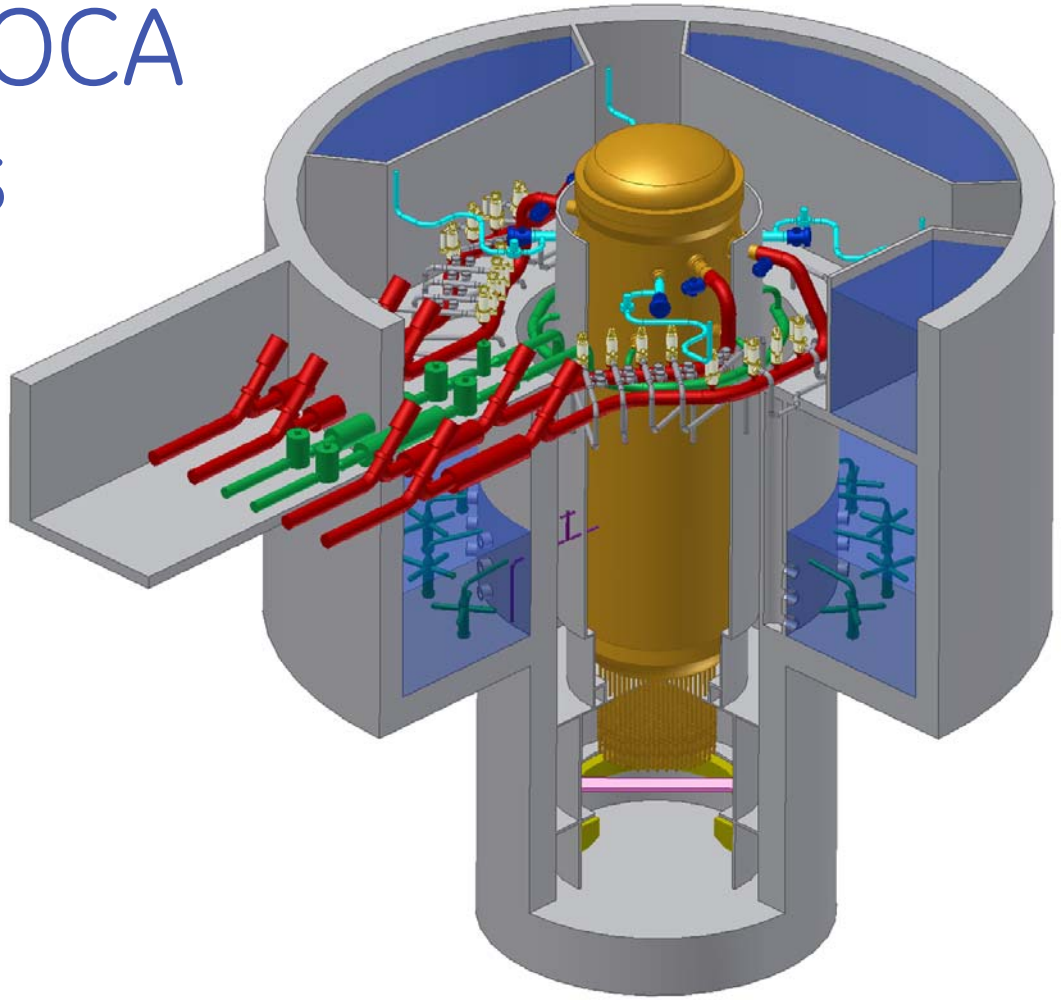
Chapter 5 Over-pressure protection & Chapter 6 LOCA Analysis



ESBWR Response to Over pressure protection

Conservatively assumes direct scram on MSIV position fails

Assumes 1 of 4 IC fails

FW trip assumed simultaneous with isolation (no credit for FW scram/condensation)

Result – Maximum pressure is approximately the SRV set pressure, little dynamic overshoot

Table 5.2-2. Safety/-Relief Valve and Depressurization Valve Settings and/or Capacities

Valve Type SRV /DPV	**Number of Valves**(1)	**Spring Setpoint Maximum Safety Analytical Limit** MPa gauge (psig)	**ASME Rated Capacity at 103% of Safety Analytical Limit Spring Setpoint Pressure** (kg/s each)
ADS SRV	10[ACE1]	8.618 (1250)[ACE2]	124[ACE3]
Non-ADS SRV	8[ACE4]	8.756 (1270)[ACE5]	126[ACE6]

Table 5.2-3. Systems That May Initiate or Trip During Overpressure Event

Systems	Initiating/Trip Signal
Reactor Protection	Reactor shutdown on high flux[ACE1]
IC	Initiated on high reactor pressure or reactor isolation or low reactor water level when mode switch is in "run"[ACE2]
CRD	ON when reactor water level is at L2
RWCU/SDC	OFF when reactor water level is at L2[ACE3]

Figure 5.2-4a. MSIV Closure – Flux Scram

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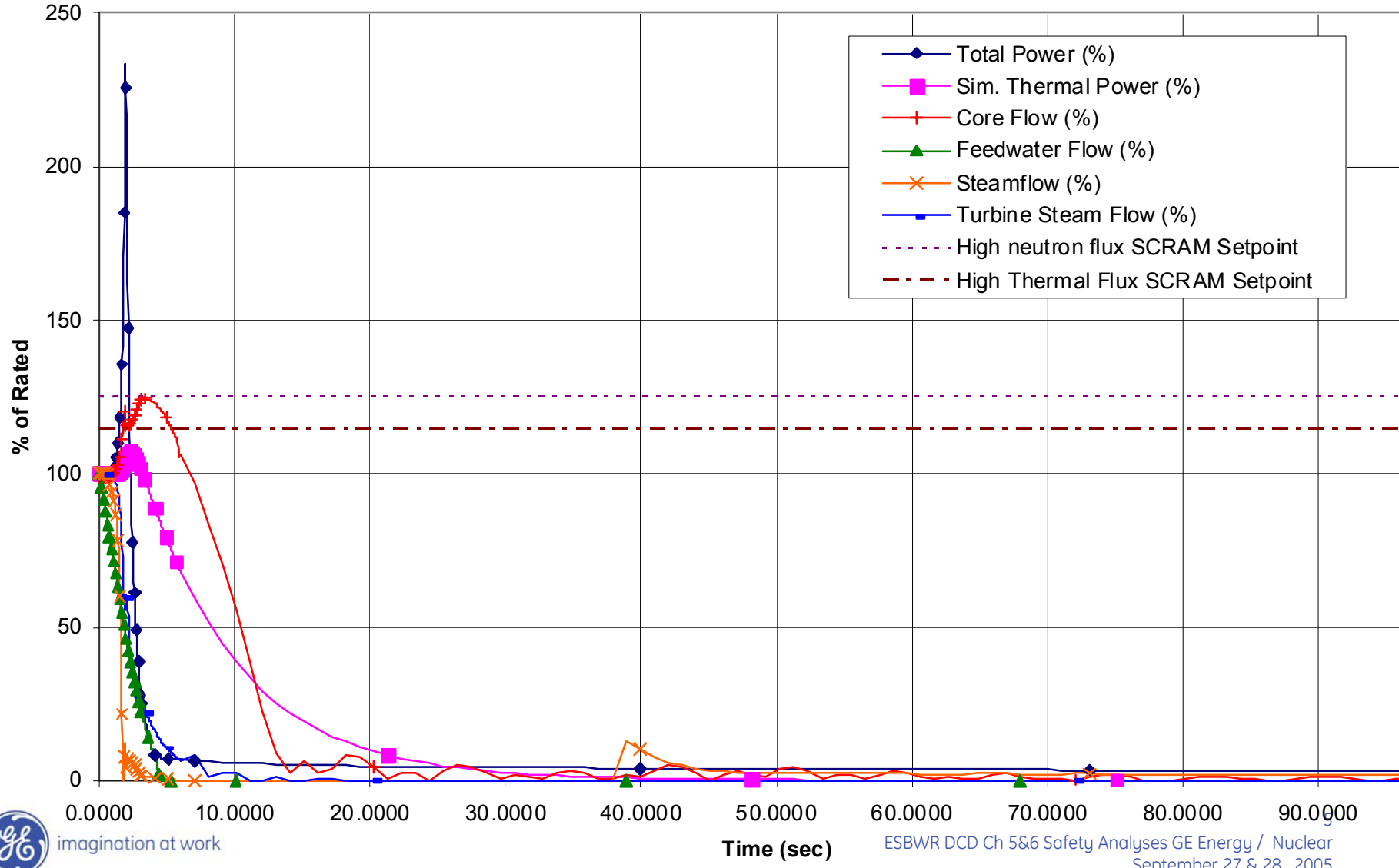
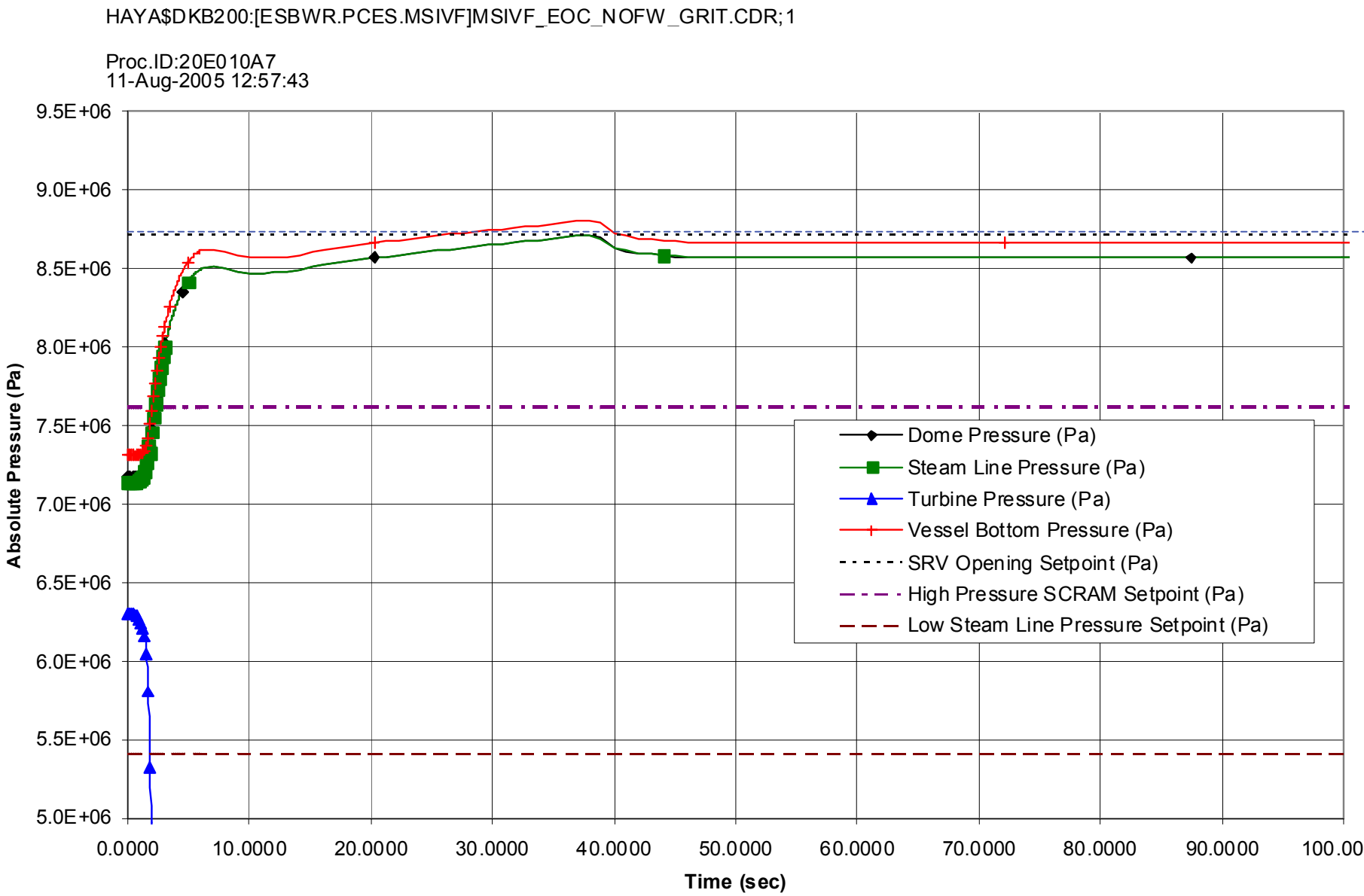


Figure 5.2-4d. MSIV Closure – Flux Scram



TRACG Applied to all Thermal Hydraulic evaluations of ESBWR

Follows process described in ESBWR Licensing topical reports:

NEDE-33083 (LOCA and AOO's)

NEDE-33083 Supplement 1 (Stability)

