Transient Overview (Student Handout)

R504B – Chapter 5

Objectives

Learning objectives:

1. **Given a transient curve:**
   - **At selected numbered points, explain what caused the parameter to change.**
   - **At selected numbered 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 or the time designated in the scenario**

Types of Transients Presented

Anticipated Operational Occurrences (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

RPV PRESSURE DECREASE EVENTS
- Safety lifting
- ADS actuation
- EHC Failure
- Bypass Valve(s) opening

RPV PRESSURE INCREASE EVENTS
- EHC Malfunction
- Generator Load Reject
- Turbine Trip/Loss of Vacuum
- MSIV Closure (Fast and Slow)

DECREASE IN REACTOR COOLANT SYSTEM FLOWRATE
- Recirculation Pump Trip(s)
- Recirculation Flow Control Failure

REACTOR COOLANT INVENTORY INCREASE
- HPCI Initiation
- FWLC failure

REACTOR COOLANT INVENTORY DECREASE
- FWLC Failure
- SRV Opening
- Loss of Feed (partial and total)

REACTIVITY EVENTS
- Routine Power Change (not an AOO)
- Manual Reactor Trip
- Control Rod Withdrawal Error
- Recirculation Flow Control Failure
- SLC Initiation
- Loss of Feed Water Heating

Transient Parameters Recorded

Average Power Range Monitor (APRM) ‘A’

Reactor Pressure (PSIG)

Total Reactor Steam Flow (Mlbm/hr)

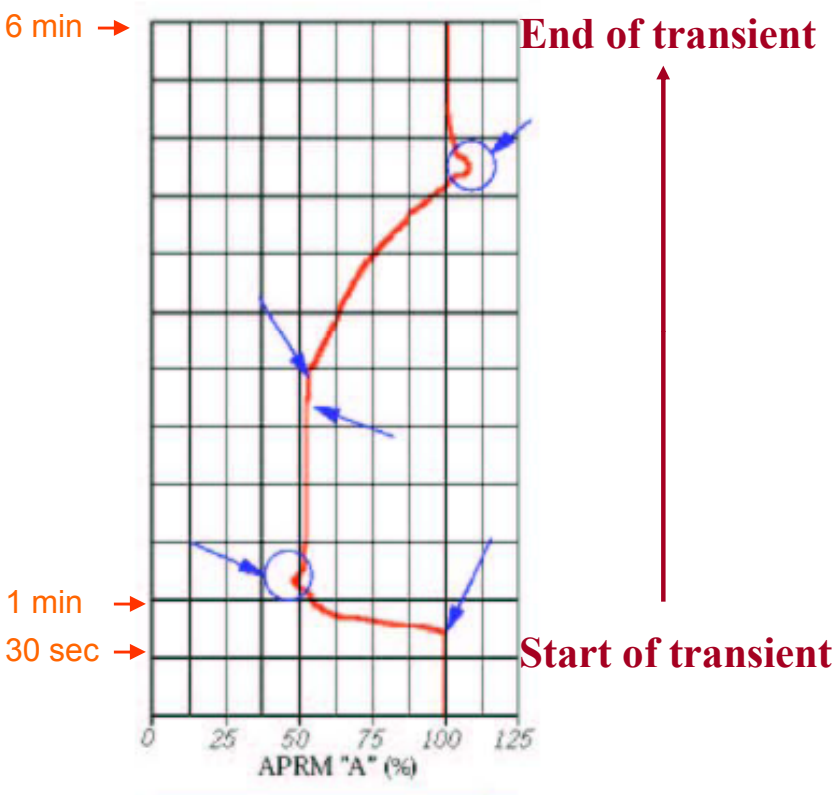
Turbine Steam Flow (Mlbm/hr)

Total Feedwater Flow (Mlbm/hr)

Narrow Range Reactor Water Level (in)

Total Core Flow (Mlbm/hr)

Strip Chart Protocol



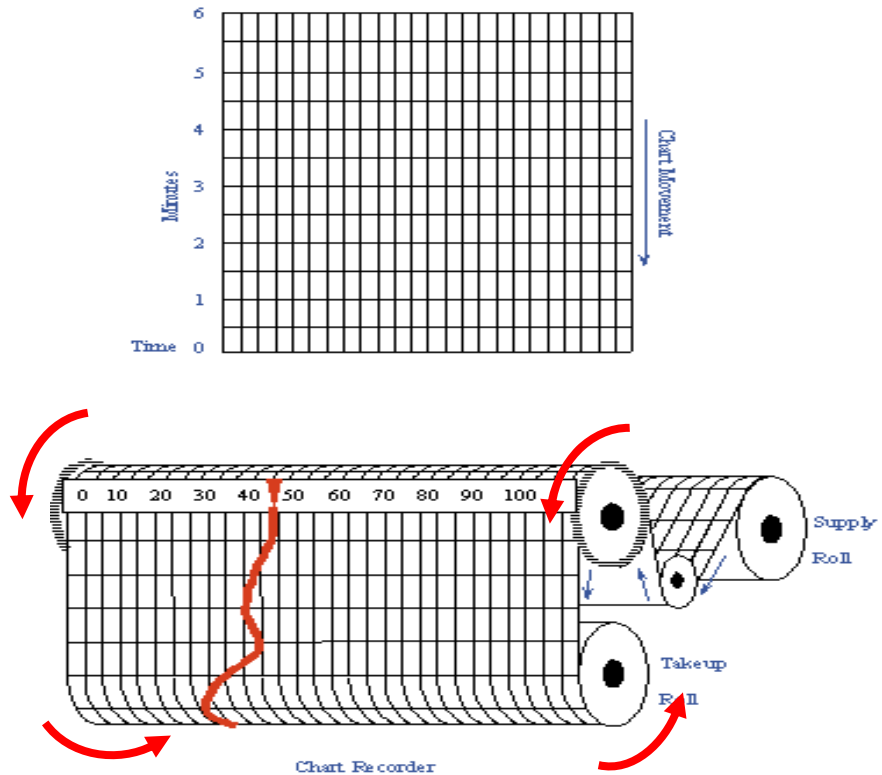
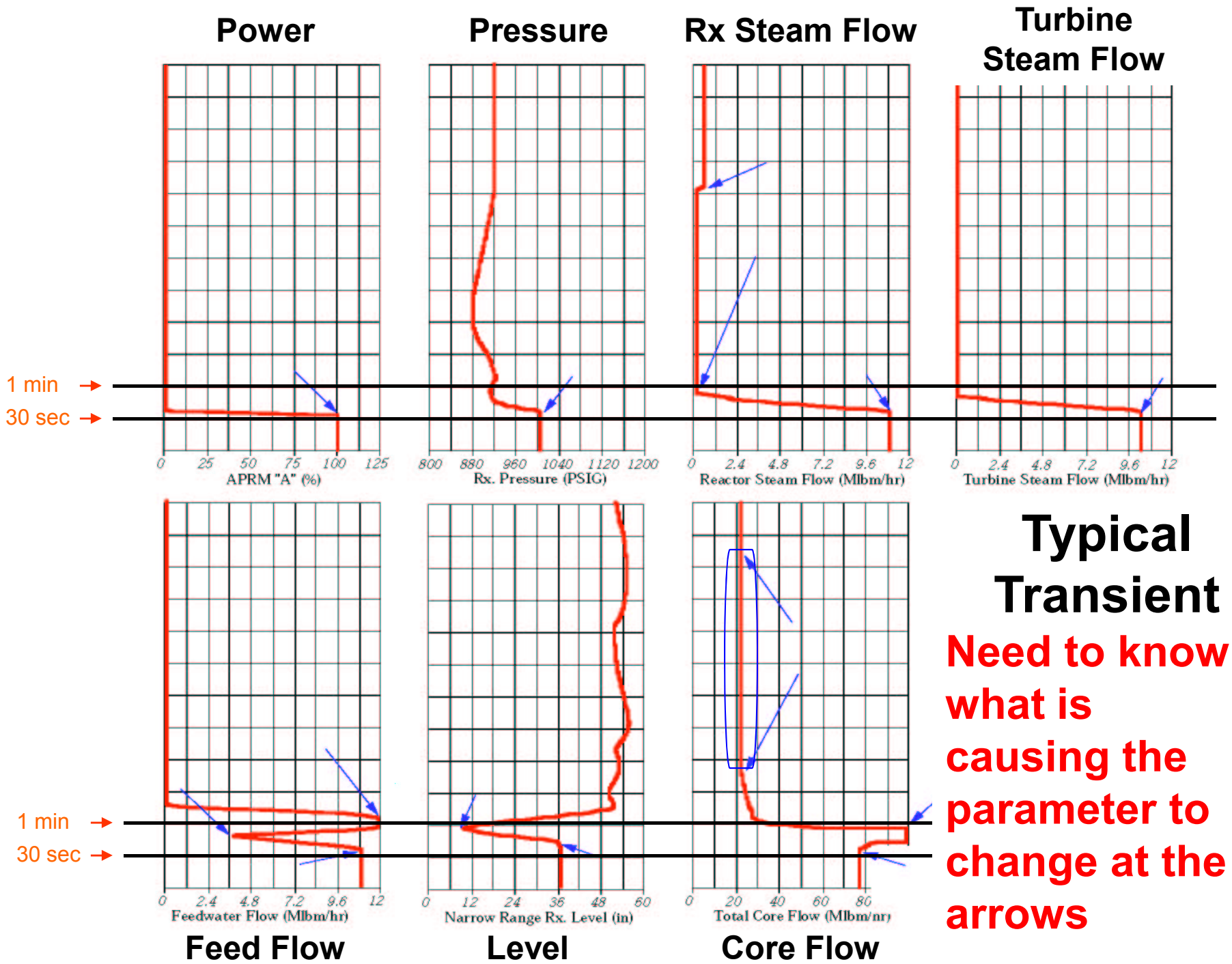


