RAIO-0918-61805

Docket No. 52-048

September 14, 2018

U.S. Nuclear Regulatory Commission
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SUBJECT: NuScale Power, LLC Response to NRC Request for Additional Information No. 438 (eRAI No. 9491) on the NuScale Design Certification Application

REFERENCE: U.S. Nuclear Regulatory Commission, "Request for Additional Information No. 438 (eRAI No. 9491)," dated April 26, 2018

The purpose of this letter is to provide the NuScale Power, LLC (NuScale) response to the referenced NRC Request for Additional Information (RAI).

The Enclosure to this letter contains NuScale's response to the following RAI Question from NRC eRAI No. 9491:

- 15.09-2

This letter and the enclosed response make no new regulatory commitments and no revisions to any existing regulatory commitments.

If you have any questions on this response, please contact Paul Infanger at 541-452-7351 or at pinfanger@nuscalepower.com.

Sincerely,

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Enclosure 1: NuScale Response to NRC Request for Additional Information eRAI No. 9491

Enclosure 1:

NuScale Response to NRC Request for Additional Information eRAI No. 9491

Response to Request for Additional Information
Docket No. 52-048

eRAI No.: 9491
Date of RAI Issue: 04/26/2018

NRC Question No.: 15.09-2

Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, Appendix A, General Design Criterion (GDC) 10 – Reactor Design, states that the reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits (SAFDLs) are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences (AOOs). GDC 12-Suppression of Reactor Power Oscillations requires that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be detected and suppressed. Design-Specific Review Standard (DSRS) 15.9 states that the reviewer verifies that all analysis methodologies, including treatment of uncertainties, are acceptable. DSRS 15.0 indicates that the reviewer verify that applicant has identified major input parameters and initial conditions used in the analyses, included the initial values of other initial values if they are used in the analyses, provided the bases and degree of conservatism for numerical values of the input parameters and initial conditions, and evaluate the applicant's claims that AOOs are limiting or nonlimiting, or bounded by other AOOs.

The applicant performed stability analyses over a spectrum of events that includes perturbation of steady state and transient operations where the initiating events are variations of selected anticipated operational occurrences (AOO) discussed in other FSAR chapter 15 subsections. The applicant states "The operation events are analogous to the licensing basis AOOs. However, typical licensing basis AOO scenarios are chosen to provide limiting system response and generally result in a reactor trip … The stability operational events are constructed to avoid a reactor trip in order to assess the stability of the NPM." The applicant considers events from six AOO classification types listed in DSRS 15.0. However, a list or table of key parameters, values, and uncertainty biases for each limiting event was not found in Section 15.9 of the FSAR. In addition, it is not clear if the events analyzed are the most limiting stability events for the given classification type. Several 15.9 subsections of the FSAR, including

15.9.3.1, 15.9.3.2, 15.9.3.5, 15.9.4.1, and 15.9.4.2 refer to the stability methodology topical report (TR), TR-0516- 49417-P, for additional event specific information, however staff was unable to find the aforementioned proposed key parameter tables in the TRTo make an affirmative finding associated with the above regulatory requirement important to safety, NRC staff requests NuScale to:

1. Provide, in the FSAR, tables of key initial conditions and parameters, their values, and their biases, that were applied to the limiting events for a given event category. Initial condition and parameter tables similar to those provided for AOO events in sections 15.1 and 15.2 of the FSAR are acceptable to staff. Examples include: Tables 15.1-2 – through 15.1-4, or Tables 15.2-1 through 15.2-3, of the FSAR. Initial values of amplitude and frequency (or period) should be included in key initial condition parameter tables for stability events where external oscillations are imposed on the reactor system model.

2. Provide, in the FSAR, tables containing acceptance criteria values for limiting stability events. The tables should include decay ratios.

NuScale Response:

1. As shown in the attached markups, FSAR Section 15.9 has been updated to include tables of key initial conditions and parameters and their values that were applied to the limiting events for a given event category. Initial values of amplitude and frequency (or period) were also included as appropriate.

Since higher or lower parameter values are not necessarily conservative due to the nonlinear behavior of the system, biasing would not necessarily produce a limiting analysis. No biases are considered because parametric sensitivity studies shown in responses to RAI numbers 8801 (ML17219A739), 8937 (ML17271A286), 8921 (ML17268A389), 8944 (ML17271A238), 9017 (ML17268A379), 9104 (ML17324B101), 9136 (ML17353A495 and ML18002A611), 9417 (ML18149A652), 9438 (ML18150A708), and 9440 (ML18137A618) indicated no significant changes in results.

2. As shown in the attached markups, FSAR Section 15.9 has been updated to include tables containing acceptance criteria values (including decay ratios) for limiting stability events.

Additionally, the RAI noted "it is not clear if the events analyzed are the most limiting stability events for the given classification type" in reference to the six general classifications analogous to licensing basis AOOs presented in FSAR 15.9.3 and analyzed in FSAR 15.9.3.1 (increase in heat removal by the secondary system), FSAR 15.9.3.2 (decrease in heat removal by the secondary system), FSAR 15.9.3.3 (decrease in reactor coolant system flow rate), FSAR 15.9.3.4 (increase in reactor coolant inventory), FSAR 15.9.3.5 (reactivity and power distribution anomalies), and FSAR 15.9.3.6 (decrease in reactor coolant inventory).

There is no definite limiting event as the system is stable under normal operation for all events and decay ratio is not an appropriate metric for transient operations. However the events provided are representative and in aggregate the number of events and sensitivity studies illustrates a thorough investigation into the nonlinear system that provides reasonable assurance that GDC 10 and GDC 12 are met.

Note that the previously presented extreme bounding 100-20% power change event in FSAR 15.9.3.2 has been removed from the FSAR because the conservative Doppler and moderator reactivity assumptions in other FSAR 15.9 analyses make the previously presented extreme bounding 100-20% power change event unnecessary.

Note that FSAR Section 15.9.3.7 "Effect of Oscillating Feedwater Flow" is removed because there is no appropriate acceptance criteria by which to judge the event. The response to RAI 9089 (ML18019A949) provides analysis of the "Effect of Oscillating Feedwater Flow" event, however the event will not be maintained with the FSAR.

Note that analyses in FSAR Section 15.9.4 "Demonstration of Module Protection System Functions to Preclude Instability" have been removed, and are instead replaced by a discussion noting how the MPS ensures no divergent flow oscillation can occur.

Impact on DCA:

FSAR Section 15.9 has been revised as described in the response above and as shown in the markup provided in this response.

15.9 Stability

In current generation plants, events that could result in thermal-hydraulic instability within the reactor vessel are considered significant only for boiling water reactors (BWRs). Individual fuel assemblies with high power-to-flow ratios may undergo instabilities or the neutronic conditions may lead to power oscillation. Current generation pressurized water reactors use pumps for forced circulation, which keeps core flow essentially constant with power level. The NuScale Power Module (NPM) employs natural circulation. With this design feature, flow through the core is not held constant by pumps providing forced circulation. Thus, variations in flow may result in changes in power level and vice versa. The identification and evaluation of the significance of these mechanisms is addressed in Section 4.4.7. The analysis of the NPM to representative perturbations and the behavior to bounding flow instability are evaluated in this section. The evaluation is based on reactivity coefficients that span the full range associated with beginning to end of cycle and demonstrates that the NPM is protected from unstable flow oscillations provided that operation is limited by a defined pressure-temperature exclusion zone such that no boiling in the riser area above the core is allowed. A large negative moderator reactivity coefficient may stabilize the flow even if riser boiling occurs but this is conservatively not credited in the stability methodology.

15.9.1 Consideration of Thermal-Hydraulic Stability

The NuScale Stability Evaluation Methodology Topical Report (Reference 15.9-1) presents a comprehensive analysis of the thermal hydraulic stability of the NPM and demonstrates compliance with 10 CFR 50, Appendix A, General Design Criteria (GDC) 10 and GDC 12. The topical report considers potential power and hydraulic stability mechanisms during anticipated operational occurrences (AOOs) and normal operating conditions. Thermal-hydraulic instability during infrequent events or accidents is not considered because the acceptance criteria for such events allow for conditions beyond the specified acceptable fuel design limits imposed on AOO events experiencing instabilities. The topical report considers flow stability from a fundamental conceptual perspective without making assumptions based on similarities to or differences from other nuclear systems. The topical report describes computational methods developed for the analysis of the limiting instability modes for the NPM design during steady state, normal operation and anticipated transients.

RAI 15.09-2, RAI 15.09-3

The region exclusion stability protection solution is shown in Reference 15.9-1 to be an acceptable approach for preventing the occurrence of instabilities in the NPM. This solution precludes occurrence of ~~an~~ instability by tripping the plant before entering a region where instability may occur. The Module Protection System (MPS) trips the NPM at a minimum of five (5) degrees F before reaching the region where instability is possible. This is shown schematically in Figure 15.9-1~~Figure 15.9-14~~, which shows decay ratio versus riser subcooling. The operational domain identified with potential instability is characterized by loss of subcooling in the riser (Figure 5.1-3). The riser is considered to be adiabatic in that no heat is added or removed and the liquid entering the riser from the core experiences a gradual decrease in pressure but no change in temperature. The loss of riser subcooling can lead to boiling which can be destabilizing because enthalpy changes to a boiling fluid have a much more significant effect on density than they do on single phase fluids and thus is destabilizing. This phenomenon is described in more detail in Reference 15.9-1. This condition is already excluded by the module protection system (MPS) for considerations other than flow stability.

The limiting instability mode is a natural circulation instability that shares some attributes with density wave instability but is dominated by the adiabatic riser response rather than wave propagation in the core. This mode is unique to the NuScale design and identified as riser instability. Stability is influenced by the dynamics of the helical coil steam generator (SG) and the fission power response of the core to reactivity feedback.

Important distinctions from the typical density wave instabilities in a BWR are:

- negative moderator reactivity feedback is stabilizing in the NPM.
- increasing core inlet subcooling is not destabilizing.
- the period of flow and power oscillations in the NPM is one to two orders of magnitude higher than the oscillation period in a BWR, hence the preference for a regional exclusion stability solution instead of a detect and suppress solution.

15.9.2 Stability Analyses

RAI 15.09-2, RAI 15.09-3

~~In Reference 15.9-1, the NPM is~~Several cases were analyzed over a wide range of power and primary system flow operating conditions and possible scenarios to demonstrate that stability is maintained~~. This reference also demonstrates~~ during routine power operations in the NPM, and the limiting case is presented in Section 15.9.2.1. Adequate stability performance when the plant systems remain within MPS settings during transient scenarios is demonstrated in Section 15.9.3. Finally, scenarios in which MPS setpoints are exceeded and a reactor trip occurs are ~~described in detail~~discussed in Section 15.9.4.

The operating states and events addressed include:

- stability of various steady-state operating power levels (at the corresponding natural circulation flow) is analyzed to demonstrate the operating behavior with regard to the stability of the NPM during power operations. Stability at beginning of cycle (BOC) and end of cycle (EOC) conditions are verified to address moderator reactivity variations.

RAI 15.09-2, RAI 15.09-3

- stability during transients is analyzed to demonstrate the operating behavior of the NPM during operational events, such as minor changes in feedwater flow, ~~that~~which may occur during normal operations and during AOOs.~~ Also considered is the behavior of the NPM to respond to gradual trends in feedwater flow, in which core thermal power responds to changing primary coolant conditions.~~ The NPM is demonstrated to return to stable operations, possibly at a new power level or flow condition, for situations in which the riser subcooling is maintained.

RAI 15.09-2, RAI 15.09-3

Since primary system flow is driven by natural circulation, the range of flow for which the NPM can operate in steady-state at a given power level is narrow, and is influenced by effects such as pressure losses and the SG pressure and level. The system stability performance representative of fixed points along the power and flow operating line are presented in ~~this section~~Section 15.9.2.1. The NPM response to transients is discussed in Section 15.9.3. These sections address the behavior of the NPM as it transitions through power, flow, and other state variables that may not be experienced in steady state operation and shows that these transitory conditions and the endpoint condition are stable. Alternatively, the MPS mitigates any potentially unstable conditions before instability can occur. Such situations are identified in Section 15.9.3.1 through Section 15.9.3.6~~8~~ and ~~evaluated in more detail~~discussed in Section 15.9.4.

RAI 15.09-2, RAI 15.09-3

15.9.2.1 Stability Analysis for Power Operations

The first demonstration of the stability performance of the NPM is for power operations over a range of power level and flow conditions in the presence of a small perturbation in operating conditions. Primary system flow, core inlet temperature, secondary inlet flow and temperature, and the secondary steam pressure conditions are specified at each power level. Modeling incorporates the effects of ambient heat losses and heat loss through the non-regenerative heat exchanger in the chemical and volume control system (CVCS) to assure consistent thermodynamic modeling of NPM operations. Primary system coolant is withdrawn by the CVCS from the downcomer and returned to the riser at all power levels. The water returned to the riser is colder than water removed from the downcomer as a result of heat removal by the non-regenerative heat exchanger.

RAI 15.09-2, RAI 15.09-3

Calculations are performed at representative thermal power levels of 160, 120, 80, 40, 32, and 1.6 MW. These conditions are equivalent to 100 percent, 75 percent, 50 percent, 25 percent, 20 percent, and 1 percent of rated power, respectively. The power level of 32 MW is considered in order to address effects related to activation of the turbine and feedwater heater system. Only the limiting case is presented in detail in Section 15.9.2.1.1 through Section 15.9.2.1.4.

RAI 15.09-2, RAI 15.09-3

After reaching steady state conditions in each calculation, a small perturbation is applied to the steady conditions. In applying the perturbation for determining stability performance, the magnitude of the resulting initial disturbance is not important as long as the disturbance is small enough to not introduce nonlinear effects or cause flow regime or heat transfer transitions. The important variable is the relative change of the perturbation as the disturbance propagates in time. The perturbation is applied to the steady conditions by the following approach~~es~~:

- Momentary increase in pressure loss residual (pressure in the system after allowance for pressure losses) in the natural circulation primary coolant circuit. The momentary pressure residual perturbation is the main approach because of its reliable effect on initiating a system-wide response and for exciting possible modes in the NPM that may produce oscillations.

RAI 15.09-2, RAI 15.09-3

- ~~One-cycle sinusoidal oscillation of pressure loss residual with specified oscillation periods. This approach is used to selectively excite particular oscillation periods.~~

RAI 15.09-2, RAI 15.09-3

- ~~Change in the feedwater conditions that results in a primary system flow disturbance. The feedwater perturbation is provided to illustrate an alternate approach for perturbing the system in selected cases.~~

After the primary system flow is perturbed, the stability is determined from the core inlet flow as function of time. There are two different considerations in interpreting the transient response.

- The short window immediately after the perturbation highlights the apparent decay ratio of the system to a perturbation. This apparent decay ratio illustrates the rapid response of the system to a perturbation. The system quickly attempts to return to the initial conditions.
- The relatively long-term transient response of the system is to show very small magnitude oscillations relative to the initial response to a sharp perturbation. These oscillations are related to loop dynamics, where the longest period oscillation is characterized by the overall time for fluid to transit the natural circulation loop.

RAI 15.09-2, RAI 15.09-3

Analyses are performed at each condition for a duration of~~that represents approximately ten circuits of coolant in the primary system. The time for coolant to make one circuit corresponds to the primary system coolant mass (not including water in the pressurizer) divided by the flow rate. This analysis duration is chosen to allow~~ sufficient time for the short-lived effects to dampen out, leaving a clear indication of the longer-lived effects.

RAI 15.09-2, RAI 15.09-3

The conclusions from the analyses show that the NPM is highly stable at power levels above 50 percent, with EOC conditions providing more damping (i.e. more stability) than BOC conditions. The NPM is stable between 20 percent and 50 percent power, with some damped, long-term primary system flow oscillations evident. The condition at 20 percent power represents the point at which the turbine is placed on line.~~The analysis was therefore performed with and without feedwater heaters. The NPM remains stable with higher feedwater temperature being the more stable condition.~~

RAI 15.09-2, RAI 15.09-3

The flow stability condition that is the least stable occurs at 1.6 MW core power (1 percent of rated) with a BOC reactivity condition. The core inlet temperature is slightly above 420 degrees Fahrenheit~~with a slightly positive moderator reactivity coefficient~~. ~~However, the overall net reactivity coefficient is negative as a result of the fuel Doppler coefficient.~~ The primary coolant flow response shows damped oscillations with a period of several minutes at this power level. The flow is less stable than the higher power cases, but with the low power level (<20 percent), there is no challenge to fuel limits.

RAI 15.09-2, RAI 15.09-3

~~Cases at 100 percent and 25 percent power are also run by initiating a feedwater perturbation of about 20 percent. The NPM exhibits highly stable conditions at BOC~~

~~and EOC conditions. The NPM again showed higher stability at EOC conditions because the reactivity coefficient is more negative.~~

RAI 15.09-2, RAI 15.09-3

15.9.2.1.1 Identification of Causes and Event Description

RAI 15.09-2, RAI 15.09-3

The 1.6 MW power case at BOC was found to be the least stable of all power operations considered.

RAI 15.09-2, RAI 15.09-3

15.9.2.1.2 Sequence of Events and Systems Operation

RAI 15.09-2, RAI 15.09-3

No systems operations occur in response to the event.

RAI 15.09-2, RAI 15.09-3

15.9.2.1.3 Input Parameters and Initial Conditions

RAI 15.09-2, RAI 15.09-3

Input parameters and initial conditions for the limiting event are presented in Table 15.9-3.

RAI 15.09-2, RAI 15.09-3

The event is analyzed for BOC reactivity conditions.

RAI 15.09-2, RAI 15.09-3

15.9.2.1.4 Results

RAI 15.09-2, RAI 15.09-3

The analysis that produced the most limiting results is described in Table 15.9-4 and in Figure 15.9-2 and Figure 15.9-3.

15.9.3 Stability Analysis for Operational Occurrences

The nature of the natural circulation system performance narrows the analysis down to examining transients that are credible in the NPM. Several operational events are investigated with externally imposed boundary conditions applied to influence the system response. These boundary conditions include reactivity insertion (either directly in the core or via changes in primary system conditions) and realistic changes in primary and secondary conditions.

