ENCLOSURE 2

MFN 06-057

Presentation Regarding TRACG Application for ESBWR ATWS –

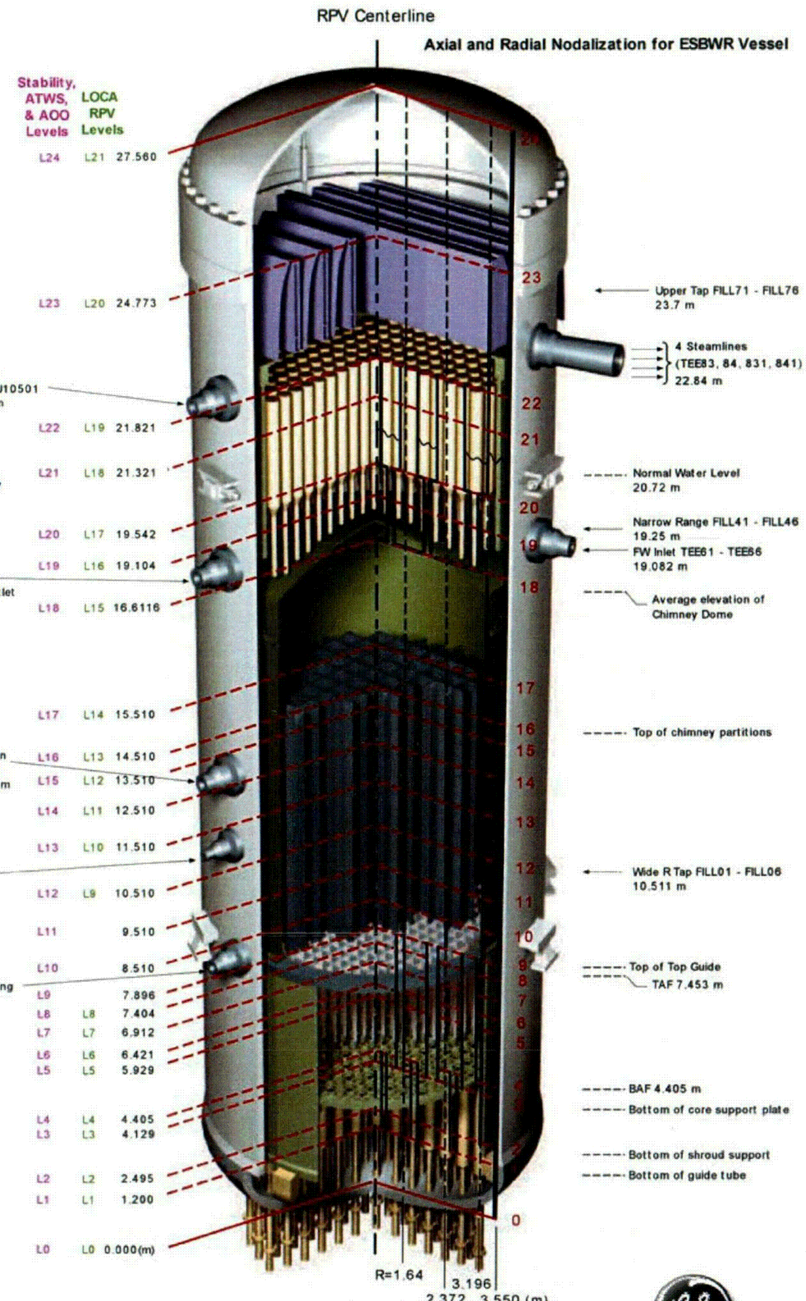
January 18, 2006

Non Proprietary Version

TRACG Application for ESBWR ATWS

NRC Review kickoff

January 18, 2006



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TRACG ESBWR ATWS Application Methodology

- Background
- Licensing Requirements and Acceptance Criteria
- CSAU Application Methodology
- Scenario Description
- Phenomena Identification and Ranking
- Model Capability and Qualification
- Model Uncertainties

Background

GE ATWS analysis of BWRs currently performed with ODYN or TRACG for peak pressure

- ODYN for steam flow to pool
- TASC code for PCT
- Energy balance model for Suppression pool heat-up

NRC recently approved ESBWR TRACG AOO for the TRACG application to LOCA

- ESBWR AOO follows approved TRACG forced circ. application methodology

ESBWR TRACG ATWS analysis for RPV pressure, PCT, and Pool temperature

- References or follows analysis models, nodalization, procedures, tests and qualification, which have been previously been submitted or approved by the NRC.
- Justify TRACG adequate w.r.t. phenomenon or models that have not been reviewed by NRC in prior TRACG applications

Scope of Review

GE will request NRC approval of TRACG for use in analysis of ESBWR ATWS transients.

Licensing Requirements and Scope of Application

- **10CFR50 Appendix A**
  Anticipated Transient Without Scram (ATWS)
  Anticipated Operational Occurrence (AOO) followed by failure of the reactor trip portion of the protection system

10CFR50.62: Features required to mitigate ATWS

1) An ARI system that utilizes sensors and logic which are diverse and independent of the RPS,
2) An automatic standby liquid control system (SLCS) with a minimum capacity equivalent to 86 gpm of 13 weight percent sodium pentaborate solution.
3) Automatic recirculation pump trip (RPT)
   - HW requirements, rather than acceptance criteria.
   - BWR performance with the required hardware shown to meet specific criteria in NED-24222.

Prevention/mitigation features of ESBWR

1) An ARI system that utilizes sensors and logic which are diverse and independent of the RPS,
2) An automatic standby liquid control system (SLCS) with a minimum capacity equivalent to 86 gpm of 13 weight percent sodium pentaborate solution.
3) Electrical insertion of FMCRDs from diverse sensors and logic
4) Automatic feedwater runback from diverse sensors and logic
   - ESBWR has no recirculation pumps to be tripped; no RPT logic.
   - 3) & 4) are additional features provided not required by 10CFR50.62

NED 24222 Acceptance Criteria

RPV Integrity

- Primary System pressure is limited to ASME Emergency Limit (1500 psi)

Fuel Integrity

- 2200 deg. F PCT
- 17% local oxidation (same as 10CFR50.46)

Containment Integrity

- Pressure & Temperature limited to design limits

Long-Term Shutdown Cooling

- Reactor brought to a safe shutdown condition, cooled down and maintained in cold shutdown.

Critical safety parameters

Reactor pressure vessel (RPV) pressure,

Fuel clad temperature (PCT) and oxidation,

Suppression pool temperature and

Containment pressure.

Standard Review Plan Guidelines (NUREG 800)

- The guidelines provided in the Standard Review Plan 15.8, ATWS predate 10CFR50.62.

Current Implementation and Practices

- NRC has approved TRACG for forced circ plant AOO and ATWS peak pressure. GE also uses ODYN for ATWS analysis of operating plant pres., pool temp. and PCT.

Consideration of Uncertainties/Use of Nominal values

NED 24222:

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Applying CSAU methodology to ESBWR ATWS

CSAU: Evaluating the total model and plant parameter uncertainty for a nuclear power plant calculation.

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Intent of application in ESBWR: assure results are not non-conservative

Conformance with CSAU Process

CSAU Step	Description	Addressed In
1	Scenario Specification	AOO without Scram
2	Nuclear Power Plant Selection	ESBWR 4500 MWt
3	Phenomena Identification and Ranking	Table 3.1-1
4	Frozen Code Version Selection	TRACG04
5	Code Documentation	References [1,2,6,7,11]
6	Determination of Code Applicability	Table 4.2-1
7	Establishment of Assessment Matrix	Table 4.2-2
8	Nuclear Power Plant Nodalization Definition	Section 5
9	Definition of Code and Experimental Accuracy	Section 5
10	Determination of Effect of Scale	Section 5
11	Determination of the Effect of Reactor Input Parameters and State	Section 6
12	Performance of Nuclear Power Plant Sensitivity Calculations	Section 8
13	Determination of Combined Bias and Uncertainty	Section 8
14	Determination of Total Uncertainty	Section 8

Sections & Table nos. refer to LTR

Advantages of TRACG Compared to the Current Process

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Implementation Requirements

-Review and approval by the NRC of the process for analyzing ATWS events

Review Requirements For Updates

-Similar to TRACG AOO

Nuclear Power Plant Selection

-ESBWR

ATWS Scenarios include AOO initiating events

- Pressurization events
- Depressurization events
- Core flow transients (NA for ESBWR)
- Cold water events
- Level transient events
- Accidents are not combined w/ failure to scram e.g. load rejection w/ bypass failure

Category I Limiting scenarios,

- Main Steamline Isolation Valve Closure
- Loss of Condenser Vacuum
- Loss of FW Heating (SCRRI rod insertion failure)
- MSIVC was chosen for uncertainty evaluation

Category II Moderate Impact scenarios

- Loss of Normal AC Power to Station Auxiliaries
- Loss of Feedwater Flow
- Load Rejection with a Single Failure in the Turbine Bypass System
- Results presented in DCD

Category III: Minimum Impact Events

These events do not significantly influence the design of ATWS mitigation. No results provided.

- Closure of One Turbine Control Valve
- Generator Load Rejection/Turbine Trip with Bypass
- Closure of One Main Steam Isolation Valve
- Loss of Shutdown Cooling Function of RWCU/SDC System
- Runout of One Feedwater Pump
- Opening of One Control or Turbine Bypass Valve
- Loss of Unit Auxiliary Transformer
- Inadvertent Isolation Condenser Initiation

Scenario selection summary

- Limiting scenarios for ATWS overpressure and PCT:
  - Main Steam Line Isolation Valve Closure (MSIVC),
  - Loss of Feedwater Heating, and
  - Loss of Condenser Vacuum
- Loss of Condenser Vacuum gives slightly higher values, the MSIVC uncertainty evaluation is applied to LCV.
- LOFWH is evaluated to check PCT

Phenomena Identification and Ranking TABLES (PIRT)

Divide the limiting scenarios into four phases:

1) Short term pressurization, neutron flux increase, and fuel heatup
2) Water level reduction (about 80% of the pool heatup occurs prior to the power reduction via water level, and 95% prior to SLC injection)
3) Boron injection, mixing and negative reactivity insertion. (about 5% of the pool heatup occurs during boron shutdown.)
4) Post-shutdown suppression pool heatup
5) Depressurization (if reqd. by EOP)

Phenomenon described in TAPD PIRT submittal to NRC.

3.0 Phenomena Identification and Ranking Tables (PIRT)

Critical safety parameters, for ESBWR ATWS analyses,

- Reactor pressure vessel (RPV) pressure,
- Peak fuel Clad Temperature (PCT),
- Containment pressure and suppression pool temperature.

Phenomena Identification and Ranking Tables (PIRT)

Scale of high importance to low importance or not applicable, as defined by the following categories:

- *High importance (H):* These phenomena have a significant impact on the primary safety parameters and should be included in the overall uncertainty evaluation. An example of such a parameter would be the *void coefficient* during the short term pressurization phase (C1AX in Table 3-1). The void coefficient determines the amount of reactivity change due to void collapse during this phase.
- *Medium importance (M):* These phenomena have insignificant impact on the primary safety parameters and may be excluded in the overall uncertainty evaluation. An example of such a parameter would be the *direct moderator heating* during the pressurization, level reduction and boron injection phases (C3DX in Table 3-1). Direct moderator heating deposits some of the core energy in the in-channel and bypass moderator in the initial steady state and during the transient. Its modeling can be expected to have some effect on the results, but the critical safety parameter will not be highly sensitive to modeling uncertainty in this phenomenon.

Phenomena Identification and Ranking Tables (PIRT)

- *Low importance (L) or not applicable (N/A):* These phenomena have no impact on the primary safety parameters and need not be considered in the overall uncertainty evaluation. An example of such phenomena would be *Steam Dome Condensation on Walls* during the pressurization phase of an ATWS (K2 in Table 3-1). The maximum energy that could be absorbed in the steam dome metal, is a small fraction of the core power, and it could not impact the critical parameters in any significant way.

For ESBWR ATWS evaluation, the following specific definitions are employed:

ATW1 Boron mixing/entrainment between the jets downstream of the injection nozzle.

ATW2 Boron settling in the guide tubes or lower plenum/

ATW3 Boron transport and distribution through the vessel, particularly in the core bypass region.

Table 3-1 Highly Ranked PIRTs

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4.0 Applicability of TRACG to ATWS Analyses

4.1 Model Capability

The capability to calculate an event for a nuclear power plant depends on four elements:

- Conservation equations, which provide the code capability to address global processes.
- Correlations and models, which provide code capability to model and scale particular processes.
- Numerics, which provide code capability to perform efficient and reliable calculations.
- Structure and nodalization, which address code capability to model plant geometry and perform efficient and accurate plant calculations.
- 4.1 Model Capability matrix correlates the phenomena to section of the model description report

4.2 Applicability of TRACG to ATWS Analyses (continued)

Model qualification matrix correlates the phenomena to:

- Separate Effects Qualification
- Component Performance Qualification
- Integral System Qualification
- Plant Data Qualification

5.0 Model Uncertainties and Biases

The uncertainty of the code in predicting the phenomena is quantified

Some of the key phenomena are discussed in the following slides

ATW1 Boron Mixing and Distribution

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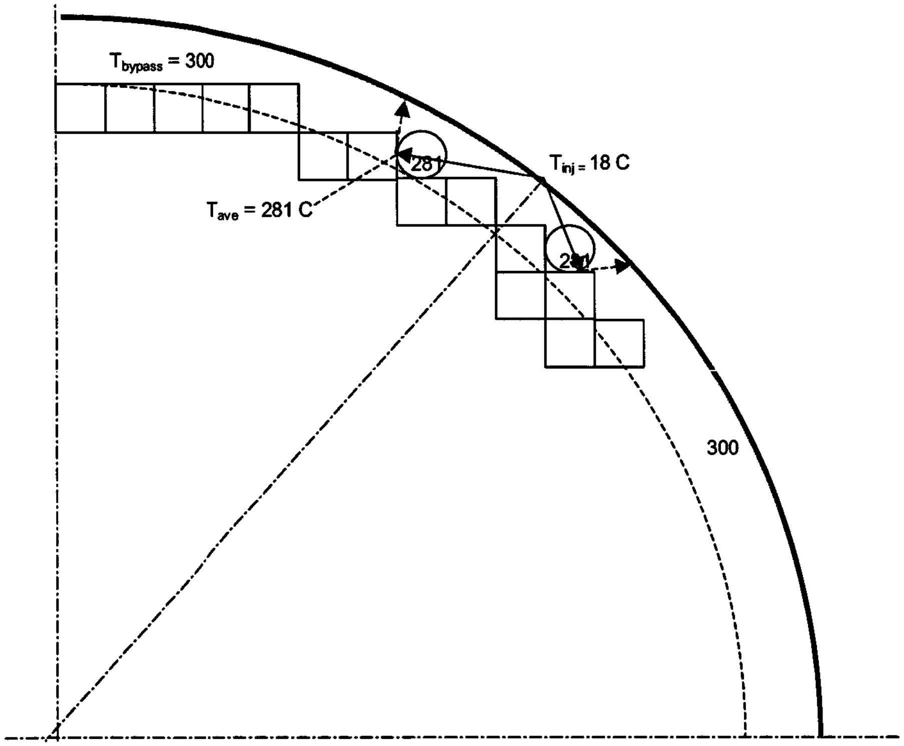
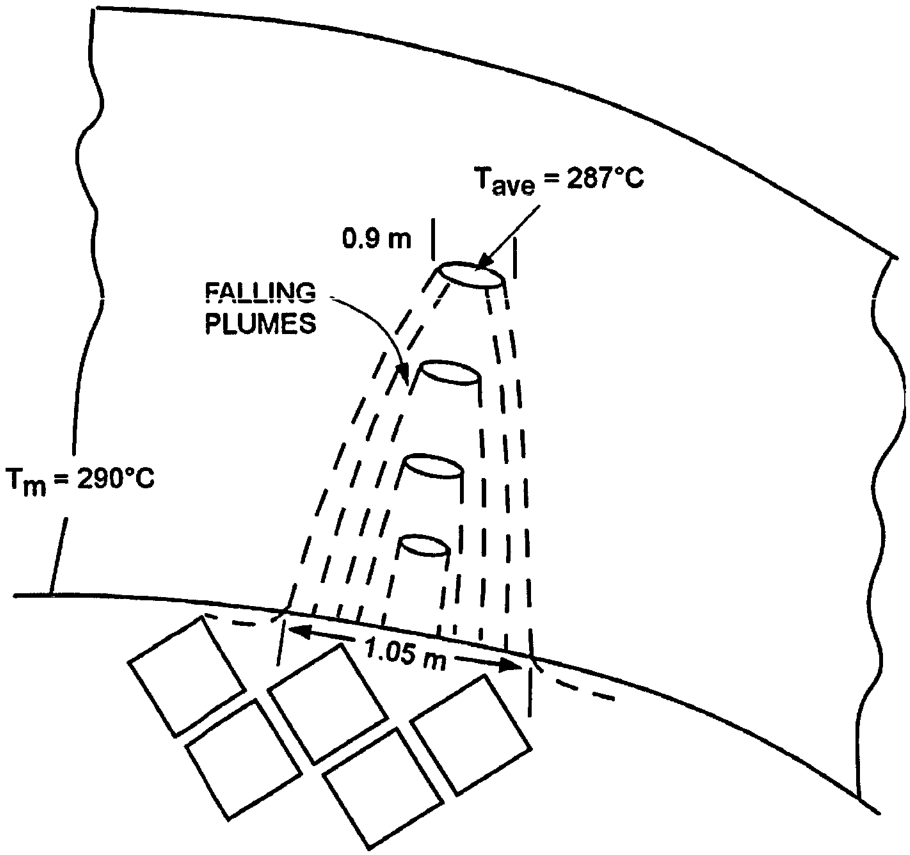
Jet Entrainment in the bypass