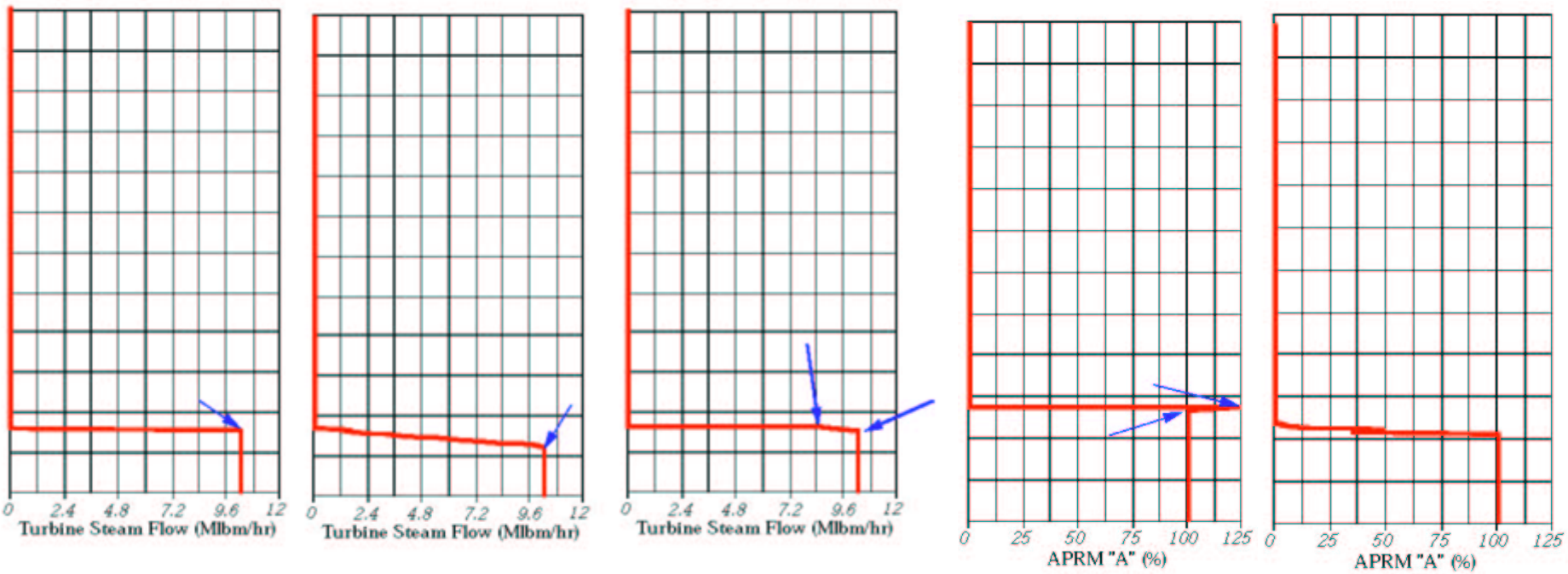
Figure 5.1-1 Chart Recorder



Typical Transient

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

Learn to distinguish between a "trip" and rapid decrease

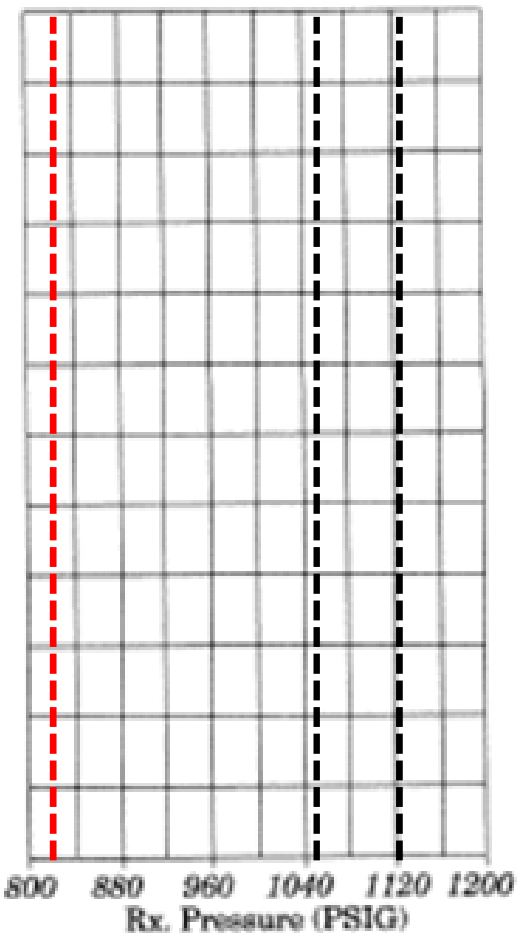


Turbine Steam Flow

Power

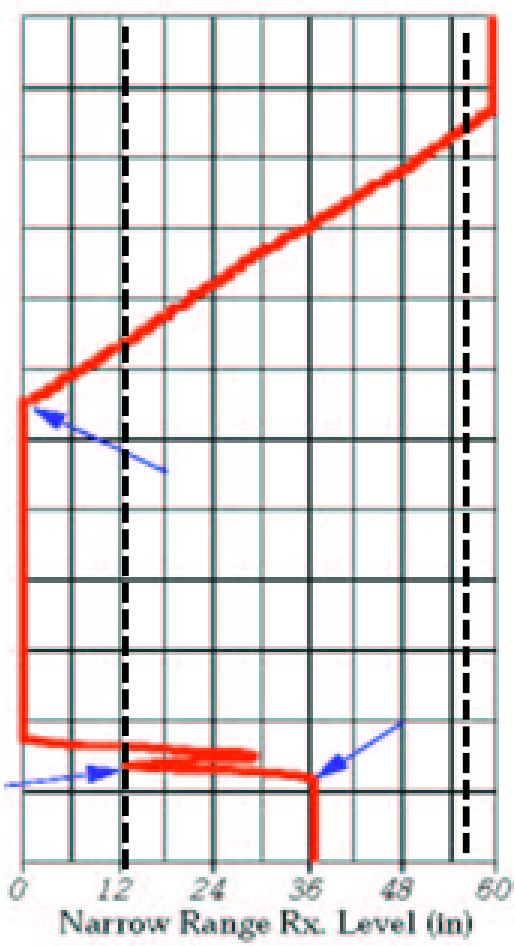
Note Setpoints Available

Pressure



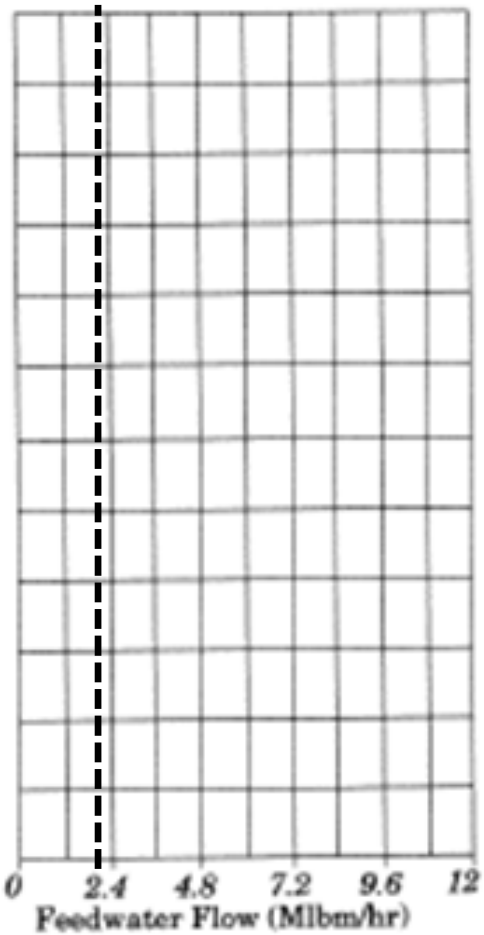
1120 psig – ATWS-RPT
1043 psig – RPS Trip
825 psig – Group 1 Isol
(Header Pressure)

