Transient Introduction

R504B – Chapter 5

Objectives

1. Given a transient curve:
   - At selected points, explain what caused the parameter to change.
   - At selected areas of the curve, explain why the parameter is trending in that area.
   - State the cause of the transient (initiating event).
2. Given a plant transient scenario, explain the behavior of selected parameters, control systems, and equipment for the time designated in the scenario.

Types of Transients Presented

<u>Anticipated Operational Occurrences</u> (10 CFR 50 Appendix A):

Those conditions of normal operation which are expected to occur one or more times during the life of the plant

All start at 100% power with NO Operator Action

NO Design Basis Accidents

- LOCAs
- MSLBs
- Rod Drop
- ATWS

AOO EXAMPLES

INCREASE IN HEAT REMOVAL BY THE SECONDARY SYSTEM

- EHC system failure that results in increased steam flow
- Turbine bypass valves fail open
- Safety relief valve lifting

DECREASE IN HEAT REMOVAL BY THE SECONDARY SYSTEM

- EHC system malfunction that results in decreased steam flow
- Generator load reject/Loss of off-site power
- Turbine trip
- Loss of condenser vacuum or condenser cooling
- MSIV closure

DECREASE IN RCS FLOW RATE

- Recirculation pump trip (single and dual)
- Recirculation pump runbacks
- Recirculation Flow Control system failure that results in decreased flow

AOO EXAMPLES

INCREASE IN REACTOR COOLANT INVENTORY

- HPCI Initiation
- FWC failure that results in increased feedwater flow

DECREASE IN REACTOR COOLANT INVENTORY

- FWC failure that results in decreased feedwater flow
- SRV opening
- Loss of normal feedwater (total or partial loss)

REACTIVITY AND POWER DISTRIBUTION ANOMALIES

- Inadvertent control rod withdrawal or insertion
- Recirculation Flow Control system failure that results in increased flow
- Startup of an idle recirculation pump in a cold loop
- Loss of feedwater heating
- Operation with a fuel assembly in an improper position

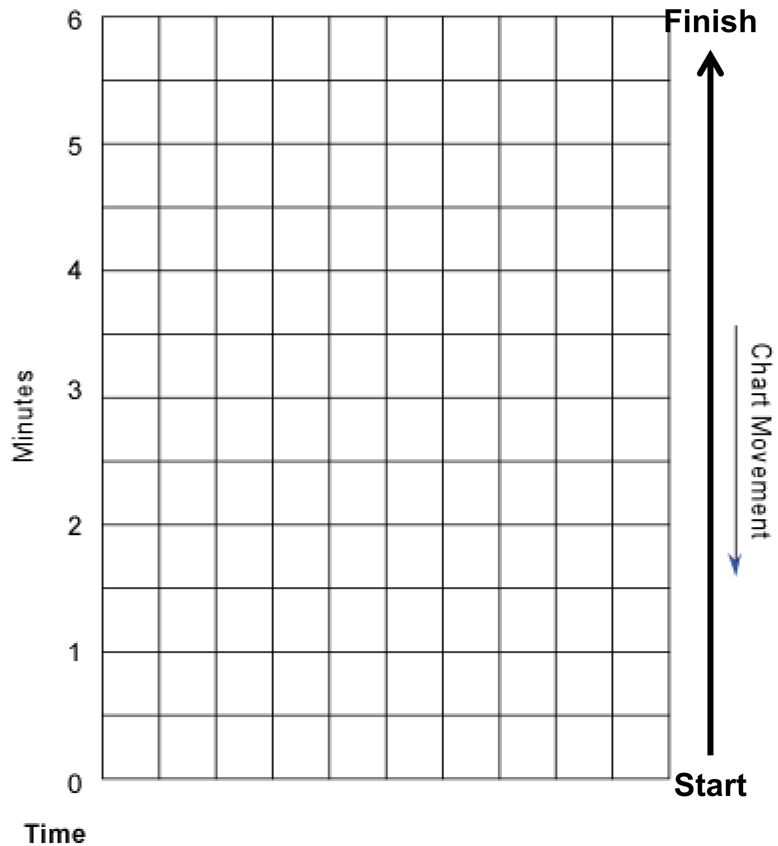
Types of Transients Presented

These transients are a snapshot of a specific point in core life, power history and core design.

FSAR Chapter 15 analysis and accompanying transient graphs are based on worst case conditions.

Post-Trip reviews are required (Salem event) and each will depend on the specific circumstances involved (power history, time in life, equipment OOS etc…).

Strip Chart Protocol



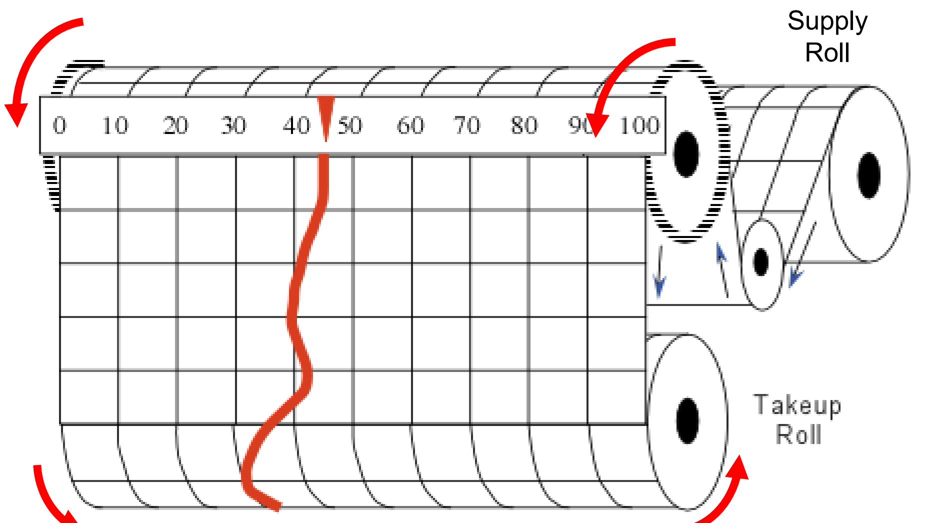


Chart Recorder

Digital Recorder

Transient Parameters Recorded

Average Power Range Monitor (APRM) ‘A’

Reactor Pressure (PSIG)

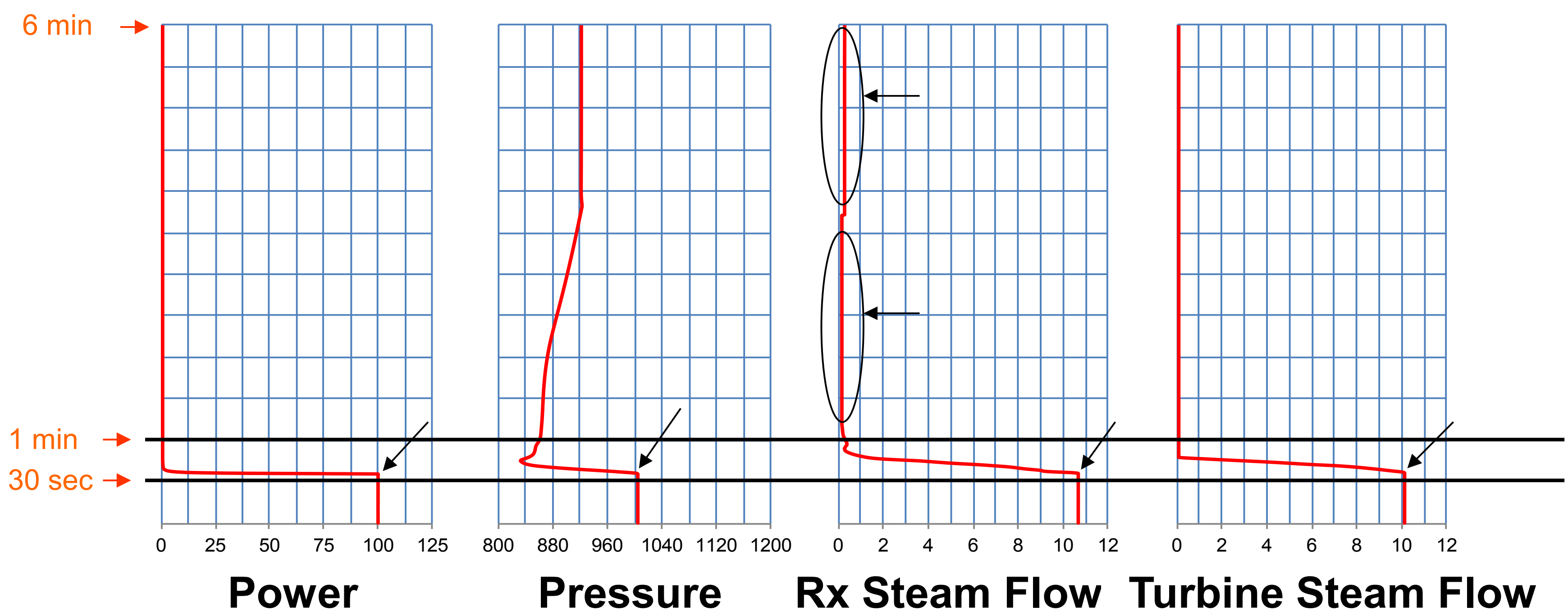
Total Reactor Steam Flow (Mlbm/hr)

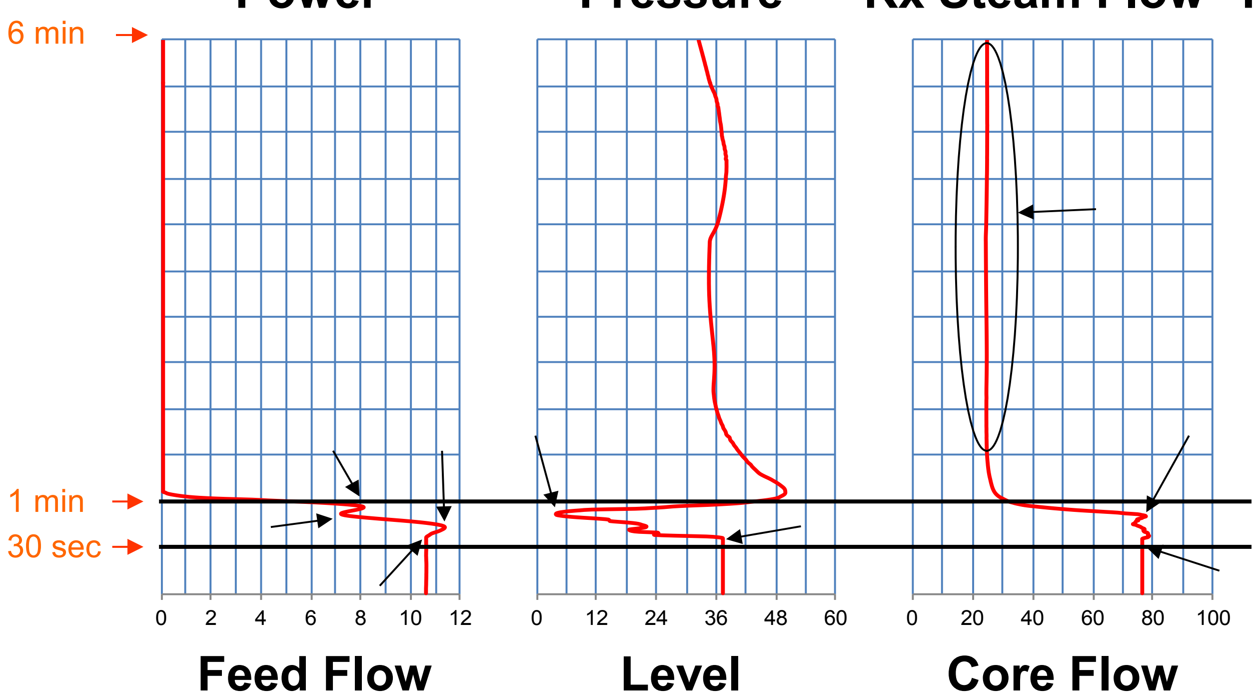
Turbine Steam Flow (Mlbm/hr)

