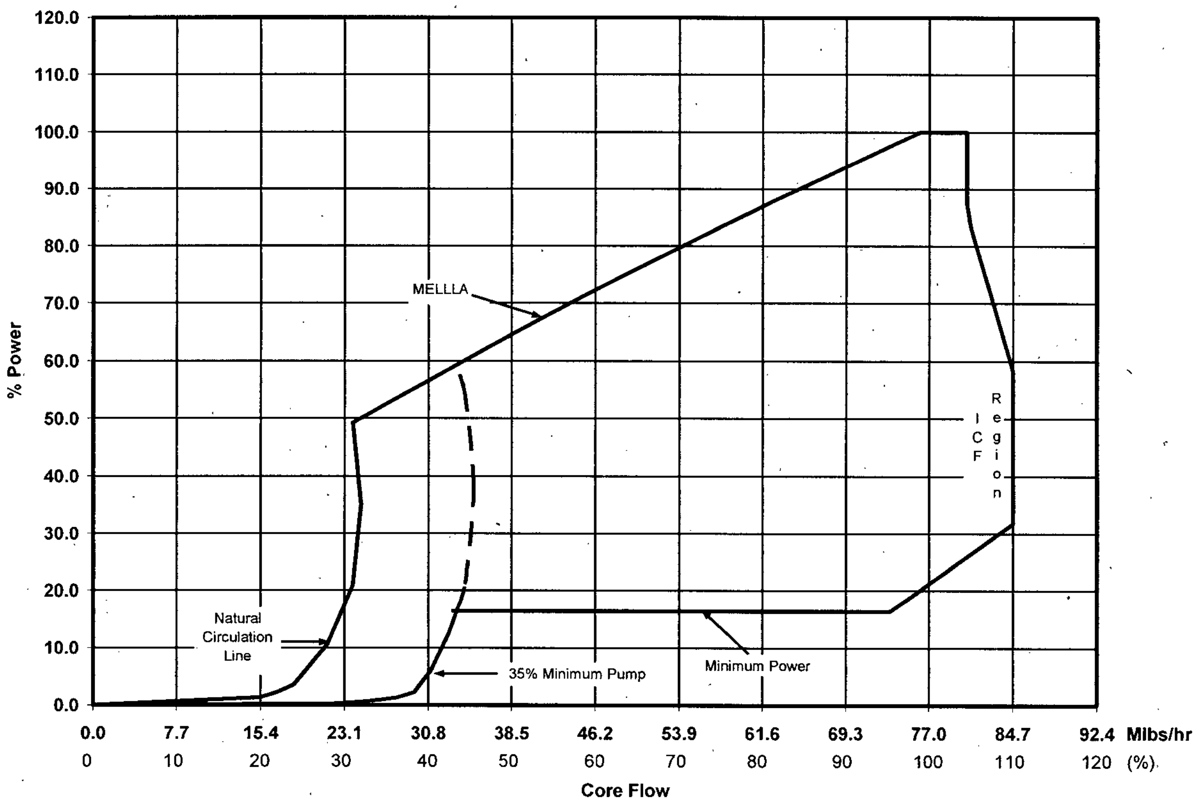

Figure 1.1 Brunswick Unit 2 Power/Flow Map

2.0 Disposition of Events

A disposition of events to identify the limiting events which need to be analyzed to support operation at the Brunswick Steam Electric Plant (BSEP) was performed for the introduction of ATRIUM-10 fuel. Events and analyses identified as potentially limiting were either evaluated generically for the introduction of ATRIUM-10 fuel or are performed on a cycle-specific bases. The results of the disposition of events are presented in Reference 3. The Reference 4 calculation plan for the Brunswick Unit 2 Cycle 19 reload licensing analyses was based on the disposition of events.

The parameter differences between those used in the initial Brunswick ATRIUM-10 licensing analyses and the planned analyses for the Brunswick Unit 2 Cycle 19 reload were reviewed to determine if the conclusions remain applicable. The review concluded that analyses affected by the differences were included in the Reference 4 calculation plan.

2.1 *Variable Frequency Drive Implementation*

Progress Energy is planning on replacing the recirculation pump motor generator (MG) sets with variable frequency drive (VFD) systems. While a firm implementation schedule for the VFDs is not yet available, Progress Energy has indicated that the licensing analyses for Brunswick Unit 2 Cycle 19 should support operation with either the MG sets or the VFDs. The disposition of events was reviewed to evaluate the impact of the VFD implementation. In addition, a review of the Brunswick Unit 2 Cycle 19 licensing analyses was performed to ensure that the analyses remain applicable and/or bounding for operation with the VFDs. Reference 33 provides the VFD parameters used in the disposition of events evaluation.

2.1.1 VFD Impact on the Disposition of Events

The AOOs, accident and other fuel design and fuel related events and analyses were reviewed to determine if any event or analysis that was previously identified as non-limiting has the potential to become limiting with the VFD installation. Any new potentially limiting event would need to be evaluated to ensure that appropriate operating limits are established. The review concluded that while some of the events will be affected by the VFD implementation, in most cases the relative severity of the events will not change. The two events which were previously identified as either non-limiting or needing to be addressed for the initial reload that required additional evaluation are the trip of two recirculation pumps and the turbine trip without bypass

(TTNB). Both of these events were analyzed using AREVA's approved transient analysis methodology to determine if they could become limiting. The results are discussed below.

- Trip of Two Recirculation Pumps. With the VFDs, the effective recirculation pump inertia decreases which results in a faster pump coastdown and a more severe event. While the event becomes more severe, analysis results show that the event remains a benign event and no further analysis is required.

- Turbine Trip No Bypass. Analyses performed with the MG driven recirculation pumps showed that the consequences of the TTNB event are bound by the generator load rejection without bypass (LRNB) event at all power levels. With the VFD implementation, there will no longer be a recirculation pump overspeed during a LRNB event so the consequences will become slightly less severe and may no longer bound the consequences of the TTNB event at all power levels. Analysis results demonstrate that with the VFD implementation, the consequences of the LRNB event will no longer bound those of the TTNB event at rated power and below P_{bypass}. Therefore, with the VFD implementation, the TTNB event should be considered a potentially limiting event at high powers and below P_{bypass}.

It is also noted that the lower effective recirculation pump inertia with the VFD implementation will result in a faster recirculation pump coastdown during a LOCA. While the LOCA is identified as a potentially limiting event, only the heatup portion of the analysis is addressed each reload. For a given plant, the system analysis is a one-time analysis performed for each fuel design. The impact of the VFD implementation on the system analysis should be reviewed.

2.1.2 VFD Impact on Cycle 19 Licensing Analyses

The Brunswick Unit 2 Cycle 19 licensing analyses presented in this report are based on operation with the MG sets. As a result, the LRNB analysis results include the impact of the recirculation pump overspeed and are conservative for operation with the VFDs. Cycle 19 analysis results also show that the consequences of the LRNB event (with the pump overspeed) bound those of the TTNB event. Cycle 19 analyses for the trip of two recirculation pumps with the lower effective recirculation pump inertia associated with the VFDs show that the event remains non-limiting.

As noted above, the faster recirculation pump coastdown with the VFDs will impact the LOCA analyses. The ATRIUM-10 LOCA analysis presented in References 24 and 25 conservatively did not include the inertia of the MG sets. Therefore the recirculation pump inertia used is consistent with the VFDs. The results therefore support operation with either the MG sets or the VFDs. It is recommended that the current GE14 LOCA analysis be evaluated for continued applicability since the VFDs can make the event more severe.

The disposition and/or analysis for the other events are either unaffected by the VFD implementation or the evaluation performed assuming operation with the MG sets remains applicable and/or bounding.

3.0 Mechanical Design Analysis

The mechanical design analysis is presented in the applicable mechanical design report (Reference 5). The maximum exposure limits for the ATRIUM-10 reload fuel are:

54.0 GWd/MTU average assembly exposure
62.0 GWd/MTU rod average exposure (full-length fuel rods)

Even though the ATRIUM-10 design is licensed for operation to a peak rod average exposure of 62 GWd/MTU, it will be limited to 60 GWd/MTU as prescribed in Brunswick Unit 2 license amendment 153 (Reference 6).

The ATRIUM-10 LHGR limits are presented in Section 8.0. The GE14 MAPLHGR limits discussed in Section 8.0 ensure that the thermal-mechanical design criteria for GE14 fuel are satisfied. The fuel cycle design analyses (Reference 1) have verified that all GE and ATRIUM-10 fuel assemblies remain within licensed burnup limits.

4.0 Thermal-Hydraulic Design Analysis

4.1 *Thermal-Hydraulic Design and Compatibility*

The results of the thermal-hydraulic characterization and compatibility analyses are presented in the thermal-hydraulic design report (Reference 7). The analysis results demonstrate that the thermal-hydraulic design and compatibility criteria are satisfied for the Brunswick Unit 2 transition core consisting of ATRIUM-10 and GE14 fuel.

4.2 *Safety Limit MCPR Analysis*

The safety limit MCPR (SLMCPR) is defined as the minimum value of the critical power ratio which ensures that less than 0.1% of the fuel rods in the core are expected to experience boiling transition during normal operation or an anticipated operational occurrence (AOO). The SLMCPR for all fuel in the Brunswick Unit 2 Cycle 19 core was determined using the methodology described in Reference 8. The analysis is performed with a power distribution that conservatively represents expected reactor operating states that could both exist at the MCPR operating limit and produce a MCPR equal to the SLMCPR during an AOO.

The Brunswick Unit 2 Cycle 19 SLMCPR analysis used the SPCB critical power correlation additive constants and additive constant uncertainty for ATRIUM-10 fuel described in References 9 and 10. The SPCB additive constants and additive constant uncertainty for the coresident GE14 fuel were developed using the indirect approach described in Reference 11.

The determination of the SLMCPR explicitly includes the effects of channel bow relying on the following assumptions: Cycle 19 will not contain fuel channels used for more than one fuel bundle lifetime, and the average assembly burnup in Cycle 19 is less than 45 GWd/MTU for ATRIUM-10 fuel and 55 GWd/MTU for GE14 fuel. The channel bow local peaking uncertainty is a function of the nominal and bowed local peaking factors and the standard deviation of the channel bow.

The fuel- and plant-related uncertainties used in the SLMCPR analysis are presented in Table 4.1. The radial power uncertainty used in the analysis includes the effects of up to 40% of the TIP channels out-of-service, up to 50% of the LPRMs out-of-service, and a 2500 EFPH LPRM calibration interval.

The analysis results support a two-loop operation (TLO) SLMCPR of 1.11 and a single-loop operation (SLO) SLMCPR of 1.12. The Cycle 19 MCPR operating limits are based on SLMCPR values of 1.11 for TLO and 1.13 for SLO, the values currently in the plant Technical Specifications. Table 4.2 presents a summary of the analysis results including the SLMCPR and the percentage of rods expected to experience boiling transition.

4.3 *Core Hydrodynamic Stability*

Brunswick has implemented BWROG Long Term Stability Solution Option III (Oscillation Power Range Monitor-OPRM). Reload validation has been performed in accordance with Reference 12. The stability based Operating Limit MCPR (OLMCPR) is provided for two conditions as a function of OPRM amplitude setpoint in Table 4.3. The two conditions evaluated are for a postulated oscillation at 45% core flow steady state operation (SS) and following a two recirculation pump trip (2PT) from the limiting full power operation state point. The Cycle 19 power- and flow-dependent limits provide adequate protection against violation of the SLMCPR for postulated reactor instability as long as the operating limit is greater than or equal to the specified value for the selected OPRM setpoint. The results in Table 4.3 are valid for normal and reduced feedwater temperature (including FHOOS and FFTR) operation.

AREVA has performed calculations for the relative change in CPR as a function of the calculated hot channel oscillation magnitude (HCOM). These calculations were performed with the RAMONA5-FA code in accordance with Reference 13. This code is a coupled neutronic-thermal-hydraulic three-dimensional transient model for the purpose of determining the relationship between the relative change in ΔCPR and the HCOM on a plant specific basis. The stability-based OLMCPRs are calculated using the most limiting of the calculated change in relative ΔCPR for a given oscillation magnitude or the generic value provided in Reference 12. The generic value was determined to be limiting for Cycle 19.

In cases where the OPRM system is declared inoperable for Brunswick Unit 2 Cycle 19, Backup Stability Protection (BSP) in accordance with Reference 14 is provided. BSP curves have been evaluated using STAIF (Reference 15) to determine endpoints that meet decay ratio criteria for the BSP Base Minimal Region I (scram region) and Base Minimal Region II (controlled entry region). Stability boundaries based on these endpoints are then determined using the generic shape generating function from Reference 14. Analyses have been performed to support operation with nominal feedwater temperature conditions and reduced feedwater temperature conditions (both FFTR and FHOOS). The endpoints for the BSP regions are provided in Table 4.4 and are the same as the regions presented in Reference 3.

Table 4.1 Fuel- and Plant-Related Uncertainties for Safety Limit MCPR Analyses

Parameter	Uncertainty
Fuel-Related Uncertainties	
[	
	]
Plant-Related Uncertainties	
Feedwater flow rate	1.8%
Feedwater temperature	0.8%
Core pressure	0.8%
Total core flow rate TLO SLO	 2.5% 6%

* [ ]

Table 4.2 Results Summary for Safety Limit MCPR Analyses

SLMCPR*	Percentage of Rods in Boiling Transition
TLO – 1.11	0.089
SLO – 1.12	0.057

* Note that the Cycle 19 MCPR operating limits are based on SLMPCR values of 1.11 for TLO and 1.13 for SLO, the Unit 2 values currently in the plant Technical Specifications.

Table 4.3 OPRM Setpoints

OPRM Setpoint	OLMCPR (SS)	OLMCPR (2PT)
1.05	1.20	1.18
1.06	1.22	1.20
1.07	1.24	1.21
1.08	1.26	1.23
1.09	1.28	1.25
1.10	1.30	1.27
1.11	1.32	1.29
1.12	1.34	1.31
1.13	1.36	1.33
1.14	1.38	1.35
1.15	1.40	1.38
Acceptance Criteria	Less than or equal to the Off-Rated OLMCPR at 45% Flow	Less than or equal to the Rated Power OLMCPR as described in Section 8.0

**Table 4.4 BSP Endpoints for
Brunswick Unit 2 Cycle 19**

Feedwater Temperature Operation Mode	Region	End Point Designation	Power (% rated)	Flow (% rated)
Nominal	Scram	IA	56.6	40.0
Nominal	Scram	IB	40.7	31.0
Nominal	Controlled entry	IIA	64.5	50.0
Nominal	Controlled entry	IIB	28.5	31.0
FFTR/ FHOOS	Scram	IA	64.9	50.5
FFTR/ FHOOS	Scram	IB	37.3	31.0
FFTR/ FHOOS	Controlled entry	IIA	66.1	52.0
FFTR/ FHOOS	Controlled entry	IIB	28.5	31.0

5.0 Anticipated Operational Occurrences

This section describes the analyses performed to determine the power- and flow-dependent MCPR operating limits for base case operation at Brunswick Unit 2 Cycle 19.