Down Flow of Mixed Solution in Bypass

Figure 5.1-3. Downward Plumes in Annular Space



Radial Flow in Lower Bypass

Figure 5.1-4. Boron Settling in guide Tubes and Lower Plenum

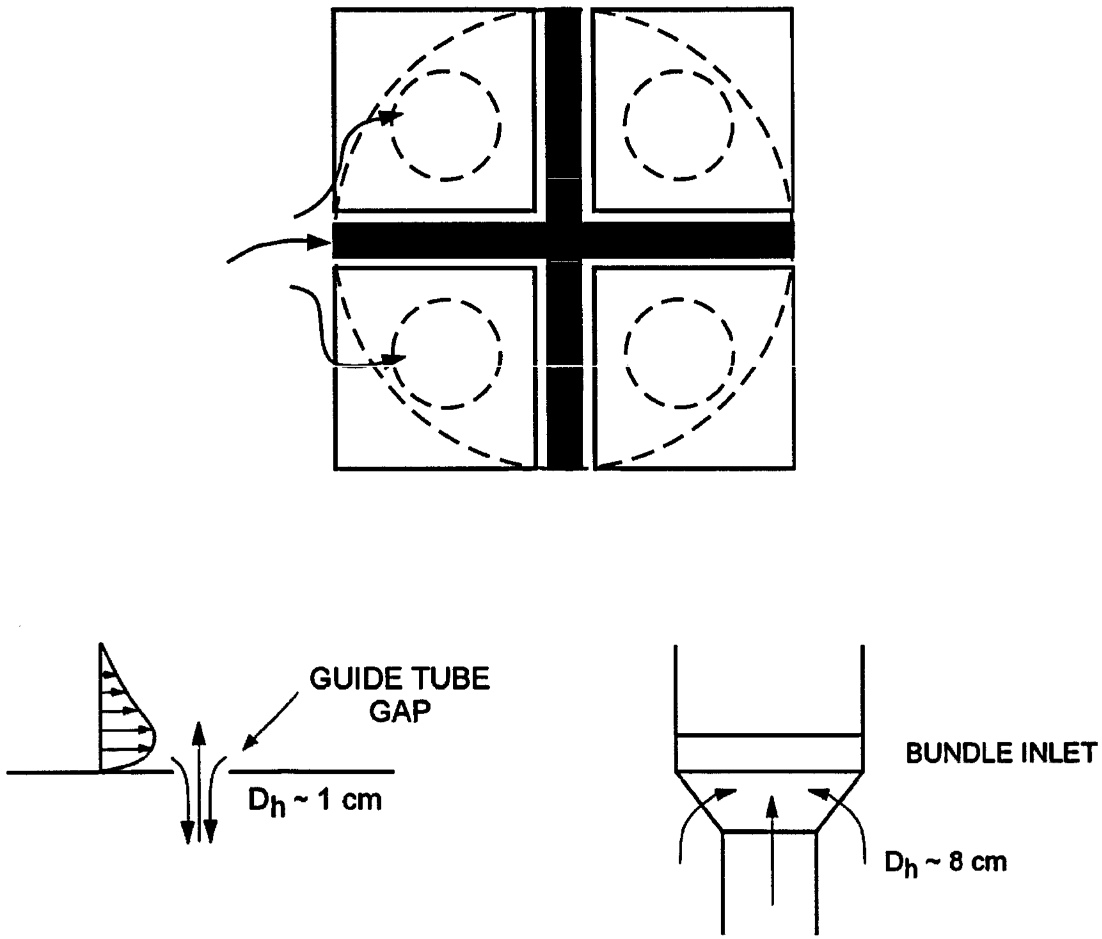


Figure 5.1-5. Liquid Temperatures Calculated in the Bypass Region by TRACG at Level 7 (above injection elevation)

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Figure 5.1-6. Liquid Temperatures Calculated in the Bypass Region by TRACG at Level 5 (injection elevation)

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Conclusions for Boron Mixing

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ATW5: Boron reactivity

B10 total cross section modeled by 1/v relationship

- Accounts for effects of fuel temperature and boron self-shielding

Calibrated against GE lattice physics model (TGBLA06) over range of lattices

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C2AX: Interfacial shear

TRACG qualification was extended to cover low pressure Toshiba void fraction tests

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C2AX: Interfacial shear

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Sensitivity of TRACG Prediction of Toshiba Void Fraction to PIRT Multiplier on $(C_0\text{-}1)$

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Sensitivity of TRACG Prediction of Toshiba Void Fraction to PIRT Multiplier on Entrainment Coefficient, η

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Lognormal Probability Distribution for PIRT22 and PIRT52

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C13: Dryout (Steady State and Transient Effects)

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C13: Modified Zuber Correlation Statistics

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C17: Steam Cooling (H)

Error in applying Dittus-Boelter correlation (used in TRACG) for superheated steam evaluated vs. rod bundle superheated steam tests

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C17: Steam Cooling (H)

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Minimum Film Boiling Temperature (C19X)

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L1: SRV critical flow

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However, for ATWS application, nameplate capacity is used as limiting value

Table 5.1-1. Bias and Uncertainty for High Ranked ATWS Model Parameters

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6.0 Application Uncertainties and Biases
6.1 Input

Code inputs can be divided into four broad categories:

(1) Geometry inputs;

(2) Model selection inputs;

(3) Initial conditions inputs; and

(4) Plant parameters

6.2 Initial Conditions

As described in Section 6.2 of Reference 1 *initial conditions* are those conditions that define a steady-state operating condition. Initial conditions may vary due to the allowable operating range or due to uncertainty in the measurement at a given operating condition. The key plant initial conditions and associated uncertainties are given in Table 8.2-1.

Due to the extremely low probability of the occurrence of an ATWS, the NRC Staff has accepted nominal initial conditions for ATWS analysis. However, as previously mentioned, defining a nominal initial condition is not always straightforward. Consequently, the transients will be initiated from the limiting point(s) in the allowed operating domain. Specifically, the impact of a particular initial condition on the results is characterized in the following manner:

- The results are sensitive to the initial condition and a basis for the limiting initial condition cannot be established. Future plant analyses will consider the full allowable range of the initial condition.
- The results are sensitive to the initial condition and a basis for the limiting initial condition can be established. Future plant analyses will consider the parameter to be at its limiting initial condition.
- The results are not sensitive to the initial condition and a nominal initial condition will be assumed for the parameter.

7.0 Combination of Uncertainties

Table 7-1. Methods for Combining Uncertainty

Method	Description
Propagation of Errors	Uncertainties in the calculated safety parameters to individual phenomena are evaluated from single perturbations and the overall uncertainty is determined as the square root of the sum of the squares of the individual uncertainties.
Response Surface Technique	Response surface for the safety parameter is generated from parameter perturbations. Statistical upper bound is determined from the Monte Carlo method using a response surface.
Order Statistics Method - Single Bounding Value (GRS Method)	Monte Carlo method using random perturbations of all important parameters. Sample size defined to yield desired statistical confidence. Statistical upper bound is determined from most limiting perturbation (for first order statistics).
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Table 7-2. Comparison of Methods for Combining Uncertainties

Method for Combining Uncertainties	Advantages	Disadvantages
Propagation of Errors	Relatively small number computer runs, when the number of input variables is small. The number of cases is linearly related to the number of input parameter uncertainties considered.	Approximate because it involves linearization. Necessary either to demonstrate independence of effects of individual uncertainties on responses, or else must include covariances explicitly.
Response Surface	Very precise statistical characterization of results with a large number of Monte Carlo Trials using response surface. Different distributions can be specified for each input uncertainty. Independence of the effect of individual input parameters on response is not necessary.	Number of computer runs depends on the response surface model and increases exponentially with the number of input parameter uncertainties considered. Interactions between input parameters have to be established and considered in the development of the response surface.

Table 7-2. Comparison of Methods for Combining Uncertainties

Method for Combining Uncertainties	Advantages	Disadvantages
Order Statistics (GRS)	The number of random trials is independent of the number of input parameters considered. The method requires no assumption about the PDF of the output parameter. It is not necessary to perform separate calculations to determine the sensitivity of the response to individual input parameters. It is not necessary to make assumptions about the effect on the output of interactions of input parameters.	Since the tolerance limits are based on order statistics, they will vary from one set of TRACG trials to another, and these differences may be substantial, especially for small sets of TRACG trials, and particularly if the tolerance bound is the sample extreme.
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7.1 Recommended Approach for Combining Uncertainties

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8.0 Demonstration Analysis

The TRACG performance is demonstrated on the MSIVC, LCV, and LFWH scenarios specified in Section 2.7. This demonstration includes:

1. A TRACG baseline analysis for the three category 1 scenarios using an equilibrium core designed for the ESBWR,
2. A demonstration of the sensitivity of the transient to initial conditions and plant parameters for the limiting scenario of MSIVC, and
3. A demonstration of the sensitivity of the transient to the individual model uncertainties using the limiting scenario of MSIVC.

The analyses provided in this section form the bases for future application of TRACG for the ESBWR. The baseline analysis (Section 8.1) is a demonstration of the process. The initial conditions (Section 8.2.1) and plant parameters (Section 8.2.2) analyses are performed to determine the sensitivity to the critical parameters. Section 8.2.3 contains details of analyses performed to demonstrate core stability during an ATWS event. Section 8.3 presents the analyses performed to quantify the sensitivity of the critical parameters to individual model uncertainties.

8.1 Baseline Analysis

The ESBWR plant has 1132 bundles and a rated thermal power of 4500 MWth. The vessel modeling is illustrated in Figure 8.1-1. The plant has an equilibrium core of GE14 10x10 fuel. Figure 8.1-2 also shows the average bundle power in the core sectors utilized in the model for azimuthal nodalization. The bundles in Ring 3 are grouped into two groups, with the bundles with inlet orificing corresponding to the peripheral region having a much lover average power level. Figure 8.1-3 illustrates the TRACG core map showing the thermal hydraulic channel groups. The number of channels in each thermal hydraulic group and the peaking factors for each group are shown in Table 8.1-1. Channel groups were created based on core position, chimney position, orifice geometry, and peaking factor. [[

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The model used for the baseline analysis has a simple model of the S/RV discharge line and the suppression pool (see Figure 8.1-4). The pool cooling system is modeled using the TRACG control system.

The SLCS system in the ESBWR consists of two accumulators, each pressurized to 17.2 MPa, which adiabatically expand upon opening the valves to inject the hot shutdown volume of 10.8 m^3 (5.4 m^3 from each accumulator) at an approximate vessel pressure of 8.6 MPa.

The SLCS is modeled using the TRACG control system and a flow velocity profile versus time for the accumulators. The average velocity at the flow nozzles that inject the solution into the bypass region is 30.5 m/s during the first half of the injection of the volume stipulated to achieve hot shutdown. Based on the velocity versus time profile, the total volume of 10.8 m^3 is injected at high pressure into the bypass in about 9 minutes. A delay time of 2s for the SLCS valve opening and a further delay of 3s for the solution to reach the nozzle after initiation are assumed. This is in addition to the 18s delay for SLCS initiation amounting to a total delay of 189 seconds (for the MSIVC case) after the start of the transient.

Figure 8.1-1. TRACG ESBWR Vessel R-Z modeling

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Figure 8.1-2. TRACG Core Map with Sector Average Bundle Power

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Figure 8.1-3. TRACG Channel Grouping for ESBWR Core

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Figure 8.1-4 SR/V Discharge Line and Suppression Pool Nodalization

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Table 8.1-1. TRACG Channel Grouping (MOC)

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Table 8.1-1. TRACG Channel Grouping (MOC)

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The baseline models also has conservatisms included in it to bound model phenomena or certain plant component specifications. [[

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8.1.1 MSIV Closure ATWS (MSIVC) Baseline Analysis

The MSIV stroke time for these analyses is set at the minimum value of 3s. ESBWR includes an automated feedwater runback on ATWS signal, to reduce core power. This is modeled through the feedwater level control system. To simulate the FW runback, and EPG actions, the vessel level setpoint is dropped to 1.524m (5') above TAF over a period of 15s and maintained at this minimum level through the event. Analyses were performed to ensure that refilling the vessel did not lead to recriticality. The suppression pool cooling model is activated at the set point of 322K. A hot rod model is included for the four hot channels. In addition, a bundle power peaking is applied to one of the hot channels to operate at a CPR of 1.2; this is conservatively lower than the present OLMCPR of 1.3 and provides margin for future reduction in the OLMCPR. This adds a further measure of conservatism to the model from a standpoint of the radial peaking. Table 8.1-2 presents the initial conditions, Table 8.1-3 presents the equipment performance characteristics as modeled in the baseline analysis, and Table 8.1-4 presents a summary of main events in the transient scenario.

Table 8.1-2. ATWS Initial Operating Conditions

Parameters	Value
Dome Pressure, MPa (psia)	7.17 (1040)
Power, MW	4500
Steam/Feed Flow, kg/sec (Mlbm/hr)	2433 (19.31)
Feedwater Temperature, °C (°F)	215.6 (420)
Initial Suppression Pool Temperature, °C (°F)	43.3 (110)

Table 8.1-3. ATWS Equipment Performance Characteristics

Parameters	Value
Nominal MSIV Closure Time, sec	3.0
Safety/Relief Valve (S/RV) System Capacity, % of Rated Steam Flow / No. of Valves	≥89.5 / 18
S/RV Setpoint Range, MPaG (psig)	8.618 to 8.756 (1250-1270)
S/RV Opening Time, sec	<1.7
ATWS Dome Pressure Sensor Time Constant, sec	0.5
ATWS Logic Time Delay, sec	≤1
Pool Cooling Capacity, KW/C	430.6
Temperature For Automatic Pool Cooling, °C (°F)	48.9 (120)
IC Capacity	135 MWth

Table 8.1-4. Sequence of Events for MSIVC

Time (s)	Event
0	MSIV Closure starts
0.3	Feedwater runback initiated
2	IC initiation
4	ATWS trip set at high pressure
5	SRVs open
19	Suppression pool cooling starts
25	Feedwater runback complete
42	Level drops below L2 set point
52	HPCRD flow starts
189	SLCS injection starts
312	Peak Pool Temperature
384	Hot shutdown achieved
710	High pressure design volume of borated solution injected into bypass

At approximately 188.5s (trip time of 3.5s+ 180s delay+ 5s delay for valve opening and initial flow at nozzle), the SLCS flow is activated (see Figure 8.1-10) and the borated solution starts to flow into the bypass. With the external circulation loop cut off by the low water level (see Figure 8.1-7), flow to the fuel channels from the vessel lower plenum will match what is required to makeup for steam generation in the core. The total channel mass flow will be higher than this, due to liquid entering from the core bypass through the Lower Tie Plate (LTP) holes. The LTP flow direction is reversed from normal operation. Liquid exiting the top of channels recirculates down the bypass, and re-enters the LTP holes. Because the flow in the bypass is downward under these conditions, the diluted plume of boron will move with the bulk bypass flow. Boron will enter the LTP holes and flow up the channel. [[

]] As boron is transported to the center of the core, the power level drops due to the large negative reactivity insertion (see Figure 8.1-10) and reaches decay heat levels after 159s from the time of injection (power is within half a percent of the decay heat). The S/RV discharge into the suppression pool stops at about 450s into the transient and the pool temperature peaks at 351K. This is well below the HCTL limit for the pool at the corresponding dome pressure (see Figure 8.1-11).

Table 8.1-5 summarizes the key results from the baseline analysis of the MSIVC event.

