15.2 Increase in Reactor Pressure

15.2.1 Pressure Regulator Failure—Closed

15.2.1.1 Identification of Causes and Frequency Classification

15.2.1.1.1 Identification of Causes

The ABWR Steam Bypass and Pressure Control System (SB&PCS) uses a triplicated digital control system instead of an analog system as used in BWR/2 through BWR/6. The SB&PCS controls turbine control valves and turbine bypass valves to maintain reactor pressure. As presented in Subsection 15.1.2.1.1, no credible single failure in the control system will result in a minimum demand to all turbine control valves and bypass valves. A voter or actuator failure may result in an inadvertent closure of one turbine control valve or one turbine bypass valve if it is open at the time of failure. In this case, the SB&PCS will sense the pressure change and command the remaining control valves or bypass valves, if needed, to open, and thereby automatically mitigate the transient and try to maintain reactor power and pressure.

Because turbine bypass valves are normally closed during normal full power operation, it is assumed for purposes of this transient analysis that a single failure causes a single turbine control valve to fail closed. Should this event occur at full power, the opening of remaining control valves may not be sufficient to maintain the reactor pressure, depending on the turbine design. Neutron flux will increase due to void collapse resulting from the pressure increase. A reactor scram will be initiated when the high flux scram setpoint is exceeded.

No single failure will cause the SB&PCS to issue erroneously a minimum demand to all turbine control valves and bypass valves. However, as discussed in Subsection 15.1.2.1.1, multiple failures might cause the SB&PCS to fail and erroneously issue a minimum demand. Should this occur, it would cause full closure of turbine control valves as well as inhibit steam bypass flow and thereby increase reactor power and pressure. When this occurs, reactor scram will be initiated when the high reactor flux scram setpoint is reached. This event is analyzed here as the simultaneous failure of two control processors, called “pressure regulator downscale failure.” However, the probability of this event occurring is extremely low, and hence the event is considered as a limiting fault.

15.2.1.1.2 Frequency Classification

15.2.1.1.2.1 Inadvertent Closure of One Turbine Control Valve

This event is conservatively treated as a moderate frequency event, although the voter/ actuator failure rate is very low.

15.2.1.1.2.2 Pressure Regulator Downscale Failure

The probability of occurence of this event is calculated to be extremely low, as shown in Appendix 15D. This event is treated as a limiting fault.

15.2.1.2 Sequence of Events and System Operation

15.2.1.2.1 Sequence of Events

15.2.1.2.1.1 Inadvertent Closure of One Turbine Control Valve

Postulating an actuator failure of the SB&PCS (Subsection 15.2.1.1.1) will cause one turbine control valve to close. The pressure will increase because the reactor is still generating the initial steam flow. The SB&PCS will open the remaining control valves and some bypass valves. This sequence of events is listed in Table 15.2-1A for Figure 15.2-1A, for a fast closure, and in Table 15.2-1B for Figure 15.2-1B, for a slow closure.

15.2.1.2.1.2 Pressure Regulator Downscale Failure

Table 15.2-2 lists the sequence of events for Figure 15.2-2.

15.2.1.2.1.3 Identification of Operator Actions

The operator should:

(1) Monitor that all rods are in

(2) Monitor reactor water level and pressure

(3) Observe turbine coastdown and break vacuum before the loss of steam seals (check turbine auxiliaries)

(4) Observe that the reactor pressure relief valves open at their setpoint

(5) Monitor reactor water level and continue cooldown per the normal procedure

(6) Complete the scram report and initiate a maintenance survey of pressure regulator before reactor restart

15.2.1.2.2 Systems Operation

15.2.1.2.2.1 Inadvertent Closure of One Turbine Control Valve

Normal plant instrumentation and control are assumed to function. This event takes credit for high neutron flux scram to shut down the reactor.

After a closure of one turbine control valve, the steam flow rate that can be transmitted through the remaining three turbine control valves depends upon the turbine configuration. For plants with full-arc turbine admission, the steam flow through the remaining three turbine control valves is at least 95% of rated steam flow. On the other hand, this capacity drops to about 85% of rated steam flow for plants with partial-arc turbine admission. Therefore, this transient is less severe for plants with full-arc turbine admission. In this analysis, the case with partial-arc turbine admission is analyzed to cover all potential operating conditions.

This event is sensitive to the closure time of the turbine control valve, and the bypass capacity available during this event. A wide range of closure time, including very slow closure, has been assumed in the analysis. A fast closure causes the reactor to be scrammed on high neutron flux trip, while a slow closure allows the reactor to settle in another steady state.

The turbine bypass capacity during this event is controlled by the setpoint of the maximum combined steam flow limiter in the pressure control system. A nominal 115% setpoint will allow for about 12% bypass capacity, while a nominal 125% setpoint will allow for about 22% bypass capacity, assuming a 3% bypass bias. It is concluded from analysis that the nominal setpoint for the maximum combined flow limiter should be set at approximately 115% for plants with full-arc turbine admission, and at approximately 125% for plants with partial-arc turbine admission.

15.2.1.2.2.2 Pressure Regulator Downscale Failure

Analysis of this event assumes normal functioning of plant instrumentation and controls, and plant protection and reactor protection systems. Specifically, this event takes credit for high neutron flux scram to shut down the reactor. High system pressure is limited by the pressure relief valve system operation.

15.2.1.3 Core and System Performance

15.2.1.3.1 Inadvertent Closure of One Turbine Control Valve

A simulated fast closure of one turbine control valve (2.5 sec) is presented in Figure 15.2-1A. The analysis assumes that about 85% of rated steam flow can pass through the remaining three turbine control valves.

Neutron flux increases rapidly because of the void reduction caused by the pressure increase. The neutron flux increase is limited to 115% NBR narrowly avoiding a scram. Since the available turbine bypass capacity is high enough to bypass all steam flow not passing through the remaining three turbine control valves, the reactor power settles back to its steady state. Peak fuel surface heat flux does not exceed 105% of its initial value. MCPR for this transient is still above the safety MCPR limit (ΔCPR = 0.10). Therefore, the design basis is satisfied.

A slow closure of one turbine control valve is also analyzed as shown in Figure 15.2-1B. In this case, the neutron flux increase does not reach the high neutron flux scram setpoint. Since the available turbine bypass capacity is high enough to bypass all steam flow not passing through the remaining three turbine control valves, the reactor power settles back to its steady state. During the transient, the peak fuel surface heat flux does not exceed 103.6% of its initial value. MCPR is still above the safety limit (ΔCPR = 0.06). Therefore, the design basis is satisfied.

The applicant will provide reanalysis of this event for the specific core configuration. See Subsection 15.2.10.1 for COL license information requirements.

15.2.1.3.2 Pressure Regulator Downscale Failure

A pressure regulator downscale failure is simulated at 102% NBR power and 90% core flow as shown in Figure 15.2-2.

Neutron flux increases rapidly because of the void reduction caused by the pressure increase. When the sensed neutron flux reaches the high neutron flux scram setpoint, a reactor scram is initiated. The neutron flux increase is limited to 139% NBR by the reactor scram. Peak fuel surface heat flux does not exceed 110% of its initial value. It is estimated that less than 0.2% of rods will get into transition boiling. Therefore, the design limit for the limiting fault event is met.

15.2.1.4 Barrier Performance

15.2.1.4.1 Inadvertent Closure of One Turbine Control Valve

Peak pressure at the SR valves reaches 7.34 MPaG. The peak vessel bottom pressure reaches 7.65 MPaG, which is below the transient pressure limit of 9.48 MPaG.

15.2.1.4.2 Pressure Regulator Downscale Failure

Peak pressure at the SRVs reaches 8.28 MPaG. The peak nuclear system pressure reaches 8.62 MPaG at the bottom of the vessel, which is below the nuclear barrier pressure limit.

15.2.1.5 Radiological Consequences

15.2.1.5.1 Inadvertent Closure of One Turbine Control Valve

The consequences of this event do not result in any fuel failures, nor any discharge to the suppression pool. Therefore, the radiological exposures noted in Subsection 15.2.4.5 cover the consequences of this event.

15.2.1.5.2 Pressure Regulator Downscale Failure

During this event, less than 0.2% of fuel rods get into transition boiling. No fuel failures are expected. However, it is conservatively assumed that 0.2% of fuel rods fail in the radiological dose calculation. The results show that both the whole body dose and thyroid dose are well within 10% of 10CFR100 requirements. Therefore, the acceptance criteria are met.

15.2.2 Generator Load Rejection

15.2.2.1 Identification of Causes and Frequency Classification

15.2.2.1.1 Identification of Causes

Fast closure of the turbine control valves (TCVs) is initiated whenever electrical grid disturbances occur which result in significant loss of electrical load on the generator. The TCVs are required to close as rapidly as possible to prevent excessive overspeed of the turbine-

generator (T-G) rotor. Closure of the main TCVs will cause a sudden reduction in steam flow, which results in an increase in system pressure and reactor shutdown.

After sensing a significant loss of electrical load on the generator, the TCVs are commanded to close rapidly. At the same time, the turbine bypass valves are signaled to open in the “fast” opening mode by the SB&PCS, which uses a triplicated digital controller. As presented in Subsection 15.1.2.1.1, no single failure can cause all turbine bypass valves (TBVs) to fail to open on demand. The worst single failure can only cause one TBV fail to open on demand. Therefore, the probability of this to occur is very low. Therefore, generator load rejection with failure of one TBV is considered an infrequent event, while generator load rejection with failure of all TBVs is a limiting fault.

15.2.2.1.2 Frequency Classification

15.2.2.1.2.1 Generator Load Rejection with Bypass

This event is categorized as an incident of moderate frequency.

15.2.2.1.2.2 Generator Load Rejection with Failure of One Bypass Valve

This event should be categorized as an infrequent event. However, criteria for moderate frequent incidents are conservatively applied.

15.2.2.1.2.3 Generator Load Rejection with Failure of All Bypass Valves

Frequency Basis: Thorough search of domestic plant operating records have revealed three instances of bypass failure during 628 bypass system operations. Combining the actual frequency of a generator load rejection with the failure rate of bypass yields a frequency of a generator load rejection with bypass failure. With the triplicated fault-tolerant design used in ABWR, this failure frequency is lowered much more. Therefore, this event should be classified as a limiting fault; however, criteria for moderate frequent incidents are conservatively applied.

15.2.2.2 Sequence of Events and System Operation

15.2.2.2.1 Sequence of Events

15.2.2.2.1.1 Generator Load Rejection—Turbine Control Valve Fast Closure

A loss of generator electrical load from high power conditions produces the sequence of events listed in Table 15.2-3.

15.2.2.2.1.2 Generator Load Rejection with Failure of One Bypass Valve

A loss of generator electrical load from high power conditions with failure of one bypass valve produces the sequence of events listed in Table 15.2-4.

15.2.2.2.1.3 Generator Load Rejection with Failure of All Bypass Valves

A loss of generator electrical load at high power with failure of all bypass valves produces the sequence of events listed in Table 15.2-5.

15.2.2.2.1.4 Identification of Operator Actions

The operator should:

(1) Verify proper bypass valve performance

(2) Observe that the feedwater/level controls have maintained the reactor water level at a satisfactory value

(3) Observe that the pressure regulator is controlling reactor pressure at the desired value

(4) Observe reactor peak power and pressure

(5) Verify relief valve operation

15.2.2.2.2 System Operation

15.2.2.2.2.1 Generator Load Rejection with Bypass

To properly simulate the expected sequence of events, the analysis of this event assumes normal functioning of plant instrumentation and controls, plant protection and reactor protection systems unless stated otherwise.

Turbine control valve (TCV) fast closure initiates a scram trip signal for power levels greater than 40% NB rated. In addition, a trip of four of ten RIPs is initiated. Both of these trip signals satisfy the single-failure criterion and credit is taken for these protection features.

The pressure relief system, which operates the relief valves independently when system pressure exceeds relief valve instrumentation setpoints, is assumed to function normally during the time period analyzed.

All plant control systems maintain normal operation unless specifically designated to the contrary.

15.2.2.2.2.2 Generator Load Rejection with Failure of One Bypass Valve

Same as Subsection 15.2.2.2.2.1, except that failure of one main TBV is assumed for the entire event.

15.2.2.2.2.3 Generator Load Rejection with Failure of All Bypass Valves

Same as Subsection 15.2.2.2.2.1, except that failure of all TBVs is assumed for the entire event.

15.2.2.3 Core and System Performance

15.2.2.3.1 Input Parameters and Initial Conditions

The turbine electrohydraulic control system (EHC) detects load rejection before a measurable turbine speed change takes place.

The TCV trip closure time is 0.08 seconds or greater.

The reactor is operating in the manual flow-control mode when load rejection occurs. Results do not significantly differ if the plant had been operating in the automatic flow-control mode.

The bypass valve opening characteristics are simulated using the specified delay together with the specified opening characteristic required for bypass system operation.

Events caused by low water level trips such as an initiation of the RCIC System function is not required. Should this event occur, it will follow sometime after the primary concerns of fuel thermal margin and overpressure effects have occurred, and is expected to be less severe than those already experienced by the system.

15.2.2.3.2 Results

15.2.2.3.2.1 Generator Load Rejection with Bypass

Figure 15.2-3 shows the results of the generator trip from the 102% rated power and 90% flow conditions. Peak neutron flux rises to 121% of NB rated conditions.

The average fuel surface heat flux shows a small increase from its initial value, and MCPR has a short term (~1 second) reduction below its initial value. However, it is not as severe as for the case where all bypass valves are assumed to fail (Subsection 15.2.2.3.2.3). Therefore, this event does not have to be reanalyzed for a specific core configuration.

15.2.2.3.2.2 Generator Load Rejection with Failure of One Bypass Valve

Figure 15.2-4 shows that, for the case of one bypass valve failure, peak neutron flux reaches about 121% of rated, and the average fuel surface heat flux still shows no increase from its initial value.

The MCPR for this event has a short-term (~1 second) reduction below its initial value. However, it is not as severe as for the case where all bypass valves are assumed to fail (Subsection 15.2.2.3.2.3) is above the safety limit. Therefore, this event does not have to be analyzed for a specific core configuration.

15.2.2.3.2.3 Generator Load Rejection with Failure of All Bypass Valves

Figure 15.2-5 shows that, for the case of all bypass valves failure, peak neutron flux reaches about 123% of rated, and average surface heat flux reaches 102.3% of its initial value. The

MCPR for this event is right at the safety limit and meets the criteria for moderate frequent incidents. The event should be analyzed for a specific core configuration. See Subsection 15.2.10.2 for COL license information requirements.

15.2.2.4 Barrier Performance

15.2.2.4.1 Generator Load Rejection with Bypass

Peak pressure at the SRVs reaches 8.04 MPaG. The peak vessel bottom pressure reaches 8.17 MPaG, below the transient pressure limit of 9.48 MPaG.

15.2.2.4.2 Generator Load Rejection with Failure of One Bypass Valve

Peak pressure at the SRVs reaches 8.16 MPaG. The peak vessel pressure at the bottom of the vessel reaches 8.31 MPaG, below the pressure limit.

15.2.2.4.3 Generator Load Rejection with Failure of All Bypass Valves

Peak pressure at the SRVs reaches 8.47 MPaG. The peak nuclear system pressure reaches 8.51 MPaG at the bottom of the vessel, below the pressure limit.

15.2.2.5 Radiological Consequences

While the consequences of the events identified previously do not result in any fuel failures, radioactivity is nevertheless discharged to the suppression pool as a result of SRV actuation. However, the mass input, and hence activity input, for this event is much less than those consequences identified in Subsection 15.2.4.5. Therefore, the radiological exposures noted in Subsection 15.2.4.5 for Type 2 exposure cover these consequences of this event.

15.2.3 Turbine Trip

15.2.3.1 Identification of Causes and Frequency Classification

15.2.3.1.1 Identification of Causes

A variety of turbine or nuclear system malfunctions will initiate a turbine trip. Some examples are moisture separator and heater drain tank high levels, large vibrations, operator lockout, loss of control fluid pressure, low condenser vacuum and reactor high water level.

After the main turbine is tripped, turbine bypass valves are opened in their fast opening mode by the SB&PCS. As presented in Subsection 15.2.2.1.1, any single failure can only cause one bypass valve fail to open on demand. Only multiple failures can cause all bypass valves fail to open on demand.

15.2.3.1.2 Frequency Classification

15.2.3.1.2.1 Turbine Trip with Bypass

This transient is categorized as an incident of moderate frequency. In defining the frequency of this event, turbine trips which occur as a byproduct of other transients such as loss of condenser vacuum or reactor high level trip events are not included. However, spurious low vacuum or high level trip signals which cause an unnecessary turbine trip are included in defining the frequency. To get an accurate event-by-event frequency breakdown, this type of division of initiating causes is required.

15.2.3.1.2.2 Turbine Trip with Failure of One Bypass Valve

This event is conservatively considered as an incident of moderate frequency.

15.2.3.1.2.3 Turbine Trip with Failure of All Bypass Valves

This disturbance should be categorized as a limiting fault. Frequency is as follows:

Frequency Basis: The failure rate of the bypass is presented in Subsection 15.2.2.1.2.3. Combining this with the turbine trip frequency yields the frequency in general. The ABWR design reduces this frequency much more to classify as a limiting fault. However, criteria for moderate frequent incidents are conservatively applied.

15.2.3.2 Sequence of Events and Systems Operation

15.2.3.2.1 Sequence of Events

15.2.3.2.1.1 Turbine Trip with Bypass

Turbine trip at high power produces the sequence of events listed in Table 15.2-6.

15.2.3.2.1.2 Turbine Trip with Failure of One Bypass Valve

Turbine trip at high power with failure of one bypass valve produces the sequence of events listed in Table 15.2-7.

15.2.3.2.1.3 Turbine Trip with Failure of All Bypass Valves

Turbine trip at high power with failure of all bypass valves produces the sequence of events listed in Table 15.2-8.

15.2.3.2.1.4 Identification of Operator Actions

The operator should:

(1) Verify auto-transfer of buses supplied by generator to incoming power (if automatic transfer does not occur, manual transfer must be made)

(2) Monitor and maintain reactor water level at required level

(3) Check turbine for proper operation of all auxiliaries during coastdown

(4) Depending on conditions, initiate normal operating procedures for cooldown, or maintain pressure for restart purposes

(5) Put the mode switch in the startup position before the reactor pressure decays to <5.86 MPaG

(6) Secure the RCIC operation if auto initiation occurred due to low water lever

(7) Monitor control rod drive positions and the SRNMS

(8) Investigate the cause of the trip, make repairs as necessary, and complete the scram report

(9) Cool down the reactor per standard procedure if a restart is not intended

15.2.3.2.2 Systems Operation

15.2.3.2.2.1 Turbine Trip with Bypass

All plant control systems maintain normal operation unless specifically designated to the contrary.

Turbine stop valve closure initiates a reactor scram trip via position signals to the protection system. Credit is taken for successful operation of the Reactor Protection System (RPS).

Turbine stop valves closure initiates a trip of four RIPs, thereby reducing the core flow.

The pressure relief system, which operates the relief valves independently when system pressure exceeds relief valve instrumentation setpoints, is assumed to function normally during the time period analyzed.

15.2.3.2.2.2 Turbine Trip with Failure of One Bypass Valve

Same as Subsection 15.2.3.2.2.1, except that a failure of one bypass valve is assumed.

15.2.3.2.2.3 Turbine Trip with Failure of All Bypass Valves

Same as Subsection 15.2.3.2.2.1, except that failure of all main turbine bypass valves is assumed for the entire transient time period analyzed.

15.2.3.3 Core and System Performance

15.2.3.3.1 Input Parameters and Initial Conditions

Turbine stop valves full stroke closure time is 0.1 seconds.

A reactor scram is initiated by position switches on the stop valves when the valves are less that 85% open.

Reduction in core recirculation flow is initiated by position switches on the main stop valves, which actuate trip circuitry which trips four of the reactor internal pumps.

15.2.3.3.2 Results

15.2.3.3.2.1 Turbine Trip with Bypass

A turbine trip with the bypass system operating normally is simulated at 102% NBR power and 90% core flow conditions as shown in Figure 15.2-6.

Neutron flux increases rapidly because of the void reduction caused by the pressure increase. However, the flux increase is limited to 115% of rated by the stop valve scram and the trip of four RIPs. Peak fuel surface heat flux does not exceed its initial value. This transient is less severe than the generator load rejection with failure of bypass transient in Subsection 15.2.2.3.2.3. Therefore, this event does not have to be reanalyzed for a specific core configuration.

15.2.3.3.2.2 Turbine Trip with Failure of One Bypass Valve

Same as Subsection 15.2.3.3.2.1, except the peak neutron flux is 116% of rated. This event is shown in Figure 15.2-7. This transient is less severe than the generator load rejection with failure of bypass transient presented in Subsection 15.2.2.3.2.3. Therefore, this event does not have to be reanalyzed for a specific core configuration.

15.2.3.3.2.3 Turbine Trip with Failure of All Bypass Valves

A turbine trip with failure of the bypass system is simulated at 102% NBR power and 90% core flow conditions in Figure 15.2-8.

Peak neutron flux reaches 120% of its rated value, and average surface heat flux reaches 101% of its initial value. This transient is less severe than the generator load rejection with failure of bypass transient presented in Subsection 15.2.2.1.3.3. However, for partial arc control, that result may be less limiting than turbine trip with failure of all bypass valves. Therefore, this event should be reanalyzed for a specific core configuration if the turbine control method is partial-arc.

15.2.3.4 Barrier Performance

15.2.3.4.1 Turbine Trip with Bypass

Peak pressure in the bottom of the vessel reaches 8.16 MPaG, which is below the ASME Code limit of 9.48 MPaG for the reactor coolant pressure boundary. Vessel dome pressure does not exceed 8.03 MPaG. The severity of turbine trips from lower initial power levels decreases to

the point where a scram can be avoided if auxiliary power is available from an external source and the power level is within the bypass capability.

15.2.3.4.2 Turbine Trip with Failure of One Bypass Valve

Peak pressure at the bottom of the vessel reaches 8.30 MPaG, while vessel dome pressure does not exceed 8.17 MPaG. Both are below the pressure limit of 9.48 MPaG.

15.2.3.4.3 Turbine Trip with Failure of All Bypass Valves

The SRVs open and close sequentially as the stored energy is dissipated and the pressure falls below the setpoints of the valves. Peak nuclear system pressure reaches 8.51 MPaG at the vessel bottom; therefore, the overpressure event is below the RCPB pressure limit. Peak dome pressure does not exceed 8.37 MPaG.

15.2.3.5 Radiological Consequences

While the consequences of this event do not result in any fuel failures, radioactivity is nevertheless discharged to the suppression pool as a result of SRV actuation. However, the mass input, and hence activity input, for this event is less than those consequences identified in Subsection 15.2.4.5 for a Type 2 event. Therefore, the radiological exposures noted in Section 15.2.4.5 cover the consequences of this event.

15.2.4 MSIV Closures

15.2.4.1 Identification of Causes and Frequency Classification

15.2.4.1.1 Identification of Causes

Various steamline and nuclear system malfunctions, or operator actions, can initiate main steamline isolation valve (MSIV) closure. Examples are low steamline pressure, high steamline flow, low water level or manual action.

15.2.4.1.2 Frequency Classification

15.2.4.1.2.1 Closure of All Main Steamline Isolation Valves

This event is categorized as an incident of moderate frequency. To define the frequency of this event as an initiating event and not the byproduct of another transient, only the following contribute to the frequency: (1) manual action (purposely or inadvertent); (2) spurious signals such as low pressure, low reactor water level, low condenser vacuum and, (3) equipment malfunctions such as faulty valves or operating mechanisms. A closure of one MSIV may cause an immediate closure of all other MSIVs, depending on reactor conditions. If this occurs, it is also included in this category. During the MSIV closure, position switches on the valves provide a reactor scram if the valves in two or more main steamlines are less than 85% open (except for interlocks which permit proper plant startup). Protection system logic, however, permits the test closure of one valve without initiating scram from the position switches.

15.2.4.1.2.2 Closure of One Main Steamline Isolation Valve

This event is categorized as an incident of moderate frequency. One MSIV may be closed at a time for testing purposes; this is done manually. Operator error or equipment malfunction may cause a single MSIV to be closed inadvertently. If reactor power is greater than about 80% when this occurs, a high flux scram may result (if all MSIVs close as a result of the single closure, the event is considered as a closure of all MSIVs).

15.2.4.2 Sequence of Events and Systems Operation

15.2.4.2.1 Sequence of Events

Table 15.2-9 lists the sequence of events for Figure 15.2-9.

15.2.4.2.1.1 Identification of Operator Actions

The following is the sequence of operator actions expected during the course of the event, assuming no restart of the reactor. The operator should:

(1) Observe that all rods have inserted

(2) Observe that the relief valves have opened for reactor pressure control

(3) Check that RCIC auto starts on the impending low reactor water level

(4) Switch the feedwater controller to the manual position

(5) Secure RCIC when the reactor vessel level has recovered to a satisfactory level

(6) Initiate RHR operation when the reactor pressure has decayed sufficiently

(7) Determine the cause of valve closure before resetting the MSIV isolation

(8) Observe turbine coastdown and break vacuum before the loss of sealing steam (check T-G auxiliaries for proper operation)

(9) Check that conditions are satisfactory prior to opening and resetting MSIVs

(10) Survey maintenance requirements and complete the scram report

15.2.4.2.2 Systems Operation

15.2.4.2.2.1 Closure of All Main Steamline Isolation Valves

MSIV closure initiates a reactor scram trip via position signals to the protection system.

Credit is taken for successful operation of the protection system.

The pressure relief system, which initiates opening of the relief valves when system pressure exceeds relief valve instrumentation setpoints, is assumed to function normally during the time period analyzed.

All plant control systems maintain normal operation unless specifically designated to the contrary.

15.2.4.2.2.2 Closure of One Main Steamline Isolation Valve

A closure of a single MSIV at any given time will not initiate a reactor scram directly. This is because the valve position scram trip logic is designed to accommodate single valve operation and testability during normal reactor operation at limited power levels. Credit is taken for the operation of the pressure and flux signals to initiate a reactor scram.

All plant control systems maintain normal operation unless specifically designated to the contrary.

15.2.4.3 Core and System Performance

15.2.4.3.1 Input Parameters and Initial Conditions

The main steam isolation valves close in 3 to 4.5 seconds. The worst case (the 3 second closure time) is assumed in this analysis. No credit was taken for instrument delay.

Position switches on the valves initiate a reactor scram when the valves are less than 85% open. Closure of these valves causes the dome pressure to increase. Four RIPs are tripped when the high pressure setpoint is reached.