COTRANSA2 (Reference 16), XCOBRA-T (Reference 17), XCOBRA (Reference 18), and CASMO-4/MICROBURN-B2 (Reference 19) are the major codes used in the thermal limits analyses as described in the AREVA THERMEX methodology report (Reference 18) and neutronics methodology report (Reference 19). COTRANSA2 is a system transient simulation code, which includes an axial one-dimensional neutronics model that captures the effects of axial power shifts associated with the system transients. XCOBRA-T is a transient thermal-hydraulics code used in the analysis of thermal margins for the limiting fuel assembly. XCOBRA is used in steady-state analyses. The SPCB critical power correlation (References 9 and 10) is used to evaluate the thermal margin of the ATRIUM-10 and GE14 fuel. The application of the SPCB correlation to GE14 fuel follows the indirect process described in Reference 11. Fuel pellet-to-cladding gap conductance values are based on RODEX2 (Reference 20) calculations for the Brunswick Unit 2 Cycle 19 core.

5.1 *System Transients*

The reactor plant parameters for the system transient analyses are presented in Reference 2. Analyses have been performed to determine power-dependent MCPR limits that protect operation in the MELLLA region of the power/flow domain.

At Brunswick, direct scram on turbine stop valve (TSV) position and turbine control valve (TCV) fast closure are bypassed at power levels less than 26% of rated (P_{bypass}). Scram will occur when the high pressure or high neutron flux scram setpoint is reached. Reference 2 indicates that MCPR limits only need to be monitored at power levels greater than or equal to 23% of rated, which is the lowest power analyzed for this report.

The limiting exposure for rated power pressurization transients is typically at end of full power (EOFP) when the control rods are fully withdrawn. To provide additional margin to the operating limits earlier in the cycle, analyses were also performed to establish operating limits at a near end-of-cycle (NEOC) exposure of 16,300 MWd/MTU. Analyses were performed at cycle exposures prior to NEOC to ensure that the operating limits provide the necessary protection. The end-of-cycle licensing basis (EOCLB) analysis was performed at EOFP + 14 EFPD

(18,760 MWd/MTU). Analyses were also performed to support extended cycle operation with final feedwater temperature reduction (FFTR) and power coastdown. The Brunswick Unit 2 Cycle 19 licensing basis exposures used to develop the neutronics inputs to the transient analyses are presented in Table 5.1.

All pressurization transients assumed that one of the lowest setpoint safety relief valves (SRV) was inoperable. This basis supports operation with 1 SRV out-of-service.

The Brunswick Unit 2 turbine bypass system includes 10 bypass valves. However, for base case analyses in which credit is taken for turbine bypass operation, only 8 of the turbine bypass valves are assumed operable.

Reductions in feedwater temperature of less than 10°F from the nominal feedwater temperature are considered base case operation, not an EOOS condition. This decrease in feedwater temperature causes a small increase in the core inlet subcooling which changes the axial power shape and core void fraction. In addition, the steam flow for a given power level decreases since more power is used to increase the coolant enthalpy to saturated conditions. The consequences of the FWCF event are more severe as a result of the increase in core inlet subcooling during the overcooling phase of the event. Analyses were performed to demonstrate that reduced feedwater temperature is limiting for the FWCF event. While a decrease in steam flow tends to make the LRNB event less severe, the TCV initial position is further closed which tends to make the event more severe, especially at higher power levels. LRNB events for base case operation were evaluated for both nominal and 10°F reduced feedwater temperatures.

FFTR is used to extend rated power operation by decreasing the feedwater temperature. The amount of feedwater temperature reduction is a function of power with the maximum decrease of 110.3°F at rated power. Analyses were performed to support both nominal and constant rated dome pressure with combined FFTR/Coastdown operation to a cycle exposure of 20,655 MWd/MTU. The FWCF analyses were performed with the lowest feedwater temperature associated with the initial power level.

The results of the system pressurization transients are sensitive to the scram speed used in the calculations. To take advantage of average scram speeds faster than those associated with the Technical Specifications requirements, scram speed-dependent $MCPR_p$ limits are provided. The nominal scram speed (NSS) insertion times and the Technical Specifications scram speed

(TSSS) insertion times used in the analyses are presented in Table 5.2. The NSS $MCPR_p$ limits can only be applied if the scram speed test results meet the NSS insertion times. System transient analyses were performed to establish $MCPR_p$ limits for both NSS and TSSS insertion times. The Brunswick Unit 2 Technical Specifications (Reference 21) allow for operation with up to 10 "slow" and 1 stuck control rod. One additional control rod is assumed to fail to scram. Conservative adjustments to the NSS and TSSS scram speeds were made to the analysis inputs to appropriately account for these effects on scram reactivity. For cases below 26% power, the results are relatively insensitive to scram speed, and only TSSS analyses are performed. At 26% power (P_{bypass}), FWCF analyses were performed both with and without bypass of the direct scram function which can result in a step change in the operating limits.

5.1.1 Load Rejection No Bypass (LRNB)

The load rejection causes a fast closure of the turbine control valves. The resulting compression wave travels through the steam lines into the vessel and creates a rapid pressurization. The increase in pressure causes a decrease in core voids, which in turn causes a rapid increase in power. The fast closure of the turbine control valves also causes a reactor scram. Turbine bypass system operation, which also mitigates the consequences of the event, is not credited. The excursion of the core power due to the void collapse is terminated primarily by the reactor scram and revoiding of the core.

For power levels less than 50% of rated, the LRNB analyses assume that the power load unbalance (PLU) is inoperable. With the PLU inoperable, the LRNB sequence of events is different than the standard event. Instead of a fast closure, the TCVs close in servo mode and there is no direct scram on TCV closure. The power and pressure excursion continues until the high pressure scram occurs. Given that there is no direct scram when the PLU is inoperable, the above and below P_{bypass} results at 26% power will be identical.

During an LRNB event with the recirculation pump power supplied by the Unit Auxiliary Transformer (UAT) the recirculation pump speed increases causing an increase in core flow and a corresponding increase in power. The result is a slightly more severe event. All LRNB analyses were performed assuming the UAT supplies power to the recirculation pumps.

LRNB analyses were performed for a range of power/flow conditions to support generation of the thermal limits. Tables 5.3 and 5.4 present the base case limiting LRNB transient analysis results used to generate the NEOC and EOCLB operating limits for both TSSS and NSS insertion times. Figures 5.1 – 5.3 show the responses of various reactor and plant parameters during the LRNB event initiated at 100% of rated power and 104.5% of rated core flow with TSSS insertion times.

5.1.2 Turbine Trip No Bypass (TTNB)

The turbine trip causes a closure of the turbine stop valves. The resulting compression wave travels through the steam lines into the vessel and creates a rapid pressurization. The increase in pressure causes a decrease in core voids, which in turn causes a rapid increase in power. The closure of the turbine stop valves also causes a reactor scram. Turbine bypass system operation, which also mitigates the consequences of the event, is not credited. The excursion of the core power due to the void collapse is terminated primarily by the reactor scram and revoiding of the core.

Results presented in Reference 3 demonstrate that the consequences of the TTNB event are bound by those of the LRNB event. Analyses were performed to demonstrate that the LRNB is also bounding for Unit 2. TTNB analyses were performed for power/flow conditions at 100% power and below P_{bypass}. Tables 5.5 and 5.6 present the base case TTNB transient analysis results for both TSSS and NSS insertion times for Cycle 19.

5.1.3 Feedwater Controller Failure (FWCF)

The increase in feedwater flow due to a failure of the feedwater control system to maximum demand results in an increase in the water level and a decrease in the coolant temperature at the core inlet. The increase in core inlet subcooling causes an increase in core power. As the feedwater flow continues at maximum demand, the water level continues to rise and eventually reaches the high water level trip setpoint. The initial water level is conservatively assumed to be at the low level normal operating range to delay the high-level trip and maximize the core inlet subcooling that results from the FWCF. The high water level trip causes the turbine stop valves to close in order to prevent damage to the turbine from excessive liquid inventory in the steam line. The valve closures create a compression wave that travels to the core causing a void collapse and subsequent rapid power excursion. The closure of the turbine stop valves also initiates a reactor scram. Eight of the ten installed turbine bypass valves are assumed operable and provide pressure relief. The core power excursion is mitigated in part by the pressure relief, but the primary mechanism for termination of the event is reactor scram.

FWCF analyses were performed for a range of power/flow conditions to support generation of the thermal limits. Tables 5.7 and 5.8 present the base case limiting FWCF transient analysis results used to generate the NEOC and EOCLB operating limits for both TSSS and NSS insertion times. Figures 5.4 – 5.6 show the responses of various reactor and plant parameters during the FWCF event initiated at 100% of rated power and 104.5% of rated core flow with TSSS insertion times.

5.1.4 Pressure Regulator Failure Downscale (PRFDS)

The pressure regulator failure downscale event occurs when the pressure regulator fails and sends a signal to close all four turbine control valves in control mode. Normally, the backup pressure regulator would take control and maintain the setpoint pressure, resulting in a mild pressure excursion and a benign event. If one of the pressure regulators were out-of-service, there would be no backup pressure regulator and the event would be more severe. The core would pressurize resulting in void collapse and a subsequent power increase. The event would be terminated by scram when either the high-neutron flux or high-pressure setpoint is reached. Operation with one pressure regulator out-of-service is not supported for Brunswick over the entire power/flow map. However, Progress Energy requested that AREVA review the PRFDS event with one pressure regulator out-of-service to determine if it is bound by the LRNB event at power levels greater than 90% of rated and less than 50% or rated. Analysis results demonstrate that the LRNB is more limiting at power levels greater than 90% of rated. Since LRNB analyses assume the PLU is inoperable below 50% of rated power, the TCVs close in servo or control mode without a direct scram on fast closure. Therefore, the consequences of the PRFDS event with one pressure regulator out of service are no more severe than the LRNB event at power levels less than 50% of rated.

5.1.5 Loss of Feedwater Heating

The loss of feedwater heating (LFWH) event analysis supports an assumed 100°F decrease in the feedwater temperature. The result is an increase in core inlet subcooling, which reduces voids thereby increasing the core power and shifting the axial power distribution toward the bottom of the core. As a result of the axial power shift and increased core power, voids begin to build up in the bottom region of the core, acting as negative feedback to the increased subcooling effect. The negative feedback moderates the core power increase. Although there is a substantial increase in core thermal power during the event, the increase in steam flow is much less because a large part of the added power is used to overcome the increase in inlet subcooling. The increase in steam flow is accommodated by the pressure control system via the TCVs or the turbine bypass valves, so no pressurization occurs. For Brunswick Unit 2 Cycle 19, a cycle-specific analysis was performed in accordance with the Reference 22 methodology to determine the change in MCPR for the event. The LFWH results are presented in Table 5.9.

5.1.6 Control Rod Withdrawal Error

The control rod withdrawal error (CRWE) transient is an inadvertent reactor operator initiated withdrawal of a control rod. This withdrawal increases local power and core thermal power, lowering the core MCPR. The CRWE transient is typically terminated by control rod blocks initiated by the rod block monitor (RBM). The CRWE event was analyzed assuming no xenon and allowing credible instrumentation out-of-service in the rod block monitor (RBM) system. The analysis further assumes that the plant could be operating in either an A or B sequence control rod pattern. The rated power CRWE results are shown in Table 5.10 for the analytical RBM high power setpoint values of 108% to 117%. An assumed RBM high power setpoint of 108% was used to develop the $MCPR_p$ limits consistent with the direction provided by Progress Energy in Reference 23. At all intermediate and lower power setpoint values, the $MCPR_p$ values for ATRIUM-10 and GE14 fuel bound or are equal to the CRWE MCPR values. AREVA analyses show that standard filtered RBM setpoint reductions are supported. Analyses demonstrate that the 1% strain and centerline melt criteria are met for both ATRIUM-10 and GE14 fuel with the LHGR and MAPLHGR limits and their associated multipliers presented in Sections 8.2 and 8.3. The recommended operability requirements based on the unblocked CRWE results are shown in Table 5.11 based on the SLMCPR values presented in Section 4.2.

5.2 *Slow Flow Runup Analysis*

Flow-dependent MCPR and LHGR limits are established to support operation at off-rated core flow conditions. The limits are based on the CPR and heat flux changes experienced by the fuel during slow flow excursions. The slow flow excursion event assumes a failure of the recirculation flow control system such that the core flow increases slowly to the maximum flow physically attainable by the equipment (107% of rated core flow). An uncontrolled increase in flow creates the potential for a significant increase in core power and heat flux. Operation with One MSIVOOS causes a larger increase in pressure and power during the flow excursion which results in a steeper flow runup path. A conservatively steep flow runup path was used in the analysis. The slow flow runup analyses were performed to support operation in all the EOOS scenarios.

$MCPR_f$ limits are determined for both ATRIUM-10 and GE14 fuel. XCOBRA is used to calculate the change in critical power ratio during a two-loop flow runup to the maximum flow rate. The $MCPR_f$ limit is set so that the increase in core power resulting from the maximum increase in core flow is such that the TLO safety limit MCPR is not violated. Calculations were performed for a range of initial flow rates to determine the corresponding MCPR values that put the limiting assembly on the safety limit MCPR at the high flow condition at the end of the flow excursion.

Results of the flow runup analysis are presented in Table 5.12. $MCPR_f$ limits that provide the required protection are presented in Table 8.7. The Cycle 19 $MCPR_f$ limits are applicable for all Cycle 19 exposures.

Flow runup analyses were performed with CASMO-4/MICROBURN-B2 to determine flow-dependent LHGR multipliers ($LHGRFAC_f$) for ATRIUM-10 fuel. The analysis assumes that the recirculation flow increases slowly along the limiting rod line to the maximum flow physically attainable by the equipment. A series of flow excursion analyses were performed at several exposures throughout the cycle starting from different initial power/flow conditions. Xenon is assumed to remain constant during the event. The $LHGRFAC_f$ multipliers are established to provide protection against fuel centerline melt and overstraining of the cladding during a flow runup. The Cycle 19 $LHGRFAC_f$ multipliers are presented in Table 8.13. A process consistent with the GNF thermal-mechanical methodology was used to determine flow-dependent MAPLHGR multipliers ($MAPFAC_f$) for GE14 fuel. These $MAPFAC_f$ multipliers, presented in Table 8.16, provide protection against fuel centerline melt and overstraining of the cladding for GE14 fuel during operation at off-rated core flow conditions.

The maximum flow during a flow excursion in single-loop operation is much less than the maximum flow during two-loop operation. Therefore, the flow-dependent MCPR limits and LHGR/MAPLHGR multipliers for two-loop operation are applicable for SLO.

5.3 *Equipment Out-of-Service Scenarios*

The following equipment out-of-service (EOOS) scenarios are supported for Brunswick Unit 2 Cycle 19 operation:

- Feedwater heater out-of-service (FHOOS) – up to 110.3°F feedwater temperature reduction
- Turbine bypass valves out-of-service (TBVOOS)
- Combined FHOOS and TBVOOS
- One safety/relief valve out-of-service (One SRVOOS)
- One main steam isolation valve out-of-service (One MSIVOOS)
- Single-loop operation (SLO)

5.3.1 FHOOS

The FHOOS analyses protect operation with the feedwater temperature reduction characteristic presented in Reference 2. This results in a feedwater temperature reduction of 110.3°F at rated power and steam flow. The effect of the reduced feedwater temperature is an increase in the core inlet subcooling which can change the axial power shape and core void fraction. In addition, the steam flow for a given power level decreases since more power is used to increase the enthalpy of the coolant to saturated conditions. The consequences of the FWCF event are more severe as a result of the increase in core inlet subcooling during the overcooling phase of the event. While the decrease in steam flow tends to make the LRNB event less severe, the TCV initial position is further closed which tends to make the event more severe, especially at higher power levels. FWCF events were analyzed to ensure that appropriate FHOOS operating limits are established.