Table 8.1-5. Key Results from MSIVC

Parameter	Value	Time
Maximum Neutron Flux, %	228	3s
Maximum Vessel Bottom Pressure, MPaG (psig)	9.76 (1415)	29s
Maximum Bulk Suppression Pool Temperature, ºC (ºF)	78.2 (172.8)	312s
Associated Containment Pressure, MPaG (psig)	0.193(27.96)	312s
Peak Cladding Temperature, ºC (ºF)	915.5(1679.8)	24s

Figure 8.1-5. MSIVC Neutron Flux and Core Flow

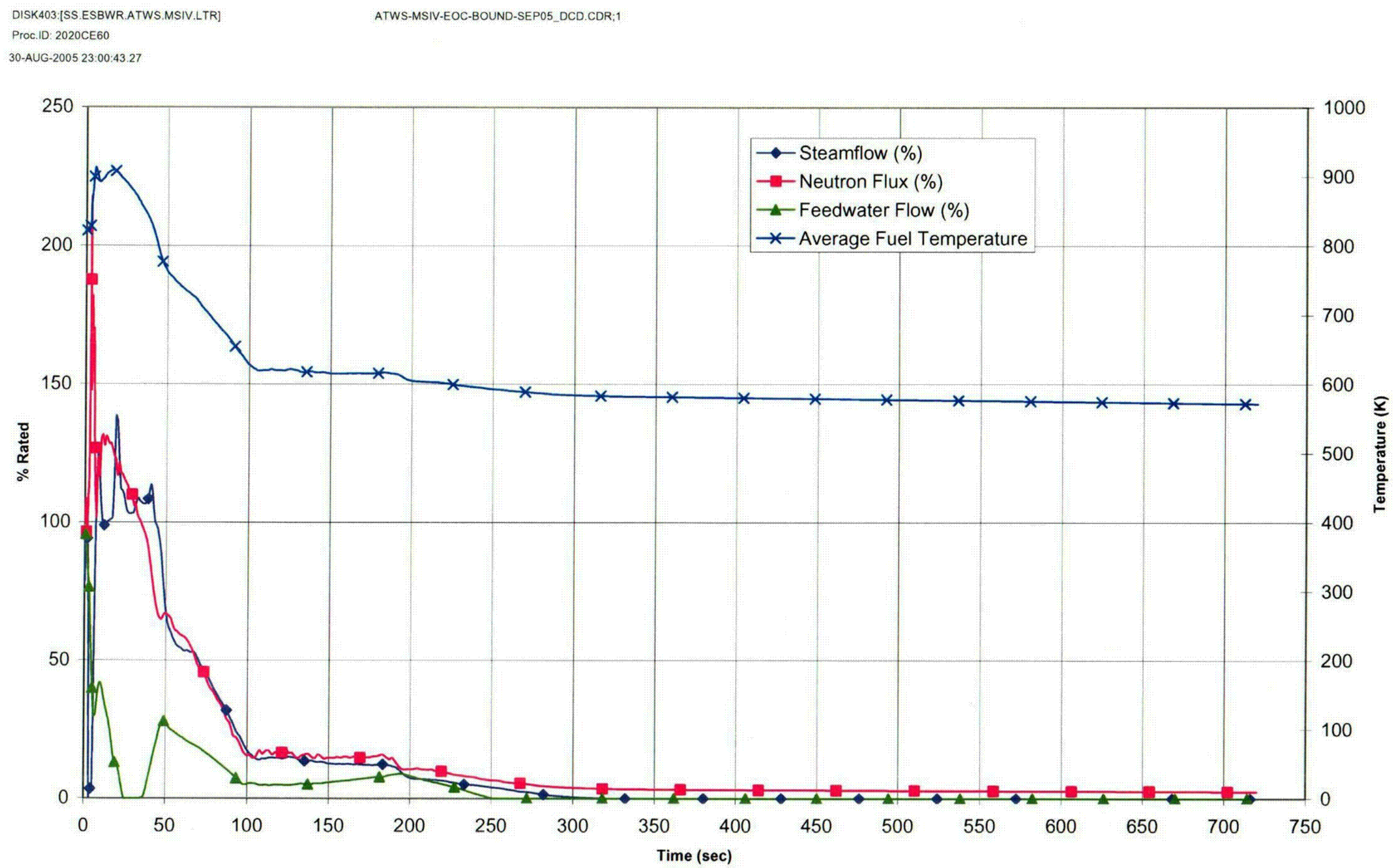

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Figure 8.1-6. MSIVC Steam and Feedwater Flow

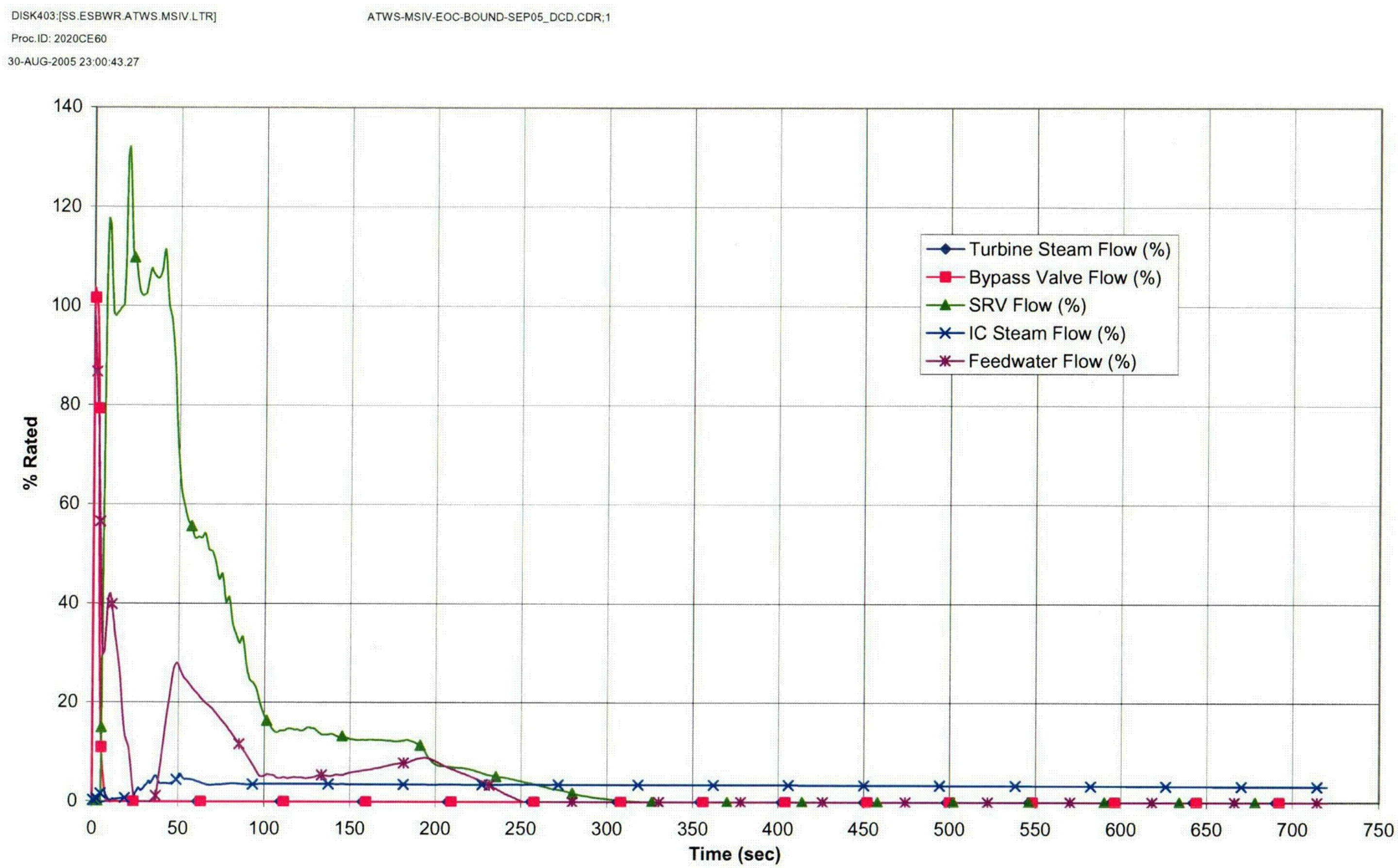

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Figure 8.1-7. MSIVC Water Levels

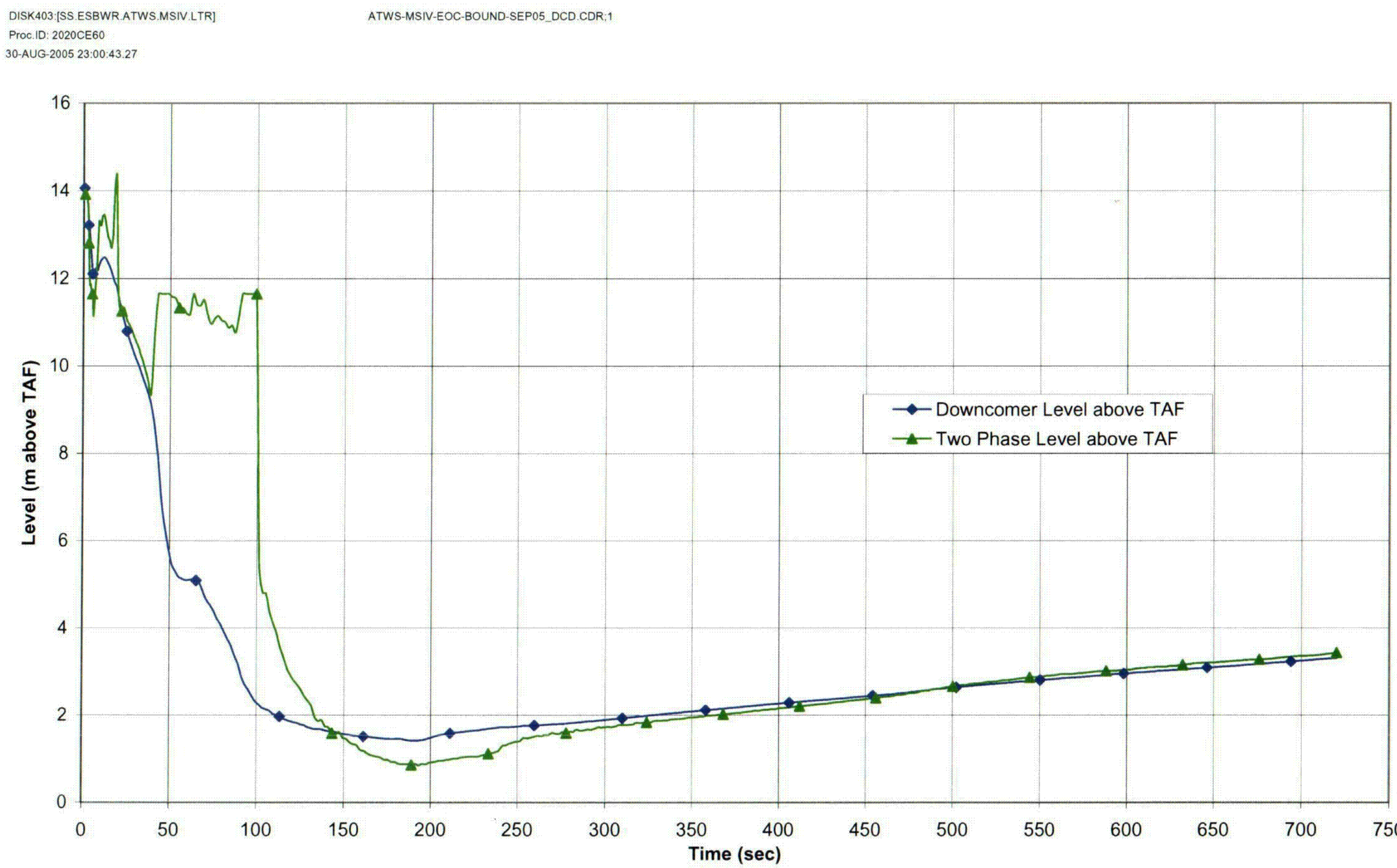

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Figure 8.1-8. MSIVC Dome Pressure and Pool Temperature

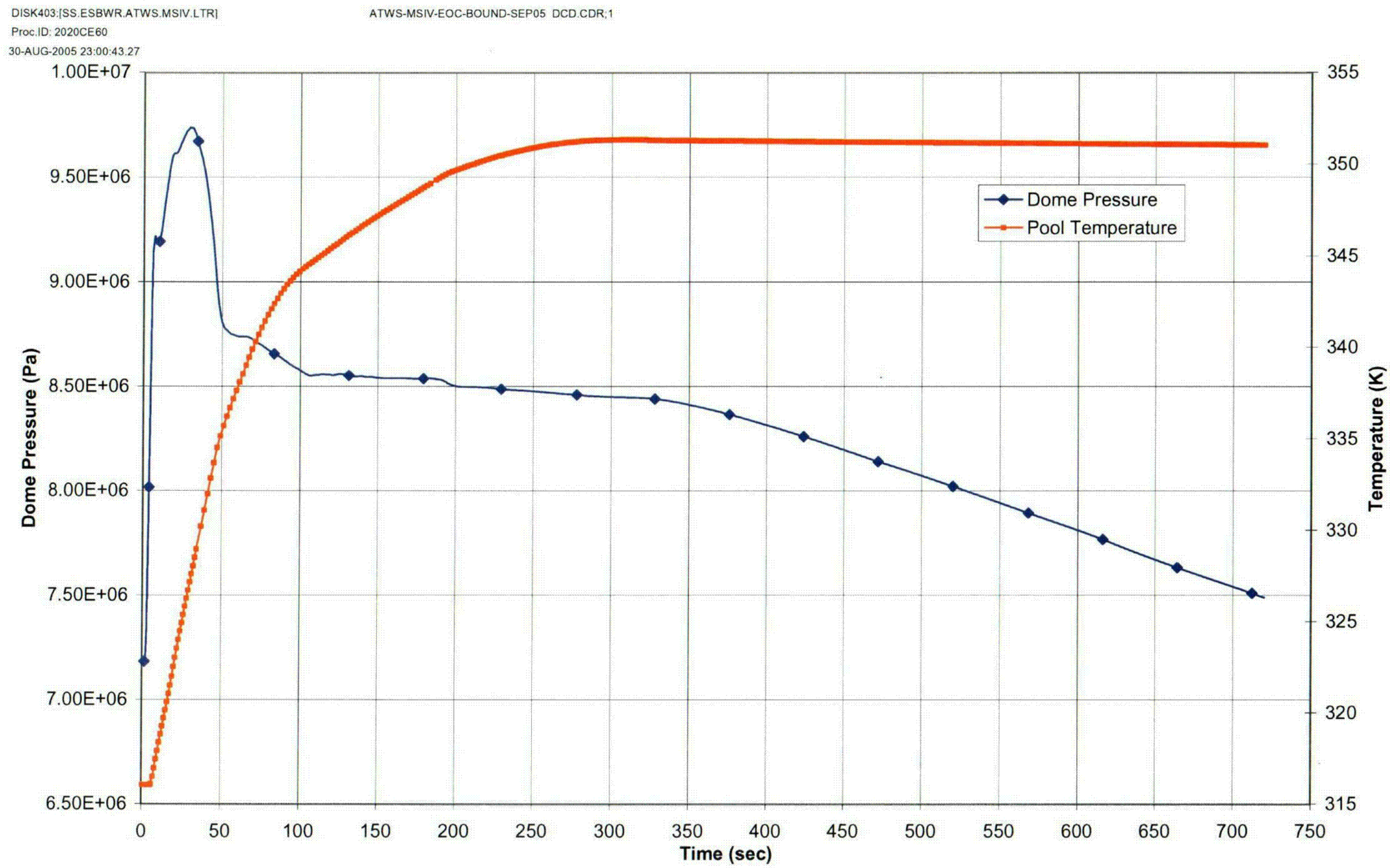

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Figure 8.1-9. MSIVC Neutron Flux and Core Flow

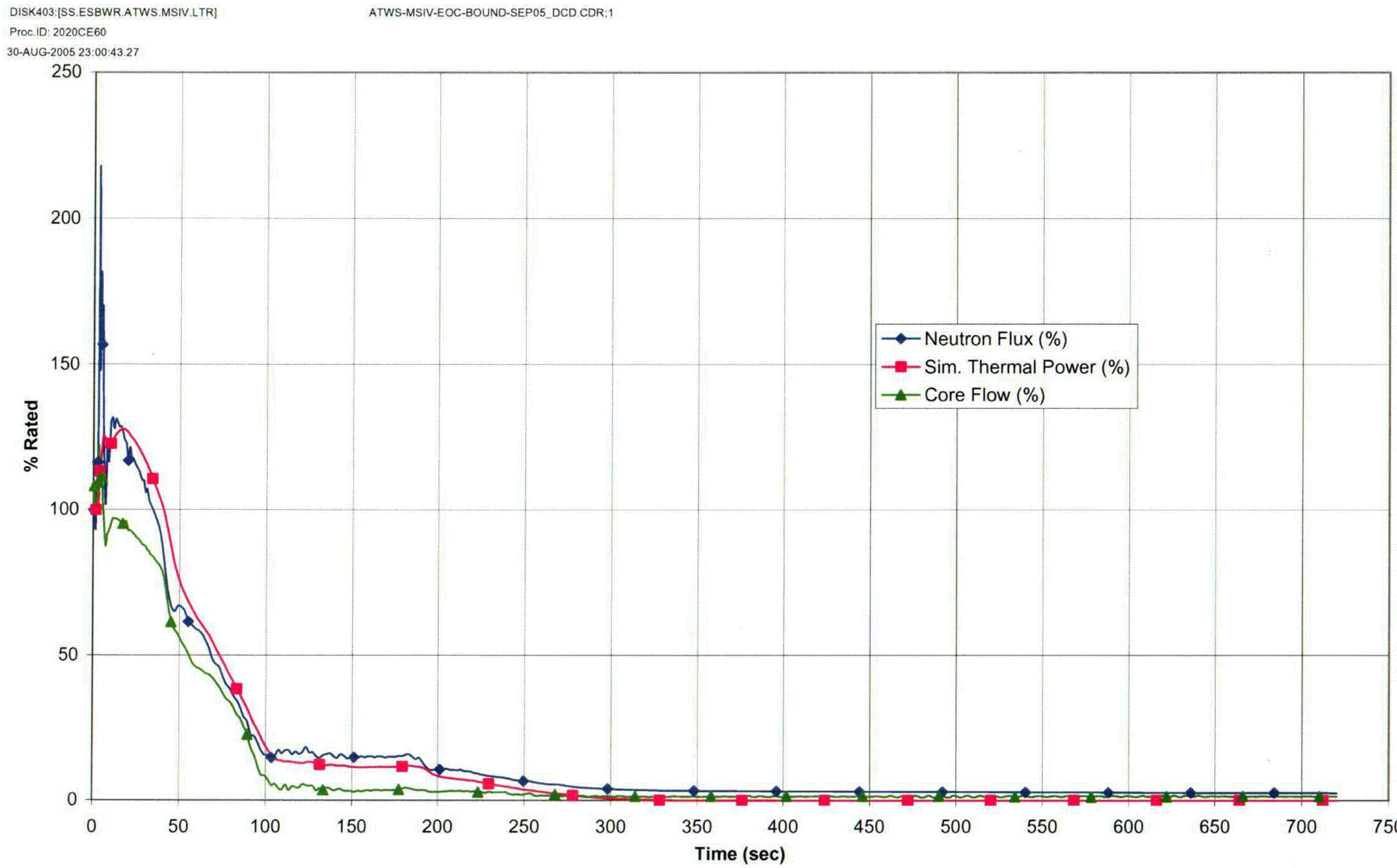

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Figure 8.1-10. MSIVC Reactivity Feedback and Boron Concentration