Level



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

Feed Flow



20% FW Flow –
Recirc Pump 30% Limiter

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)	Low level alarm, **AND** permissive for Recirc pump runback to 45%
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)

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

Note: These trips are in sequence

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)

1.5 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 (%)

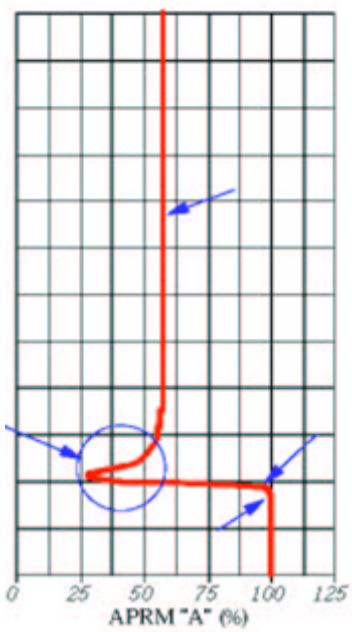
20% RWM rod blocks bypassed at > 20% power as sensed by steam flow

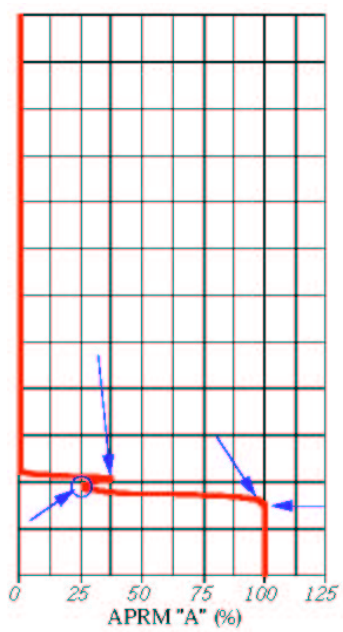
30% RWM Alarms bypassed at > 30% power as sensed by steam flow

Arrows provide clues

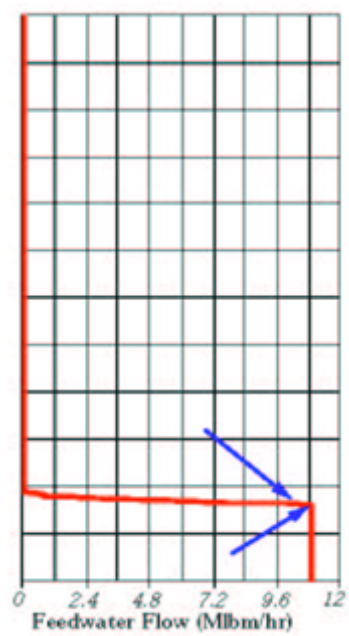
Subtle changes pointed out with arrows.

Typically, the last arrow is the major affect.

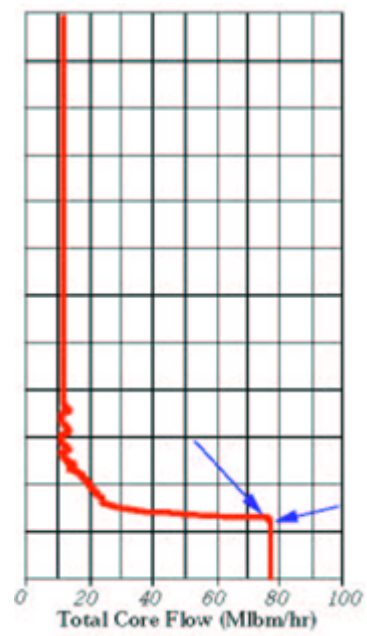




Power



Feed Flow



Core Flow

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)

Big Picture

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

- Rods
- Voids:
  - Recirc Flow
  - Pressure changes
- Poison
- FTC
- MTC (amount of subcooling)

Big Picture

<u>Pressure</u>: Follows Power change

- Power ↑, Steam production > Steam Demand , Pressure ↑, EHC opens TCVs to match power (steam production) with turbine load (steam demand)
- Power ↓, Steam production < Steam Demand , Pressure ↓, EHC closes TCVs to match power (steam production) with turbine load (steam demand)

Big Picture

<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

<u>Core Flow</u>:

- Recirculation Pump Speed (RFC)
- Flow Resistance (voids)

Big Picture

<u>Feedwater Flow</u>:

- Controlled by FWLC System based on:
  - Level Deviation from Setpoint, and
  - Steam Flow/Feed Flow Mismatch

<u>Reactor Level</u>:

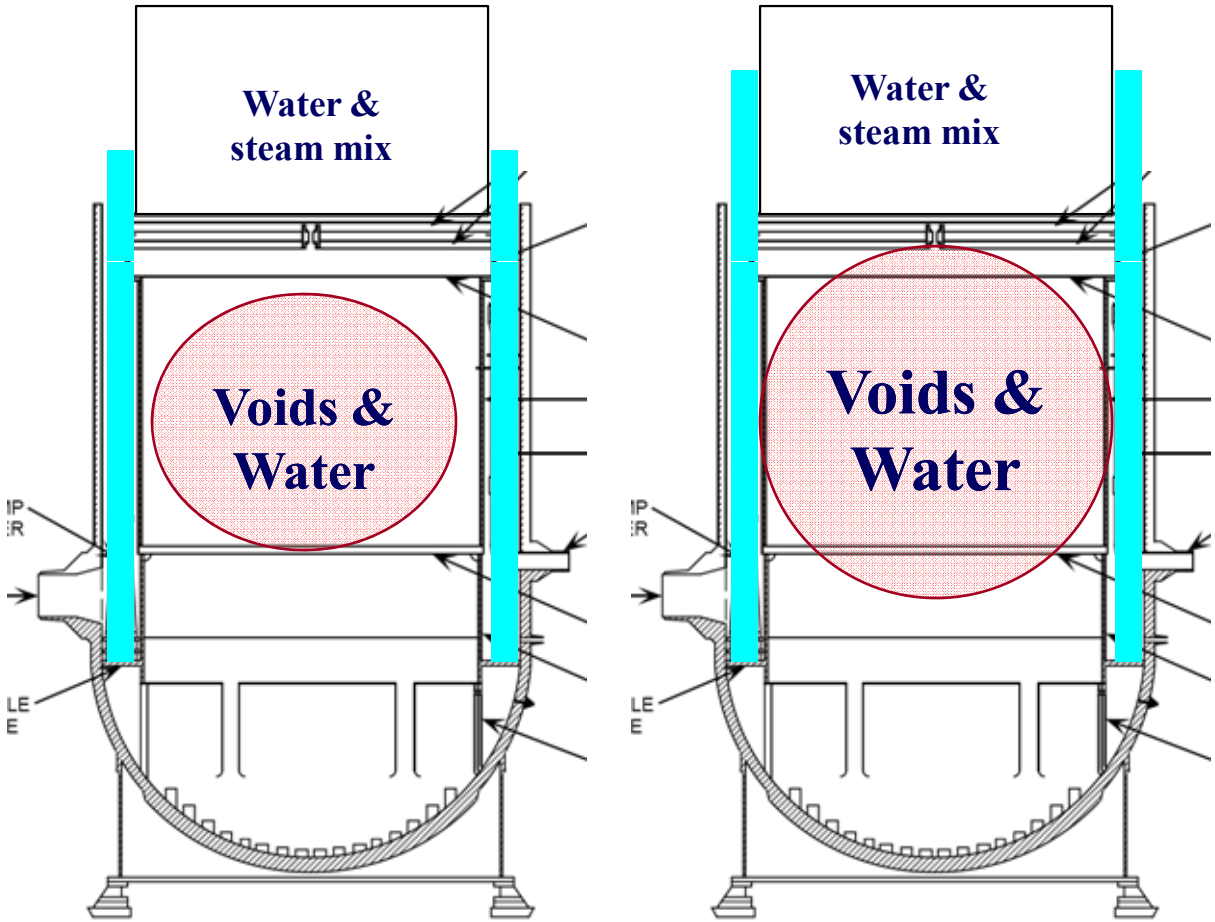
- FWLC System
- Voids

Voids Impact on Level

NR and WR level are measured in the annulus.