Total Feedwater Flow (Mlbm/hr)

Narrow Range Reactor Water Level (in)

Total Core Flow (Mlbm/hr)





Typical Transient

Need to know what is causing the parameter to change at the arrows

Setpoint Sheet Provided

Reactor Level

Level 1 (-132.5)	Initiate CS **AND** LPCI, Start EDG, ADS signal, **AND** Isolate MSIVs
Level 2 (-38)	Initiate RCIC and HPCI, RWCU **and** other selected system isolations **AND** ATWS-ARI **AND** ATWS-RPT
Level 3 (12.5)	Reactor scram, Recirc pump runback to 30%, ADS signal **AND** RHR Isolation signal
Level 4 (33.5)	Low level alarm, **AND** permissive for Recirc pump runback to 40%
Level 7 (40.5)	High level alarm
Level 8 (56.5)	Trip of main turbine, RFP, RCIC, **AND** HPCI

Setpoint Sheet Provided

Reactor Pressure (psig)

50 & 100	RCIC & HPCI Isolations
125	RHR SDC Isolation
310	Reactor Recirculation loop discharge valves close during LOCA
338 & 465	Permissive for LPCI **AND** CS injection valve opening on a LOCA
1025	High Pressure Alarm
1043	High Pressure Reactor Scram
1115/1125/1135	4/4/3 SRVs Safety Mode Opening Pressures
1120	ATWS-RPT **AND** ATWS-ARI

Main Steam Line Pressure (psig)

825	Closes MSIVs in RUN Mode

Setpoint Sheet Provided

Condenser Vacuum (inches of Hg vacuum)

25.0	Low Condenser Vacuum alarm
22.5	Turbine trip
20.0	RFP trip
8.5	MSIV closure
7	BPV closure

Turbine First Stage Pressure (%)

30%	Bypass EOC-RPT **AND** Reactor Scrams (due to TSV closure & TCV fast closure) if <30% power as sensed by first stage pressure

Setpoint Sheet Provided

Drywell Pressure (psig)

0.75 High pressure alarm

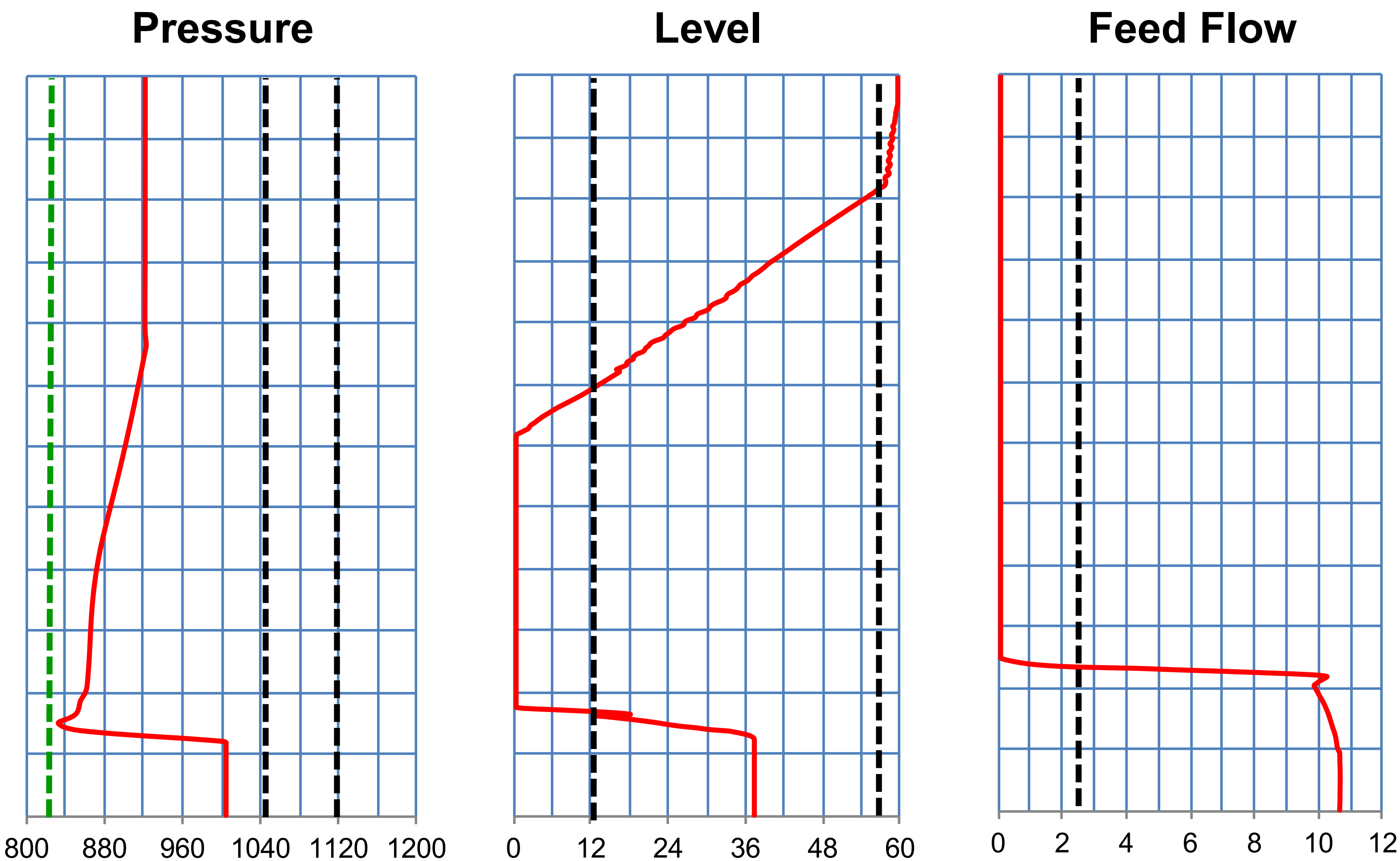
1.69 LOCA Signal: Initiate HPCI, CS **AND** RHR, Start D/G and RBSVS, **AND** isolation signal for selected plant systems

FWCS Steam Flow (%)

20% RWM rod blocks bypassed at > 20% power as sensed by steam flow

30% RWM Alarms bypassed at > 30% power as sensed by steam flow

Setpoints Available on Graphs



1120 psig – ATWS-RPT
1043 psig – RPS Trip
825 psig – Group 1 Isol (Header Pressure)

Level 8 – Turb trip, RFP Trip
Level 3 – RPS Trip, 30% Limiter
Level 2 – ATWS-RPT, HPCI Init (Off the Chart)

20% FW Flow – Recirc Pump 30% Limiter

What Affects These Parameters?

Average Power Range Monitor (APRM) ‘A’

Reactor Pressure (PSIG)

Total Reactor Steam Flow (Mlbm/hr)

Turbine Steam Flow (Mlbm/hr)

Total Feedwater Flow (Mlbm/hr)

Narrow Range Reactor Water Level (in)

Total Core Flow (Mlbm/hr)

Power (APRM)

<u>Power</u>: Changes with Reactivity Changes

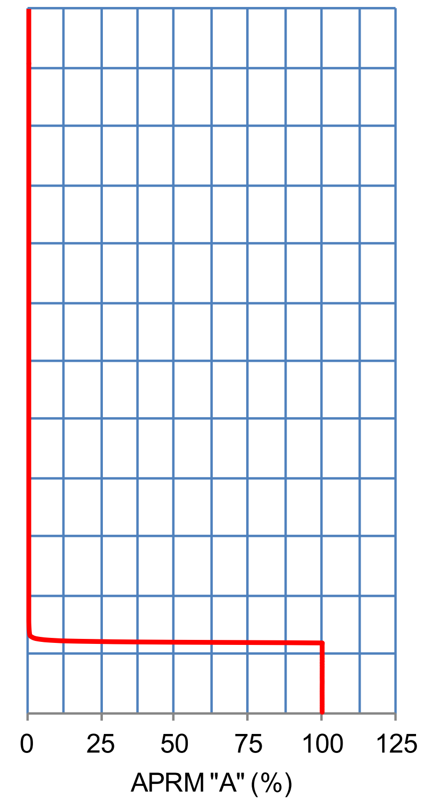
- Rods: Scram, RMCS, Rod Drift in or out
- Voids:
  - Recirc Flow
  - Pressure changes
- FTC: Fuel Time Constant
- Core Inlet Subcooling
- Poison: SLC

Power (APRM)

Control Rods

- Rapid change
- Insertion adds negative reactivity
- Scram causes power to rapidly go to zero

Power (APRM)



<u>Power</u>: Scram (RPS Setpoints in TS)

- **Hi Power (APRM)**
- **Hi Pressure (1043 psig)**
- **Low Level (Level 3)**
- **Turbine Trip (manual, lo vacuum, Level 8)**
- **MSIV Closure (manual, low MS press, lo vacuum)**
- **High Drywell Pressure (<u>not an AOO</u>)**
- **Other (manual, High SDV level, ARI actuation)**

Power (APRM)

Voids

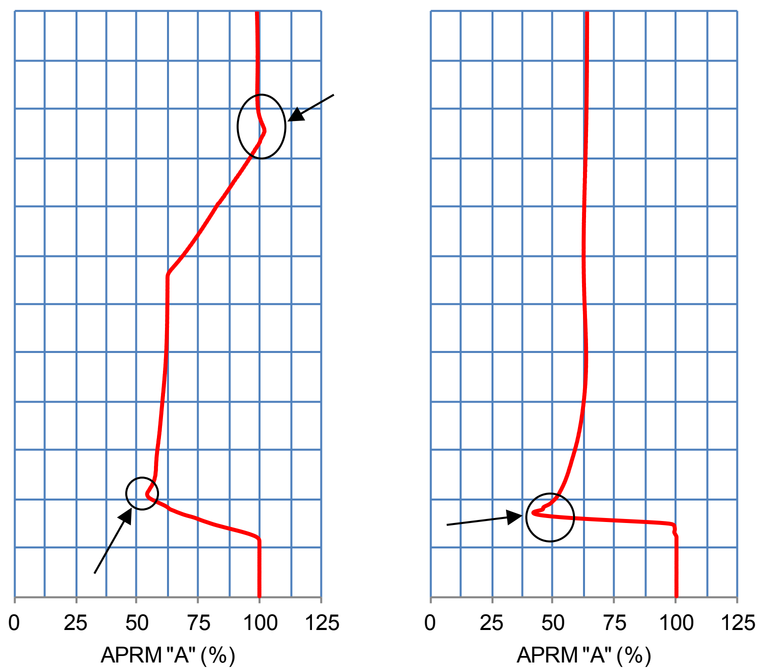
- Affect moderator density: reactivity
- Increased voids adds negative reactivity
  - Reduced core flow
  - Pressure drop
- Void reduction adds positive reactivity
  - Increase in core flow
  - Pressure increase

Power (APRM)

<u>Fuel Time Constant</u> (power overshoot if critical)

On downpower, fuel temp takes some time to cool which will add positive reactivity and increase power

On power increase, fuel temp takes some time to heat up which will add negative reactivity and decrease power.