5.3.2 TBVOOS

For this EOOS scenario, operation with TBVOOS means that the fast opening capability of three or more of the turbine bypass valves cannot be assured, thereby reducing the pressure relief capacity during fast pressurization transients. While the base case LRNB and TTNB events are analyzed assuming the turbine bypass valves out-of-service, operation with TBVOOS has an adverse effect on the FWCF event. Analyses of the FWCF event with TBVOOS were performed to establish the TBVOOS operating limits.

5.3.3 Combined FHOOS and TBVOOS

FWCF analyses with both FHOOS and TBVOOS were performed to support Cycle 19 operation. Operating limits for this combined EOOS scenario were established using these FWCF results.

5.3.4 One SRVOOS

As noted earlier, all pressurization transient analyses were performed with one of the lowest setpoint SRVs assumed inoperable. Therefore, the base case operating limits support operation with one SRVOOS. The EOOS operating limits also support operation with one SRVOOS.

5.3.5 One MSIVOOS

Operation with One MSIVOOS is supported for operation less than 70% of rated power. At these reduced power levels, the flow through any one steam line will not be greater than the flow at rated power when all MSIVs are available. Since all four turbine control valves are available, adequate pressure control can be maintained. The main difference in operation with One MSIVOOS is that the steam line pressure drop between the steam dome and the turbine valves is higher than if all MSIVs are available. Since low steam line pressure drop is limiting for pressurization transients, the results of the pressurization events with all MSIVs in service bound the results with One MSIVOOS. In addition, operation with One MSIVOOS has no impact on the other non-pressurization events evaluated to establish power-dependent operating limits. Therefore, the power-dependent operating limits applicable to base case operation with all MSIVs in service remain applicable for operation with One MSIVOOS for power levels less than or equal to 70% of rated. As noted earlier, slow flow runup analyses were performed to support operation with One MSIVOOS.

5.3.6 Single-Loop Operation

In SLO, the two-loop operation ΔCPRs and LHGRFAC/MAPFAC multipliers remain applicable. The only impacts on the MCPR, LHGR, and MAPLHGR limits for SLO are an increase of 0.02 in the SLMCPR as discussed in Section 4.2, and the application of an SLO MAPLHGR multiplier discussed in Section 8.3. The net result is a 0.02 increase in the base case $MCPR_p$ limits and a decrease in the MAPLHGR limit. The same situation is true for the EOOS scenarios. Adding 0.02 to the corresponding two-loop operation EOOS $MCPR_p$ limits results in SLO $MCPR_p$ limits for the EOOS conditions. The TLO EOOS LHGRFAC and MAPFAC multipliers limits remain applicable in SLO.

5.4 *Licensing Power Shape*

The licensing axial power profile used by AREVA for the plant transient analyses bounds the projected end of full power axial power profile. The conservative licensing axial power profile generated at the EOCLB core average exposure of 32,881 MWd/MTU is given in Table 5.13. Cycle 19 operation is considered to be in compliance when:

- The normalized power generated in the bottom 7 nodes from the projected EOFP solution at the state conditions provided in Table 5.13 is greater than the normalized power generated in the bottom 7 nodes in the licensing basis axial power profile.
- The projected EOFP condition occurs at a core average exposure less than or equal to EOCLB.

If the criteria cannot be fully met (i.e., not all 7 nodes are at a higher power than the licensing profile), the licensing basis may nevertheless remain valid but further assessment will be required.

The licensing basis power profile in Table 5.13 was calculated using the MICROBURN-B2 code. Compliance analyses must also be performed using MICROBURN-B2. Note that the power profile comparison should be done without incorporating instrument updates to the axial profile because the updated power is not used in the core monitoring system to accumulate assembly burnups.

Table 5.1 Exposure Basis for Brunswick Unit 2 Cycle 19 Transient Analysis

Cycle Exposure at End of Interval (MWd/MTU)	Core Average Exposure (MWd/MTU)*	Comments
0	14,121	Beginning of cycle
16,300	30,421	Break point for exposure-dependent $MCPR_p$ limits (NEOC)
18,760	32,881	Design basis rod patterns to EOFP + 14 EFPD (EOCLB)
20,655	34,776	Maximum licensing core exposure – including FFTR/Coastdown

* Note that the limits presented in Tables 8.1 – 8.6 and Tables 8.9 – 8.12 are based on core average exposure.

Table 5.2 Scram Speed Insertion Times

Control Rod Position (notch)	TSSS Time (sec)	NSS Time (sec)
48 (*full-out*)	0.000	0.000
48	0.200	0.200
46	0.440	0.322
36	1.080	0.862
26	1.830	1.422
6	3.350	2.593
0 (*full-in*)	3.806	2.944

Table 5.3 NEOC Base Case LRNB Transient Results

Power	ATRIUM-10 ΔCPR	ATRIUM-10 HFR	GE14 ΔCPR
TSSS Insertion Times			
100	0.34	1.35	0.36
90	0.35	1.36	0.37
80	0.36	1.37	0.38
70	0.36	1.36	0.38
60	0.35	1.34	0.37
50	0.33	1.31	0.34
50 at > 65%F PLU inoperable	0.84	1.87	0.90
50 at ≤ 65%F PLU inoperable	0.62	1.66	0.66
26 at > 65%F PLU inoperable	1.14	2.10	1.10
26 at ≤ 65%F PLU inoperable	0.88	1.92	0.89
26 at > 65%F below P_{bypass}	1.14	2.10	1.10
26 at ≤ 65%F below P_{bypass}	0.88	1.92	0.89
23 at > 65%F below P_{bypass}	1.19	2.14	1.14
23 at ≤ 65%F below P_{bypass}	0.96	1.98	0.96
NSS Insertion Times			
100	0.24	1.26	0.26
90	0.27	1.29	0.29
80	0.29	1.31	0.31
70	0.30	1.31	0.32
60	0.30	1.30	0.32
50	0.28	1.27	0.29
50 at > 65%F PLU inoperable	0.81	1.84	0.87
50 at ≤ 65%F PLU inoperable	0.60	1.63	0.64
26 at > 65%F PLU inoperable	1.12	2.08	1.08
26 at ≤ 65%F PLU inoperable	0.87	1.89	0.88

Table 5.4 EOCLB Base Case LRNB Transient Results

Power	ATRIUM-10 ΔCPR	ATRIUM-10 HFR	GE14 ΔCPR
TSSS Insertion Times			
100	0.37	1.35	0.38
90	0.38	1.35	0.38
80	0.39	1.45	0.39
70	0.39	1.44	0.39
60	0.38	1.41	0.38
50	0.35	1.36	0.35
50 at > 65%F PLU inoperable	0.86	1.94	0.90
50 at ≤ 65%F PLU inoperable	0.64	1.69	0.66
26 at > 65%F PLU inoperable	1.14	2.10	1.10
26 at ≤ 65%F PLU inoperable	0.88	1.96	0.89
26 at > 65%F below P_{bypass}	1.14	2.10	1.10
26 at ≤ 65%F below P_{bypass}	0.88	1.96	0.89
23 at > 65%F below P_{bypass}	1.19	2.14	1.14
23 at ≤ 65%F below P_{bypass}	0.96	2.00	0.96
NSS Insertion Times			
100	0.32	1.35	0.33
90	0.34	1.35	0.34
80	0.36	1.35	0.36
70	0.36	1.41	0.36
60	0.36	1.39	0.36
50	0.33	1.34	0.33
50 at > 65%F PLU inoperable	0.82	1.90	0.87
50 at ≤ 65%F PLU inoperable	0.61	1.67	0.64
26 at > 65%F PLU inoperable	1.12	2.08	1.08
26 at ≤ 65%F PLU inoperable	0.87	1.94	0.88

Table 5.5 NEOC Base Case TTNB Transient Results

Power	ATRIUM-10 ΔCPR	ATRIUM-10 HFR	GE14 ΔCPR
TSSS Insertion Times			
100	0.33	1.33	0.35
26 at > 65%F below P_{bypass}	1.00	1.89	0.98
26 at ≤ 65%F below P_{bypass}	0.83	1.72	0.83
23 at > 65%F below P_{bypass}	1.05	1.93	1.02
23 at ≤ 65%F below P_{bypass}	0.89	1.78	0.89
NSS Insertion Times			
100 / 104.5	0.24	1.25	0.25

Table 5.6 EOCLB Base Case TTNB Transient Results

Power	ATRIUM-10 ΔCPR	ATRIUM-10 HFR	GE14 ΔCPR
TSSS Insertion Times			
100	0.36	1.35	0.36
26 at > 65%F below P_{bypass}	1.00	1.89	0.98
26 at ≤ 65%F below P_{bypass}	0.83	1.75	0.83
23 at > 65%F below P_{bypass}	1.05	1.93	1.02
23 at ≤ 65%F below P_{bypass}	0.89	1.79	0.89
NSS Insertion Times			
100 / 104.5	0.31	1.35	0.32

Table 5.7 NEOC Base Case FWCF Transient Results

Power	ATRIUM-10 ΔCPR	ATRIUM-10 HFR	GE14 ΔCPR
TSSS Insertion Times			
100	0.21	1.21	0.22
90	0.23	1.23	0.24
80	0.25	1.25	0.26
70	0.28	1.27	0.29
60	0.30	1.29	0.32
50	0.33	1.32	0.35
26	0.51	1.50	0.53
26 at > 65%F below P_{bypass}	0.58	1.58	0.61
26 at ≤ 65%F below P_{bypass}	0.37	1.35	0.39
23 at > 65%F below P_{bypass}	0.63	1.63	0.66
23 at ≤ 65%F below P_{bypass}	0.41	1.37	0.43
NSS Insertion Times			
100	0.15	1.15	0.15
90	0.17	1.18	0.18
80	0.20	1.21	0.21
70	0.23	1.23	0.24
60	0.27	1.26	0.28
50	0.31	1.30	0.32
26	0.47	1.49	0.49

**Table 5.8 EOCLB Base Case FWCF
Transient Results**

Power	ATRIUM-10 ΔCPR	ATRIUM-10 HFR	GE14 ΔCPR
TSSS Insertion Times			
100	0.24	1.26	0.24
90	0.25	1.27	0.24
80	0.26	1.29	0.26
70	0.28	1.31	0.29
60	0.30	1.33	0.32
50	0.33	1.34	0.35
26	0.51	1.50	0.53
26 at > 65%F below P_{bypass}	0.58	1.58	0.61
26 at ≤ 65%F below P_{bypass}	0.37	1.35	0.39
23 at > 65%F below P_{bypass}	0.63	1.63	0.66
23 at ≤ 65%F below P_{bypass}	0.41	1.37	0.43
NSS Insertion Times			
100	0.20	1.22	0.20
90	0.21	1.24	0.21
80	0.23	1.26	0.23
70	0.25	1.29	0.25
60	0.27	1.31	0.28
50	0.31	1.33	0.32
26	0.47	1.49	0.49

Table 5.9 Loss of Feedwater Heating Transient Analysis Results

Power (% rated)	ATRIUM-10/GE14 ΔCPR
100	0.10
90	0.11
80	0.12
70	0.13
60	0.14
50	0.16
40	0.19
30	0.24
23	0.30

Table 5.10 Control Rod Withdrawal Error ΔCPR Results

Analytical RBM Setpoint (without filter) (%)	ΔCPR*
108	0.18
111	0.22
114	0.27
117	0.33

* Results are for the most limiting of the ATRIUM-10 or GE14 fuel in the core.

Table 5.11 RBM Operability Requirements

Thermal Power (% rated)	Applicable ATRIUM-10/GE14 MCPR
≥ 29% and < 90%	1.53 TLO 1.55 SLO
≥ 90%	1.47 TLO

Table 5.12 Flow-Dependent MCPR Results

Core Flow (% rated)	ATRIUM-10 Limiting MCPR	GE14 Limiting MCPR
31	1.59	1.57
40	1.55	1.50
50	1.49	1.45
60	1.43	1.42
70	1.36	1.35
80	1.30	1.29
90	1.24	1.23
100	1.18	1.17
107	1.11	1.11

Table 5.13 Licensing Basis Core Average Axial Power Profile

State Conditions for Power Shape Evaluation	
Power, MWt	2923.0
MICROBURN-B2 pressure, psia	1044.5
Inlet subcooling, Btu/lbm	20.61
Flow, Mlb/hr	80.46
Control state	ARO
Core average exposure (EOCLB), MWd/MTU	32,881

Licensing Axial Power Profile
(Normalized)

Node	Power
Top 25	0.194
24	0.617
23	0.803
22	0.923
21	1.010
20	1.080
19	1.140
18	1.196
17	1.245
16	1.297
15	1.332
14	1.435
13	1.445
12	1.433
11	1.398
10	1.342
9	1.262
8	1.158
7	1.037
6	0.909
5	0.790
4	0.697
3	0.619
2	0.497
Bottom 1	0.143