TRACG model of ESBWR reactor vessel

2D Reactor vessel for LOCA

3D Reactor vessel for AOO, ATWS and Stability

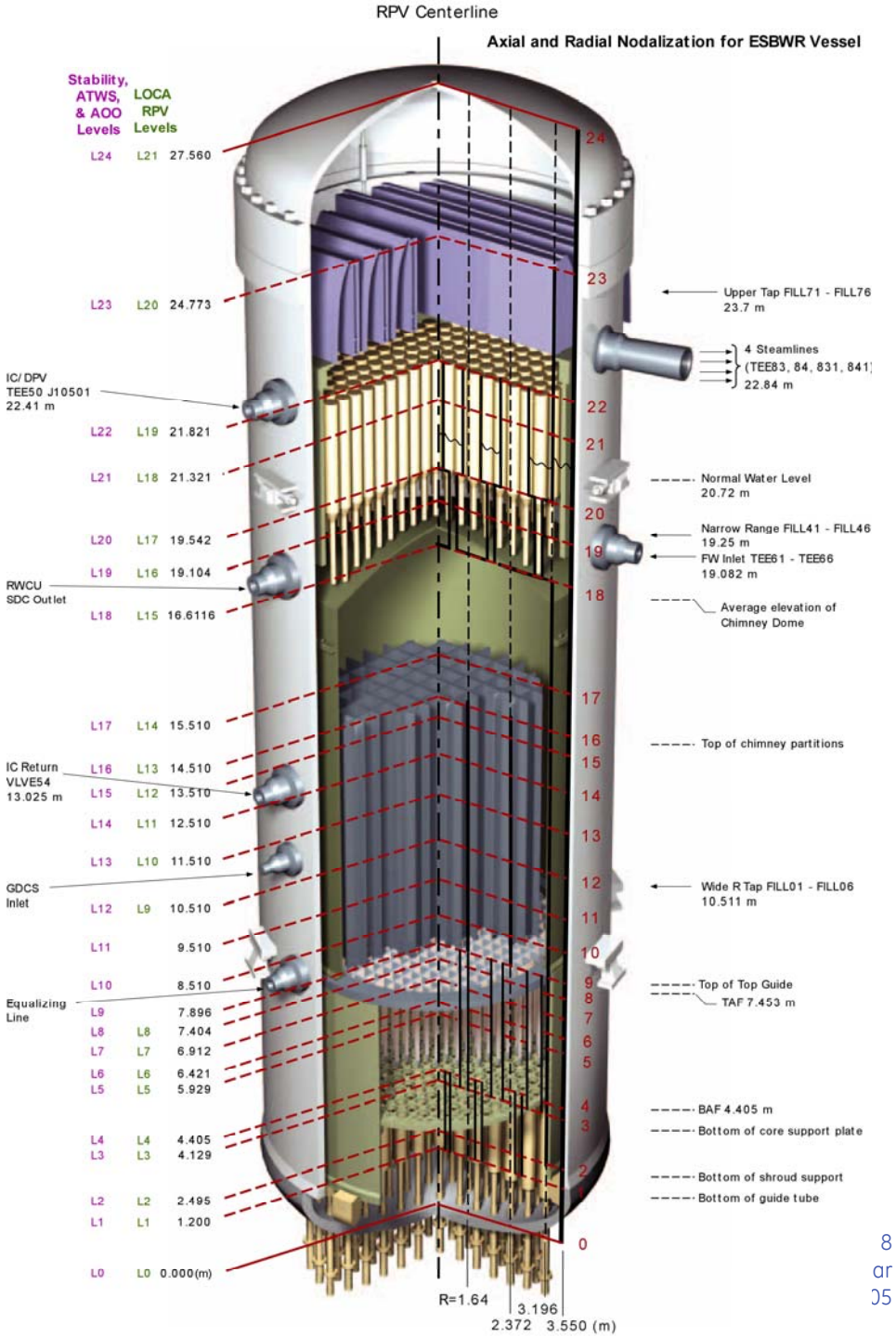


Figure 6.2-6. TRACG Nodalization of the ESBWR RPV

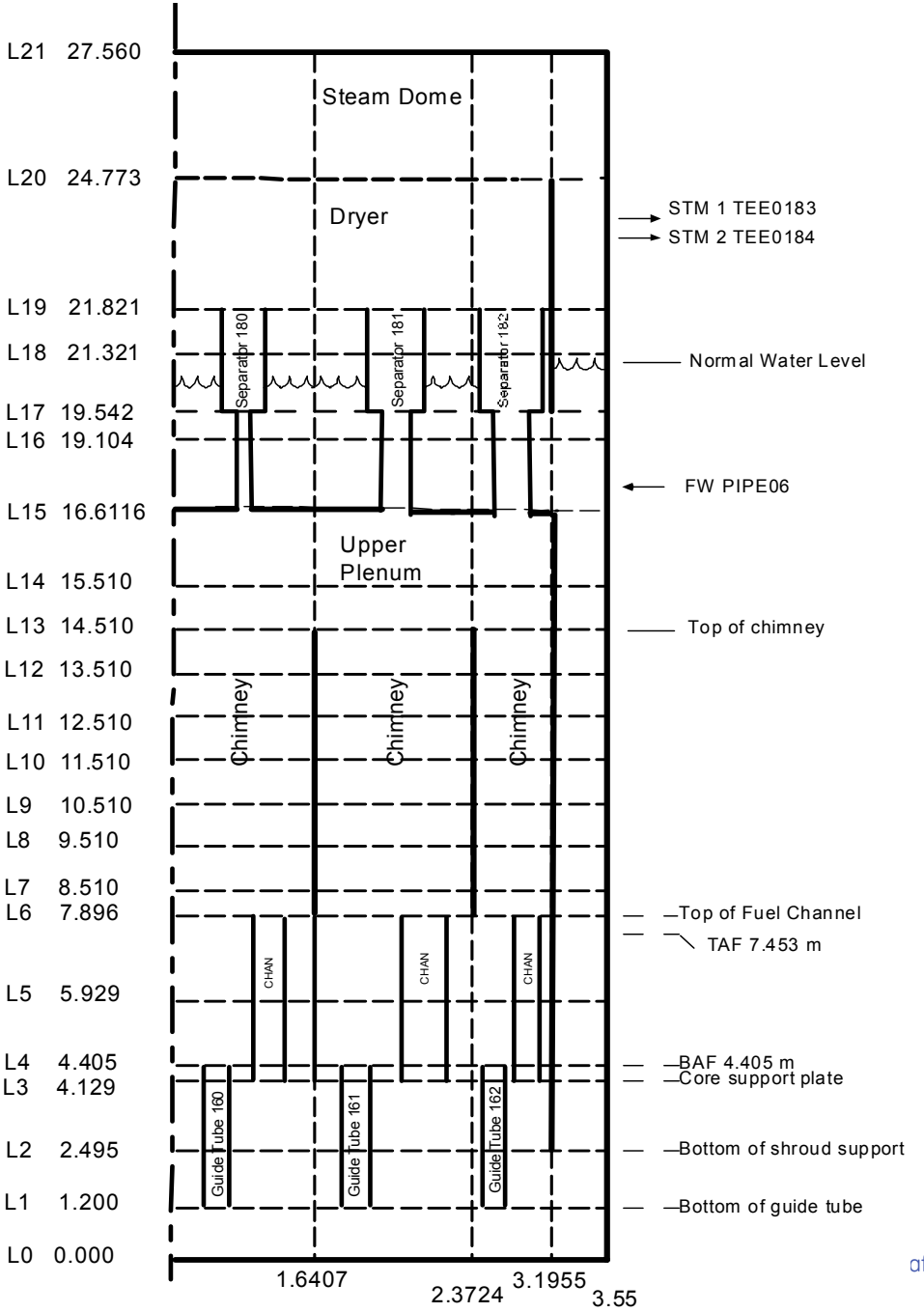


Figure 6.2-7. TRACG Nodalization of the ESBWR Containment

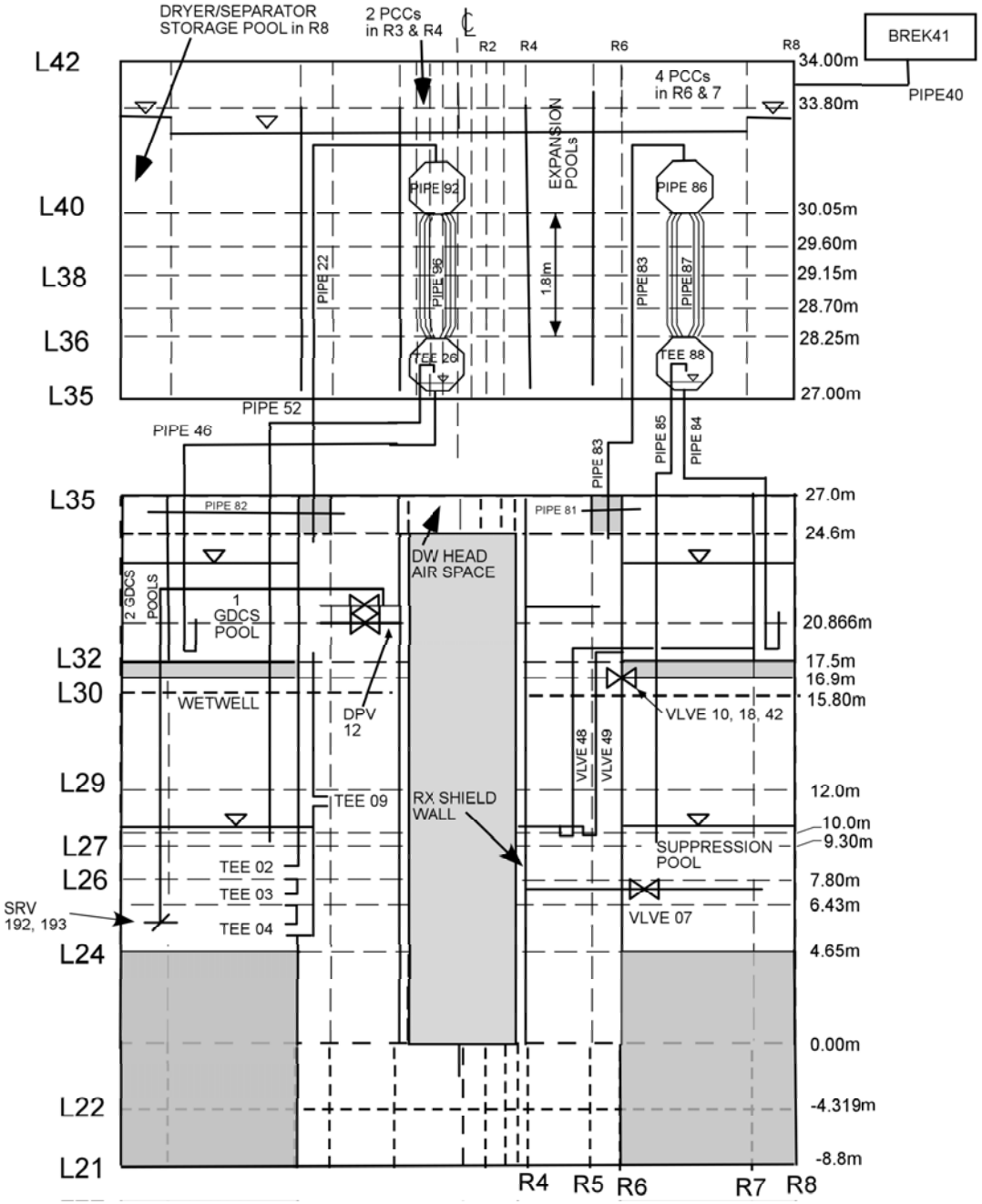
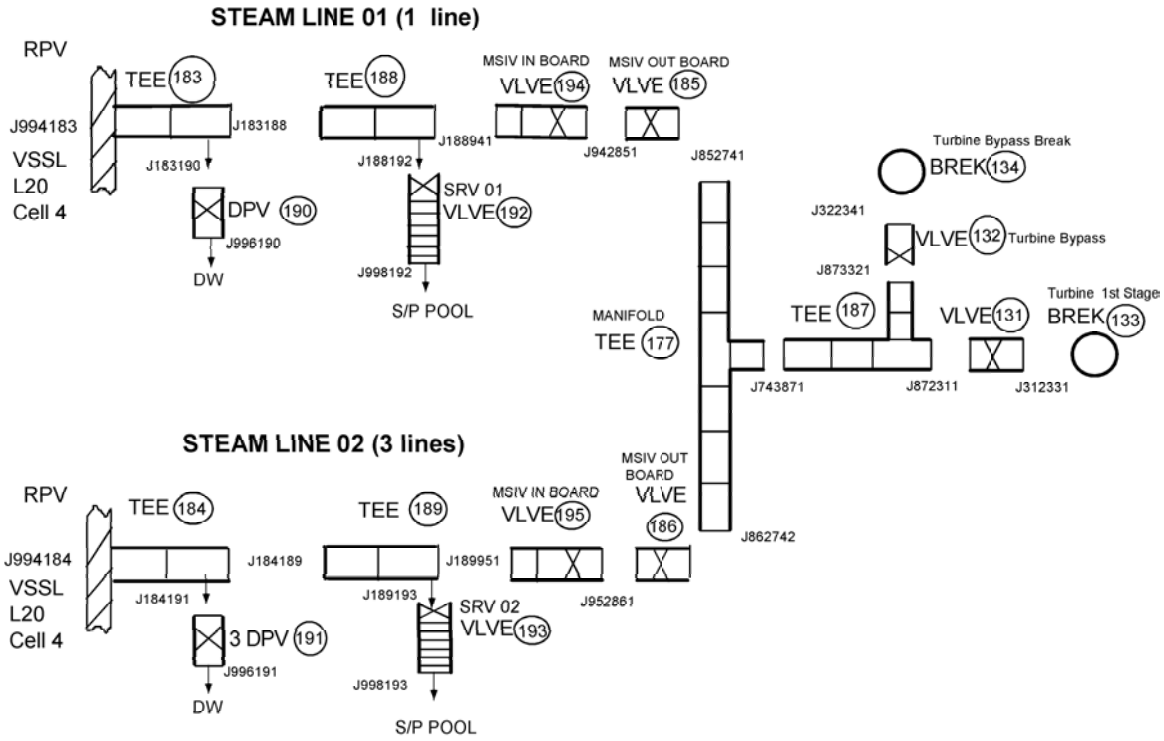