Voids go up, “forces water out of shroud into annulus”, level goes up

Voids go down, “water rushes in from the annulus to fill the space, level goes down



What Affects Reactor Power

Rods:

- Scram (manual or RPS auto initiation)
- RMCS (manual)
- Rod drifts in/out or multiple rod insertion/withdraw

Recirc Flow (intentional, limiters or RPT)

SLC Injection

Feedwater Temperature

Short term transient affects:

- Pressure
- Fuel Time Constant or Thermal Time Constant

Reactor Power

Which are immediate (as opposed to parameter trends)

Scram:

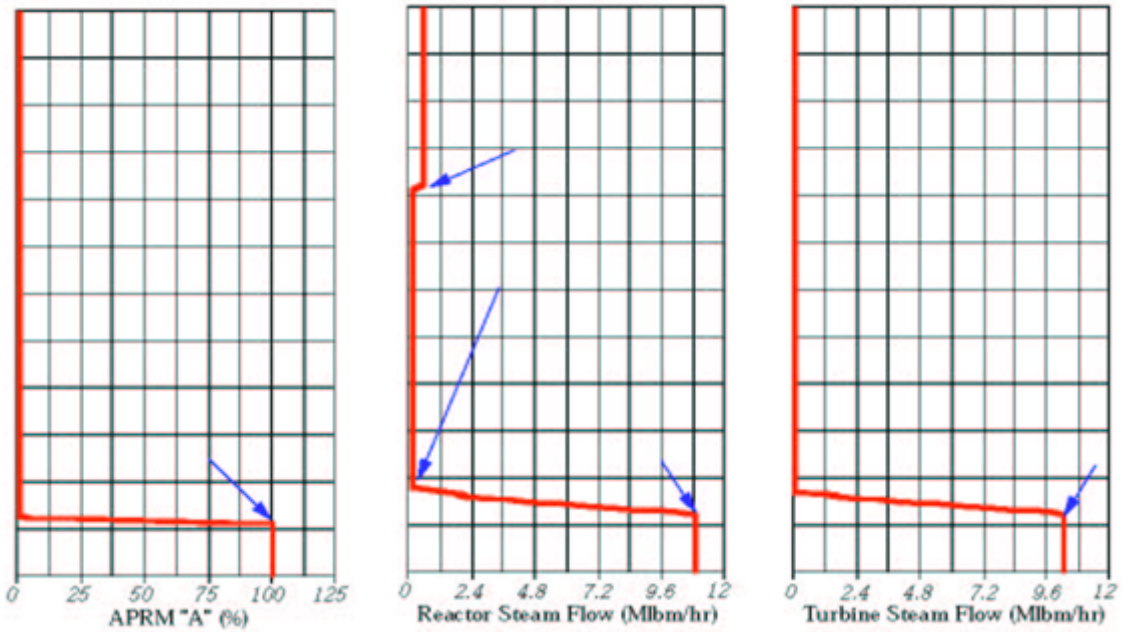
- **Manual/Mode Switch to Shutdown**
- Hi Power (APRM, etc..)
- Low Level (Level 3)
- **Turbine trip (>30% power):**

  Manual, Level 8, **Low Vacuum (22.5”),** others
- Reactor Pressure High (1043 psig)
- **MSIV Closure (Mode switch in Run):**

  Manual, Low Steam Header Pressure (825 psig), Low Vac. (8.5”), Hi Steam Flow (134%) , Level 1, others
- Others (SDV High Level, MS Line Hi Rad, High DW Pressure)

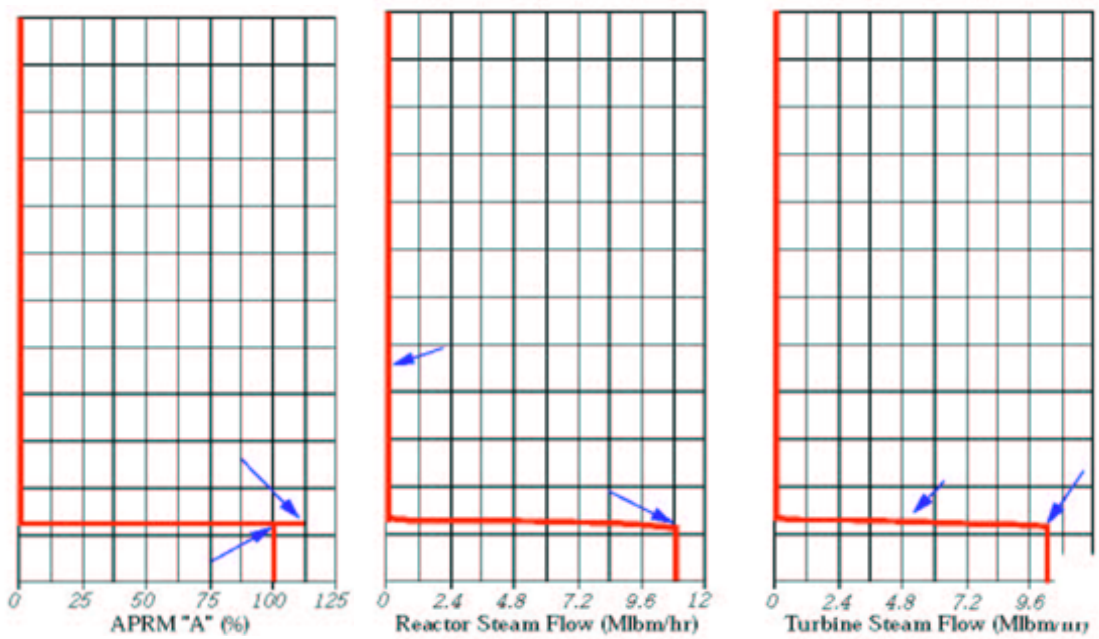
Immediate Scrams

Manual Scram



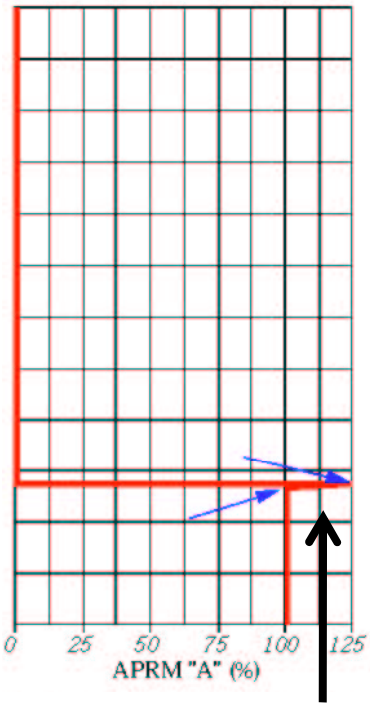
Power **Rx Stm Flow** **Turb Stm Flow**

Manual MSIV Closure



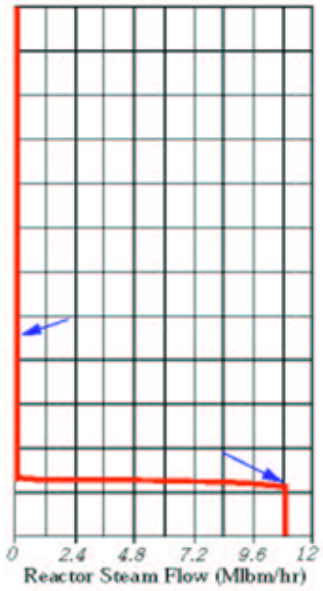
Immediate Scrams

Power

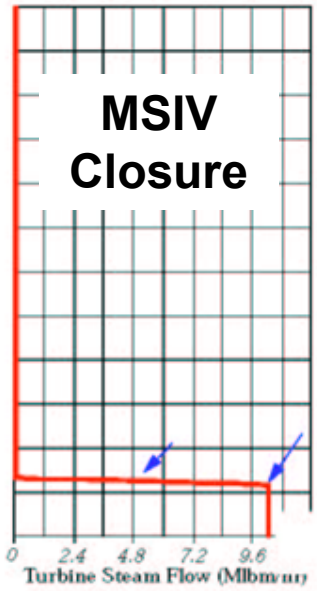


TT or MSIV Closure causes pressure spike which collapse the voids causing a power spike