The results of these analyses demonstrate an acceptable operating region for the NPM where instability does not occur. Events considered fall into the following general classifications:

- increase in heat removal by the secondary system
- decrease in heat removal by the secondary system
- decrease in reactor coolant system (RCS) flow rate
- increase in reactor coolant inventory
- reactivity and power distribution anomalies
- decrease in reactor coolant inventory

RAI 15.09-2, RAI 15.09-3

The operational events considered are analogous to licensing basis AOOs. However, typical licensing basis AOO scenarios are chosen to provide a limiting system response and generally result in a reactor trip that mitigates the event. The stability operational events are constructed to initiate~~avoid~~ a reactor trip, which is not credited, in order to assess the stability of the NPM. This is a key consideration, because any event that quickly results in an MPS trip does not experience unstable flow oscillations; by not crediting the MPS trip, this effectively bounds any scenario in which MPS trip limits are not reached. ~~A relatively mild event within the limits of an MPS trip is evaluated to establish that the NPM does not progress toward unstable operation.~~

The NPM system response is obtained by the computer code, PIM, which is used in demonstrating system stability at initially steady-state operation. The PIM code is described in Section 4.4.7. An input forcing function is applied to the appropriate boundary condition to initiate the transient, for example, a user-specified feedwater flow changing as a function of time to simulate a decrease in heat removal by the secondary system.

RAI 15.09-2, RAI 15.09-3

~~In addition to the above event classes, additional events are addressed that do not fall into the classifications. These are identified considering events that may occur in the NPM, but may typically be of low interest in safety analysis since they show non-limiting transient response outside of stability considerations. The following additional events are also addressed:~~

RAI 15.09-2, RAI 15.09-3

- ~~effect of oscillating secondary system flow~~
- ~~stability during gradual shutdown~~

RAI 15.09-2, RAI 15.09-3

~~While typically a non-limiting operational event, effects of sinusoidal flow oscillations in the secondary system arising from a controller or valve behavior that may produce sinusoidal oscillations in feedwater flow, temperature or steam pressure are considered. This sinusoidal behavior is addressed to evaluate the primary system response to an externally driven influence to show the NPM does not experience resonant response to the excitation that may lead to large oscillations in the primary system. Also, the additional events related to gradual shutdown of the NPM by following changes in feedwater flow are evaluated.~~

15.9.3.1 Increase in Heat Removal by the Secondary System

RAI 15.09-2, RAI 15.09-3

15.9.3.1.1 Identification of Causes and Event Description

Stability perturbations can occur from a rapid increase of feedwater flow. The flow increase can be caused by feedwater pump speed increase, valve alignment changes, or other causes. However, the analyzed change is sufficiently small that the MPS does not actuate and control systems, such as those for steam pressure, maintain other parameters at the original value.

Other causes of increased heat removal, such as decreasing feedwater temperature or decreasing steam pressure (that causes increased boiling in the SGs), are generally bounded by changes in feedwater flow. This is because the potential for change in feedwater temperature is more gradual when considering the entire feedwater system train (preheaters, piping lengths, etc.) and large rapid changes in steam pressure are expected to cause either compensating control actions or MPS trips.

RAI 15.09-2, RAI 15.09-3

~~An event is analyzed in Reference 15.9-1 at 100 percent power with feedwater flow being rapidly increased by 2.2 pounds per second after 10 seconds using both BOC and EOC reactivity conditions. This relatively small change is chosen because larger changes result in a trip on high reactor power.~~

RAI 15.09-2, RAI 15.09-3

~~An event at 32 MW and 200°F feedwater temperature where feedwater flow increases rapidly by 2.2 pounds per second after 10 seconds is considered in Reference 15.9-1. Both BOC and EOC reactivity conditions are considered. This power level and feedwater condition is chosen for analysis in-part because it is the expected power where the turbine comes on-line and feedwater heating begins.~~

RAI 15.09-2, RAI 15.09-3

~~The results indicate the NPM is highly stable at BOC and EOC conditions.~~

RAI 15.09-2, RAI 15.09-3

15.9.3.1.2 Sequence of Events and Systems Operation

RAI 15.09-2, RAI 15.09-3

A disturbance results in feedwater flow being rapidly increased by 10 percent in 0.1 seconds. This change is chosen because, while it would normally cause a reactor trip, this trip is not credited and, thus, it conservatively bounds smaller changes to feedwater flow that would not result in a reactor trip. No systems operations occur in response to the event, so no sequence of events table is generated.

RAI 15.09-2, RAI 15.09-3

15.9.3.1.3 Input Parameters and Initial Conditions

RAI 15.09-2, RAI 15.09-3

The event is analyzed for both the reactor at 100 percent power and the reactor at 32 MW to simulate the expected power during startup at which the turbine comes on-line and feedwater heating begins. Input parameters and initial conditions for the 100 percent and 20 percent power cases are presented in Table 15.9-1 and Table 15.9-2 respectively. Both BOC and EOC reactivity conditions were considered in each analysis, but only EOC results are presented as they are the most limiting results.

RAI 15.09-2, RAI 15.09-3

15.9.3.1.4 Results

RAI 15.09-2, RAI 15.09-3

The results are presented in Table 15.9-5 and Figure 15.9-4 and Figure 15.9-5 for 100 percent of rated power and EOC reactivity. Additional results are presented in Table 15.9-6 and Figure 15.9-6 and Figure 15.9-7 for 20 percent of rated power and EOC reactivity. These results indicate that the plant is highly stable during a postulated increase in heat removal by the secondary system.

15.9.3.2 Decrease in Heat Removal by the Secondary System

RAI 15.09-2, RAI 15.09-3

15.9.3.2.1 Identification of Causes and Event Description

Stability following reduction of feedwater flow is addressed in this section. A hypothetical rapid decrease in feedwater flow occurs because of feedwater pump speed change, valve alignment changes, or other causes. However, complete loss of feedwater is not considered because it would result in actuation of the MPS and a trip.

Other causes of decreased heat removal, such as increasing feedwater temperature or increasing steam pressure are generally bounded by changes in feedwater flow because larger changes would result in a trip on high reactor power.

RAI 15.09-2, RAI 15.09-3

~~The response to an event at rated power with feedwater flow decreased rapidly by 50 percent after 10 seconds while maintaining feedwater temperature and steam pressure is analyzed using the PIM code in Reference 15.9-1. Both BOC and EOC reactivity conditions are considered. This magnitude of change is chosen to determine the acceptability of a partial loss of a feedwater and a control system response that avoids a reactor trip.~~

RAI 15.09-2, RAI 15.09-3

~~The resulting reduction in the heat removal from the primary coolant flow initiates a transient in which primary coolant temperature starts to rise and negative moderator feedback reduces the fission power. The combined reduction of the heat sink and core power restores the primary coolant temperature to a value above its initial value. The Doppler reactivity compensates for the difference and~~

~~the net average reactivity is restored to zero. The density head driving the primary coolant flow is also reduced and the flow changes from its initial value to about 75 percent of its initial value.~~

RAI 15.09-2, RAI 15.09-3

~~The NPM is highly stable at BOC and EOC conditions for a decrease in secondary heat removal. Additionally, the NPM response mirrors the response to an increase in feedwater flow although the magnitude is larger because of the larger relative change in feedwater flow.~~

RAI 15.09-2, RAI 15.09-3

~~It is important to recognize that the MPS may actuate and cause a reactor trip during these events due to a large rate of change in neutron flux. Such a trip is not credited in these stability considerations, but provides additional assurance that rapidly changing fission power is detected and mitigated.~~

RAI 15.09-2, RAI 15.09-3

~~The response to a rapid reduction in feedwater flow at 32 MW with initial decay heat consistent with 32 MW is stable. An alternate event where the NPM is initially at rated power and rapidly maneuvered to 32 MW is analyzed in Reference 15.9-1. Feedwater flow is rapidly decreased by 50 percent before the decay heat associated with full power drops to the decay heat level for 32 MW. This hypothetical scenario increases the decay heat fraction to 35 percent for the 32 MW initial power level and it is then held constant for the duration of the analysis. Because decay heat is not affected by reactivity feedback mechanisms, the resulting effect is equivalent to a strong reduction in both Doppler and moderator reactivity feedback.~~

RAI 15.09-2, RAI 15.09-3

~~The NPM shows stable behavior at BOC and EOC conditions for this case. Oscillations in flow that are observed are caused by the changes in core power. While the choices of input (35 percent decay heat, and maintaining decay heat constant through the analysis) are extreme, the results show the NPM is stable even under these extreme assumptions.~~

RAI 15.09-2, RAI 15.09-3

15.9.3.2.2 Sequence of Events and Systems Operation

RAI 15.09-2, RAI 15.09-3

Feedwater flow is decreased rapidly by 10 percent in 0.1 seconds while maintaining feedwater temperature and steam pressure. This magnitude of change is chosen to determine the acceptability of a partial loss of feedwater. While this magnitude of change would normally cause a reactor trip, this trip is not credited and, thus, it conservatively bounds smaller changes to feedwater flow that would not result in a reactor trip.

RAI 15.09-2, RAI 15.09-3

The resulting reduction in the heat removal from the primary coolant flow initiates a transient in which primary coolant temperature starts to rise and negative moderator feedback reduces the fission power. The combined reduction of the heat sink and core power restore the primary coolant temperature to a value above its initial value. The Doppler reactivity compensates for the difference and the net average reactivity is restored to zero. The density head driving the primary coolant flow is also reduced and the flow changes from its initial value to about 90 percent of its initial value.

RAI 15.09-2, RAI 15.09-3

No systems operations occur in response to the event.

RAI 15.09-2, RAI 15.09-3

15.9.3.2.3 Input Parameters and Initial Conditions

RAI 15.09-2, RAI 15.09-3

The event is analyzed for both the reactor at 100 percent power and the reactor at 32 MW to simulate the expected power during startup at which the turbine comes on-line and feedwater heating begins. Input parameters and initial conditions for the 100 percent and 20 percent power cases are presented in Table 15.9-1 and Table 15.9-2 respectively. Both BOC and EOC reactivity conditions were considered in each analysis, but only EOC results are presented as they are the most limiting results.

RAI 15.09-2, RAI 15.09-3

15.9.3.2.4 Results

RAI 15.09-2, RAI 15.09-3

The results are presented in Table 15.9-7 and Figure 15.9-8 and Figure 15.9-9 for 100 percent of rated power and EOC reactivity. Results are also presented in Table 15.9-8 and Figure 15.9-10 and Figure 15.9-11 for the case at 20 percent of rated power with EOC reactivity. These results indicate that the plant is highly stable during a postulated decrease in heat removal by the secondary system.

15.9.3.3 Decrease in Reactor Coolant System Flow Rate

The effect of a decrease in primary system flow rate (in isolation from other effects) is not considered a credible event for stability analysis. This is because there is no source for changing the primary system flow without other influences, and because there are no primary system pumps in the NPM to directly influence primary system flow.

15.9.3.4 Increase in Reactor Coolant Inventory

The effects of increasing RCS inventory are not important in the stability assessment because subcooled margin in the riser increases with increasing primary system pressure and overall stability behavior is not sensitive to pressure changes for a single-phase system.

The effect of adding cold water via the CVCS during an increasing RCS inventory event is generally bounded by analyses of increased heat removal by the secondary system. The potential for minor reduction in primary system flow can occur from adding cooler water to the riser. However, the relatively small cooldown that may occur at high power conditions and the very long time for coolant to transit from the CVCS return line located in the riser, around the primary system, and into the core in low power operations makes this a secondary consideration in comparison to secondary side cooldowns.

15.9.3.5 Reactivity and Power Distribution Anomalies

RAI 15.09-2, RAI 15.09-3

15.9.3.5.1 Identification of Causes and Event Description

The effect on NPM stability from a reactivity anomaly can be caused by changes in boron concentration, by an uncontrolled control rod assembly withdrawal or similar events that result in reactivity insertion.

RAI 15.09-2, RAI 15.09-3

~~The effect of a change in boron concentration is bounded by small variations in both BOC and EOC conditions.~~

RAI 15.09-2, RAI 15.09-3

~~Reactivity increases that do not result in reactor trip on high flux or high flux rate develop slowly and are bounded by effects of increasing heat removal from the secondary side. These events cause pressurizer insurges that maintain or increase subcooling in the riser.~~

RAI 15.09-2, RAI 15.09-3

~~An analysis performed at 32 MW and 200 degrees Fahrenheit feedwater temperature in Reference 15.9-1 demonstrates the stability behavior of the NPM for reactivity and power distribution conditions. In a five second interval, 0.25 dollars of reactivity is added to the core while other reactivity components perform normally. Both BOC and EOC core reactivity conditions are considered. The choice of 32 MW allows margin to the reactor trip setpoint and the high flux rate trip is not considered.~~

RAI 15.09-2, RAI 15.09-3

~~The results indicate stable behavior at BOC and EOC conditions for this addition of reactivity event.~~

RAI 15.09-2, RAI 15.09-3

15.9.3.5.2 Sequence of Events and Systems Operation

RAI 15.09-2, RAI 15.09-3

Reactor power is 32 MW when enough reactivity is added to the core to initiate a high flux rate trip while other reactivity components perform normally. The choice of 32 MW allows margin to the reactor trip setpoint; the high flux rate trip is not credited to conservatively bound smaller reactivity insertions that would not initiate this trip.

RAI 15.09-2, RAI 15.09-3

15.9.3.5.3 Input Parameters and Initial Conditions

RAI 15.09-2, RAI 15.09-3

Input parameters and initial conditions for the limiting event are presented in Table 15.9-2.

RAI 15.09-2, RAI 15.09-3

The event is analyzed with the reactor at 32 MW. Both BOC and EOC reactivity conditions are considered, but only EOC conditions are presented as they were the most limiting. At EOC, 0.65 dollars of reactivity is added.

RAI 15.09-2, RAI 15.09-3

15.9.3.5.4 Results

RAI 15.09-2, RAI 15.09-3

The effect of a change in boron concentration is slow to develop and is bounded by the applied variations in reactivity conditions.

RAI 15.09-2, RAI 15.09-3

Reactivity increases that do not result in reactor trip on high flux or high flux rate develop slowly and are bounded by effects of increasing heat removal from the secondary side. These events cause pressurizer insurges that maintain or increase subcooling in the riser.

RAI 15.09-2, RAI 15.09-3

The results are presented in Table 15.9-9 and Figure 15.9-12 and Figure 15.9-13 for 20 percent of rated power and EOC reactivity. These results indicate that the plant is highly stable during a postulated addition of reactivity event.

15.9.3.6 Decrease in Reactor Coolant Inventory

Decreasing RCS inventory without changes in primary pressure is not important in the stability assessment. Riser subcooling will be maintained and the protection system will trip the NPM on low pressurizer level before any appreciable effect can be seen regarding stability.

Decreasing reactor coolant inventory that results in decreasing pressure but without a level trip is expected to produce no significant effect on stability as long as the primary coolant in the riser remains subcooled. The MPS includes measurement of the hot leg temperature and system pressure, which generate MPS trip signals that protect against an instability event before loss of riser subcooling can occur.

RAI 15.09-2, RAI 15.09-3

~~Section 15.9.4 discusses this and other cases where the existing MPS trips are shown to protect the plant against instability.~~

RAI 15.09-2, RAI 15.09-3

15.9.3.7 ~~Effect of Oscillating Feedwater Flow~~

RAI 15.09-2, RAI 15.09-3

~~The effect on stability of oscillating feedwater flow that may result from cycling a feedwater pump, valve, or other component is assessed. This event is of interest in examining the magnitude of the effect on the primary coolant flow. Of particular interest is the condition where the feedwater oscillation period is resonant with the primary coolant flow period. Net heat sink oscillation feedback to the primary system caused by unstable density waves in the individual SG tubes are not possible because the out-of-phase tube oscillations cancel out as discussed in Reference 15.9-1.~~

RAI 15.09-2, RAI 15.09-3

~~The feedwater flow oscillation amplitude of 0.05 kg/second is imposed as a boundary forcing function at 32 MW and EOC conditions in Reference 15.9-1, where the large negative reactivity allows the core power to follow the flow more closely than at BOC. Various oscillation periods are evaluated for possible resonance including using 122 seconds consistent with the loop transit time at the particular operating conditions.~~

RAI 15.09-2, RAI 15.09-3

~~The results show the primary flow does not respond with a resonance that might otherwise induce large-amplitude primary flow oscillations.~~

RAI 15.09-2, RAI 15.09-3

~~Evaluation of this oscillatory response in secondary conditions shows the NPM does not undergo a resonant excitation that could cause large primary system oscillations.~~

RAI 15.09-2, RAI 15.09-3

15.9.3.8 ~~Stability During Gradual Shutdown by Feedwater Reduction~~

RAI 15.09-2, RAI 15.09-3

~~Gradual shutdown of the fission power in response to changes in the feedwater system is analyzed to illustrate the expected behavior in a load reduction. Starting from rated power conditions with BOC core reactivity (where response of power to changing~~

~~primary coolant temperature is slow compared to EOC), the feedwater flow is reduced at the arbitrary rate of one percent per minute while feedwater temperature is held constant. Unlike the case with a large sudden reduction of the feedwater flow, the slow reduction of feedwater flow produces no oscillations. Therefore, artificial pressure perturbations are applied every 1000 seconds to provide indication if the system has transitioned into unstable conditions. The oscillations that occur during the decreasing power trend show the same characteristics as oscillations seen for the steady state power cases presented in Section 15.9.2.~~

RAI 15.09-2, RAI 15.09-3

~~The results indicate the NPM is highly stable during a gradual shutdown. Sensitivity analysis with EOC reactivity coefficients shows no discernible difference in the results.~~

RAI 15.09-2, RAI 15.09-3

15.9.4 Demonstration of Module Protection System~~s~~ Functions to Preclude Instability

RAI 15.09-2, RAI 15.09-3

At rated power, the minimum loop time for the NPM is more than 60 seconds. The response delay for the MPS is no more than 8.0 seconds for setpoints that are pertinent to stability analysis and the scram time is less than 2.5 seconds. The time from the first scram setpoint being reached to the control rods being fully inserted is less than 11 seconds, which is significantly less than the minimum loop time for the NPM. Therefore, the MPS will shut down the reactor before any potential instability manifests itself as a divergent primary flow oscillation.