Figure 6.2-8. TRACG Nodalization of the ESBWR Main Steam Lines



Containment Pressure and Temperature Analysis

ESBWR design provides more than the 15% margin required at the PSAR stage

Table 6.2-5. Summary of Calculated Results for A FW Line Break with Failure of One DPV

	Peak DW Pressure (a)	Peak DW Pressure (g)	Margin to Design Pressure of 45 psig (%)
Nominal Case	322 kPa (46.7 psia)	221 kPa (gauge) (32.0 psig)	29
Bounding Case	342 kPa (49.6 psia)	241 kPa (gauge) (34.9 psig)	22

	Short-term DW Temperature (C)	Long-term DW Temperature (C)	Long-term WW Temperature (C)
Nominal Case	168	141	90
Bounding Case	170	144	87

Table 6.2-6. Plant Initial Conditions Considered in the Containment DBA Cases

No.	Plant Parameter	Nominal Value	Bounding Value
1	RPV Power	100%	102%
2	WW relative humidity	100%	100%
3	PCC pool level	4.8 m	4.8 m
4	PCC pool temperature	110°F (316.5°K)	110°F (316.5°K)
5	DW Pressure	14.7 psia (101.3 kPa)	16.0 psia (110.3 kPa)
6	DW Temperature	115°F (319.3°K)	115°F (319.3°K)
7	WW Pressure	14.7 psia (101.3 kPa)	16.0 psia (110.3kPa)
8	WW Temperature	110°F (316.5°K)	110°F (316.5°K)
9	Suppression pool Temp.	110°F (316.5°K)	110°F (316.5°K)
10	GDCS pool temperature	115°F (319.3°K)	115°F (319.3°K)
11	Suppression pool level	5.45 m	5.50 m
12	GDCS pool level	6.60 m	6.60 m
13	DW relative humidity	20%	20%
14	RPV pressure	1040 psia (7.17 MPa)	1055 psia (7.274 MPa)
15	RPV Water Level	NWL	NWL+0.3m

Table 6.2-7. Operational Sequence of ECCS For A Feedwater Line Break with Failure of One DPV (Nominal Case)

Time (sec)	**Events**
~0	Guillotine break of feedwater line inside containment; normal auxiliary power assumed to be lost; feedwater is lost; Scram signal initiated.
~1	High drywell pressure setpoint for ADS is reached.
~2	Loss of normal auxiliary power confirmed; reactor scram initiated; IC initiated.
~5	Level 3 is reached; Reactor receives second signal to scram.
~6	Maximum (first peak) DW pressure of 322 kPa (46.7 psia) is reached.
~9	Level 2 is reached; Reactor isolation timer initiated.
~14	Level 1.5 is reached; Reactor isolation initiated; ADS/GDCS timer initiated.
~17	IC drain valve begins to open.
~24	Level 1.5 signal confirmed; ADS-SRV actuation begins.
~33	IC drain valve fully open.
~74	DPV actuation begins; SLC system signaled to start.
~100	Minimum chimney water level is reached.
~164	GDCS timer timed out. GDCS injection valves open.
~250	Vessel pressure decreases below maximum injection pressure of GDCS. GDCS flow into the vessel begins. Chimney and downcomer water levels start to rise.
from ~250 to 259000 (72 hrs)	RPV water level remains higher than Level 0.5. Therefore equalizing line valves are not expected to open for this event.
~ 140000 (39 hrs)	PCC pool level drops below the elevation of 29.6 m; top ¼ portion of the PCC tube length becomes uncover; Connection valves open to allow the water from the Dryer/Separator storage pool to flow into the PCC pools.
~ 250000 (70 hrs)	Long-term DW pressure (2nd peak) of 290 kPa (42 psia) is reached.

Table 6.2-8. Model Parameters for Containment Bounding Calculation

No.	Model Parameter	Base value	Distribution	Uncertainty (1 sigma)	Bounding case	Bounding value used
1	Crit Flow (PIRT84)	1.0	Normal	9.5%	- 2 sigma	0.81
2	Decay Heat Mult.	1.0	Normal	~0.05	+ 2 sigma	D.H. + 2 sigma
3	Surf. HT (PIRT07)	100	Uniform	1 to 200	Lower bound	1
4	PCC inlet Loss (k/A^2)	$1065m^{-4}$	Normal	$260.0m^{-4}$	+ 2 sigma	$1585m^{-4}$
5	PCC HT (PIRT78)	1.0	Normal	7.9% (bias – 6.0%)	- 2 sigma	0.902
6	VB Loss (k/A^2)	$169.0m^{-4}$	Normal	$21.18m^{-4}$	+ 2 sigma	$211.4m^{-4}$

Figure 6.2-9. Feedwater Line Break (Nominal Case) — Containment Pressures

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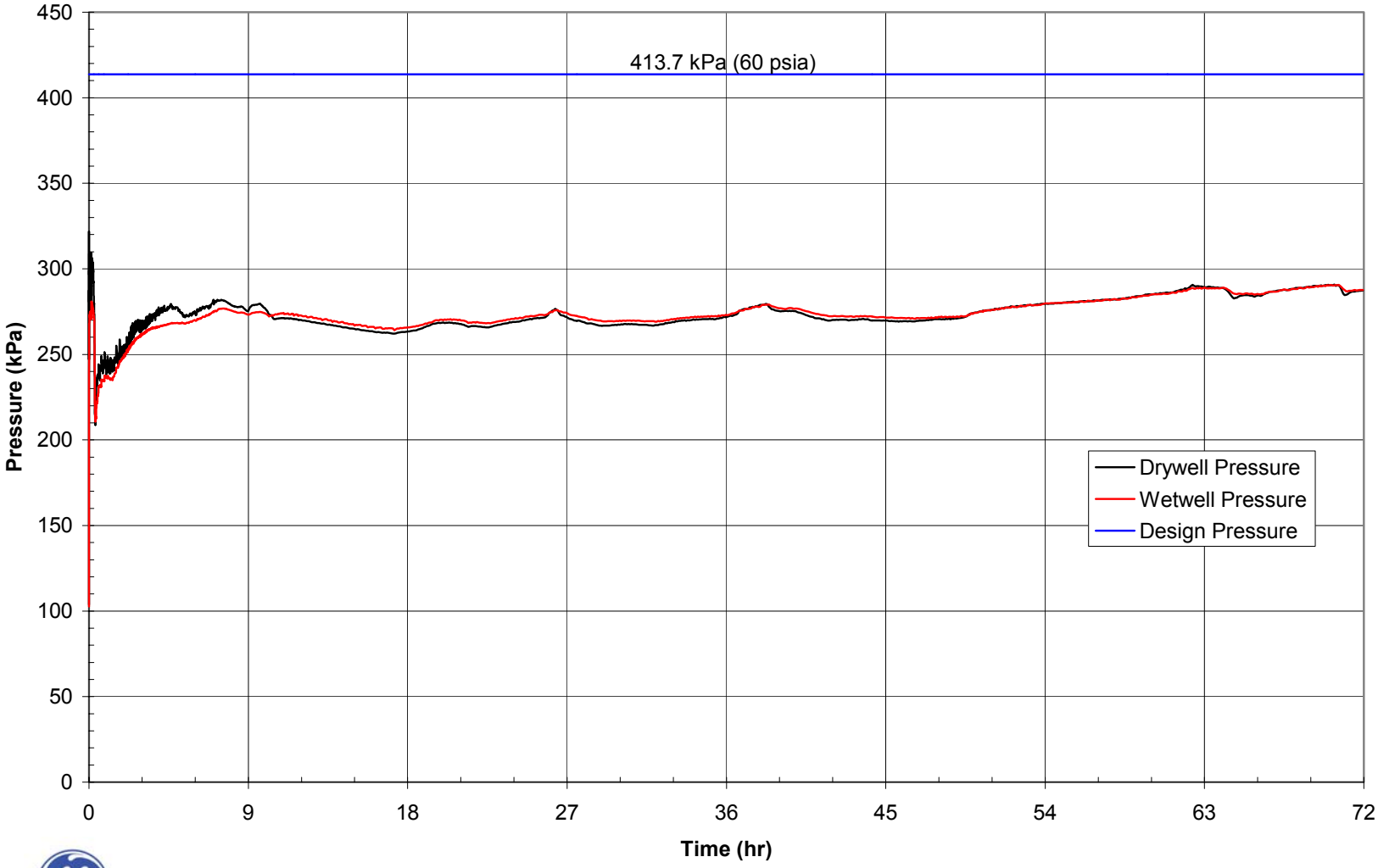

Figure 6.2-10. Feedwater Line Break (Nominal Case) — Containment Temperatures

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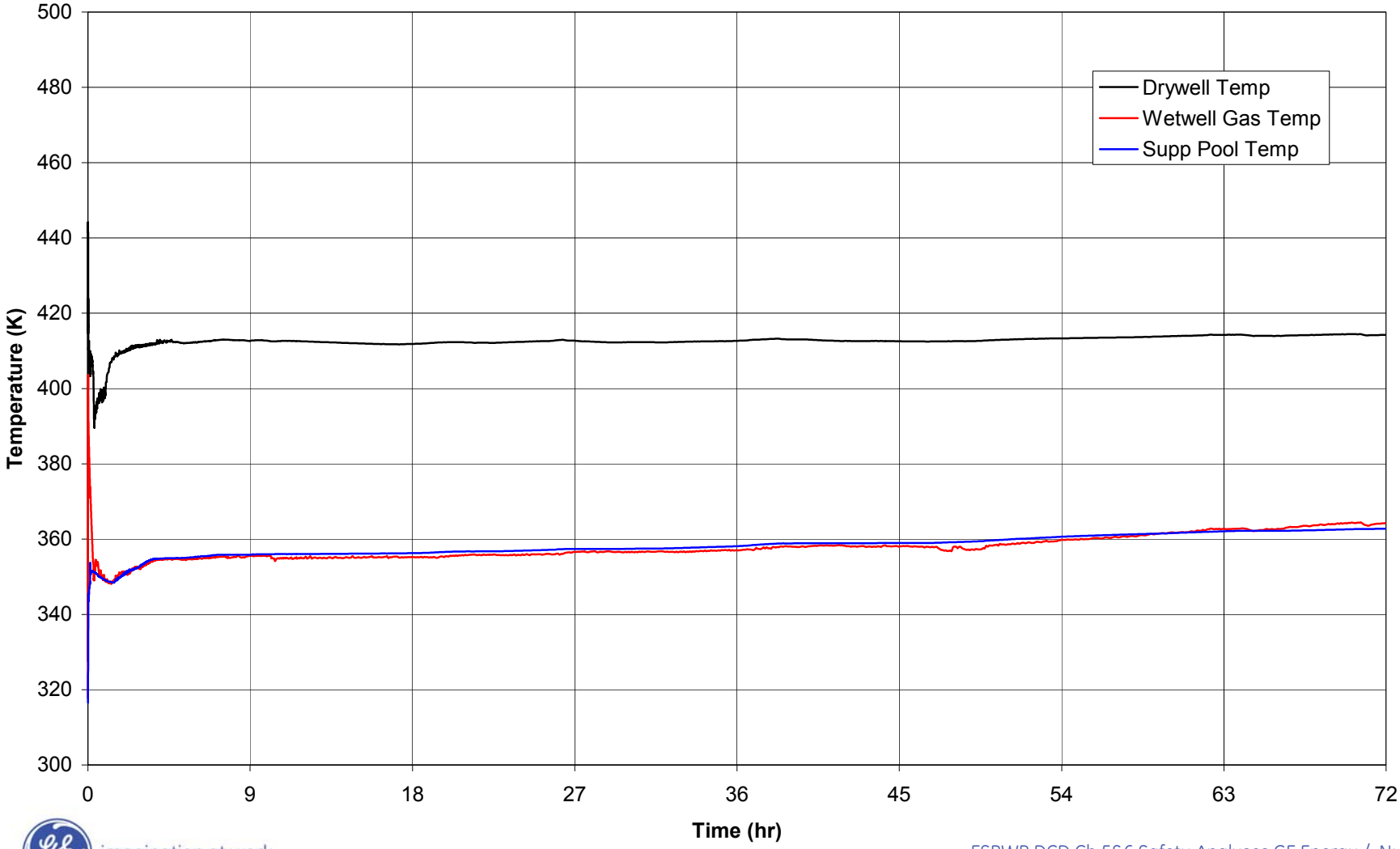

Figure 6.2-11. Feedwater Line Break (Nominal Case) — PCCS Heat Removal versus Decay Heat