Power (APRM)

Core Inlet Subcooling

Some of the power generated in the core has to be used to heat the incoming water to saturation:

- The colder the water (the greater the subcooling), the higher the power needed to generate the same amount of steam.
- The warmer the water (the lower the subcooling), the less reactor power needed to generate the same amount of steam.

Power (APRM)

Core Inlet Subcooling

Core inlet temperature is determined by the amount of subcooled feedwater and its temperature and the amount of saturated water returning to the annulus from the moisture separator drains and steam dryer drains.

$$\dot{m}_{fw} T_{fw} + \dot{m}_{drains} T_{sat} = \dot{m}_{core\ inlet} T_{core\ inlet}$$

Where the ratio of drain flow ($\dot{m}_{drains}$) to feed flow ($\dot{m}_{fw}$) is approximately 6 to 1

Power (APRM)

Core Inlet Subcooling

If $\dot{m}_{fw} \uparrow$ or $T_{fw} \downarrow$, $T_{core\ inlet} \downarrow$ and subcooling $\uparrow$: power $\uparrow$

- Reducing Turbine Steam Flow (lower power level): Less extraction steam to FW heaters and more condensate depression resulting in lower feedwater temperature and increasing power gradually over several minutes.
- HPCI or RCIC initiation causes feed temperature to lower (cold CST water mixes in) causing a more rapid increase in power.

Power (APRM)

Core Inlet Subcooling

If $\dot{m}_{fw} \downarrow$ or $T_{fw} \uparrow$, $T_{core\ inlet} \uparrow$ and subcooling $\downarrow$: power $\downarrow$

- Rising Turbine Steam Flow (higher power level): More extraction steam to FW heaters and less condensate depression resulting in higher feedwater temperature and lowering power gradually over several minutes.
- Single or Dual Feed Pump trip causes feedwater flow to drop significantly (less subcooled feedwater mixing with drains in annulus) causing a more rapid decrease in power.

Pressure

<u>Pressure</u>: changes with change in steam production rate (power) or steam demand

- Steam Production = Steam Demand, Pressure is constant
- Steam Production > Steam Demand , Pressure ↑
- Steam Production < Steam Demand, Pressure ↓

Pressure

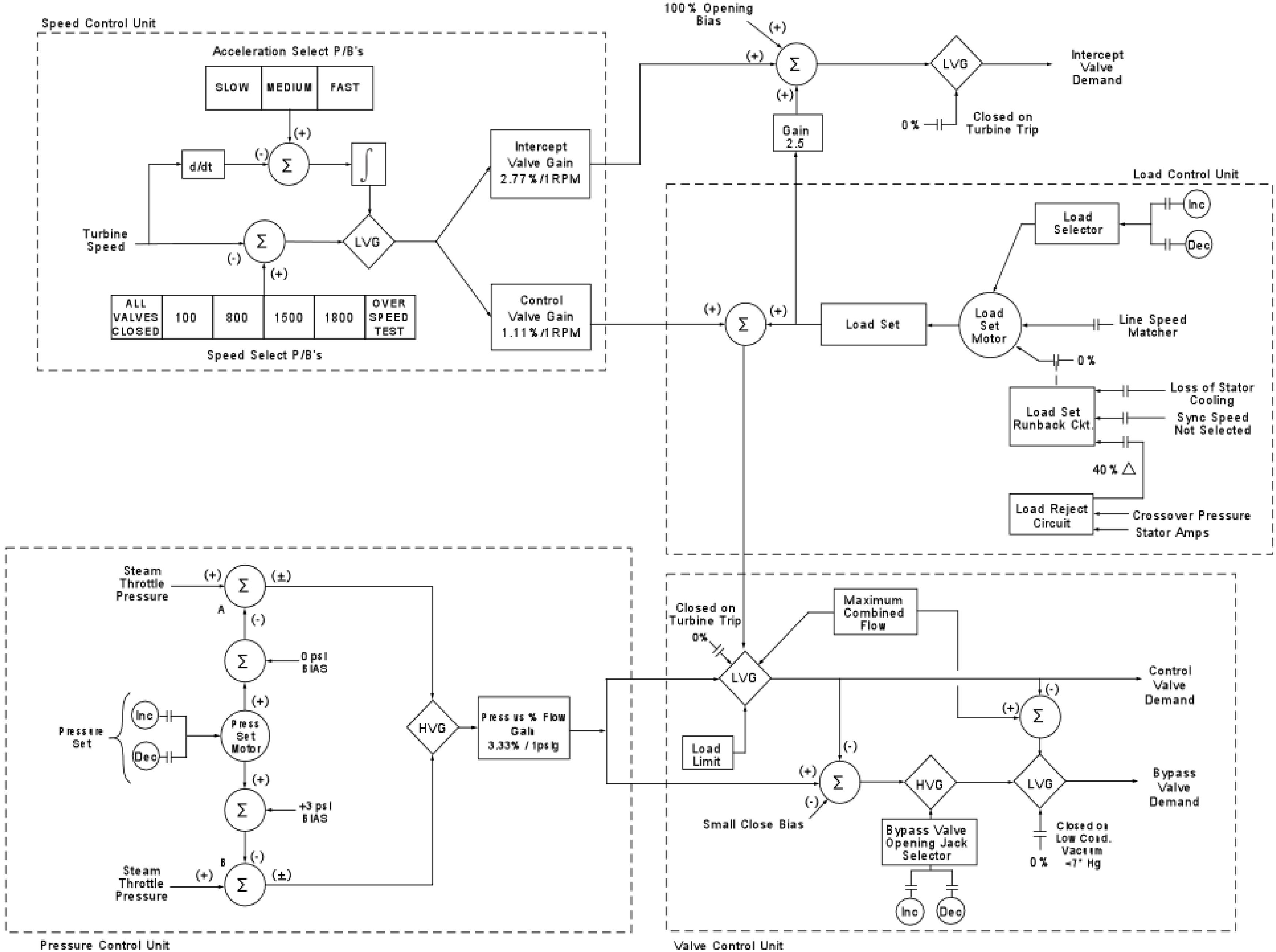
<u>Increase Steam Production rate, Pressure ↑</u>

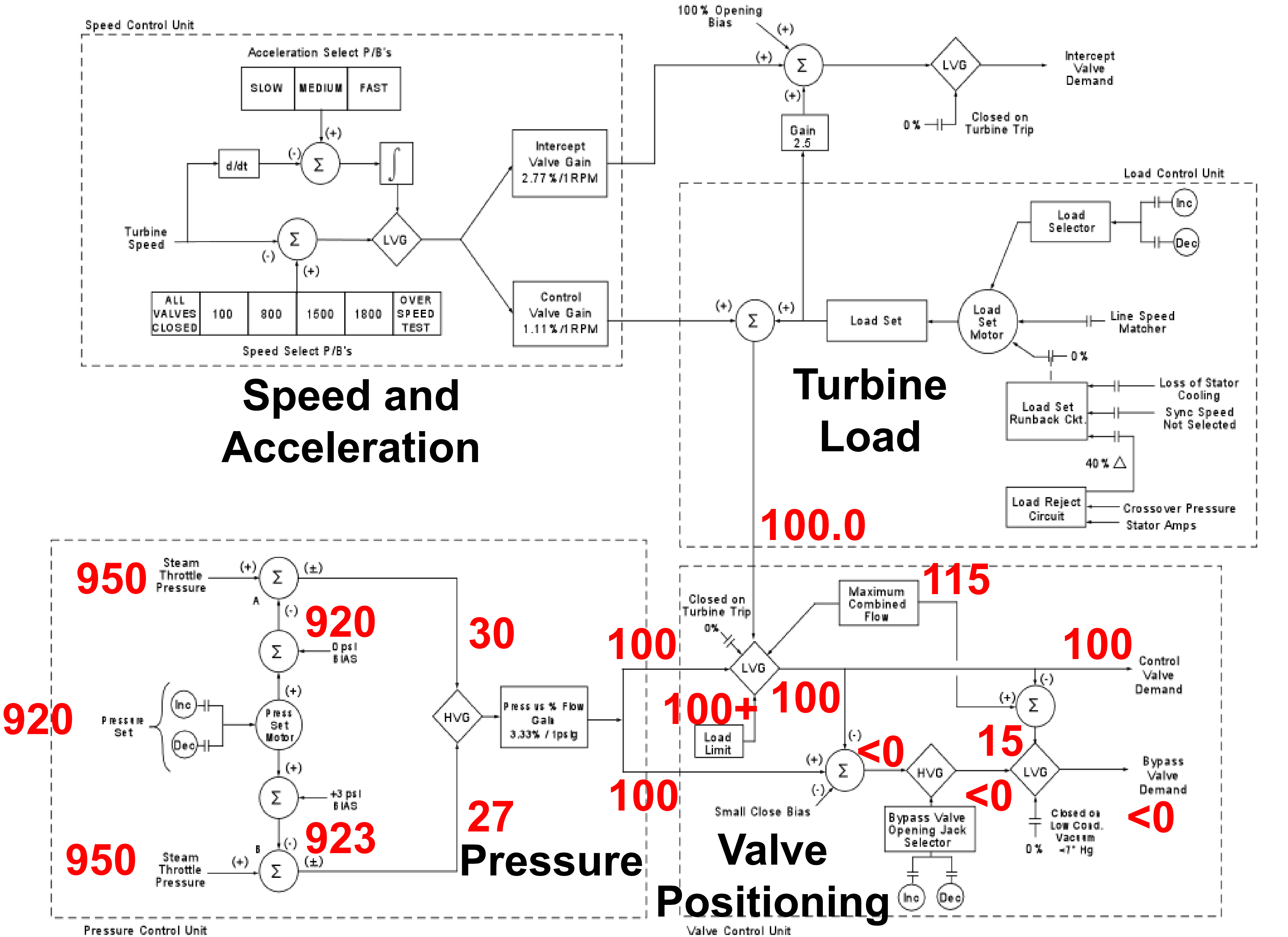
- Power ↑,
- Steam Production > Steam Demand ,
- Reactor Pressure ↑,
- Steam Header Pressure ↑,
- EHC system throttles TCVs open to match turbine load (steam demand) with reactor power (steam production)
- Pressure stabilizes at higher pressure

Pressure

Decrease Steam Production rate, Pressure ↓

- Power ↓,
- Steam Production < Steam Demand ,
- Reactor Pressure ↓,
- Steam Line Pressure ↓,
- EHC system throttles TCVs closed to match turbine load (steam demand) with reactor power (steam production)
- Pressure stabilizes at lower pressure


Speed Control Unit
Acceleration Select P/B's
SLOW
MEDIUM
FAST
d/dt
Turbine Speed
LVG
ALL VALVES CLOSED
100
800
1500
1800
OVER SPEED TEST
Speed Select P/B's
Intercept Valve Gain 2.77%/1RPM
Control Valve Gain 1.11%/1RPM
100% Opening Bias
Gain 2.5
LVG
Intercept Valve Demand
0%
Closed on Turbine Trip
Load Control Unit
Load Selector
Inc
Dec
Load Set
Load Set Motor
Line Speed Matcher
0%
Load Set Runback Ckt.
Loss of Stator Cooling
Sync Speed Not Selected
40% △
Load Reject Circuit
Crossover Pressure
Stator Amps
Steam Throttle Pressure
A
0 psi BIAS
Pressure Set
Inc
Dec
Press Set Motor
+3 psi BIAS
B
Steam Throttle Pressure
HVG
Pressure Control Unit
Closed on Turbine Trip
0%
LVG
Maximum Combined Flow
Load Limit
Control Valve Demand
Small Close Bias
HVG
Bypass Valve Opening Jack Selector
Inc
Dec
LVG
Bypass Valve Demand
0%
Valve Control Unit