ABWR has motor-driven feedwater pumps. However, a conservative feedwater flow coastdown model was used in order to bound both the motor-driven and steam turbine driven feedwater pump designs.

15.2.4.3.2 Results

15.2.4.3.2.1 Closure of All Main Steamline Isolation Valves

Figure 15.2-9 shows the changes in important nuclear system variations for the simultaneous isolation of all main steamlines while the reactor is operating at 102% of NBR power and 90% core flow. Neutron flux increases slightly to 102% , and fuel surface heat flux shows no increase.

Four RIPs are tripped due to high pressure. Water level decreases sufficiently to cause a trip of remaining 6 RIPs and the initiation of the RCIC system on the Level 2 (L2) trip at some time greater than 10 seconds. However, there is a delay up to 30 seconds before the water supply enters the vessel. Nevertheless, there is almost no change in the thermal margins. Therefore, this event does not have to be reanalyzed for specific core configurations.

15.2.4.3.2.2 Closure of One Main Steamline Isolation Valve

Only one isolation valve is permitted to be closed at a time for testing purposes to prevent scram. Normal test procedure requires an initial power reduction to approximately 75 to 80% of design conditions in order to avoid high flux scram, high pressure scram, or full isolation from high steam flow in the “live” lines. With a 3 second closure of one MSIV during 102% rated power and 90% core flow conditions, the steam flow disturbance may raise vessel pressure and reactor power enough to initiate a high neutron flux scram. This transient is considerably milder than closure of all MSIVs at full power. No quantitative analysis is furnished for this event. However, no significant change in thermal margins is experienced and no fuel damage occurs. Peak pressure remains below SRV setpoints. Therefore, this event does not have to be reanalyzed for specific core configurations.

15.2.4.4 Barrier Performance

15.2.4.4.1 Closure of All Main Steamline Isolation Valves

The nuclear system relief valves begin to open at approximately 2.9 seconds after the start of isolation. The valves close sequentially as the stored heat is dissipated but continue to discharge the decay heat intermittently. Peak pressure at the vessel bottom reaches 8.49 MPaG, below the pressure limits of the reactor coolant pressure boundary. Peak pressure in the main steamline is 8.33 MPaG.

15.2.4.4.2 Closure of One Main Steamline Isolation Valve

No significant effect is imposed on the RCPB, since, if closure of the valve occurs at an unacceptable high operating power level, a flux or pressure scram may result. The main turbine bypass system continues to regulate system pressure via the other three open steamlines.

15.2.4.5 Radiological Consequences

15.2.4.5.1 General Observations

The radiological impact of transients involves consequences which do not lead to fuel rod damage as a direct result of the event itself. Additionally, many events do not lead to the depressurization of the primary system but only the venting of sensible heat and energy via fluids at coolant loop activity through relief valves to the suppression pool. In the case of previously defective fuel rods, a depressurization transient will result in considerably more fission product carryover to the suppression pool than hot-standby transients. The time duration of the transient varies from several minutes to more than four hours.

These observations lead to the realization that radiological aspects can involve a broad spectrum of results. For example:

(1) Transients where appropriate operator action (seconds) results in quick return (minutes) to planned operation, little radiological impact results.

(2) Where major RCPB equipment failure requires immediate plant shutdown and its attendant depressurization under controlled shutdown timetables (4 hours), the radiological impact is greater.

To envelope the potential radiological impact, a worst case like example No. 2 is described below. However, it should be noted that most transients are like example (1) and the radiological envelope conservatively overpredicts the actual radiological impact by a factor greater than 100. It should be noted that the type of fuel used in the core will have no impact on the radiological evaluation.

15.2.4.5.2 Depressurization—Shutdown Evaluation

15.2.4.5.2.1 Fission Product Release from Fuel

While no fuel rods are damaged as a consequence of this event, fission product activity associated with normal coolant activity levels as well as that released from previously defective rods will be released to the suppression pool as a consequence of SRV actuation and vessel depressurization. The release of activity from previously defective rods is based in part upon measurements obtained from operating BWR plants (Reference 15.2-1).

Because each of those transients identified previously (which cause SRV actuation) will result in various vessel depressurization and steam blowdown rates, the transient evaluated in this section is that one which maximizes the radiological consequences for all transients of this nature. This transient is the closure of all main steamline isolation valves. The activity airborne in the containment is based on the analysis presented in Reference 15.2-1. The results of these analyses are presented in Table 15.2-10, which was used in evaluating the radiological dose consequences in this section.

15.2.4.5.2.2 Fission Product Release to Environment

Because this event does not result in the immediate need to purge the containment, it is assumed that purging of the containment through the SGTS occurs under average annual meteorological conditions and commences 8 hours after initiation of the event. The SGTS efficiency for iodine is 99% for organic forms and 99.9% for other forms. Reference 15.2-2 contains a description of the containment purge release model used. The integrated release to the environment is presented in Table 15.2-11.

15.2.4.5.3 Radiological Exposures

The offsite radiological doses for this event are presented in Table 15.2-12. COL applicants need to update the calculations to conform to the as-designed plant and site specific parameters (see Subsection 15.2.10.3 for COL license information requirements). It should be noted that the radiological doses in the table are exposures per event. For the isolation transient, this event is not expected to occur more than 2.5 times per year; therefore, it is conservative to assume the yearly commitments for these transients will be ~2.5 times the individual values.

15.2.5 Loss of Condenser Vacuum

15.2.5.1 Identification of Causes and Frequency Classification

15.2.5.1.1 Identification of Causes

Various system malfunctions which can cause a loss of condenser vacuum due to some single equipment failure are designated in Table 15.2-13.

15.2.5.1.2 Frequency Classification

Although the frequency of occurrence of this event is expected to be infrequent, this event is categorized as an incident of moderate frequency.

15.2.5.2 Sequence of Events and Systems Operation

15.2.5.2.1 Sequence of Events

Table 15.2-14 lists the sequence of events for Figure 15.2-10.

15.2.5.2.1.1 Identification of Operator Actions

The operator should:

(1) Verify auto transfer of buses supplied by generator to incoming power—if automatic transfer has not occurred, manual transfer must be made

(2) Monitor and maintain reactor water level at required level

(3) Check turbine for proper operation of all auxiliaries during coastdown

(4) Depending on conditions, initiate normal operating procedures for cooldown, or maintain pressure for restart purposes

(5) Put the mode switch in the STARTUP position before the reactor pressure decays to <5.86 MPaG

(6) Secure the RCIC operation if the auto-initiation occurred due to low water level

(7) Monitor control rod drive positions and the SRNM

(8) Investigate the cause of the trip, make repairs as necessary, and complete the scram report

(9) Cooldown the reactor per standard procedure if a restart is not intended

15.2.5.2.2 Systems Operation

In establishing the expected sequence of events and simulating the plant performance, it was assumed that normal functioning occurred in the plant instrumentation and controls, plant protection and reactor protection systems.

Tripping functions incurred by sensing main turbine condenser vacuum are presented in Table 15.2-15.

15.2.5.3 Core and System Performance

15.2.5.3.1 Input Parameters and Initial Conditions

Turbine stop valves full stroke closure time is 0.1 seconds.

A reactor scram is initiated by position switches on the stop valves when the valves are less than 85% open. This stop valve scram trip signal is automatically bypassed when the reactor is below 40% NBR power level.

The analysis presented here is a hypothetical case with a conservative 6.79 kPa/s vacuum decay rate. Thus, the bypass system is available for several seconds, because the bypass is signaled to close at a vacuum level of about 44 kPa less than the stop valve closure.

15.2.5.3.2 Results

Under this hypothetical 6.79 kPa/s vacuum decay condition, the turbine bypass valves and MSIV closure would follow main turbine trip about 6 seconds after it initiates the transient. This transient, therefore, is similar to a normal turbine trip with bypass. The effect of MSIV closure tends to be minimal, because the closure of main turbine stop valves, and subsequently the bypass valves, has already shut off the main steamline flow. Figure 15.2-10 shows the transient expected for this event. It is assumed that the plant is initially operating at 102% of NBR power and 90% core flow conditions. Peak neutron flux reaches 115% of NBR power, while average fuel surface heat flux shows no increase. SRVs open to limit the pressure rise, then sequentially reclose as the stored energy is dissipated. This transient is less severe than the generator load rejection with failure of bypass transient presented in Subsection 15.2.2.3.2.3 or the turbine trip with failure of bypass presented in Subsection 15.2.3.3.2.3. Therefore, this event does not have to be reanalyzed for specific core configurations.

15.2.5.4 Barrier Performance

Peak nuclear system pressure is 8.16 MPaG at the vessel bottom. The overpressure transient is below the RCPB transient pressure limit of 9.48 MPaG. Vessel dome pressure does not exceed 8.03 MPaG. A comparison of these values to those for turbine trip at high power shows the similarities between these two transients. The prime difference is the subsequent main steamline isolation.

15.2.5.5 Radiological Consequences

While the consequences of the events identified previously do not result in any fuel failures, radioactivity is nevertheless discharged to the suppression pool as a result of SRV actuation. However, the mass input, and hence activity input, for this event is much less than those consequences identified in Subsection 15.2.4.5; therefore, the radiological exposures noted in Subsection 15.2.4.5 for Type 2 events cover the consequences of this event.

15.2.6 Loss of Non-Emergency AC Power to Station Auxiliaries

15.2.6.1 Identification of Causes and Frequency Classification

15.2.6.1.1 Identification of Causes

The non-emergency AC power to the station auxiliaries is provided by three unit auxiliary transformers. The unit auxiliary transformers are powered by the unit turbine/generator via a medium voltage generator breaker. Two of the unit auxiliary transformers (UAT) provide power to two electrical buses which provide power to the unit's auxiliary loads, including the reactor internal pumps (RIPs), as follows: UAT-A and UAT-B each provide power to a RIP MG set with 3 RIPs and both UATs have a separate bus providing power to 2 RIPs directly (i.e. no MG set). Following a generator trip and during plant startup, the medium voltage generator breaker is open but the high voltage breaker at the switchyard remains closed to backfeed power from the normal preferred power grid to the unit auxiliary transformers.

15.2.6.1.1.1 Loss of Unit Auxiliary Transformer

Causes for interruption or loss of power from the unit auxiliary transformers can arise from transformer (main or unit auxiliary) malfunction or isolated phase bus failures.

A loss of a unit auxiliary or main transformer is assumed to result in a generator trip and the opening of the generator and high voltage breakers. The generator trip will cause a reactor scram and an immediate trip of four RIPs not connected to M/G sets immediately. The opening of generator and high voltage breakers will result in a loss of power to all unit auxiliary transformers. However, the remaining six RIPs are powered by M/G sets. The M/G sets are capable of holding the RIPs at their original speeds for one second, then the RIPs will coastdown at a speed of 10%/s for two seconds, and trip at three seconds after the start of the event.

15.2.6.1.1.2 Loss of Grid Connections

Loss of grid connection can result from major shifts in electrical loads, loss of loads, lightning, storms, wind, etc., which contribute to electrical grid instabilities. These instabilities could cause equipment damage if unchecked. Protective relay schemes automatically disconnect electrical sources and loads to mitigate damage and regain electrical grid stability.

Should this occur, it would result in the same sequence of events as described above in Subsection 15.2.6.1.1.1.

15.2.6.1.2 Frequency Classification

15.2.6.1.2.1 Loss of Unit Auxiliary Transformer

Although the frequency of this event is low enough to be an infrequent event, this transient disturbance is analyzed as an incident of moderate frequency.

15.2.6.1.2.2 Loss of Grid Connections

Although the frequency of this event is low enough to be an infrequent event, this transient disturbance is analyzed as an incident of moderate frequency.

15.2.6.2 Sequence of Events and Systems Operation

15.2.6.2.1 Sequence of Events

15.2.6.2.1.1 Loss of Unit Auxiliary Power Transformer

Table 15.2-16 lists the sequence of events for Figure 15.2-11.

15.2.6.2.1.2 Loss of Grid Connections

This event is similar to a loss of unit auxiliary transformer as discussed in Subsection 15.2.6.2.1.1.

15.2.6.2.1.3 Identification of Operator Actions

The operator should (1) maintain the reactor water level by use of the RCIC System and control reactor pressure by use of the safety/relief valves, (2) verify that the turbine DC oil pump is operating satisfactorily to prevent turbine bearing damage, and (3) verify proper switching and loading of the emergency diesel generators.

The following is the sequence of operator actions expected during the course of the events when no immediate restart is assumed. The operator should:

(1) Verify all rods are in

(2) Check that diesel generators start and carry the vital loads

(3) Check that the RCIC System starts when reactor vessel level drops to the initiation point after the relief valves open

(4) Break vacuum before the loss of sealing steam occurs

(5) Check T-G auxiliaries during coastdown

(6) Secure the RCIC System when both reactor pressure and level are under control

(7) Continue cooldown per the normal procedure

(8) Complete the scram report and survey the maintenance requirements

15.2.6.2.2 Systems Operation

15.2.6.2.2.1 Loss of Unit Auxiliary Transformer

This event, unless otherwise stated, assumes and takes credit for normal functioning of plant instrumentation and controls, plant protection and reactor protection systems.

The reactor is subjected to a complex sequence of events when the plant loses all auxiliary power. Estimates of the responses of the various reactor systems (assuming loss of the unit auxiliary transformer) provide the following simulation sequence:

(1) A generator trip occurs at time = 0, which initiates a scram and trip of four RIPs (already tripped at time = 0, see (2) below).

(2) All electrical pumps, including feedwater pumps, including 4 RIPs not connected to the M/G sets, are tripped at a reference time, t = 0, with normal coastdown times for the reactor internal pumps.

(3) The remaining six RIPs powered by M/G sets are capable of maintaining their original speeds for one second, then coast down at a speed of 10%/s for two seconds, and trip at three seconds after the start of the event.

(4) The loss of the main condenser circulating water pumps, occurs at the same time normal power is lost to the system (t=0) which is conservatively assumed to cause the condenser vacuum to drop to the main turbine trip setting, within 8 seconds causing stop valve closure, assuming 1.69 kPa/s vacuum decay rate.

(5) At approximately 28 seconds, the loss of condenser vacuum is expected to reach the MSIV and bypass valves closure setpoint and initiate steamline isolation.

Operation of the RCIC System function is not simulated in this analysis as its operation occurs at some time beyond the primary concerns of fuel thermal margin and overpressure effects of this analysis.

15.2.6.2.2.2 Loss of Grid Connections

Same as Subsection 15.2.6.2.2.1.

15.2.6.3 Core and System Performance

15.2.6.3.1 Loss of Unit Auxiliary Power Transformer

Figure 15.2-11 shows graphically the simulated transient. The initial portion of the transient is similar to the load rejection transient.

Sensed level drops to the RCIC initiation setpoint at approximately 13 seconds after loss of auxiliary power.

MCPR has a short-term (1 second) reduction below its initial value due to core flow. However, it is not as severe as for the case where all bypass valves are assumed to fail (Subsection 15.2.2.3.2.3). Fuel thermal margins are not threatened and the design basis is satisfied. Therefore, this event does not have to be reanalyzed for specific core configurations.

15.2.6.3.2 Loss of Grid Connections

Same as Subsection 15.2.6.3.1. This event does not have to be reanalyzed for specific core configurations.

15.2.6.4 Barrier Performance

15.2.6.4.1 Loss of Unit Auxiliary Transformer

The consequences of this event do not result in any significant temperature or pressure transient in excess of the criteria for which the fuel, pressure vessel or containment are designed; therefore, these barriers maintain their integrity and function as designed.

Safety/relief valves open in the pressure relief mode of operation as the pressure increases beyond their setpoints. The pressure at the bottom of the vessel is limited to a maximum value of 8.12 MPaG, which is below the vessel pressure limit of 9.48 MPaG.

15.2.6.4.2 Loss of Grid Connections

Same as Subsection 15.2.6.4.1.

15.2.6.5 Radiological Consequences

While the consequences of the events identified previously do not result in any fuel failures, radioactivity is nevertheless discharged to the suppression pool as a result of SRV actuation. However, the mass input, and hence activity input, for this event is much less than those consequences identified in Subsection 15.2.4.5; therefore, the radiological exposures noted in Subsection 15.2.4.5 for Type 2 events cover the consequences of this event.

15.2.7 Loss of Feedwater Flow

15.2.7.1 Identification of Causes and Frequency Classification

15.2.7.1.1 Identification of Causes

A loss of feedwater flow could occur from pump failures, loss of electrical power, operator errors, or reactor system variables such as a high vessel water level (L8) trip signal.

15.2.7.1.2 Frequency Classification

This transient disturbance is categorized as an incident of moderate frequency.

15.2.7.2 Sequence of Events and Systems Operation

15.2.7.2.1 Sequence of Events

Table 15.2-17 lists the sequence of events for Figure 15.2-12.

15.2.7.2.1.1 Identification of Operator Actions

The operator should ensure RCIC actuation so that water inventory is maintained in the reactor vessel. Additionally, the operator should monitor reactor water level and pressure control and T-G auxiliaries during shutdown.

The following is the sequence of operator actions expected during the course of the event when no immediate restart is assumed. The operator should:

(1) Verify all rods in, following the scram

(2) Verify trip of four RIPs

(3) Verify RCIC initiation

(4) Verify that the remaining recirculation pumps trip on reactor low level (L2)

(5) Continue operation of the RCIC System until decay heat diminishes to a point where the RHR System can be put into service

(6) Monitor turbine coastdown, break vacuum as necessary

(7) Complete scram report and survey maintenance requirements

15.2.7.2.2 Systems Operation

Loss of feedwater flow results in a reduction of vessel inventory, causing the vessel water level to drop. The first corrective action is the low level (L3) scram trip actuation. The Reactor Protection System responds within one second after this trip to scram the reactor. The low level

(L3) scram trip function meets the single-failure criterion. Four of the RIPs are tripped at Level 3.

15.2.7.3 Core and System Performance

The results of this transient simulation are presented in Figure 15.2-12. Feedwater flow terminates at approximately 5 seconds from the trip of the feedwater pumps. Subcooling decreases, causing a reduction in core power level and pressure. As power level is lowered, the turbine steam flow starts to drop off because the pressure regulator is attempting to maintain pressure for the first 10 seconds. Water level continues to drop until, first, the recirculation flow is runback at Level 4 (L4) and then the vessel level (L3) scram trip setpoint is reached, whereupon the reactor is shut down and the four RIPs are tripped. Vessel water level continues to drop to the L2 trip. At this time, the remaining six RIPs are tripped and the RCIC operation is initiated. MCPR remains considerably above the safety limit, because increases in heat flux are not experienced. Therefore, this event does not have to be reanalyzed for specific core configurations.

15.2.7.4 Barrier Performance

The consequences of this event do not result in any temperature or pressure transient in excess of the criteria for which the fuel, pressure vessel or containment are designed; therefore, these barriers maintain their integrity and function as designed.

15.2.7.5 Radiological Consequences

The consequences of this event do not result in any fuel failure or lifting of SRVs. Therefore, no analysis of the radiological consequences is required.

15.2.8 Feedwater Line Break

Refer to Subsection 15.6.6.

15.2.9 Failure of RHR Shutdown Cooling

The RHR System performs low pressure core cooling, containment heat removal, containment spray and shutdown cooling functions. The RHR System has three independent divisions, each of which contains the necessary piping, pumps, valves, heat exchangers, instrumentation and electrical power for operation. Each division also has its own cooling water supply, diesel generator and room cooling system. For the shutdown cooling function, each division has its own suction line from and return line to the RPV. Thus, each of the three RHR divisions is completely independent of the other divisions in its shutdown cooling function. The RHR System reduces the primary system temperature to 60°C within 24 hours of plant shutdown.

Normally, in evaluating component failure considerations associated with RHR System shutdown cooling mode operation, active pumps, valves or instrumentation would be assumed to fail. If the single active failure criterion is applied to the RHR System, one of the three RHR

divisions would be inoperable. However, the two operable RHR divisions could achieve cold shutdown to 100°C within 36 hours after reactor shutdown.

Failure of offsite power is another case which could affect the shutdown cooling function. The plant will have two independent offsite power supplies. If either or both offsite power supplies are lost, each RHR division has its own diesel generator which will permit operating that division at its rated capacity. Application of the single active failure criterion would still leave two RHR divisions operational.

The RHR System description and performance evaluation in Subsection 5.4.7 describes the models, assumptions and results for shutdown cooling with two RHR divisions operational.

15.2.10 COL License Information

15.2.10.1 Effects of Inadvertent Closure of One Turbine Control Valve

The applicant shall analyze the inadvertent closure of one turbine control valve for the specific core configuration (Subsection 15.2.1.3.1).

15.2.10.2 Effects of Generator Load Rejection with Failure of All Bypass Valves

The applicant shall analyze the generator load rejection with failure of all bypass valves for the specific core configuration (Subsection 15.2.2.3.2.3).

15.2.10.3 Radiological Effects of MSIV Closures

COL applicants will evaluate the radiological effects of the inadvertent closure of MSIVs for the final plant design and the site parameters (Subsection 15.2.4.5.3).

15.2.11 References

15.2-1 F. G. Brutshscy, et al., “Behavior of Iodine in Reactor Water During Plant Shutdown and Startup”, August 1972 (NEDO-10585).

15.2-2 H. Careway, V. Nguyen, and P. Stancavage, “Radiological Accident—The CONAC03 CODE”, December 1981 (NEDO-21143-1).

Table 15.2-1A Sequence of Events for Figure 15.2-1A (Fast Closure of One Turbine Control Valve)

Time (s)	Event
0.00	Simulation starts
1.01	Fast closure of one TCV is initiated
3.53	TBV opening
3.58	TCVs fully closed
4.09	Max neutron flux
5.32	Max steam dome pressure
~30	The reactor settles at a new steady state

Table 15.2-1B Sequence of Events for Figure 15.2-1B (Slow Closure of One Turbine Control Valve)

TIme (s)	Event
0.00	Simulation starts
1.01	Slow closure of one TCV is initiated
10.3	Opening of TBVs
21.5	TCVs fully closed
~40	The Reactor settles at a new steady state.

Table 15.2-2 Sequence of Events for Figure 15.2-2

Time (s)	Event
0.00	Simulation starts
1.00	TCV closure initiated
2.50	Reactor scram initiated by high neutron flux
2.74	Control rods start to move
2.75	Max neutron flux
3.39	Opening of SRVs according to their pressure setpoints
3.83	RPT of 4 RIPs initiated by high pressure
3.57	TCVs fully closed
4.37	Max steam dome pressure
6.27	Control rods fully inserted
13.83	RPT of remaining 6 RIPs by low level L2. RCIC is started
~44	RCIC flow into vessel (not included in simulation)

Table 15.2-3 Sequence of Events for Figure 15.2-3 (Generator Load Rejection with Bypass)

Time (s)	Event
0.00	Simulation starts
1.00	Load rejection
1.00	TCV fast closure is initiated
1.02	Reactor scram is initiated by TCV fast closure
1.08	TCVs are closed
1.12	TBV opening
1.16	RPT of 4 RIPs initiated by TCV closure
1.29	Control rods start to move
1.44	Max neutron flux
2.78	Opening of SRVs according to their setpoints
3.66	Max steam dome pressure
4.82	Control rods fully inserted

Table 15.2-4 Sequence of Events for Figure 15.2-4 (Load Rejection with One Bypass Valve Failure)

Time (s)	Event
0.00	Simulation starts
1.00	Load rejection
1.00	TCV fast closure is initiated
1.02	Reactor scram is initiated by TCV fast closure
1.08	TCVs are closed
1.12	TBV opening
1.16	RPT of 4 RIPs initiated by TCV closure
1.29	Control rods start to move
1.44	Max neutron flux
2.46	Opening of SRVs at their pressure setpoints
3.41	Max steam dome pressure
4.82	Control rods fully inserted

Table 15.2-5 Sequence of Events for Figure 15.2-5 (Load Rejection with All Bypass Valves Failure)

TIme (s)	Event
0.00	Simulation starts
1.00	Load rejection
1.00	TCV fast closure is initiated
1.02	Reactor scram is initiated by TCV fast closure
1.08	TCVs are closed
1.16	RPT of 4 RIPs initiated by TCV closure
1.28	Control rods start to move
1.47	Max Neutron flux
2.14	Opening of SRVs according to their pressure setpoints
2.98	Max steam dome pressure
4.81	Control rods fully inserted
11.23	RPT of remaining 6 RIPs by low level L2. RCIC is started
>40	RCIC flow into vessel (not included in simulation)

Table 15.2-6 Sequence of Events for Figure 15.2-6 (Turbine Trip with Bypass)

Time (s)	Event
0.00	Simulation starts
1.00	Turbine trip initiated
1.00	TSV closure initiated
1.03	Reactor scram is initiated by TSV position
1.10	TSVs are closed
1.10	TBV opening
1.16	RPT of 4 RIPs initiated by TSV closure
1.27	Control rods start to move
1.43	Max neutron flux
2.84	Opening of SRVs according to their setpoints
3.73	Max steam dome pressure
4.80	Control rods fully inserted

Table 15.2-7 Sequence of Events for Figure 15.2-7 (Turbine Trip with One Bypass Valve Failure)

Time (s)	Event
0.00	Simulation starts
1.00	Turbine trip initiated
1.00	TSV closure initiated
1.03	Reactor scram is initiated by TSV position
1.10	TSVs are closed
1.10	TBV opening
1.16	RPT of 4 RIPs initiated by TSV closure
1.27	Control rods start to move
1.44	Max neutron flux
2.50	Opening of SRVs at their pressure setpoints
3.45	Max steam dome pressure
4.80	Control rods fully inserted

Table 15.2-8 Sequence of Events for Figure 15.2-8 (Turbine Trip with All Bypass Valves Failure)

Time (s)	Event
0.00	Simulation starts
1.00	Turbine trip initiated
1.00	TSV closure initiated
1.03	Reactor scram is initiated by TSV closure
1.10	TSVs are closed
1.16	RPT of 4 RIPs initiated by TSV closure
1.27	Control rods start to move
1.53	Max neutron flux
2.16	Opening of SRVs according to their pressure setpoints
3.00	Max steam dome pressure
4.80	Control rods fully inserted
11.21	RPT of remaining 6 RIPs by low level L2. RCIC is started
>40	RCIC flow into vessel (not included in simulation)

Table 15.2-9 Sequence of Events for Figure 15.2-9(MSIV Closure Direct Scram)

Time (s)	Event
0.00	Simulation starts
1.00	Inadvertent MSIV closure is initiated
1.46	Reactor scram initiated by MSIV closure
1.46	Feedwater pump runback initiated by scram signal
1.71	Control rods start to move
3.00	Feedwater pump trip initiated 2 sec after the MSIV closure
3.47	SRV opening
3.72	RPT of 4 RIPs by low level L3
4.00	MSIVs are fully closed
4.38	Max steam dome pressure
5.24	Control rods fully inserted
11.08	RPT of remaining 6 RIPs by low level L2. RCIC is started
>40	RCIC flow into vessel (not included in simulation).