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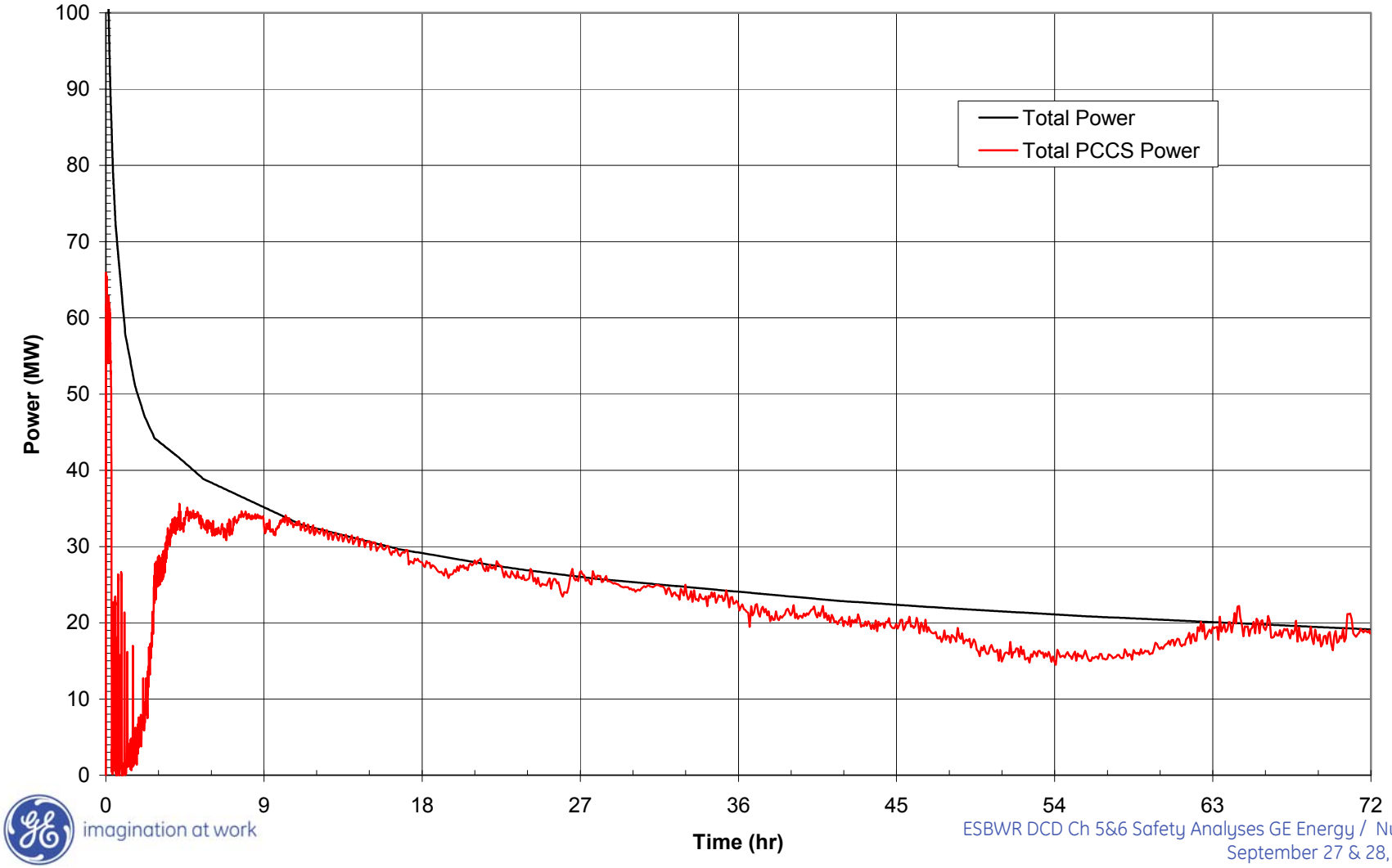

Figure 6.2-12. Feedwater Line Break (Bounding Case) — Containment Pressures

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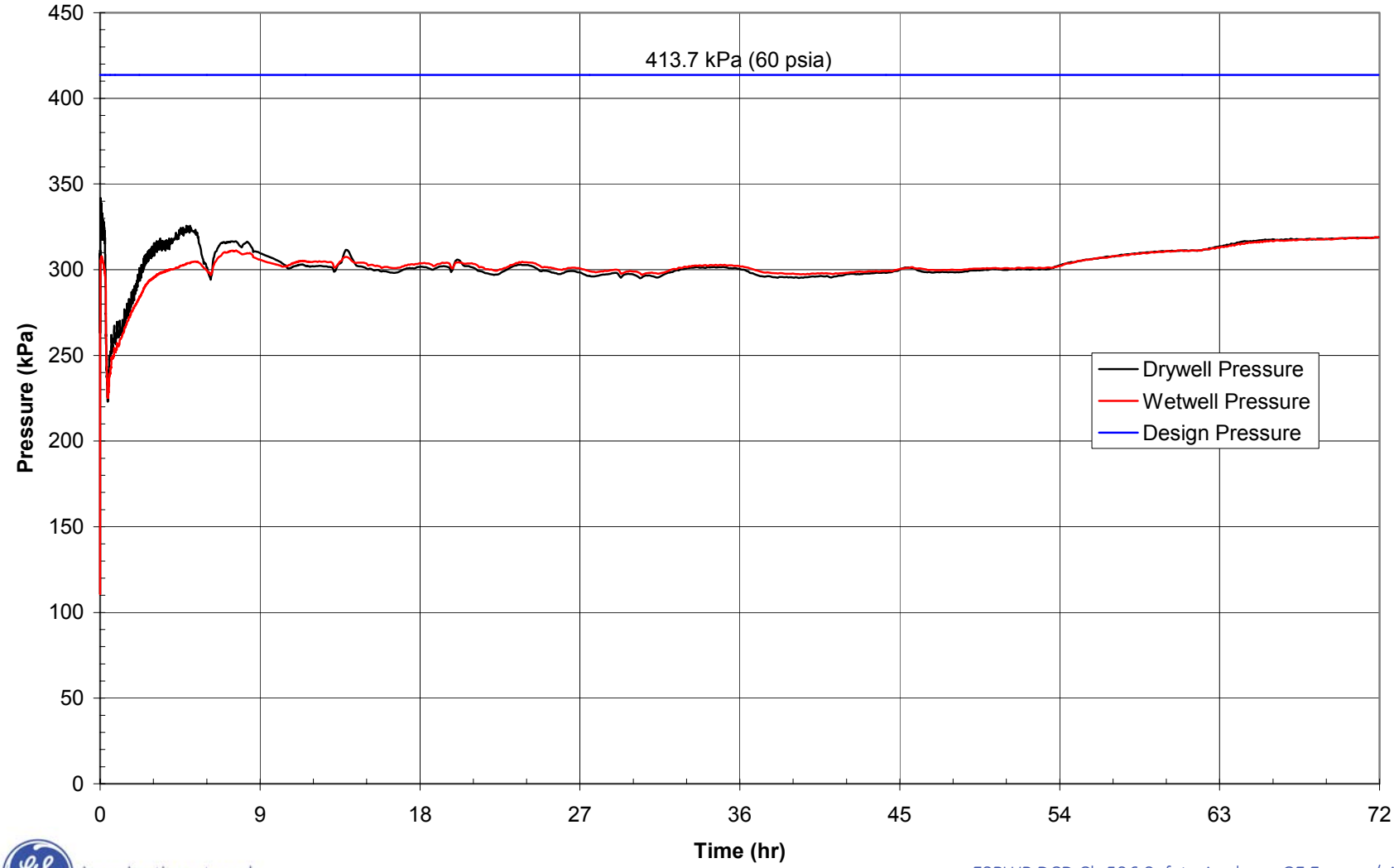

Figure 6.2-13. Feedwater Line Break (Bounding Case) — Containment Temperatures

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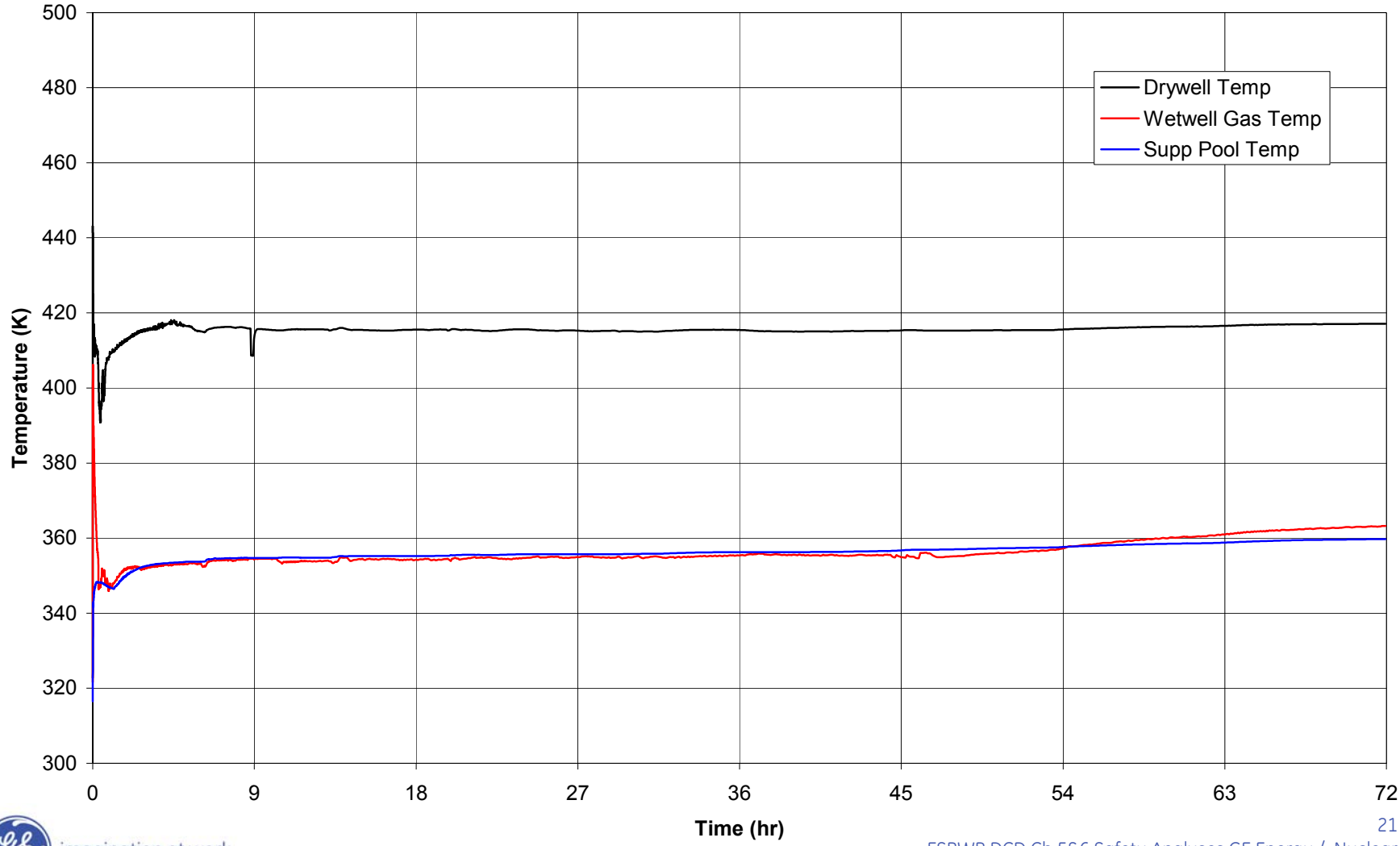

Figure 6.2-14. Feedwater Line Break (Bounding Case) — PCCS Heat Removal versus Decay Heat

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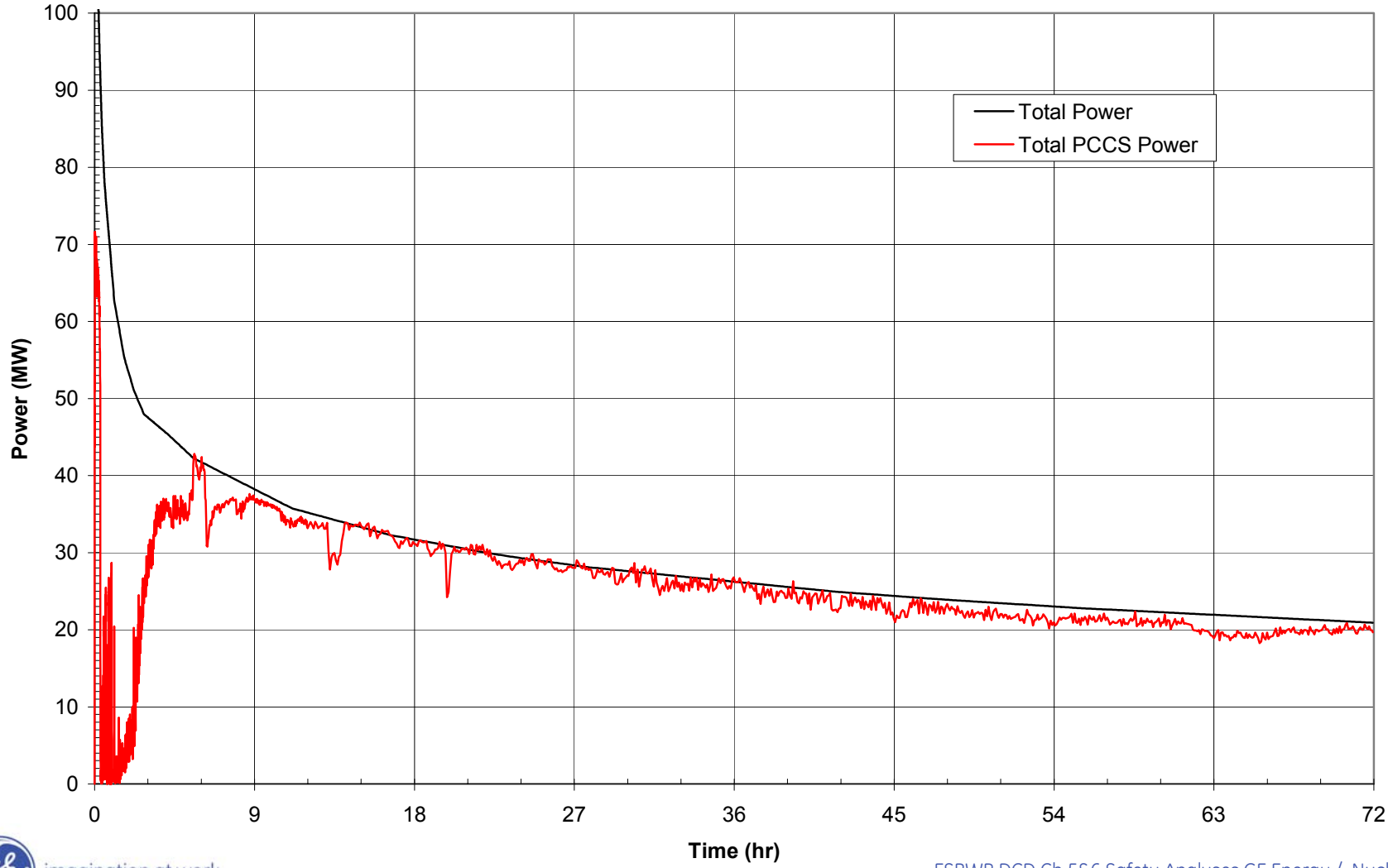