RAI 15.09-2, RAI 15.09-3

~~In selected circumstances, the NPM relies on actuation of the MPS to preclude onset of unstable conditions during an operational event. As demonstrated below, the MPS actuation occurs in time to prevent the onset of oscillations.~~

RAI 15.09-2, RAI 15.09-3

~~Events relying on a trip parameter accompanied by a loss of subcooling in the riser are the only events that are important in stability protection. The loss of subcooling, if left unmitigated, can lead to undamped flow instabilities.~~

RAI 15.09-2, RAI 15.09-3

15.9.4.1 ~~Decrease in Heat Removal by the Secondary System~~

RAI 15.09-2, RAI 15.09-3

~~Stability following reduction of feedwater flow for a condition where the moderator reactivity coefficient is set to zero is analyzed in this section as follow-on to Section 15.9.3.2. In the earlier section, the core power responds quickly to changes in the loss of heat removal so that saturated conditions in the riser do not occur. This section provides analysis with the PIM code using a zero moderator reactivity coefficient so that core power only responds to changes in fuel temperature and not to changes in coolant temperature.~~

RAI 15.09-2, RAI 15.09-3

~~The event starts at 10 seconds with a 50 percent reduction in feedwater flow while the feedwater and steam pressure remain at initial values. Figure 15.9-15 shows the coolant temperature through 120 seconds, which includes indication of the time of MPS trip (about 90 seconds after the change in feedwater flow). This trip occurs when the riser temperature in the vicinity of the hot leg temperature sensors is within 5 degrees Fahrenheit of the saturation temperature at the pressurizer pressure, which is assumed constant in the analysis. The local saturation temperature in the riser is slightly higher because of static head, but this small effect is not evaluated.~~

RAI 15.09-2, RAI 15.09-3

~~The control rods insert into the core within 10 seconds after the trip. This delay time accounts for physical lag of the temperature sensor instrumentation, delays in the MPS electronics and the time to unlatch the control rod couplings. The time when shutdown by control rods occurs is indicated in Figure 15.9-15. However, the effect of the shutdown is not included in the analysis for about 30 seconds to demonstrate that there are no sudden or drastic changes in the behavior of the NPM once the riser reaches saturation temperature. This behavior can be seen in the core flow in Figure 15.9-16.~~

RAI 15.09-2, RAI 15.09-3

~~The power response is shown in Figure 15.9-17. Power reduction is a consequence of fuel temperature increase, not the moderator temperature increase.~~

RAI 15.09-2, RAI 15.09-3

~~The void fraction exiting the core and at the top of the riser is indicated in Figure 15.9-18. Early voiding that occurs at the core exit is related to subcooled boiling in the core and does not adversely impact results prior to the riser actually reaching saturated conditions. The voids generated by subcooled boiling quickly condense. Such localized boiling does not affect results since the total core heat addition is preserved.~~

RAI 15.09-2, RAI 15.09-3

15.9.4.2 ~~Decrease in Reactor Coolant Inventory~~

RAI 15.09-2, RAI 15.09-3

~~Decreasing reactor coolant inventory that results in decreasing pressure (but does not result in a level trip) is not expected to produce any significant effect on stability as long as the primary coolant in the riser remains subcooled as described in Section 15.9.3.6. However, further depressurization beyond the trip setpoint that results in riser voiding can destabilize the system. This section provides analysis results using the PIM code that show the effects of depressurization and the ability of the MPS to mitigate the event, including consideration of the effects of sensor and hardware delays.~~

RAI 15.09-2, RAI 15.09-3

~~Results for the event are provided for BOC core conditions. The event starts at zero seconds with an approximately 14.5 psi per minute depressurization. The depressurization continues for 2000 seconds until the pressure is 1378 psia as shown in Figure 15.9-19. At this pressure, the riser is at saturated conditions and the depressurization is halted to allow the system to show unstable behavior. At this point, the system would have already tripped and shut down. However, the effect of the shutdown is not included in the analysis. The core is assumed to remain at power to demonstrate the extended duration prior to significant changes in the behavior of the NPM.~~

RAI 15.09-2, RAI 15.09-3

~~Figure 15.9-20 shows the coolant temperature until 3000 seconds and indicates the time MPS would trip on loss of subcooling. This trip occurs when the riser temperature in the vicinity of the hot leg temperature sensors is within 5 degrees Fahrenheit of the saturation temperature at the pressurizer pressure. The trip on low pressurizer pressure at 1600 psia would have occurred much sooner, but was also not modeled in this analysis. The control rods would insert into the core by 10 seconds after the trip, but the effect of the shutdown is not included in the analysis. Instead, the event is continued to demonstrate the behavior of the NPM once the riser reaches saturation temperature as seen by inspecting the core flow in Figure 15.9-21.~~

RAI 15.09-2, RAI 15.09-3

~~The power response is shown in Figure 15.9-22. The figure shows that limit-cycle oscillations in reactor power are established for this condition after the depressurization is stopped at 2000 seconds. The limit-cycle characteristics are discussed more below.~~

RAI 15.09-2, RAI 15.09-3

~~The void fraction exiting the core and at the top of the riser is indicated in Figure 15.9-23. Early voiding that occurs at the core exit is related to subcooled boiling in the core as observed for the partial loss of feedwater event.~~

RAI 15.09-2, RAI 15.09-3

~~Limit-cycle oscillatory behavior is observable in the results. The behavior arises from non-linearities in NPM behavior that dampen the oscillation magnitude and prevent the continued oscillation growth. Limit cycle oscillations in primary system flow are shown in Figure 15.9-24 for a duration of 120 seconds. Oscillations with a period of about 17 seconds are evident in the figure. This period is related to the time for coolant to transit from the core to the top of the riser.~~

RAI 15.09-2, RAI 15.09-3

~~Growth of the oscillation amplitude seen in Figure 15.9-24 is saturated and reaches a limit cycle because of nonlinear effects that limit further increase of the destabilizing phenomena. In this case, the full collapse of the riser voids seen in Figure 15.9-23 marks the maximum ability of the system to generate larger amplitudes as the range of the density head variation becomes saturated.~~

RAI 15.09-2, RAI 15.09-3

~~Analysis of conditions at EOC for the same depressurization scenario described above illustrates the importance of reactivity feedback on instability well-after the expected shutdown time. Figure 15.9-25 and Figure 15.9-26 show the primary system flow and void fraction for this condition. The relatively strong negative moderator reactivity feedback allows the plant to reach a new steady state (oscillation-free) condition after a short transient behavior.~~

15.9.5 Conclusions

There are two main aspects of the stability methodology. The first is the use of a regional exclusion as the stability solution type and the rationale for its selection. The second aspect is the demonstration that the NPM maintains stability within the region of operation allowed by the MPS. The NPM returns to the original oscillation-free condition after steady state conditions are perturbed.

RAI 15.09-2, RAI 15.09-3

Operational events do not result in unstable plant behavior. At EOC values, the negative moderator coefficient suppresses the oscillation growth. At BOC, oscillations could occur; however, these oscillations do not occur because events that result in loss of riser subcooling and unstable operation are precluded by the region exclusion solution prior to ~~an~~ instability.

RAI 15.09-2, RAI 15.09-3

The radiological consequences of all events shown in Section 15.9.3 are bounded by the design basis accident analyses presented in Section 15.0.3.

15.9.6 References

15.9-1 NuScale Power, LLC, "Evaluation Methodology for Stability Analysis of the NuScale Power Module," TR-0516-49417-P, Revision 0, August 2016.

RAI 15.09-2, RAI 15.09-3

Table 15.9-1: Initial Conditions (100 Percent of Rated Power Cases)

Parameter		Analysis Value[1]
Initial reactor power		160 MWt
Core inlet temperature		496.6 ° F
Core inlet mass flow rate		587.0 kg/s
Pressurizer pressure		1850 psia
Feedwater temperature		299.7 ° F
Feedwater flow		1155 gpm
Steam generator pressure		461.1 psia
Moderator density coefficients, EOC[2]	b0	0.4850
	b1	1.4877
	b2	-1.8359
	b3	1.3687
	b4	-0.4568
Doppler reactivity coefficient, EOC[3]		2.15×10^{-3} pcm/K$^{1.5}$

1. No biases are considered, as parametric sensitivity studies showed no significant changes in results and nonlinear response.
2. Moderator density coefficients are implemented as described in Section 5.6.1.2 of Reference 15.9-1, but with the coefficients shown in this table instead of the coefficients shown in Reference 15.9-1.
3. Doppler reactivity coefficient is implemented as described in Section 5.6.1.1 of Reference 15.9-1, but with the coefficient shown in this table instead of the coefficients shown in Reference 15.9-1.

RAI 15.09-2, RAI 15.09-3

Table 15.9-2: Initial Conditions (20 Percent of Rated Power Cases)

Parameter	Analysis Value[1]
Initial reactor power	32 MWt
Core inlet temperature	525.6 °F
Core inlet mass flow rate	312.4 kg/s
Pressurizer pressure	1850 psia
Feedwater temperature	199.9 °F
Feedwater flow	202.5 gpm
Steam generator pressure	628.4 psia
Moderator density coefficients, EOC	See Table 15.9-1
Doppler reactivity coefficient, EOC[2]	1.87×10^{-3} pcm/$K^{1.5}$

1. No biases are considered, as parametric sensitivity studies showed no significant changes in results and nonlinear response.
2. Doppler reactivity coefficient is implemented as described in Section 5.6.1.1 of Reference 15.9-1, but with the coefficient shown in this table instead of the coefficients shown in Reference 15.9-1.

RAI 15.09-2, RAI 15.09-3

Table 15.9-3: Initial Conditions (1 Percent of Rated Power Cases)

Parameter		Analysis Value[1]
Initial reactor power		1.6 MWt
Core inlet temperature		426.7 °F
Core inlet mass flow rate		94.75 kg/s
Pressurizer pressure		1850 psia
Feedwater temperature		50.0 °F
Feedwater flow		6.226 gpm
Steam generator pressure		331.0 psia
Moderator density coefficients, BOC[2]	a0	0.7789
	a1	0.6342
	a2	-0.7009
	a3	0.4406
	a4	-0.1583
Doppler reactivity coefficient, BOC[3]		1.12×10^{-3} pcm/K$^{1.5}$

1. No biases are considered, as parametric sensitivity studies showed no significant changes in results and nonlinear response.
2. Moderator density coefficients are implemented as described in Section 5.6.1.2 of Reference 15.9-1, but with the coefficients shown in this table instead of the coefficients shown in Reference 15.9-1.
3. Doppler reactivity coefficient is implemented as described in Section 5.6.1.1 of Reference 15.9-1, but with the coefficient shown in this table instead of the coefficients shown in Reference 15.9-1.

RAI 15.09-2, RAI 15.09-3

Table 15.9-4: Normal Power Operation - Limiting Analysis Results (1 Percent of Rated Power Case)

Acceptance Criteria	Limit	Analysis Value
Decay ratio	≤0.8[1]	0.70

1. Though this limit does not apply to stability calculations below 5 percent power, it is included here because this case showed the highest decay ratio among all normal power operation analyses.

RAI 15.09-2, RAI 15.09-3

Table 15.9-5: Increase in Heat Removal by the Secondary System - Limiting Analysis Results (Rated Power Case)

Acceptance Criteria	Limit	Analysis Value
Decay ratio	≤0.8	0.03

RAI 15.09-2, RAI 15.09-3

Table 15.9-6: Increase in Heat Removal by the Secondary System - Limiting Analysis Results (20 Percent of Rated Power Case)

Acceptance Criteria	Limit	Analysis Value
Decay ratio	≤0.8	0.13

RAI 15.09-2, RAI 15.09-3

Table 15.9-7: Decrease in Heat Removal by the Secondary System - Limiting Analysis Results (Rated Power Case)

Acceptance Criteria	Limit	Analysis Value
Decay ratio	≤0.8	0.04

RAI 15.09-2, RAI 15.09-3

Table 15.9-8: Decrease in Heat Removal by the Secondary System - Limiting Analysis Results (20 Percent of Rated Power Case)

Acceptance Criteria	Limit	Analysis Value
Decay ratio	≤0.8	0.15

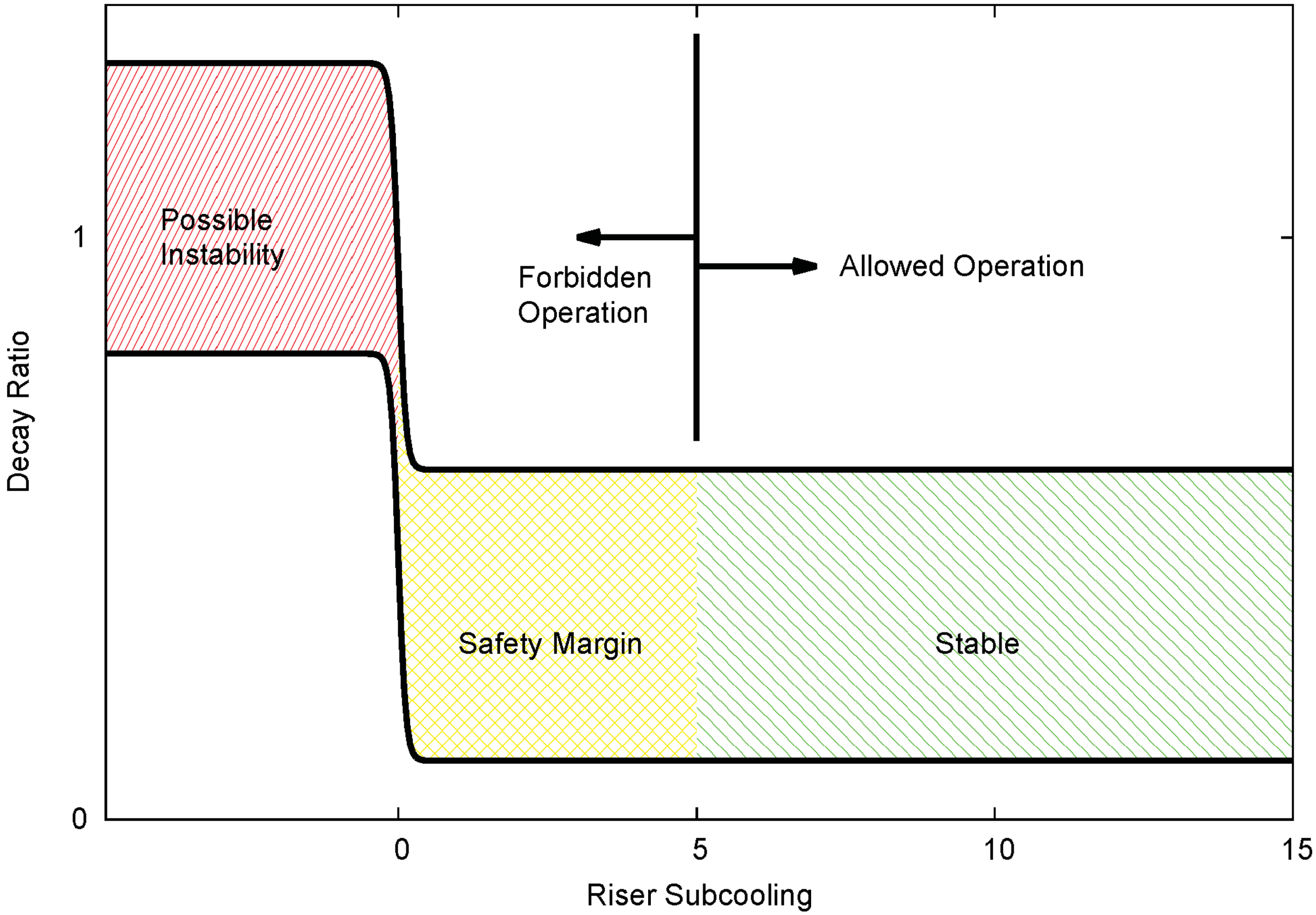
RAI 15.09-2, RAI 15.09-3

Table 15.9-9: Reactivity and Power Distribution Anomalies - Limiting Analysis Results (20 Percent of Rated Power Case)