Table 15.2-10 Post-Transient Primary Containment Inventory (Air Plus Water) (megabecqueral)

Isotope	1 Min	10 Min	1 Hour	2 Hour	4 Hour	8 Hour*	12 Hour	1 Day	4 Days	30 Days
I-131	1.1E+07	1.E+07	1.1E+07	1.0E+07	8.5E+06	6.3E+06	4.8E+06	1.9E+06	9.3E+03	
I-132	1.7E+07	1.6E+07	1.1E+07	8.1E+06	3.7E+06	8.5E+05	1.9E+05	2.2E+03	4.8E+09	
I-133	2.4E+07	2.3E+07	2.1E+07	1.9E+07	1.6E+07	1.0E+07	7.0E+06	2.0E+06	1.1E+03	
I-134	2.6E+07	2.3E+07	1.1E+07	4.8E+06	8.5E+05	2.7E+04	8.5E+02	2.7E+02		
I-135	2.3E+07	2.2E+07	1.9E+07	1.6E+07	1.1E+07	5.6E+06	2.8E+06	3.3E+05	1.0E+00	
Totals	1.0E+08	9.5E+07	7.4E+07	5.8E+07	4.0E+07	2.3E+07	1.5E+07	4.3E+06	1.0E+04	
KR-83M	7.4E+06	7.0W+06	7.0E+06	5.2E+06	3.6E+06	1.7E+06	3.7E+05	4.4E+04	7.8E+01	
KR-85M	1.6E+07	1.6E+07	1.4E+07	1.2E+07	8.9E+06	4.8E+06	1.4E+06	3.6E+04	1.0E+05	
KR-85	7.4E+05	7.4E+05	7.4E+05	7.4E+05	7.4E+05	7.4E+05	4.1E+05	6.7E+04	1.3E+00	
KR-87	3.1E+07	2.8E+07	1.8E+07	1.0E+07	3.5E+06	4.1E+05	2.5E+04	5.9E+00		
KR-88	4.4E+07	4.4E+07	3.5E+07	2.7E+07	1.7E+07	6.3E+06	1.3E+06	1.1E+04	5.2E-09	
KR-89	4.4E+07	6.3E+06	1.1E+02	2.2E-04						
XE131M	3.7E+05	3.7E+05	3.7E+05	3.7E+05	3.7E+05	3.7E+05	2.0E+05	3.3E+04	5.6E-01	
XE133M	5.6E+06	5.6E+06	5.6E+06	5.6E+06	5.2E+06	5.2E+06	2.6E+06	3.7E+05	2.8E+00	
XE-133	1.3E+08	1.3E+08	1.3E+08	1.3E+08	1.3E+08	1.3E+08	6.7E+07	1.1E+07	1.4E+02	
XE135M	2.4E+07	1.6E+07	1.8E+06	1.2E+05	5.9E+02	1.5E-02	2.0E-07			
XE-135	1.7E+07	1.7E+07	1.6E+07	1.5E+07	1.4E+07	9.3E+06	3.7E+06	2.5E+05	2.0E-02	
XE-137	1.0E+08	1.9E+07	2.3E+03	4.4E-02	1.6E+11					
XE-138	1.1E+08	6.7E+07	5.9E+06	3.1E+05	8.9E+02	7.0E-03	3.1E-08			
Totals	5.3E+08	3.6E+08	2.4E+08	2.1E+08	1.8E+08	1.6E+08	7.6E+07	1.1E+07	1.5E+02	

* Beginning of Containment Purge

Table 15.2-11 Activity Released to the Environment (megabecqueral)

Isotope	12 Hours	1 Day	4 Days	30 Days
I-131	1.0E+02	2.4E+02	3.2E+02	3.2E+02
I-132	8.5E+00	1.1E+01	1.1E+01	1.1E+01
I-133	1.6E+02	3.4E+02	4.1E+02	4.1E+02
I-134	1.5E-01	1.5E-01	1.5E-01	1.5E-01
I-135	7.8E+01	1.3E+02	1.4E+02	1.4E+02
TOTALS	3.5E+02	7.2E+02	8.7E+02	8.7E+02
KR-83M	9.3E+04	1.0E+05	1.0E+05	1.0E+05
KR-85M	1.6E+06	2.3E+06	2.3E+06	2.3E+06
KR-85	3.3E+05	6.7E+05	7.4E+05	7.4E+05
KR-87	8.1E+04	8.5E+04	8.5E+04	8.5E+04
KR-88	1.9E+06	2.4E+06	2.4E+06	2.4E+06
KR-89	Insignificant			
XE131M	1.7E+05	3.4E+05	3.7E+05	3.7E+05
XE133M	2.2E+06	4.4E+06	4.4E+06	4.4E+06
XE-133	5.9E+07	1.1E+08	1.2E+08	1.2E+08
XE135M	7.8E-04	7.8E-04	7.8E-04	7.8E-04
XE-135	3.7E+06	5.9E+06	6.3E+06	6.3E+06
XE-137	Insignificant			
XE-138	3.4E-04	3.4E-04	3.4E-04	3.4E-04
TOTALS	6.9E+07	1.3E+08	1.4E+08	1.4E+08

Table 15.2-12 Dose Evaluation and Meteorology

Dispersion sec/m^3	Thyroid mGy	W Body mGy	Beta mGy	Skin mGy
1.0E-5	3.0E-4	8.5E-3	1.3E-2	2.2E-2
5.0E-6	1.5E-4	4.3E-3	6.6E-3	1.1E-2
1.0E-6	3.0E-5	8.5E-4	1.3E-3	2.2E-3
5.0E-7	1.5E-5	4.3E-4	6.6E-4	1.1E-3
1.0E-7	3.0E-6	8.5E-5	1.3E-4	2.2E-4

Table 15.2-13 Typical Rates of Decay for Condenser Vacuum

	Cause	Estimated Vacuum Decay Rate
(1)	Failure of Isolation of Steam Jet Air Ejectors	<3.32 kPa/min
(2)	Loss of Sealing Steam to Shaft Gland Seals	Approximately 3.32 to 6.79 kPa/min
(3)	Opening of Vacuum Breaker Valves	Approximately 6.79 to 40.66 kPa/min
(4)	Loss of One or More Circulating Water Pumps	Approximately 13.56 to 81.10 kPa/min

Table 15.2-14 Sequence of Events for Figure 15.2-10 (Loss of Condenser Vacuum)

Time (s)	Event
~ –2.5	Simulation starts
1.00	Condenser vacuum has decreased to the turbine trip setpoint
1.00	Turbine trip is initiated
1.00	TSVs start to close
1.03	Reactor scram on TSV position
1.16	RPT of 4 RIPs activated by TSV closure
1.27	Control rods start to move
1.43	Max neutron flux
2.84	SRV opening at their pressure setpoints
3.73	Max steam dome pressure
4.80	Control rods fully inserted
7.48	MSIVs and BPVs start to close due to low condenser vacuum
10.68	RPT of remaining 6 RIPs by low level L2. RCIC is started
>40.0	RCIC flow into vessel (not included in simulation).

Table 15.2-15 Trip Signals Associated with Loss of Condenser Vacuum

Vacuum (cm of Hg)	Protective Action Initiated
69 to 71	Normal Vacuum Range
51 to 58	Main Turbine Trip (Stop Valve Closures)
18 to 25	Mainsteam Line Isolation Valve (MSIV) Closure and Bypass Valve Closure

Table 15.2-16 Sequence of Events for Figure 15.2-11 (Loss of AC Power)

Time (s)	Event
0.00	Simulation starts
1.00	Loss of AC power
1.00	TCV closure initiated
1.00	Trip of all RIP initiated, 6 RIPs powered by M/G-sets
1.00	Feedwater pump trip initiated due to loss of AC to pumps
1.03	Reactor scram initiated by TCV fast closure
1.27	Control rods start to move
2.91	Opening of SRVs at their pressure setpoints
3.86	Max steam dome pressure
4.80	Control rods fully inserted
13.8	Vessel water level reaches Level 2. RCIC is started
~44	RCIC flow enters vessel (not simulated).

Table 15.2-17 Sequence of Events for Figure 15.2-12 (Loss of All Feedwater Flow)

Time (s)	Event
0.00	Simulation starts
1.00	Feedwater pump trip is initiated
5.25	Max neutron flux
10.1	Reactor scram initiated by low level L3
10.3	RPT of 4 RIPs initiated by low level L3
10.4	Control rods start to move
13.9	Control rods fully inserted
18.7	RPT of remaining 6 RIPs by low level L2. RCIC is started
~49 sec	RCIC flow enters vessel (not included in simulation)