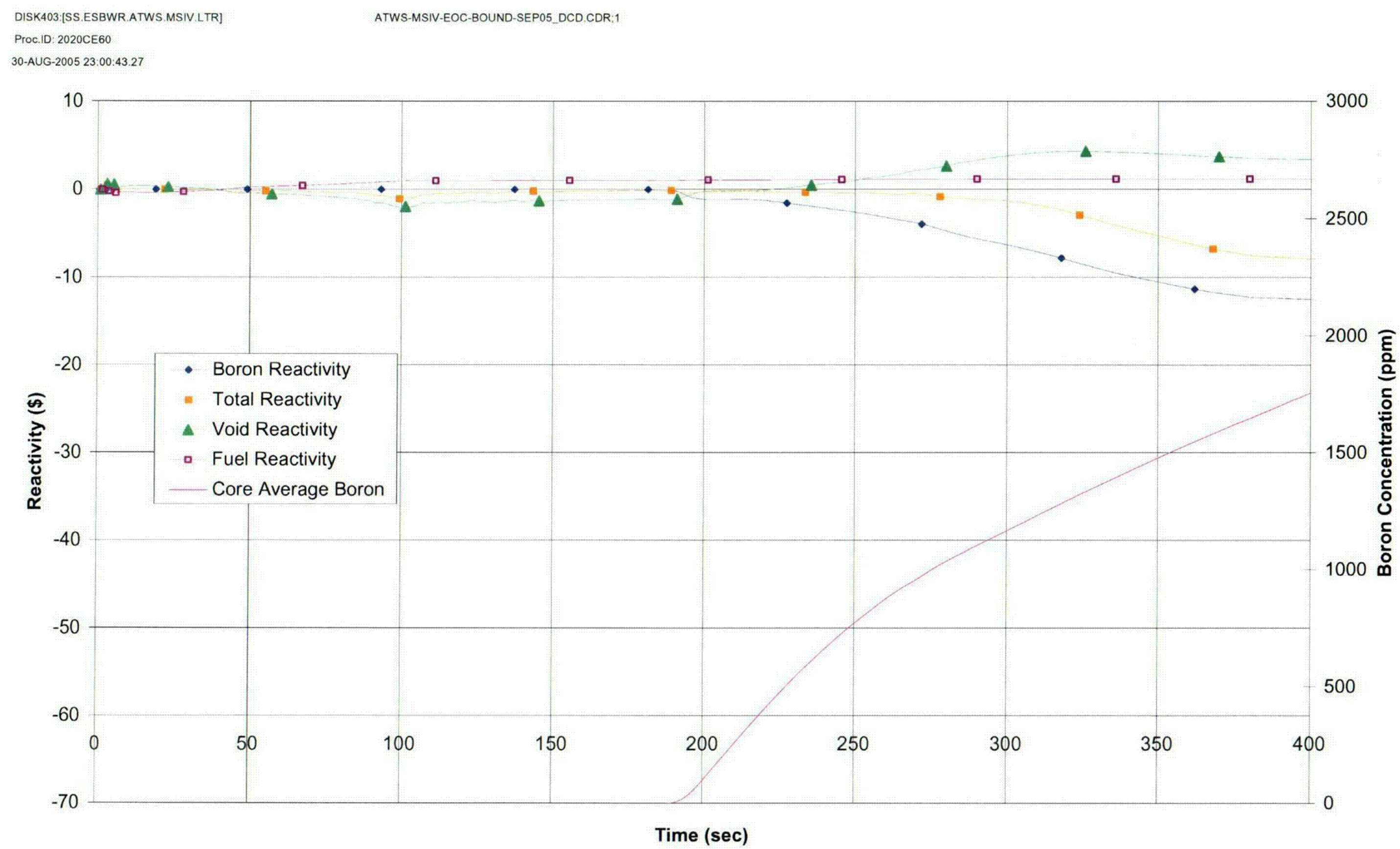

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Figure 8.1-11. MSIVC HCTL and Pool

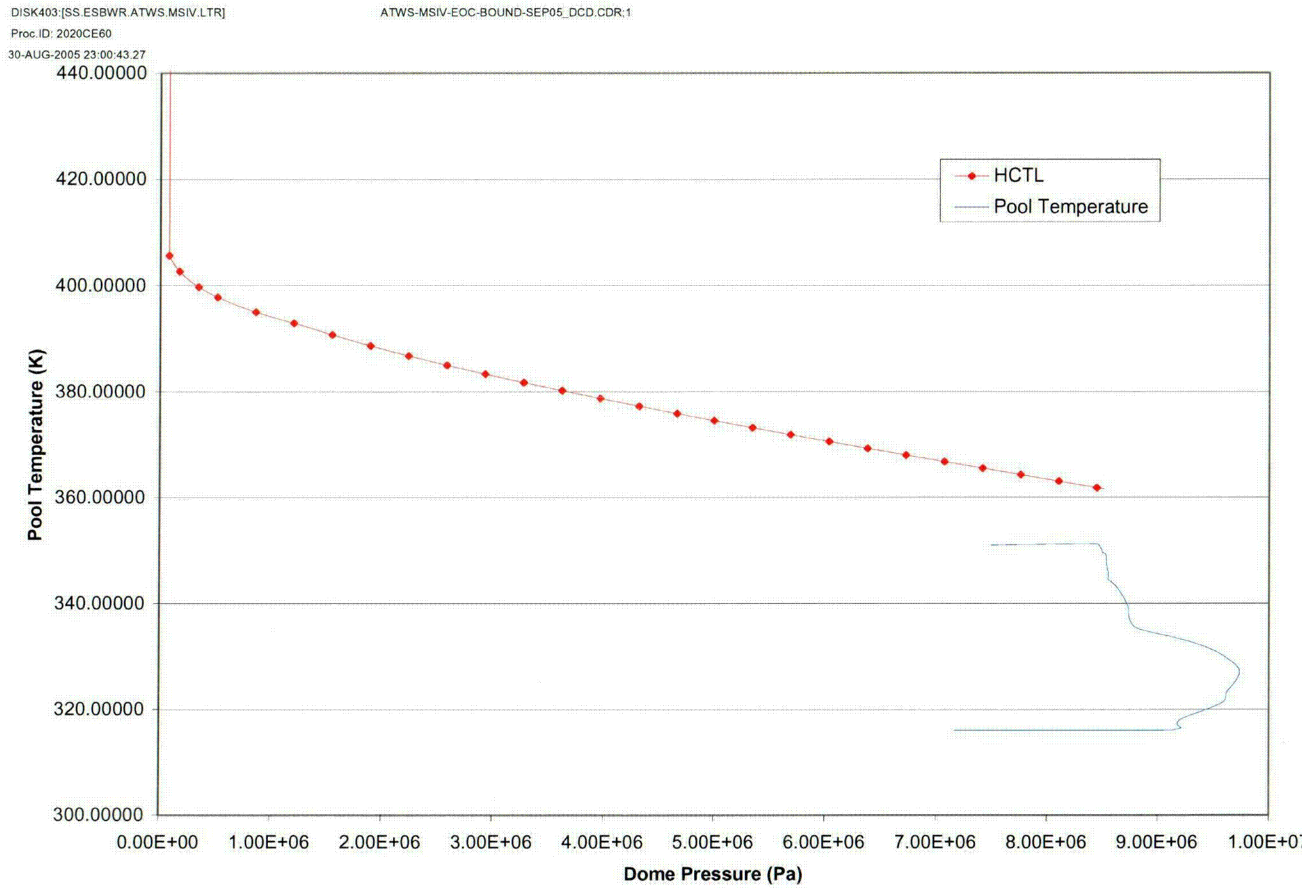

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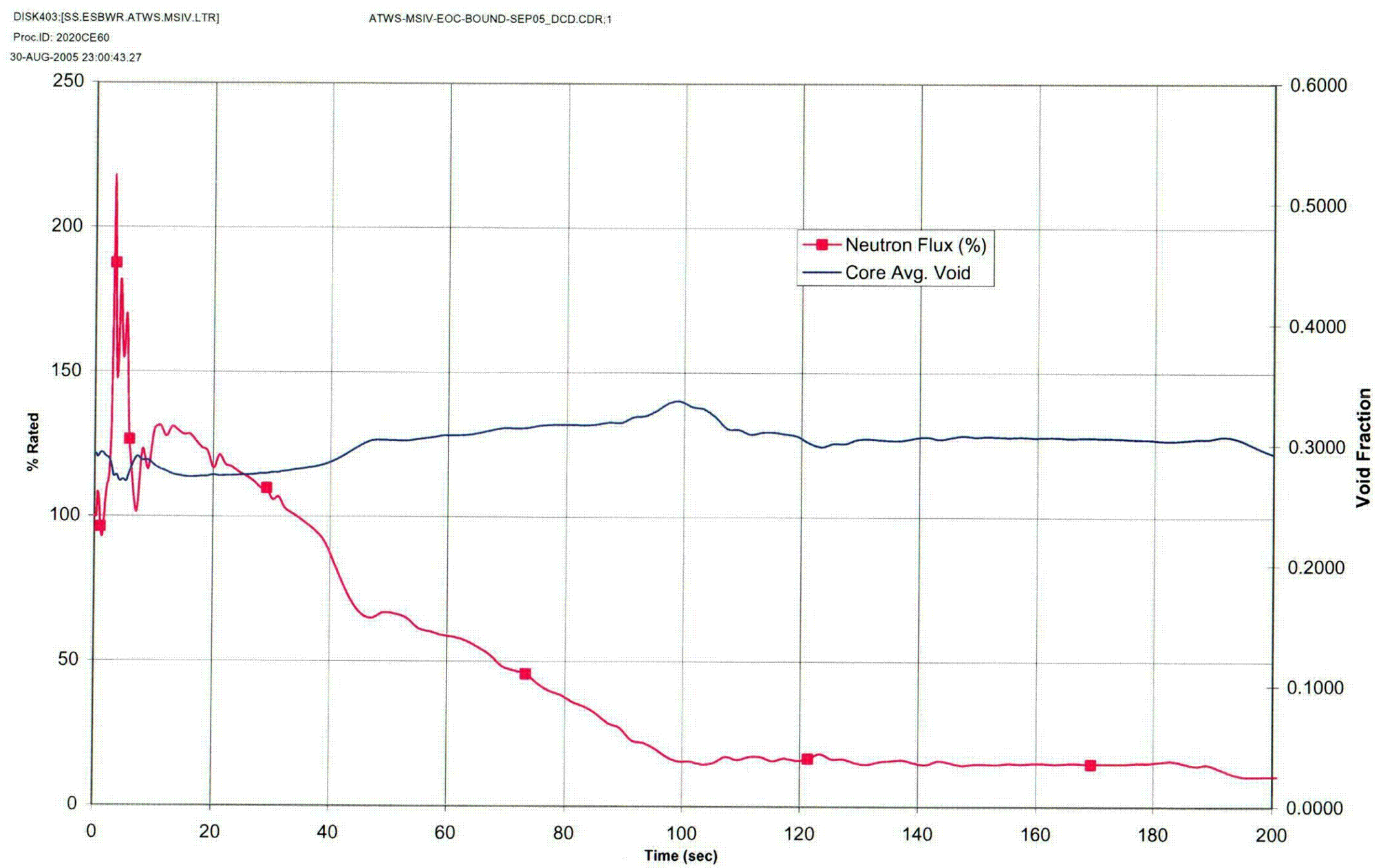
Figure 8.1-12. MSIVC Neutron Flux and Core Average Void



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8.1.2 Loss of Condenser Vacuum ATWS (LCV) Baseline Analysis

This transient starts with a turbine trip because of the low condenser vacuum; therefore, the beginning is the same as the turbine trip event. However, the MSIVs and turbine bypass valves also close after the condenser vacuum has further dropped to their closure setpoints. Hence, this event is similar to the MSIV closure event for all the key parameters. Table 8.1-6 shows the sequence of events for this transient.

Table 8.1-6. Sequence of Events for LCV

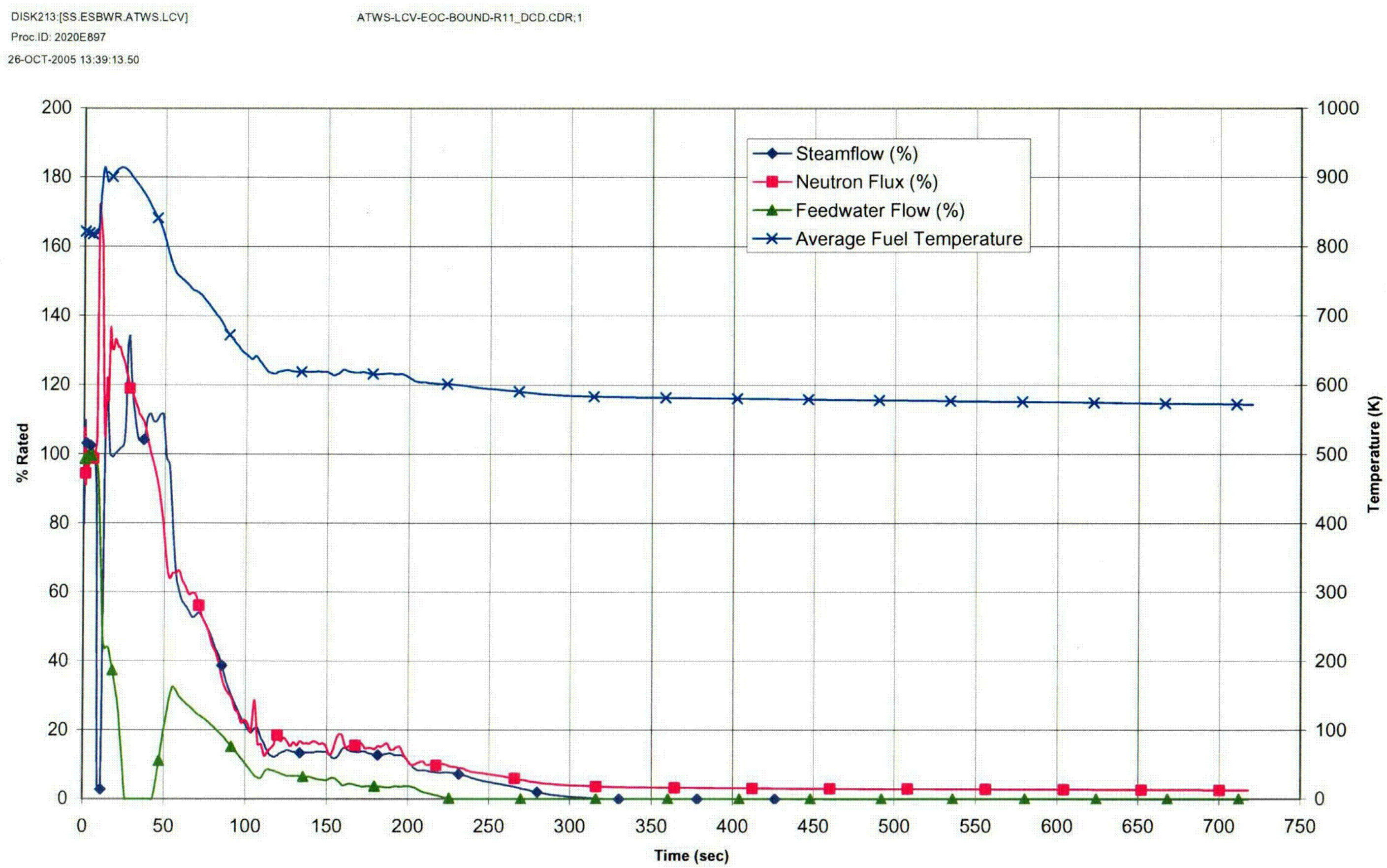
Time (s)	Event
0	Loss of Condenser Vacuum
0	Turbine Trip initiated and bypass opening
6	Bypass valves start to close, MSIVs close shortly thereafter.
8	Feedwater runback initiated
8	IC initiation
10	ATWS trip set at high pressure
11	SRVs open
26	Suppression pool cooling starts
26	Feedwater runback complete
49	Level drops below L2 set point
59	HPCRD flow starts
195	SLCS injection starts add reactor shutdown time, and time of max pool temp to all SOE tables
318	Peak Pool Temperature
390	Hot Shutdown achieved
716	High pressure design volume of borated solution injected into bypass

The key results from this analysis are presented in Table 8.1-7. and Figures 8.1-13 through 8.1-20. The results for the LCV case are very similar to those in the MSIVC case.