Acceptance Criteria	Limit	Analysis Value
Decay ratio	≤0.8	0.14

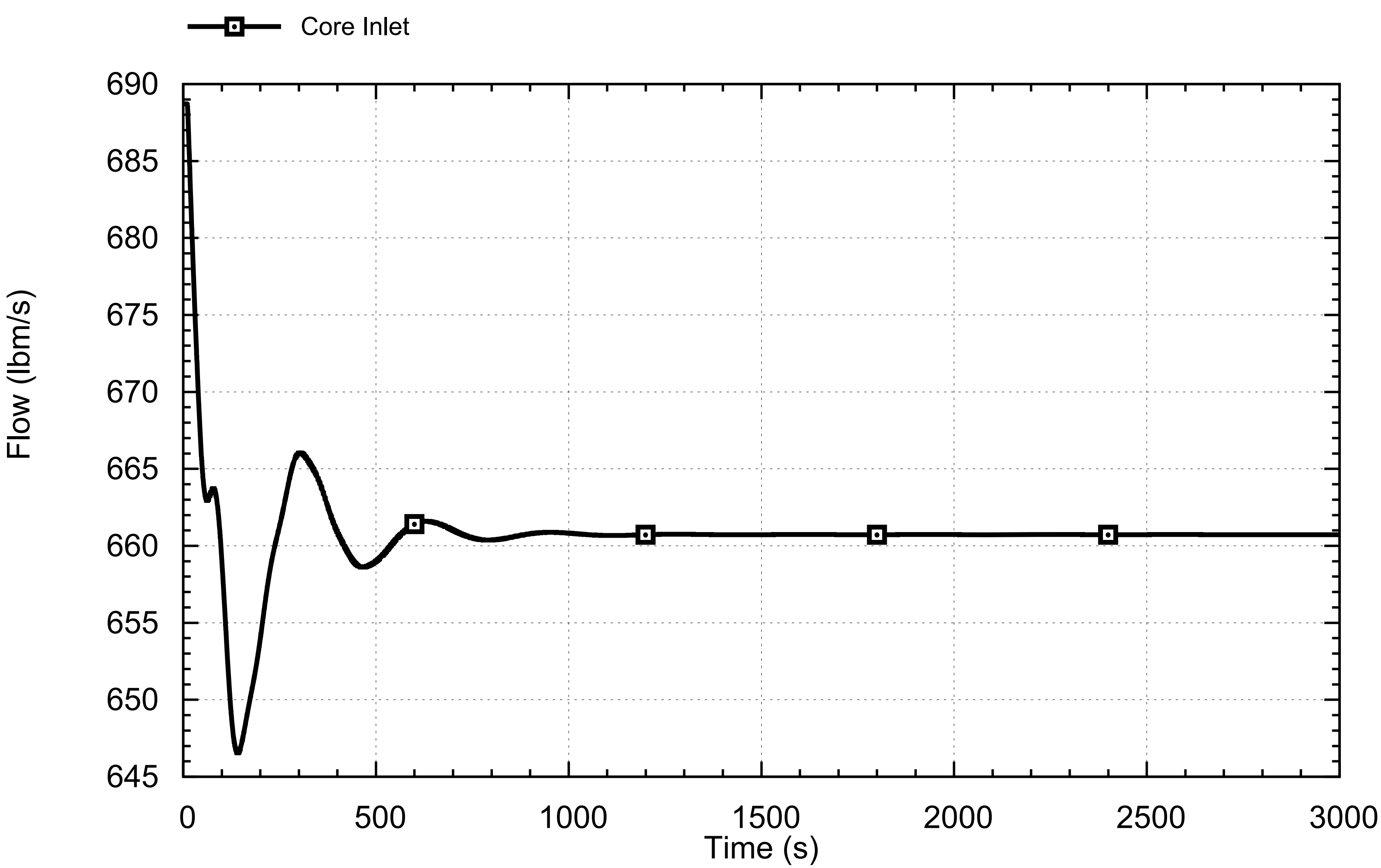
RAI 15.09-2, RAI 15.09-3

Figure 15.9-1: Illustration of Decay Ratio versus Riser Subcooling



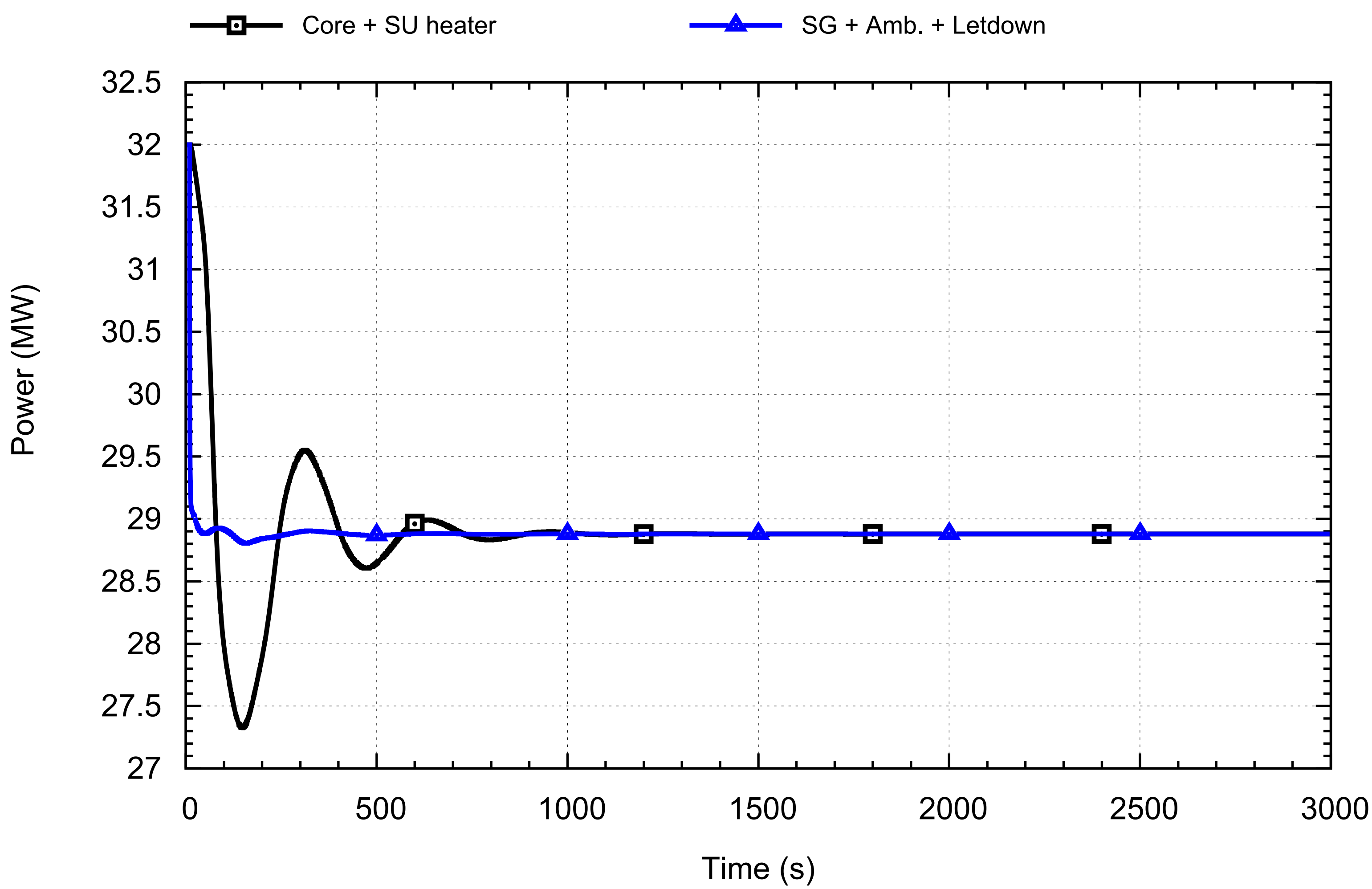
RAI 15.09-2, RAI 15.09-3

Figure 15.9-2: Time Trace of Primary Coolant Flow Response to a Perturbation at 1 Percent of Rated Power and Beginning of Cycle Reactivity



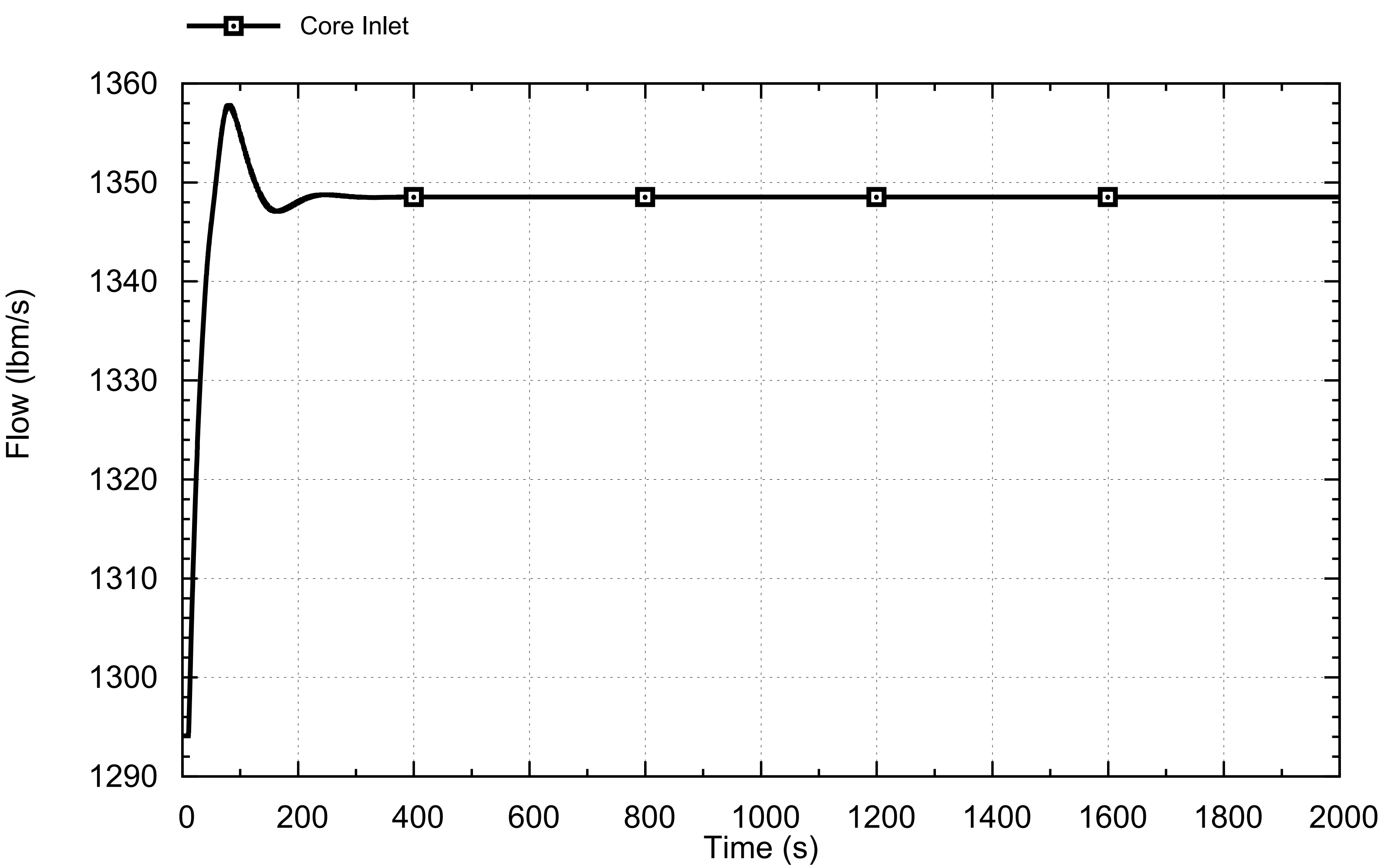
RAI 15.09-2, RAI 15.09-3

Figure 15.9-3: Time Trace of Heat Addition and Heat Removal Response to a Perturbation at 1 Percent of Rated Power and Beginning of Cycle Reactivity



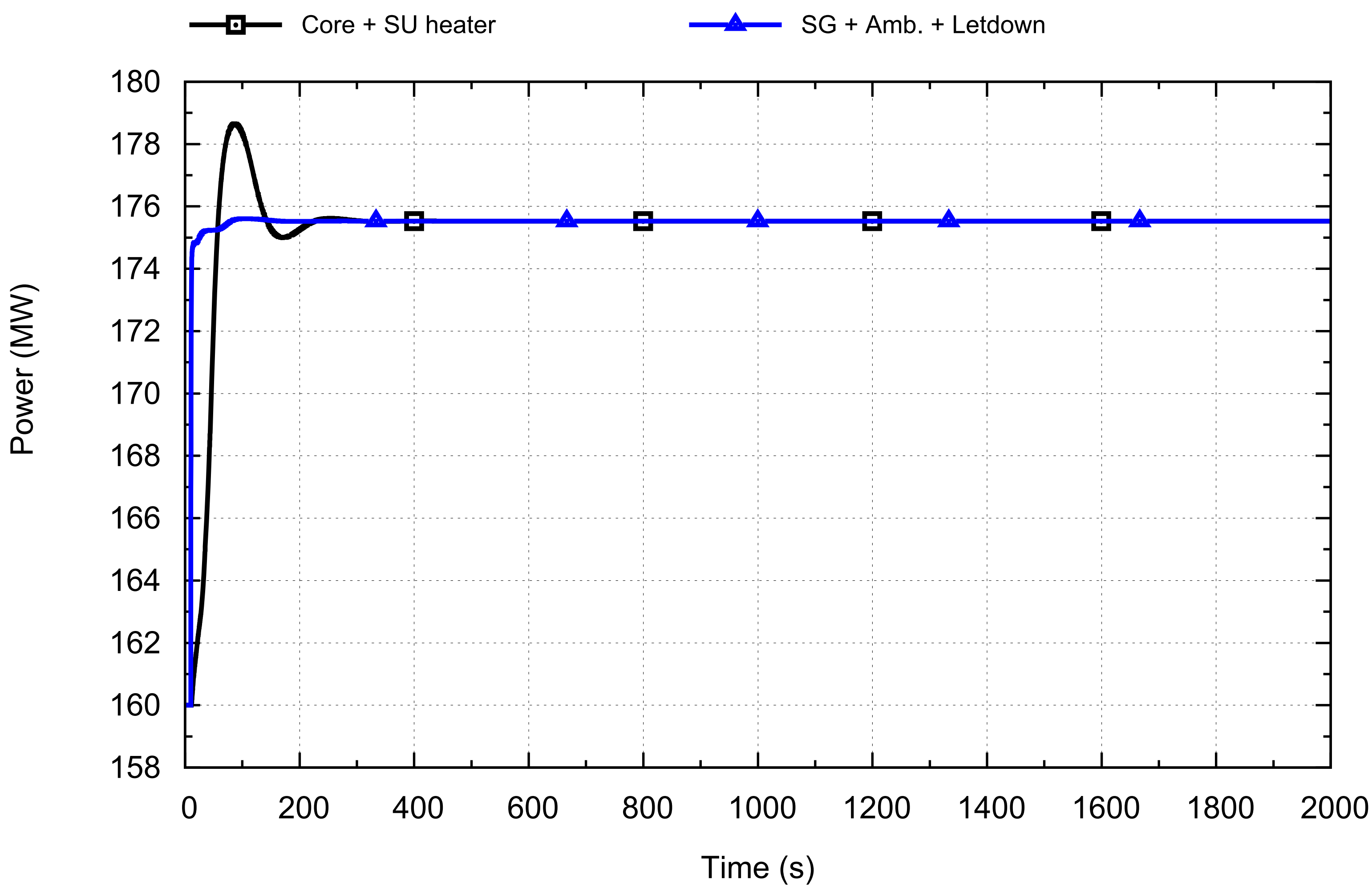
RAI 15.09-2, RAI 15.09-3

Figure 15.9-4: Time Trace of Primary Coolant Flow Response to an Increase in Heat Removal by the Secondary System at Rated Power and End of Cycle Reactivity



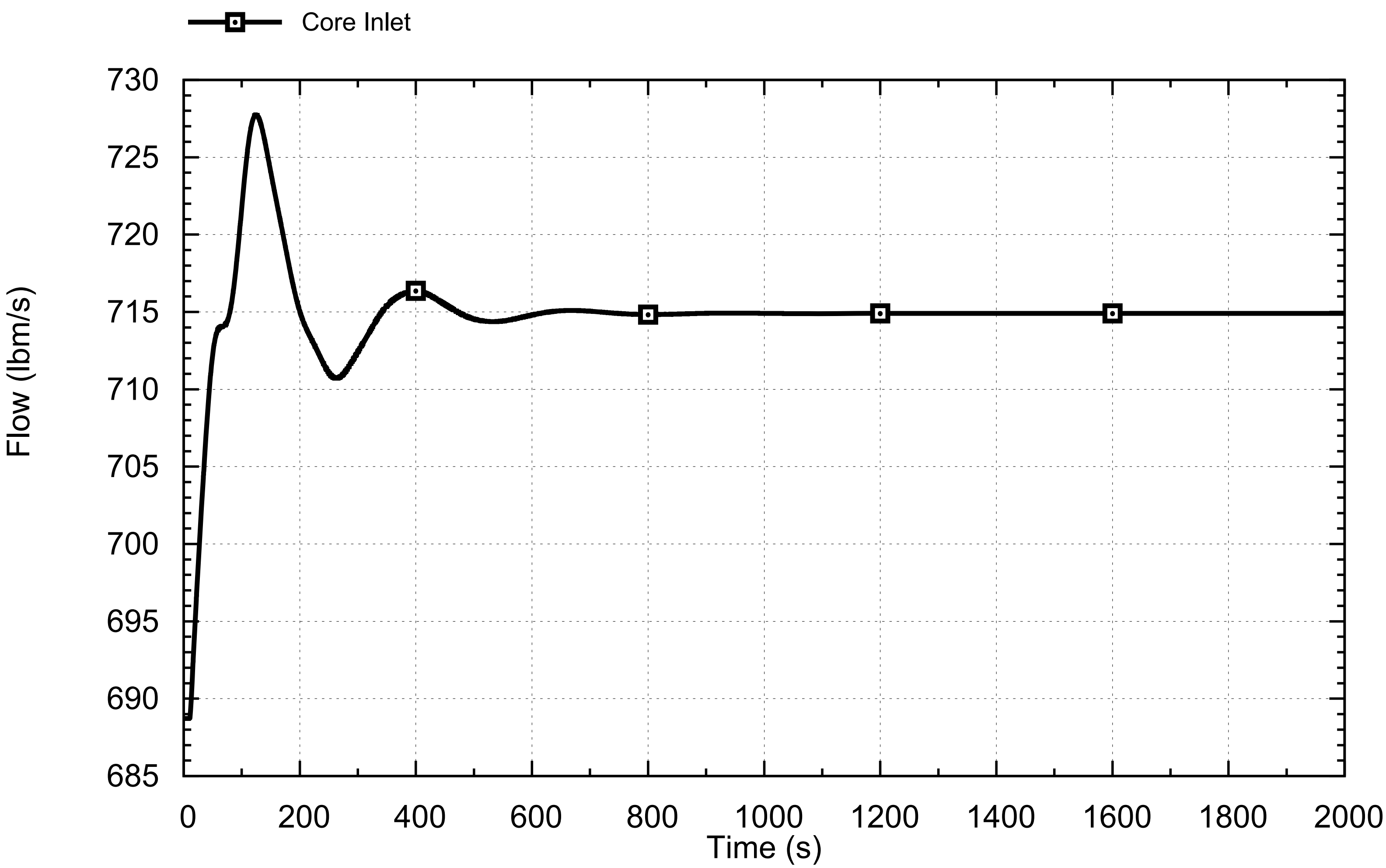
RAI 15.09-2, RAI 15.09-3

Figure 15.9-5: Time Trace of Heat Addition and Heat Removal Response to an Increase in Heat Removal by the Secondary System at Rated Power and End of Cycle Reactivity



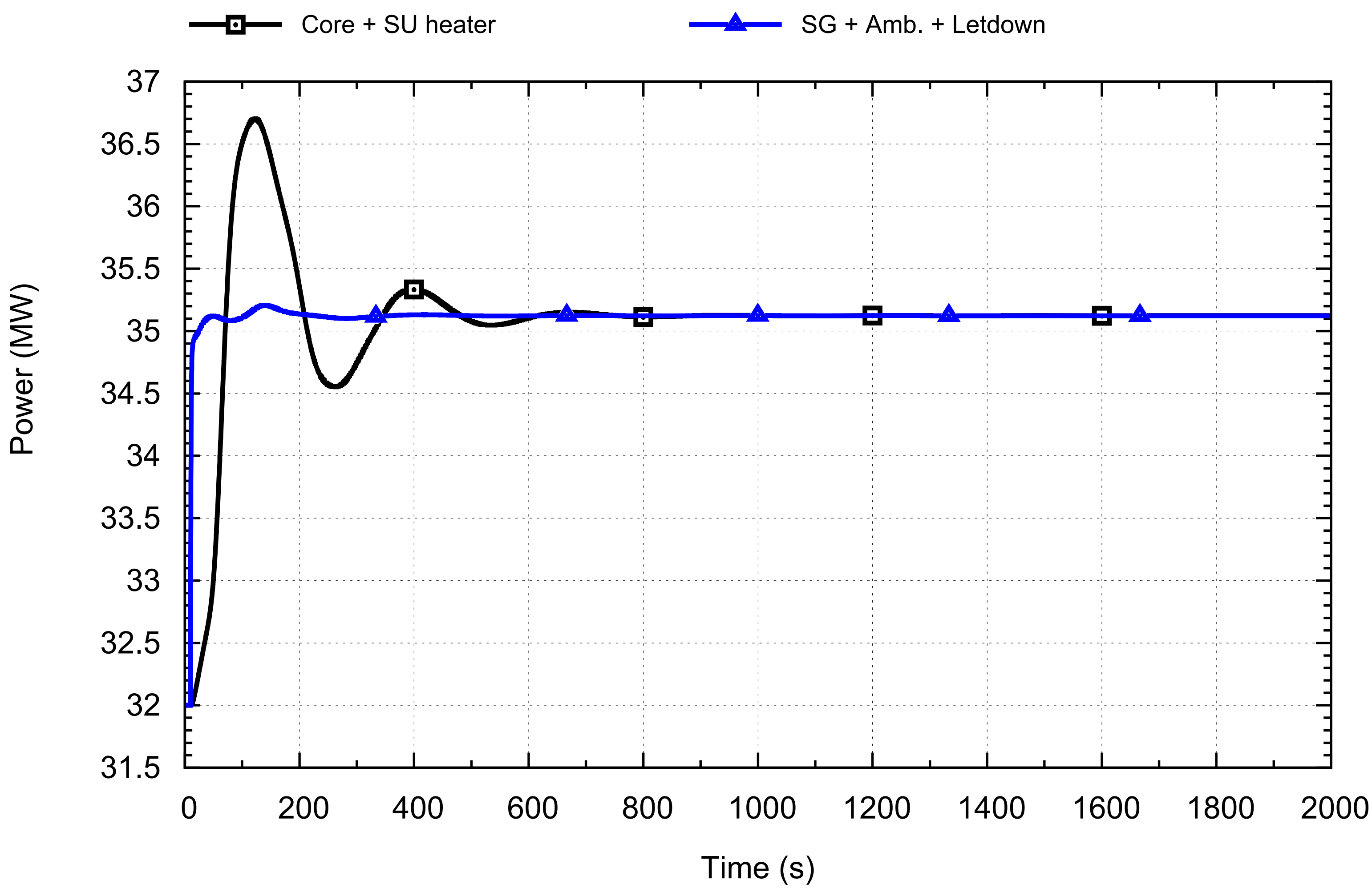
RAI 15.09-2, RAI 15.09-3

Figure 15.9-6: Time Trace of Primary Coolant Flow Response to an Increase in Heat Removal by the Secondary System at 20 Percent of Rated Power and End of Cycle Reactivity