Speed Control Unit
Acceleration Select P/B's
SLOW
MEDIUM
FAST
d/dt
Turbine Speed
LVG
Intercept Valve Gain 2.77%/1RPM
Control Valve Gain 1.11%/1RPM
ALL VALVES CLOSED
100
800
1500
1800
OVER SPEED TEST
Speed Select P/B's
Speed and Acceleration
100% Opening Bias
Gain 2.5
Intercept Valve Demand
0%
Closed on Turbine Trip
Load Control Unit
Load Selector
Inc
Dec
Load Set
Load Set Motor
Line Speed Matcher
0%
Load Set Runback Ckt.
Loss of Stator Cooling
Sync Speed Not Selected
40% △
Load Reject Circuit
Crossover Pressure
Stator Amps
Turbine Load
100.0
950
Steam Throttle Pressure
A
920
0 psi BIAS
30
920
Pressure Set
Press Set Motor
+3 psi BIAS
923
B
950
Steam Throttle Pressure
HVG
Pressure % Flow Gain 3.33% / 1psig
27
Pressure
Pressure Control Unit
100
100
Closed on Turbine Trip
0%
115
Maximum Combined Flow
100
Control Valve Demand
100+
100
Load Limit
15
<0
<0
Small Close Bias
Bypass Valve Opening Jack Selector
Closed on Low Cond. Vacuum <7" Hg
0%
Bypass Valve Demand
<0
Valve Positioning
Valve Control Unit

Reactor Pressure

vs

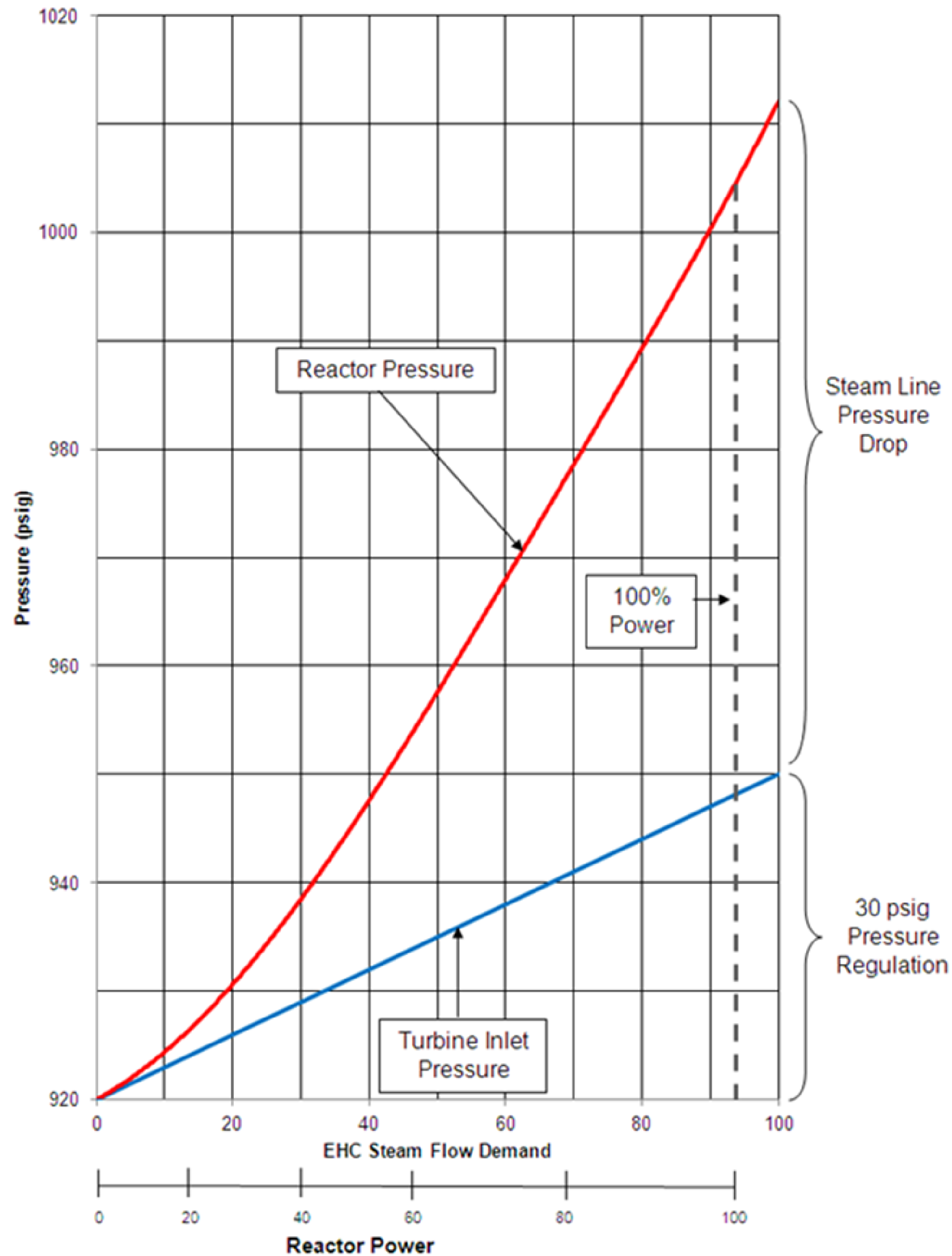
Steam Line Pressure

as a function of

Steam Flow

as controlled by

EHC Regulators



Reactor Pressure

Decrease Steam Demand, Pressure ↑

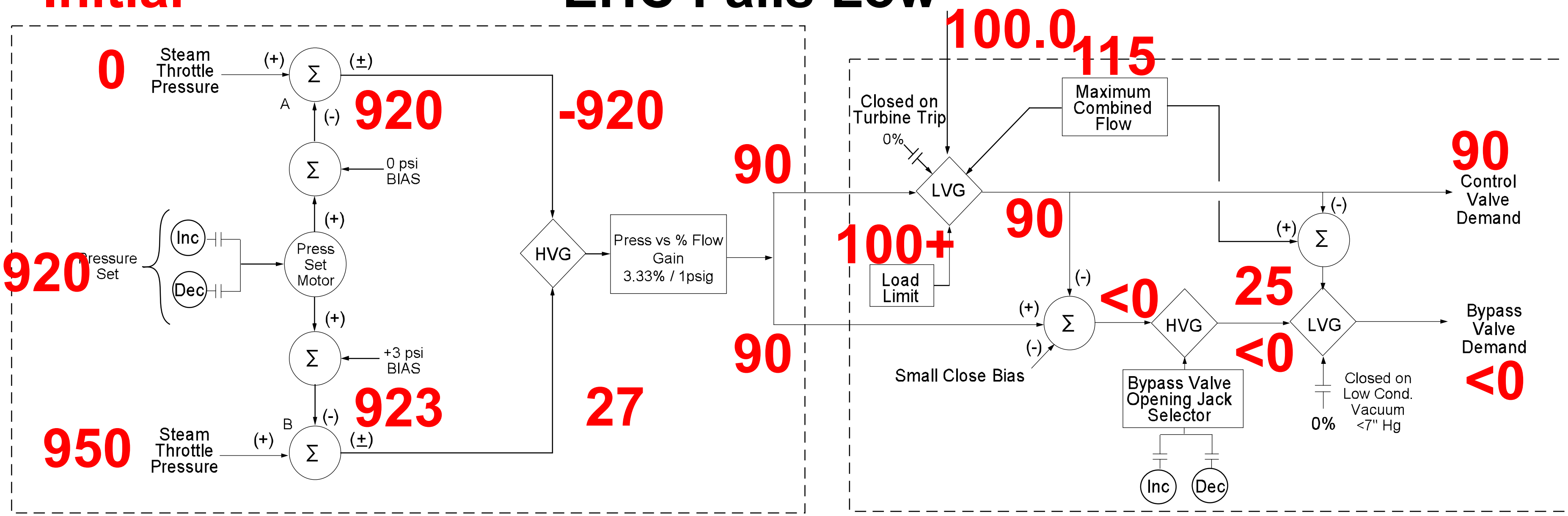
- MSIV Closure
- Turbine Trip
- EHC Fails Low