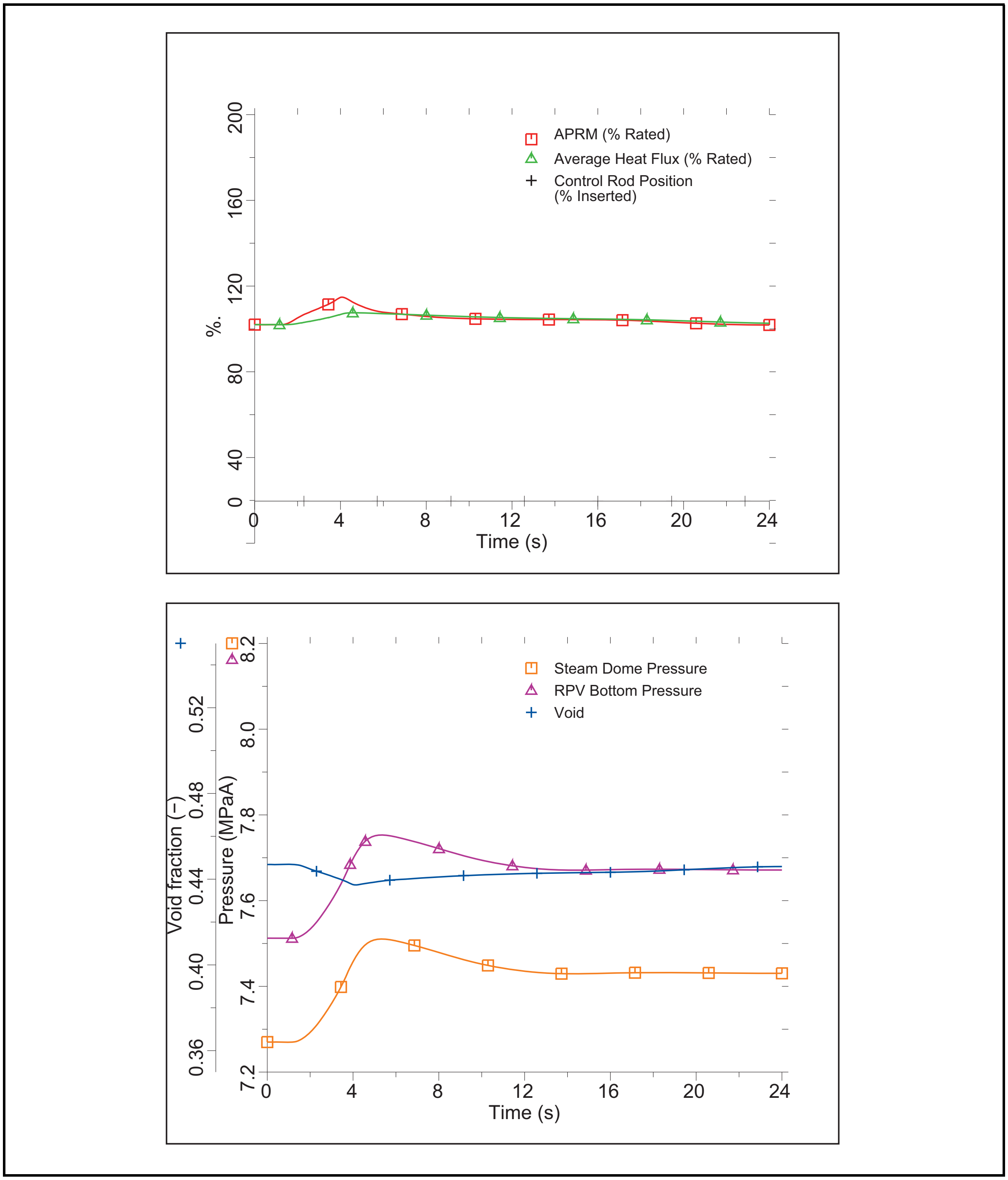


Figure 15.2-1Aa Fast Closure of One Turbine Control Valve

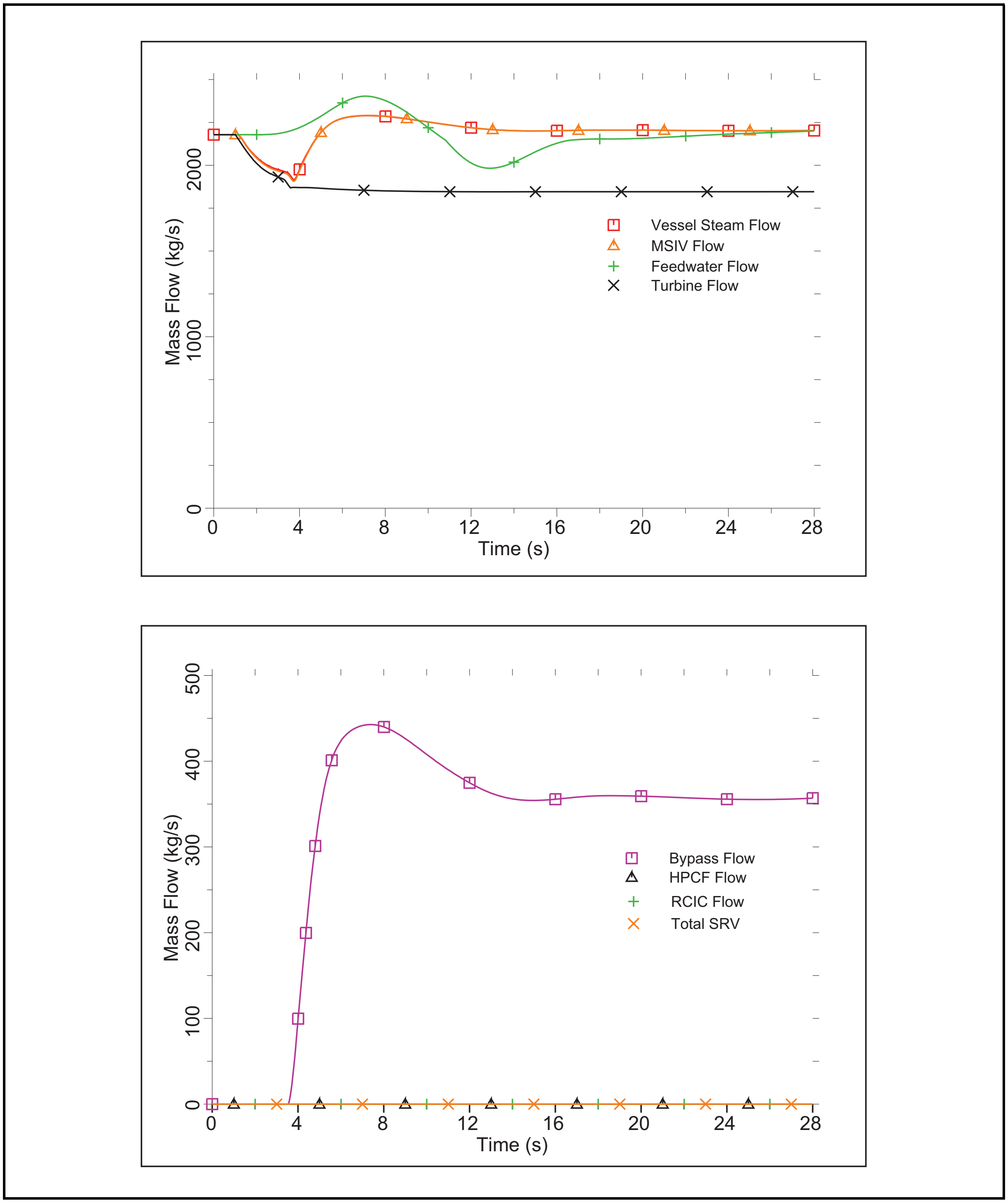


Figure 15.2-1Ab Fast Closure of One Turbine Control Valve

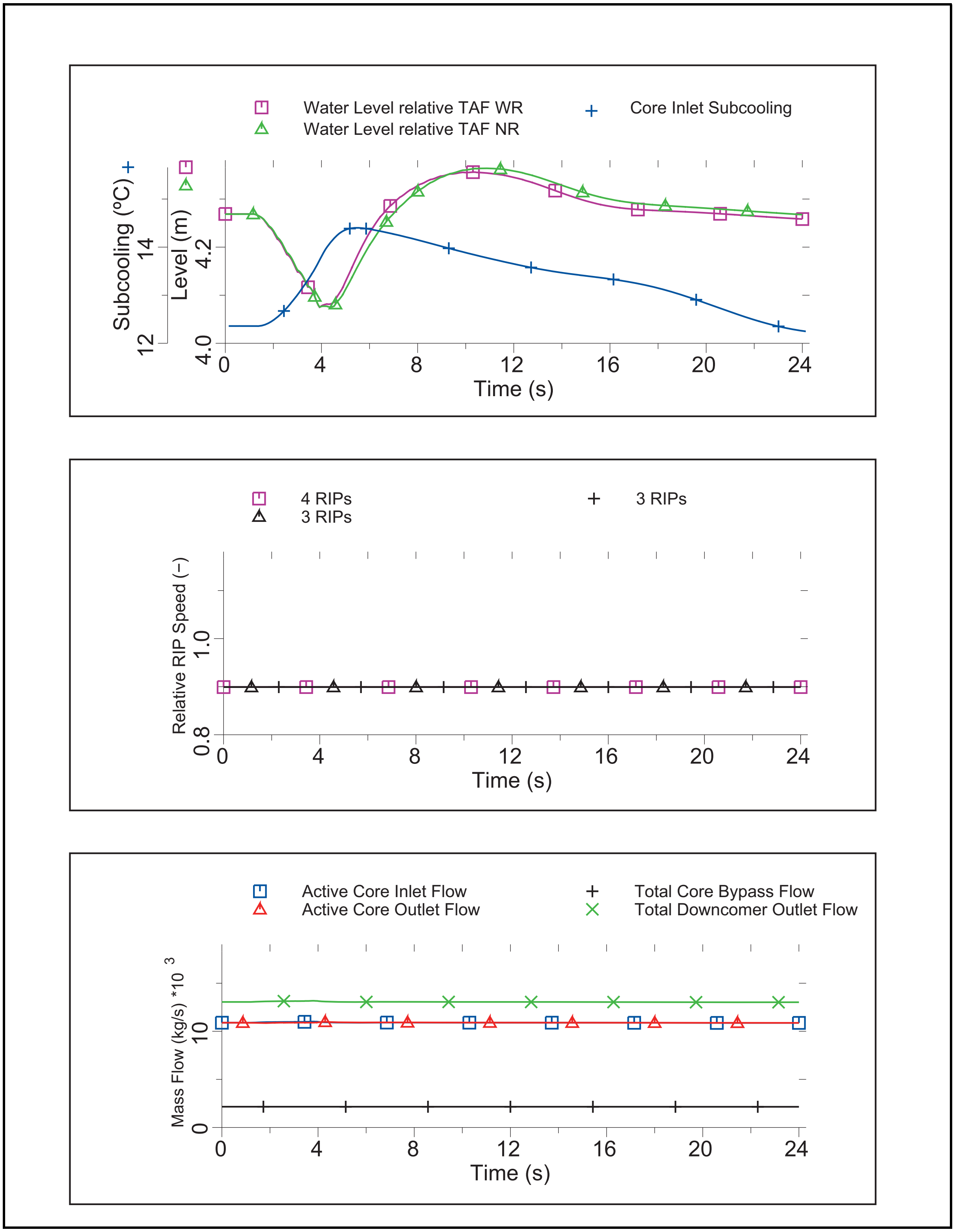


Figure 15.2-1Ac Fast Closure of One Turbine Control Valve

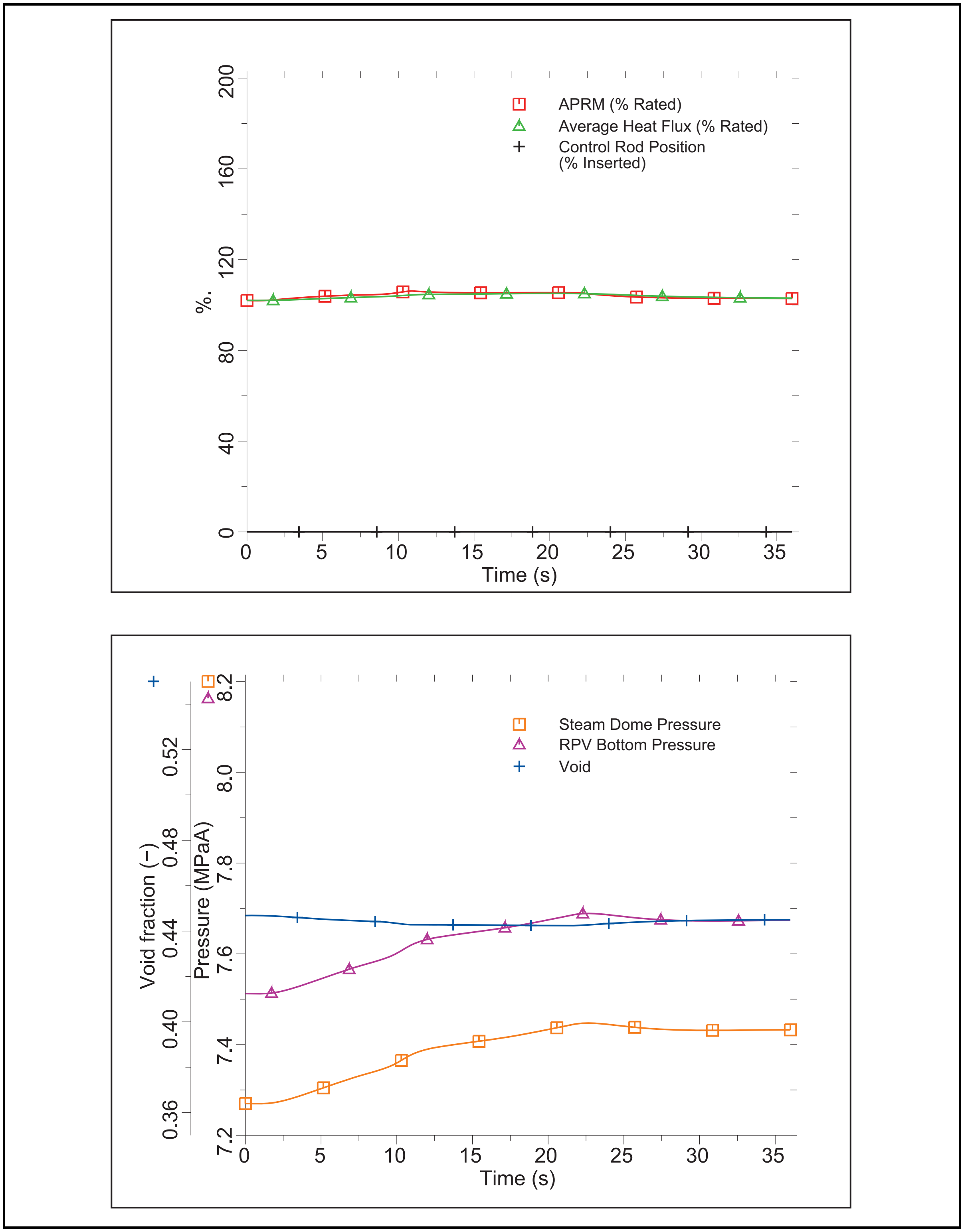


Figure 15.2-1Ba Slow Closure of One Turbine Control Valve

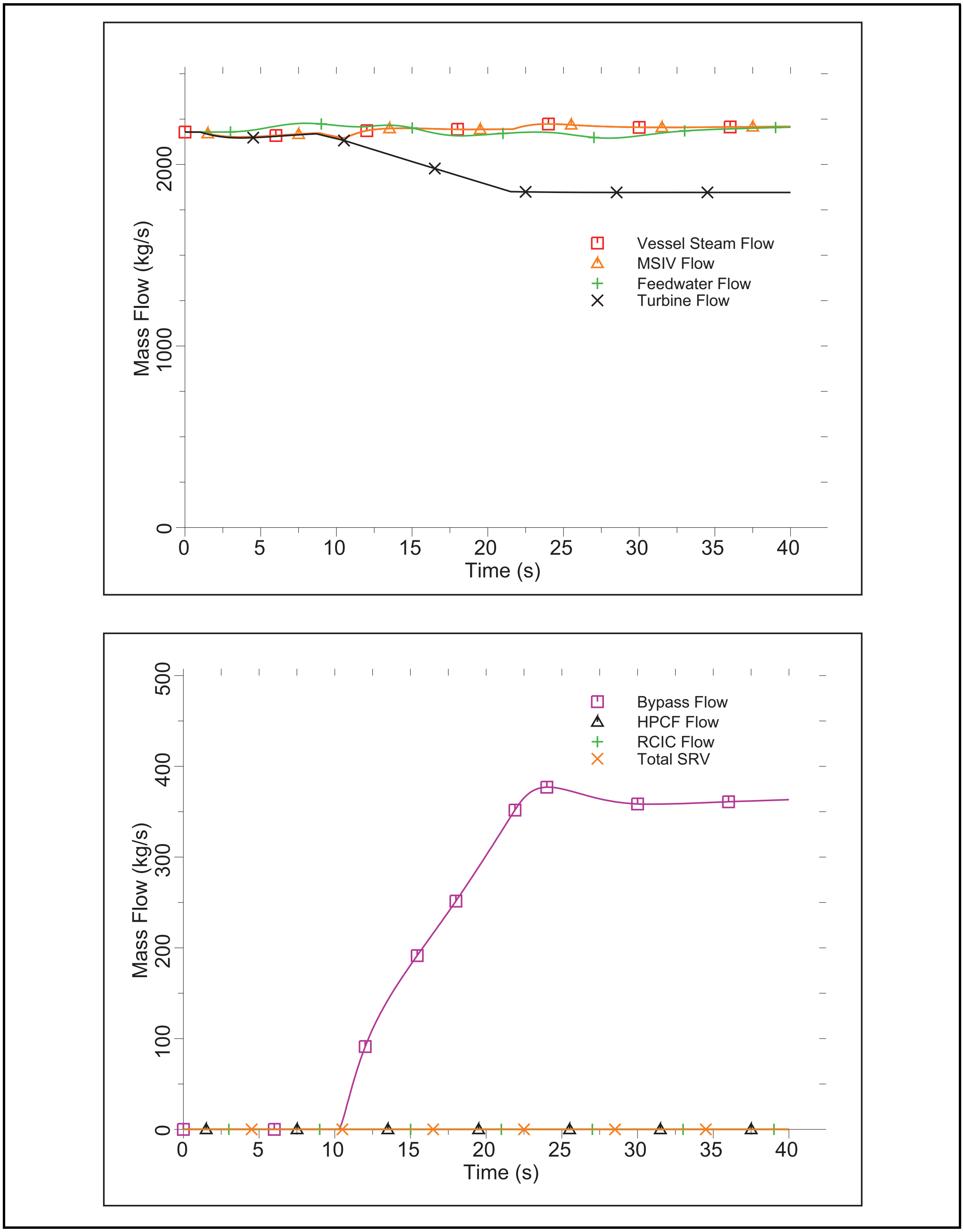


Figure 15.2-1Bb Slow Closure of One Turbine Control Valve

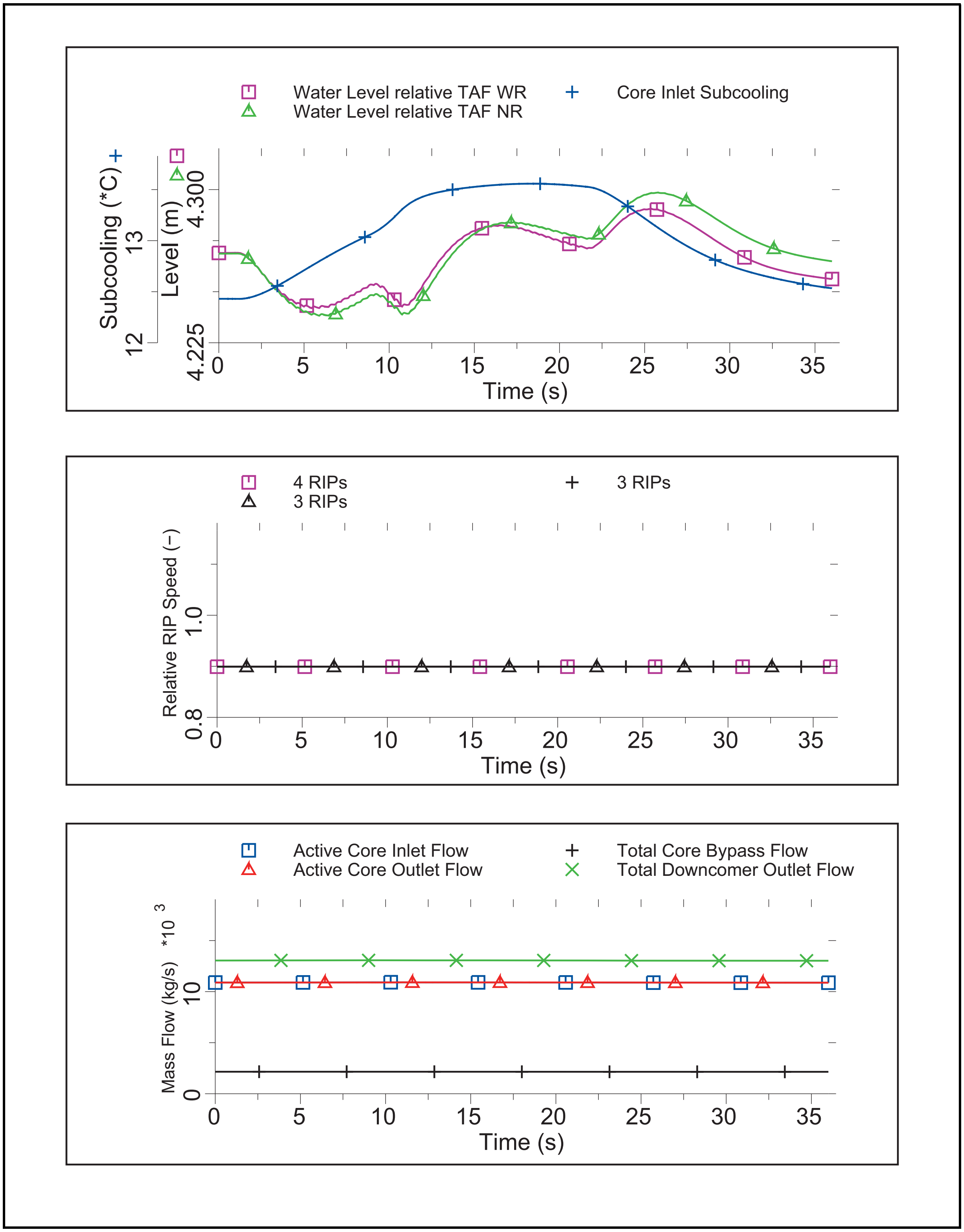


Figure 15.2-1Bc Slow Closure of One Turbine Control Valve

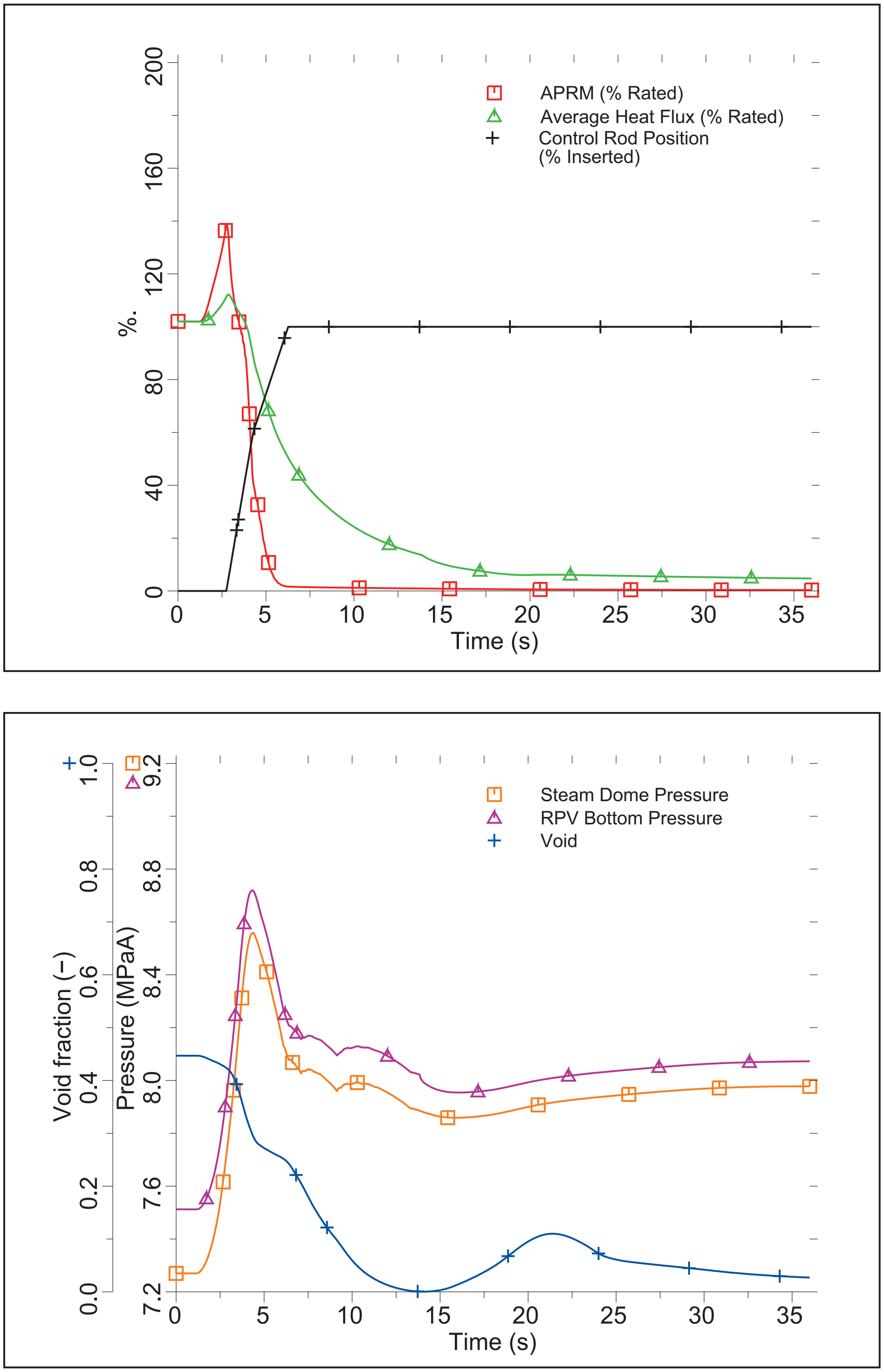


Figure 15.2-2a Pressure Regulator Downscale Failure

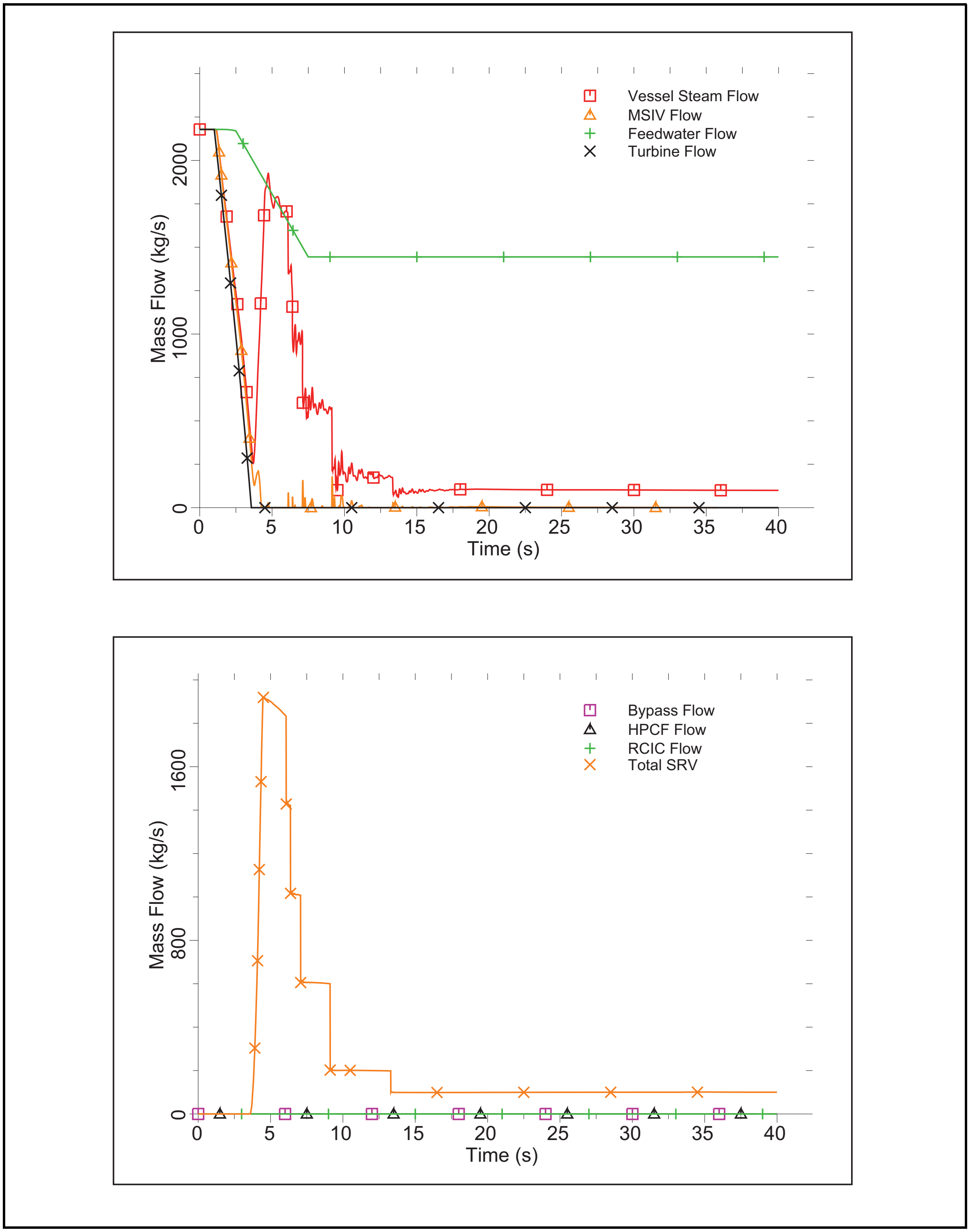