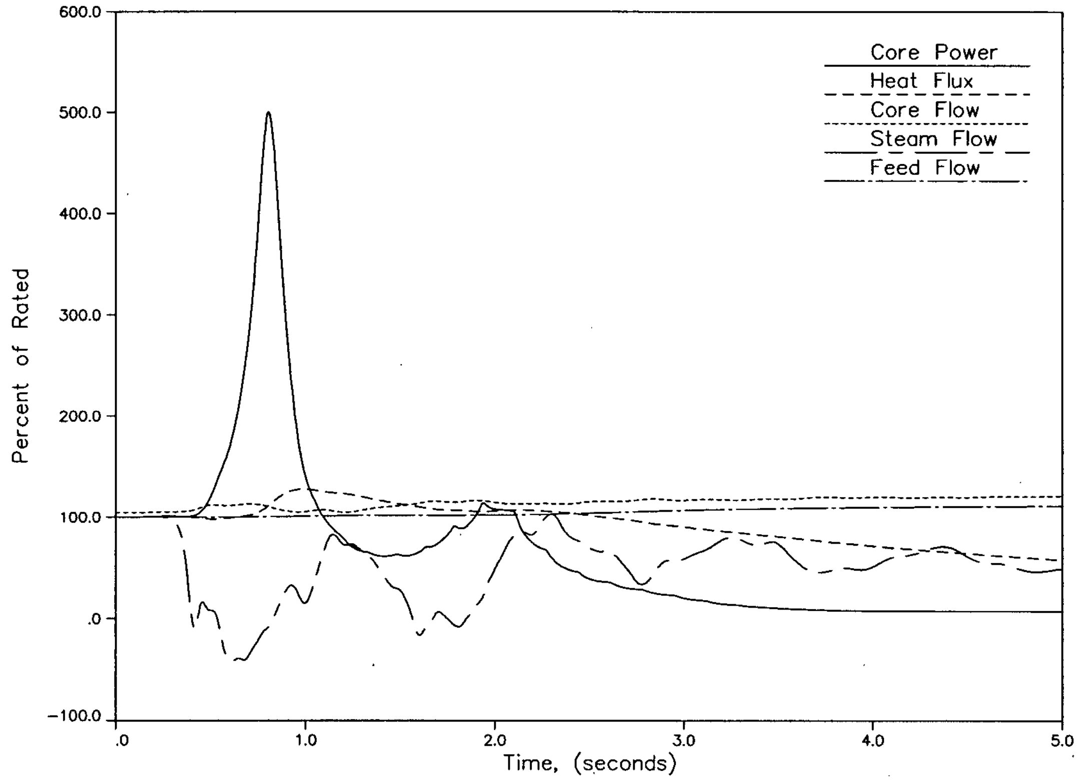

Figure 5.1 EOCLB LRNB at 100P/104.5F – TSSS Key Parameters

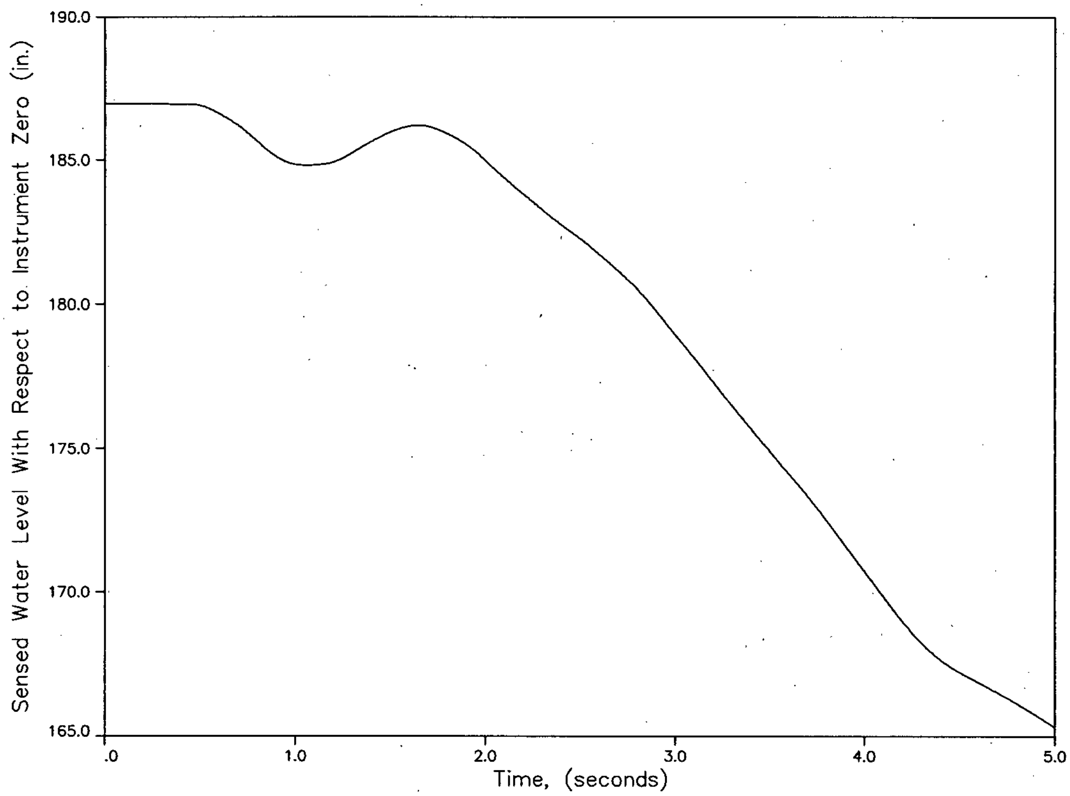

**Figure 5.2 EOCLB LRNB at 100P/104.5F – TSSS
Sensed Water Level**

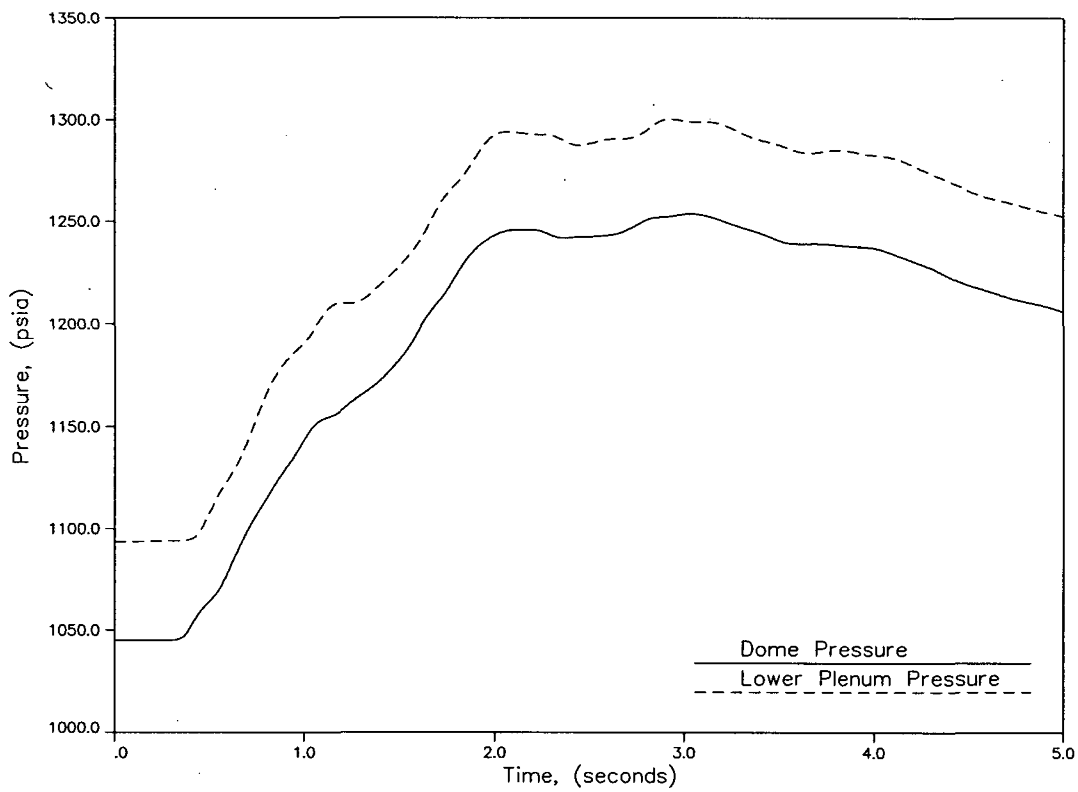

Figure 5.3 EOCLB LRNB at 100P/104.5F – TSSS Vessel Pressures

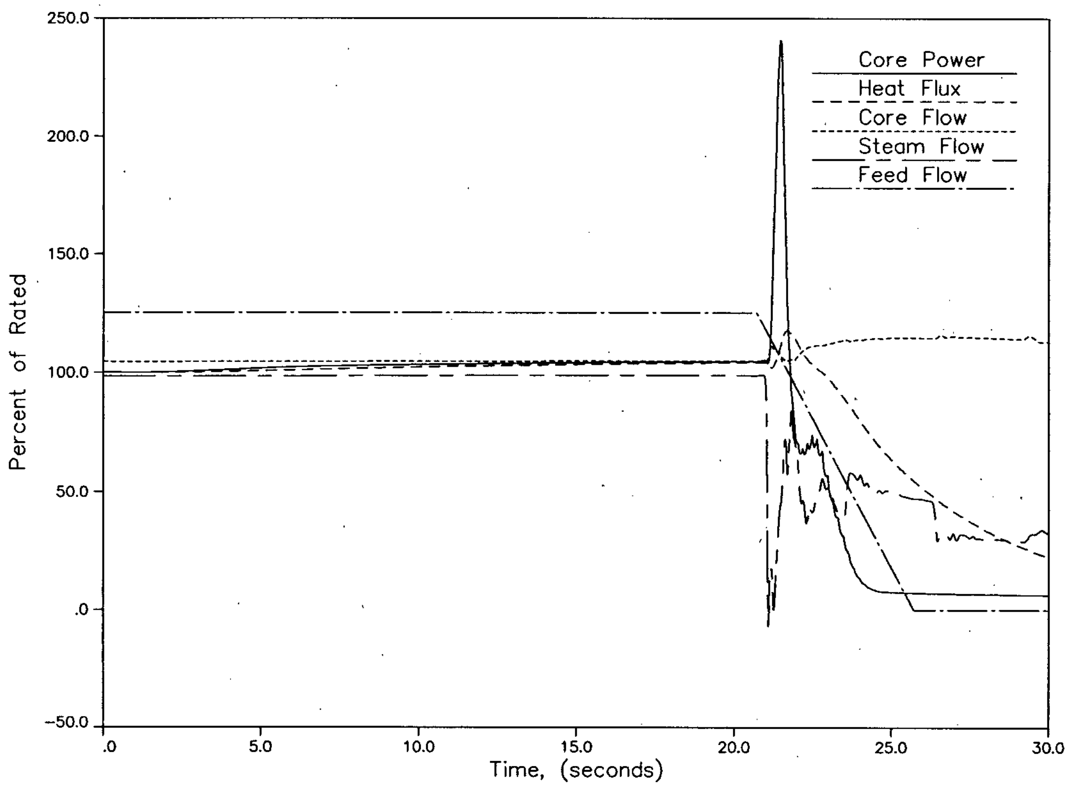

Figure 5.4 EOCLB FWCF at 100P/104.5F – TSSS Key Parameters

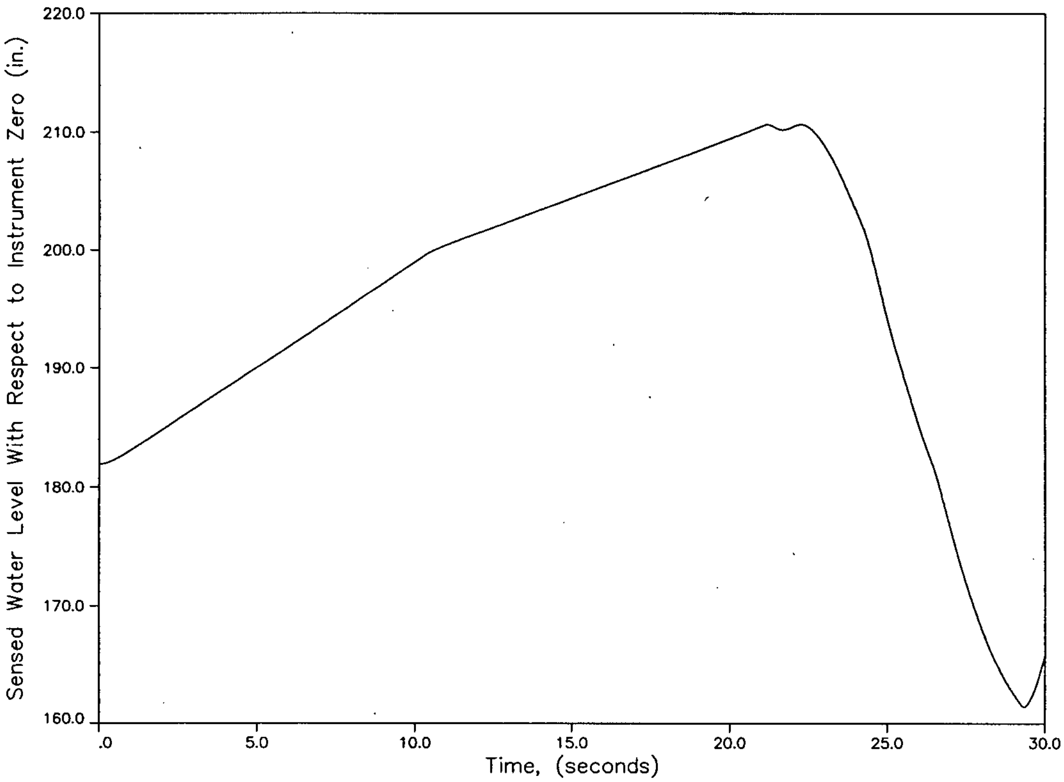

Figure 5.5 EOCLB FWCF at 100P/104.5F – TSSS Sensed Water Level

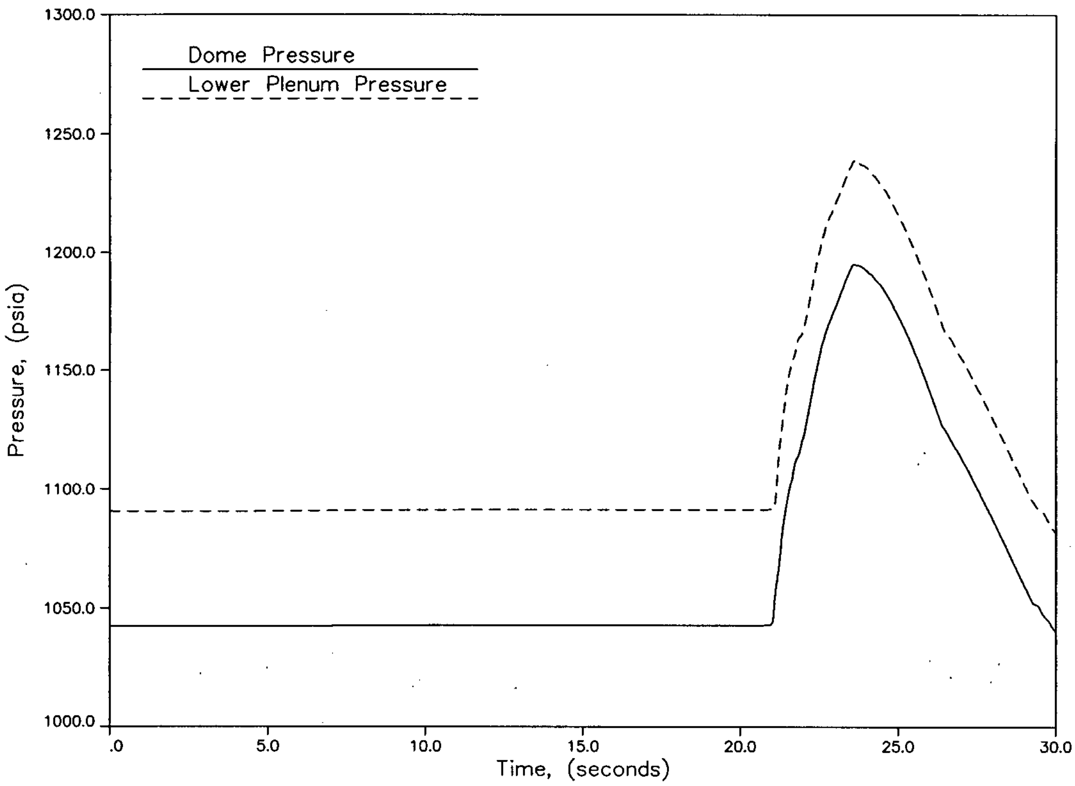

Figure 5.6 EOCLB FWCF at 100P/104.5F – TSSS Vessel Pressures

6.0 Postulated Accidents

6.1 *Loss-of-Coolant-Accident (LOCA)*

The results of the ATRIUM-10 LOCA analysis are presented in References 24 and 25. The ATRIUM-10 PCT is 1907°F which is higher than the PCT reported in Reference 3 for Brunswick Unit 1 Cycle 17. The increase in the licensing basis PCT is a result of a design change and not a change in the calculation process. The peak local metal water reaction is 1.15% and the core wide metal water reaction is < 0.50%. The SLO MAPLHGR multiplier is 0.85.

For operation with the MG sets, the GE14 LOCA analysis results are presented in Reference 26 (UFSAR). As discussed in Section 2.1.2, Progress Energy should evaluate the continued applicability of the GE14 LOCA analysis for operation with the VFDs.

6.2 *Control Rod Drop Accident (CRDA)*

Brunswick Unit 2 uses a bank position withdrawal sequence (BPWS) including reduced notch worth rod pull to limit high worth control rod movements. A CRDA evaluation was performed for both A and B sequence startups consistent with the withdrawal sequence specified by Progress Energy. Reference 27 describes the approved AREVA generic CRDA methodology. Subsequent calculations have shown that the methodology is applicable to fuel modeled with the CASMO4/MICROBURN-B2 code system. The CRDA analysis was performed with the approved methodology described in Reference 27.