Increase Steam Demand, Pressure ↓

- SRV open
- BPV open
- EHC Fails High

EHC Fails Low

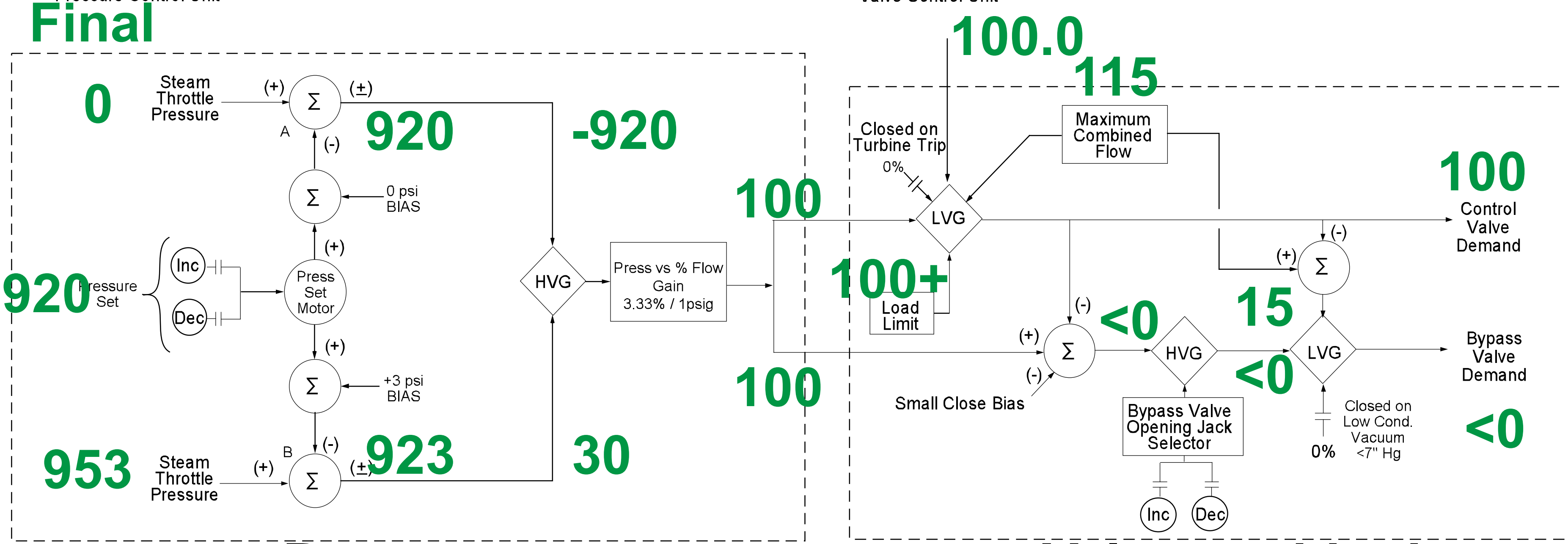
Initial



Pressure Control Unit

Valve Control Unit

Final



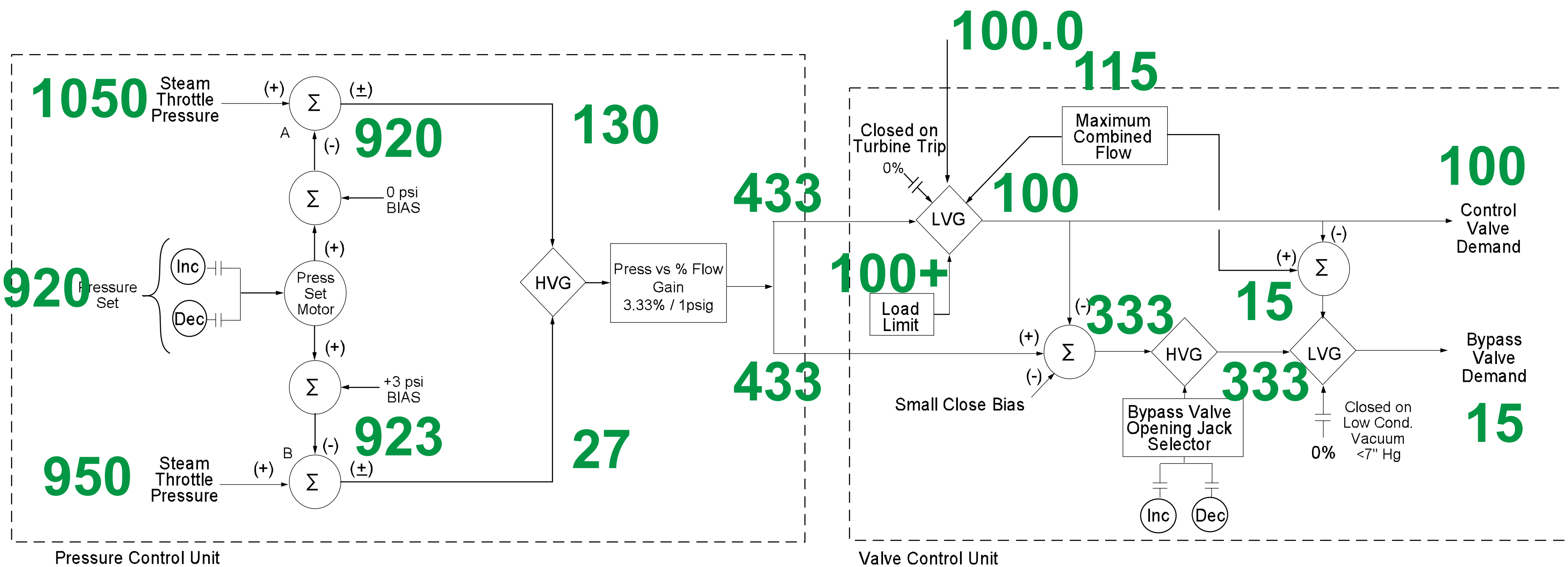
Pressure Control Unit

Pressure

Valve Control Unit

Valve positioning

EHC Fails High



Pressure

Valve positioning

Steam Flow

<u>Turbine Steam Flow</u>:

- EHC controls TCV position in response to Main Steam Line Pressure

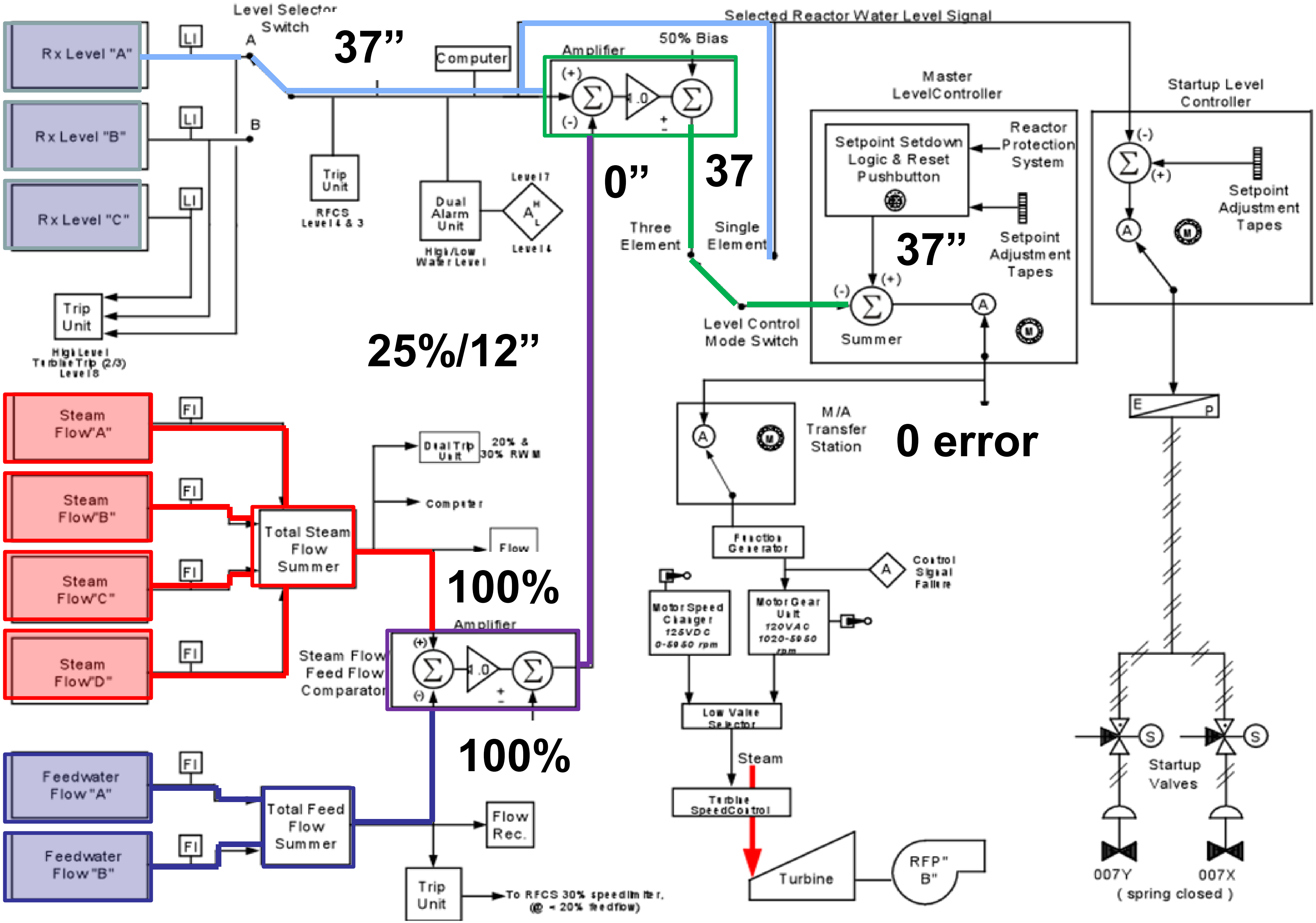
<u>Reactor Steam Flow</u>:

- Turbine Steam Flow + Bypass Valves (also controlled by EHC) + House Loads
    - Should follow turbine steam flow at power
    - Bypass and house loads post trip
    - Only stabilizes at zero if MSIVs shut

Feedwater Flow

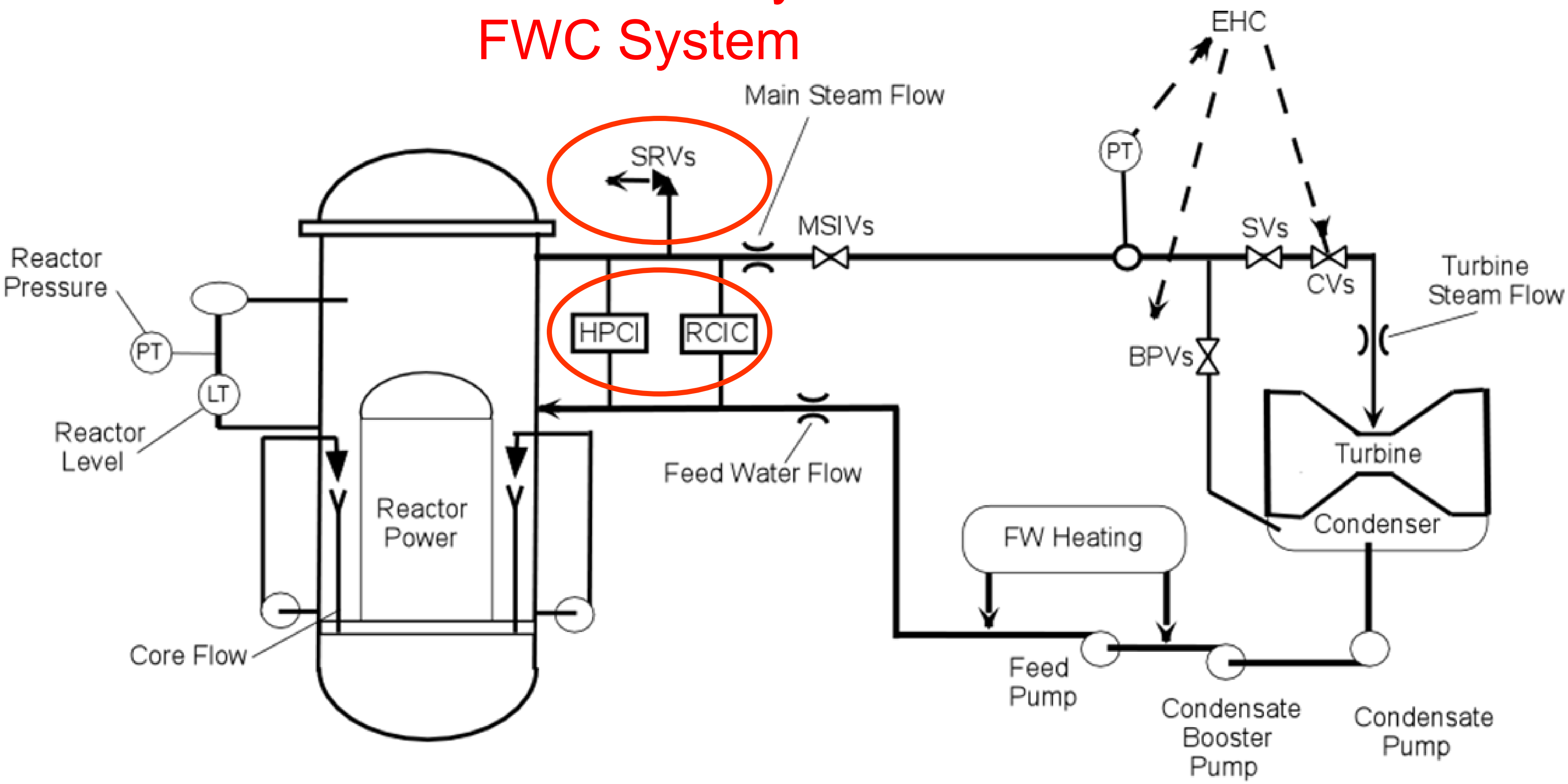
<u>Feedwater Flow</u>:

- Controlled by FWC System based on:
  - Level Deviation from Setpoint, and
  - Steam Flow/Feed Flow Mismatch
- DP between RFP discharge and Vessel Pressure
  - Rapid change in vessel pressure impacts flow
- Setpoint Setdown post scram if Level 3 (18”)



Rx Level "A"
Rx Level "B"
Rx Level "C"
LI
Level Selector Switch
A
B
37"
Computer
Amplifier
50% Bias
Selected Reactor Water Level Signal
(+)
(-)
1.0
Trip Unit
RFCS Level 4 & 3
Dual Alarm Unit
High/Low Water Level
Level 7
Level 4
0"
37
Three Element
Single Element
Master LevelController
Setpoint Setdown Logic & Reset Pushbutton
Reactor Protection System
Setpoint Adjustment Tapes
37"
Summer
Level Control Mode Switch
Startup Level Controller
Setpoint Adjustment Tapes
Trip Unit
High Level Turbine Trip (2/3) Level 8
25%/12"
Steam Flow"A"
Steam Flow"B"
Steam Flow"C"
Steam Flow"D"
FI
Total Steam Flow Summer
Dual Trip Unit
20% & 30% RWM
Computer
Flow
100%
Amplifier
Steam Flow Feed Flow Comparator
100%
M/A Transfer Station
0 error
Function Generator
Control Signal Failure
Motor Speed Changer 125VDC 0-5950 rpm
Motor Gear Unit 120VAC 1020-5950 rpm
Low Value Selector
Steam
Turbine SpeedControl
Turbine
RFP" B"
E
P
Startup Valves
S
007Y
007X
(spring closed)
Feedwater Flow "A"
Feedwater Flow "B"
Total Feed Flow Summer
Flow Rec.
Trip Unit
To RFCS 30% speedlimiter, (@ ~ 20% feedflow)