10CFR50.46 LOCA Analysis

- PCT < 2200 deg. F (no core uncovery or fuel heatup)
- Local Oxidation <17%
- Core wide oxidation < 1%
- Coolable Geometry maintained
- Long term cooling provided for 72 hrs via passive systems

Table 6.3-1. Significant Input Variables to the ECCS-LOCA Performance Analysis

A. Plant Parameters		
Variable	**Units**	**Value**
Core thermal Power	MWt	4500
Vessel Steam Output	kg/hr [lbm/hr]	8.76×10^6 19.31×10^6
Vessel Steam Dome Pressure	MPa (absolute) [psia]	7.17 1040
B. Emergency Core Cooling System Parameters **B.1 ECCS Initiation Signals**		
Variable	**Units**	**Value**
Initiating Signals: Level 1.5 plus High Drywell Pressure <u>or</u> Level 1.5 plus Delay Timer Timed Out <u>or</u> Level 1	 meters (above TAF) [ft] (above TAF) kPa (absolute) [psia] meters (above TAF) [ft] (above TAF) min meters (above TAF) [ft] (above TAF)	 5.547 [18.20] 34.457 [5] 5.547 [18.20] 15 3.547 [11.64]
Maximum Allowable Time Delay to Confirm ECCS-LOCA Signal	sec	10

Table 6.3-1. Significant Input Variables to the ECCS-LOCA Performance Analysis (Cont.)

B.2 Gravity-Driven Core Cooling System		
Variable	**Units**	**Value**
Initiating Signal	—	ECCS-LOCA confirmed initiating signal (See B.1)
GDCS Injection valve timer delay	sec	150
Minimum drainable inventory per GDCS pool		See Table 6.3-2
Minimum elevation of GDCS pool surfaces above the RPV nozzles		See Table 6.3-2
GDCS drain line loss coefficient (k/A2)	$1/m^4$ $[1/ft^4]$	$12.587*10^3$ $[1.458*10^6]$
B.3 Isolation Condenser System		
Variable	**Units**	**Value**
Initiating Signal	—	Loss of feedwater
Maximum Sensor Response Time	sec	2
Heat Removal Capacity per Unit	MW	33.75
Minimum Drainable Liquid Volume per System	m^3 $[ft^3]$	4.98
B.4 Standby Liquid Control System		
Variable	**Units**	**Value**
Initiating Signal	—	DPV actuation (See B.5)
Liquid Volume per Tank	m3 [ft3]	7.8

Table 6.3-1. Significant Input Variables to the ECCS-LOCA Performance Analysis (Cont.)

B.5 Automatic Depressurization Subsystem		
Variable	**Units**	**Value**
Initiating Signal	—	ECCS-LOCA confirmed initiating signal (See B.1)
Valve Actuation Sequence:		
5 ADS	sec	0
5 ADS	sec	10
3 DPVs	sec	50
2 DPVs	sec	100
2 DPVs	sec	150
1 DPVs	sec	200
Total Number of Safety/Relief Valves With ADS Function	—	10
Total Min. ADS Flow Capacity at Vessel Pressure	kg/hr MPa (gauge) [lbm/hr] [psig]	4.356×10^6 8.618 [9.61×10^6] [1250]
Total Number of Depressurization Valves	—	8
Total min. DPV flow capacity at vessel pressure	kg/hr MPa (gauge) [lbm/hr] [psig]	6.89×10^6 7.481 [15.2×10^6] [1085]
Total max. DPV flow capacity at vessel pressure	kg/hr MPa (gage) [lbm/hr] [psig]	8.47×10^6 7.481 [18.7×10^6] [1085]

Table 6.3-1. Significant Input Variables to the ECCS-LOCA Performance Analysis (Cont.)

C. Fuel Parameters *		
Variable	**Units**	**Value**
Fuel type	—	See Chapter 4
Peak Linear Heat Generation Rate (Bounding))	kW/m [kW/ft]	44 13.4
Initial Minimum Critical Power Ratio (Bounding)	—	1.12

Table 6.3-2. GDCS Design Basis Parameters

Parameter	Value
Number of separate/independent GDCS divisions	4
Per division, number of (short-term core cooling injection) lines from its GDCS pool	1
Per division, number of injection line RPV nozzles	2
Per division, number of equalizing line RPV nozzles	1
Minimum total drainable inventory (for 3 GDCS pools)	1760 m^3 (62,150 ft^3)
Minimum elevation of GDCS pool surfaces above the RPV nozzles	13.3 m (43.6 ft)
Minimum long-term core cooling flow delivered by the GDCS equalizing lines for a ΔP of 9.12 kPa (1.32 psid) across the equalizing lines	22.7 m^3/s (100 gpm)
Minimum flow through the deluge lines required to flood the lower drywell region	70 kg/sec (154l m/sec)*
Minimum available suppression pool water inventory 1 meter above TAF	334m^3 (11,800 ft^3)
Minimum GDCS equalizing line driving head	1.0 m (3.3 ft)

Table 6.3-7. Operational Sequence of ECCS For A Feedwater Line Break with Failure of One GDCS Injection Valve (nominal calculation)

Time (sec)	**Events**
~0	Guillotine break of feedwater line inside containment; normal auxiliary power assumed to be lost; Feedwater is lost; Scram signal initiated.
~1	High drywell pressure setpoint for ADS is reached.
~2	Loss of normal auxiliary power confirmed; reactor scram initiated; IC initiated.
~5	Level 3 is reached; Reactor receives second signal to scram.
~9	Level 2 is reached; Reactor isolation timer initiated.
~14	Level 1.5 is reached; Reactor isolation initiated; ADS/GDCS timer initiated.
~17	IC drain valve begins to open.
~24	Level 1.5 signal confirmed; ADS-SRV actuation begins.
~33	IC drain valve fully open.
~74	DPV actuation begins; SLC system signaled to start.
~101	Minimum chimney water level is reached.
~174	GDCS timer expired. GDCS injection valves open.
~250	Vessel pressure decreases below maximum injection pressure of GDCS. GDCS flow into the vessel begins. Chimney and downcomer water levels start to rise.
from ~250 to 2000	RPV water level remains higher than Level 0.5. Therefore equalizing line valves are not expected to open for this event.

Figure 6.3-7. MCPR, Feedwater Line Break, 1 GDCS Valve Failure

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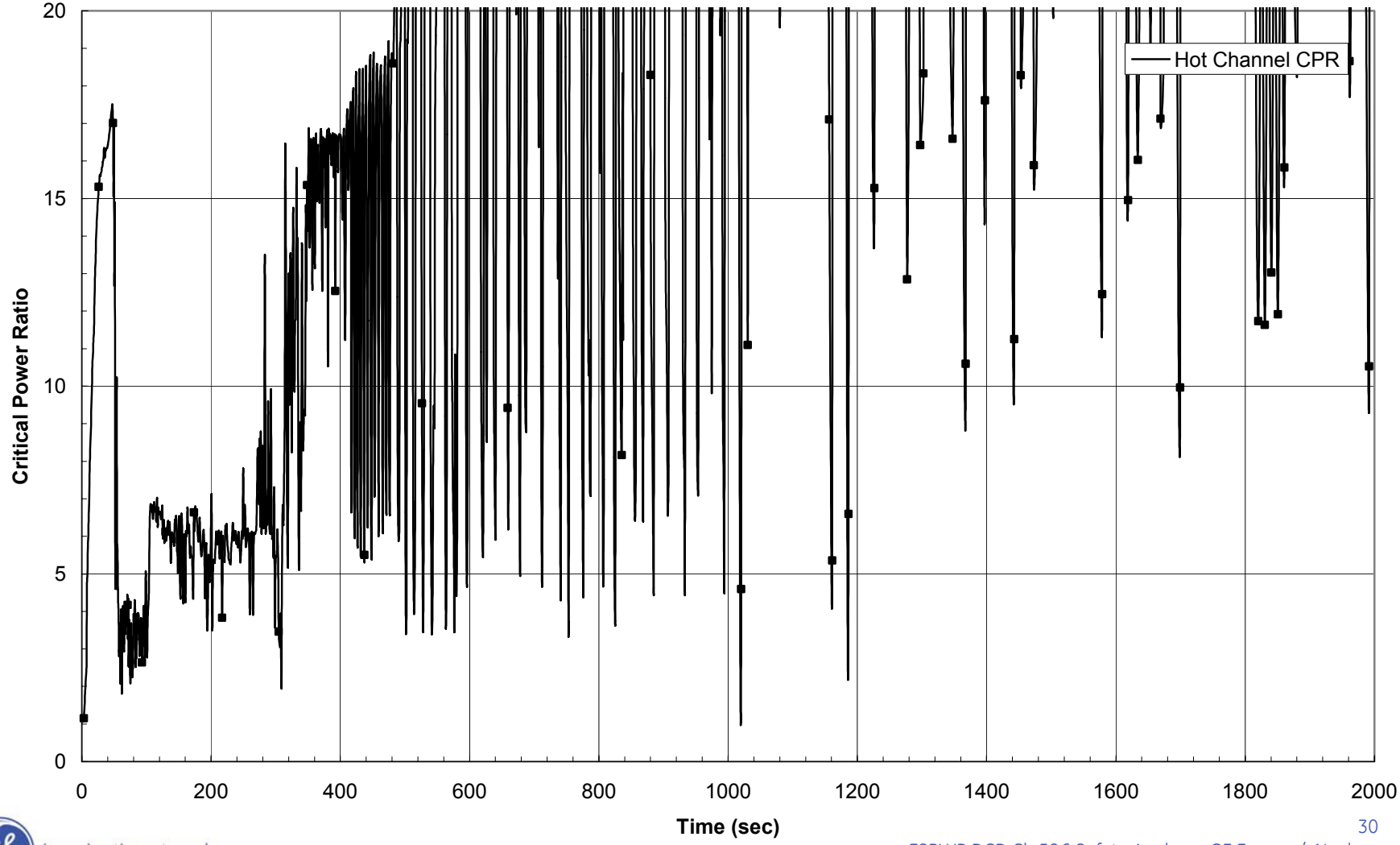

Figure 6.3-8. Chimney Water Level, Feedwater Line Break, 1 GDCS Valve Failure

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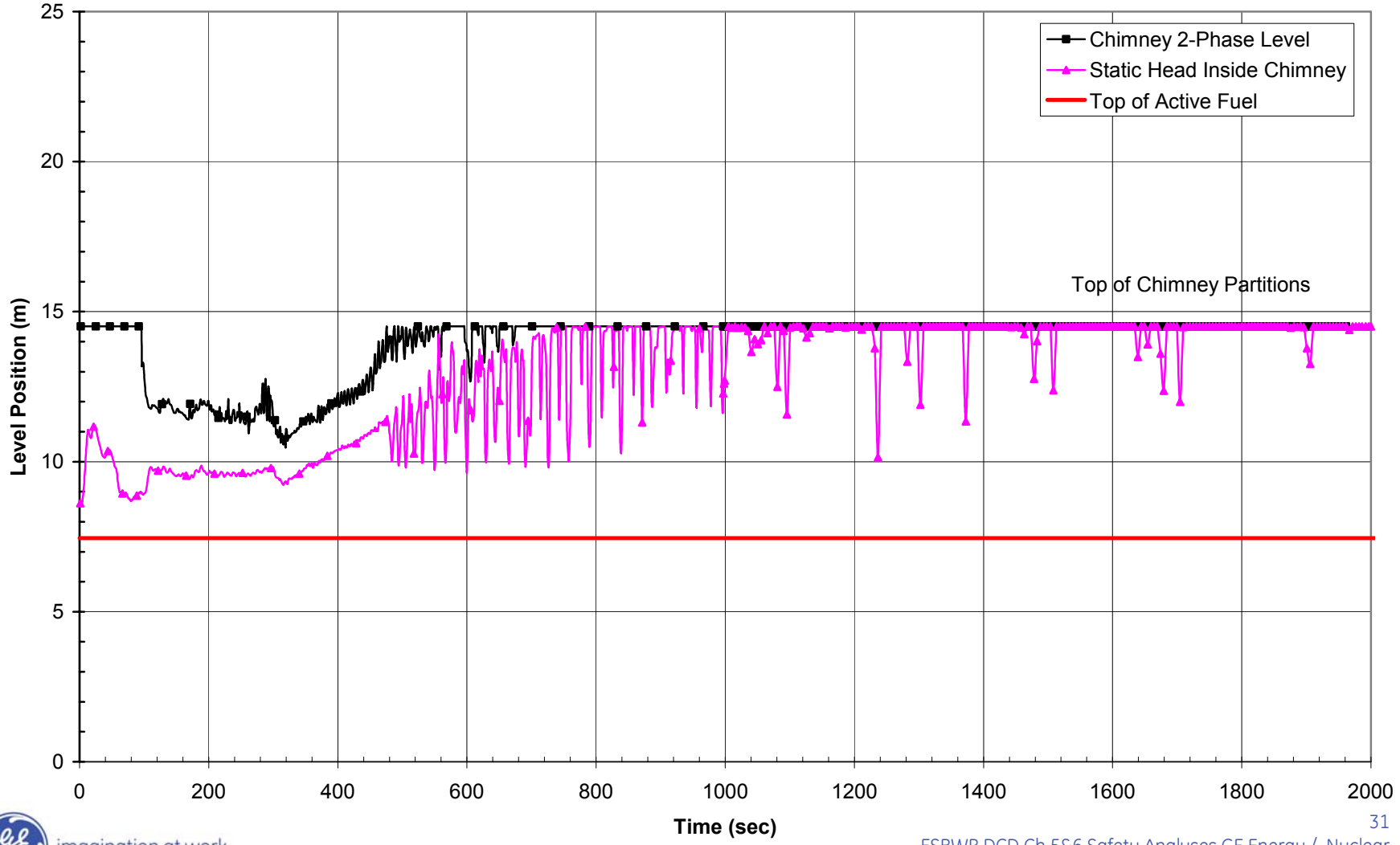