Figure 15.2-2b Pressure Regulator Downscale Failure

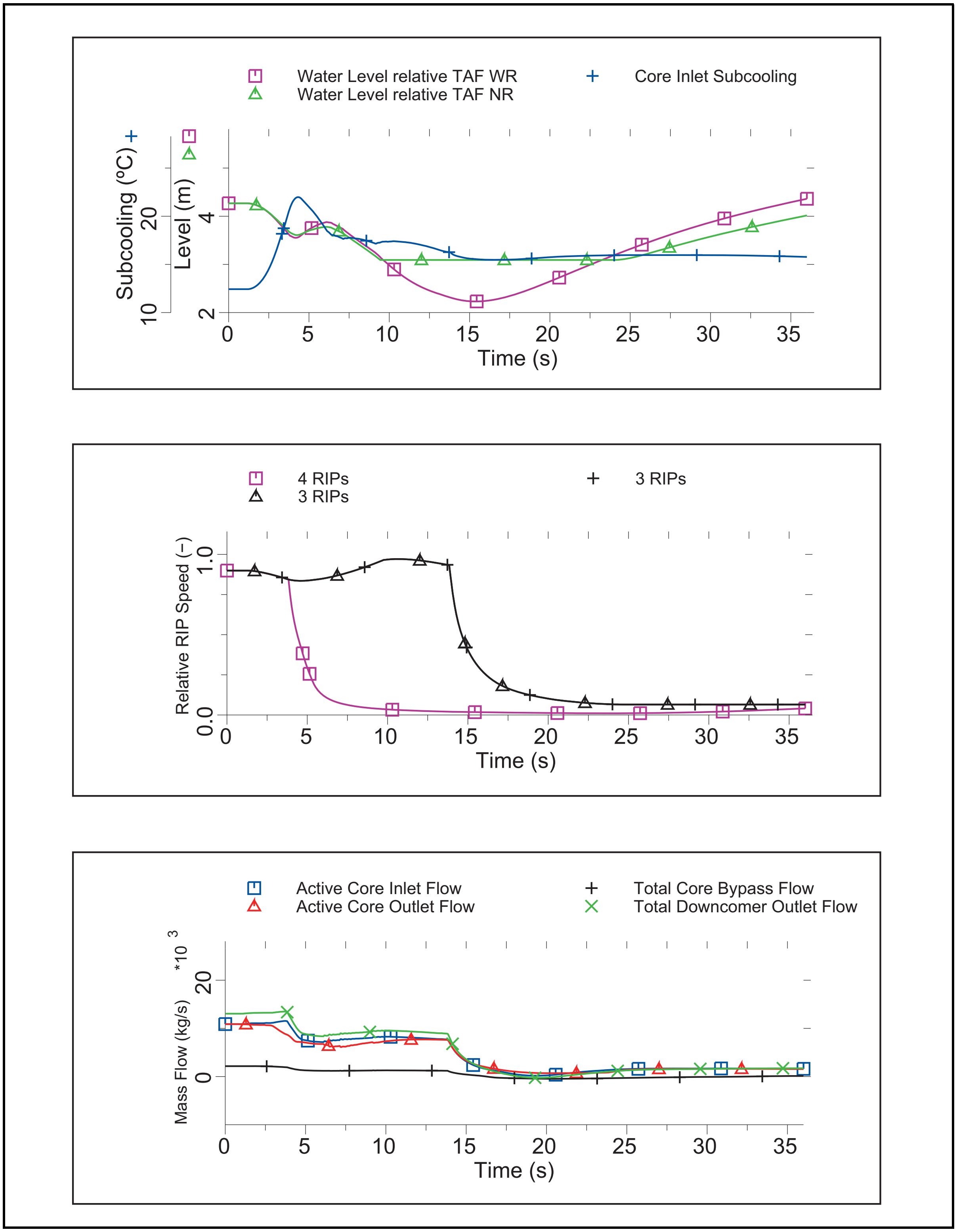


Figure 15.2-2c Pressure Regulator Downscale Failure

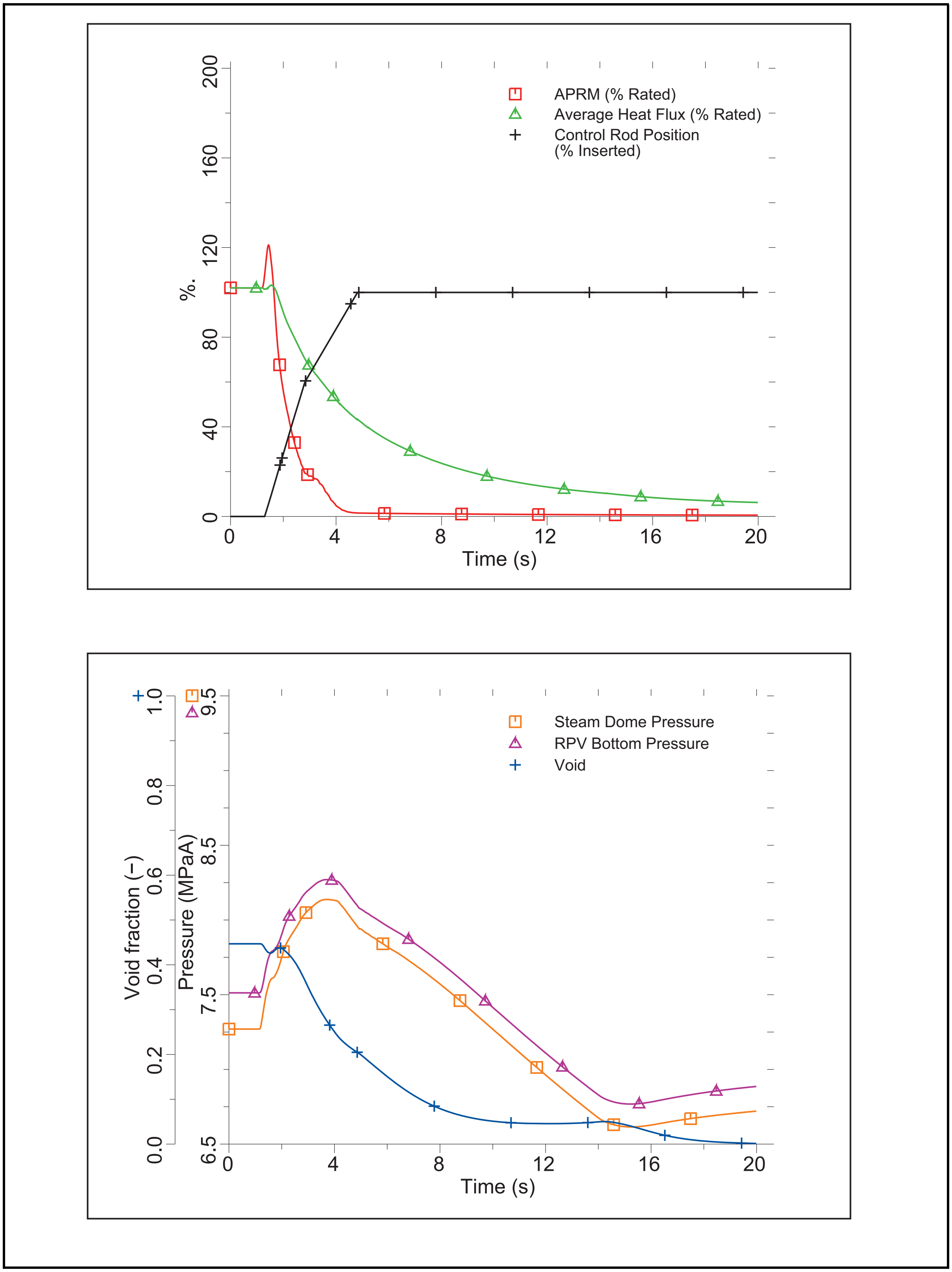


Figure 15.2-3a Generator Load Rejection with Bypass

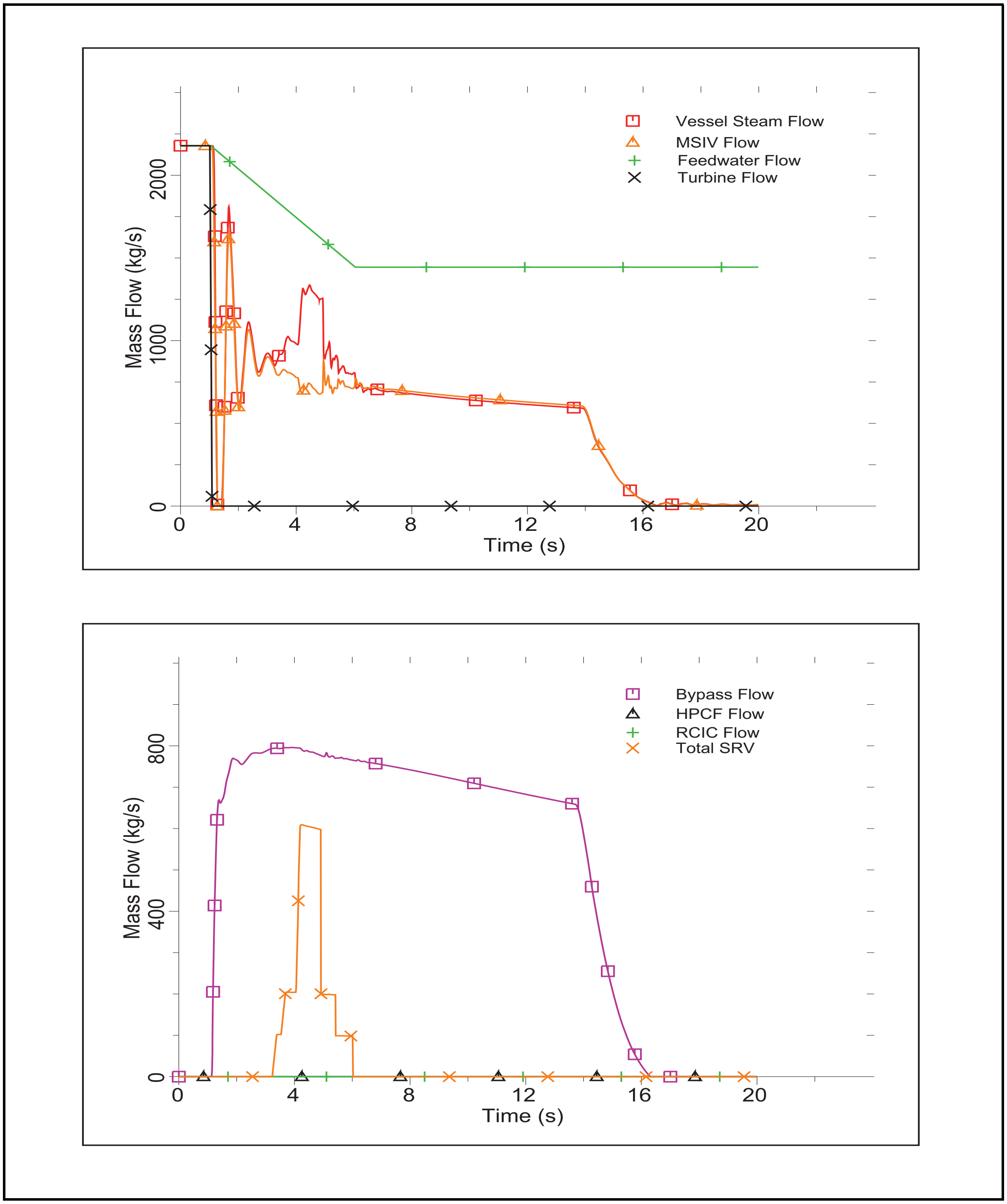


Figure 15.2-3b Generator Load Rejection with Bypass

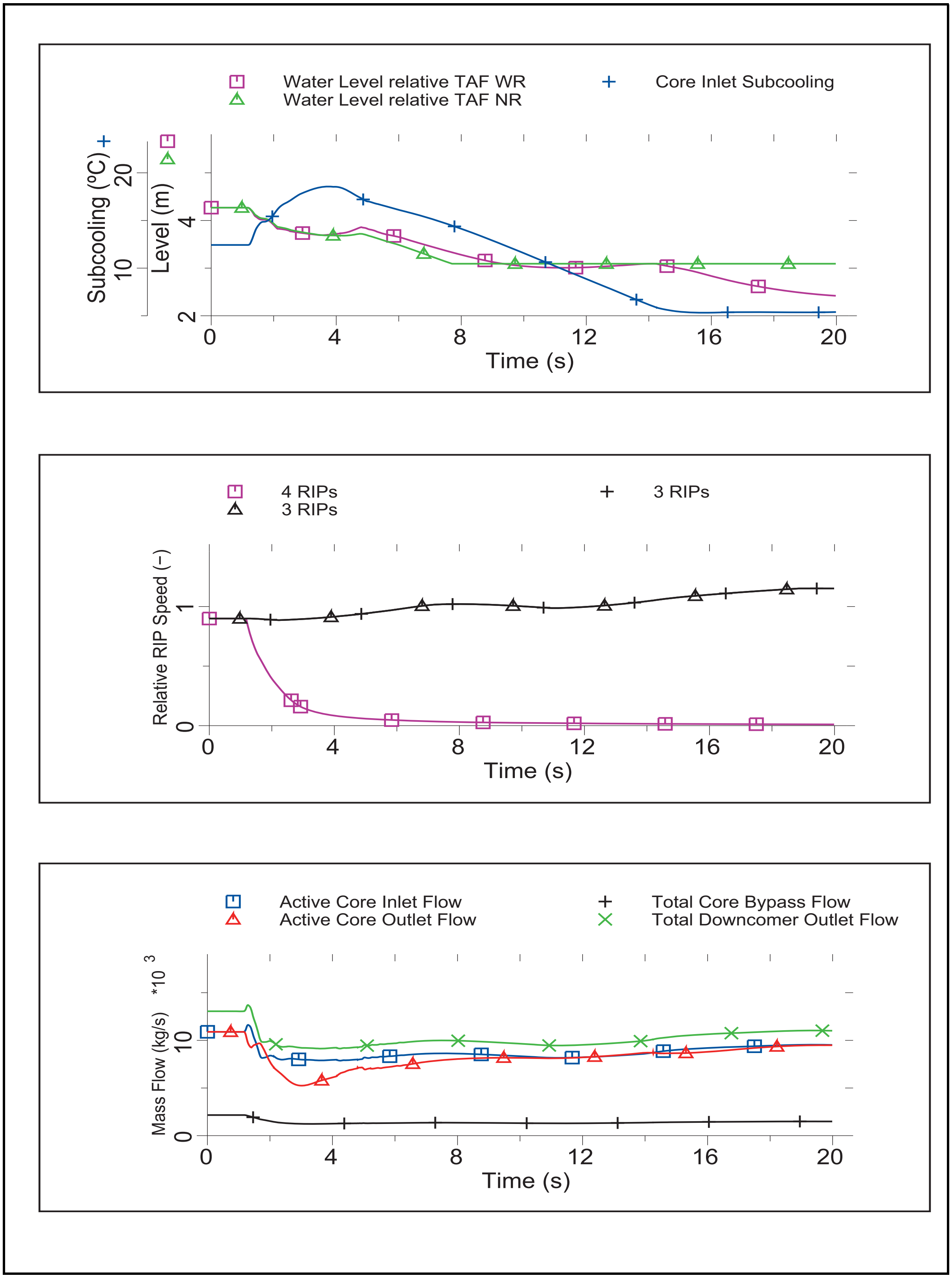


Figure 15.2-3c Generator Load Rejection with Bypass

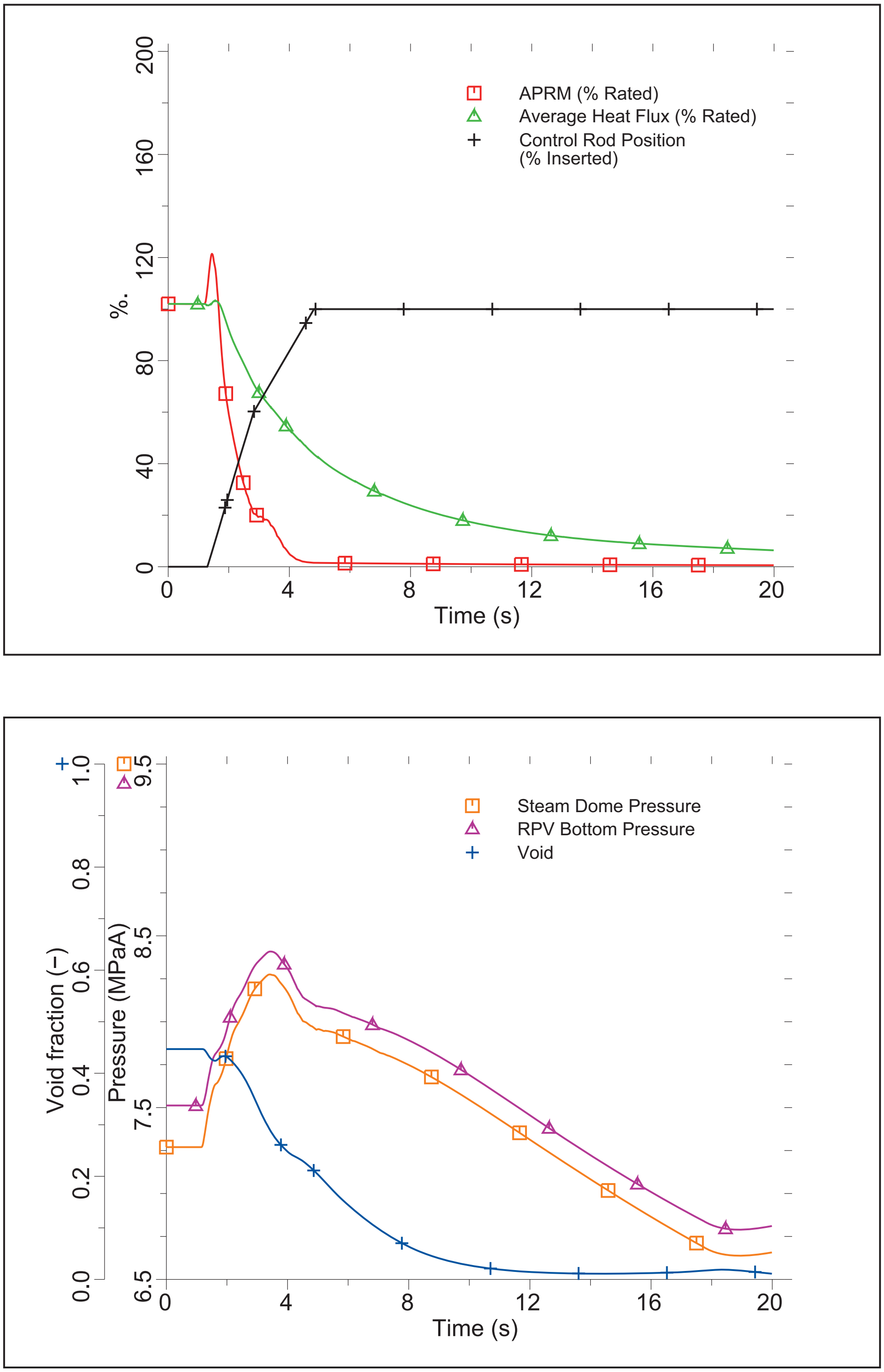


Figure 15.2-4a Load Rejection with One Bypass Valve Failure

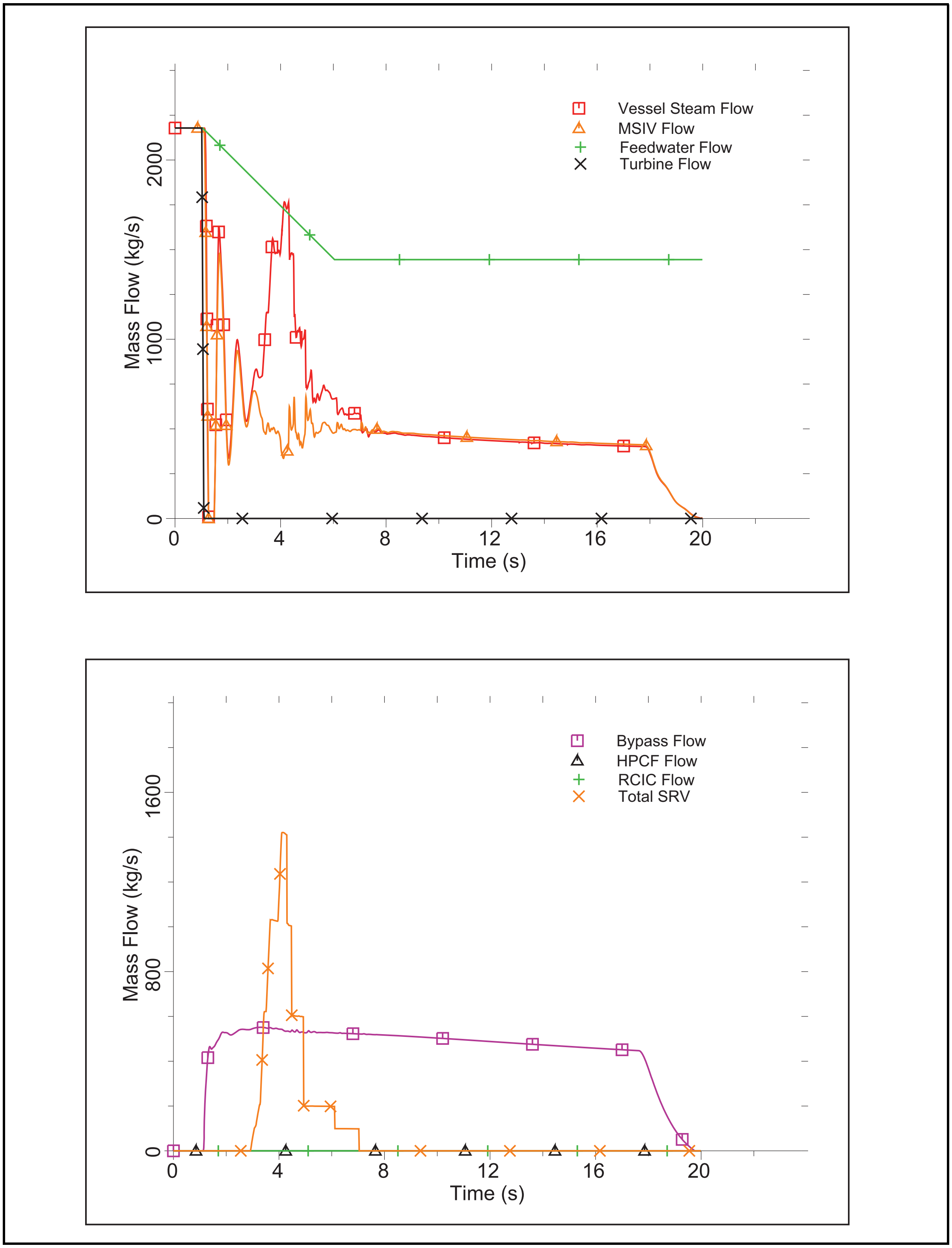


Figure 15.2-4b Load Rejection with One Bypass Valve Failure

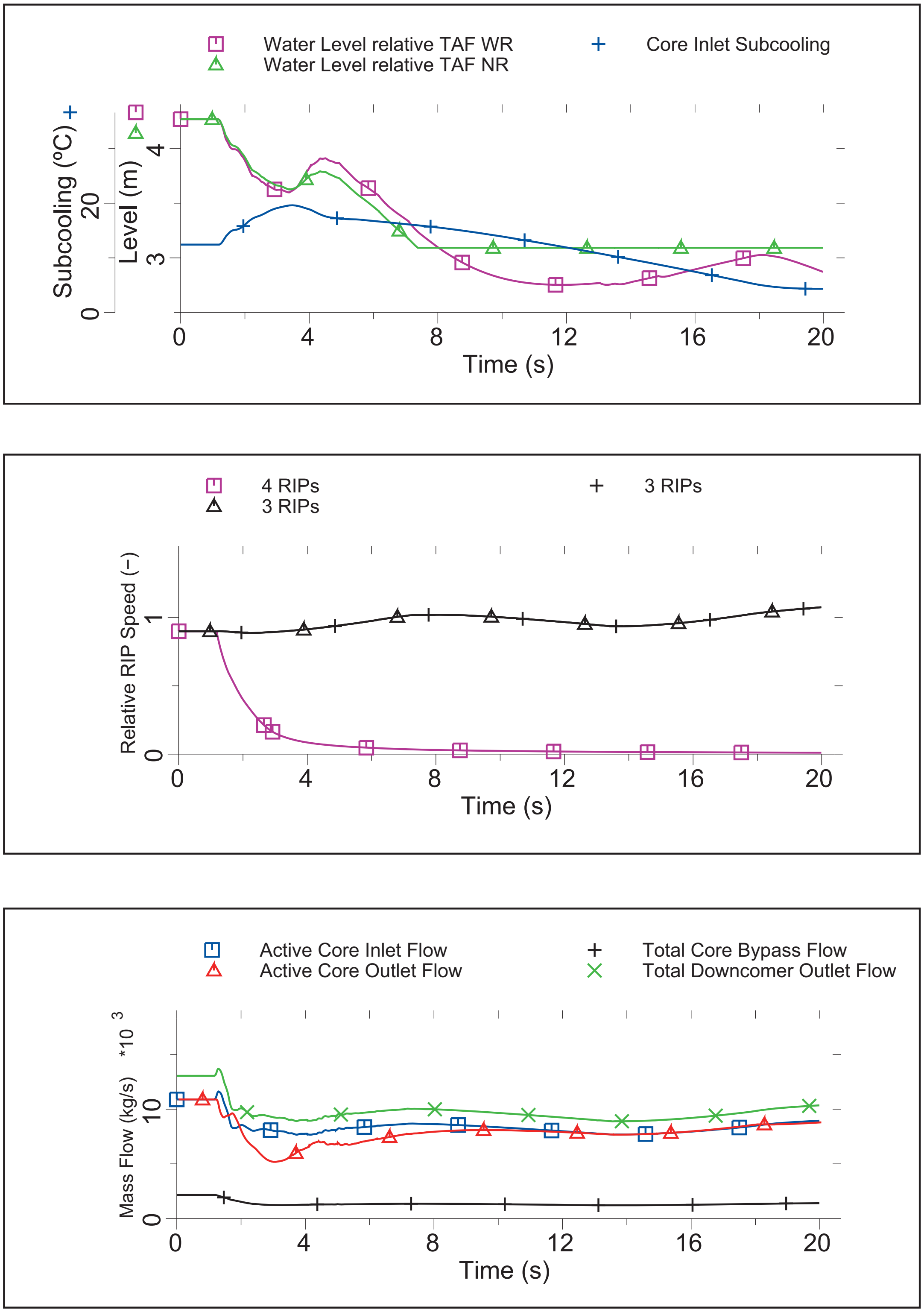