The CRDA analysis results demonstrate that the maximum deposited fuel rod enthalpy is less than the NRC threshold of 280 cal/g and that the estimated number of fuel rods that exceed the fuel damage threshold of 170 cal/g is less than the number of failed rods assumed in the Brunswick Unit 2 UFSAR radiological assessment (1200 rods).

Maximum dropped control rod worth, mk	10.9
Core average Doppler coefficient, $\Delta k/k/°F$	-10.0×10^{-6}
Effective delayed neutron fraction	0.0052
Four-bundle local peaking factor	1.407
Maximum deposited fuel rod enthalpy, cal/g	201.4
Maximum number of rods exceeding 170 cal/g	366

6.3 *Fuel and Equipment Handling Accident*

The Brunswick fuel handling accident radiological analysis implementing the alternative source term (AST) methodology was performed with consideration of GE fuel in the core inventory source terms. Progress Energy has subsequently shown that the current BNP source term is applicable to cores with ATRIUM-10 fuel. AREVA has performed an analysis that shows that the number of failed fuel rods due to a fuel handling accident impacting the ATRIUM-10 fuel is 163. This is less than the number of rods analyzed in the Brunswick AST analysis (172 rods). The analysis also shows that the slightly higher mass of the ATRIUM-10 fuel does not result in an increase in rod failures when dropped onto GE14 fuel. Therefore, the AST analysis remains applicable for either an ATRIUM-10/GE14 mixed core or a full core of ATRIUM-10 fuel.

6.4 *Fuel Loading Error (Infrequent Event)*

There are two types of fuel loading errors possible in a BWR – the mislocation of a fuel assembly in a core position prescribed to be loaded with another fuel assembly, and the misorientation of a fuel assembly with respect to the control blade. As described in Reference 28, the fuel loading error is characterized as an infrequent event. The acceptance criteria is that the offsite dose consequences due to the event shall not exceed a small fraction of the 10 CFR 50.67 limits.

6.4.1 Mislocated Fuel Bundle

AREVA has performed a bounding fuel mislocation error analysis and has demonstrated continued applicability of the bounding results to Brunswick. This analysis evaluated the impact of a mislocated assembly against potential fuel rod failure mechanisms due to increased LHGR and reduced CPR. Based on these analyses, the offsite dose criteria (a small fraction of 10 CFR 50.67) is conservatively satisfied. Since no rod approached the fuel centerline melt or 1% strain limits, and less than 0.1% of the fuel rods are expected to experience boiling transition which could result in a dryout induced failure, a dose consequence evaluation is not necessary.

6.4.2 Misoriented Fuel Bundle

AREVA has performed a bounding fuel assembly misorientation analysis. The analysis was performed assuming that the limiting assembly was loaded in the worst orientation (rotated 180°) while producing sufficient power to be on the MCPR limit if it had been oriented correctly. The analysis demonstrates that the small fraction of 10 CFR 50.67 offsite dose criteria is conservatively satisfied. A dose consequence evaluation is not necessary since no rod approached the fuel centerline melt or 1% strain limits and less than 0.1% of the fuel rods are expected to experience boiling transition.

7.0 Special Analyses

7.1 *ASME Overpressurization Analysis*

This section describes the maximum overpressurization analyses performed to demonstrate compliance with the ASME Boiler and Pressure Vessel Code. The analysis shows that the safety/relief valves at Brunswick Unit 2 have sufficient capacity and performance to prevent the reactor vessel pressure from reaching the safety limit of 110% of the design pressure.

An MSIV closure analysis was performed with the AREVA plant simulator code COTRANSA2 (Reference 16) for 102% power and 104.5% flow at the highest Cycle 19 exposure where rated power operation can be attained. The MSIV closure event is similar to the other steam line valve closure events in that the valve closure results in a rapid pressurization of the core. The increase in pressure causes a decrease in void which in turn causes a rapid increase in power. The turbine bypass valves do not impact the system response and are not modeled in the analysis. The following assumptions were made in the analysis.

- The most critical active component (direct scram on valve position) was assumed to fail. However, scram on high neutron flux and high dome pressure is available.
- To maintain consistency with the bases discussion in Reference 21, the plant configuration analyzed assumed that two of the lowest setpoint SRVs were inoperable.
- TSSS insertion times were used.
- The initial dome pressure was set at the maximum allowed by the Technical Specifications, 1059.7 psia (1045 psig).
- A fast MSIV closure time of 2.7 seconds was used.

Results of the MSIV closure and TSV closure overpressurization analyses are presented in Table 7.1. Figures 7.1 – 7.4 show the response of various reactor plant parameters during the MSIV closure event. The maximum pressure of 1362 psig occurs in the lower plenum. The maximum dome pressure for the same event is 1318 psig. The results demonstrate that the maximum vessel pressure limit of 1375 psig and dome pressure limit of 1325 psig are not exceeded.

7.2 *ATWS Event Evaluation*

7.2.1 ATWS Overpressurization Analysis

This section describes the analyses performed to demonstrate that the peak vessel pressure for the limiting ATWS event is less than the ASME Service Level C limit of 120% of the design pressure (1500 psig). The ATWS overpressurization analyses were performed at 100% power at 99% and 104.5% flow over the Cycle 19 exposure range. The MSIV closure and pressure regulator failure open (PRFO) events were evaluated. Failure of the pressure regulator in the open position causes the turbine control and turbine bypass valves to open such that 115% of rated steam flow (maximum combined steam flow limit) is attained. The system pressure decreases until the low pressure setpoint is reached, resulting in the closure of the MSIVs. The resulting pressurization wave causes a decrease in core voids, an increase in core power, and an increase in core pressure.

The following assumptions were made in the analyses.

- The analytical limit ATWS-RPT setpoint and function were assumed.
- To support operation with 1 SRVOOS, the plant configuration analyzed assumed that one of the lowest setpoint SRVs was inoperable for the 99% and 104.5% flow cases.
- All scram functions were disabled.
- The initial dome pressure was set to the nominal pressure of 1045 psia.
- A nominal MSIV closure time of 4.0 seconds was used for both events.

Results of analyses for the ATWS overpressurization analyses are presented in Table 7.2. Figures 7.5 – 7.8 show the response of various reactor plant parameters during the limiting PRFO event, the event which results in the maximum vessel pressure. The maximum lower plenum pressure is 1485 psig and the maximum dome pressure is 1463 psig. The results demonstrate that the ATWS maximum vessel pressure limit of 1500 psig is not exceeded.

7.2.2 Long-Term Evaluation

Fuel design differences may impact the power and pressure excursion experienced during the ATWS event. This in turn may impact the amount of steam discharged to the suppression pool and containment. For Unit 1 Cycle 17 (Reference 3) an evaluation was previously performed that concluded that the introduction of ATRIUM-10 fuel will not significantly impact the long term ATWS response (suppression pool temperature and containment pressure) and the current analysis remains applicable. This conclusion was confirmed by analysis for Unit 2 Cycle 19.

Relative the 10 CFR 50.46 acceptance criteria (i.e., PCT and cladding oxidation), the consequences of an ATWS event are bound by those of the limiting LOCA event.

7.3 *Standby Liquid Control System*

In the event that the control rod scram function becomes incapable of rendering the core in a shutdown state, the standby liquid control (SLC) system is required to be capable of bringing the reactor from full power to a cold shutdown condition at any time in the core life. The Brunswick Unit 2 SLC system is required to be able to inject 720 ppm natural boron equivalent at 70°F into the reactor coolant (including a 25% allowance for imperfect mixing, leakage, and volume of other piping connected to the reactor). AREVA has performed an analysis that demonstrates that the SLC system meets the required shutdown capability for Cycle 19. The analysis was performed at a coolant temperature of 360°F with a boron concentration equivalent to 720 ppm at 70°F. The temperature of 360°F corresponds to the low pressure permissive for the RHR shutdown cooling suction valves, and represents the maximum reactivity condition with soluble boron in the coolant. The analysis shows the core to be subcritical throughout the cycle by at least 2.07% $\Delta k/k$.

7.4 *Fuel Criticality*

The new fuel storage vault criticality analysis for ATRIUM-10 fuel is presented in Reference 29. The spent fuel pool criticality analysis for ATRIUM-10 fuel is presented in Reference 30. The ATRIUM-10 fuel assemblies identified for loading in Cycle 19 meet both the new and spent fuel storage requirements.

Table 7.1 ASME Overpressurization Analysis Results

Event	Peak Neutron Flux (% rated)	Peak Heat Flux (% rated)	Maximum Vessel Pressure Lower-Plenum (psig)	Maximum Dome Pressure (psig)
MSIV closure (102P/104.5F)	328	128	1362	1318

Table 7.2 ATWS Overpressurization Analysis Results

Event	Peak Neutron Flux (% rated)	Peak Heat Flux (% rated)	Maximum Vessel Pressure Lower-Plenum (psig)	Maximum Dome Pressure (psig)
MSIV closure (100P/99F)	262	135	1459	1438
PRFO (100P/104.5F)	300	145	1484	1462
PRFO (100P/99F)	286	143	1485	1463

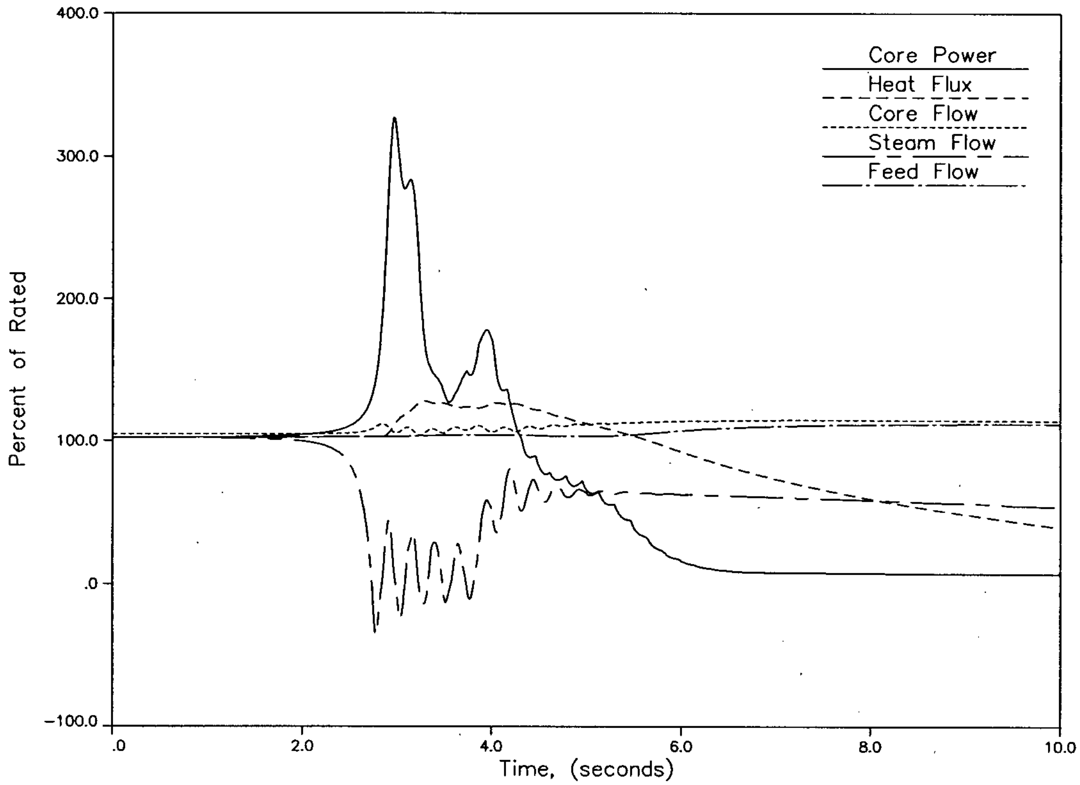

Figure 7.1 MSIV Closure Overpressurization Event at 102P/104.5F – Key Parameters

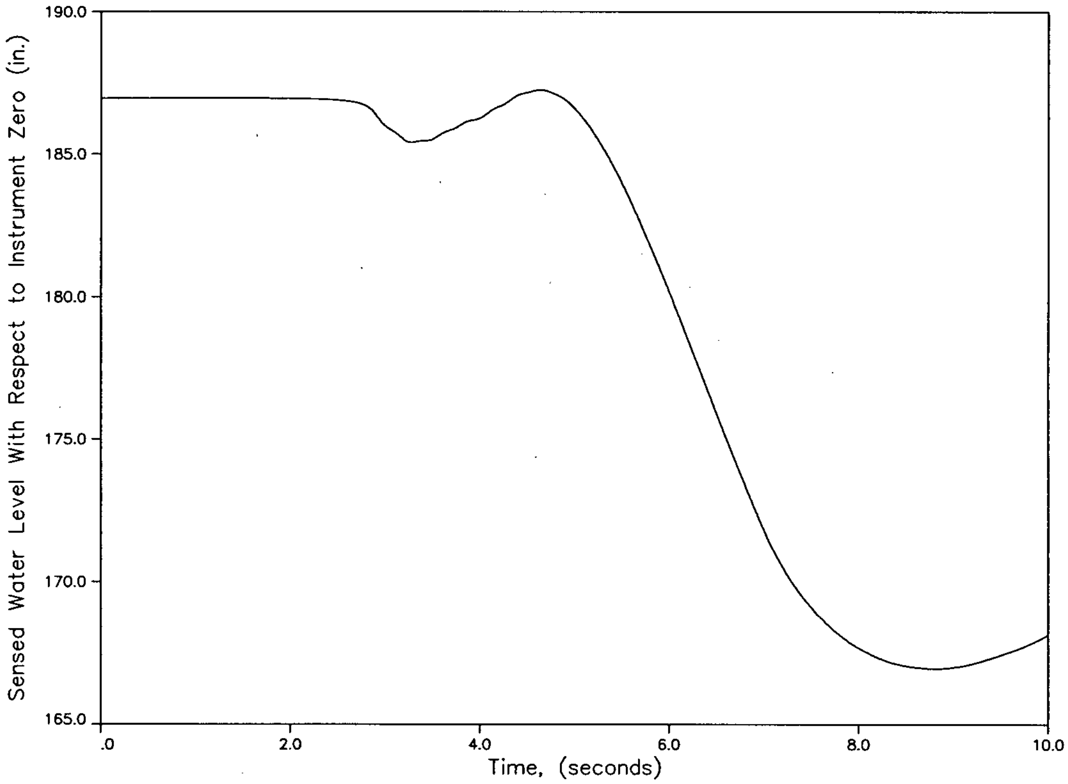

Figure 7.2 MSIV Closure Overpressurization Event at 102P/104.5F – Sensed Water Level