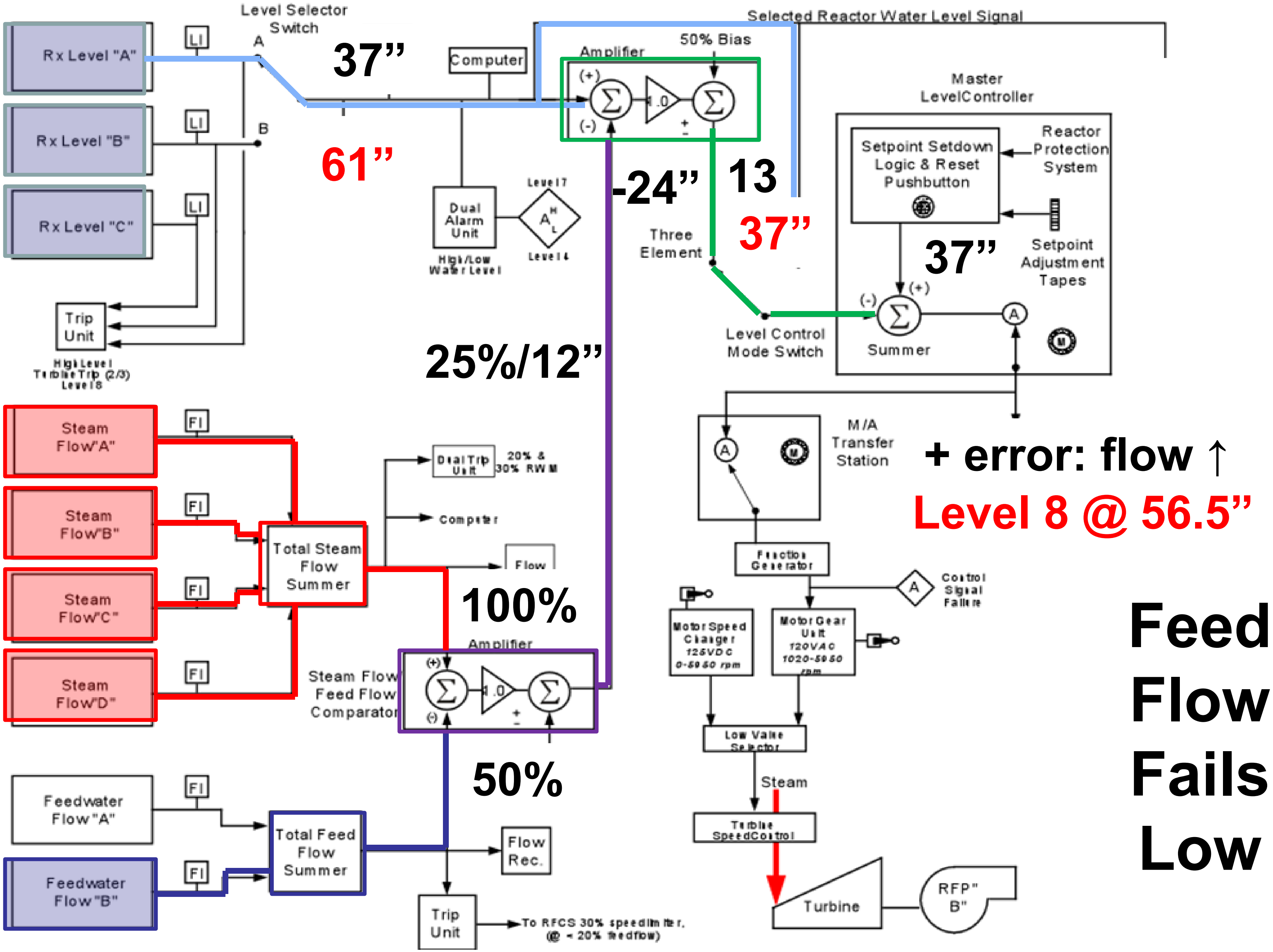
Steam and Feed Flow Not Measured by FWC System



Feedwater Flow

<u>Increase in Inventory Events</u>:

- HPCI/RCIC Initiation
- FWC System Failures
  - Level Detector Fails Low
  - Steam Flow detector Fails High
  - Feed Flow detector Fails Low

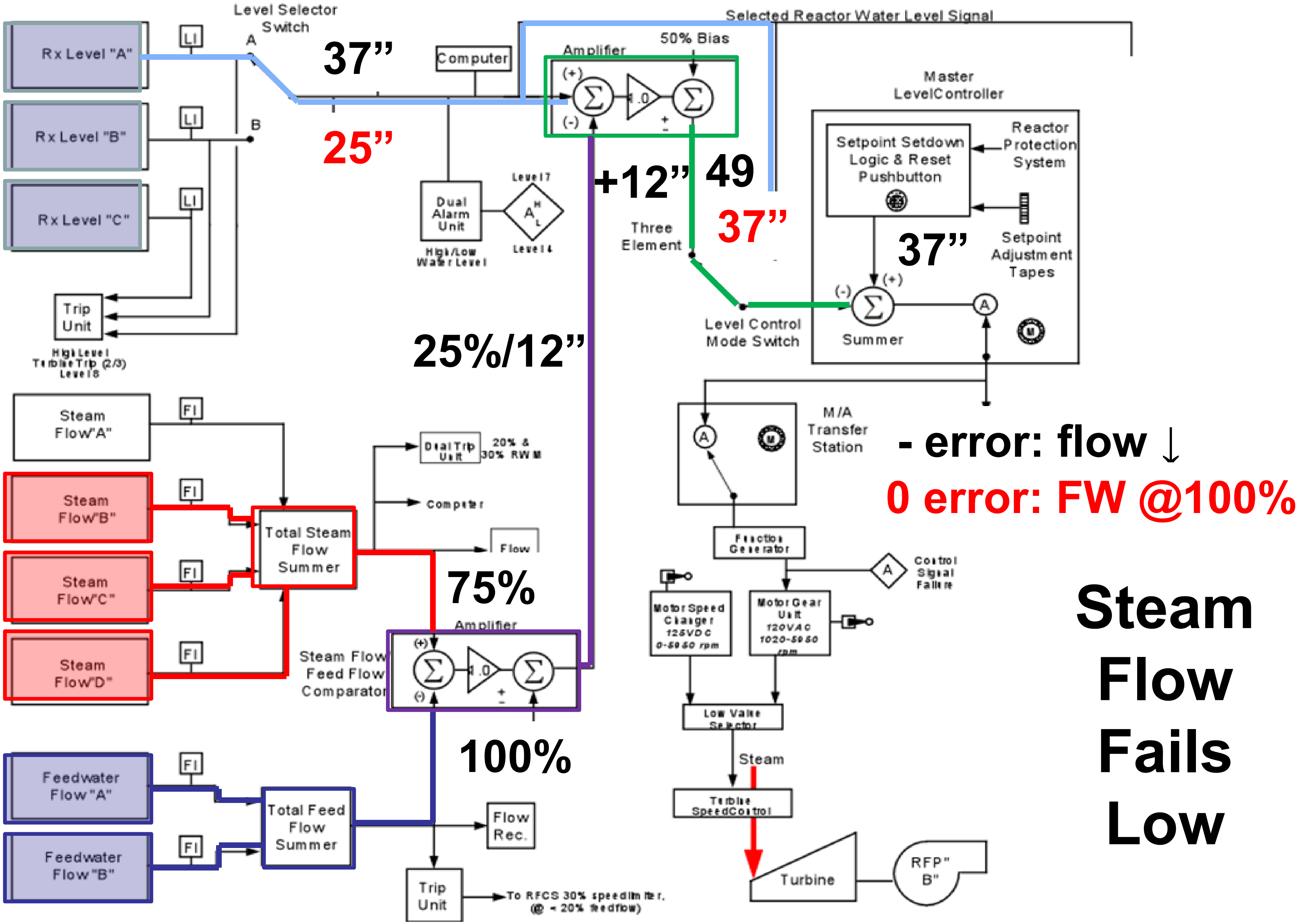


Feed Flow Fails Low
Level Selector Switch
Selected Reactor Water Level Signal
Rx Level "A"
Rx Level "B"
Rx Level "C"
LI
A
B
37”
61”
Computer
Amplifier
50% Bias
(+)
(-)
1.0
-24”
13
37”
Three Element
Level Control Mode Switch
Master LevelController
Setpoint Setdown Logic & Reset Pushbutton
Reactor Protection System
Setpoint Adjustment Tapes
37”
Summer
Dual Alarm Unit
High/Low Water Level
Level 7
Level 4
Trip Unit
High Level Turbine Trip (2/3) Level 8
25%/12”
M/A Transfer Station
+ error: flow ↑
Level 8 @ 56.5”
Steam Flow"A"
Steam Flow"B"
Steam Flow"C"
Steam Flow"D"
FI
Total Steam Flow Summer
Dual Trip Unit
20% & 30% RWM
Computer
Flow
100%
Amplifier
Steam Flow Feed Flow Comparator
50%
Feedwater Flow "A"
Feedwater Flow "B"
Total Feed Flow Summer
Flow Rec.
Trip Unit
To RFCS 30% speed limiter, (@ ~ 20% feedflow)
Function Generator
Control Signal Failure
Motor Speed Changer 125VDC 0-5950 rpm
Motor Gear Unit 120VAC 1020-5950 rpm
Low Value Selector
Steam
Turbine Speed Control
Turbine
RFP "B"

Feedwater Flow

<u>Decreased Inventory Events</u>:

- SRV Fails Open
- FWC System Failures
  - Level Detector Fails High
  - Steam Flow detector Fails Low
  - Feed Flow detector Fails High
- RFP Trips at Level 8 and on low vacuum
- RFPs need steam to operate (MSIV Closure)



Steam Flow Fails Low

Reactor level

<u>Reactor Level</u>: Actual Inventory Change

- Stable

  Steam leaving vessel = Feed Coming In

- Decrease

  Steam leaving > Feed coming in

- Increase

  Steam leaving < Feed coming in

Reactor level

<u>Reactor Level</u>: Downcomer Inventory

- Feed coming in versus flow to core
- **Recirc Pump Speed**
  - Speed ↑, More flow from downcomer induced in jet pumps into core: Level ↓
  - Speed ↓, Less flow from downcomer into core: Level ↑
- **Voiding** impact 2-phase flow resistance: flow to core from downcomer
  - Voids ↑, Resistance to flow ↑, flow ↓ , Level ↑
  - Voids ↓, Resistance to flow ↓, flow ↑, Level ↓

Reactor level

<u>Scram</u>: Voids collapse, Level goes down

<u>Recirc Flow</u>:

- Recirc Flow (Core Flow) ↓, flow from annulus to core ↓
- Water entering core has more contact time with fuel, voiding ↑, resistance to 2-phase flow ↑, flow from annulus to core ↓
- Both cause level to rise

<u>Pressure</u> :