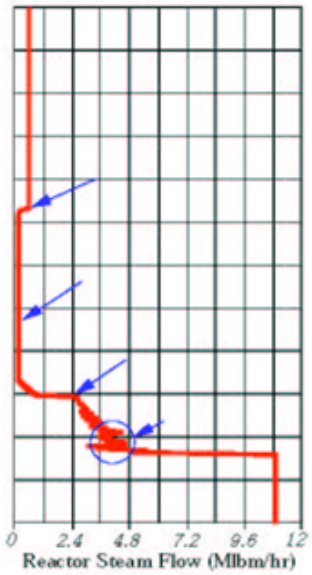
Rx Stm Flow



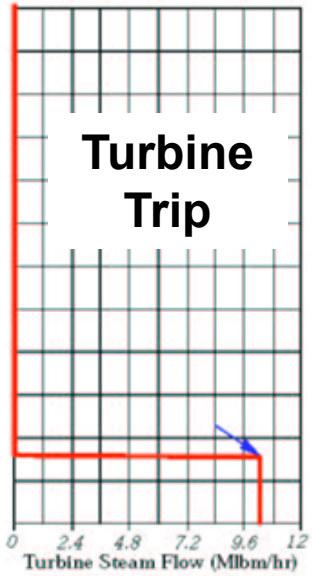
Turb Stm Flow



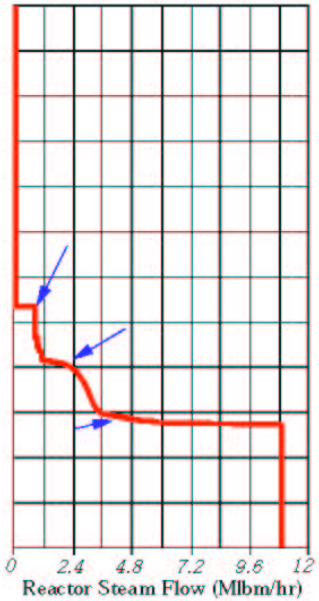
Rx Stm Flow



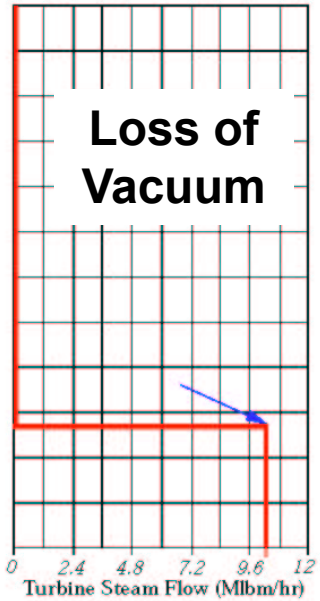
Turb Stm Flow



Rx Stm Flow



Turb Stm Flow



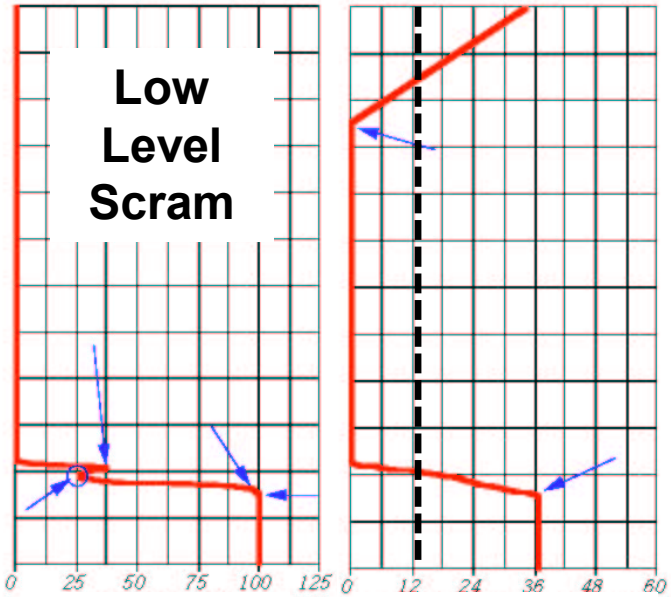
Reactor Power

What Could cause these trips?

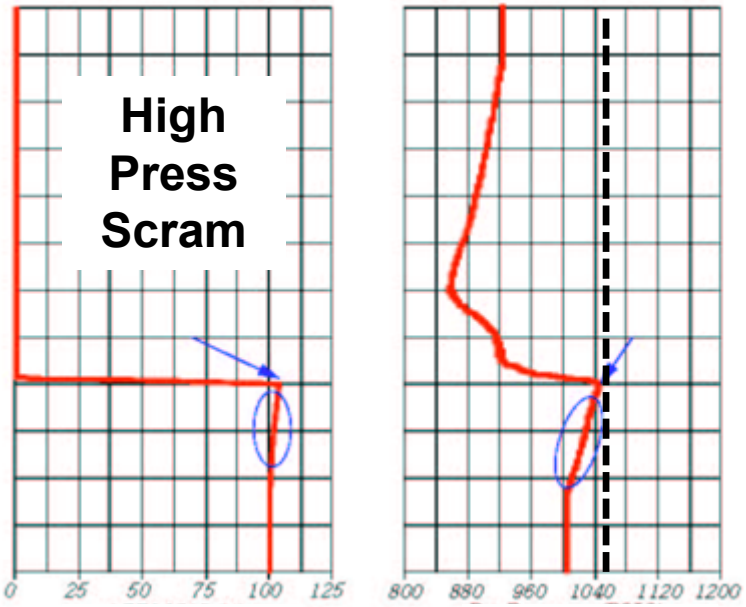
Scram:

- Vessel Low Level (Level 3)
  - Loss of feed, Feed line break, FWLC failure
- Reactor Pressure High (1043 psig)
  - EHC failure, TT?, MSIV Closure?, MSIV Slow Closure
- Low pressure MSIV Closure (Mode switch in Run):
  - EHC failure, steam line break, etc..
- High Level (Level 8) Turbine trip (>30% power):
  - FWLC failure
  - Major Void Increase: loss of recirc flow
  - Major Void Increase: major pressure reduction (ADS actuation)