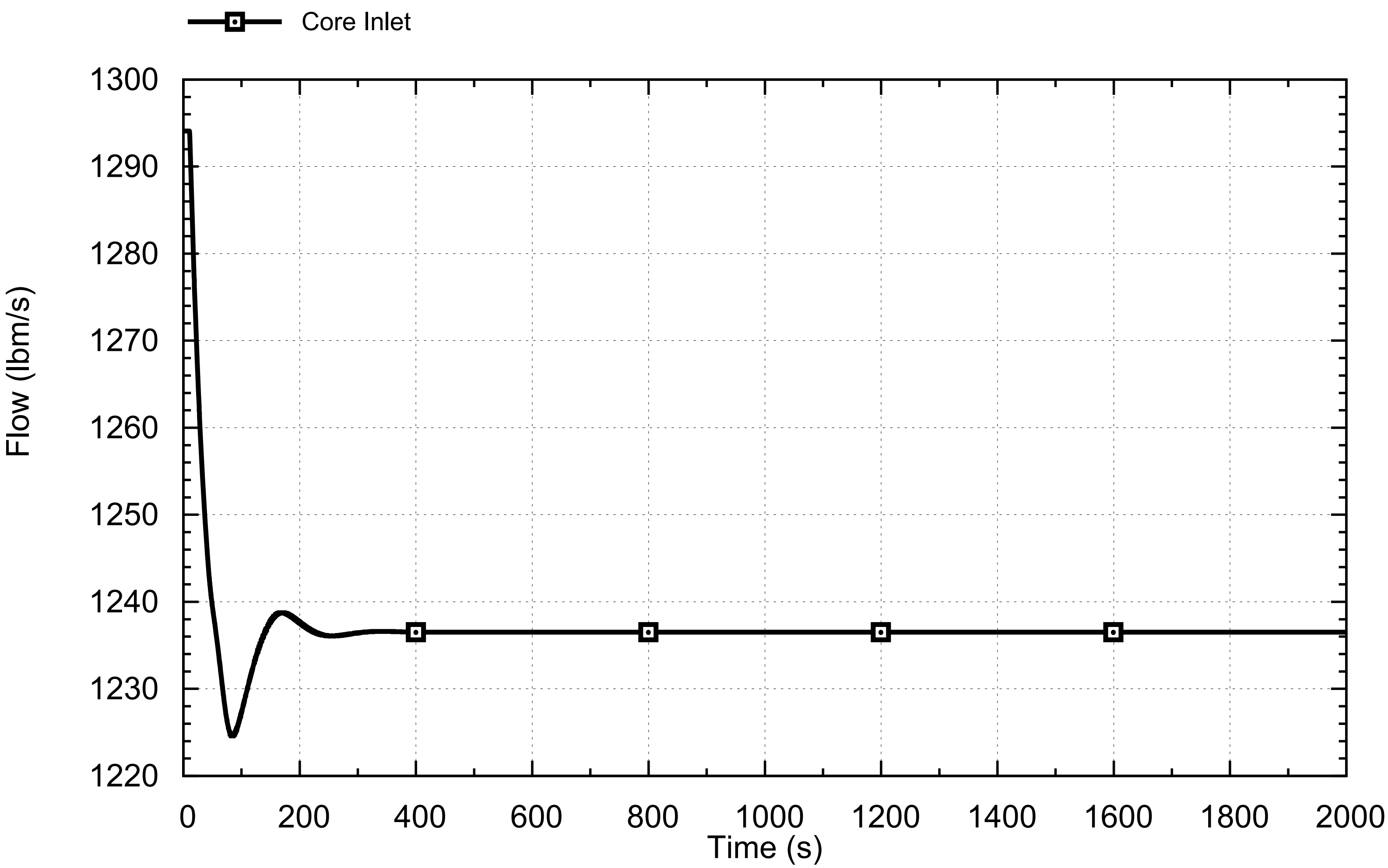
RAI 15.09-2, RAI 15.09-3

Figure 15.9-7: Time Trace of Heat Addition and Heat Removal Response to an Increase in Heat Removal by the Secondary System at 20 Percent of Rated Power and End of Cycle Reactivity



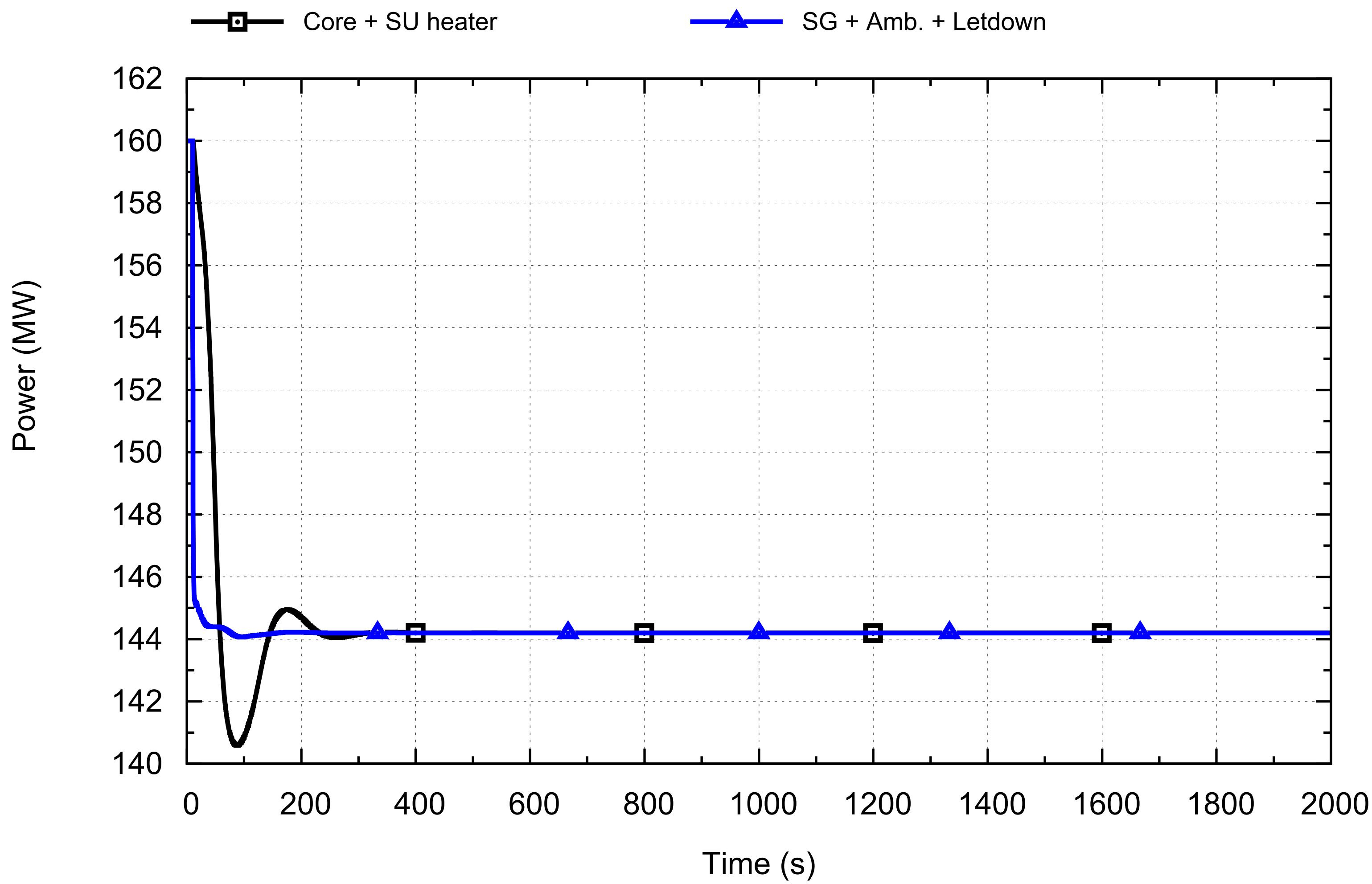
RAI 15.09-2, RAI 15.09-3

Figure 15.9-8: Time Trace of Primary Coolant Flow Response to a Decrease in Heat Removal by the Secondary System at Rated Power and End of Cycle Reactivity



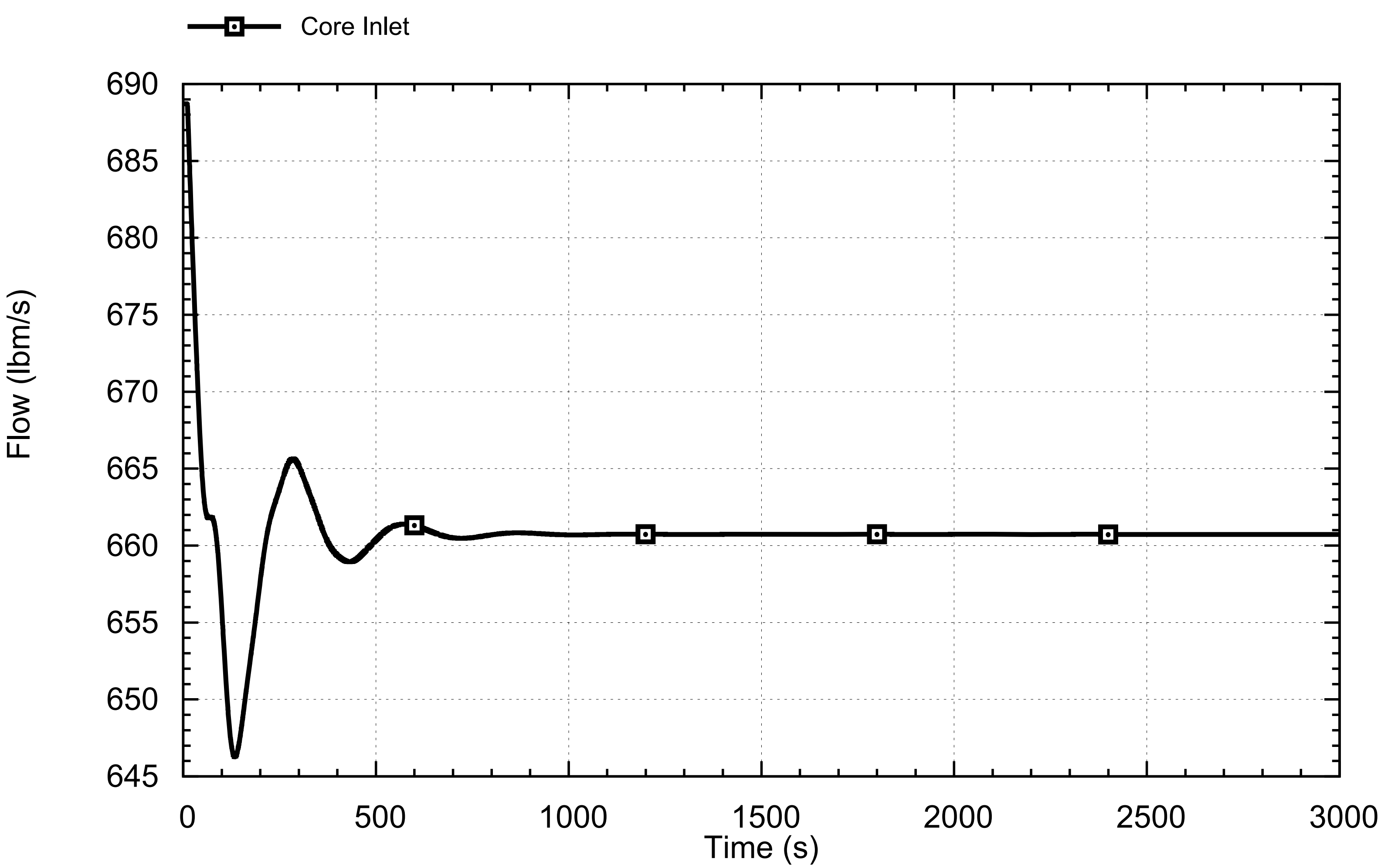
RAI 15.09-2, RAI 15.09-3

Figure 15.9-9: Time Trace of Heat Addition and Heat Removal Response to a Decrease in Heat Removal by the Secondary System at Rated Power and End of Cycle Reactivity



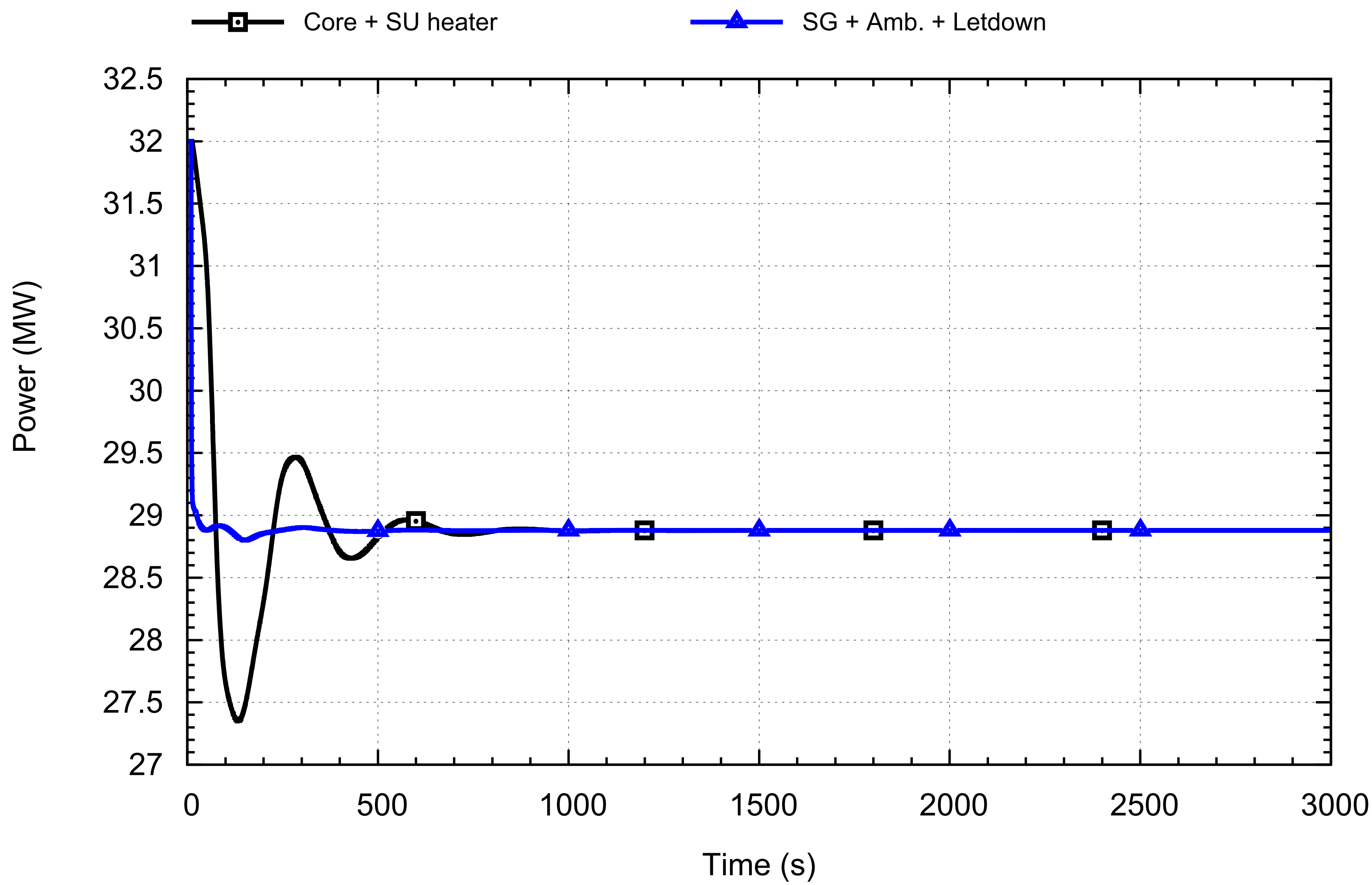
RAI 15.09-2, RAI 15.09-3

Figure 15.9-10: Time Trace of Primary Coolant Flow Response to a Decrease in Heat Removal by the Secondary System at 20 Percent of Rated Power and End of Cycle Reactivity