Increase: Voids collapse, more core flow, Level ↓

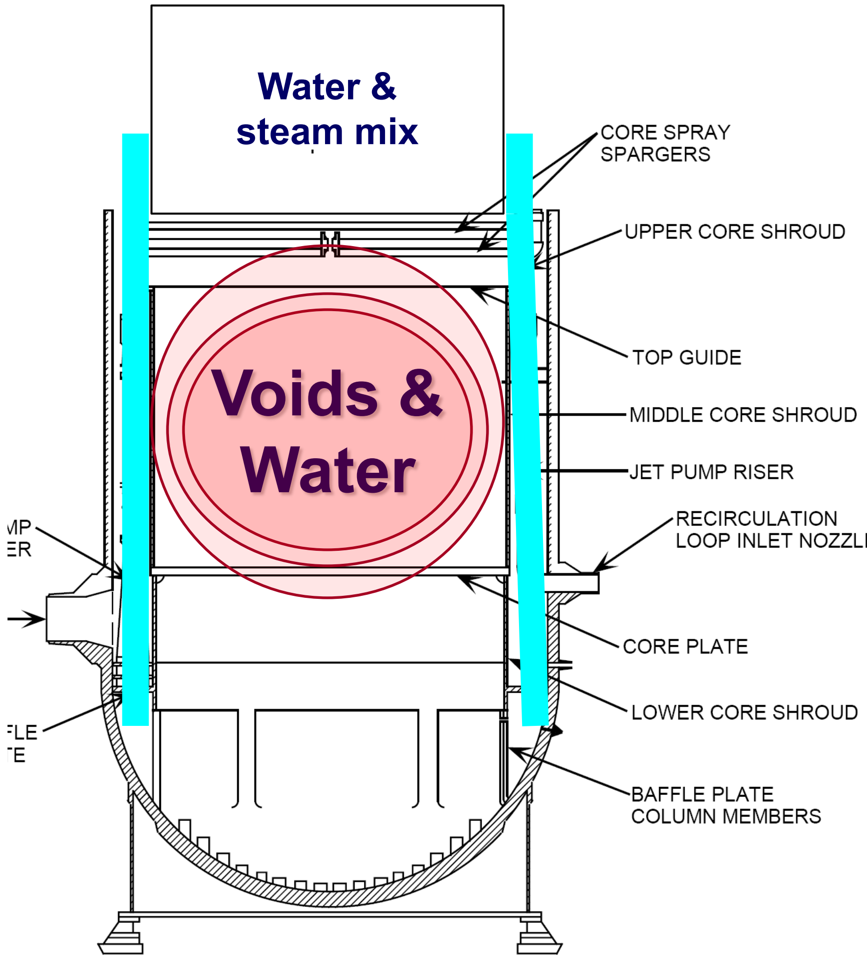
Decrease: Voids get bigger, less core flow, Level ↑

I have a Void in my head

NR and WR level are measured in the annulus.

Voids go up, less flow from annulus to core, level "backs up" in annulus

Voids go down, more water leaves annulus, level goes down

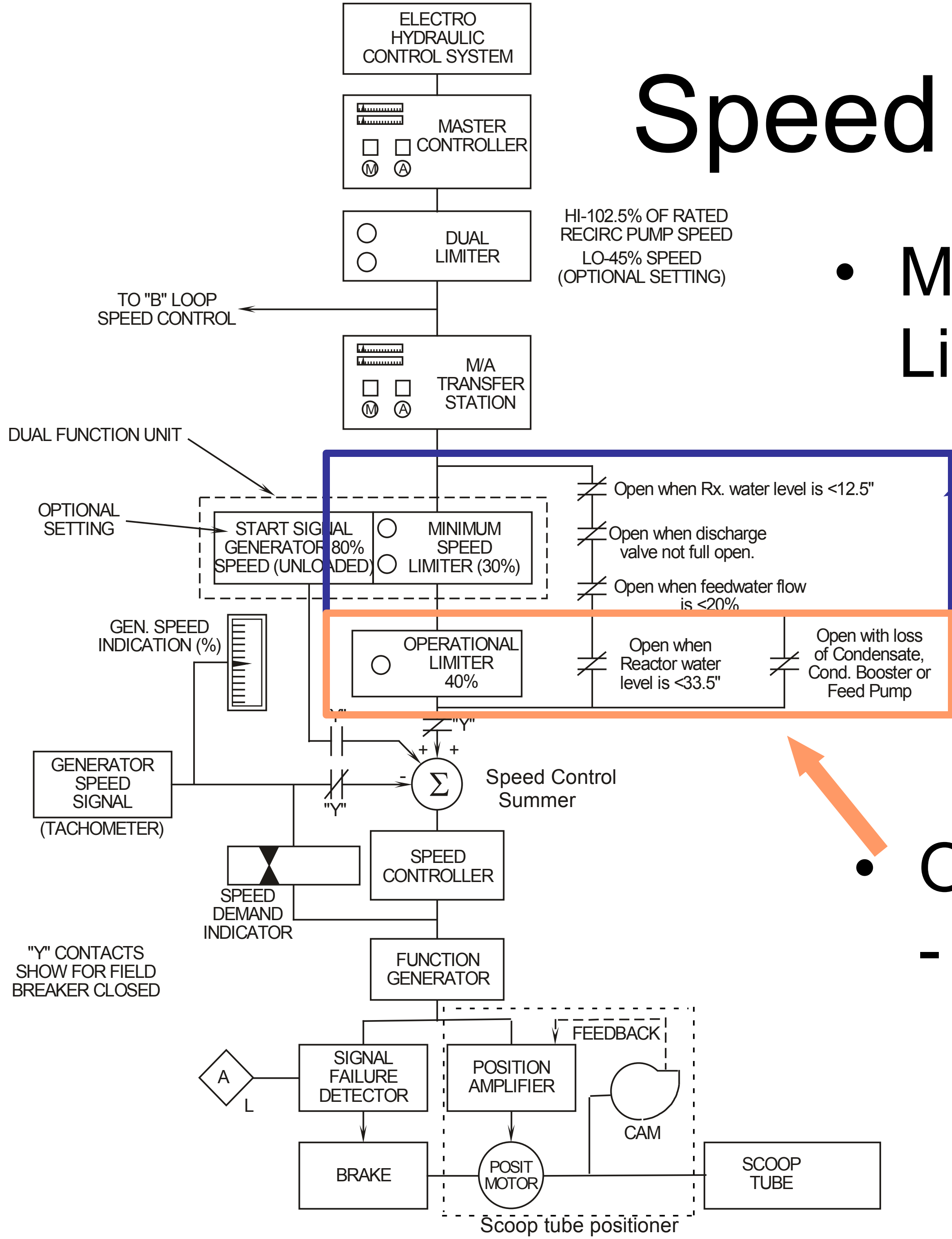


Total Core Flow

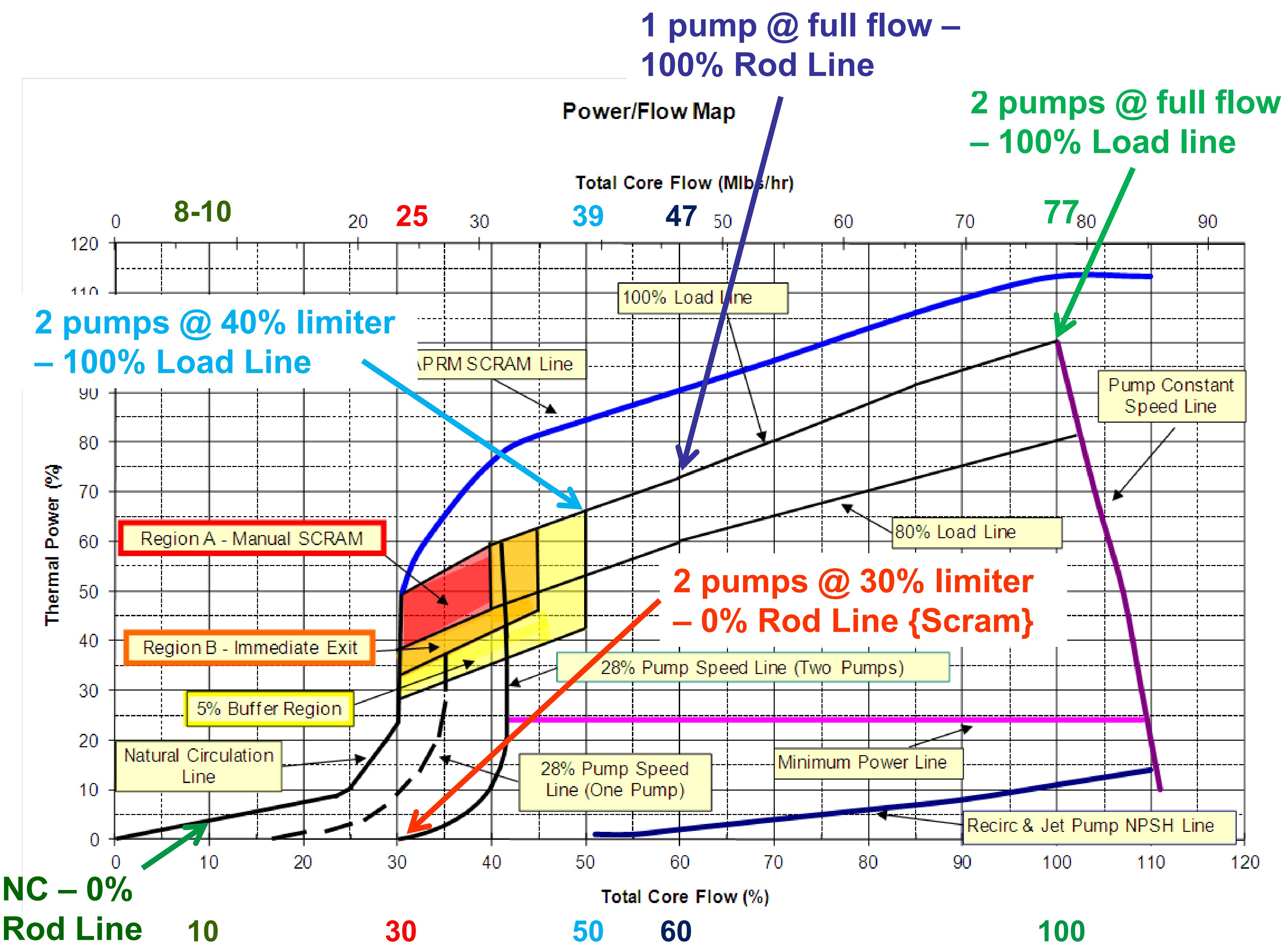
Forced Circulation:

- Recirculation Pump Speed Changes (dominates)
  - Intentional power maneuver
  - Single Pump Trip
  - Operating Limiter
  - Minimum Speed Limiter
  - Dual Pump Trip (EOC-RPT, ATWS-RPT, other)
- Resistance to 2-Phase Flow (at same speed):
  - Void Increase: Pressure drop
  - Void Decrease: Pressure rise and/or scram