Figure 6.3-9. Downcomer Water Level, Feedwater Line Break, 1 GDCS Valve Failure

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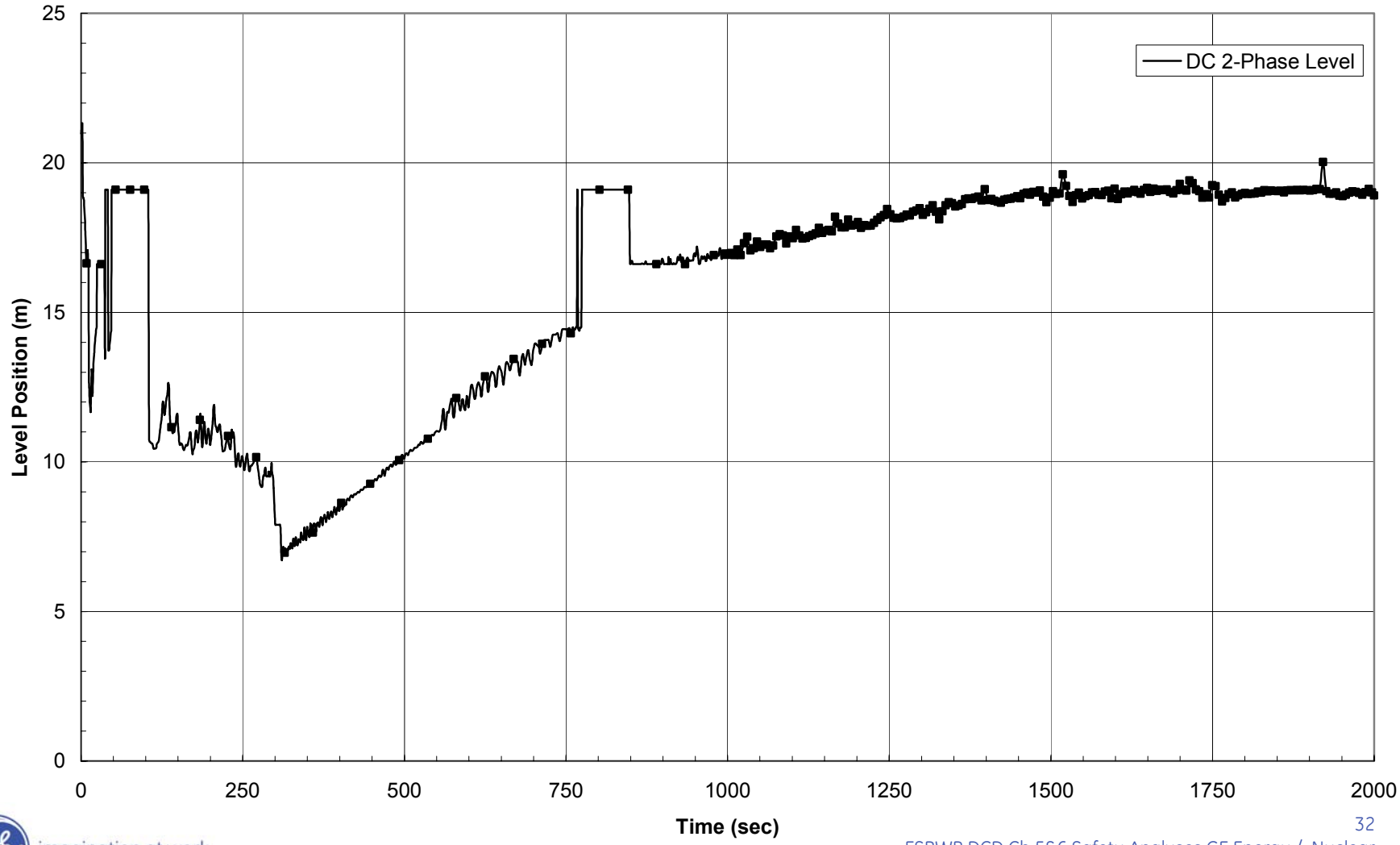

Figure 6.3-10. System Pressures, Feedwater Line Break, 1 GDCS Valve Failure

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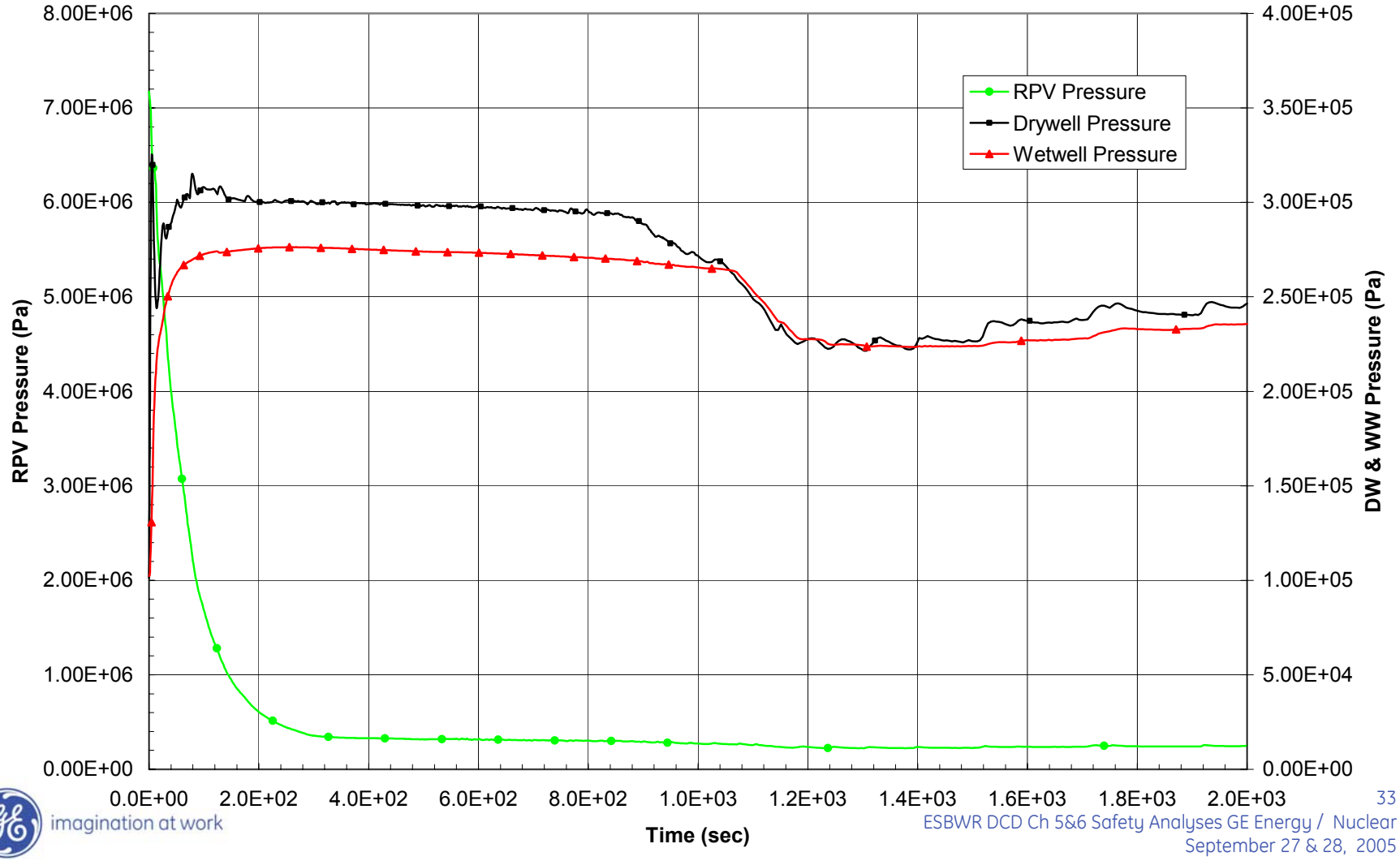

Figure 6.3-11. Steam Line and Break Flow, Feedwater Line Break, 1 GDCS Valve Failure

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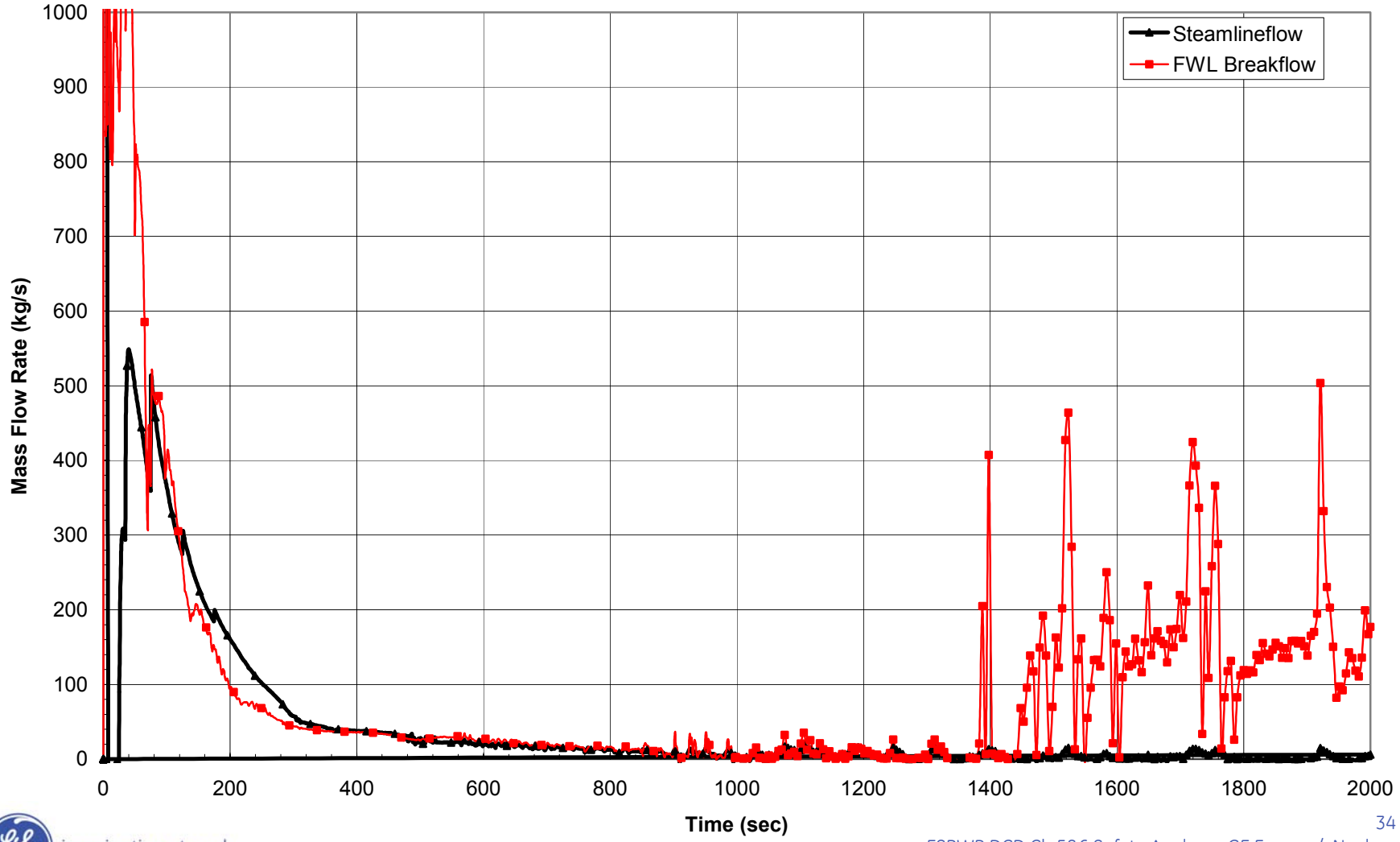