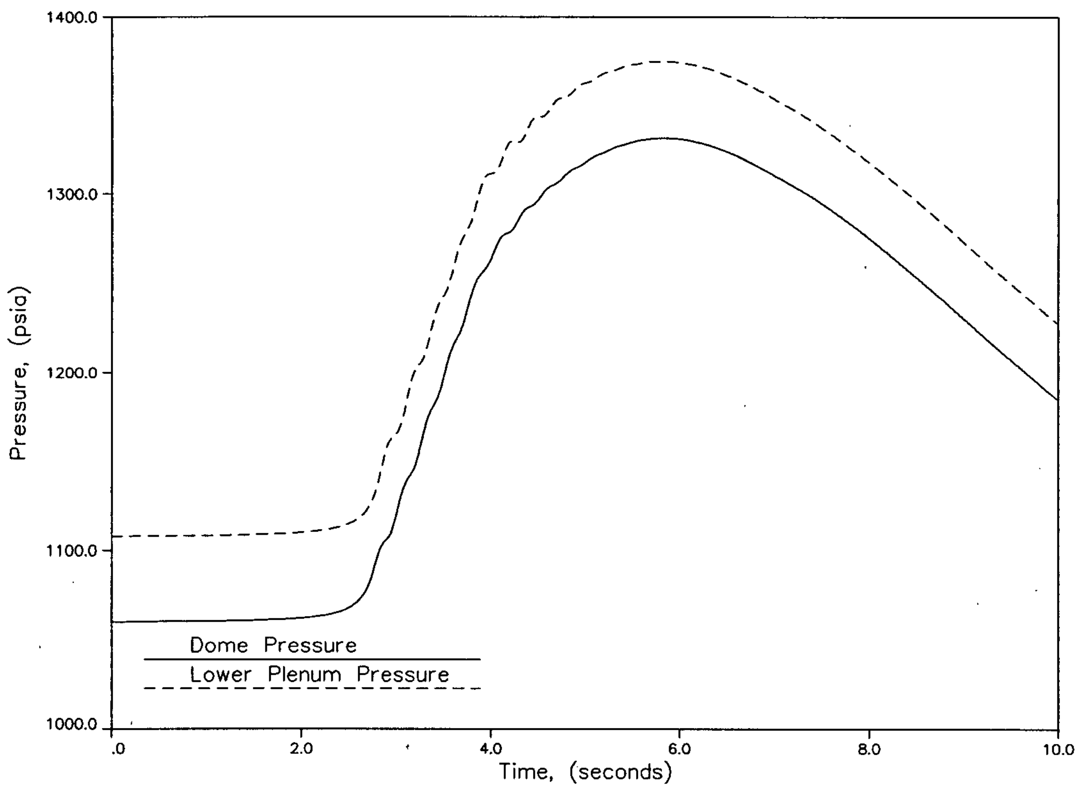

Figure 7.3 MSIV Closure Overpressurization Event at 102P/104.5F – Vessel Pressures

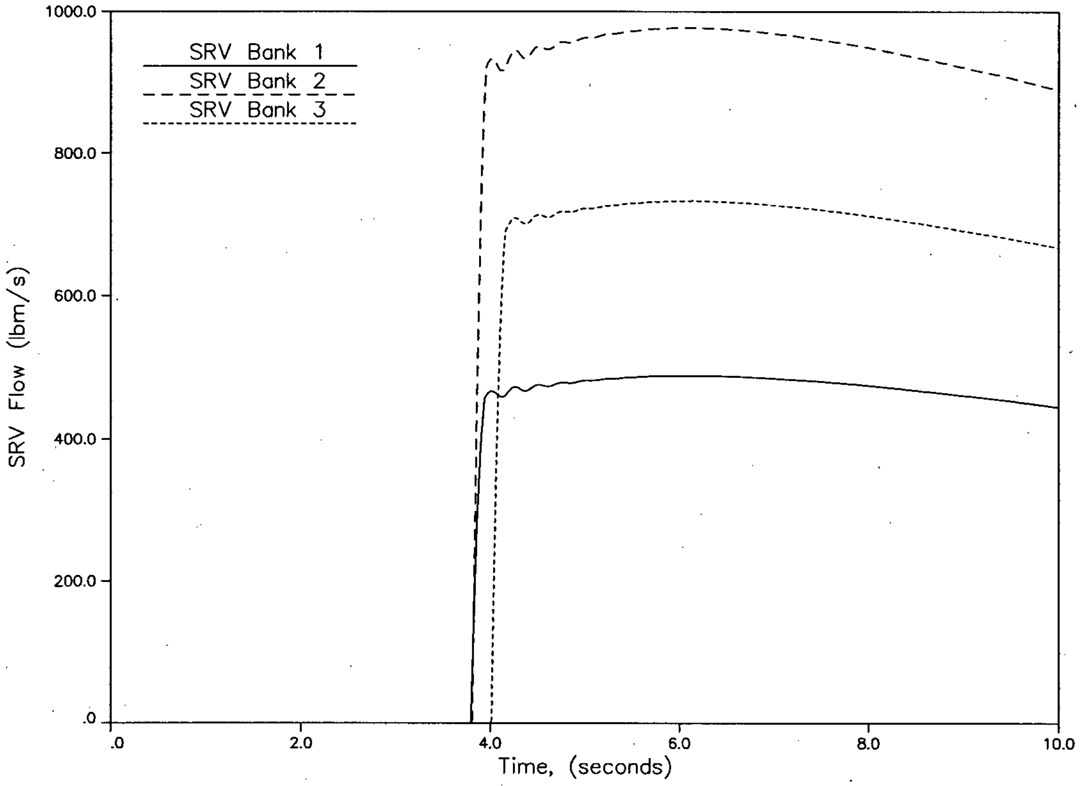

Figure 7.4 MSIV Closure Overpressurization Event at 102P/104.5F – Safety/Relief Valve Flow Rates

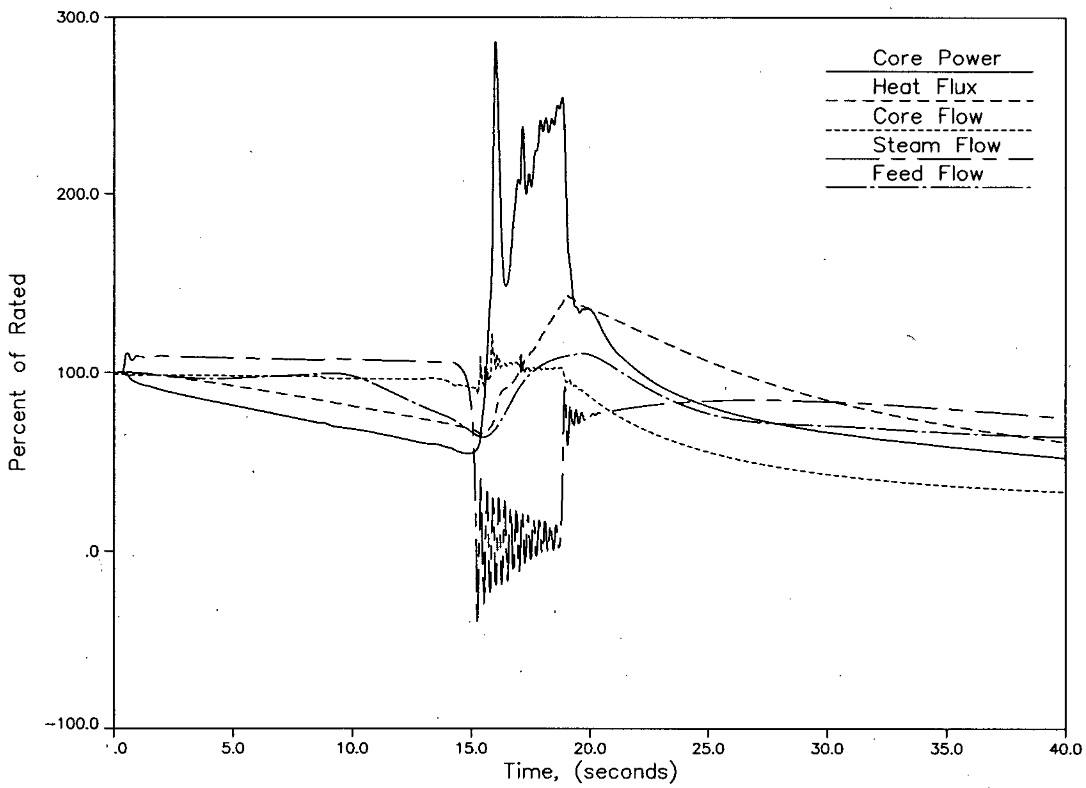

Figure 7.5 PRFO ATWS Overpressurization Event at 100P/99F – Key Parameters

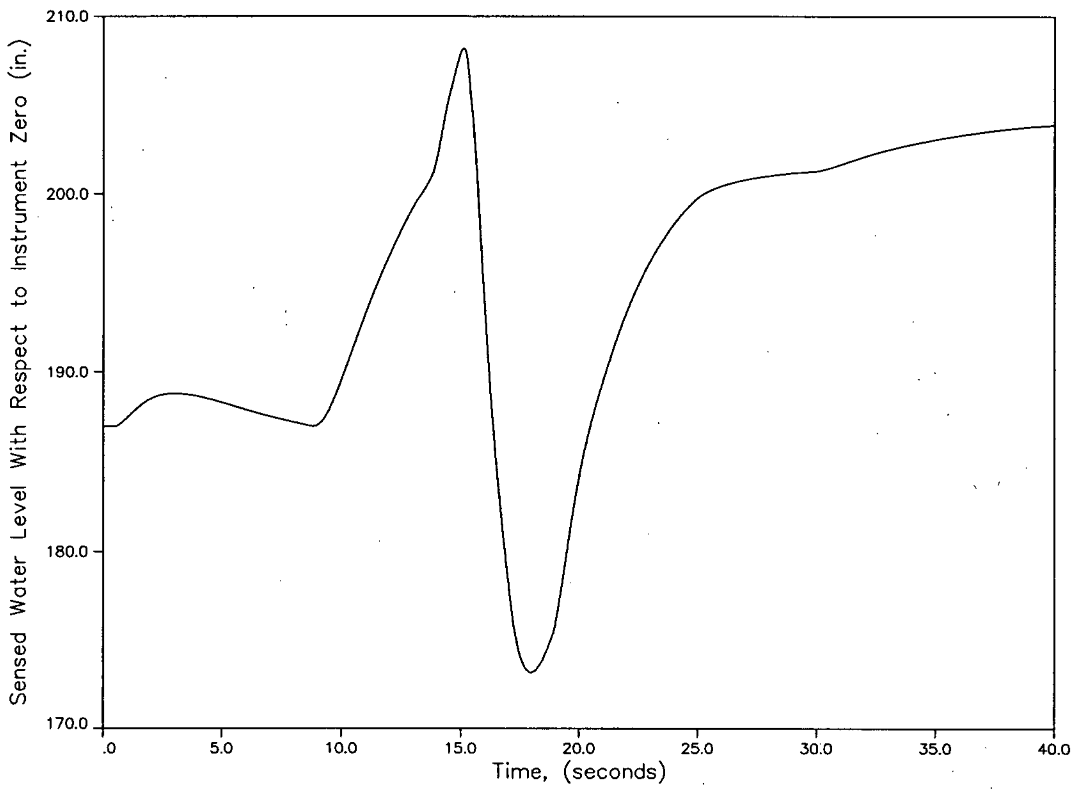

Figure 7.6 PRFO ATWS Overpressurization Event at 100P/99F – Sensed Water Level

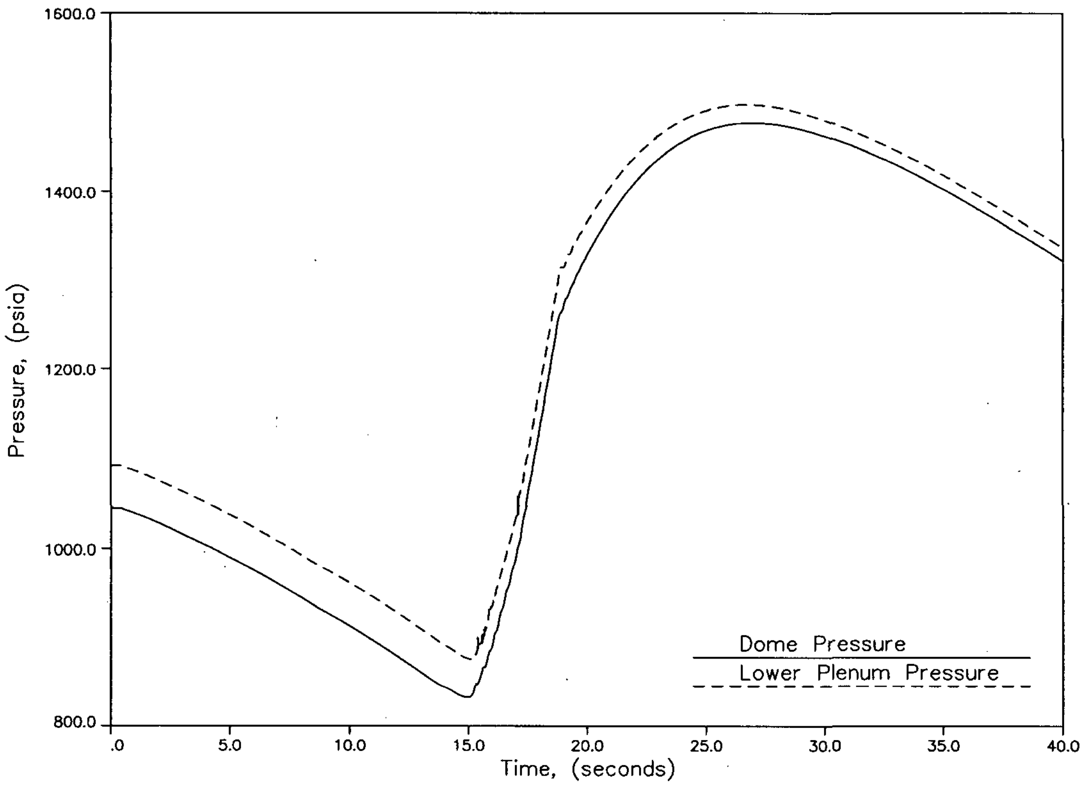

Figure 7.7 PRFO ATWS Overpressurization Event at 100P/99F – Vessel Pressures

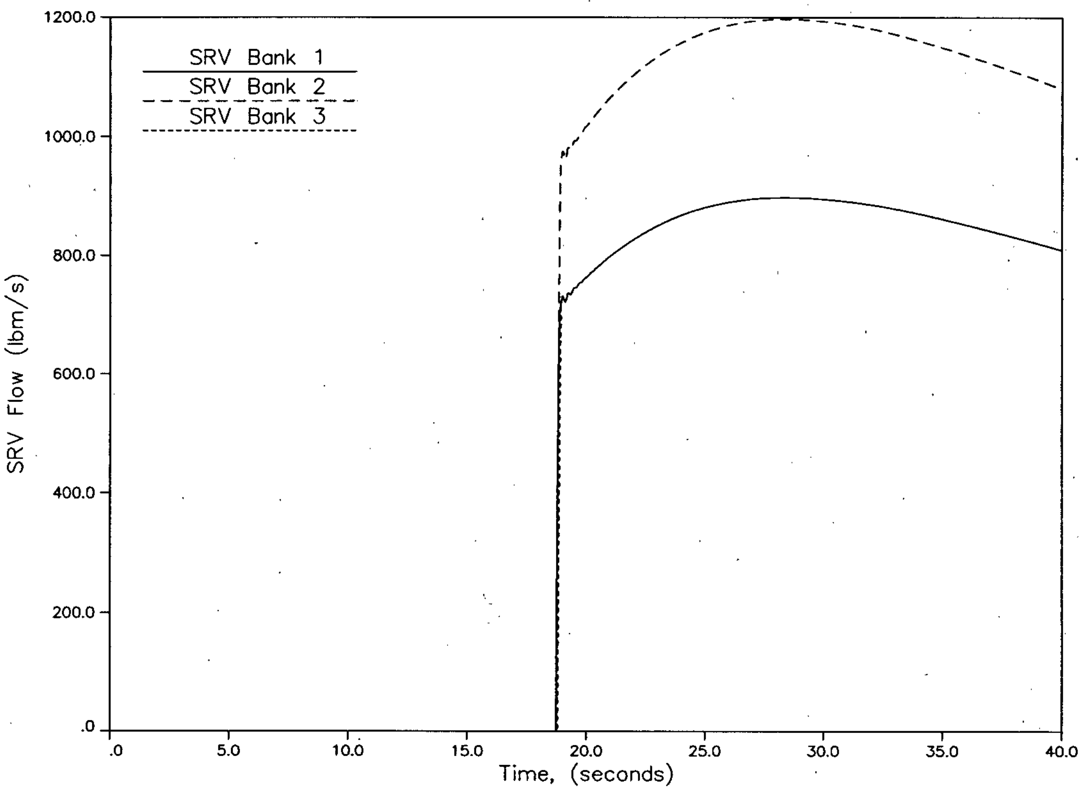

Figure 7.8 PRFO ATWS Overpressurization Event at 100P/99F – Safety/Relief Valve Flow Rates

8.0 Operating Limits and COLR Input

8.1 *MCPR Limits*

The determination of the MCPR limits for Brunswick Unit 2 Cycle 19 is based on the analyses of the limiting anticipated operational occurrences (AOOs). The MCPR operating limits are established so that less than 0.1% of the fuel rods in the core are expected to experience boiling transition during an AOO initiated from rated or off-rated conditions and are based on the Technical Specifications two-loop operation SLMCPR of 1.11 and a single-loop operation SLMCPR of 1.13. Exposure-dependent MCPR limits were established to support operation from BOC to near end-of-cycle (NEOC), NEOC to end-of-cycle licensing basis (EOCLB), and combined FFTR/Coastdown as defined by the core average exposures listed in Table 5.1. MCPR limits are established to support base case operation and the EOOS scenarios presented in Table 1.1.