Table 8.1-7. Key Results for LCV

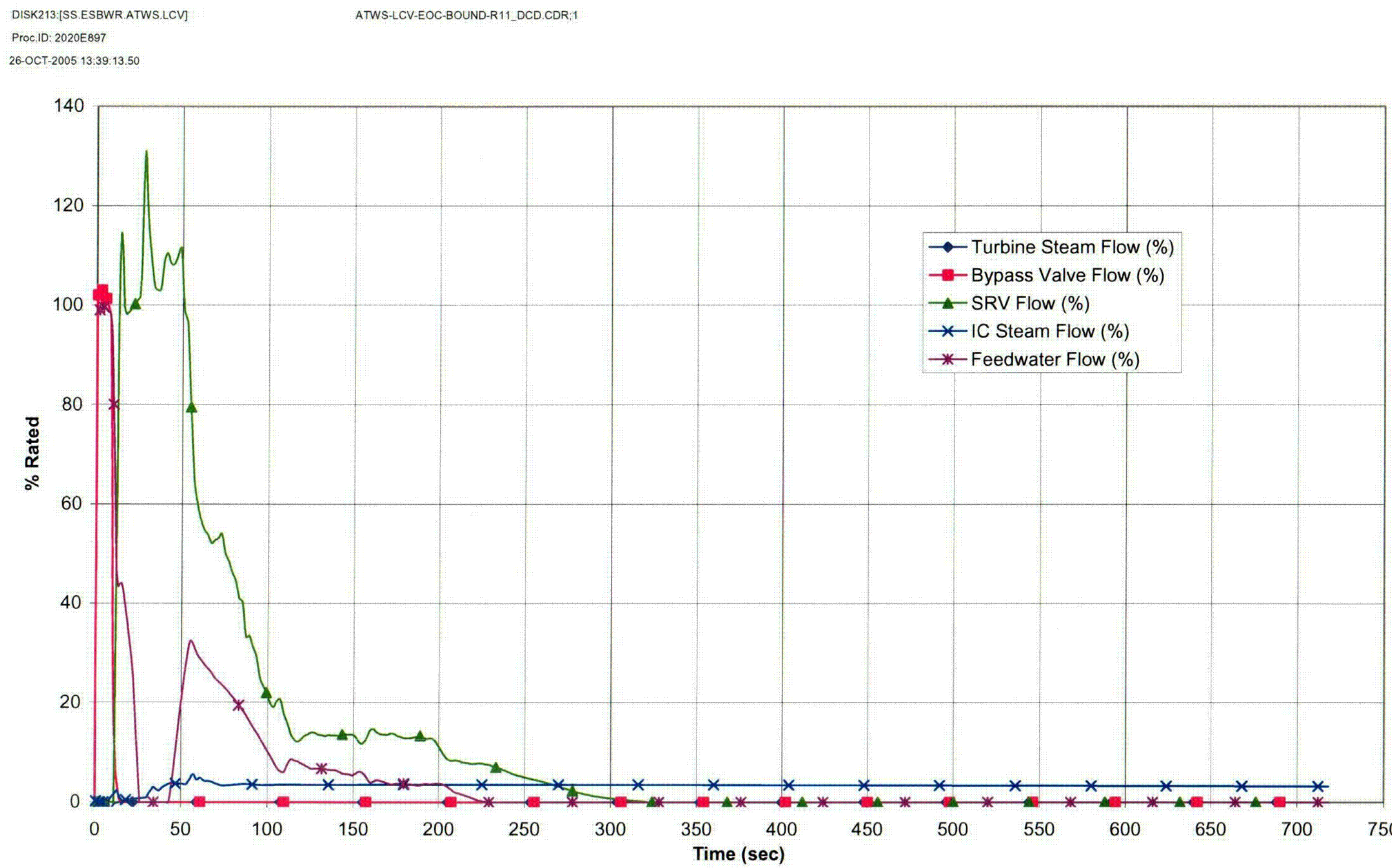
Parameter	Value	Time
Maximum Neutron Flux, %	218	9s
Maximum Vessel Bottom Pressure, MPaG (psig)	9.82(1425)	37s
Maximum Bulk Suppression Pool Temperature, ºC (ºF)	79.1(174.4)	318s
Associated Containment Pressure, MPaG (psig)	0.195(28.29)	318s
Peak Cladding Temperature, ºC (ºF)	915.3(1679.5)	31s