Figure 6.3-12. ADS Flow, Feedwater Line Break, 1 GDCS Valve Failure

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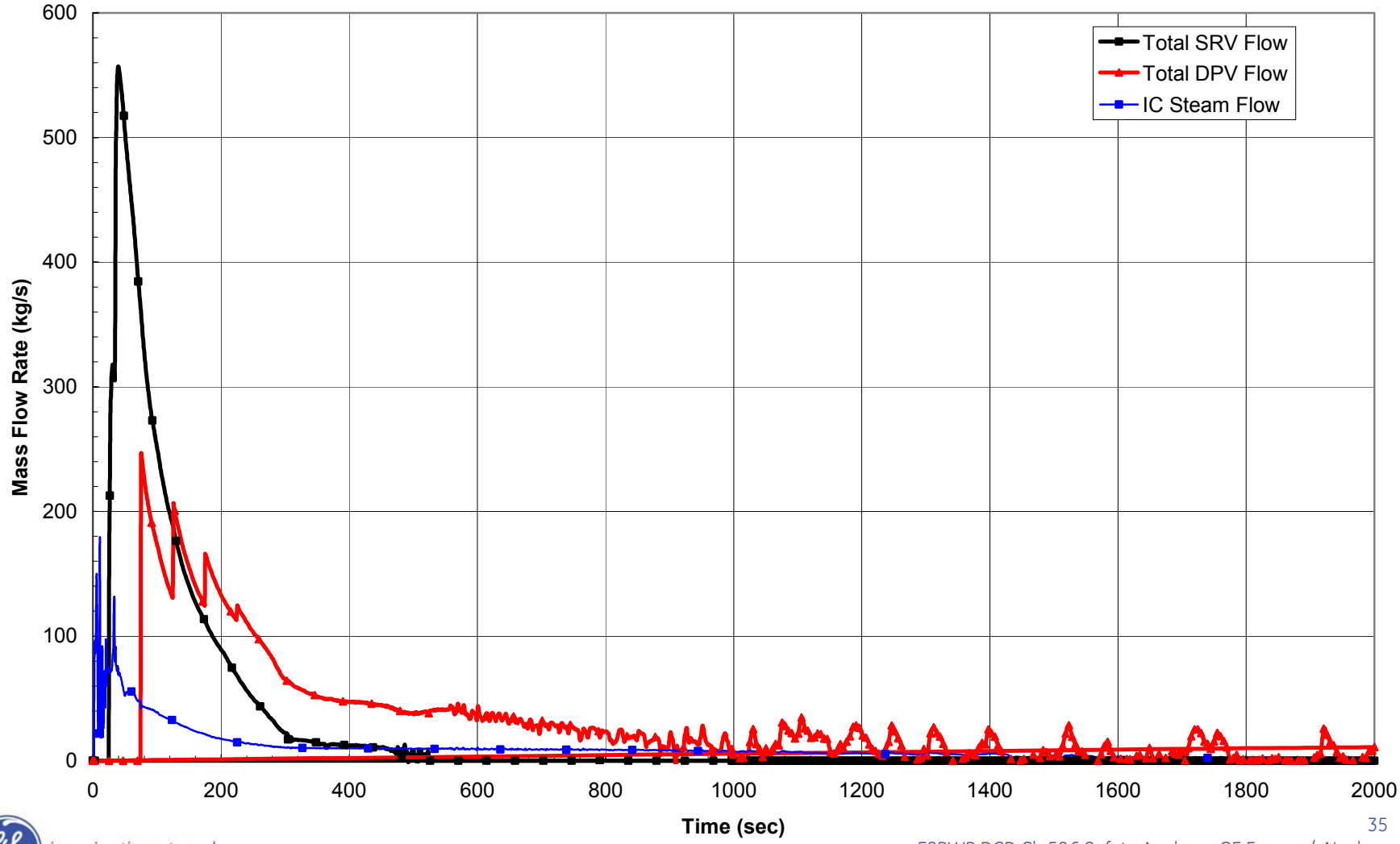

Figure 6.3-13. Flows Into Vessel, Feedwater Line Break, 1 GDCS Valve Failure

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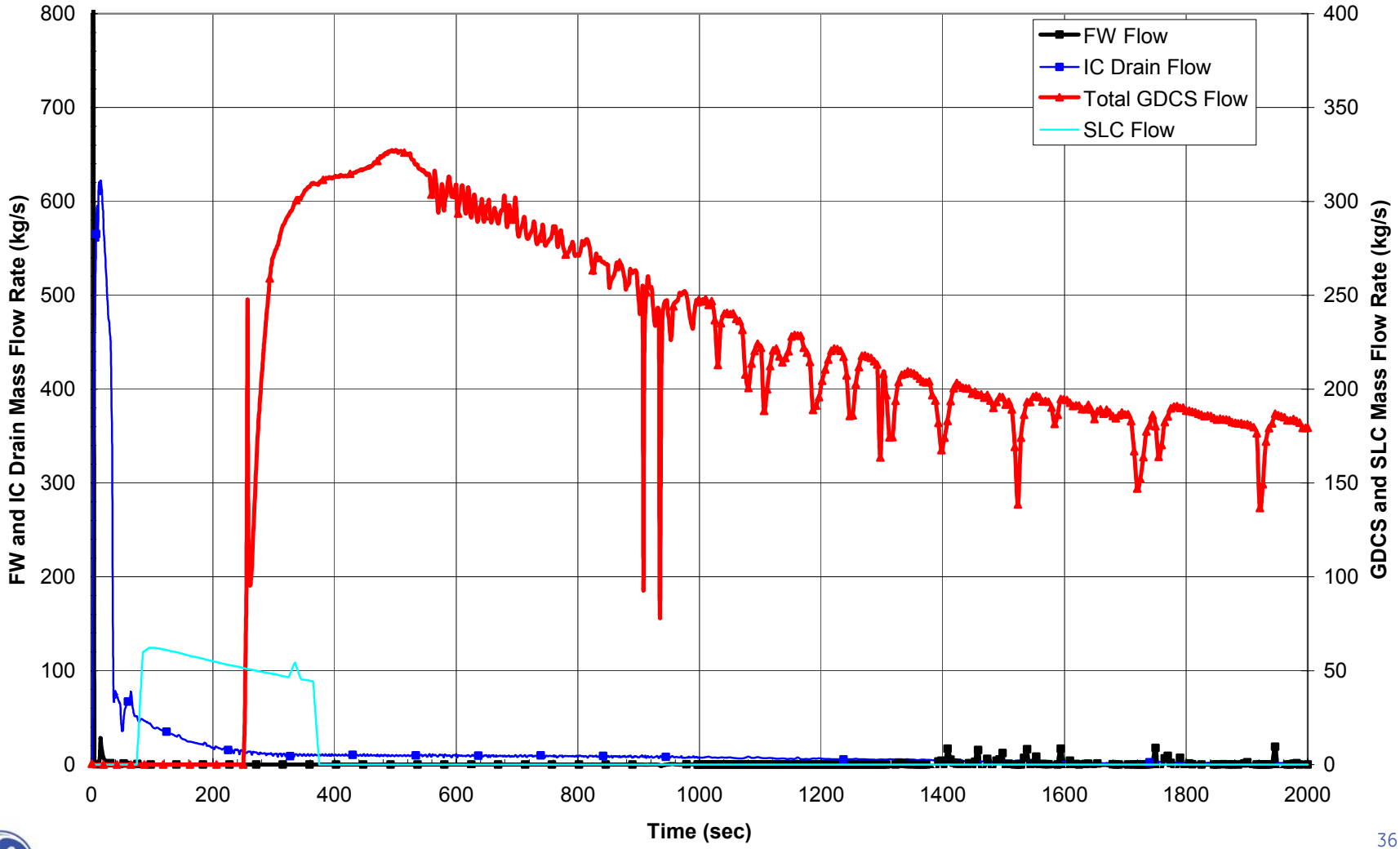

Figure 6.3-14. PCT, Feedwater Line Break, 1 GDCS Valve Failure

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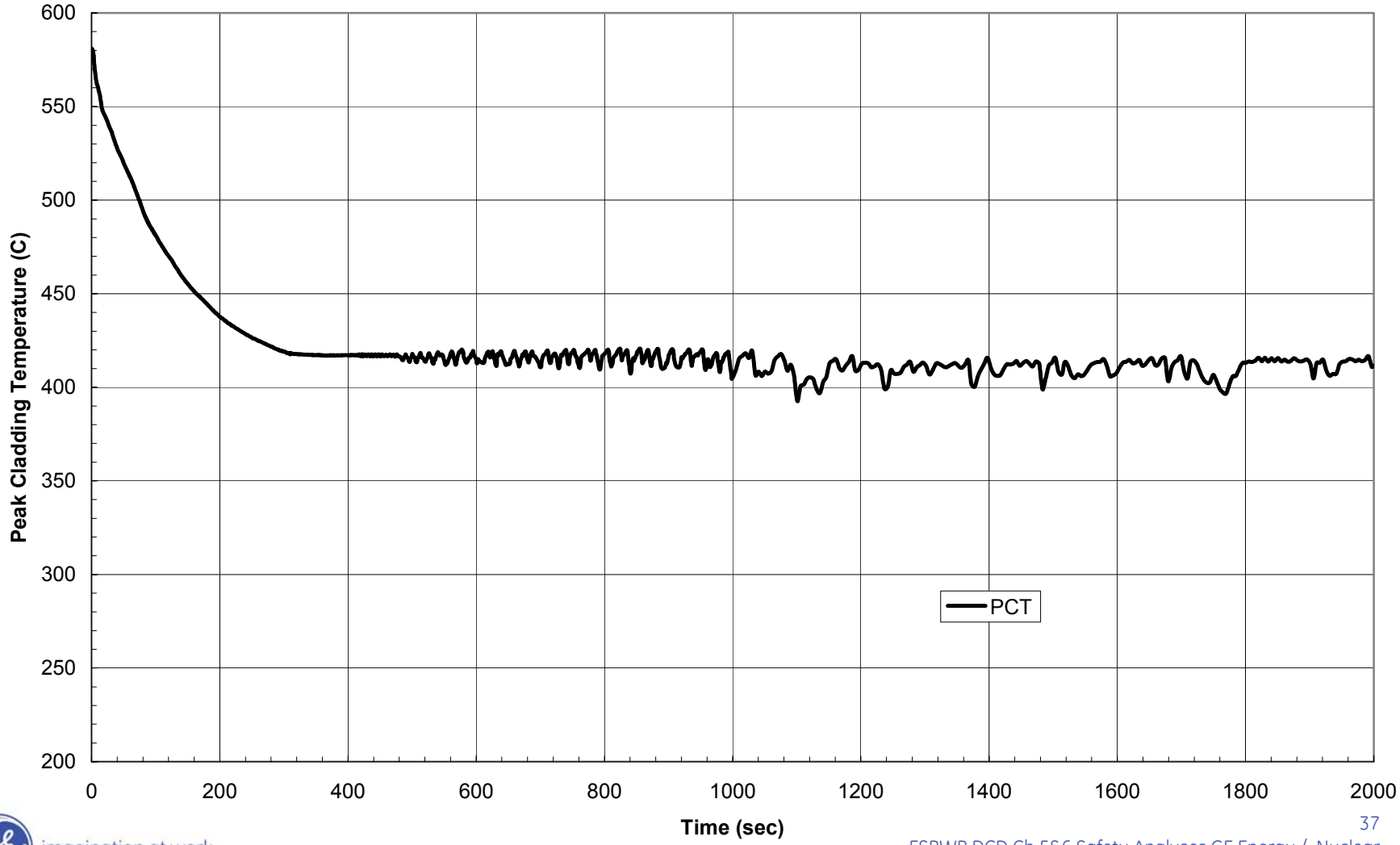


Table 6.3-6. Single Failure Evaluation

Assumed Failure*	Systems Remaining**
One Depressurization Valve	10 SRVs, 7 DPVs, 4 Ics***, 2 SLC system and 4 GDCS with 8 Injection Lines
One Safety/Relief Valve	9 SRVs, 8 DPVs 4 Ics***, 2 SLC system and 4 GDCS with 8 Injection Lines
One GDCS Injection Valve	10 SRVs, 8 DPVs 4 Ics***, 2 SLC system and 4 GDCS with 7 Injection Lines