Figure 15.2-4c Load Rejection with One Bypass Valve Failure

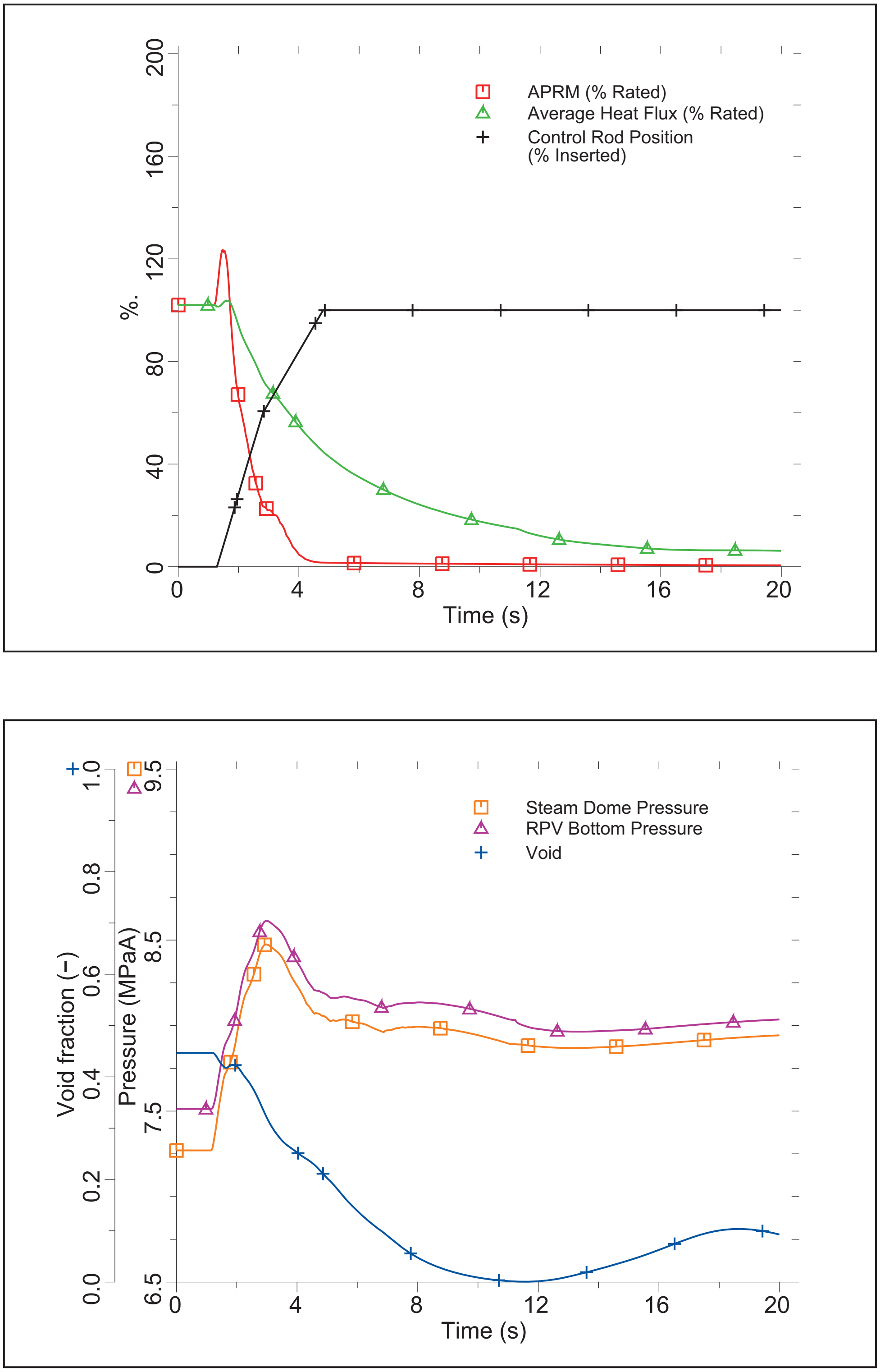


Figure 15.2-5a Load Rejection with All Bypass Valves Failure

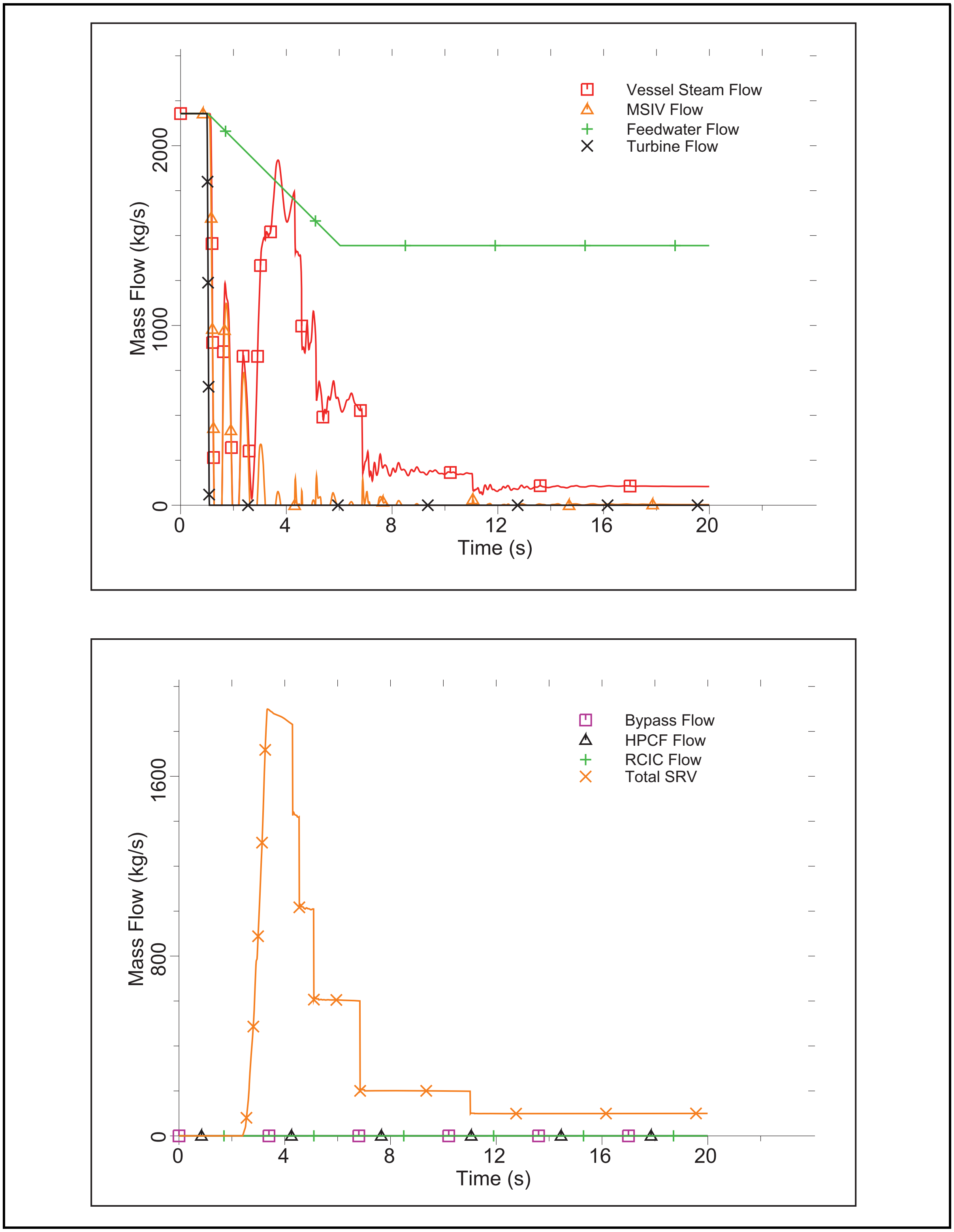


Figure 15.2-5b Load Rejection with All Bypass Valves Failure

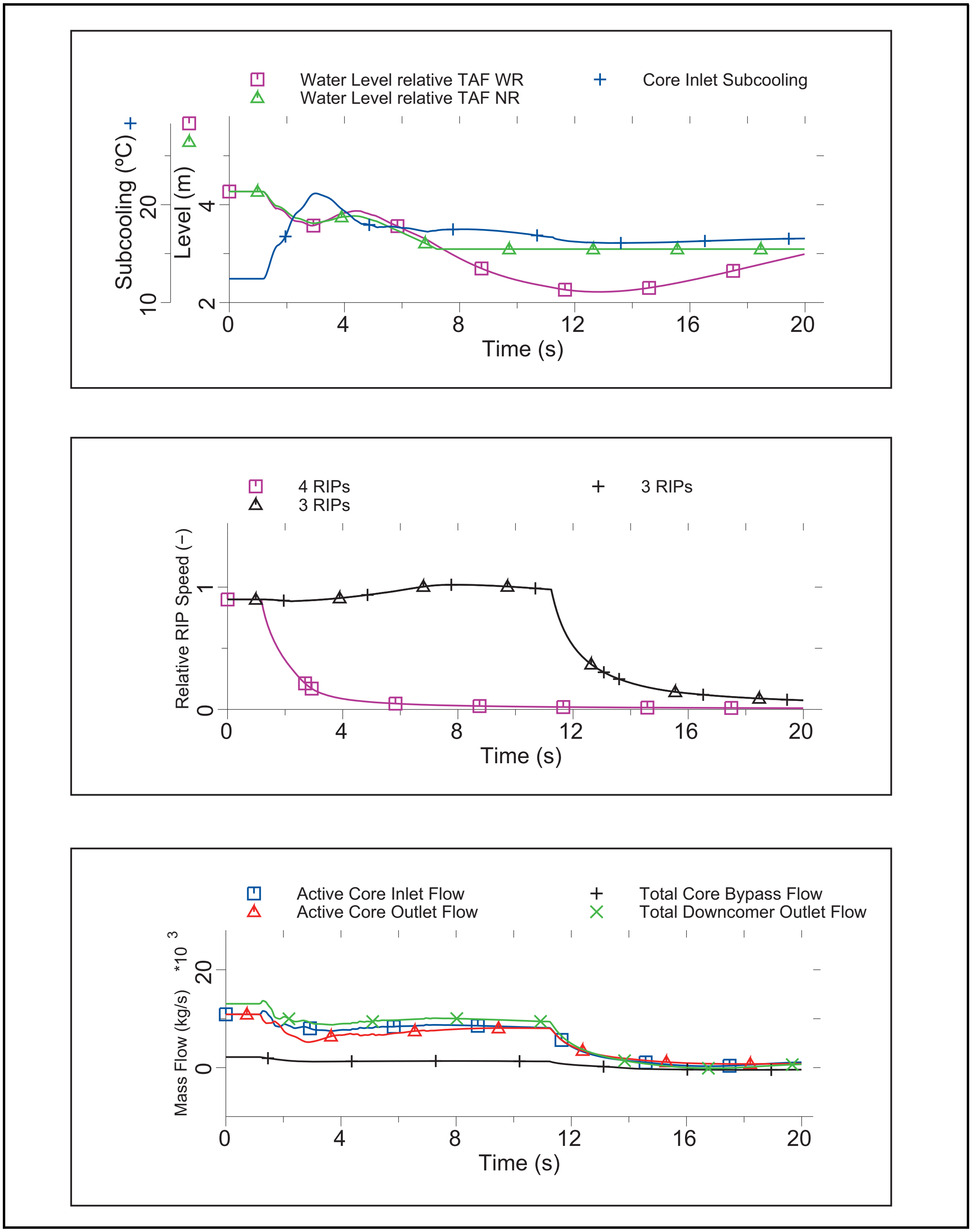


Figure 15.2-5c Load Rejection with All Bypass Valves Failure

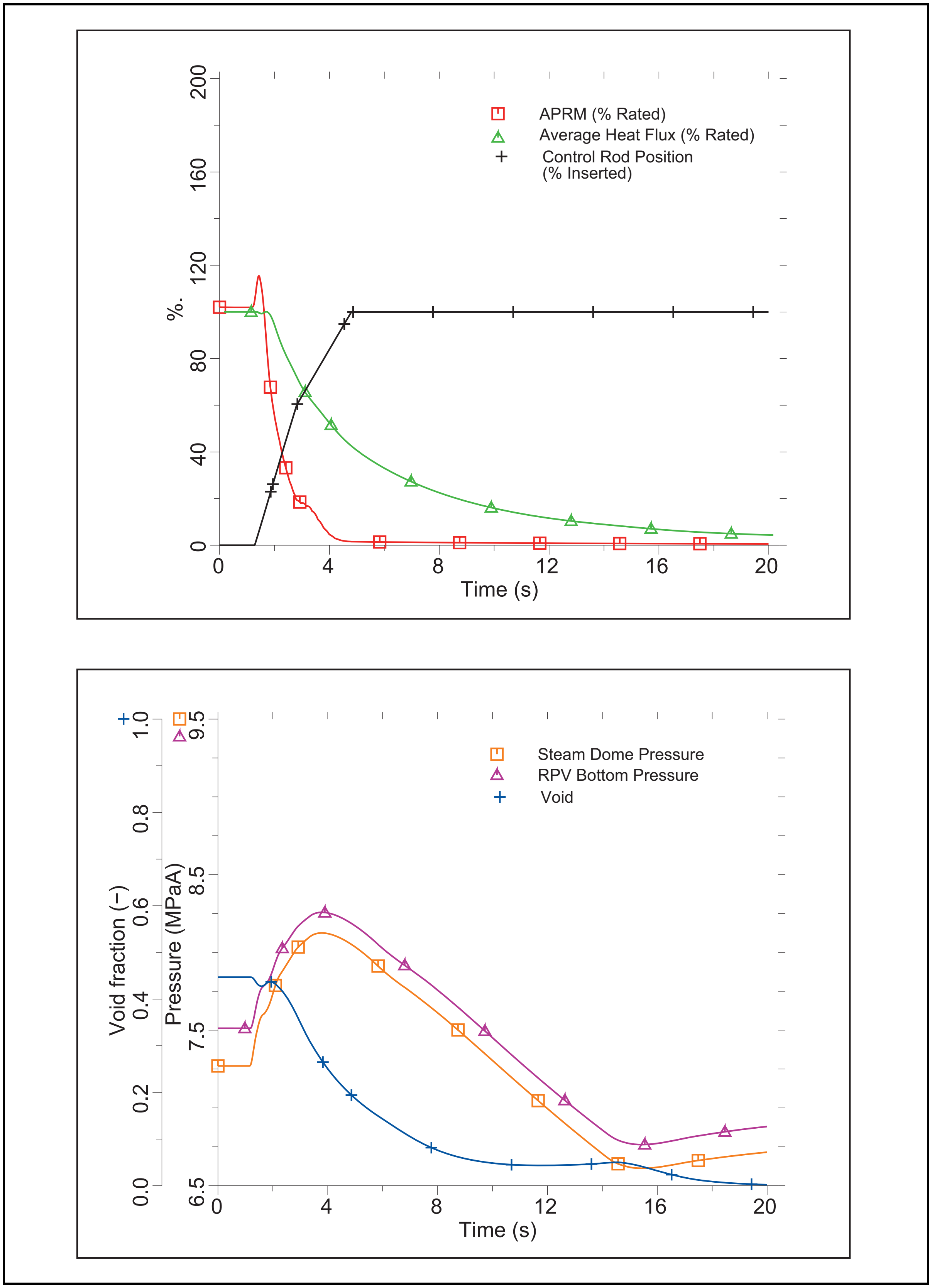


Figure 15.2-6a Turbine Trip with Bypass

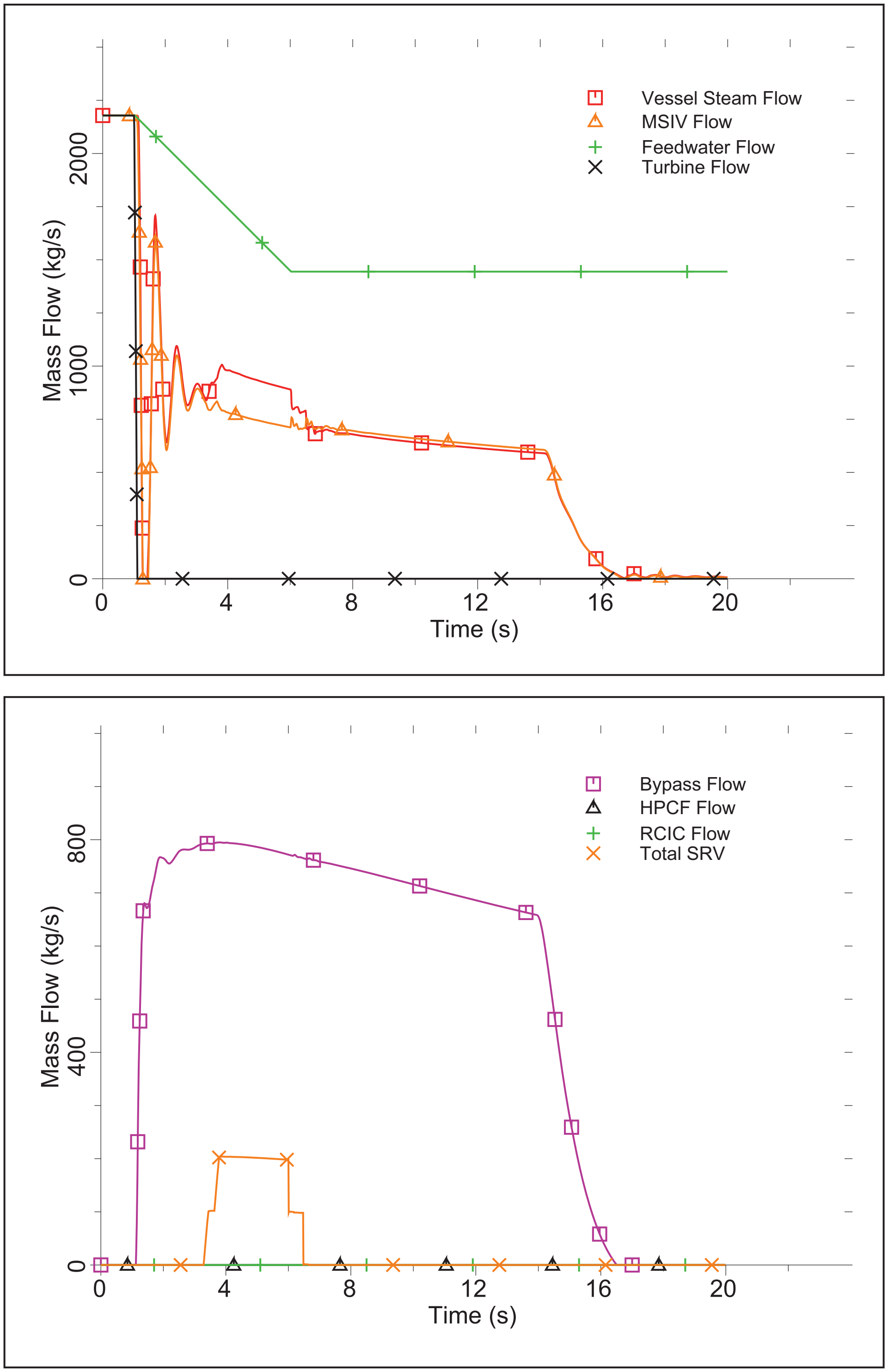


Figure 15.2-6b Turbine Trip with Bypass

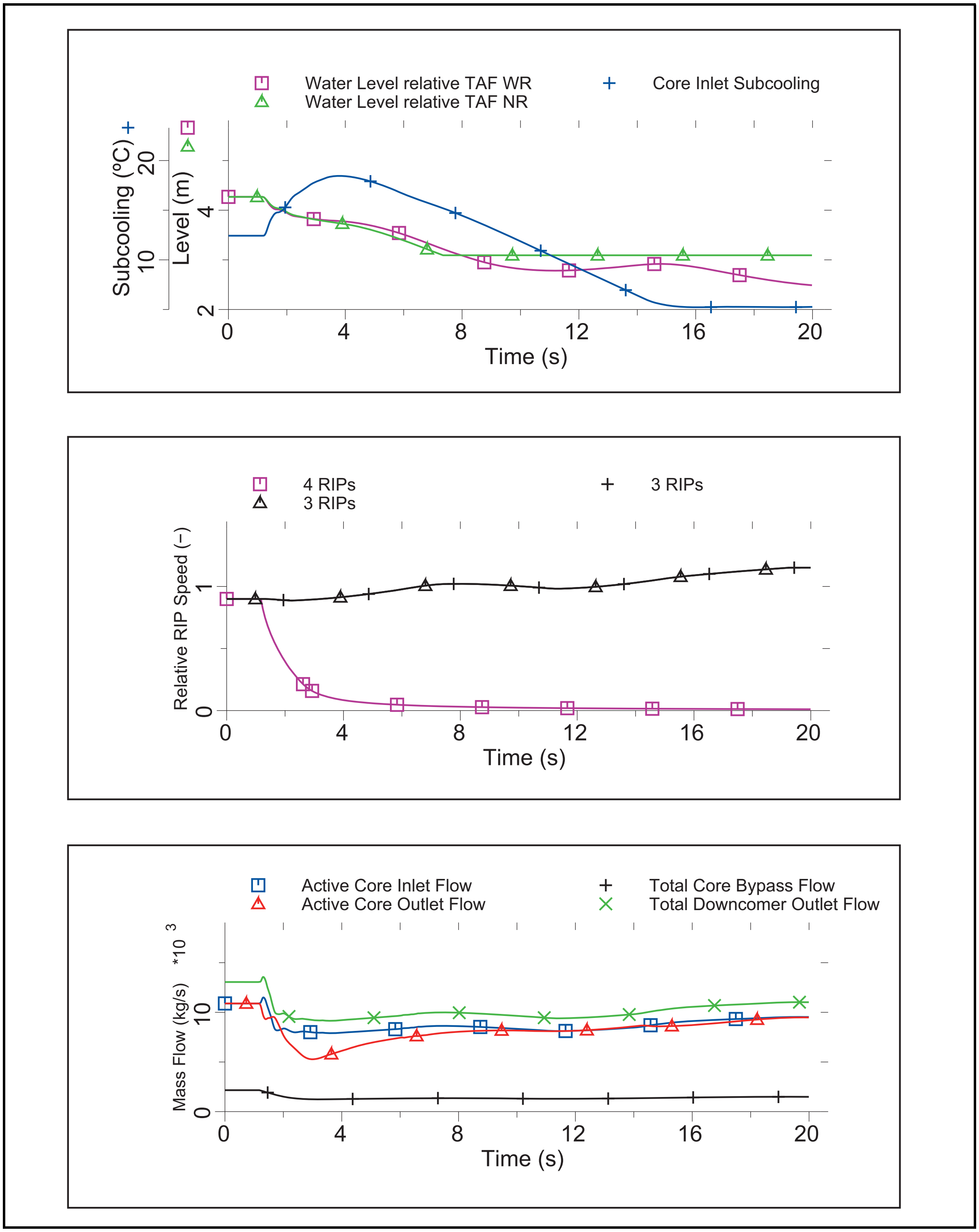


Figure 15.2-6c Turbine Trip with Bypass

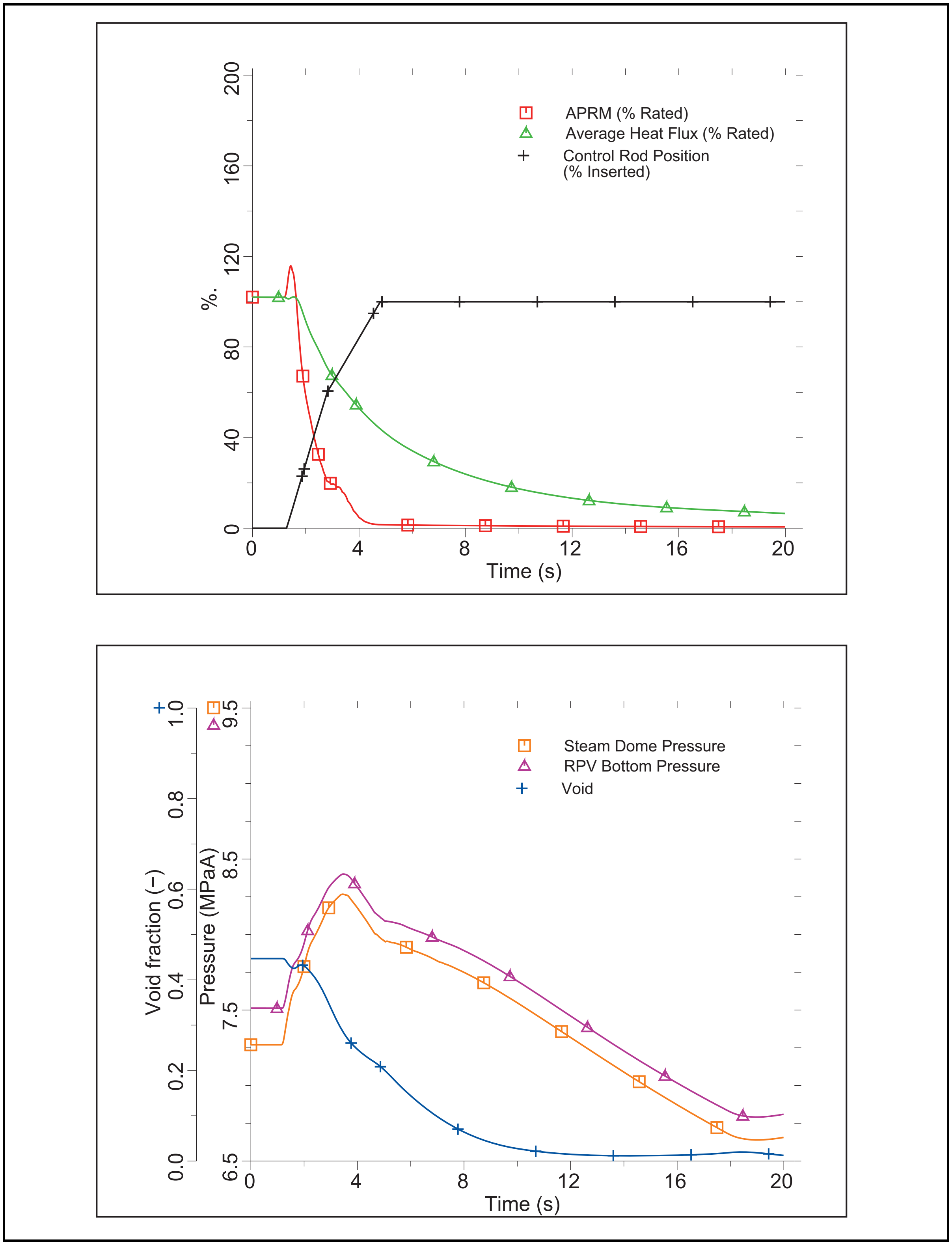


Figure 15.2-7a Turbine Trip with One Bypass Valve Failure

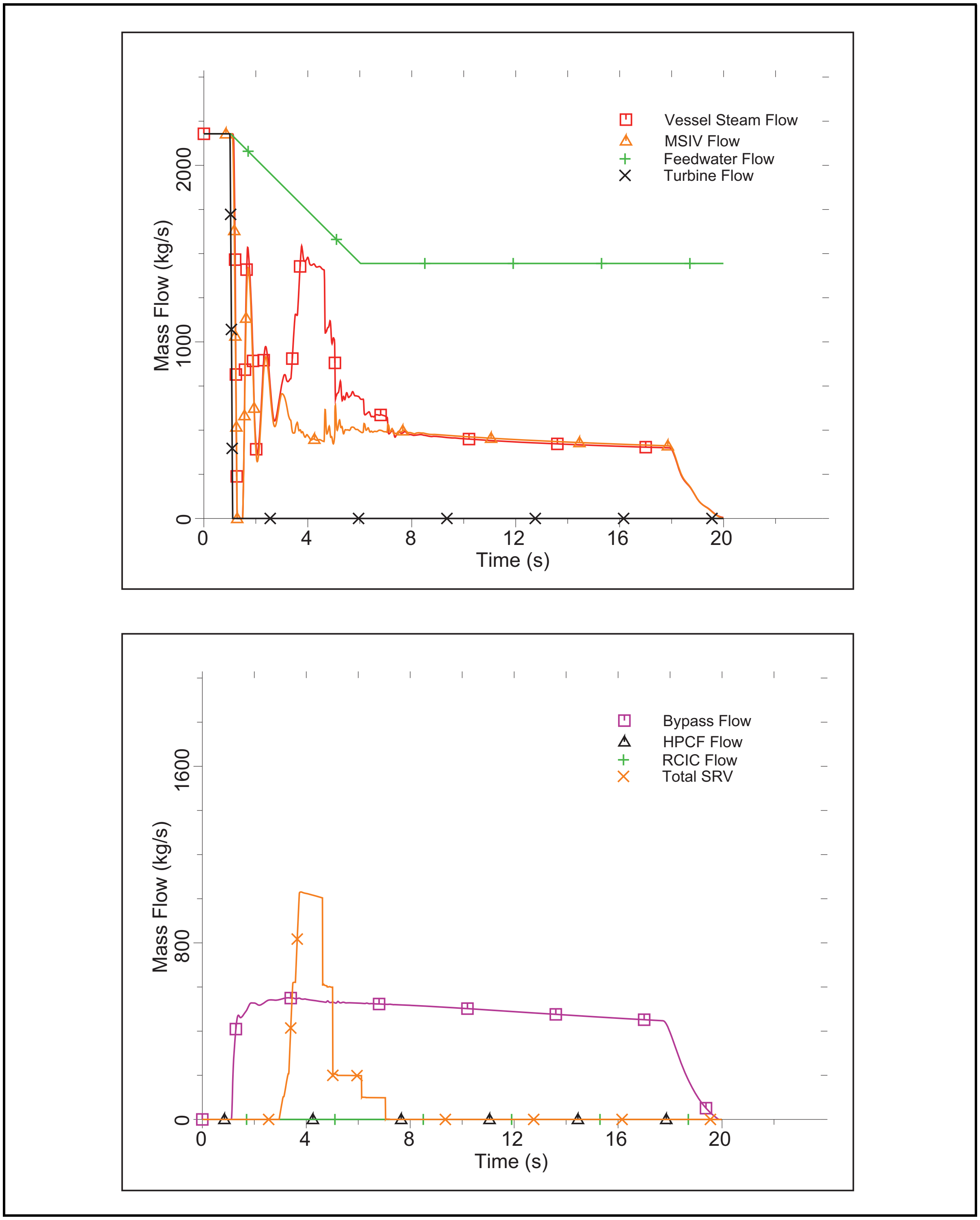