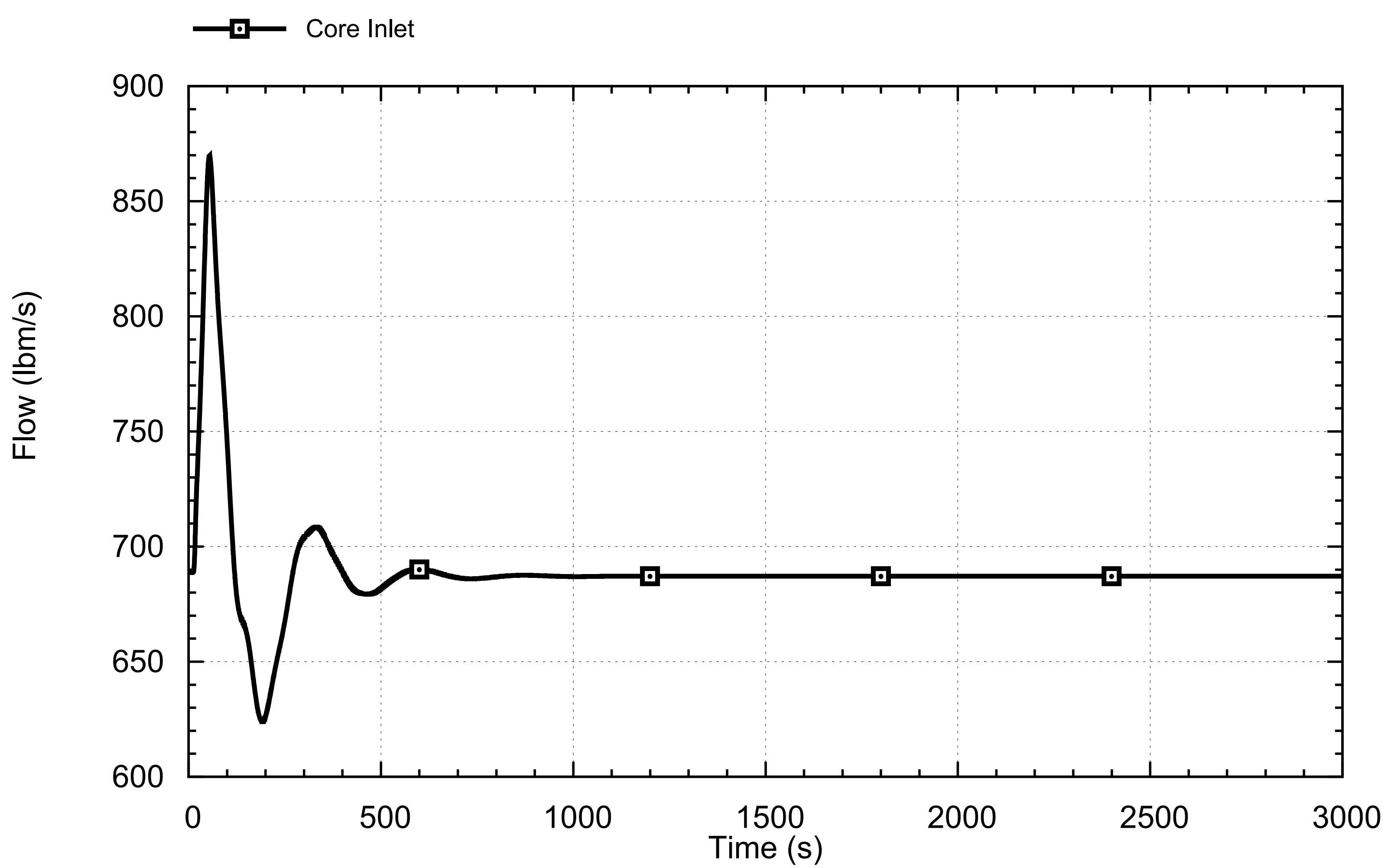
RAI 15.09-2, RAI 15.09-3

Figure 15.9-11: Time Trace of Heat Addition and Heat Removal Response to a Decrease in Heat Removal by the Secondary System at 20 Percent of Rated Power and End of Cycle Reactivity



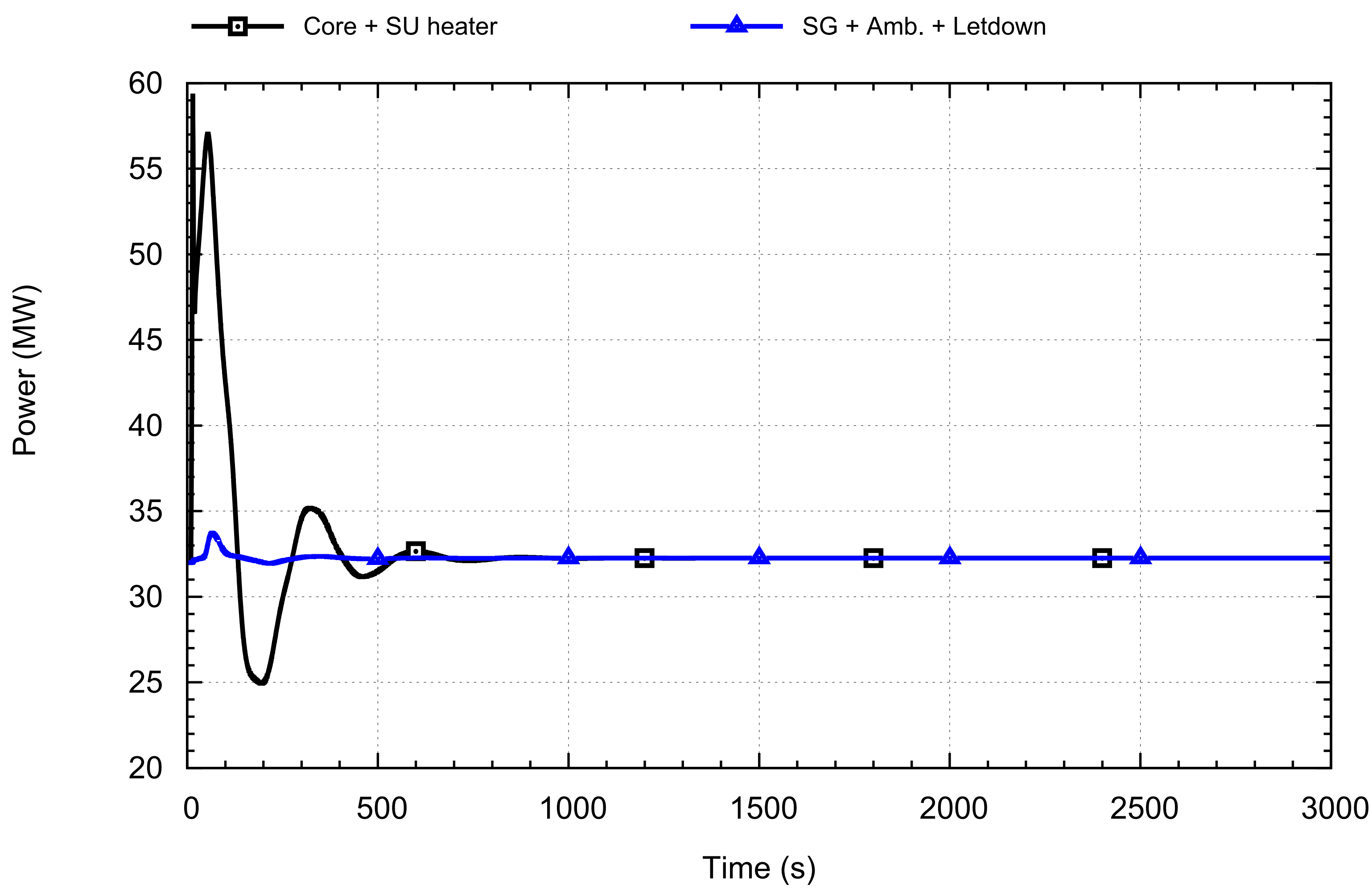
RAI 15.09-2, RAI 15.09-3

Figure 15.9-12: Time Trace of Primary Coolant Flow Response to Reactivity and Power Distribution Anomalies at 20 Percent of Rated Power and End of Cycle Reactivity



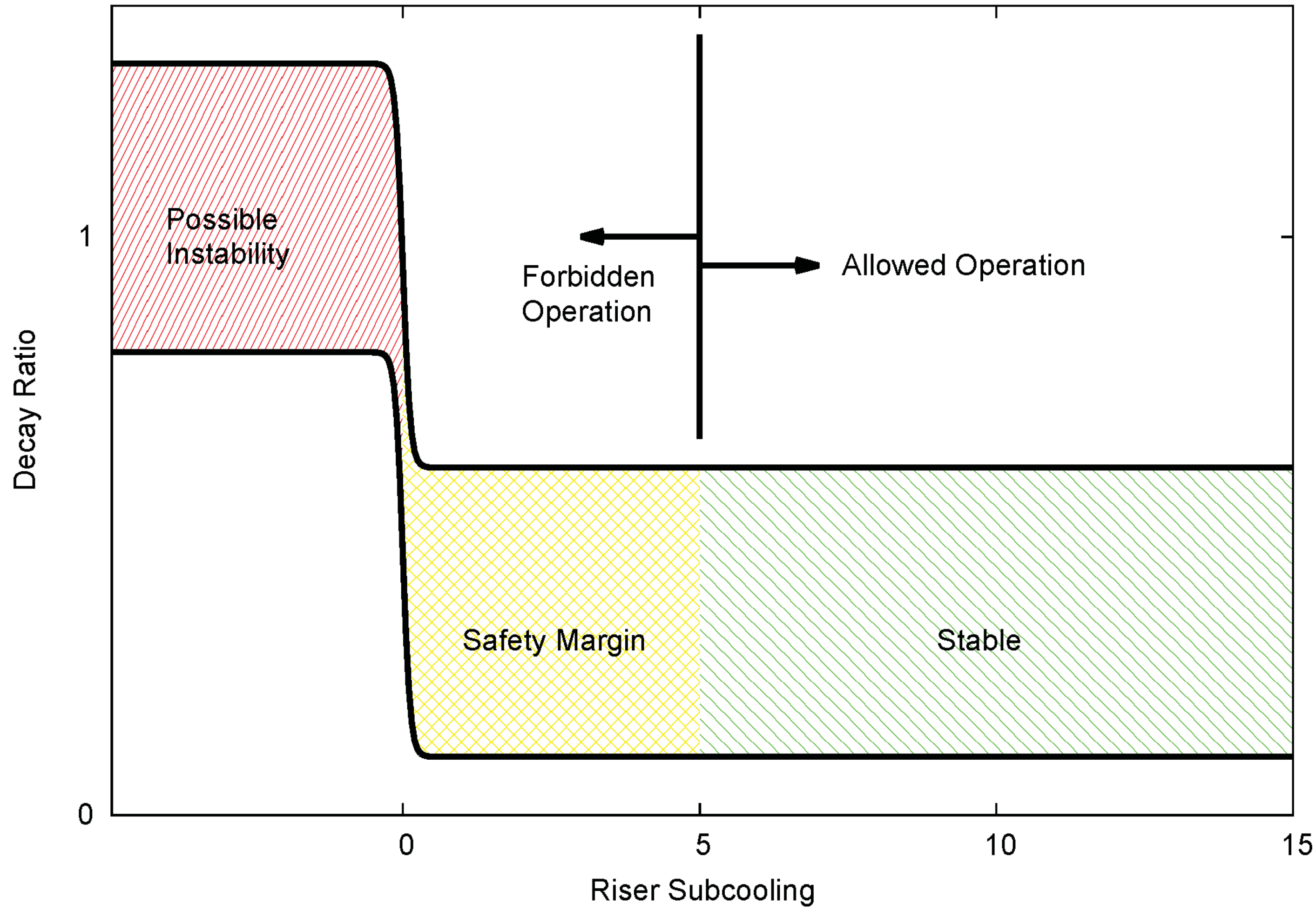
RAI 15.09-2, RAI 15.09-3

Figure 15.9-13: Time Trace of Heat Addition and Heat Removal Response to Reactivity and Power Distribution Anomalies at 20 Percent of Rated Power and End of Cycle Reactivity



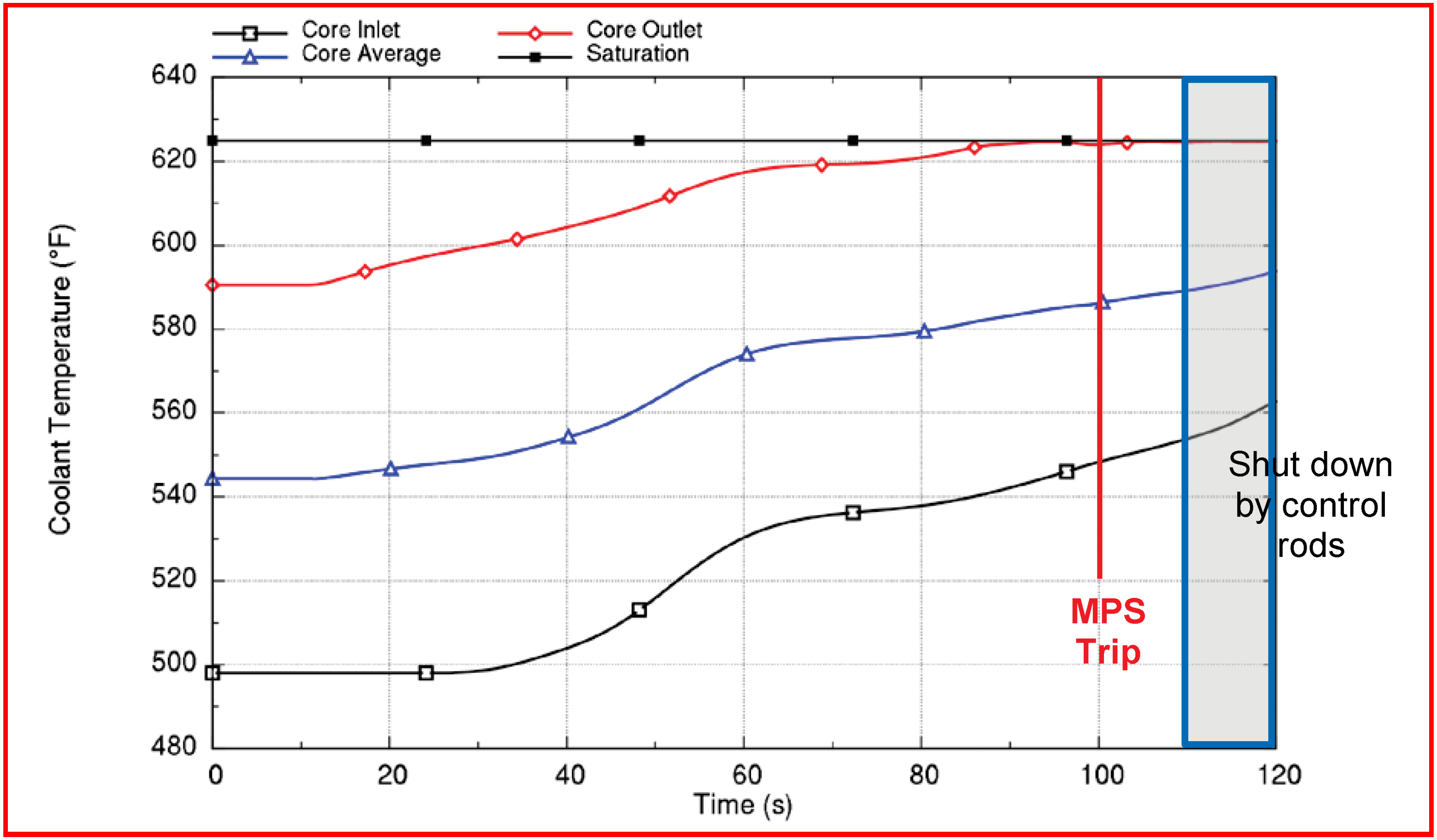
RAI 15.09-2, RAI 15.09-3

Figure 15.9-14: ~~**Illustration of Decay Ratio versus Riser Subcooling**~~



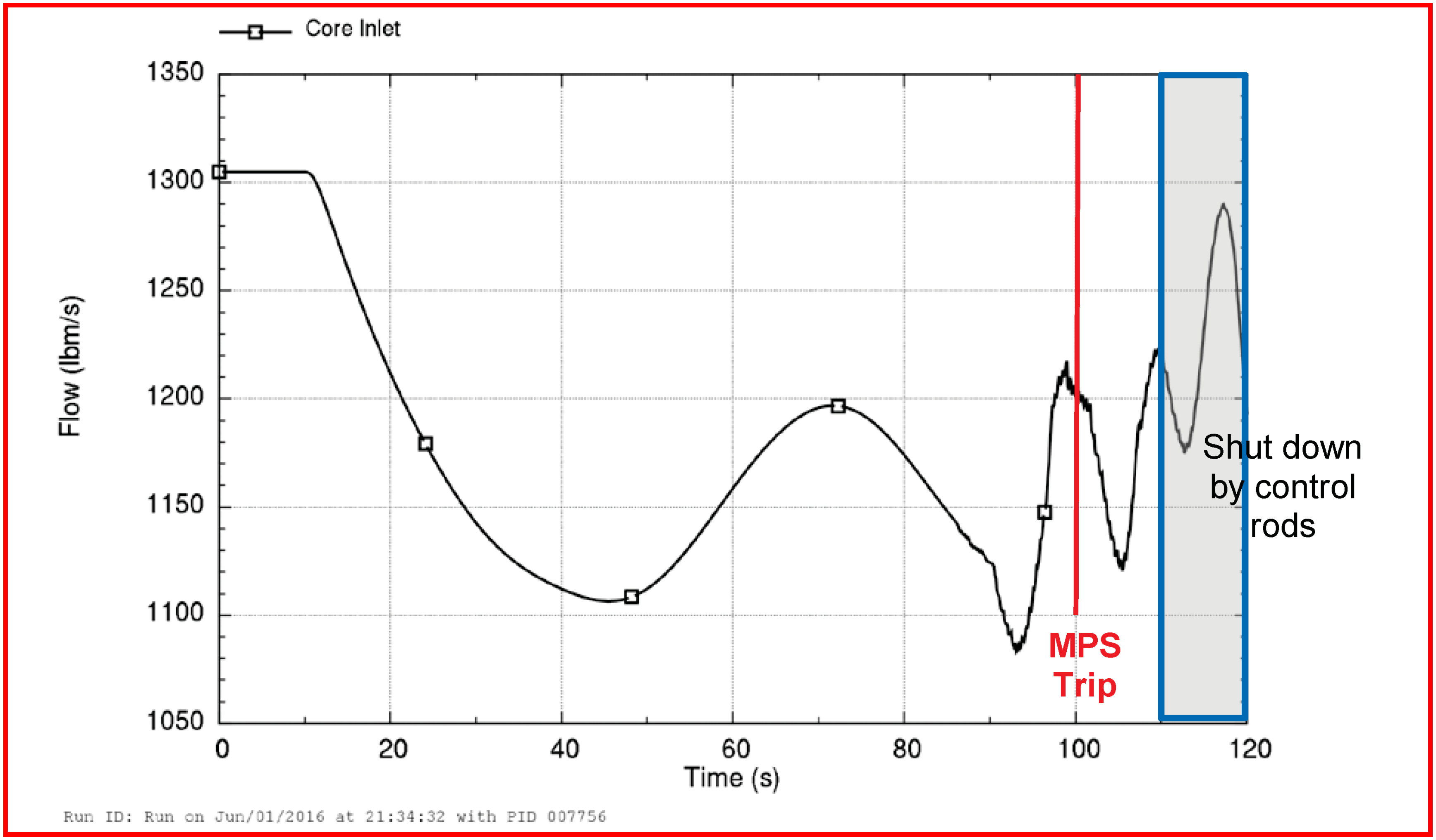
RAI 15.09-2, RAI 15.09-3

Figure 15.9-15: ~~Reactor Pressure Vessel Temperature Response to a 50% Decrease in Feedwater Flow at Hot Full Power with Zero Moderator Reactivity Feedback~~