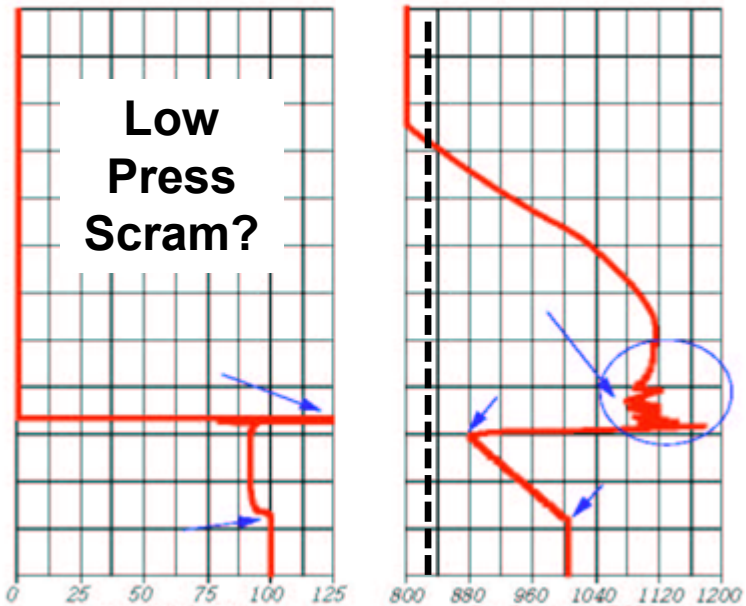
Scrams After Initiating Event



Power Level

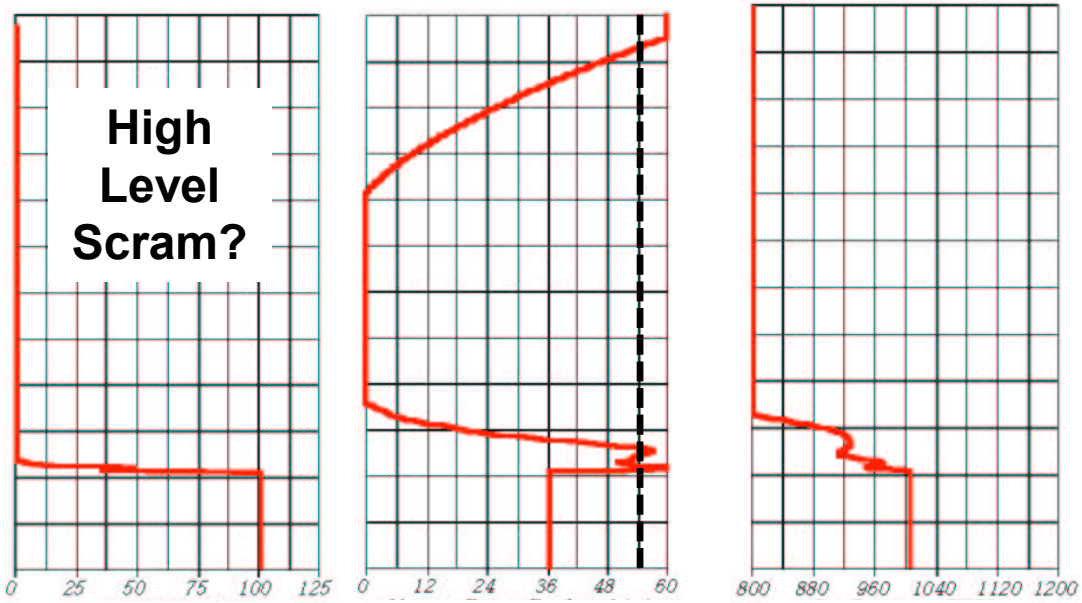


Power Pressure



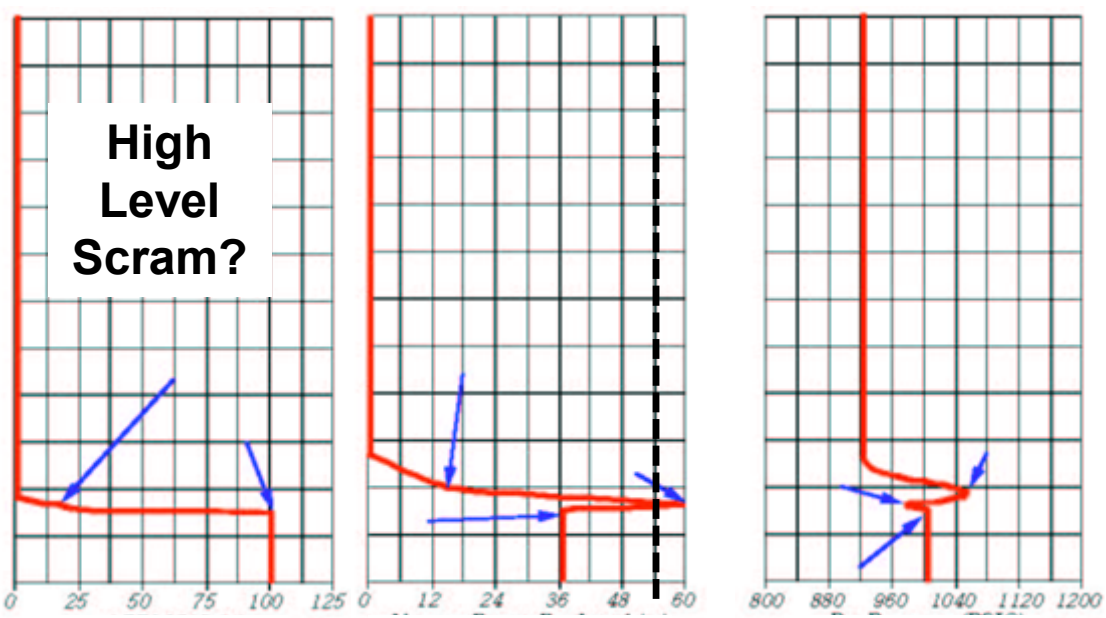
Power Pressure

Scrams After Initiating Event



Power Level Pressure

Major Void Increases



Power Level Pressure

Reactor Power

Rods

Recirc Flow:

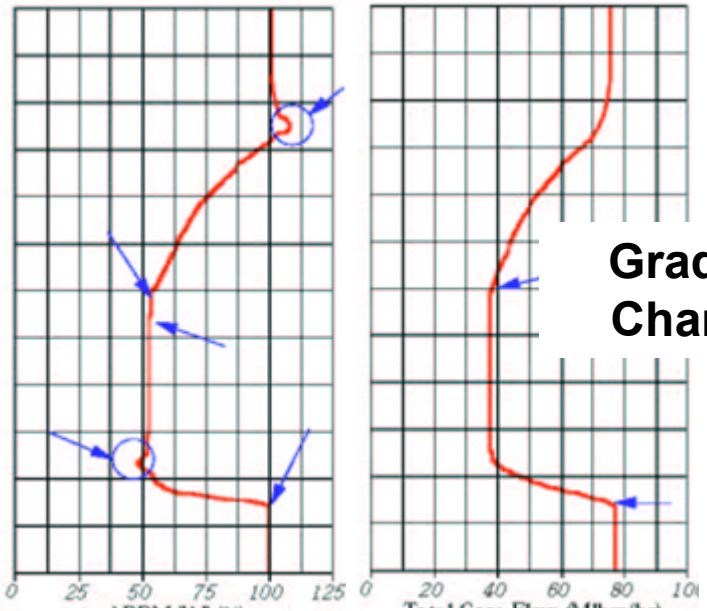
- Intentional power maneuver
- Recirc Pump trip or limiter

SLC Injection

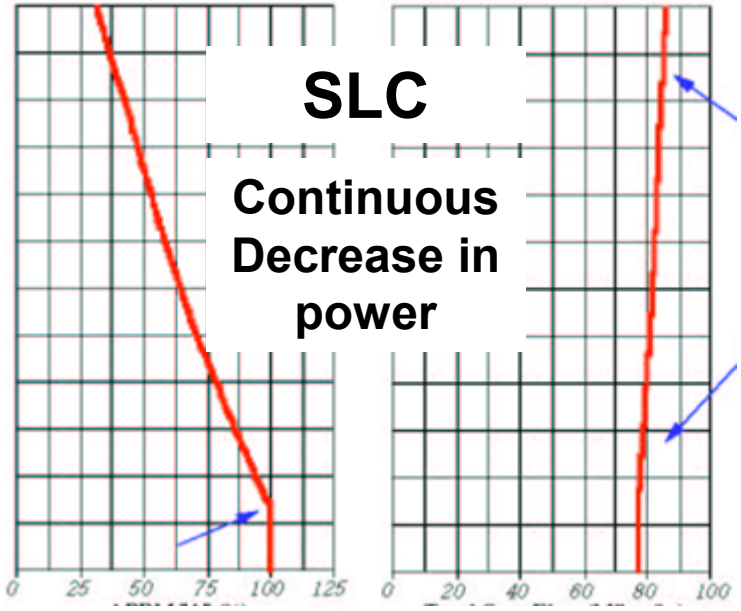
Feedwater Temperature:

- Change in stable feed flow from start to finish of transient
- HPCI/RCIC injection
- Loss of Feedwater Heating