Figure 15.2-7b Turbine Trip with One Bypass Valve Failure

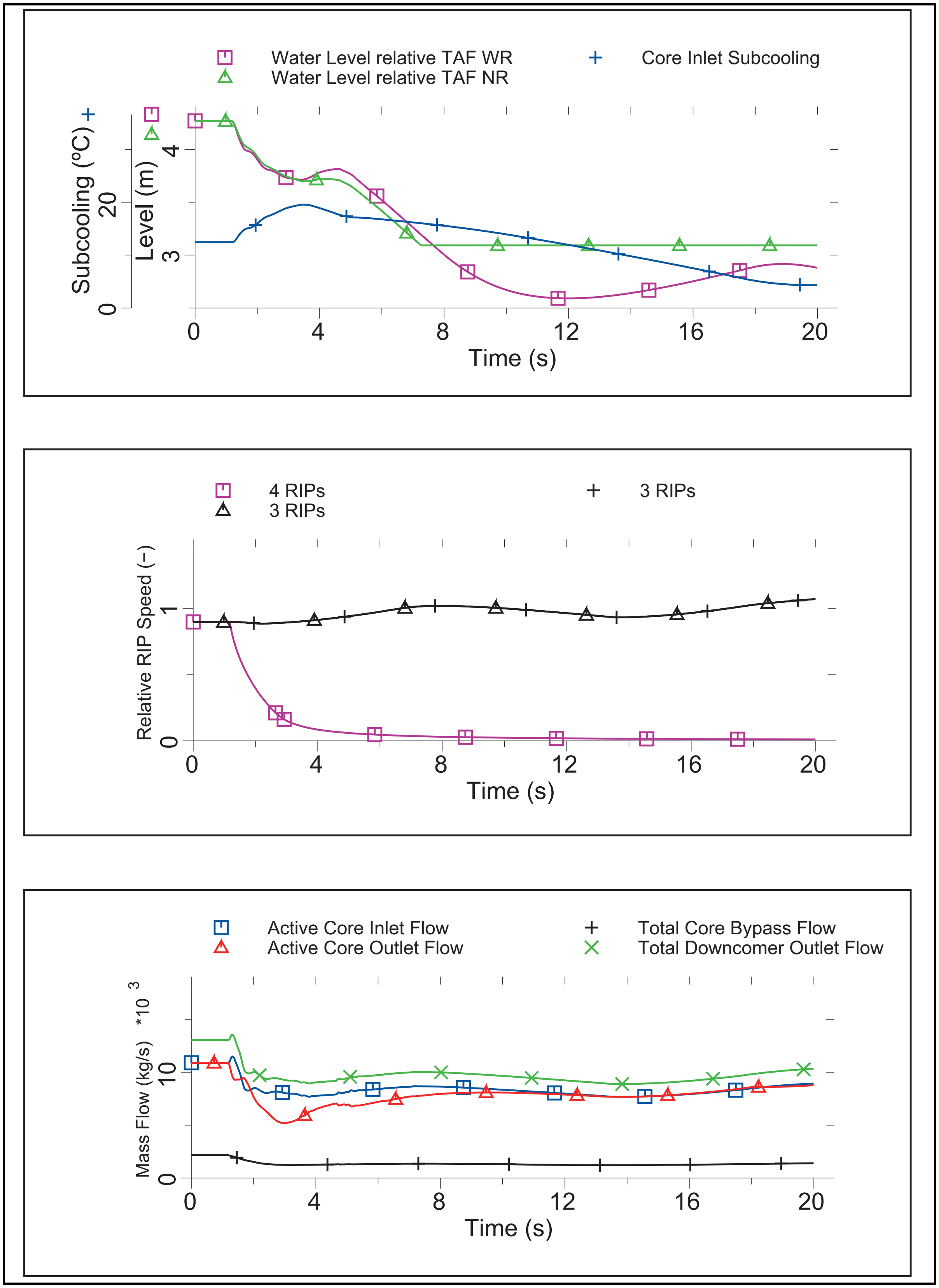


Figure 15.2-7c Turbine Trip with One Bypass Valve Failure

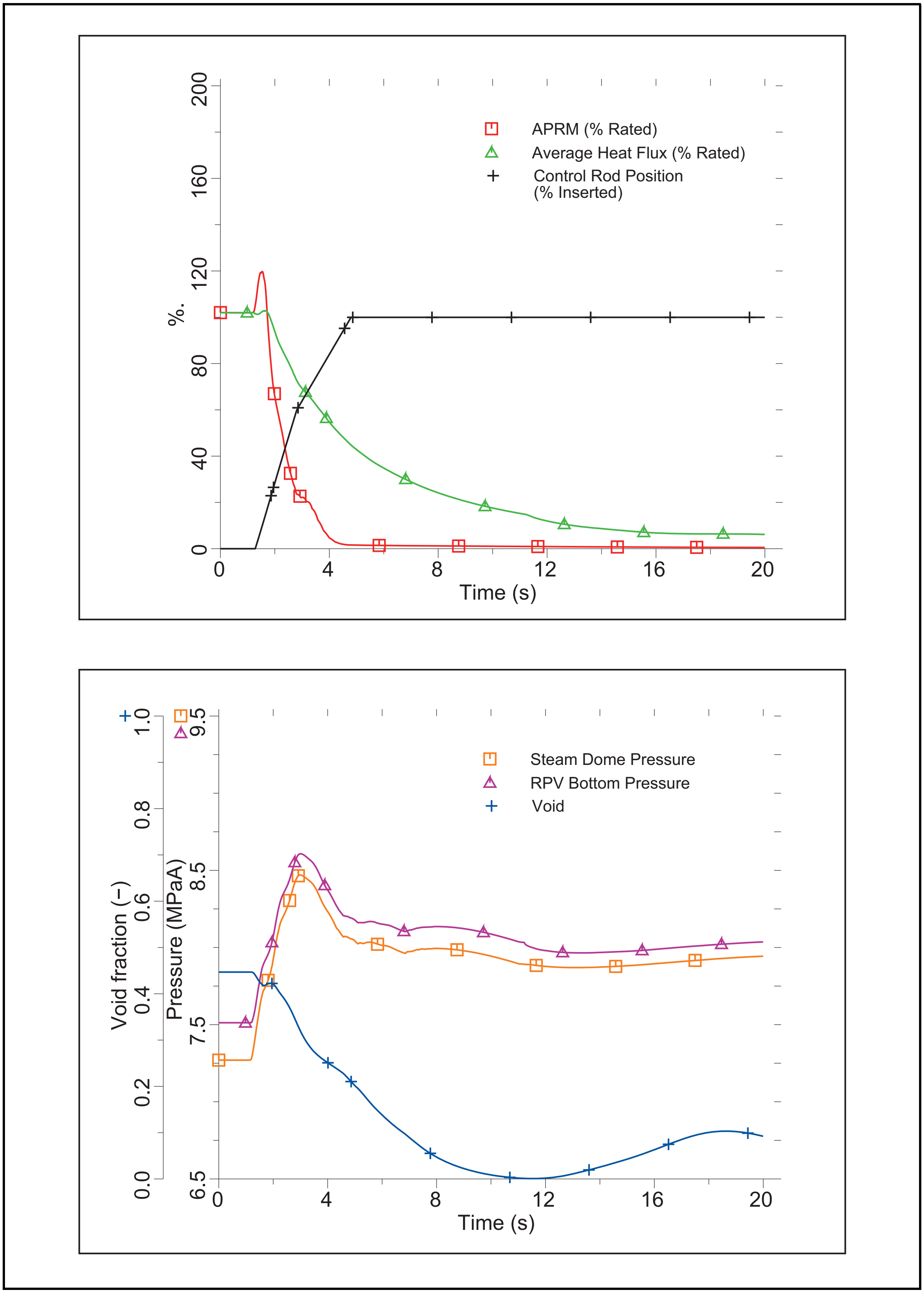


Figure 15.2-8a Turbine Trip with All Bypass Valves Failure

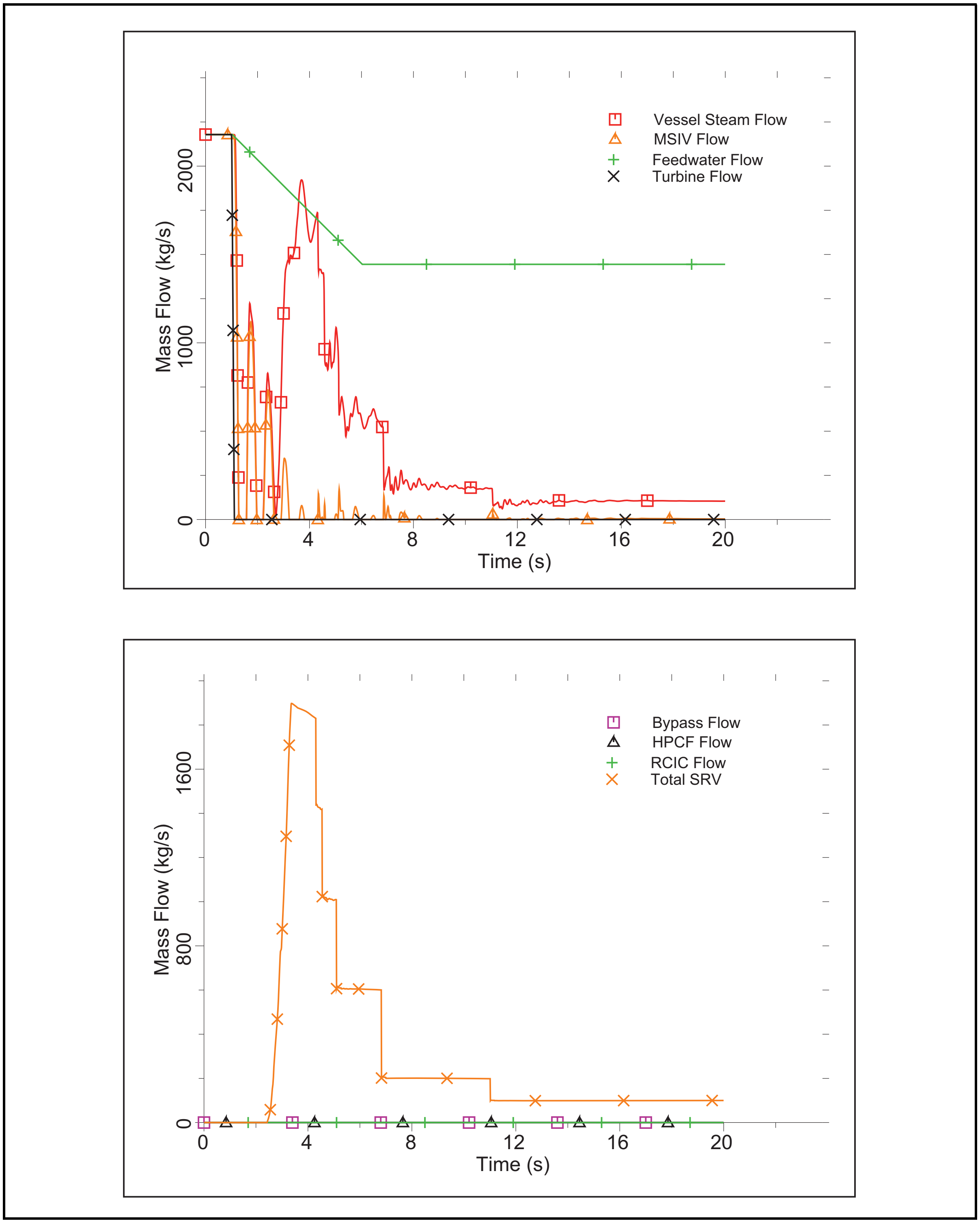


Figure 15.2-8b Turbine Trip with All Bypass Valves Failure

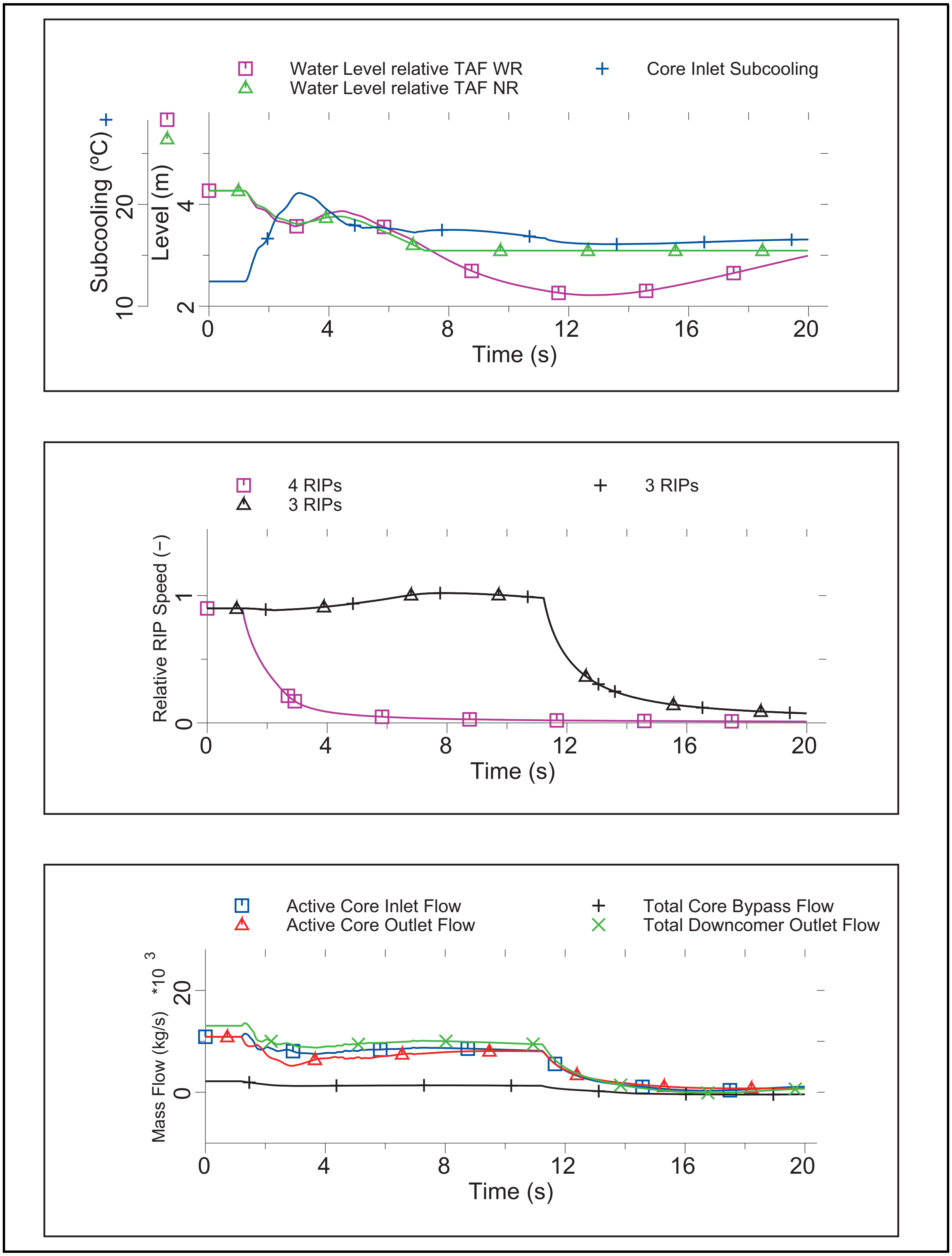


Figure 15.2-8c Turbine Trip with All Bypass Valves Failure

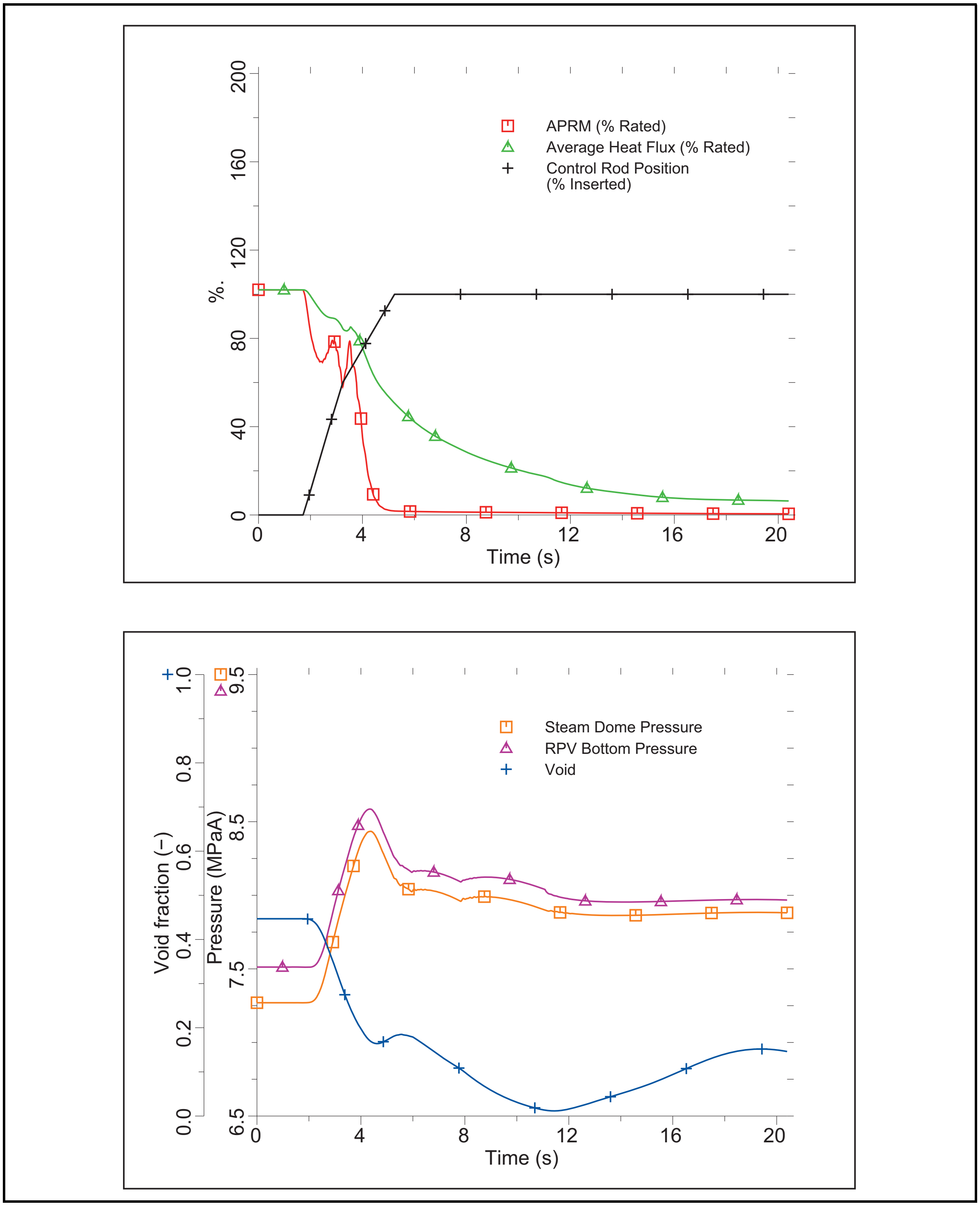


Figure 15.2-9a MSIV Closure Direct Scram

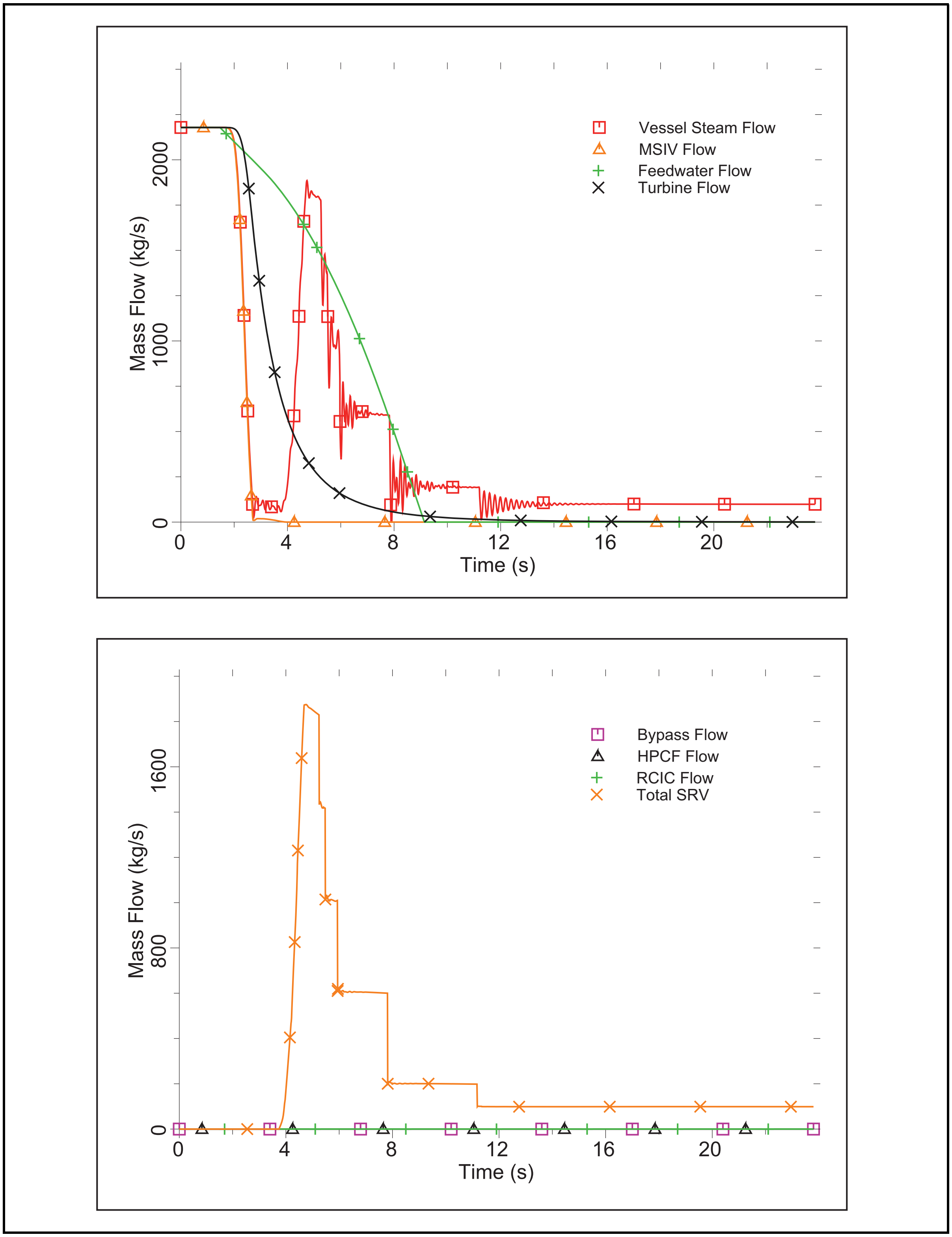


Figure 15.2-9b MSIV Closure Direct Scram

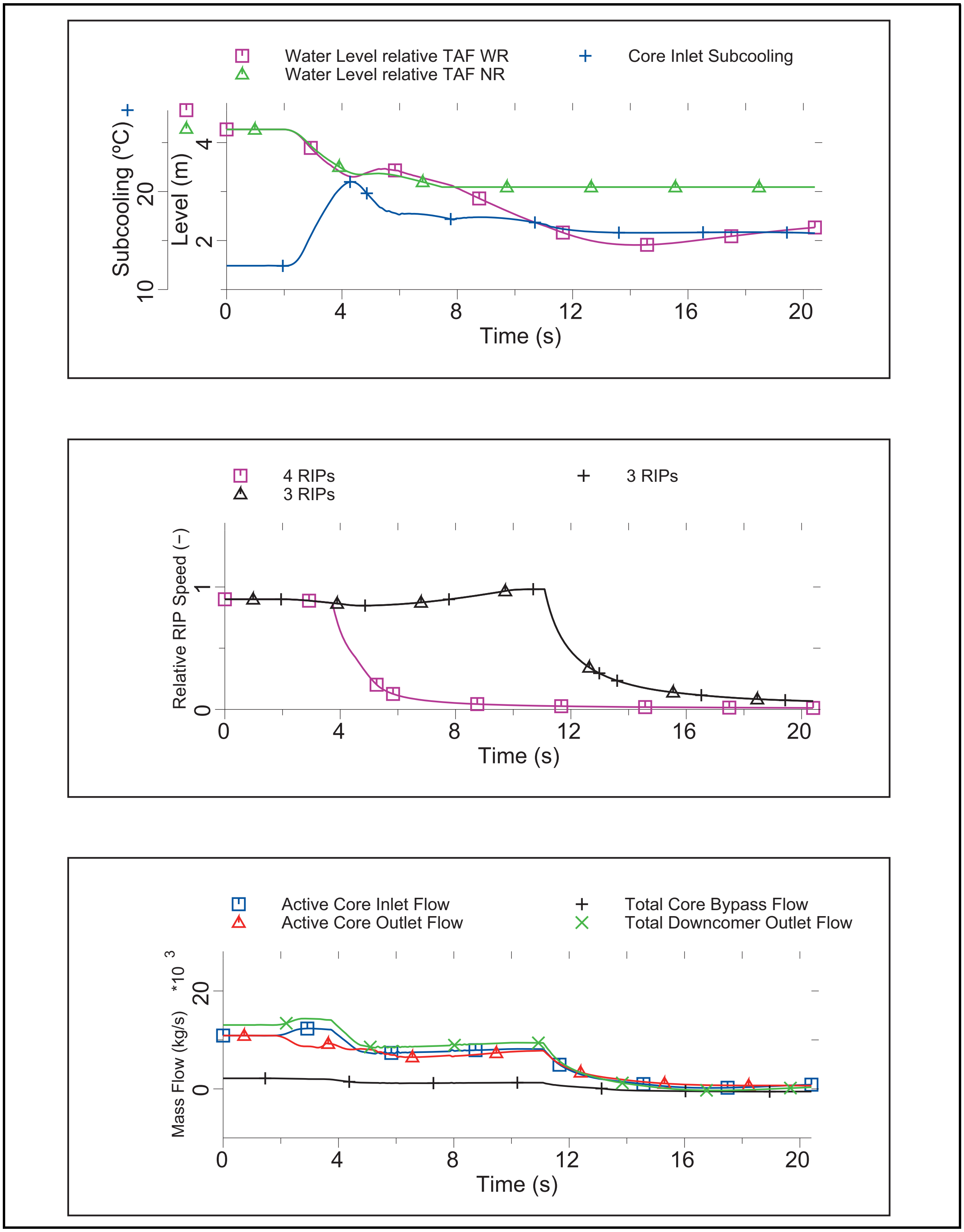
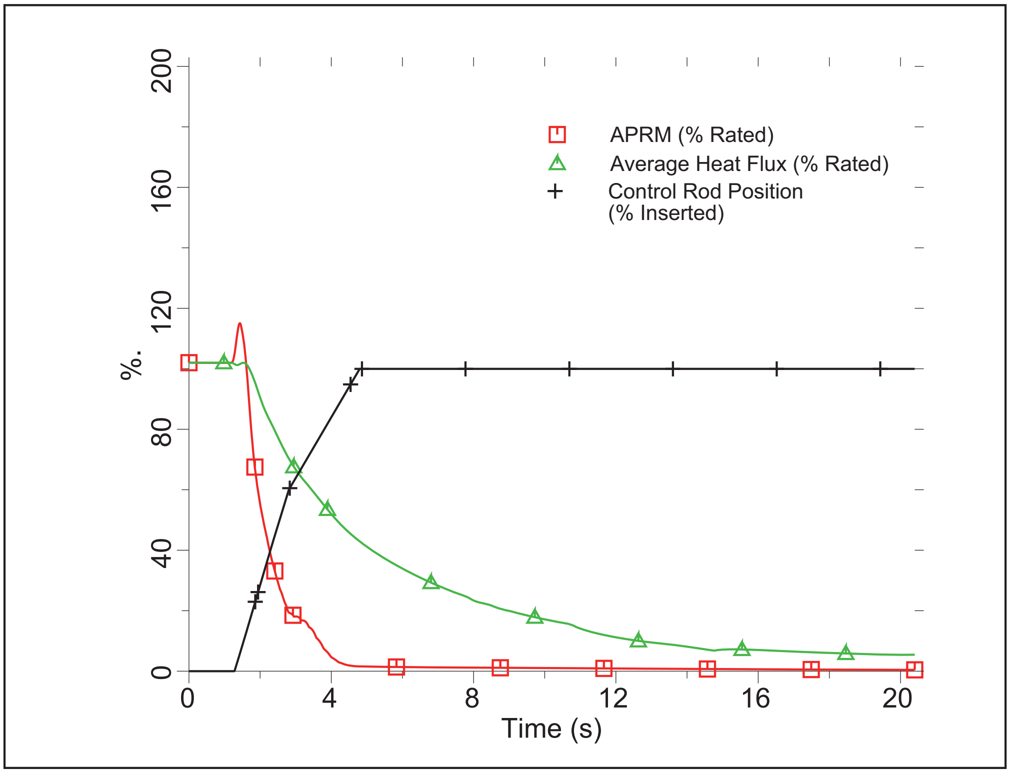