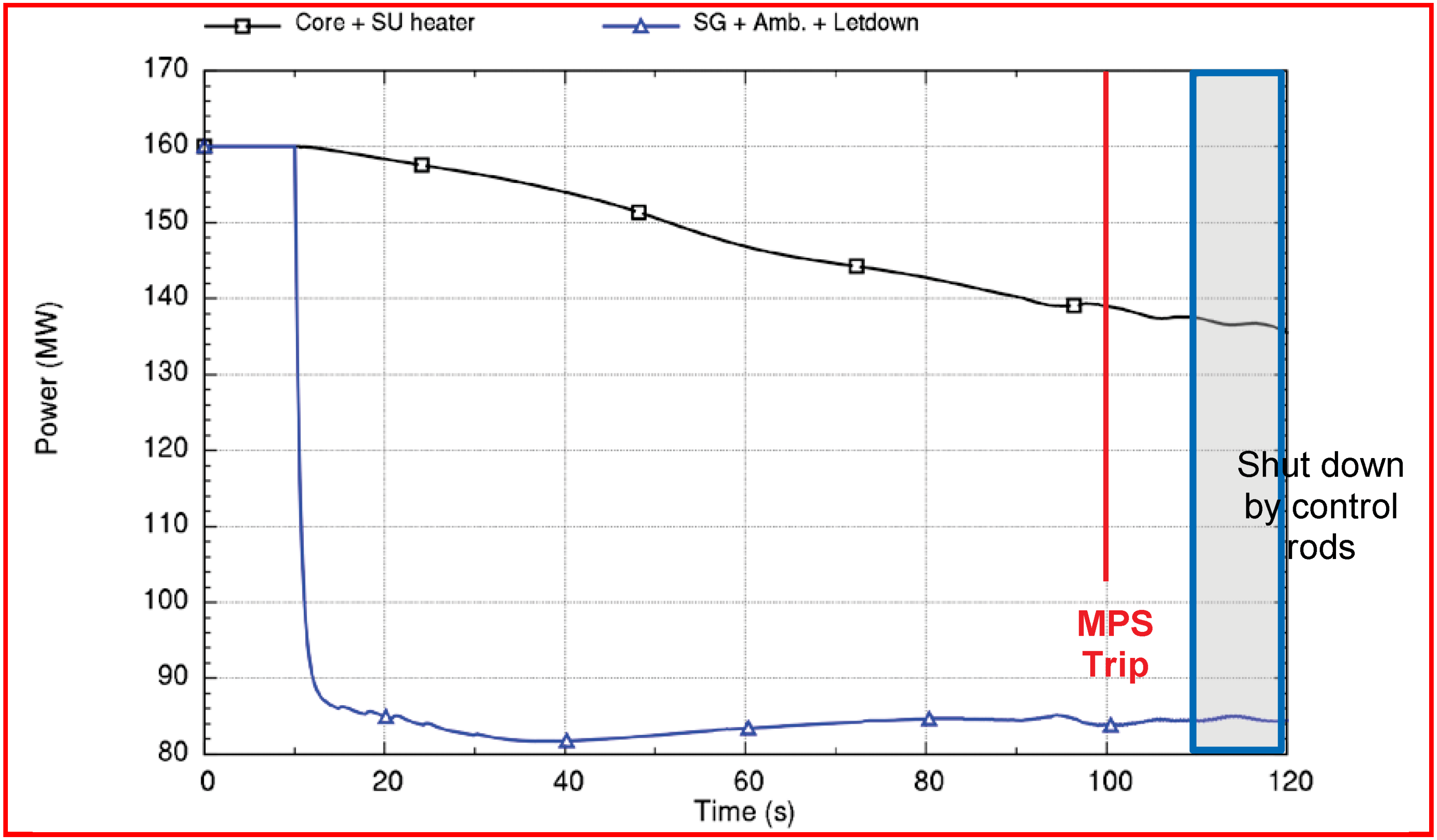
RAI 15.09-2, RAI 15.09-3

Figure 15.9-16: ~~Primary Coolant Flow Response to a 50% Decrease in Feedwater at Hot Full Power and Zero Moderator Reactivity Feedback~~



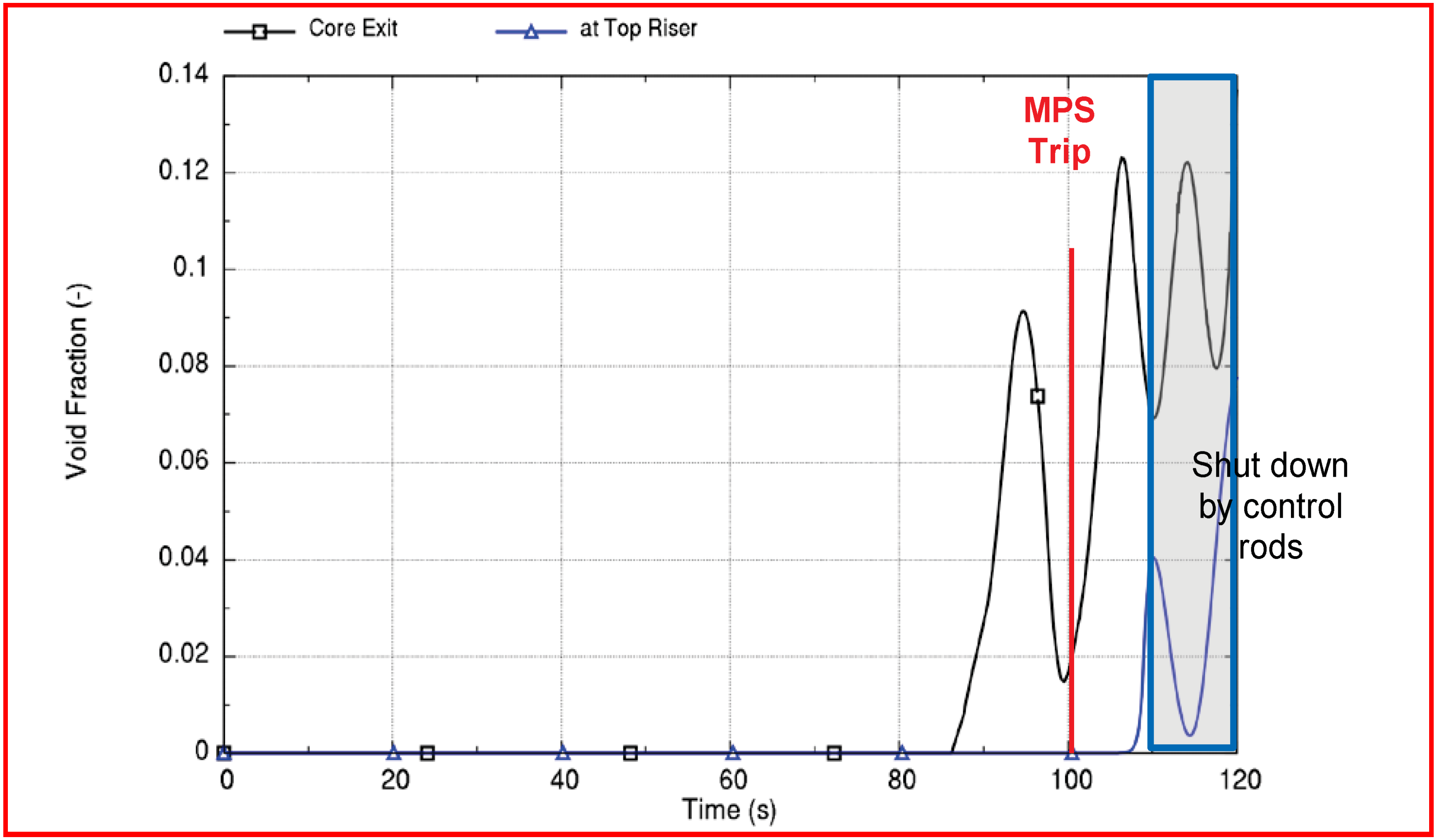
RAI 15.09-2, RAI 15.09-3

Figure 15.9-17: ~~**Heat Addition and Heat Removal Response to a 50% Decrease in Feedwater at Hot Full Power and Zero Moderator Reactivity Feedback**~~



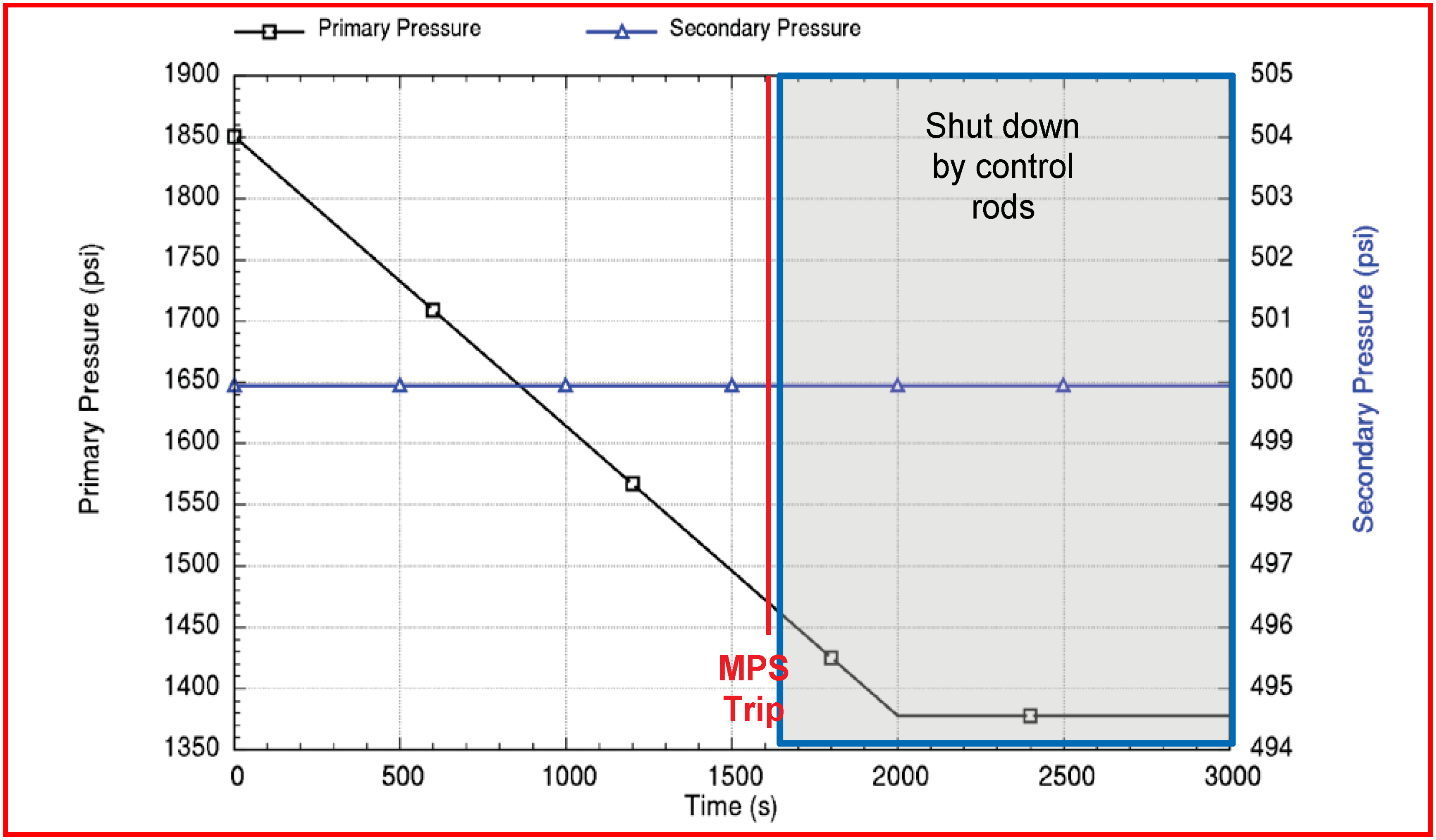
RAI 15.09-2, RAI 15.09-3

Figure 15.9-18: ~~**Void Fraction Response to a 50% Decrease in Feedwater at Hot Full Power and Zero Moderator Reactivity Feedback**~~



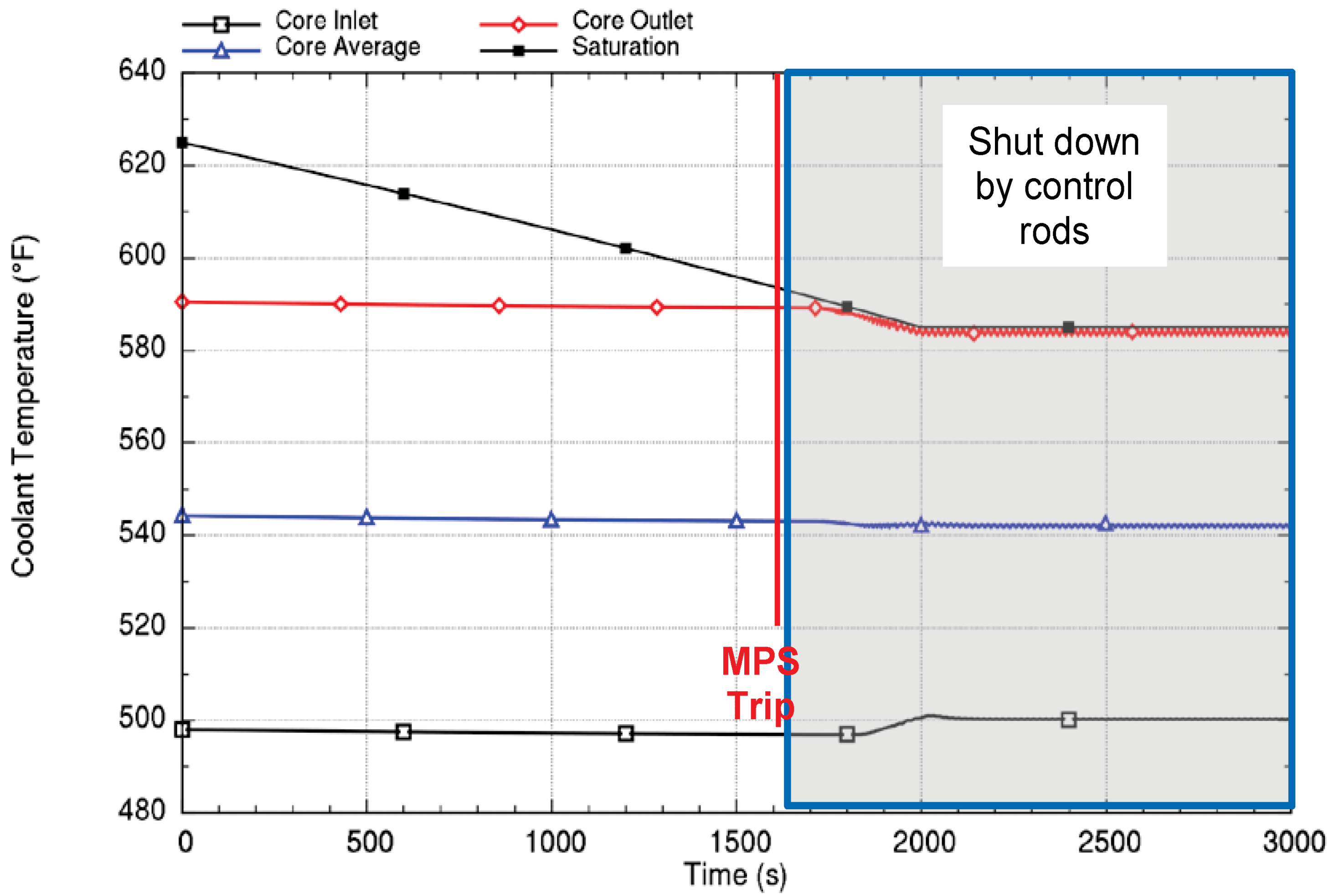
RAI 15.09-2, RAI 15.09-3

Figure 15.9-19: ~~Programmed System Pressure at Rated Power~~



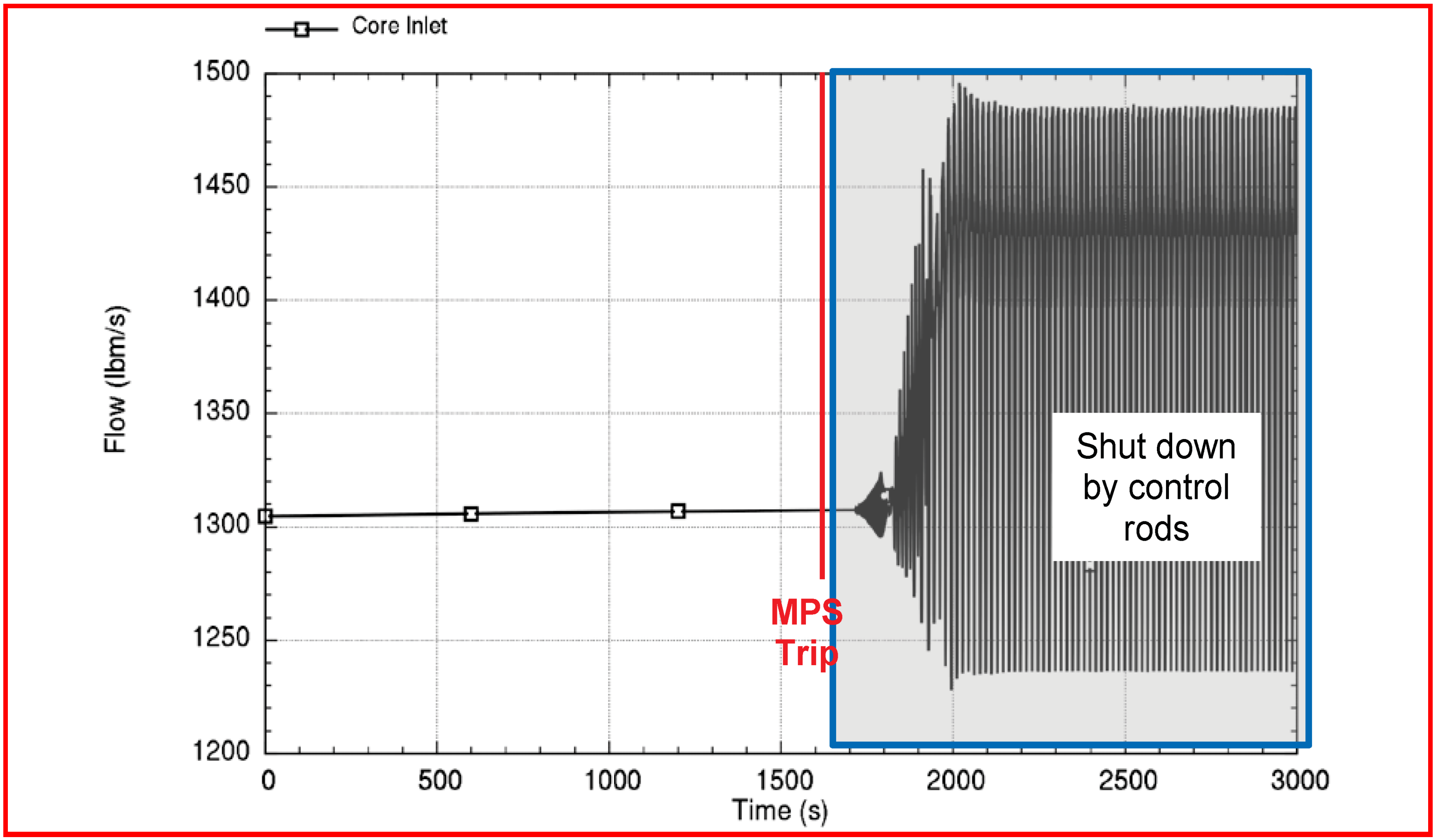
RAI 15.09-2, RAI 15.09-3

Figure 15.9-20: ~~**Coolant Temperature Response to a Depressurization at Hot Full Power and Beginning of Cycle Reactivity Feedback**~~