Power change due to change in Recirc Flow

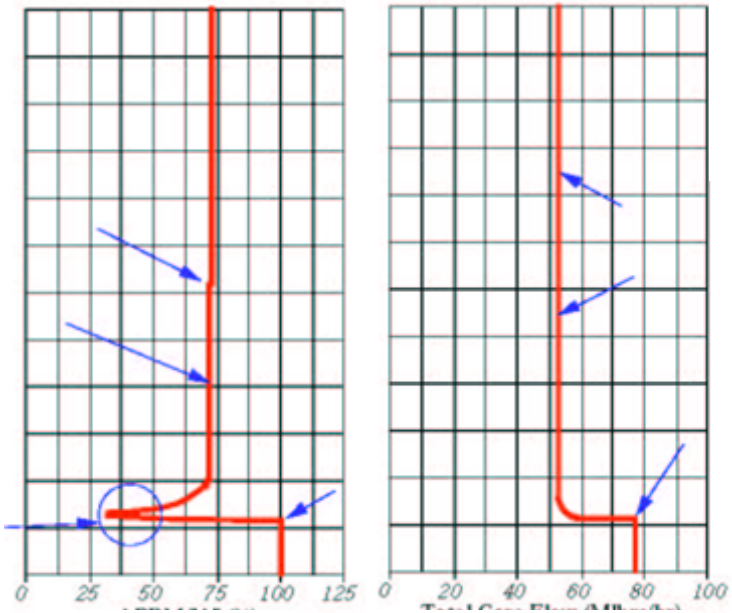


Power Core Flow

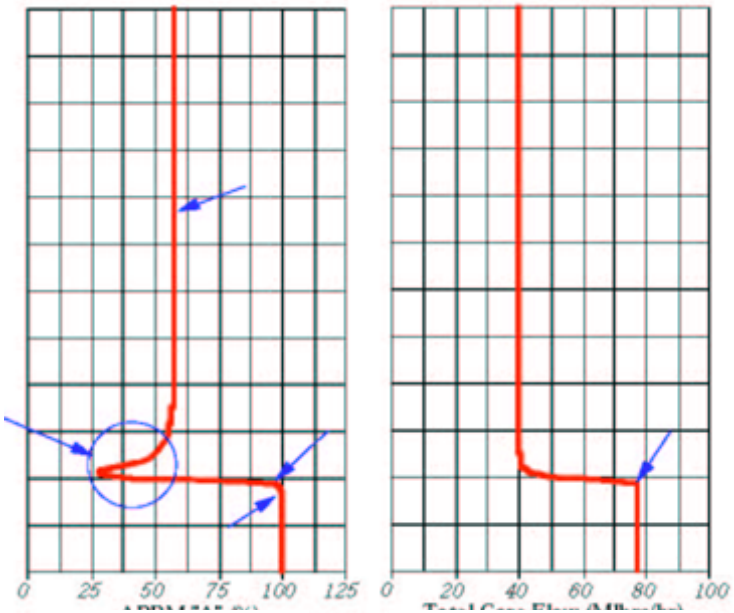


Power Core Flow

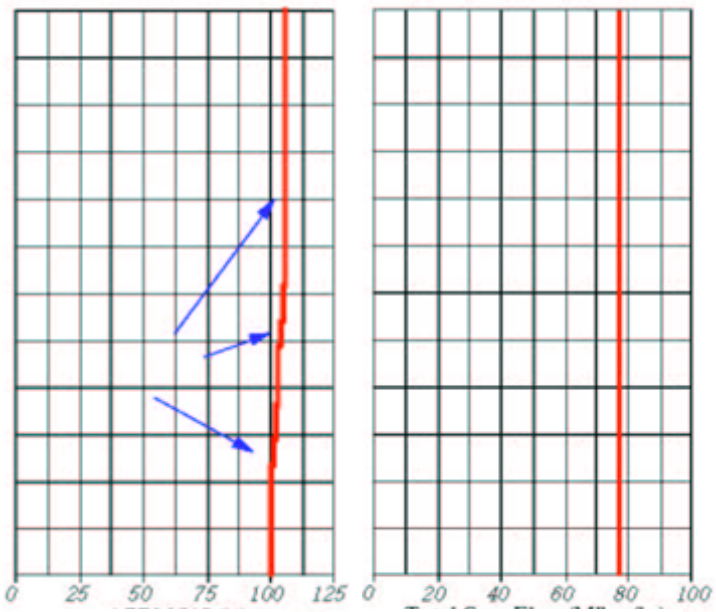
Recirc Pump Limiters



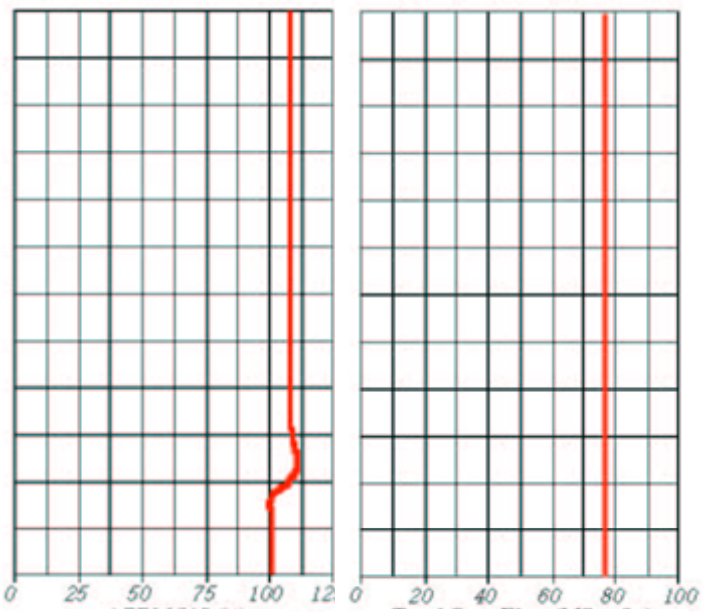
Power Core Flow



Power Core Flow



Power **Core Flow**



Power **Core Flow**

Feedwater Temperature

Reactor Power

Short term impact during a transient:

- Pressure

  Normally power change drives pressure change, but pressure can change power during transients where pressure directly impacted by initiator

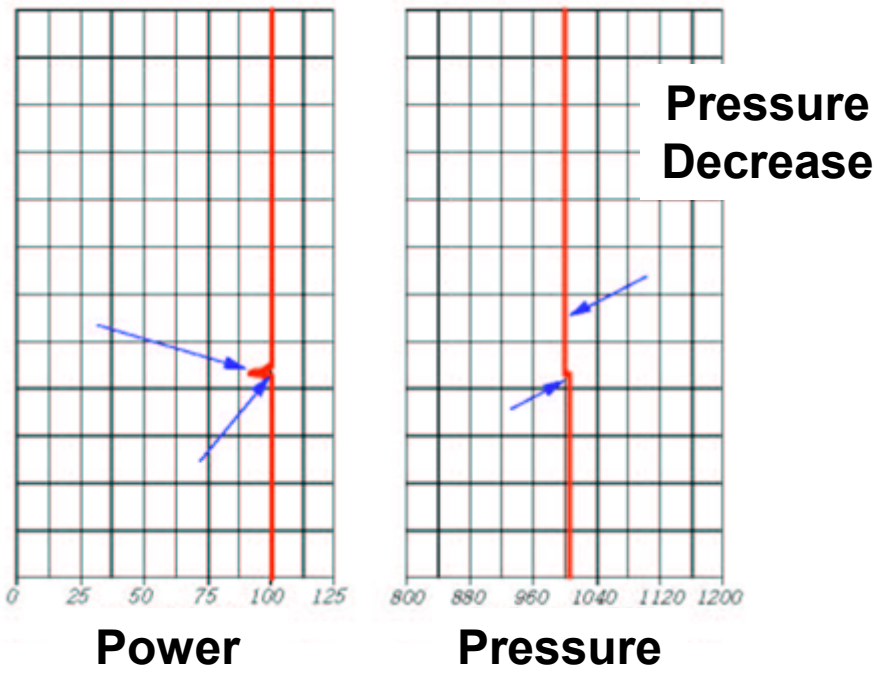
  High: Turbine trip, MSIV closure, EHC fails Low

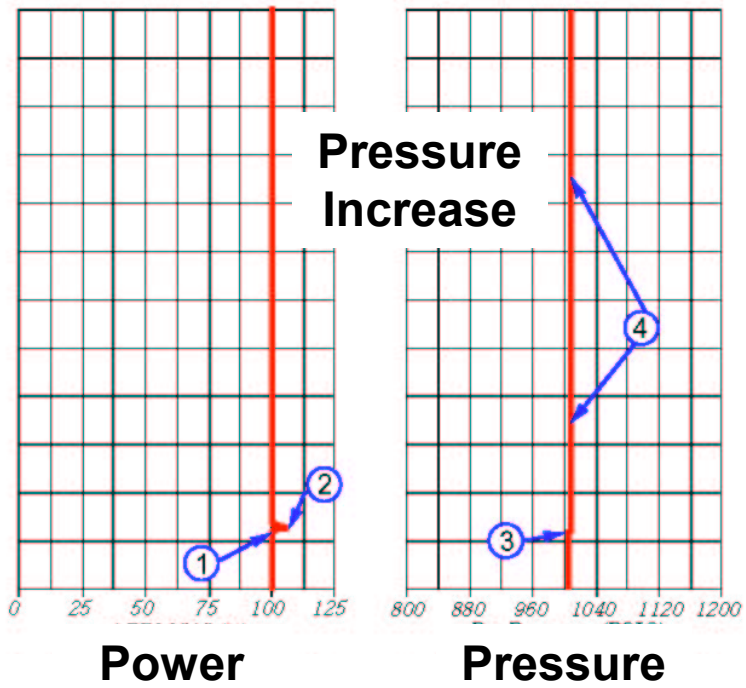
  Low: SRV open, BPV open, ADS init, EHC fails High