Cycle 19 two-loop operation $MCPR_p$ limits for ATRIUM-10 and GE14 fuel are presented in Tables 8.1 – 8.6 for base case operation and the EOOS conditions. Limits are presented for nominal scram speed (NSS) and Technical Specification scram speed (TSSS) insertion times for the exposure ranges considered. An assumed RBM high power setpoint of 108% was used to develop the $MCPR_p$ limits. Tables 8.1 and 8.2 present the $MCPR_p$ limits for the BOC to NEOC exposure range. Tables 8.3 and 8.4 present the $MCPR_p$ limits applicable for the BOC to EOCLB exposure range. Tables 8.5 and 8.6 present the $MCPR_p$ limits for FFTR/Coastdown operation. The FFTR/Coastdown limits (both base case and TBVOOS) support both nominal and constant rated dome pressure operation with feedwater temperatures consistent with the Reference 2 feedwater temperature reduction characteristic. $MCPR_p$ limits for single-loop operation are 0.02 higher for all cases.

$MCPR_f$ limits that protect against fuel failures during a postulated slow flow excursion for ATRIUM-10 and GE14 fuel are presented in Table 8.7 and are applicable for all Cycle 19 exposures and the EOOS conditions identified in Table 1.1.

8.2 *LHGR Limits*

The LHGR limits for ATRIUM-10 fuel are presented in Table 8.8. Power- and flow-dependent multipliers ($LHGRFAC_p$ and $LHGRFAC_f$) are applied directly to the LHGR limits to protect against fuel melting and overstraining of the cladding during an AOO.

$LHGRFAC_p$ multipliers are determined using the heat flux ratio results from the transient analyses. Exposure-dependent $LHGRFAC_p$ multipliers were established to support operation from BOC to EOCLB and combined FFTR/Coastdown for both NSS and TSSS insertion times and for the EOOS conditions identified in Table 1.1. The ATRIUM-10 Cycle 19 $LHGRFAC_p$ multipliers for the BOC to EOCLB exposure range are presented in Tables 8.9 and 8.10. The FFTR/Coastdown $LHGRFAC_p$ multipliers are presented in Tables 8.11 and 8.12. The FFTR/Coastdown limits (both base case and TBVOOS) support both nominal and constant rated dome pressure operation with the Reference 2 feedwater temperature reduction characteristic.

$LHGRFAC_f$ multipliers are established to provide protection against fuel centerline melt and overstraining of the cladding during a postulated slow flow excursion. For ATRIUM-10 fuel, the multipliers are presented in Table 8.13 and are applicable for all Cycle 19 exposures and the EOOS conditions identified in Table 1.1.

Note that LHGR limits are not applied to the GE14 fuel so there are no GE14 power- or flow-dependent LHGR multipliers. The fuel centerline melt and overstraining of the cladding for GE14 fuel are ensured by applying power- and flow-dependent MAPLHGR limits as discussed below.

8.3 *MAPLHGR Limits*

The ATRIUM-10 TLO MAPLHGR limits are presented in Table 8.14. For operation in SLO, a multiplier of 0.85 must be applied to the TLO MAPLHGR limits.

The MAPLHGR limits for GE14 fuel are presented in Reference 31. As discussed in Section 2.1.2, Progress Energy should evaluate the applicability of the Reference 31 GE14 MAPLHGR limits for operation with the VFDs. Power- and flow-dependent multipliers are applied to the GE14 MAPLHGR limits. Application of the $MAPFAC_p$ and $MAPFAC_f$ multipliers to the GE14 fuel ensures that the fuel centerline melt and overstraining of the cladding criteria are met during AOOs. The $MAPFAC_p$ and $MAPFAC_f$ multipliers were developed in a manner consistent with the GNF thermal-mechanical methodology for GE14 fuel.

$MAPFAC_p$ multipliers were determined using the transient analysis results. Exposure-dependent $MAPFAC_p$ multipliers were established to support operation for all Cycle 19 exposures, both NSS and TSSS insertion times and all the EOOS conditions identified in Table 1.1. The GE14 $MAPFAC_p$ multipliers for all Cycle 19 exposures are presented in Table 8.15.

$MAPFAC_f$ multipliers are established to provide protection against fuel centerline melt and overstraining of the cladding during a postulated slow flow excursion for GE14 fuel. The GE14 $MAPFAC_f$ multipliers are presented in Table 8.16 and are applicable for all Cycle 19 exposures and the EOOS conditions identified in Table 1.1.

**Table 8.1 MCPR$_p$ Limits for
NSS Insertion Times
BOC to < NEOC***

EOOS Condition	Power (% rated)	ATRIUM-10 MCPR$_p$		GE14 MCPR$_p$	
Base case operation	100.0	1.35		1.37	
	90.0	1.38		1.40	
	50.0	1.48		1.48	
		≥ 65%F	≤ 65%F	≥ 65%F	≤ 65%F
	50.0	1.94	1.73	2.00	1.77
	26.0	2.27	2.02	2.23	2.03
	26.0	2.30	2.04	2.26	2.05
	23.0	2.35	2.12	2.30	2.12
TBVOOS	100.0	1.39		1.40	
	90.0	1.42		1.43	
	50.0	1.57		1.59	
		≥ 65%F	≤ 65%F	≥ 65%F	≤ 65%F
	50.0	1.94	1.73	2.00	1.77
	26.0	2.27	2.02	2.23	2.03
	26.0	2.82	2.54	2.78	2.53
	23.0	2.96	2.74	2.94	2.73
FHOOS	100.0	1.36		1.38	
	90.0	1.39		1.41	
	50.0	1.51		1.52	
		≥ 65%F	≤ 65%F	≥ 65%F	≤ 65%F
	50.0	1.94	1.73	2.00	1.77
	26.0	2.27	2.02	2.23	2.03
	26.0	2.30	2.04	2.26	2.05
	23.0	2.35	2.12	2.30	2.12
TBVOOS and FHOOS	100.0	1.40		1.41	
	90.0	1.43		1.45	
	50.0	1.61		1.63	
		≥ 65%F	≤ 65%F	≥ 65%F	≤ 65%F
	50.0	1.94	1.73	2.00	1.77
	26.0	2.27	2.02	2.23	2.03
	26.0	2.95	2.64	2.91	2.63
	23.0	3.09	2.87	3.06	2.86

* Limits support operation with any combination of 1 SRVOOS, up to 40% of the TIP channels out-of-service, and up to 50% of the LPRMs out-of-service. For single-loop operation, MCPR$_p$ limits will be 0.02 higher.

**Table 8.2 MCPR$_p$ Limits for
TSSS Insertion Times
BOC to < NEOC***

EOOS Condition	Power (% rated)	ATRIUM-10 MCPR$_p$		GE14 MCPR$_p$	
Base case operation	100.0	1.45		1.47	
	90.0	1.46		1.48	
	50.0	1.50		1.52	
		> 65%F	≤ 65%F	> 65%F	≤ 65%F
	50.0	1.97	1.75	2.03	1.79
	26.0	2.29	2.03	2.25	2.04
	26.0	2.30	2.04	2.26	2.05
	23.0	2.35	2.12	2.30	2.12
TBVOOS	100.0	1.47		1.49	
	90.0	1.49		1.52	
	50.0	1.63		1.65	
		> 65%F	≤ 65%F	> 65%F	≤ 65%F
	50.0	1.97	1.75	2.03	1.79
	26.0	2.29	2.03	2.25	2.04
	26.0	2.82	2.54	2.78	2.53
	23.0	2.96	2.74	2.94	2.73
FHOOS	100.0	1.46		1.48	
	90.0	1.47		1.49	
	50.0	1.53		1.54	
		> 65%F	≤ 65%F	> 65%F	≤ 65%F
	50.0	1.97	1.75	2.03	1.79
	26.0	2.29	2.03	2.25	2.04
	26.0	2.30	2.04	2.26	2.05
	23.0	2.35	2.12	2.30	2.12
TBVOOS and FHOOS	100.0	1.48		1.50	
	90.0	1.50		1.53	
	50.0	1.67		1.68	
		> 65%F	≤ 65%F	> 65%F	≤ 65%F
	50.0	1.97	1.75	2.03	1.79
	26.0	2.29	2.03	2.25	2.04
	26.0	2.95	2.64	2.91	2.63
	23.0	3.09	2.87	3.06	2.86

* Limits support operation with any combination of 1 SRVOOS, up to 40% of the TIP channels out-of-service, and up to 50% of the LPRMs out-of-service. For single-loop operation, MCPR$_p$ limits will be 0.02 higher.

**Table 8.3 $MCPR_p$ Limits for
NSS Insertion Times
BOC to < EOCLB***

EOOS Condition	Power (% rated)	ATRIUM-10 $MCPR_p$		GE14 $MCPR_p$	
Base case operation	100.0	1.43		1.44	
	90.0	1.45		1.45	
	50.0	1.53		1.53	
		≥ 65%F	≤ 65%F	≥ 65%F	≤ 65%F
	50.0	1.95	1.74	2.00	1.77
	26.0	2.27	2.02	2.23	2.03
	26.0	2.30	2.04	2.26	2.05
	23.0	2.35	2.12	2.30	2.12
TBVOOS	100.0	1.45		1.46	
	90.0	1.48		1.48	
	50.0	1.59		1.59	
		≥ 65%F	≤ 65%F	≥ 65%F	≤ 65%F
	50.0	1.95	1.74	2.00	1.77
	26.0	2.27	2.02	2.23	2.03
	26.0	2.82	2.54	2.78	2.53
	23.0	2.96	2.74	2.94	2.73
FHOOS	100.0	1.44		1.45	
	90.0	1.46		1.46	
	50.0	1.53		1.53	
		≥ 65%F	≤ 65%F	≥ 65%F	≤ 65%F
	50.0	1.95	1.74	2.00	1.77
	26.0	2.27	2.02	2.23	2.03
	26.0	2.30	2.04	2.26	2.05
	23.0	2.35	2.12	2.30	2.12
TBVOOS and FHOOS	100.0	1.46		1.50	
	90.0	1.49		1.52	
	50.0	1.62		1.63	
		≥ 65%F	≤ 65%F	≥ 65%F	≤ 65%F
	50.0	1.95	1.74	2.00	1.77
	26.0	2.27	2.02	2.23	2.03
	26.0	2.95	2.64	2.91	2.63
	23.0	3.09	2.87	3.06	2.86

* Limits support operation with any combination of 1 SRVOOS, up to 40% of the TIP channels out-of-service, and up to 50% of the LPRMs out-of-service. For single-loop operation, $MCPR_p$ limits will be 0.02 higher.

Table 8.4 $MCPR_p$ Limits for TSSS Insertion Times BOC to < EOCLB*

EOOS Condition	Power (% rated)	ATRIUM-10 $MCPR_p$		GE14 $MCPR_p$	
Base case operation	100.0	1.48		1.49	
	90.0	1.49		1.49	
	50.0	1.53		1.53	
		≥ 65%F	≤ 65%F	≥ 65%F	≤ 65%F
	50.0	1.99	1.77	2.03	1.79
	26.0	2.29	2.03	2.25	2.04
	26.0	2.30	2.04	2.26	2.05
	23.0	2.35	2.12	2.30	2.12
TBVOOS	100.0	1.50		1.51	
	90.0	1.51		1.53	
	50.0	1.63		1.65	
		≥ 65%F	≤ 65%F	≥ 65%F	≤ 65%F
	50.0	1.99	1.77	2.03	1.79
	26.0	2.29	2.03	2.25	2.04
	26.0	2.82	2.54	2.78	2.53
	23.0	2.96	2.74	2.94	2.73
FHOOS	100.0	1.49		1.50	
	90.0	1.50		1.50	
	50.0	1.53		1.54	
		≥ 65%F	≤ 65%F	≥ 65%F	≤ 65%F
	50.0	1.99	1.77	2.03	1.79
	26.0	2.29	2.03	2.25	2.04
	26.0	2.30	2.04	2.26	2.05
	23.0	2.35	2.12	2.30	2.12
TBVOOS and FHOOS	100.0	1.51		1.59	
	90.0	1.52		1.61	
	50.0	1.67		1.72	
		≥ 65%F	≤ 65%F	≥ 65%F	≤ 65%F
	50.0	1.99	1.77	2.07	1.83
	26.0	2.29	2.03	2.29	2.08
	26.0	2.95	2.64	2.95	2.67
	23.0	3.09	2.87	3.10	2.90

* Limits support operation with any combination of 1 SRVOOS, up to 40% of the TIP channels out-of-service, and up to 50% of the LPRMs out-of-service. For single-loop operation, $MCPR_p$ limits will be 0.02 higher.

**Table 8.5 $MCPR_p$ Limits for
NSS Insertion Times
FFTR/Coastdown***

EOOS Condition	Power (% rated)	ATRIUM-10 $MCPR_p$		GE14 $MCPR_p$	
Base case operation	100.0	1.47		1.46	
	90.0	1.48		1.47	
	50.0	1.56		1.55	
		> 65%F	≤ 65%F	> 65%F	≤ 65%F
	50.0	1.96	1.75	2.00	1.77
	26.0	2.27	2.02	2.23	2.03
	26.0	2.30	2.04	2.26	2.05
	23.0	2.35	2.12	2.30	2.12
TBVOOS	100.0	1.47		1.50	
	90.0	1.49		1.52	
	50.0	1.62		1.63	
		> 65%F	≤ 65%F	> 65%F	≤ 65%F
	50.0	1.96	1.75	2.00	1.77
	26.0	2.27	2.02	2.23	2.03
	26.0	2.95	2.64	2.91	2.63
	23.0	3.09	2.87	3.06	2.86

* Limits support operation with any combination of 1 SRVOOS, up to 40% of the TIP channels out-of-service, and up to 50% of the LPRMs out-of-service. For single-loop operation, $MCPR_p$ limits will be 0.02 higher.