Figure 8.1-13. LCV Neutron Flux and Feedwater Flow



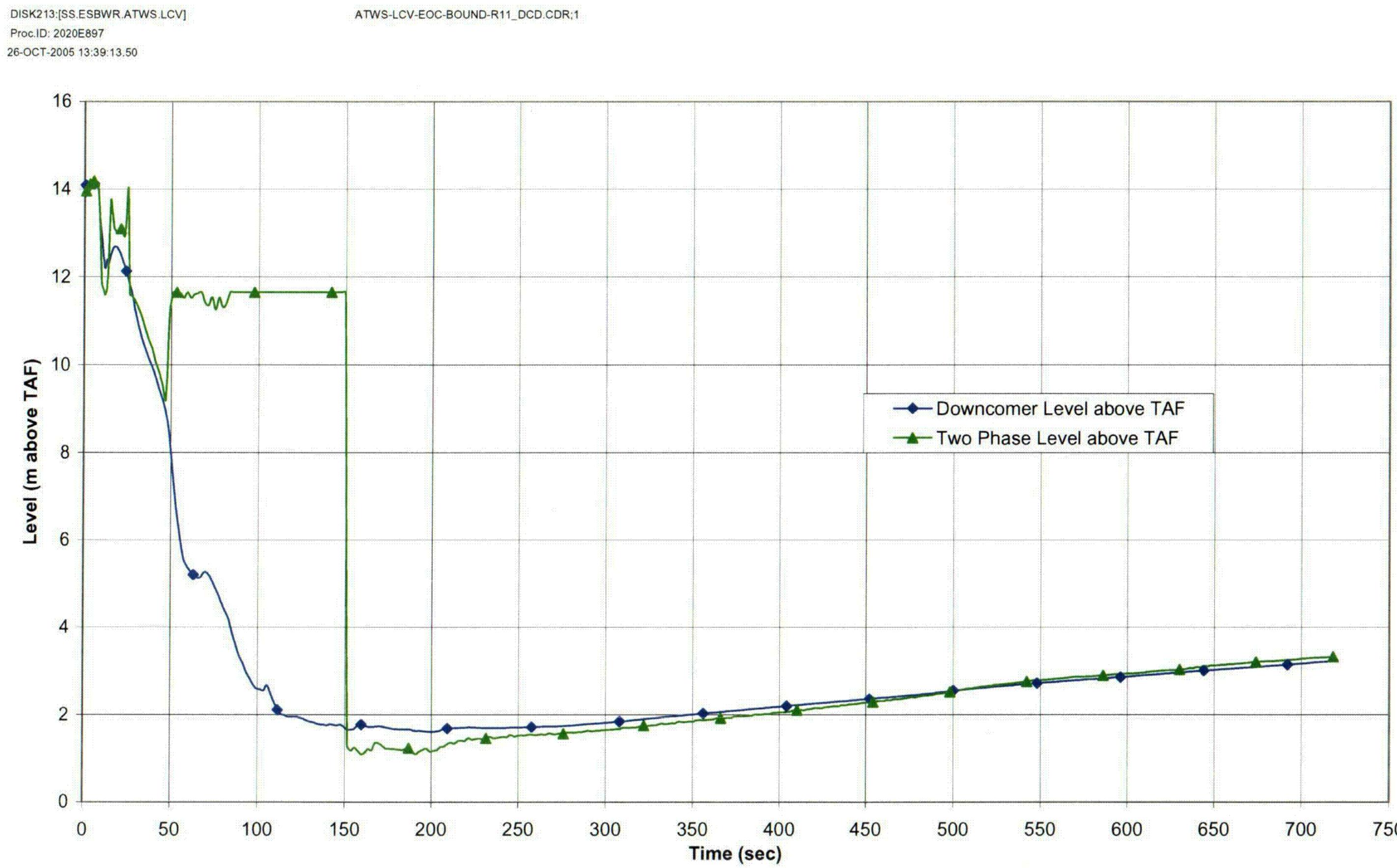
C10

Figure 8.1-14. LCV Steam Flow



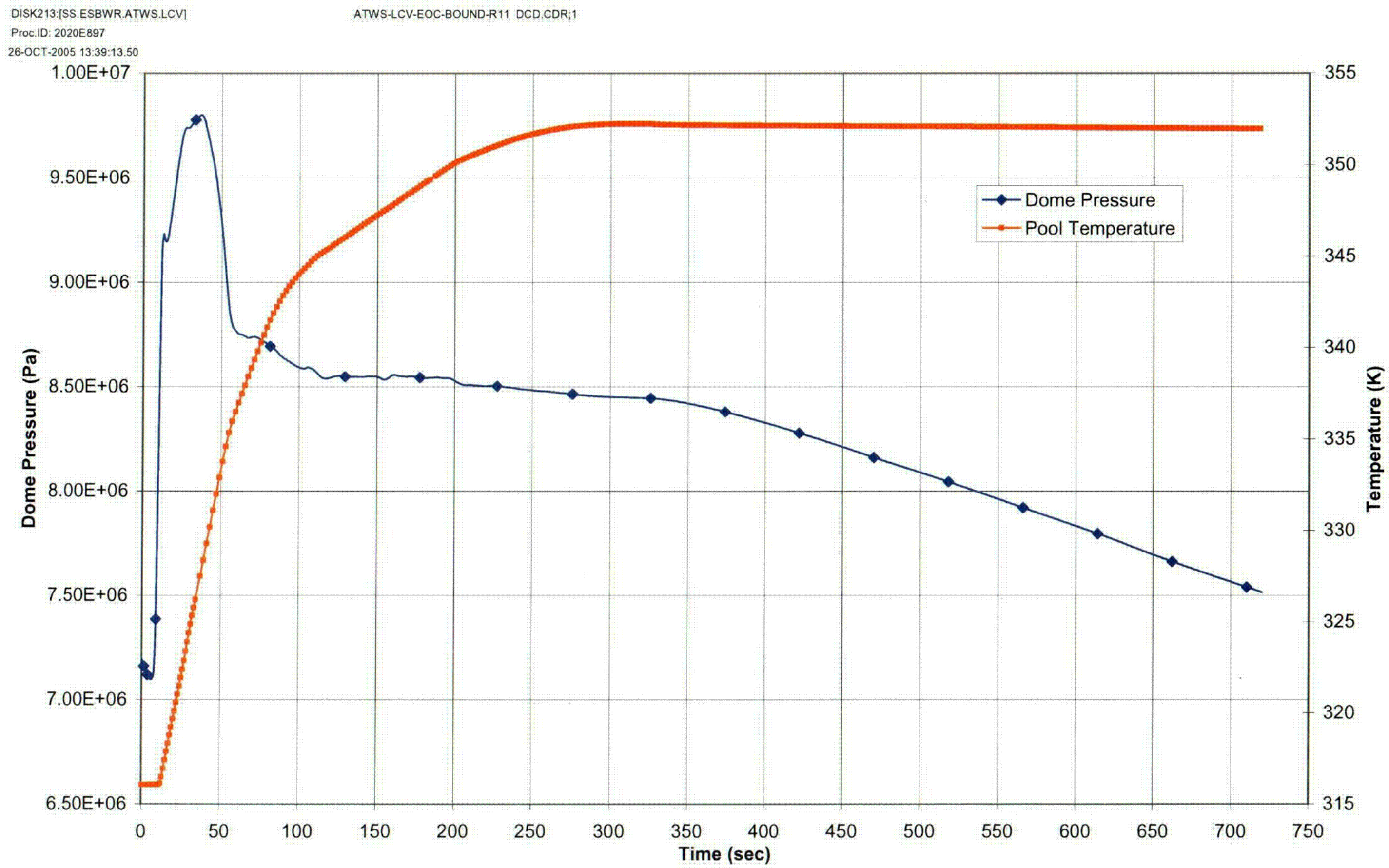
C11

Figure 8.1-15. LCV Water Level



C12

Figure 8.1-16. LCV Dome Pressure and Pool Temperature



C13

Figure 8.1-17. LCV Neutron Flux and Core Flow

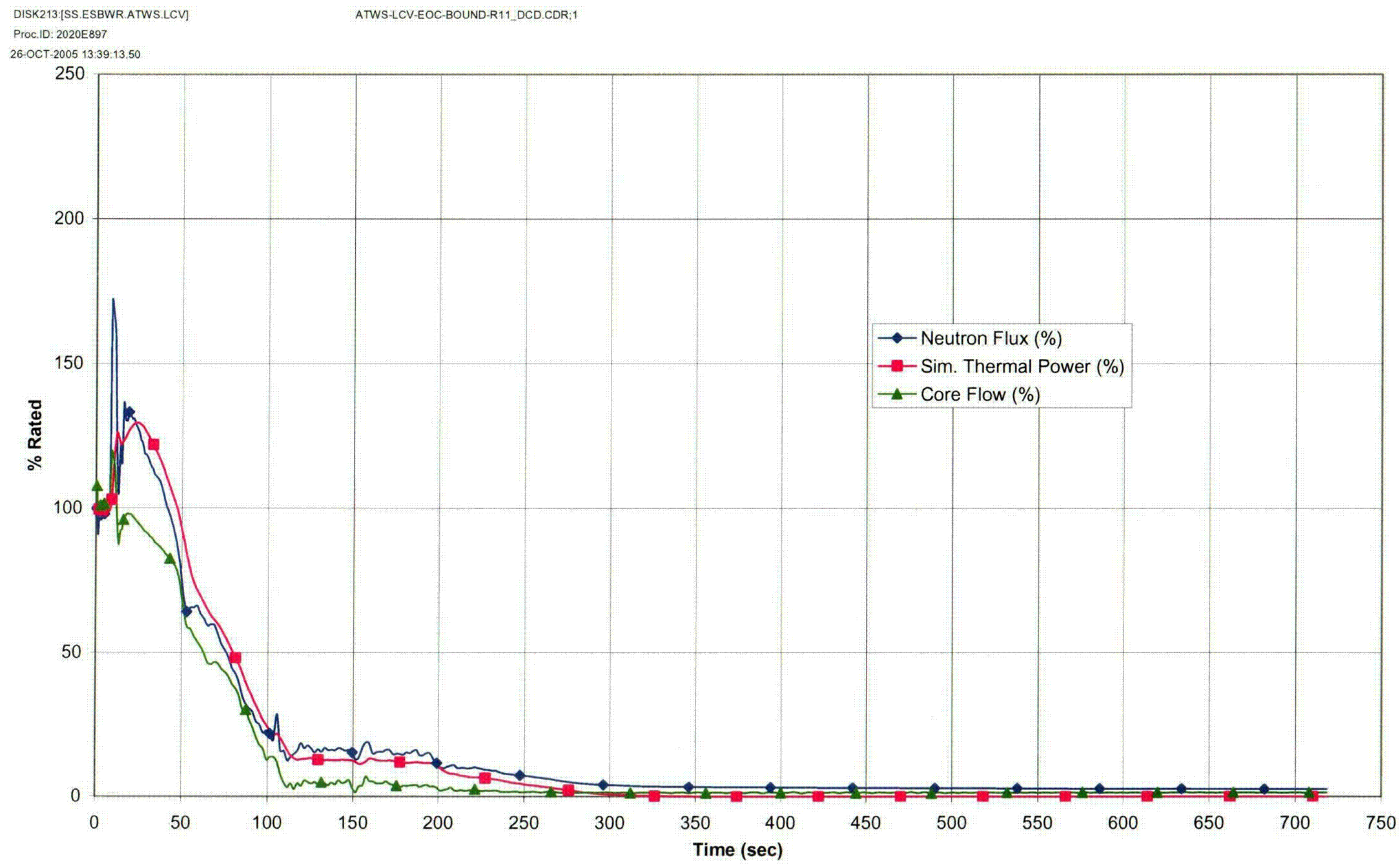


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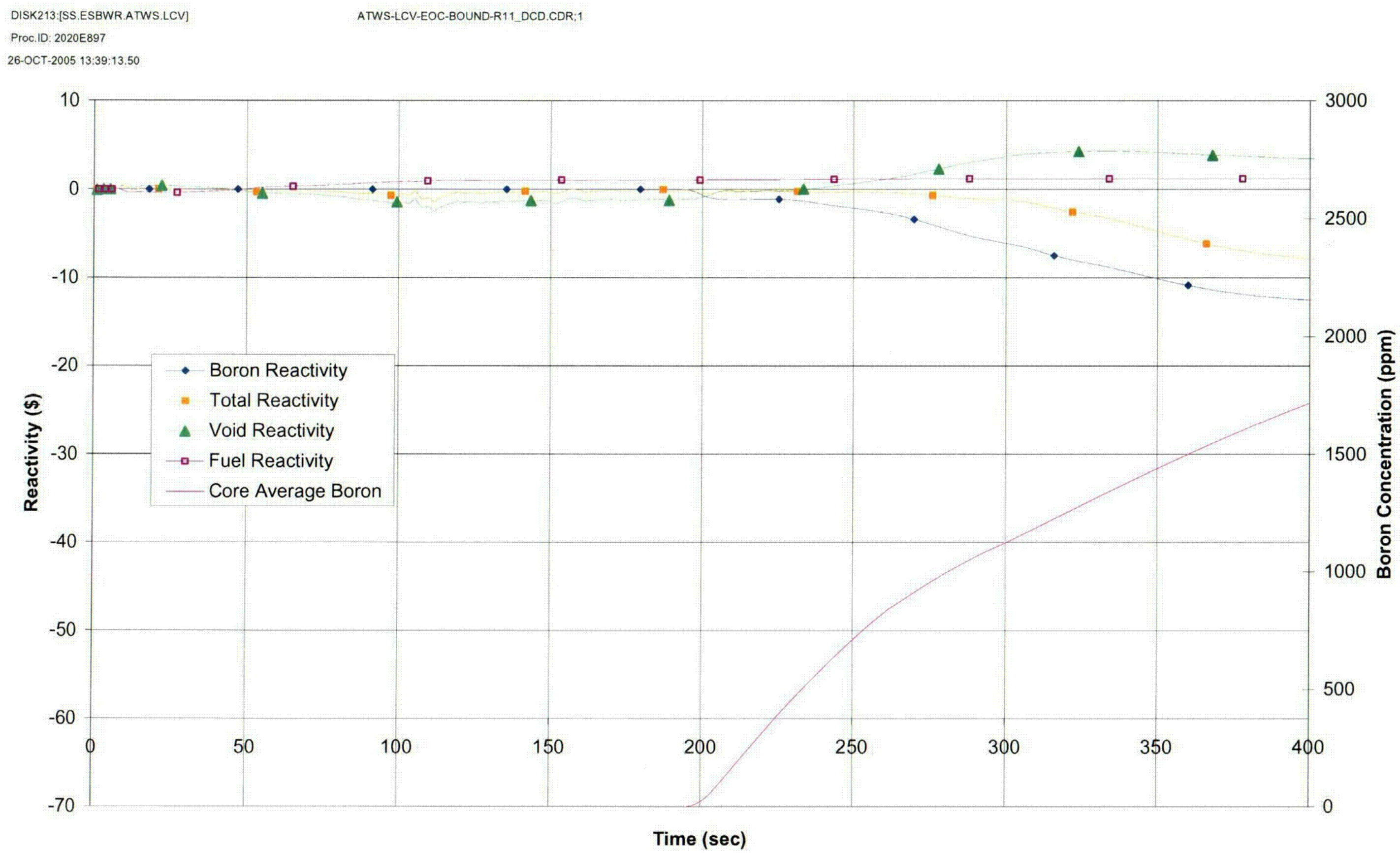
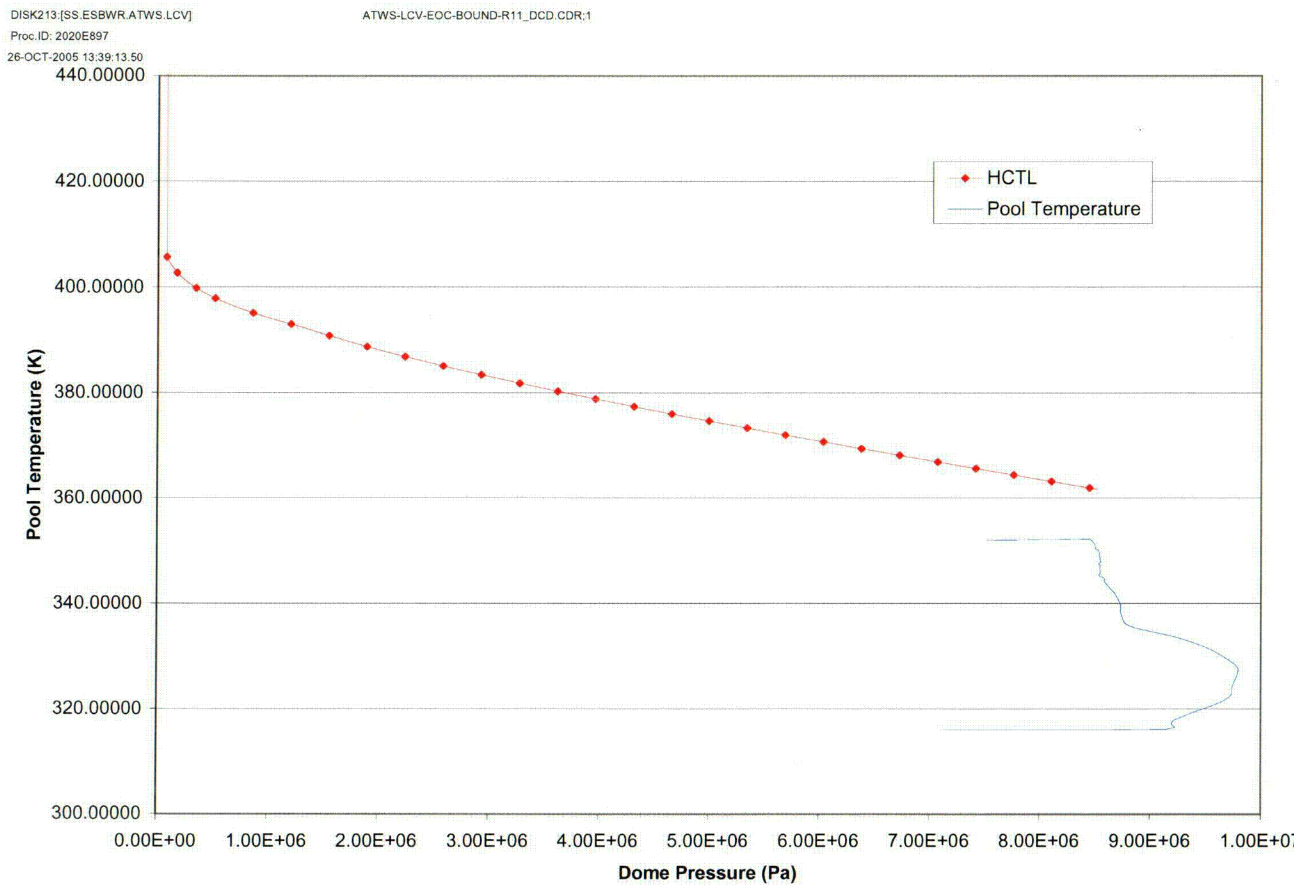
Figure 8.1-18. LCV Reactivity Feedback and Core Average Boron



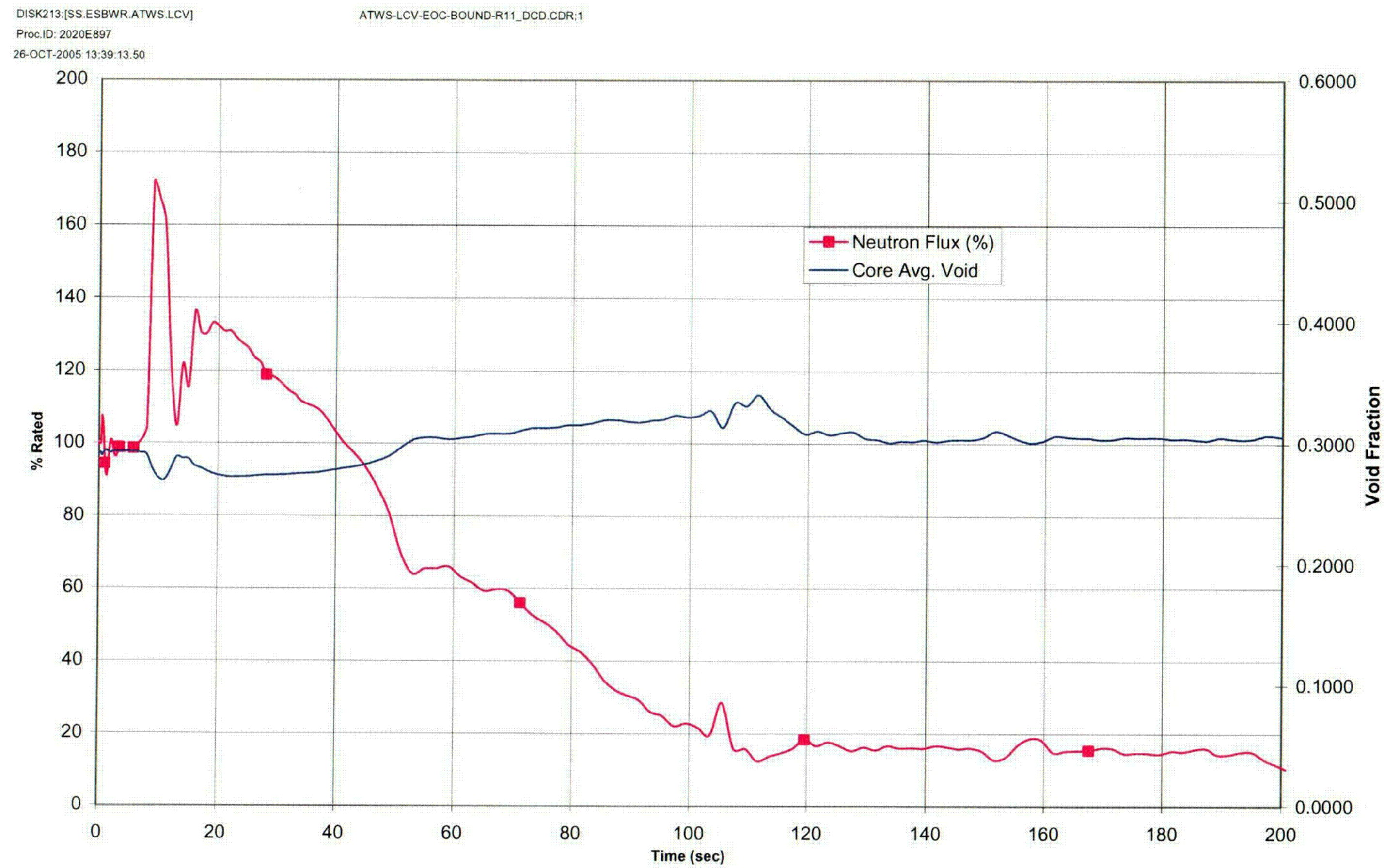
C15

Figure 8.1-19. LCV HCTL and Pool Response



C16

Figure 8.1-20. LCV Neutron Flux and Core Average Void



C17

8.1.3 Loss of Feedwater Heating ATWS (LFWH) Baseline Analysis

This transient does not trip any automatic ATWS logic. As a result of the loss of feedwater heating, the reactor power increases and settles into a new steady state. It is assumed that the operator initiates ARI at approximately 10 minutes after the beginning of this event to shut the reactor down. However, the feedwater runback initiated by manual ARI signal and APRM not-downscale signal causes the water level to drop below Level 2. Low water level results in a closure of all MSIVs, and subsequent reactor pressure increase. The pressure increase is mitigated by SRV opening. The initiation of the ATWS logic sets the SLCS timer. Upon failure of rod insertion, the SLCS initiates at about 13 minutes into the transient and the reactor is brought to a hot shutdown condition in can bring the reactor to the hot shutdown condition in little over 15 minutes after the event starts.

The sequence of events for this transient is presented in Table 8.1-8. Results are presented in Table 8.1-8 and Figures 8.1-21 through 8.1-28. The comparison of these results with the MSIVC and LCV cases indicate that this transient is not limiting for any of the key parameters.

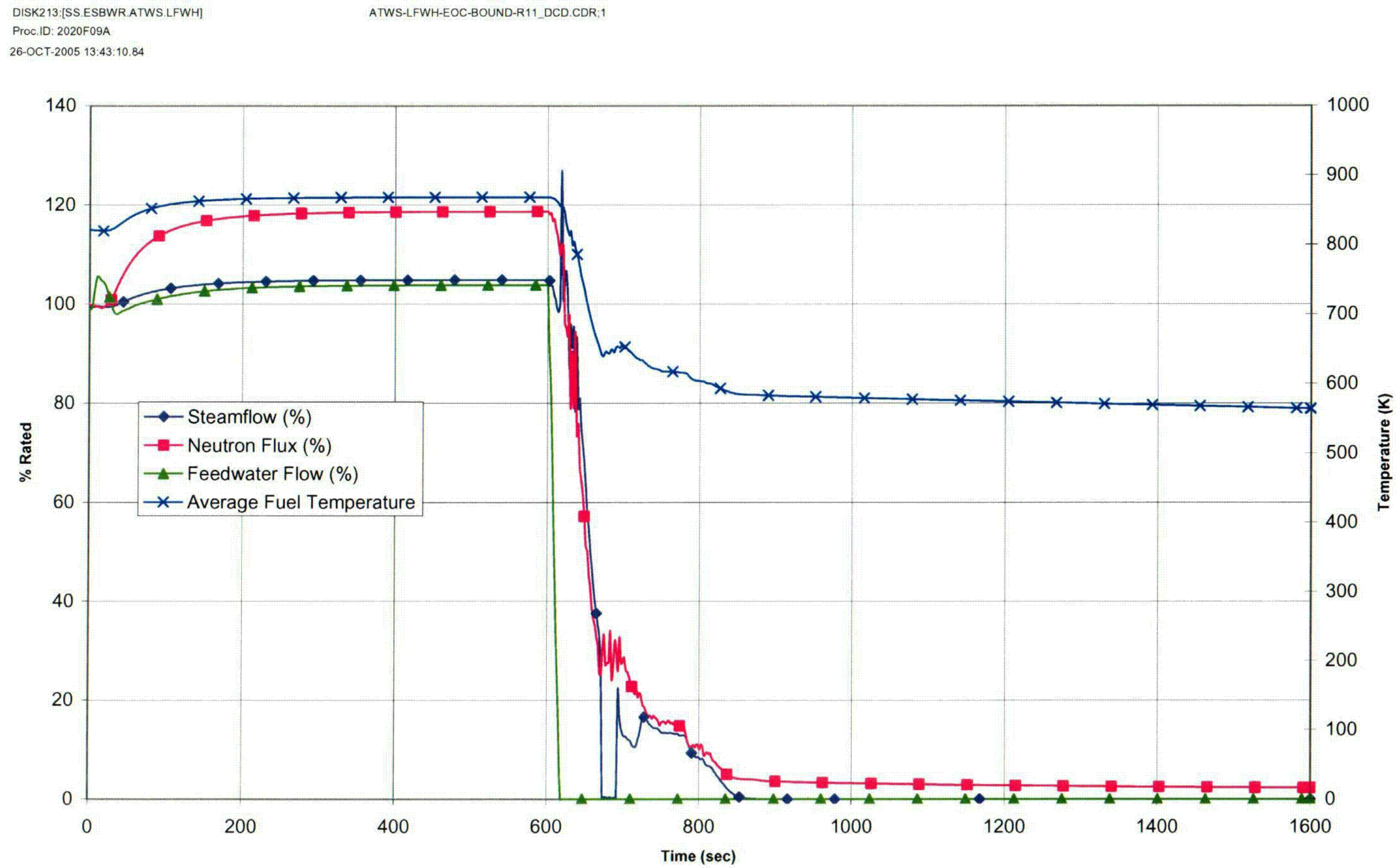
Table 8.1-8. Sequence of Events for LFWH

Time (s)	Event
0	Loss of Feedwater heating
600	Feedwater runback initiated
618	Feedwater runback completed
638	L2 setpoint reached
648	HPCRD flow starts
668	MSIV closure starts
670	IC initiation
692	SRVs open
780	SLCS flow starts
796	Suppression pool cooling starts
880	Peak Pool Temperature
926	Hot Shutdown achieved
1302	High pressure design volume of borated solution injected into bypass

Table 8.1-9. Key Results for LFWH

Parameter	Value	Time
Maximum Neutron Flux, %	120	596s
Maximum Vessel Bottom Pressure, MPaG (psig)	8.62(1250)	693s
Maximum Bulk Suppression Pool Temperature, °C (°F)	50.0(122.0)	880s
Associated Containment Pressure, MPaG (psig)	0.141(20.48)	880s
Peak Cladding Temperature, °C (°F)	316.0(600.8)	620s