Speed Limiters

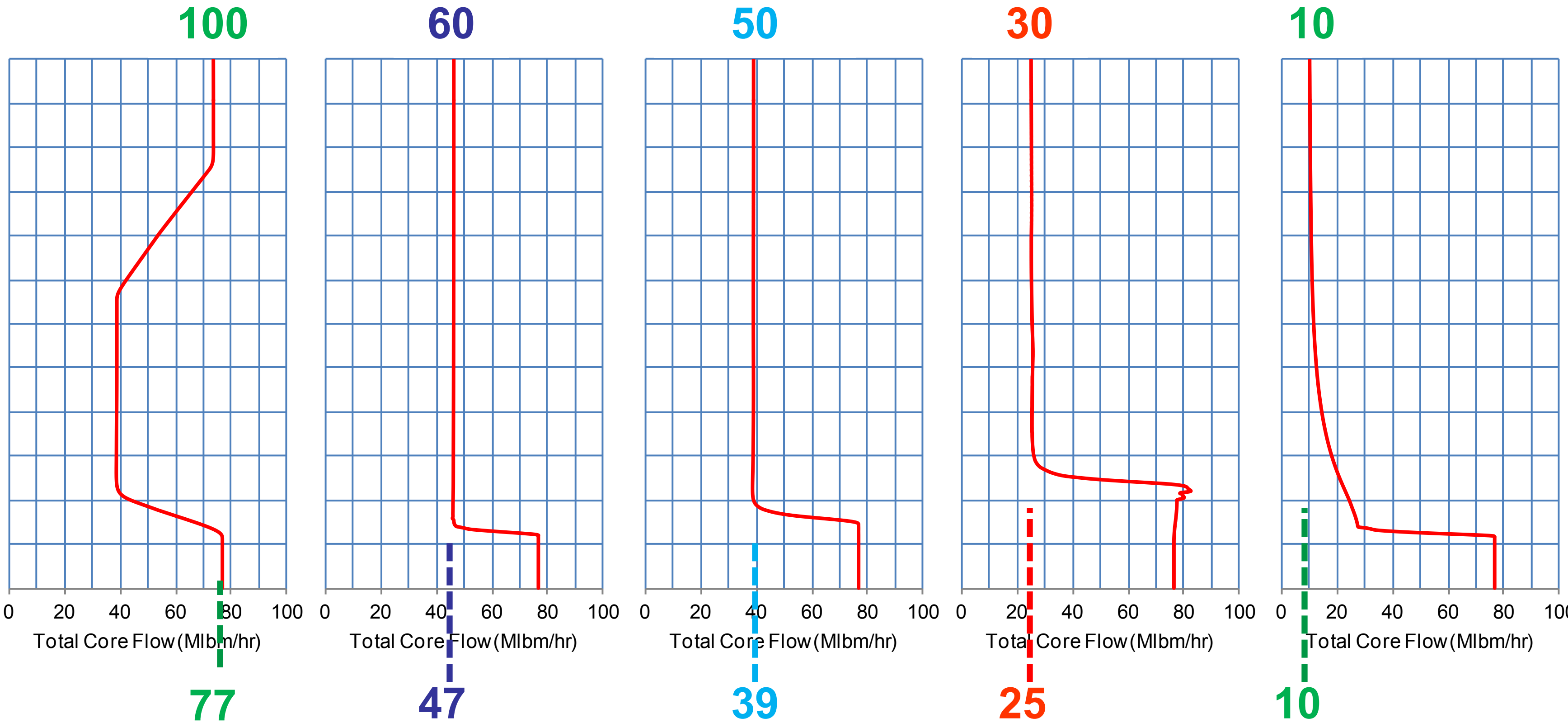


- Minimum Speed Limiter - 30% Runback
- Operational Limiter - 40% Runback



1 pump @ full flow – 100% Rod Line
2 pumps @ full flow – 100% Load line
2 pumps @ 40% limiter – 100% Load Line
2 pumps @ 30% limiter – 0% Rod Line {Scram}
NC – 0% Rod Line
Power/Flow Map
Total Core Flow (Mlbs/hr)
8-10
25
39
47
77
10
30
50
60
100
Thermal Power (%)
Total Core Flow (%)
100% Load Line
APRM SCRAM Line
Pump Constant Speed Line
80% Load Line
Region A - Manual SCRAM
Region B - Immediate Exit
5% Buffer Region
28% Pump Speed Line (Two Pumps)
Natural Circulation Line
28% Pump Speed Line (One Pump)
Minimum Power Line
Recirc & Jet Pump NPSH Line

Total Core Flow



Intentional - Gradual change, can end up at any flow

Single Pump Trip

Operational Limiter

Minimum Speed Limiter

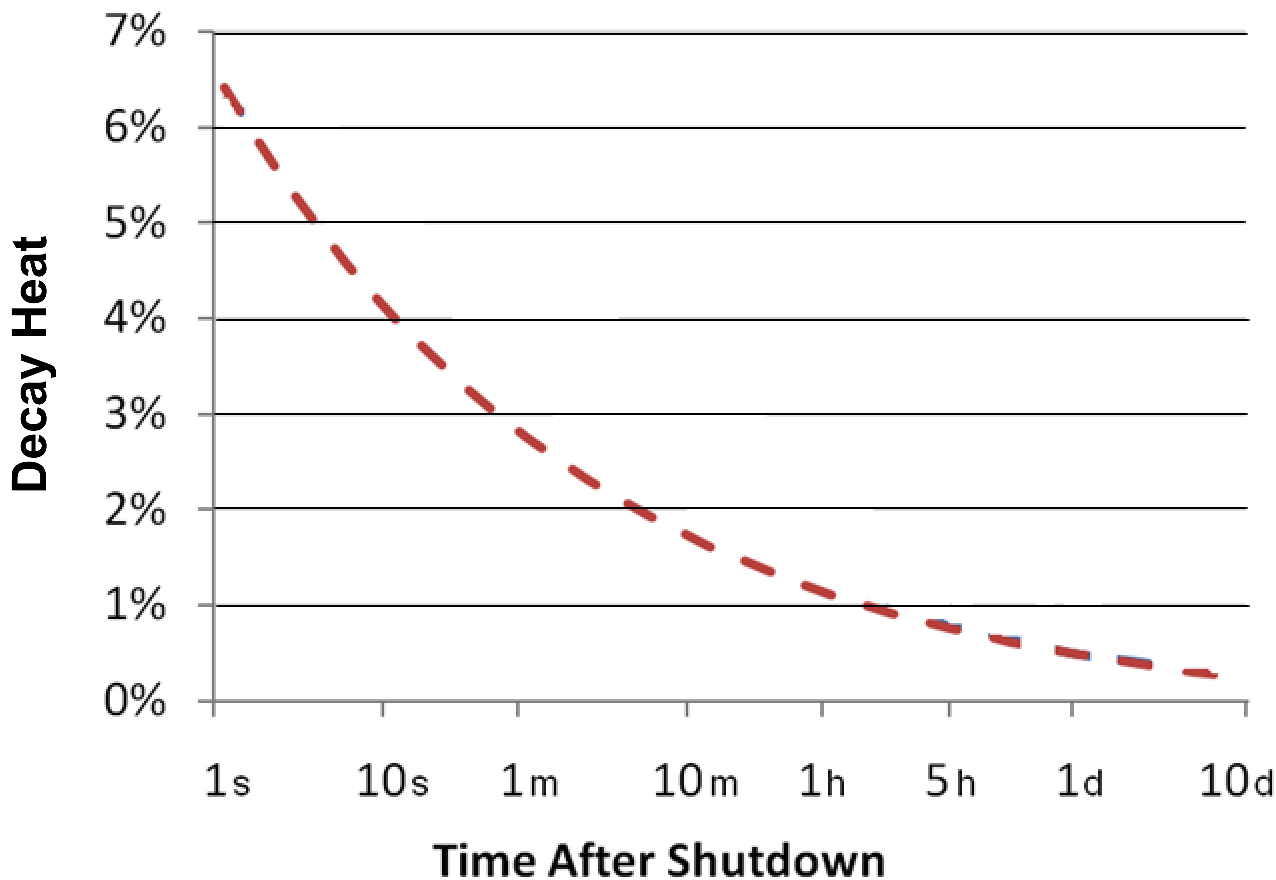
Dual Pump Trip

Total Core Flow

Natural Circulation:

- 2-phase, open-loop system in BWR
- Multiple competing factors: Need complex computer models to predict flow
- Thermal Driving Head: weight of water in annulus versus density of water/steam mixture in core column
  - Decay heat is heat source which rapidly decays away
  - Height and/or density of water in annulus ↑, TDH ↑, flow ↑
  - Voids in core column ↑, density ↓, TDH ↑, flow ↑
  - Level in downcomer ↓, carry-under ↑, feed ring uncovered, annulus temp ↑, density ↓, TDH ↓, flow ↓

Decay Heat



7%
6%
5%
4%
3%
2%
1%
0%
Decay Heat
1s
10s
1m
10m
1h
5h
1d
10d
Time After Shutdown

Fundamental Rules

1. Do not try to identify the initiating event first.
2. Start with the parameter that begins to change first.
3. Start with the parameter you know the best.
4. **Make a list of what would cause the parameter of interest to change.**
5. Start with the first item on the list and decide what direction and how much of a change to expect.
6. If expected response does not agree with parameter change or you are not sure, continue down the list.

Fundamental Rules

7. Stay in the same time frame, do not stay on the same parameter for the entire transient.

8. Go to the parameter that is affected by the one you have chosen (i.e. power effects pressure, pressure effects steam flow).

9. Test to see if all points agree with the initiating event.

10. Move to the next time frame and continue the process until all of the points are identified.

11. Use the “Rule of Arrows”

Make a list of what would cause the parameter of interest to change

Reactor power:

- Control rods (scram or individual rod movement)
- Change in voids due to recirculation pump speed change
- Change in voids due to pressure change
- Core inlet subcooling
- Fuel time constant
- Poisons

Reactor pressure:

- Change in steam production (change in power, EHC system)
- Increase in steam demand (SRV/BPV fails open, EHC fails high)
- Decrease in steam demand (turbine trip, MSIV closure, EHC fails low)

Make a list of what would cause the parameter of interest to change

<u>Turbine steam flow</u>:

- EHC throttling TCVs in response to steam line pressure
- Immediately goes to zero on a turbine trip
- Rapidly goes to zero on a scram or MSIV closure

<u>Reactor steam flow</u>:

- Sum of turbine steam flow, steam flow through the bypass valves, and house loads
- Only stabilizes at zero on a MSIV closure

Make a list of what would cause the parameter of interest to change

Feedwater flow:

- Response to FWC system inputs (reactor steam flow, feedwater flow and level) to maintain or restore modified level to setpoint.
- Lose feedwater flow on RFP trip (including level 8, and loss of vacuum) or loss of steam to drive the pumps (MSIV closure)

Reactor vessel level:

- Difference between makeup flow to the vessel and steam flow leaving the vessel.
- Normally restored to setpoint by FWC system (change in makeup flow rate)
- Rapid increase due to increasing voids (pressure reduction or recirculation pump trip or runback)
- Rapid decrease due to void collapse (scram or pressure increase)

Make a list of what would cause the parameter of interest to change

<u>Total core flow</u>:

- Recirculation pump speed changes (RFC system operation and RPTs)
  - Manual speed change (gradual)
  - Single recirculation pump trip (60% core flow)
  - Operational Limiter (50% core flow)
  - Minimum Speed Limiter (30% core flow)
  - Dual recirculation pump trip, including EOC-RPT or ATWS-RPT (8 to 10% core flow with natural circulation flow affected by a number of factors)
- Change in 2-phase flow resistance due to large void collapse or increase (without a speed change)

What to Expect

- Each transient will be presented individually during the course.
- Handouts describing each identified point will be distributed following the discussion.
- All figures and tables from this chapter will be provided during the exam.
- Only the transients presented will be on the exam.

Objectives

1. Given a transient curve:
   - At selected points, explain what caused the parameter to change.
   - At selected areas of the curve, explain why the parameter is trending in that area.
   - State the cause of the transient (initiating event).
2. Given a plant transient scenario, explain the behavior of selected parameters, control systems, and equipment for the time designated in the scenario.