Figure 15.2-9c MSIV Closure Direct Scram



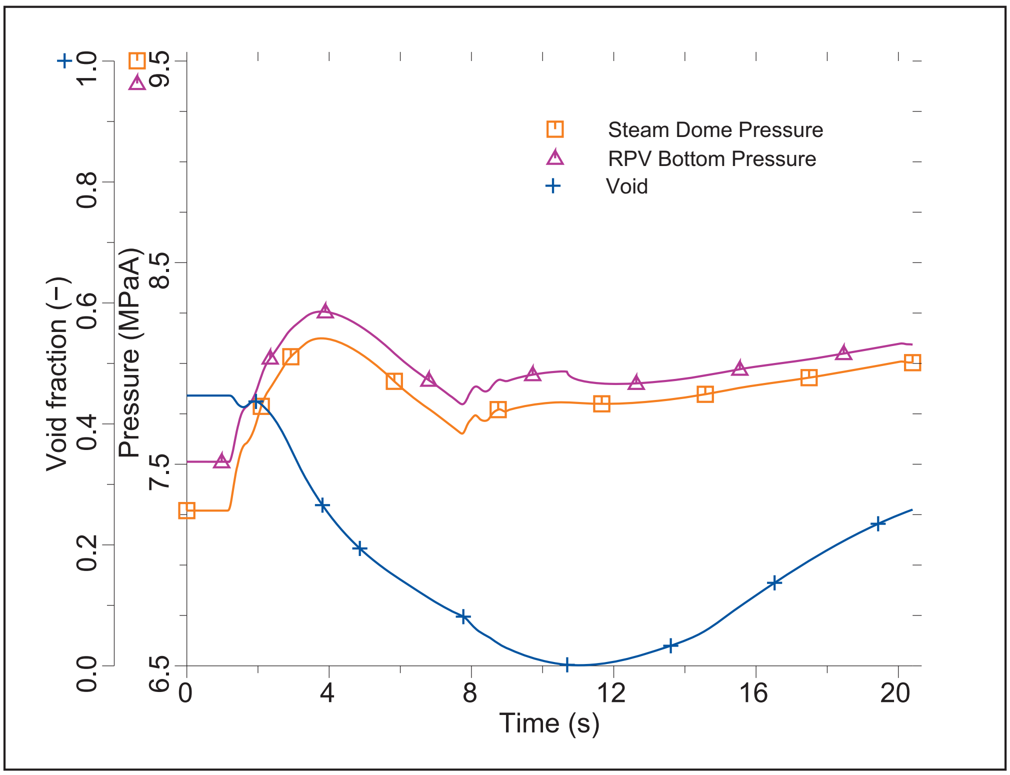


Figure 15.2-10a Loss of Condenser Vacuum

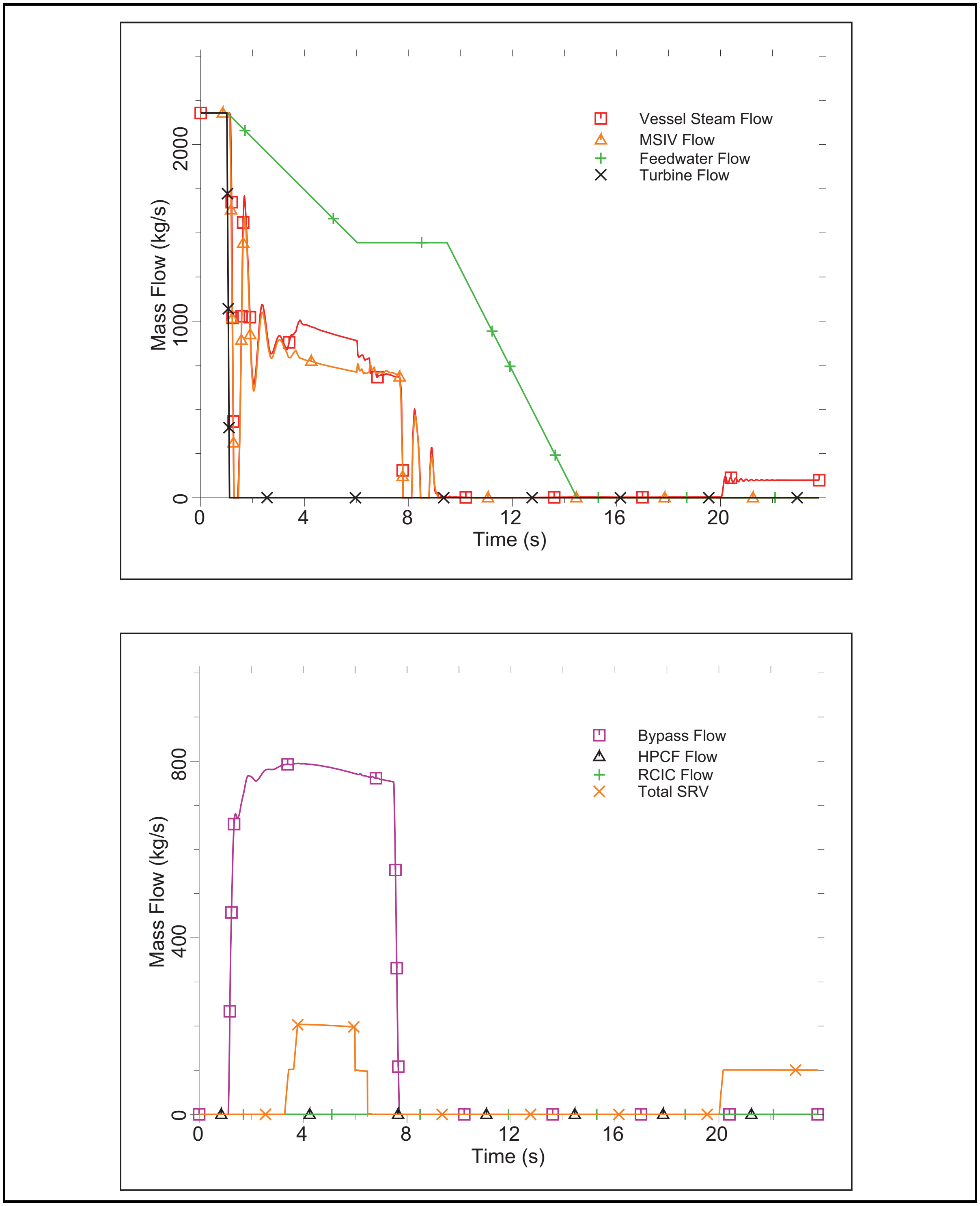


Figure 15.2-10b Loss of Condenser Vacuum

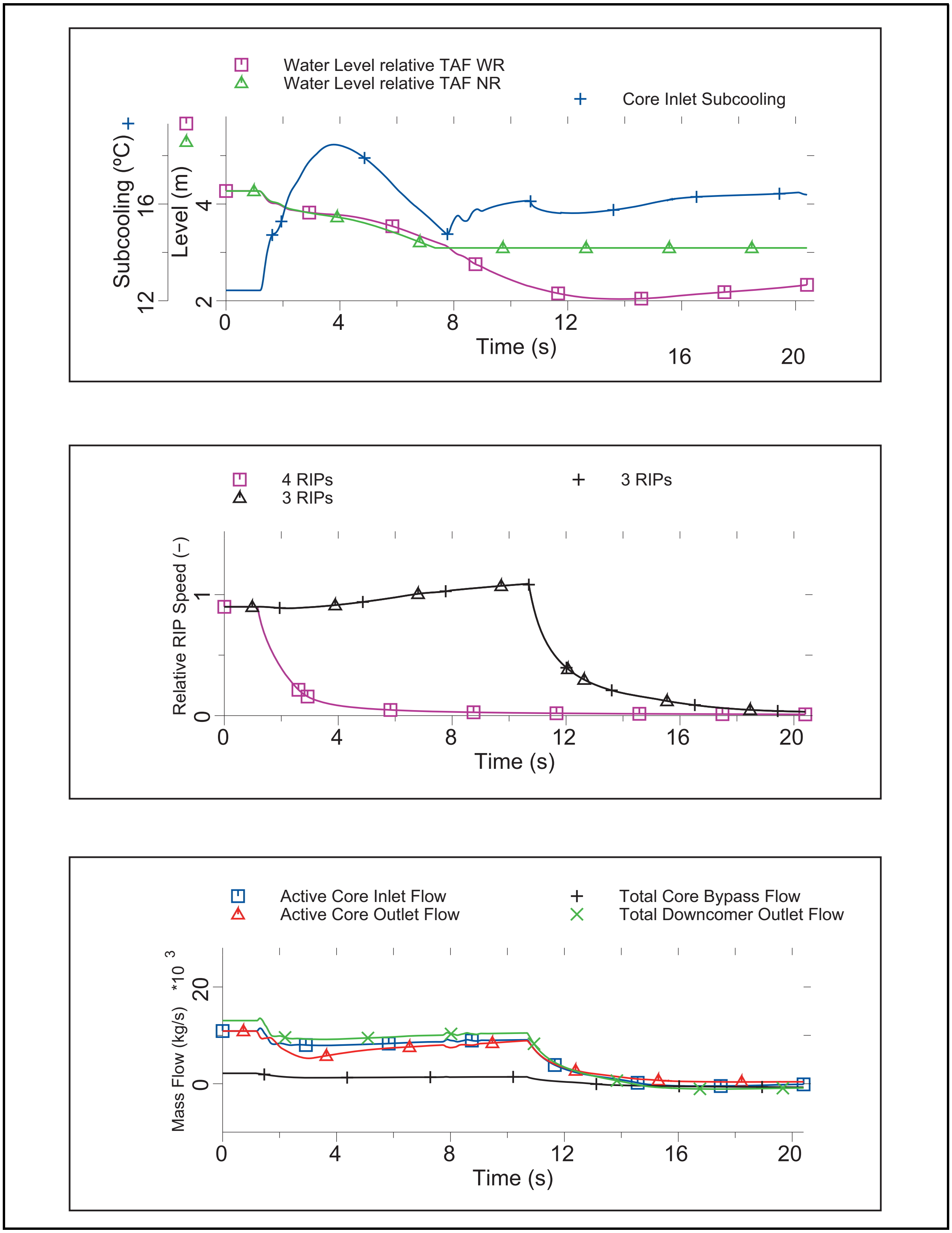


Figure 15.2-10c Loss of Condenser Vacuum

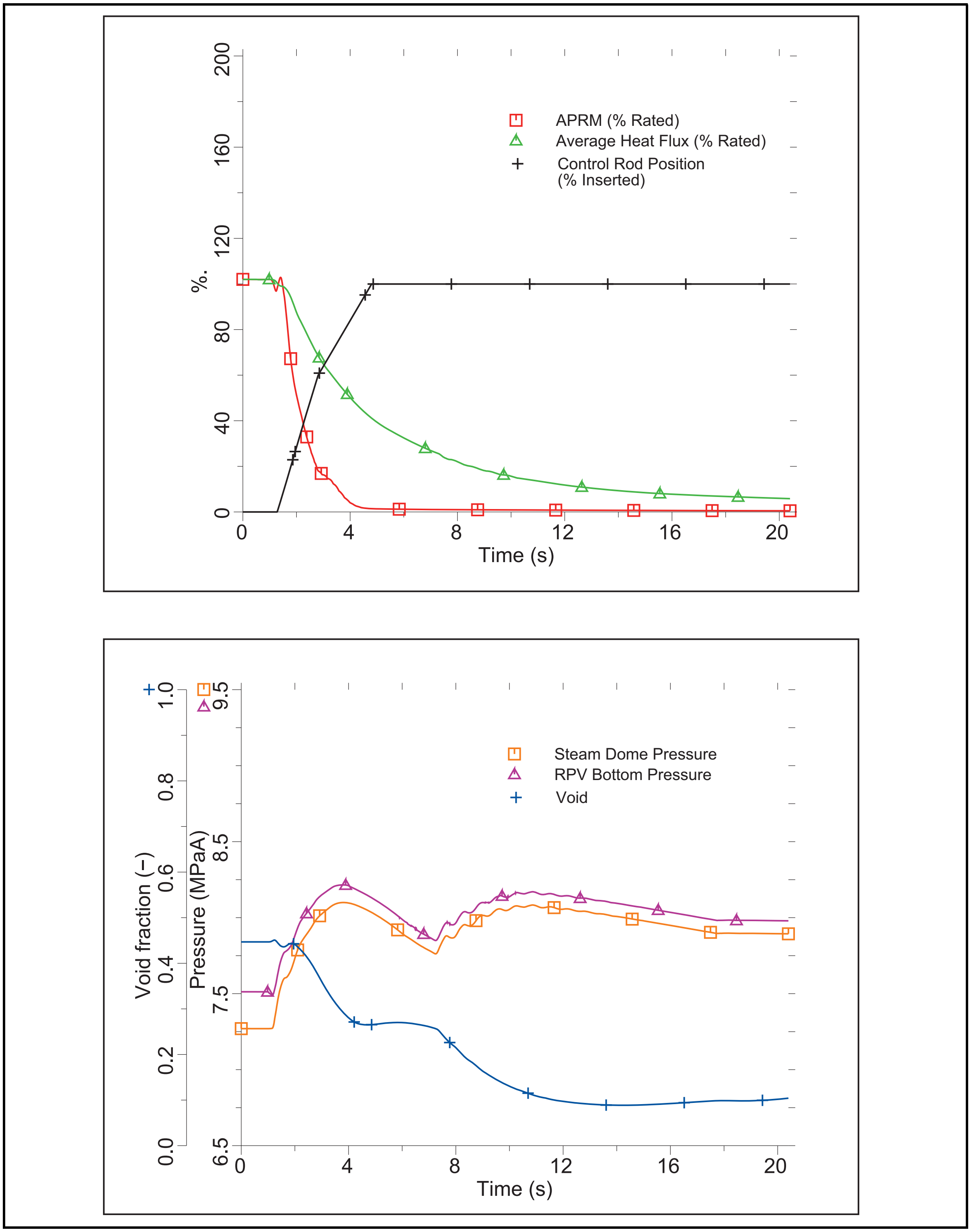


Figure 15.2-11a Loss of AC Power

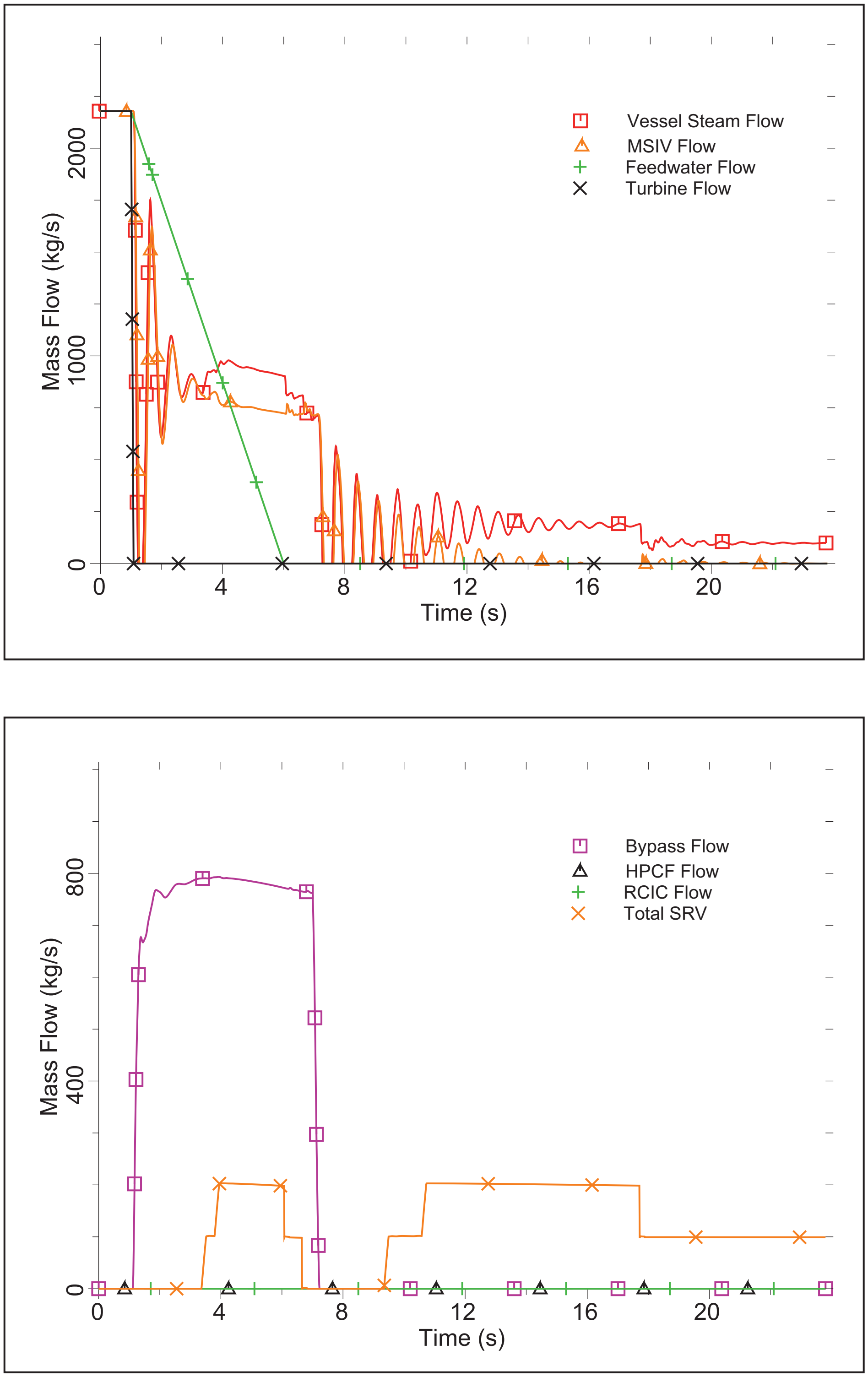


Figure 15.2-11b Loss of AC Power

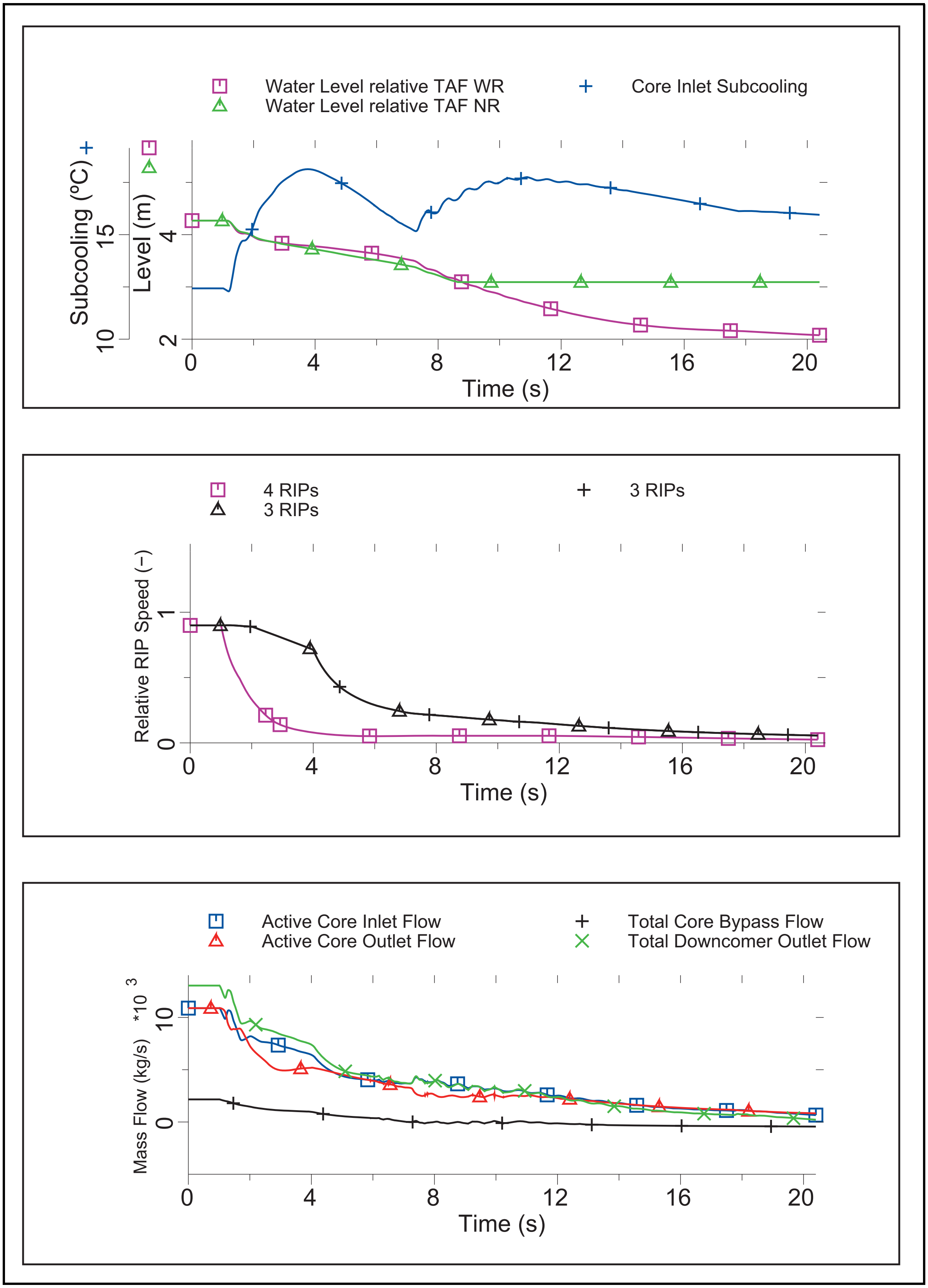


Figure 15.2-11c Loss of AC Power

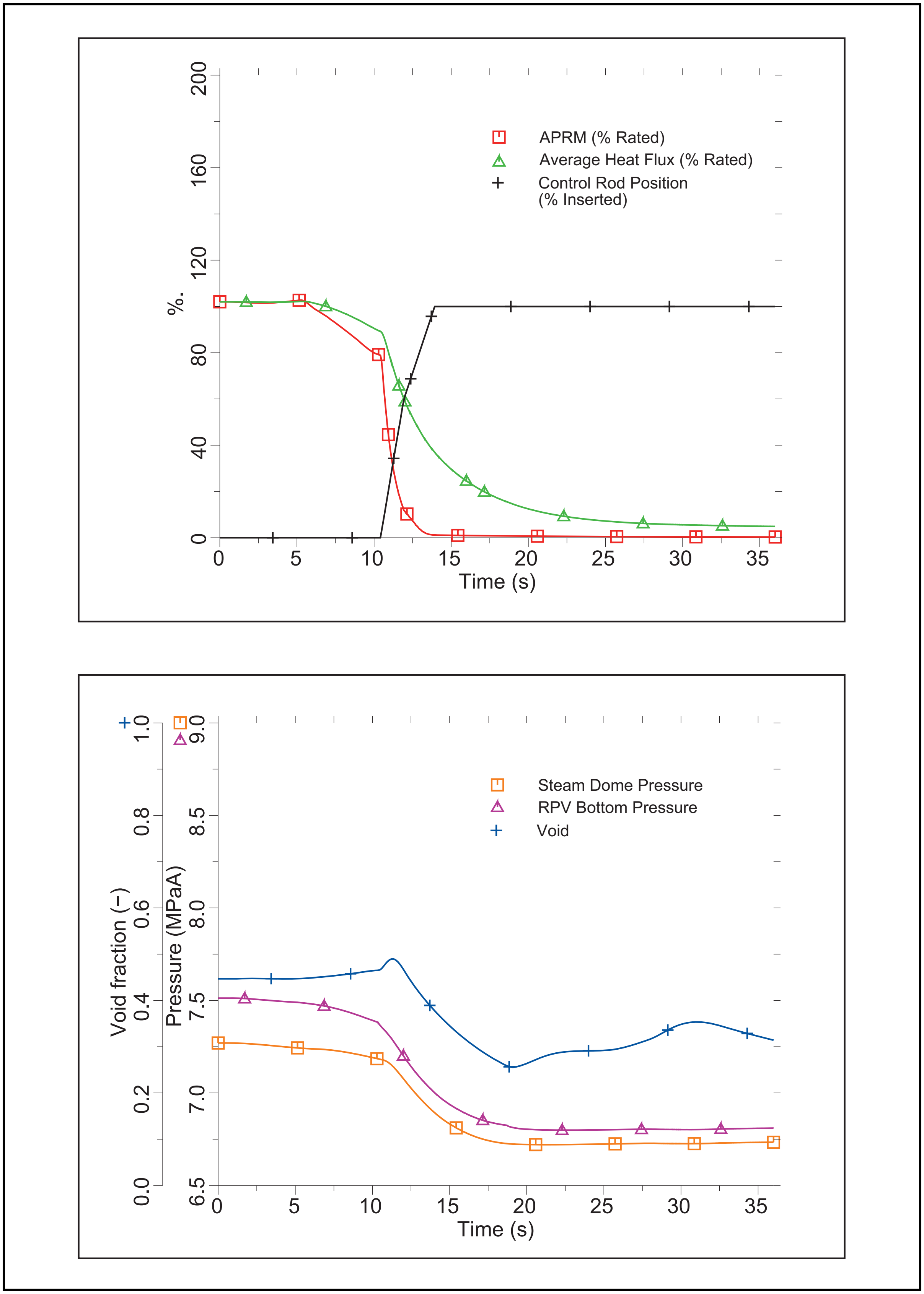


Figure 15.2-12a Loss of All Feedwater Flow

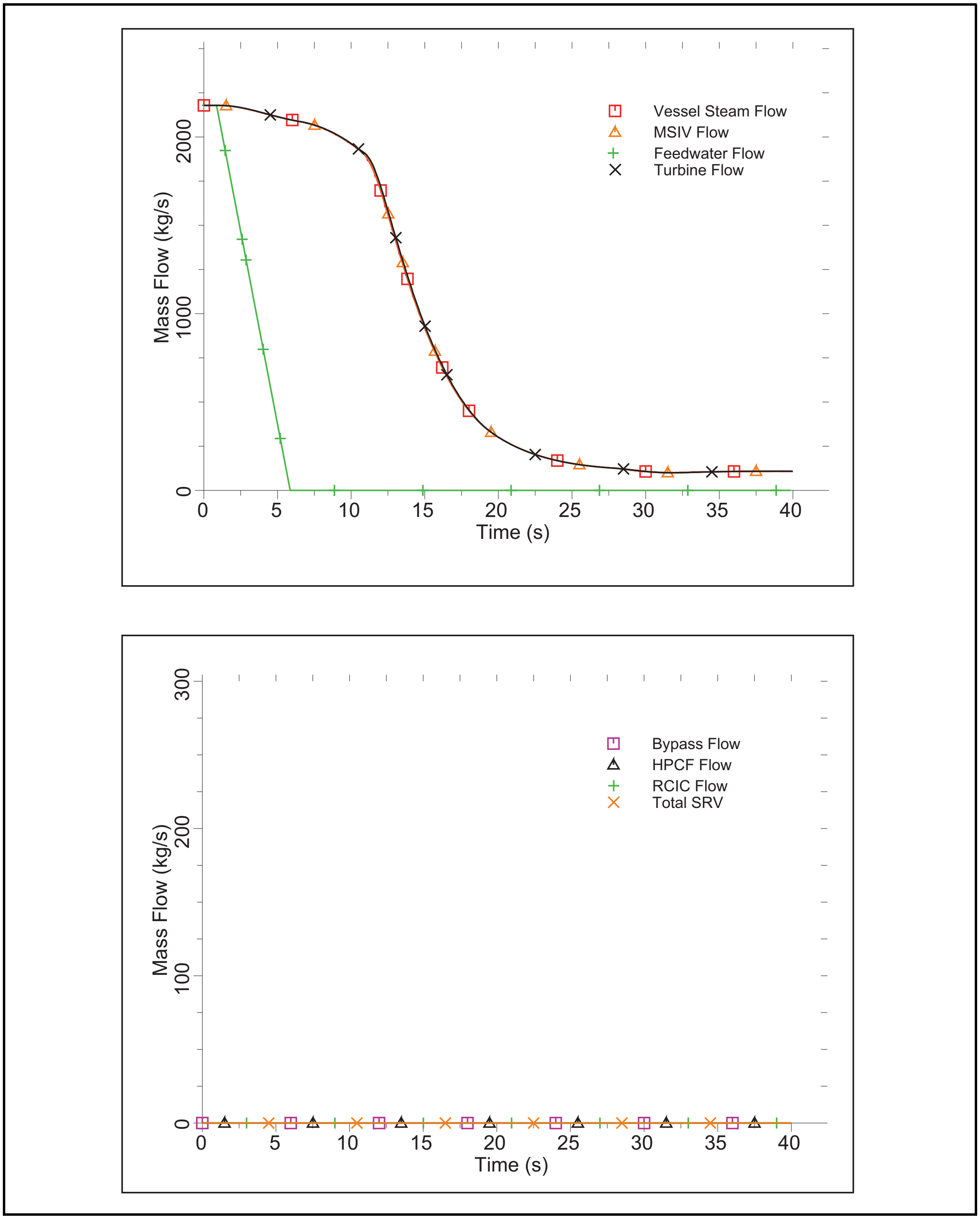


Figure 15.2-12b Loss of All Feedwater Flow

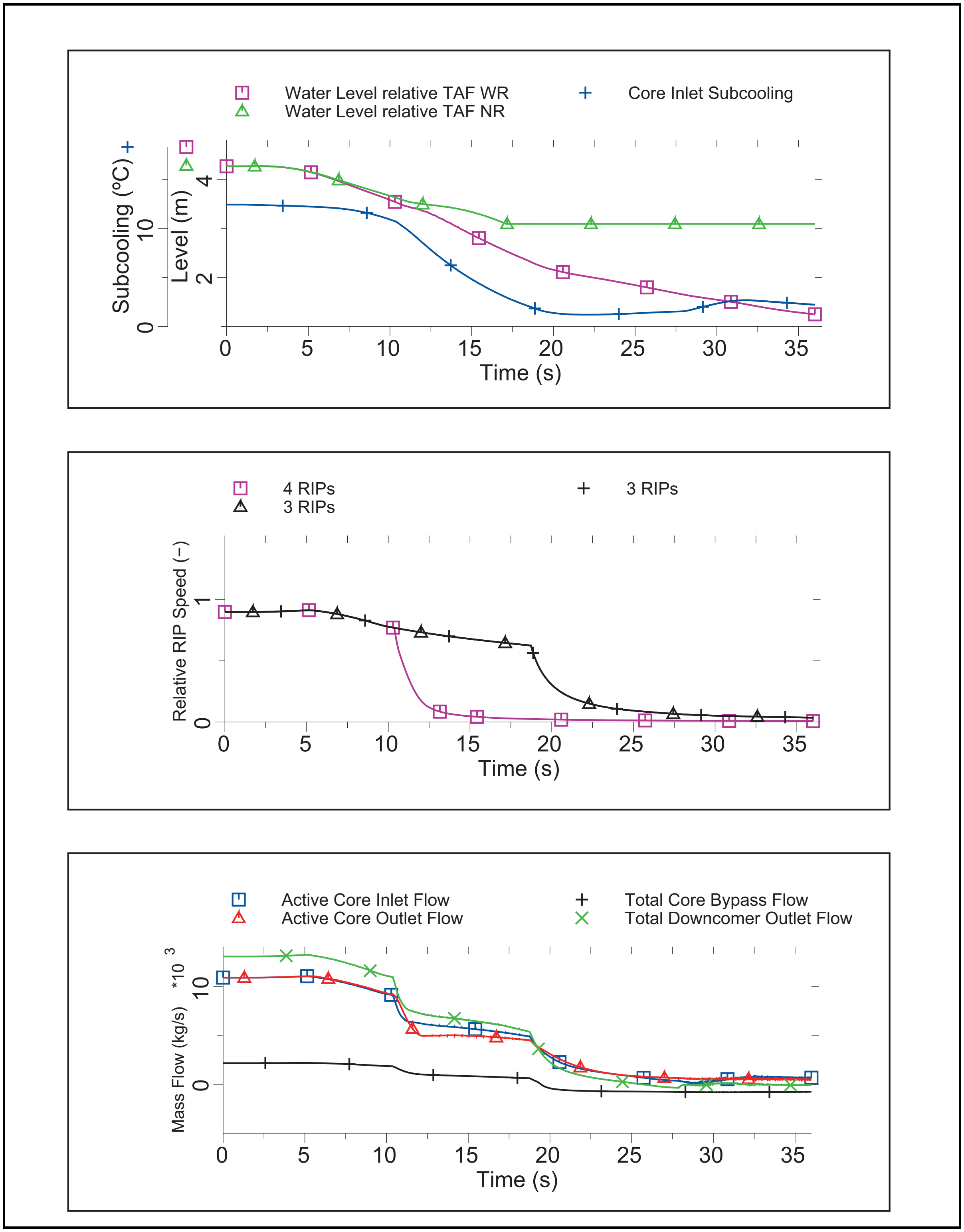


Figure 15.2-12c Loss of All Feedwater Flow