Figure 8.1-21. LFWH Neutron Flux and Feedwater Flow



C108

Figure 8.1-22. LFWH Steam Flow

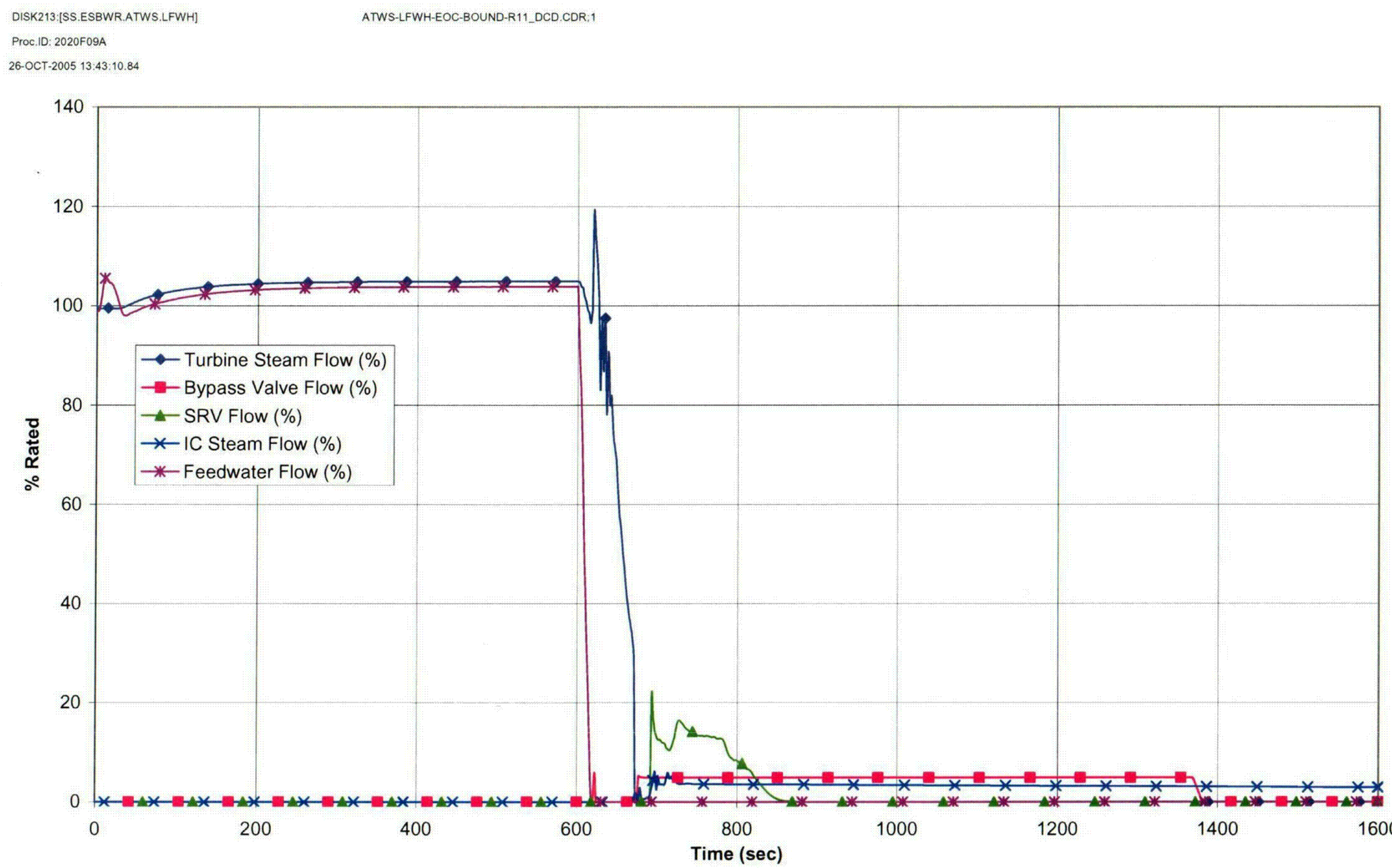


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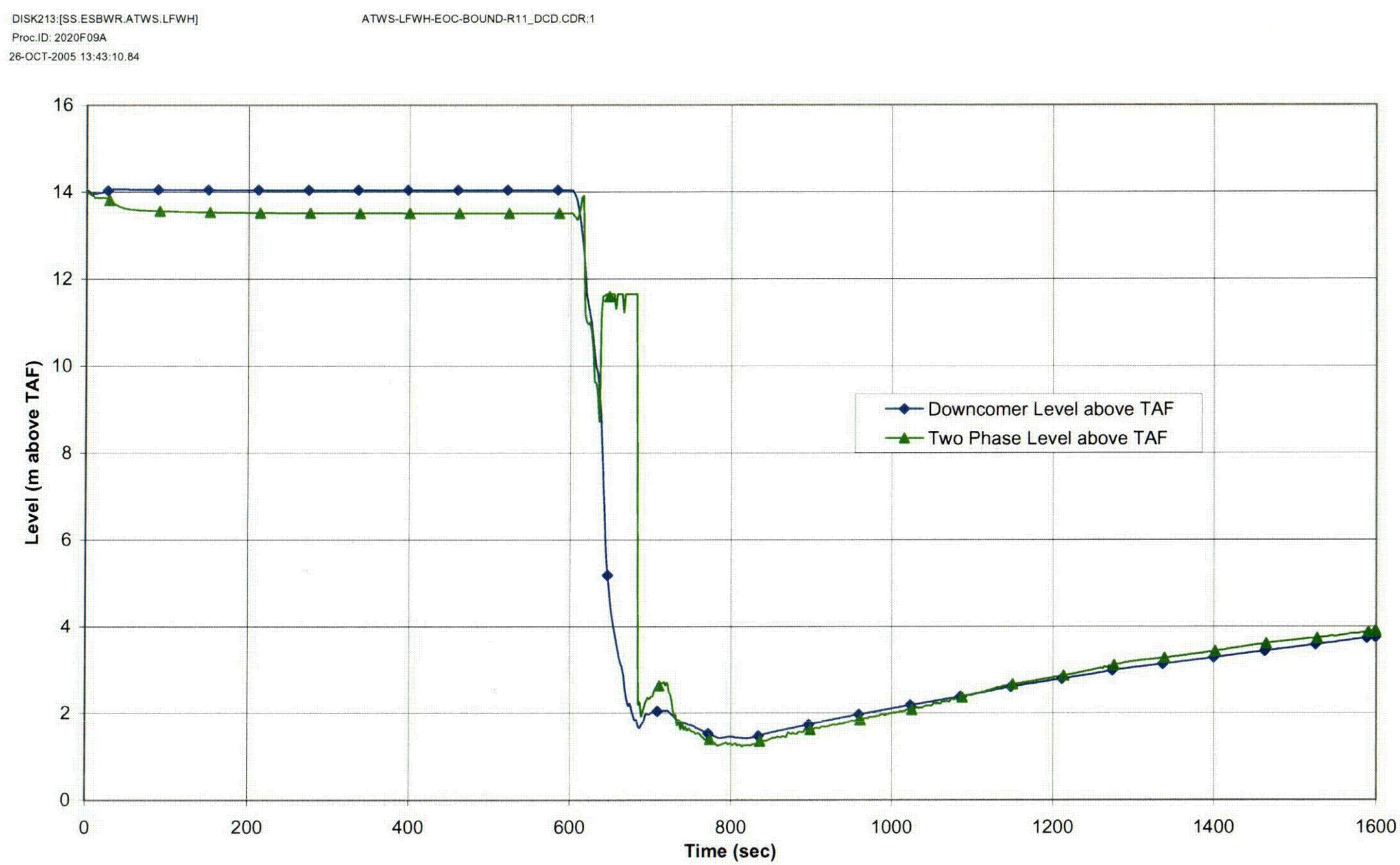
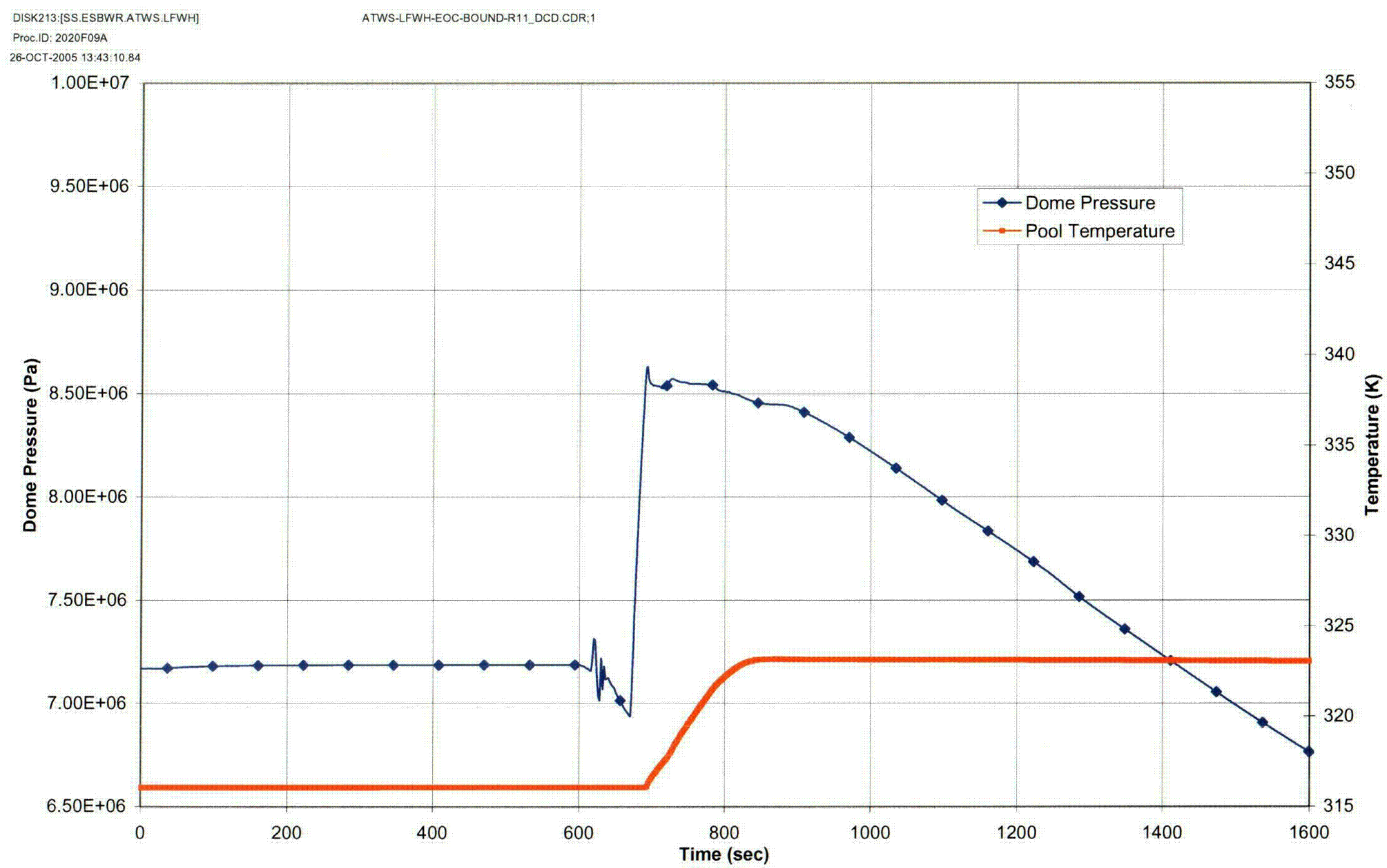
Figure 8.1-23. LFWH Water Levels