Table 8.6 $MCPR_p$ Limits for TSSS Insertion Times FFTR/Coastdown*

EOOS Condition	Power (% rated)	ATRIUM-10 $MCPR_p$		GE14 $MCPR_p$	
Base case operation	100.0	1.50		1.50	
	90.0	1.50		1.50	
	50.0	1.56		1.55	
		> 65%F	≤ 65%F	> 65%F	≤ 65%F
	50.0	2.02	1.81	2.04	1.80
	26.0	2.29	2.03	2.25	2.04
	26.0	2.30	2.04	2.26	2.05
	23.0	2.35	2.12	2.30	2.12
TBVOOS	100.0	1.51		1.59	
	90.0	1.52		1.61	
	50.0	1.67		1.72	
		> 65%F	≤ 65%F	> 65%F	≤ 65%F
	50.0	2.02	1.81	2.07	1.83
	26.0	2.29	2.03	2.29	2.08
	26.0	2.95	2.64	2.95	2.67
	23.0	3.09	2.87	3.10	2.90

* Limits support operation with any combination of 1 SRVOOS, up to 40% of the TIP channels out-of-service, and up to 50% of the LPRMs out-of-service. For single-loop operation, $MCPR_p$ limits will be 0.02 higher.

**Table 8.7 Flow-Dependent MCPR Limits
ATRIUM-10 and GE14 Fuel**

Core Flow (% of rated)	$MCPR_f$
0.0	1.65
31.0	1.65
100.0	1.20
107.0	1.20

Table 8.8 ATRIUM-10 Steady-State LHGR Limits

Peak Pellet Exposure (GWd/MTU)	LHGR (kW/ft)
0.0	13.4
18.9	13.4
74.4	7.1

Table 8.9 ATRIUM-10 $LHGRFAC_p$ Multipliers for NSS Insertion Times BOC to < EOCLB

EOOS Condition	Power (% rated)	ATRIUM-10 $LHGRFAC_p$	
Base case operation	100.0	1.00	
	90.0	1.00	
	50.0	0.90	
		> 65%F	≤ 65%F
	50.0	0.69	0.78
	26.0	0.60	0.65
	26.0	0.59	0.63
	23.0	0.58	0.62
TBVOOS	100.0	0.95	
	90.0	0.94	
	50.0	0.86	
		> 65%F	≤ 65%F
	50.0	0.69	0.78
	26.0	0.60	0.65
	26.0	0.47	0.54
	23.0	0.45	0.50
FHOOS	100.0	1.00	
	90.0	1.00	
	50.0	0.90	
		> 65%F	≤ 65%F
	50.0	0.69	0.78
	26.0	0.60	0.65
	26.0	0.59	0.63
	23.0	0.58	0.62
TBVOOS and FHOOS	100.0	0.95	
	90.0	0.94	
	50.0	0.85	
		> 65%F	≤ 65%F
	50.0	0.69	0.78
	26.0	0.60	0.65
	26.0	0.45	0.51
	23.0	0.43	0.47

Table 8.10 ATRIUM-10 LHGRFAC$_p$ Multipliers for TSSS Insertion Times BOC to < EOCLB

EOOS Condition	Power (% rated)	ATRIUM-10 LHGRFAC$_p$	
Base case operation	100.0	1.00	
	90.0	0.95	
	50.0	0.87	
		> 65%F	≤ 65%F
	50.0	0.67	0.77
	26.0	0.60	0.64
	26.0	0.59	0.63
	23.0	0.58	0.62
TBVOOS	100.0	0.93	
	90.0	0.91	
	50.0	0.86	
		> 65%F	≤ 65%F
	50.0	0.67	0.77
	26.0	0.60	0.64
	26.0	0.47	0.54
	23.0	0.45	0.50
FHOOS	100.0	1.00	
	90.0	0.95	
	50.0	0.87	
		> 65%F	≤ 65%F
	50.0	0.67	0.77
	26.0	0.60	0.64
	26.0	0.59	0.63
	23.0	0.58	0.62
TBVOOS and FHOOS	100.0	0.93	
	90.0	0.91	
	50.0	0.84	
		> 65%F	≤ 65%F
	50.0	0.67	0.77
	26.0	0.60	0.64
	26.0	0.45	0.51
	23.0	0.43	0.47

Table 8.11 ATRIUM-10 LHGRFAC$_p$ Multipliers for NSS Insertion Times FFTR/Coastdown

EOOS Condition	Power (% rated)	ATRIUM-10 LHGRFAC$_p$	
Base case operation	100.0	1.00	
	90.0	1.00	
	50.0	0.86	
		> 65%F	≤ 65%F
	50.0	0.69	0.77
	26.0	0.60	0.65
	26.0	0.59	0.63
	23.0	0.58	0.62
TBVOOS	100.0	0.93	
	90.0	0.91	
	50.0	0.85	
		> 65%F	≤ 65%F
	50.0	0.69	0.77
	26.0	0.60	0.65
	26.0	0.45	0.51
	23.0	0.43	0.47

Table 8.12 ATRIUM-10 LHGRFAC$_p$ Multipliers for TSSS Insertion Times FFTR/Coastdown

EOOS Condition	Power (% rated)	ATRIUM-10 LHGRFAC$_p$	
Base case operation	100.0	1.00	
	90.0	0.94	
	50.0	0.86	
		> 65%F	≤ 65%F
	50.0	0.67	0.76
	26.0	0.60	0.64
	26.0	0.59	0.63
	23.0	0.58	0.62
TBVOOS	100.0	0.91	
	90.0	0.90	
	50.0	0.82	
		> 65%F	≤ 65%F
	50.0	0.67	0.76
	26.0	0.60	0.64
	26.0	0.45	0.51
	23.0	0.43	0.47

**Table 8.13 ATRIUM-10 $LHGRFAC_f$ Multipliers
All Cycle 19 Exposures**

Core Flow (% of rated)	$LHGRFAC_f$
0.0	0.90
31.0	0.90
50.0	1.00
107.0	1.00

Table 8.14 ATRIUM-10 MAPLHGR Limits

Average Planar Exposure (GWd/MTU)	MAPLHGR (kW/ft)
0.0	12.5
15.0	12.5
67.0	7.3

Table 8.15 GE14 $MAPFAC_p$ Multipliers for NSS and TSSS Insertion Times All Cycle 19 Exposures

EOOS Condition	Power (% rated)	GE14 $MAPFAC_p$	
Base case and all supported EOOS Conditions	100.0	1.00	
	50.0	0.73	
		> 65%F	≤ 65%F
	50.0	0.64	0.73
	26.0	0.56	0.61
	26.0	0.43	0.49
	23.0	0.41	0.45

Table 8.16 GE14 $MAPFAC_f$ Multipliers
All Cycle 19 Exposures

Core Flow (% rated)	GE14 $MAPFAC_f$
0.0	0.56
31.0	0.56
80.0	1.00
107.0	1.00

9.0 References

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Appendix A MELLLA+ Operation

Progress Energy is considering applying for approval to operate in the Maximum Extended Load Line Limit Analysis Plus (MELLLA+) domain which would provide greater flow flexibility, especially at rated and near-rated power. The combined MELLLA/MELLLA+ power flow map is presented in Figure A.1. The EOOS conditions presented in Table A.1 are supported. While approval is not expected for Brunswick Unit 2 Cycle 19, the cycle-specific reload licensing analyses were performed to support operation in the MELLLA+ domain. Special consideration of MELLLA+ was given during the analyses for the anticipated operational occurrences (AOOs), ASME and ATWS overpressurization, stability, LOCA, and the other accidents.

Transient analyses results at state points along the MELLLA+ low flow boundary demonstrate that the events are limiting at high flow. Results for the other AOOs show that the operating limits presented in Section 8.0 remain applicable for MELLLA+. LOCA analysis results also show that high flow is limiting. Since no SRVs will be allowed out of service in MELLLA+ operation, the MELLLA+ ASME and ATWS overpressurization results are non-limiting. While most of the limiting analysis results that support the MELLLA operating limits remain limiting for the MELLLA+ domain, the stability analysis is impacted as discussed below.

Stability

The Enhanced Option III (EO-III) Long Term Stability Solution (Reference A.1) was used in the stability evaluations to support MELLLA+ operation. The cycle-specific setpoint determination was performed in accordance with the approved methodology presented in References A.1 and A.2, including the 10% penalty on the DIVOM slope discussed in the Reference A.2 NRC safety evaluation. The EO-III solution consists of two components: a single channel exclusion region, and a stability-based Operating Limit MCPR (OLMCPR).

The first component is the single channel exclusion region which is protected by automatic scram. The endpoints of the channel exclusion region are given in Table A.2. The exclusion region boundary is defined by a straight line fit through these two endpoints and is only valid for nominal feedwater temperature since FHOOS and FFTR operation are not allowed in the MELLLA+ region.

The cycle-specific DIVOM curves were generated consistent with the approach described in Reference A.1 using state points located inside the channel exclusion region. A review of the DIVOM analysis results shows that no single channel instabilities occurred, confirming that the channel exclusion region has been adequately set. The limiting calculated DIVOM results for all state points and exposures were used in the evaluation of the stability-based OLMCPRs.

The stability-based OLMCPR is provided for two conditions as a function of OPRM amplitude setpoint in Table A.3. The two conditions evaluated are for 1) a postulated oscillation at 45% core flow steady-state operation (SS) and 2) following a two recirculation pump trip (2PT) from the limiting full power state point. The Cycle 19 power- and flow-dependent MCPR limits provide adequate protection against violation of the SLMCPR for postulated reactor instability as long as the MCPR operating limit is greater than or equal to the specified value for the selected OPRM setpoint. The results in Table A.3 are valid for the full ICF/MELLLA+ operating domain.

For Backup Stability Protection (BSP) during MELLLA+ operation, AREVA has extended the Base Minimal Region I (scram region) using the generic shape generating function (Reference A.3) to the point where it intersects the extension of the MELLLA+ upper flow boundary line (68.8 %P/ 43.2 %F). STAIF analyses based on a pump-trip runback to this intersection have been performed to demonstrate that the decay ratio criteria are met. Since FFTR and FHOOS operation is not allowed in the MELLLA+ domain, these analyses have been performed only for nominal feedwater temperature operation.

There is no need to extend Base Minimal Region II (controlled entry) for MELLLA+ operation. Potential pump trips from MELLLA+ operating points that could result in a post-trip endpoint outside (above) the extended Region I boundary and above the MELLLA line but below the MELLLA+ region, are by definition outside the allowed power/flow map domain. Such a condition would require intervention to bring the core back within the allowable power/flow map operating domain. STAIF analyses at the low-flow high-power corner of the MELLLA+ domain show significant stability margin.

As discussed in Reference A.4, additional analyses are needed to ensure the acceptability of the ATWS with core instability analyses with ATRIUM-10 fuel at MELLLA+ conditions.

References

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A.3 0G02-0119-260, Backup Stability Protection (BSP) for Inoperable Option III Solution, GE Nuclear Energy, July 17, 2002.

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Table A.1 MELLLA+ EOOS Operating Conditions*, †

Turbine bypass valves out-of-service (TBVOOS)
Up to 40% of the TIP channels out-of-service (100% available at startup)
Up to 50% of the LPRMs out-of-service

* Each EOOS condition is supported in combination with up to 40% of the TIP channels out-of-service, and/or up to 50% of the LPRMs out-of-service.

† Note: Feedwater heater out-of-service, SRV out-of-service, main steam isolation valves out-of-service, and single-loop operation are not allowed in the MELLLA+ region.

Table A.2 Channel Exclusion Region Endpoints

Power (% rated)	Flow (% rated)
50.0	31.0
65.8	39.2

Table A.3 OPRM Setpoints

OPRM Setpoint	OLMCPR (SS)	OLMCPR (2PT)
1.05	1.21	1.24
1.06	1.24	1.26
1.07	1.26	1.28
1.08	1.28	1.30
1.09	1.30	1.33
1.10	1.33	1.35
1.11	1.35	1.38
1.12	1.37	1.40
1.13	1.40	1.43
1.14	1.43	1.45
1.15	1.45	1.48
Acceptance Criteria	Less than or equal to the Off-Rated OLMCPR at 45% Flow	Less than or equal to the Rated Power OLMCPR as described in Section 8.0

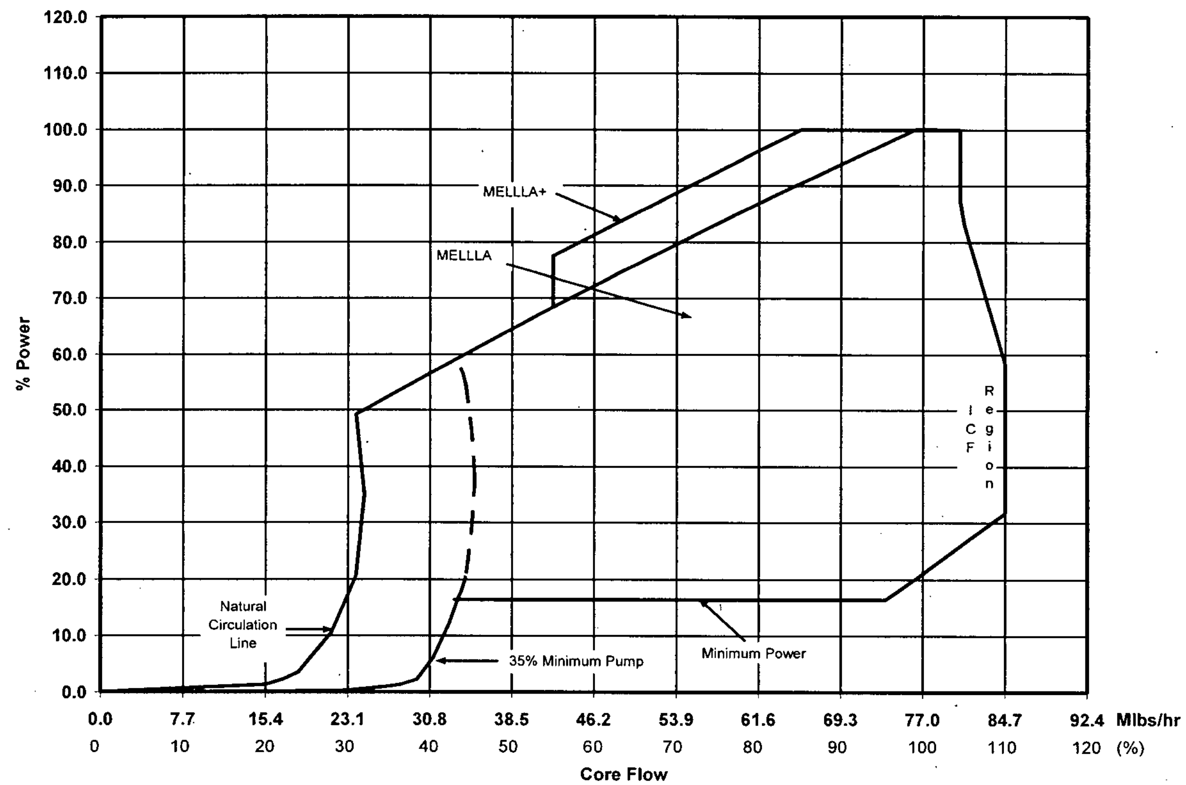

Figure A.1 Brunswick Unit 2
Power Flow Map with MELLLA+