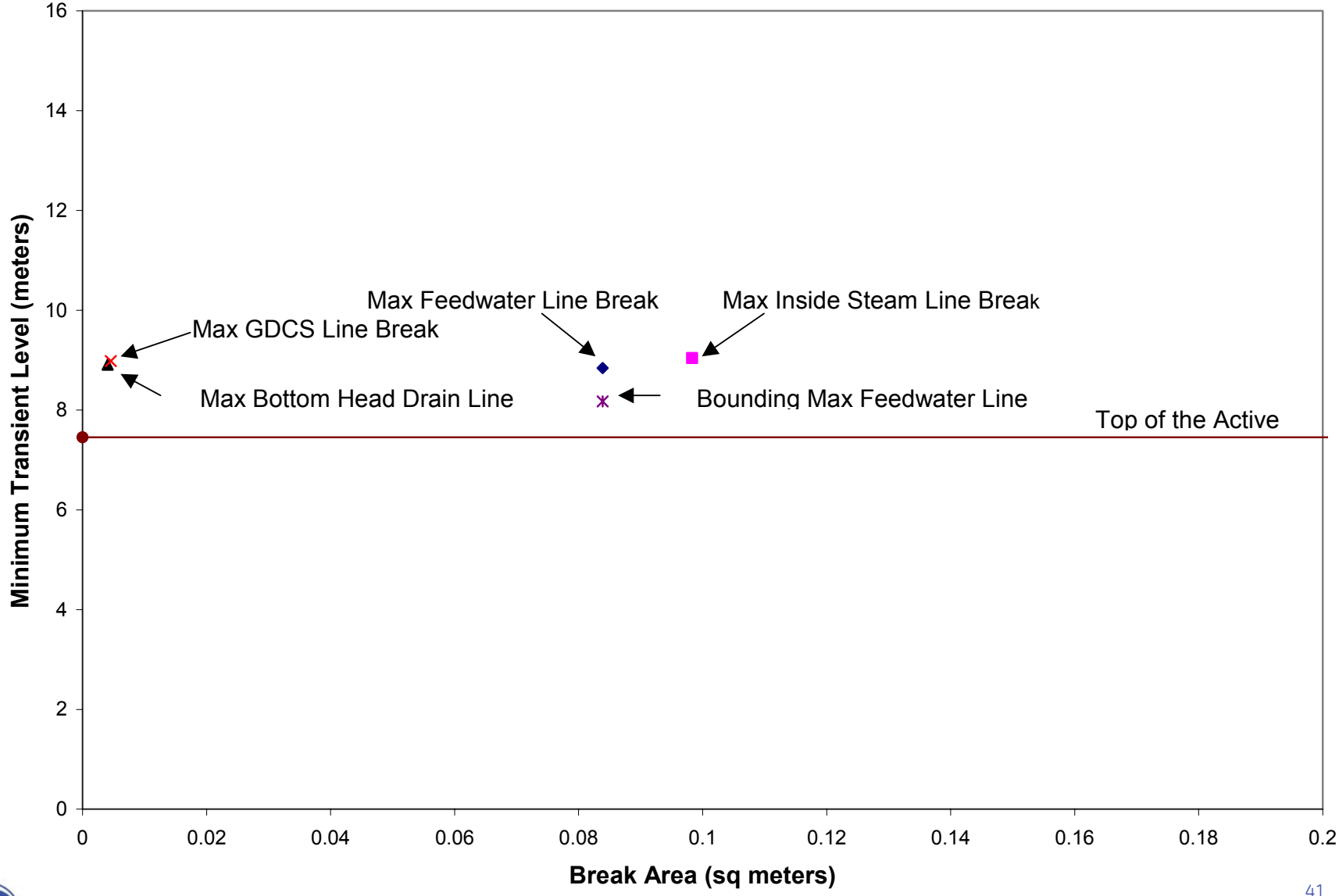
Table 6.3-11. Plant Variables with Nominal and Bounding Calculation Values

Plant Variable	Nominal Value	Bounding Calculation Value*
1. Vessel Steam Dome Pressure	7.17 MPa (1040 psia)	7.274 MPa (1055 psia)
2. Decay Heat	1979 ANS (Figure 6.3-39)	+ 2σ
3. Core Power	Rated	+ 2%
4. PLHGR	44.0 kW/m (13.4 kW/ft)	44.8 kW/m (13.7 kW/ft)
5. Initial MCPR	1.12	1.10
6. Initial Downcomer Level	NWL	NWL – 0.3m
7. Significant TRACG Modeling Parameters**	Nominal	Bounding

Table 6.3-5. Summary of ECCS-LOCA Performance Analyses

Break Location	Break Size m^2 (ft^2)	Minimum Chimney Static Head* Level Above Vessel Zero Per Active Single Failure m (ft)			PCT **	Maximum Local and Core Wide Oxidations (%) ***	Minimum Downcomer Collapsed Water Level Above Vessel Zero Per Active Single Failure m (ft)			Change in MCPR From Start of Event	Change in RPV Press. From Start of Event
		1 SRV	1 GDCS	1 DPV			1 SRV	1 GDCS	1 DPV		
Based on standard TRACG evaluation model:											
Feedwater Line	0.08387 (0.9028)	8.86 (29.07)	8.89 (29.17)	8.84 (29.00)	No heatup	<1.0	6.45 (21.16)	6.39 (20.96)	6.19 (20.31)	Increases	Decreases
Steam Line Inside Containment	0.09832 (1.058)	9.04 (29.66)	9.10 (29.86)	9.10 (29.86)	No heatup	<1.0	7.48 (24.54)	7.28 (23.88)	7.37 (24.18)	Increases	Decreases
Bottom Head Drain Line	0.004052 (0.04361)	8.94 (29.33)	8.91 (29.23)	9.04 (29.66)	No heatup	<1.0	6.88 (22.57)	6.61 (21.69)	6.71 (22.01)	Increases	Decreases
GDCS Injection Line	0.004561 (0.04910)	9.08 (29.79)	9.03 (29.63)	8.98 (29.46)	No heatup	<1.0	6.98 (22.90)	6.9 (22.64)	6.85 (22.47)	Increases	Decreases
Based on bounding values:											
Feedwater Line	0.08387 (0.9028)	—	8.17 (26.80)	8.23 (27.00)	No heatup	<1.0	—	5.22 (17.13)	5.19 (17.03)	Increases	Decreases
Bottom Head Drain Line	0.004052 (0.04361)	—	8.42 (27.62)	—	No heatup	<1.0	—	5.57 (18.27)	—	Increases	Decreases

Figure 6.3-6. Minimum Chimney Water Level vs. Break Area



Long term RPV rises to break elevation, or Spillover elevation, whichever is higher

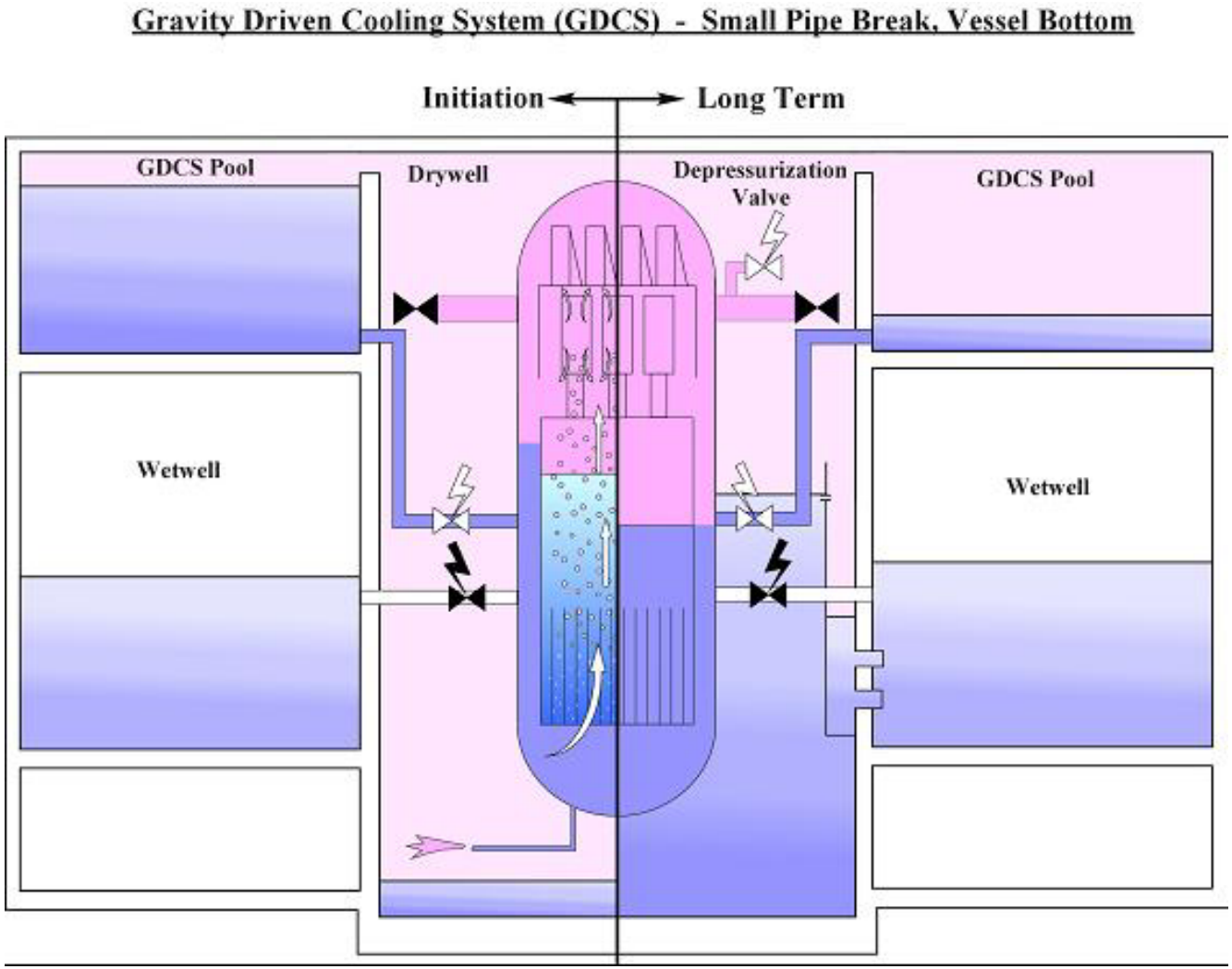


Table 6.3-8. Operational Sequence of ECCS For a Bottom Drain Line Break

Time (sec)	**Events**
~0	Guillotine break of feedwater line inside containment; normal auxiliary power assumed to be lost; Feedwater tripped; Scram signal initiated.
~2	Loss of normal auxiliary power confirmed; reactor scram initiated; IC initiated.
~5	High drywell pressure setpoint for ADS is reached.
~7	Level 3 is reached; Reactor receives second signal to scram.
~11	Level 2 is reached; Reactor isolation timer initiated.
~16	Reactor isolation initiated.
~17	IC drain valve begins to open.
~19	Level 1.5 is reached; ADS/GDCS timer initiated.
~29	Level 1.5 signal confirmed; SRV actuation begins.
~33	IC drain valve fully open.
~79	DPV actuation begins; SLC system signaled to start.
~169	GDCS timer timed out. GDCS injection valves open.
~338	Vessel pressure decreases below maximum injection pressure of GDCS. GDCS flow into the vessel begins.
~987	Minimum chimney water level is reached.
	Level 0.5 is not reached and equalizing line valves are not open.

ESBWR 10CFR50.46 LOCA/ECCS Summary

- Margin provided to core uncovery in the bounding case, considering modeling uncertainties.
- No fuel heatup, no significant clad oxidation, or H2 generation, fuel retains geometry
- Long term cooling provided
- Criteria met with only passive systems, no operator action for 72 hours.

Resolution of NRC TRACG SER commitments

- Focus in submitting DCD was to incorporate items related to the execution of the calculations
- DCD did not specifically identify which items were address
- GE transmitted letter last week, identifying items addressed in DCD analysis, and plan for addressing other items

No items	Resolution
12	Addressed in DCD analysis
4	Will be addressed in Rev 3 of TRACG model description, by end of Nov 05
3	Provide long term PIRTs, and design changes and TRACG applicability, by 3-October. At the same time GE will provide the LOCA inputs and 12 hr. cases showing long term water level.
1	Provide separate qualification paper 1 separate effect test, and 1 integral containment test by 1-April-06
1	NRC Staff action

Table 6.3-9. Operational Sequence of ECCS For a GDCS Line Break

Time (sec)	**Events**
~0	Guillotine break of feedwater line inside containment; normal auxiliary power assumed to be lost; Feedwater tripped; Scram signal initiated.
~2	Loss of normal auxiliary power confirmed; reactor scram initiated; IC initiated.
~4	High drywell pressure setpoint for ADS is reached.
~7	Level 3 is reached; Reactor receives second signal to scram.
~11	Level 2 is reached; Reactor isolation timer initiated.
~16	Reactor isolation initiated.
~17	IC drain valve begins to open.
~19	Level 1.5 is reached; ADS/GDCS timer initiated.
~29	Level 1.5 signal confirmed; SRV actuation begins.
~33	IC drain valve fully open.
~79	DPV actuation begins; SLC system signaled to start.
~169	GDCS timer timed out. GDCS injection valves open.
~332	Vessel pressure decreases below maximum injection pressure of GDCS. GDCS flow into the vessel begins.
~1281	Minimum chimney water level is reached.
	Level 0.5 is not reached and equalizing line valves are not open.

Table 6.3-10. Operational Sequence of ECCS For a Main Steam Line Break

Time (sec)	**Events**
~0	Guillotine break of feedwater line inside containment; normal auxiliary power assumed to be lost; Feedwater tripped; Scram signal initiated.
~1	High drywell pressure setpoint for ADS is reached.
~2	Loss of normal auxiliary power confirmed; reactor scram initiated; IC initiated.
~7	Level 3 is reached; Reactor receives second signal to scram.
~11	Level 2 is reached; Reactor isolation timer initiated.
~16	Reactor isolation initiated.
~17	IC drain valve begins to open.
~33	IC drain valve fully open.
~190	Level 1.5 is reached; ADS/GDCS timer initiated.
~200	Level 1.5 signal confirmed; SRV actuation begins.
~250	DPV actuation begins; SLC system signaled to start.
~340	GDCS timer timed out. GDCS injection valves open.
~430	Vessel pressure decreases below maximum injection pressure of GDCS. GDCS flow into the vessel begins.
~478	Minimum chimney water level is reached.
	Level 0.5 is not reached and equalizing line valves are not open.