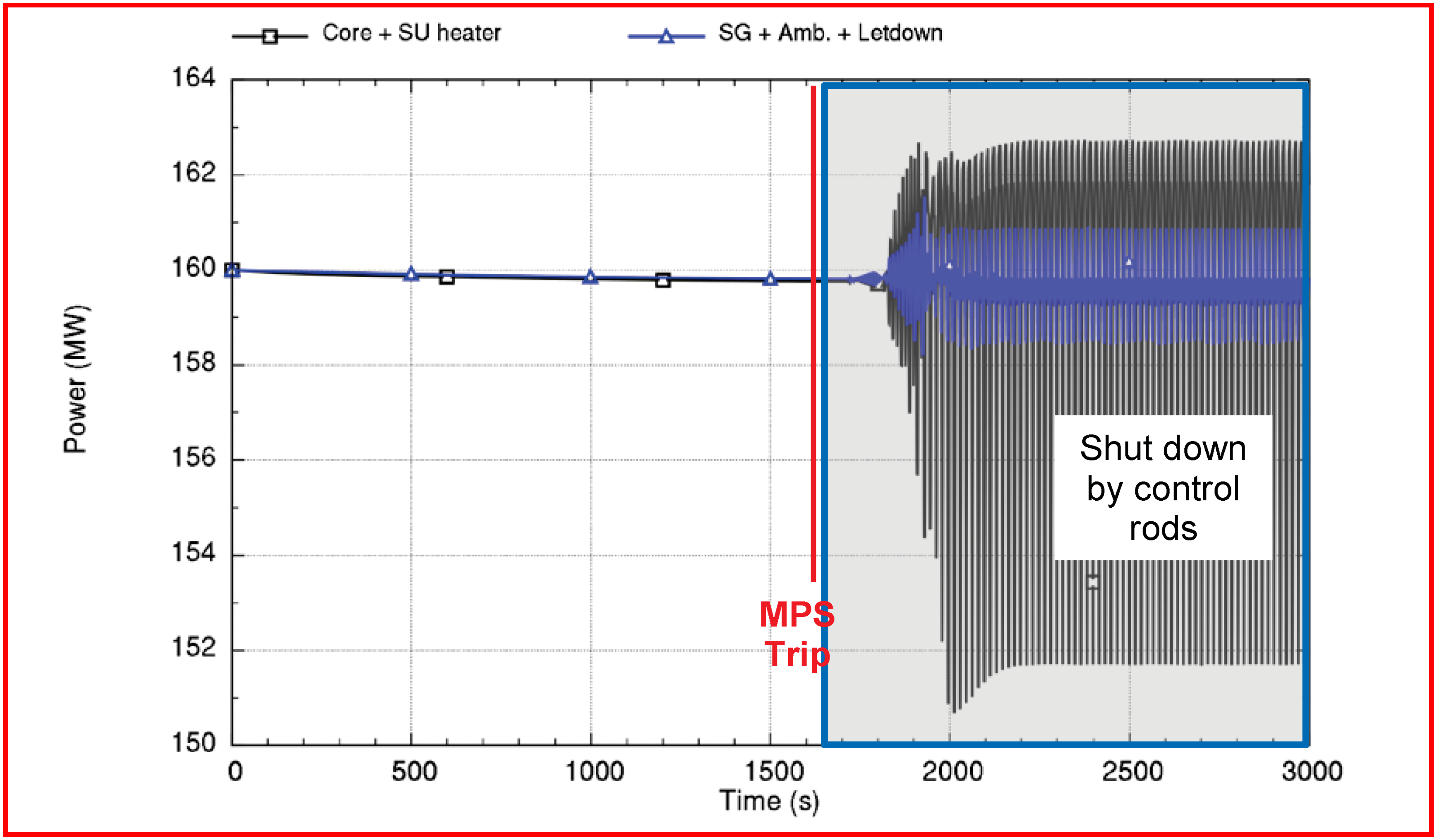
RAI 15.09-2, RAI 15.09-3

Figure 15.9-21: ~~**Primary Coolant Flow Response to a Depressurization at Hot Full Power and Beginning of Cycle Reactivity Feedback**~~



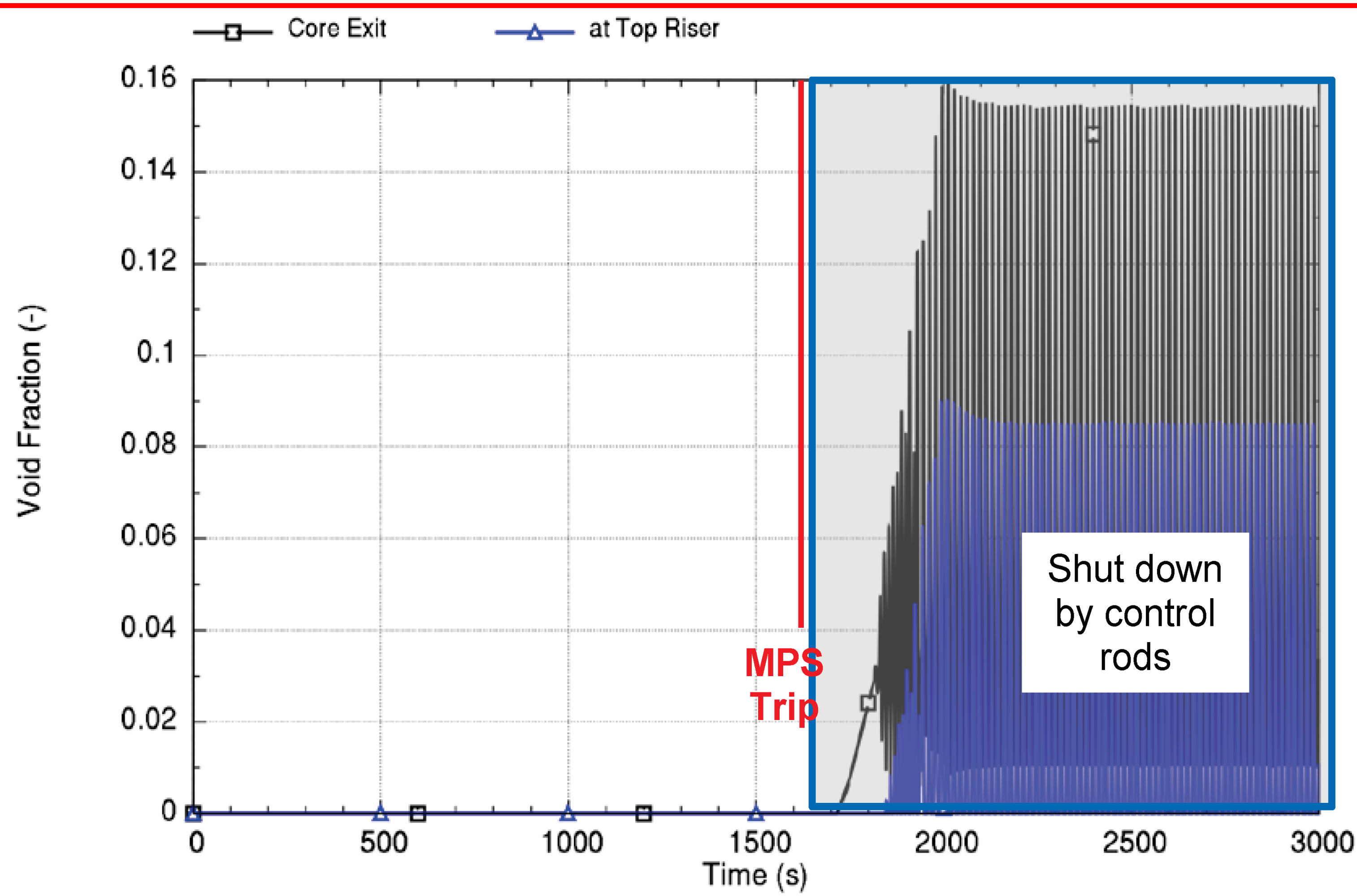
RAI 15.09-2, RAI 15.09-3

Figure 15.9-22: ~~**Heat Addition and Heat Removal Response to a Depressurization at Hot Full Power and Beginning of Cycle Reactivity Feedback**~~



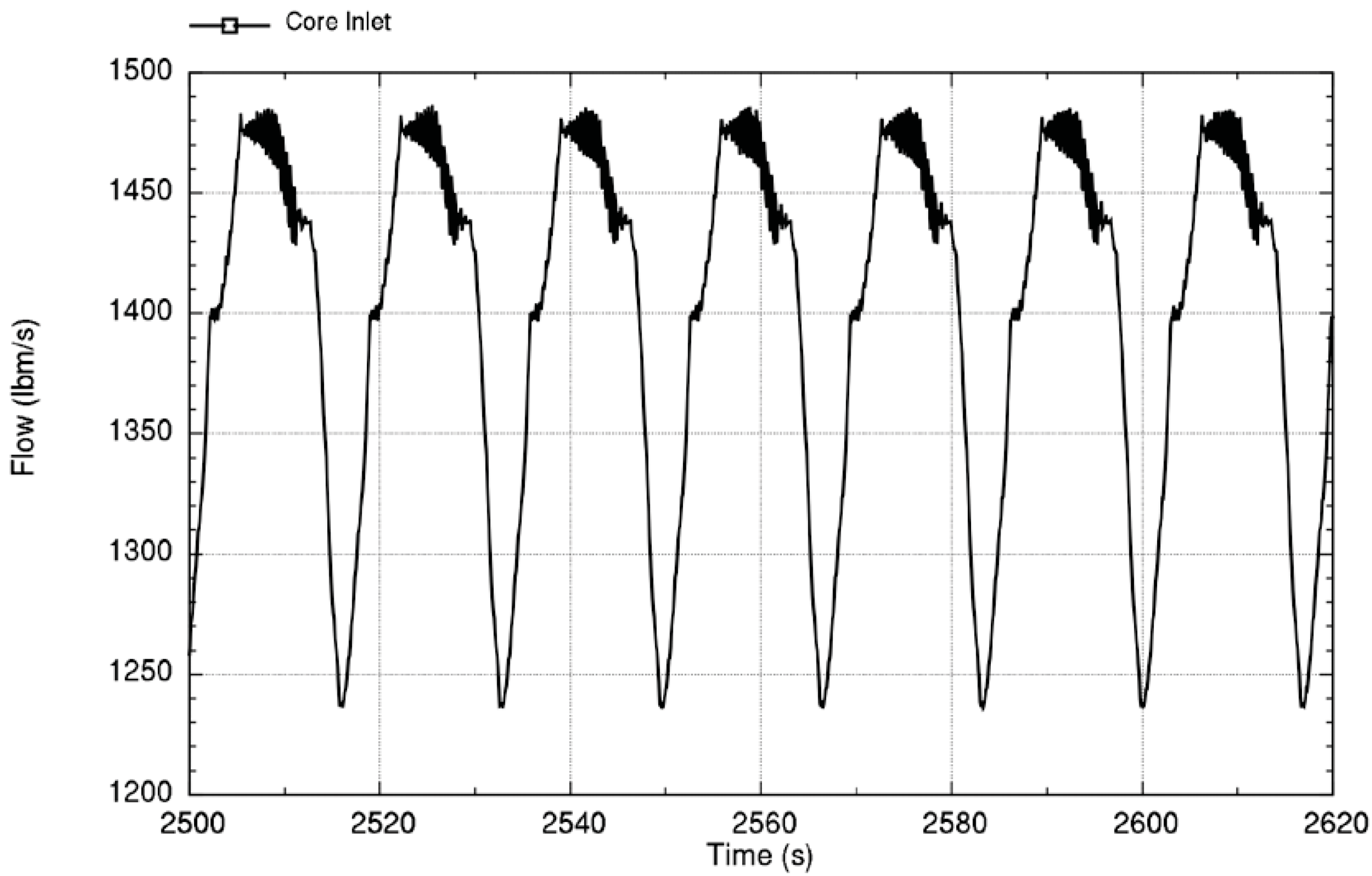
RAI 15.09-2, RAI 15.09-3

Figure 15.9-23: ~~Void Fraction Response to a Depressurization at Hot Full Power and Beginning of Cycle Reactivity Feedback~~



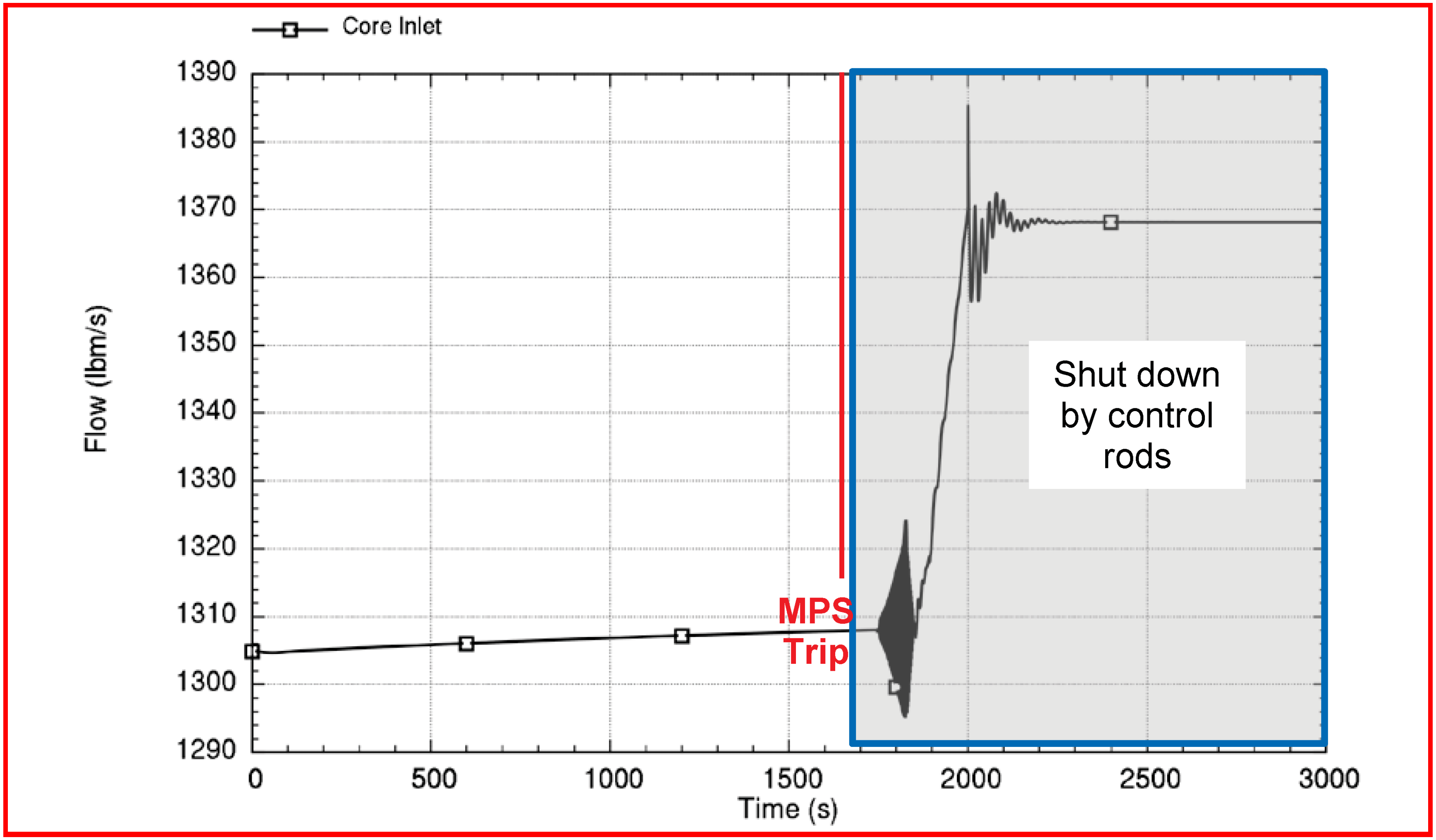
RAI 15.09-2, RAI 15.09-3

Figure 15.9-24: ~~Primary Coolant Flow Limit-Cycle Response more than 120 Seconds to a Depressurization at Hot Full Power and Beginning of Cycle Reactivity Feedback~~



RAI 15.09-2, RAI 15.09-3

Figure 15.9-25: ~~Primary Coolant Flow Response to a Depressurization at Hot Full Power and End of Cycle Reactivity Feedback~~



RAI 15.09-2, RAI 15.09-3

Figure 15.9-26: ~~Void Fraction Response to a Depressurization at Hot Full Power and End of Cycle Reactivity Feedback~~