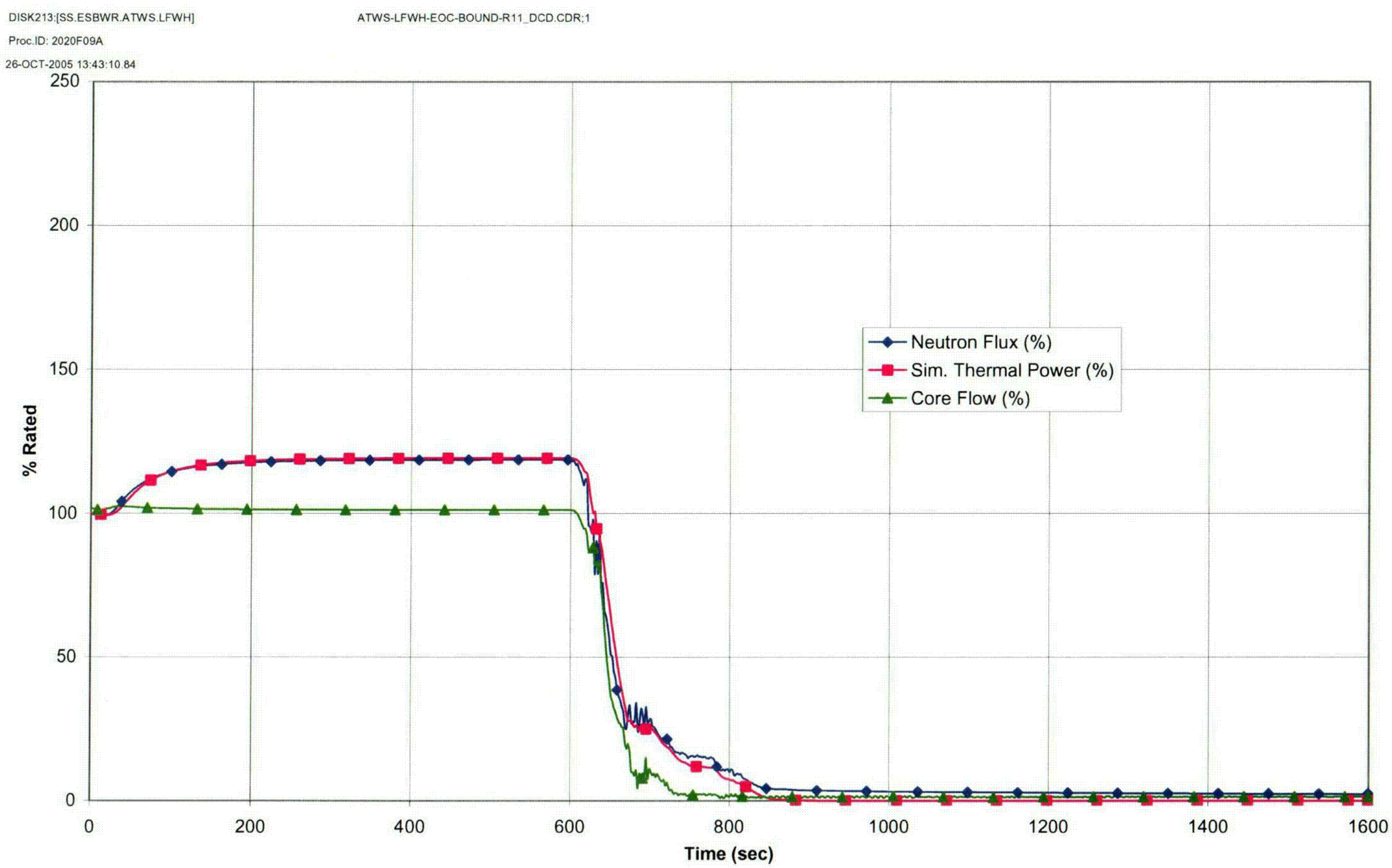
C20

Figure 8.1-24. LFWH Pressure and Pool Temperature



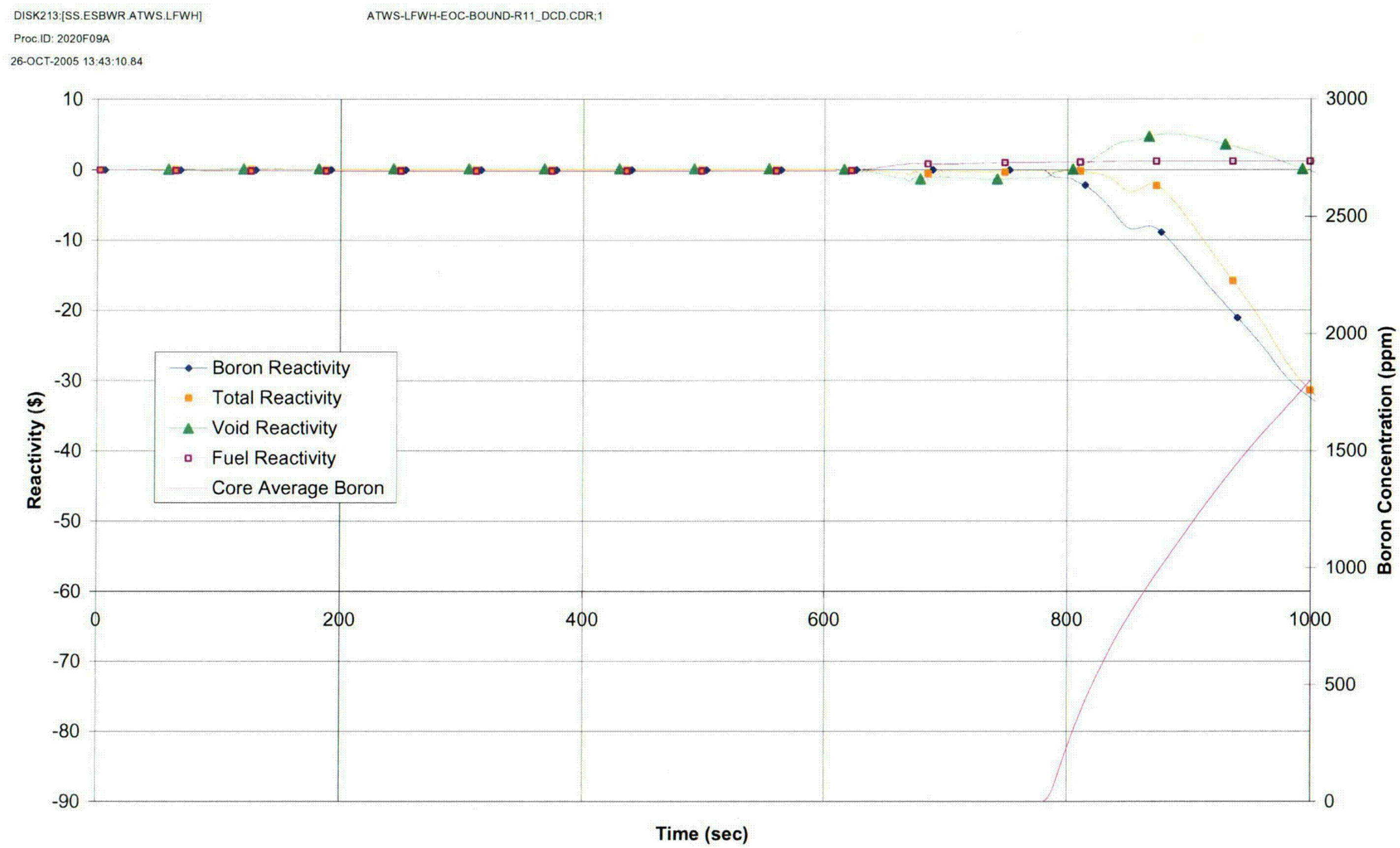
C21

Figure 8.1-25. LFWH Neutron Flux and Core Flow



C22

Figure 8.1-26. LFWH Reactivity Feedback and Core Average Boron



C23

Figure 8.1-27. LFWH HCTL and Pool Response

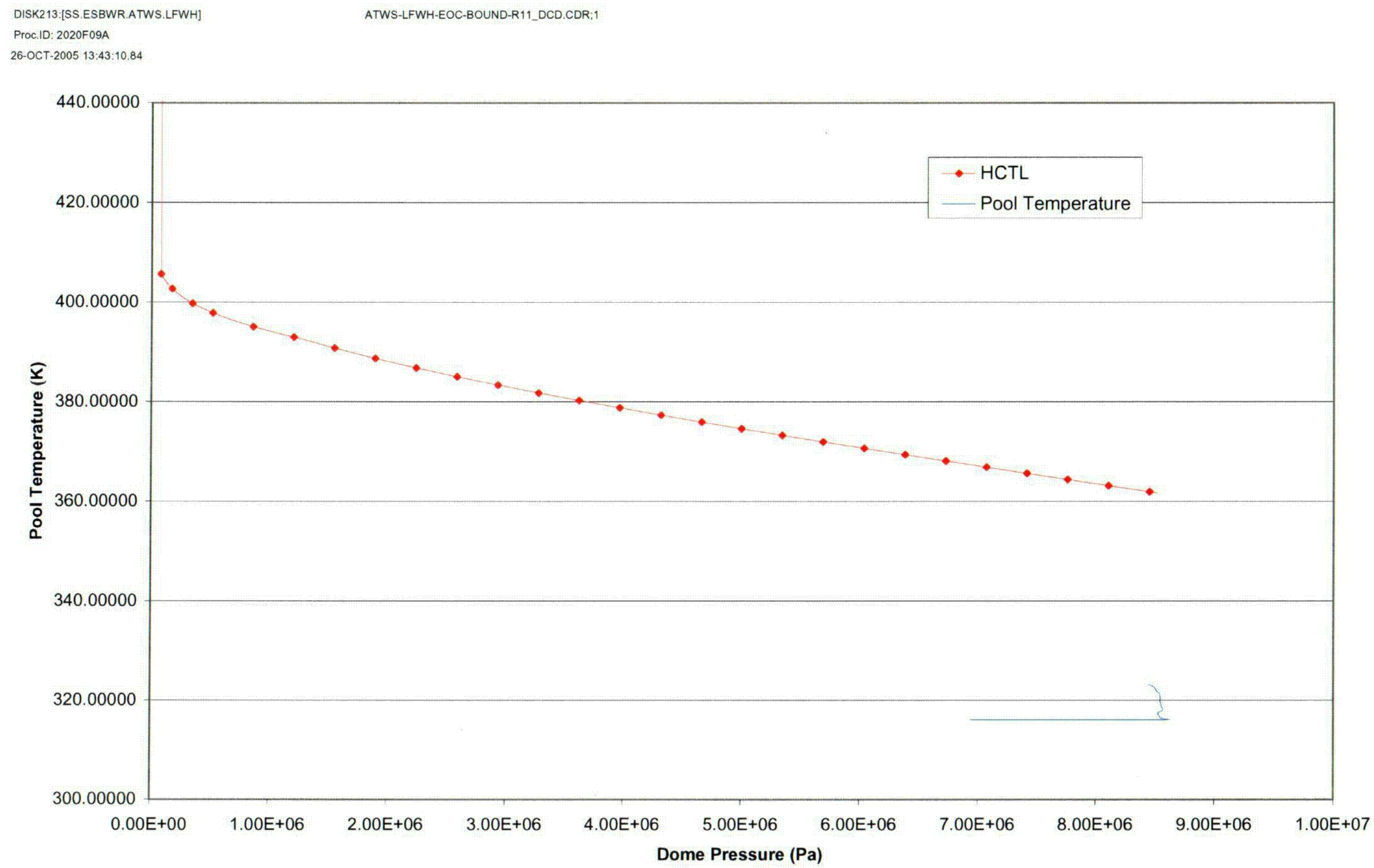


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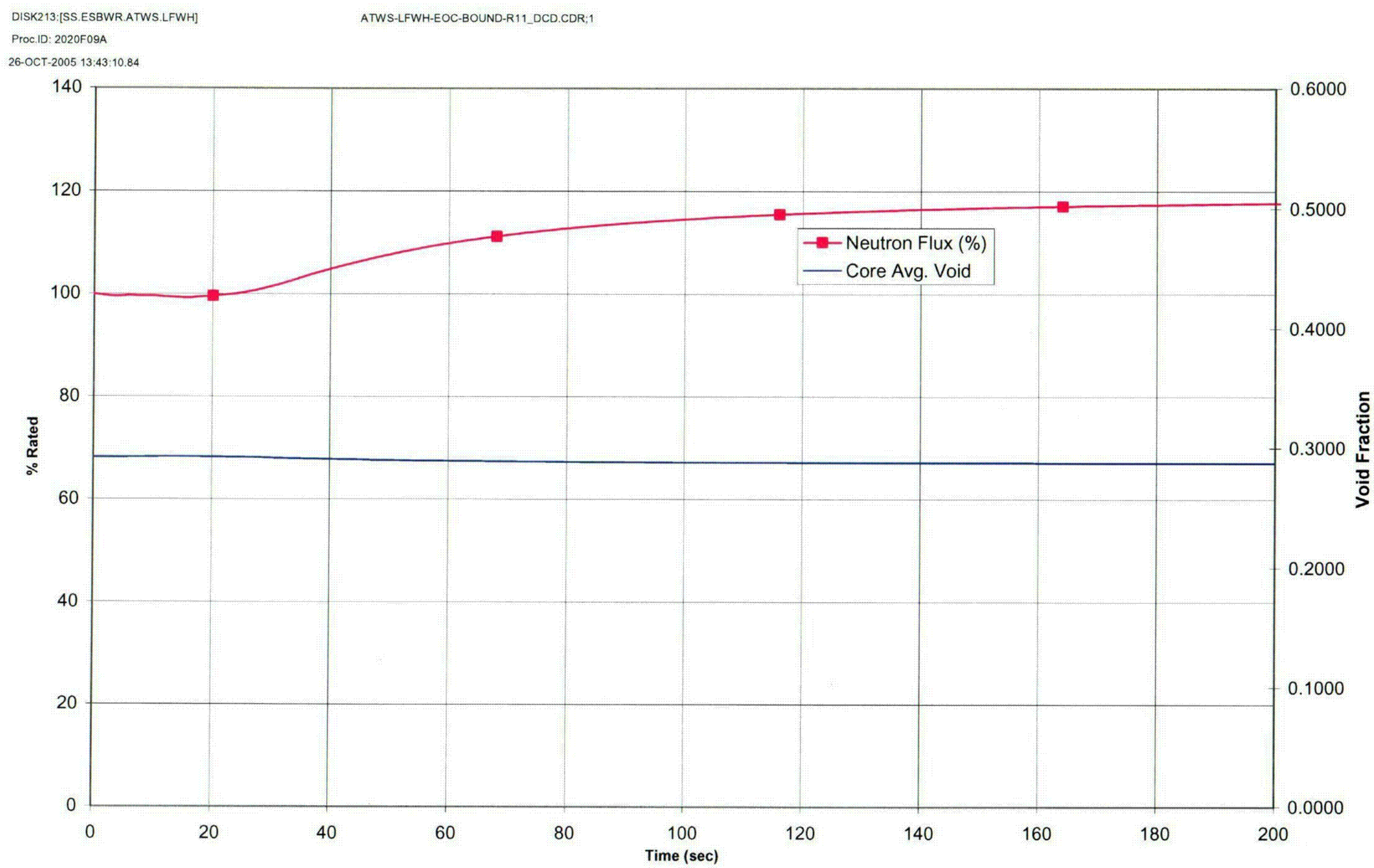
Figure 8.1-28. LFWH Neutron Flux and Core Average Void



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8.2 Initial Condition and Plant Parameter Review

8.2.1 Initial Conditions

This section will consider the sensitivity of the limiting MSIVC ATWS case to initial conditions in the plant. Table 8.2-1 summarizes the initial condition sensitivity analyses performed as part of this study. The critical parameters studied are peak pressure, peak clad temperature, peak suppression pool temperature, and peak power.

Table 8.2-1. Initial Conditions Sensitivity Analysis

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Table 8.2-1. Initial Conditions Sensitivity Analysis

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8.2.1.1 Initial Conditions Sensitivity Results

A summary of the sensitivity analysis for the MSIVC transient is provided in 8.2-2. The sensitivity analyses were performed at BOC and the changes in various parameters as a result of initial condition uncertainties are discussed in this subsection.

Figure 8.2-1. Relative Axial Power Distribution for Three Exposure State points

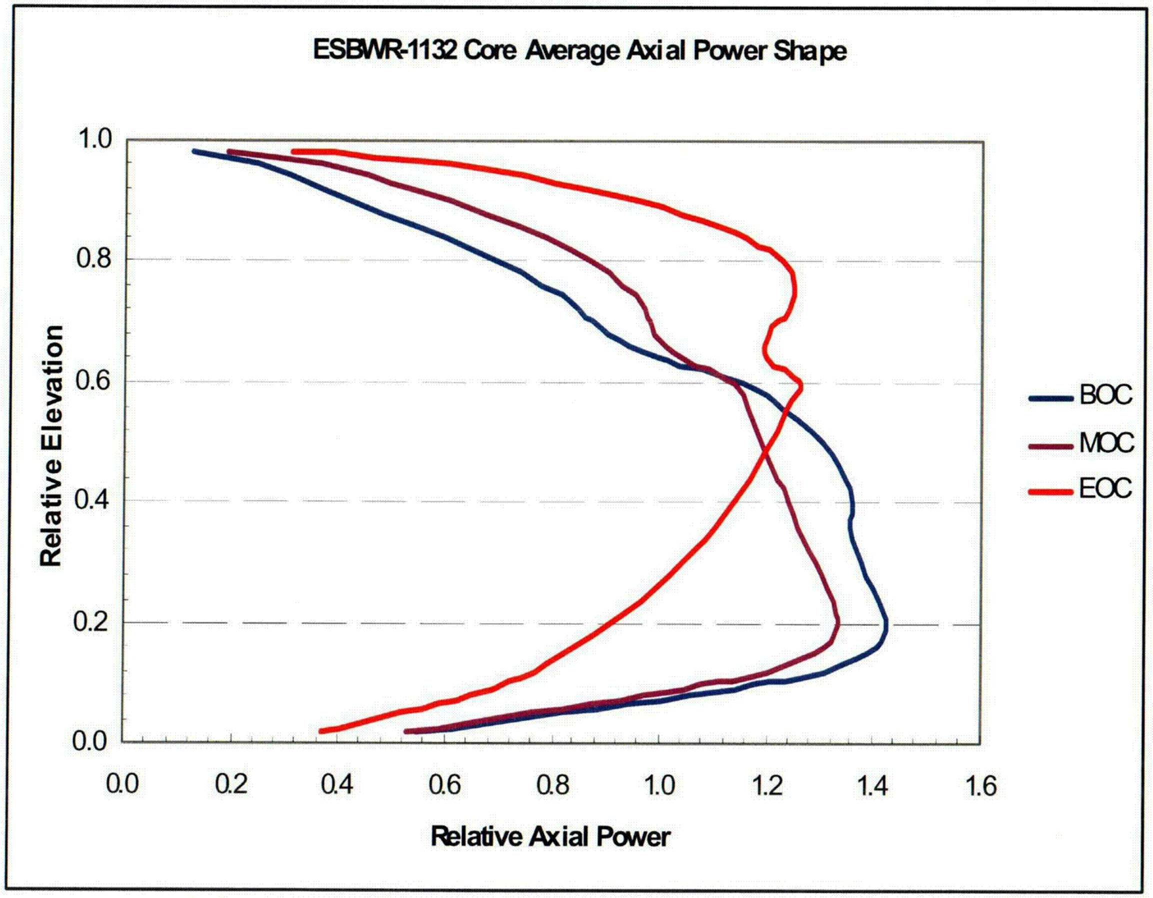

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Table 8.2-2. MSIVC Allowable Operating Range Results: Change from Base Case

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The characterization of these results is presented in Table 8.2-3.

Table 8.2-3. MSIVC Initial Conditions Characterizations

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8.2.2 Plant Parameters

As described in Section 8.1, plant parameters like S/RV capacity, MSIV stroke time, and IC capacity have been conservatively modeled in the baseline analyses. This section details the studies undertaken to determine the impact of other plant parameters that have a direct impact on one or more of the critical safety related parameters during an ATWS event. The sensitivity analyses were performed at BOC and the changes in various parameters as a result of plant parameter uncertainties are discussed in this subsection.

Table 8.2-4 presents the set of plant parameters studied with a description of how each parameter was different from the baseline analysis.

Table 8.2-4. MSIVC Plant Parameters

Plant Parameter	Base Case	Sensitivity Case	Purpose/Remarks
Lower EOP ATWS Water Level	TAF + 1.524m	TAF	Impact on pool temperature
Higher EOP ATWS Water Level	TAF + 1.524m	TAF + 3.048m	Impact on pool temperature
Boron Enrichment	94% in B-10	19.8% in B-10	Impact on pool temperature
FAPCS	On	Off	Impact on pool temperature
SLCS flow velocity at nozzle	Time dependent flow based on accumulator depressurization	Constant flow of 30.5m/s	Impact on shutdown time and potential impact on pool temperature
SLCS flow velocity at nozzle at 90%	Time dependent flow based on accumulator depressurization	Time dependent flow reduced to 90% of base case	Impact on shutdown time and potential impact on pool temperature
SRV Capacity*	Tech Spec	Nominal	Impact on Pressure, pool temperature
IC	75% IC Capacity	Full IC capacity	Impact on pool temperature
Suppression Pool HCTL	No opening of S/RVs at SLCS initiation	S/RVs open at SLCS initiation, (simulates pool reaching HCTL at the start of boron injection).	Determine whether reactor would be critical after a depressurization if the HCTL curve were reached.

8.2.2.1 Plant Parameter Sensitivity Results

Table 8.2-5 presents results from the plant parameter sensitivity studies.

The peak power was not sensitive to any of the plant parameters. Increasing the SRV capacity from the nameplate value to the nominal value (approximately 8%), decreased the peak pressure by about [[ ]] and the PCT by [[ ]]. Corresponding to this, the peak pool temperature increased by [[ ]] and the containment pressure by [[ ]]. Changes to the other plant parameters had very little effect on the key quantities. For the depressurization case, the high pool temperature is caused by dumping energy from the RPV into the pool and the reactor remains subcritical at the low pressure.

Additional cases, with and without depressurization, where the vessel was refilled to the normal water level over a period of one half hour after the termination of SLCS flow, did not lead to recriticality of the system.

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]] A case with natural boron as opposed to the 94% enriched boron used in the plant indicated that the shut down takes about [[ ]] minutes longer, for a total of [[ ]] minutes from the initiation of the SLCS.

Table 8.2-5. MSIVC Plant Parameters Sensitivity Study, Change from Base Case (% change from Base)

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8.2.3 ATWS Stability Study

The MSIVC baseline model was used to determine if any power instabilities set in during the transient. The case was run in for full transient for 720s without introducing any specific perturbation to the system. The stability studies were performed using the explicit first order integration method for the solution in all the channel components in contrast to the implicit mode used in the baseline analysis. In addition, two cases were run starting at points where the power to flow ratio was high but fairly constant. In these two cases the inlet liquid velocities in the channels were increased by 5% to introduce perturbations to the system. The first case was started at 25s and run for 20s and the second case was started at 185s and run for 35s. Figures 8.2-2, 8.2-3, and 8.2-4 show the power for the three cases. These plots show the comparison of the power profile for the baseline case (indicated as implicit) and the stability run (indicated as explicit). The effects of the perturbations were damped out in both cases and did not lead to growing oscillations.

These plots indicate that stability is not an issue during an ATWS event in ESBWR.

Figure 8.2-2. MSIVC Stability Power Comparison

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Figure 8.2-3. MSIVC Stability Power Comparison: 25s

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Figure 8.2-4. MSIVC Stability Power Comparison: 185s

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8.2.4 Summary of Initial Conditions, Plant Parameters and Stability

The following can be concluded based on the initial condition, plant parameter, and stability analyses results:

- Peak power and peak PCT are limiting for the EOC condition. Other critical parameters are not sensitive to the initial conditions. Clad oxidation is insignificant in all cases.
- The peak suppression pool temperature is reached at 254s for the MSIVC case.
- Core stability is maintained during ATWS.
- The pool heat up is impacted primarily by the core power and the SR/V steam flow before the water level is reduced by FW runback to the EOP specified level, and secondarily the core power and steam flow after level reduction. The response after SLCS injection does not have strong effect on pool temperature.
- The analyses indicate that none of the critical parameters exceeds safety limits and the plant achieves shutdown conditions safely.

8.3 Uncertainty Analysis for Licensing Events
8.3.1 Uncertainty Screening

Analyses have been performed at both the +1 σ and -1 σ level for each of the model uncertainties and initial conditions (some of these results have been discussed in Section 8.2). Figures 8.3-1 through 8.3-5 present these results.

Figure 8.3-1. MSIVC -Peak power Sensitivity

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Figure 8.3-2. MSIVC -Peak Vessel Pressure Sensitivity

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Figure 8.3-3. MSIVC –Peak Clad Temperature Sensitivity

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Figure 8.3-4. MSIVC –Peak Pool Temperature Sensitivity

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The peak power is sensitive to an increase in the interfacial shear in the core to the extent of [[ ]] with the parameter remaining insensitive to all other phenomena. The dome pressure is within [[ ]] of the peak value in the base case for all phenomena. The PCT is the most sensitive parameter and is impacted by the total power, GEXL critical quality, feedwater enthalpy, interfacial shear in the core, vapor side interfacial heat transfer, spacer loss coefficient, downcomer and upper plenum interfacial drag coefficient, and rewet quality margin. The peak pool temperature and peak containment pressure are insensitive to the application of uncertainties to the various phenomena.

8.3.2 Overall Uncertainty

The overall uncertainty applicable to each of the parameters is obtained by taking the square root of the sum of squares of the difference between the base case and the PIRT phenomena that changed these parameters in a positive sense. The uncertainty for each parameter is then compared to the difference between the values for these parameters for a bounding case when compared to a nominal case. Any excess uncertainty over this difference is added as a bias to the bounding case .

Following the uncertainty analyses, a further set of conservatisms in the form of initial condition uncertainties was added to the original bounding case viz. 102% power, 0.125 MPa lower dome pressure setpoint, and an approximate 5% increase in feedwater enthalpy. Since the containment parameters showed more conservatism when the nominal SRV capacity was used in the analyses, a separate bounding analysis was performed for the containment with a S/R valve capacity that was 7.8% above the nominal capacity. The value 7.8% represents the difference between the TS capacity and the nominal capacity.

Table 8.3-1. Main Features of the nominal, and Bounding Cases

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Table 8.3-2. Nominal and Bounding Cases: Summary

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Table 8.3-3. Summary of Uncertainty Analyses

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Table 8.3-4. Final Results with Applied Bias

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Phenomena involved each phase are included in the PIRT.

Determine the application range for ATWS and whether ATWS application falls within the range of a previously approved applications.

For phases 1,2, & 5 TRACG models and model qualification have been previously submitted and approved by the NRC.

For phase 3, identify the phenomena and rank them for evaluation of TRACG applicability and determine the uncertainty.

An uncertainty evaluation is conducted to evaluate whether the application methodology is conservative relative to the combined uncertainty.

Selected conservatisms have been included in the application methodology to assure the result is not non-conservative.

In the case that a calculated safety parameter does not bound 1-sigma uncertainty calculated by Propagation of Errors, an adder based on the uncertainty difference is applied to the result.

ATWS Methodology Summary

TRACG is well suited to ESBWR ATWS analysis

The models and qualification for most phenomenon have been previously reviewed and approved

Submittal will document applicability of boron mixing, transport and reactivity models.

Application range of the other models will be justified. Application Method Described in LTR

9.0 Conclusion

- TRACG is capable of simulating ESBWR ATWS events. It models the important phenomena, and the models of the important phenomena are qualified.
- An application methodology is defined for ESBWR ATWS analysis. The procedure for performing the calculation considers specific modeling applied in the code qualification for ESBWR.
- The nominal TRACG calculation, combined with bounding initial conditions and plant parameters, produces an overall conservative estimate of ATWS peak vessel pressure and peak fuel clad temperature.
- A conservative value of suppression pool temperature is achieved including an adder based on the combined uncertainties at the 1-sigma level.