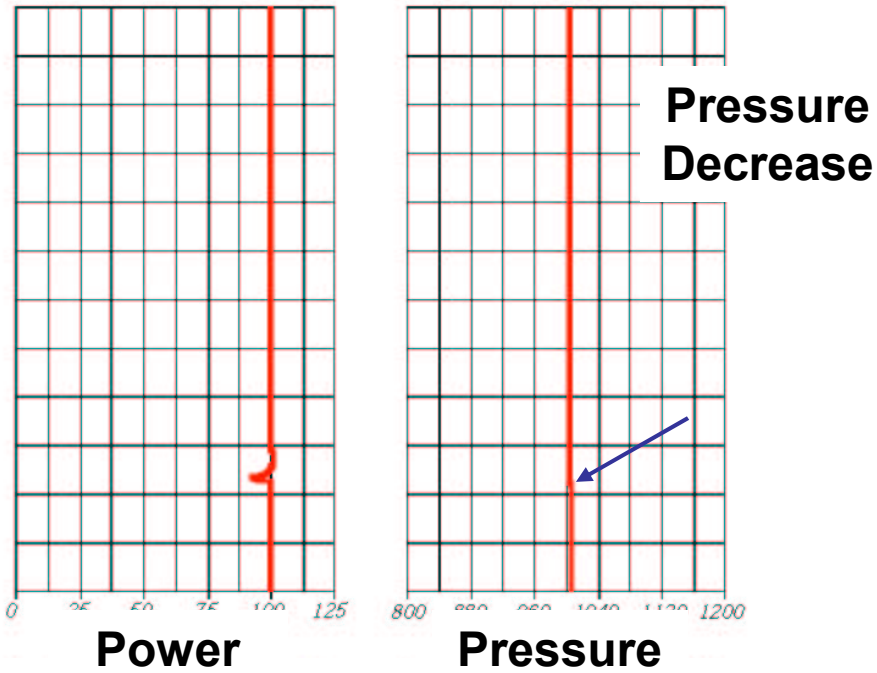
  Pressure will affect power, but (if no scram) power will return to original value:

  Pressure ↑, Voids↓ , Pwr↑ , causes more voids, Pwr ↓

  Pressure ↓, Voids↑ , Pwr↓ , causes less voids, Pwr↑







Short Term Pressure Impact on Power

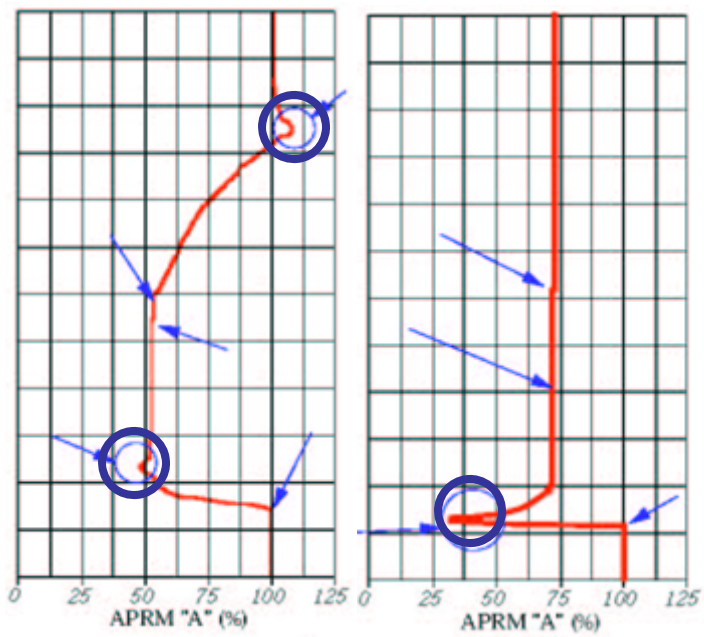
Reactor Power

Short term impact during a transient:

- Fuel Time Constant (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.



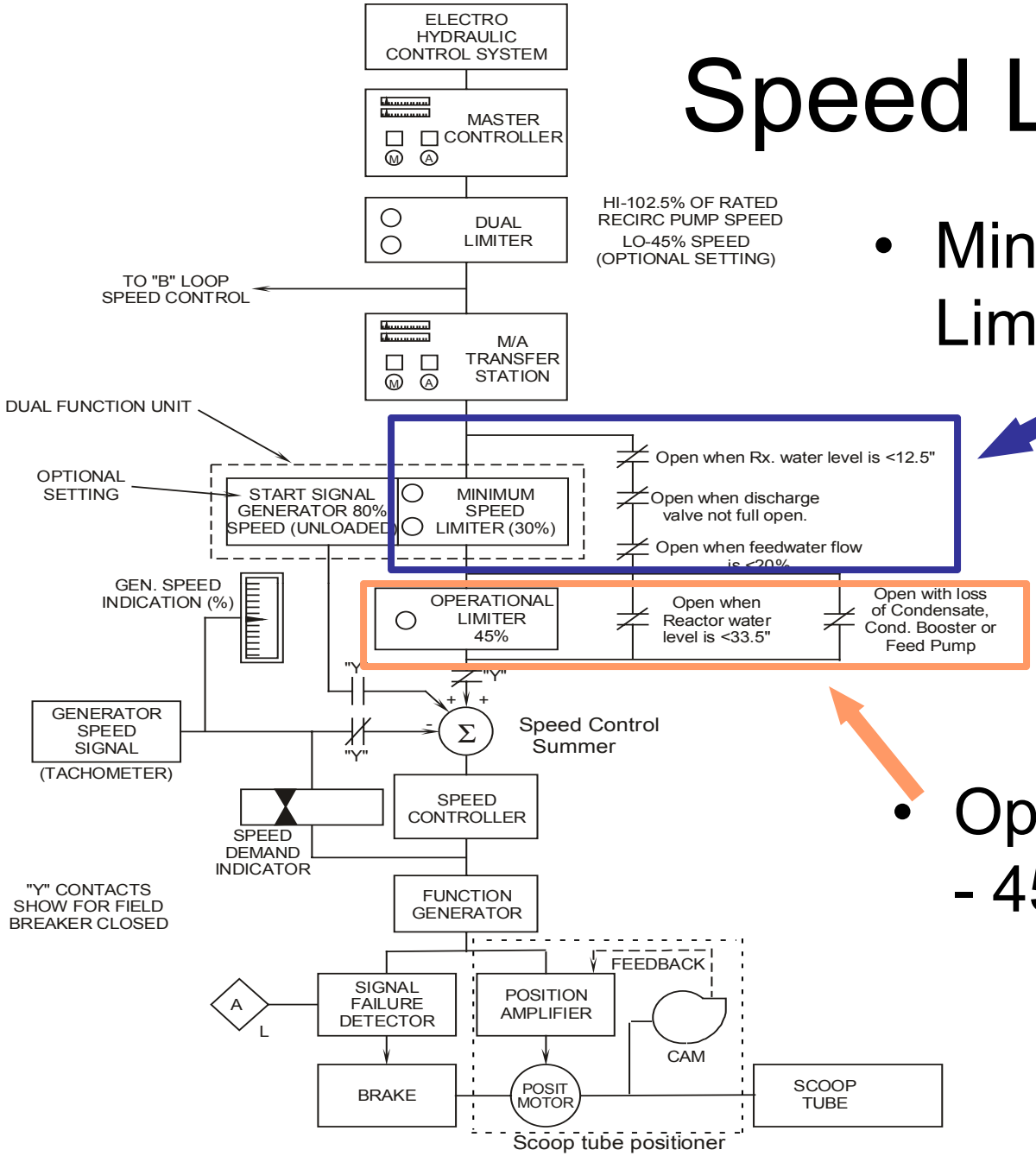
Total Core Flow

Recirc Flow Change from Recirc Pump Speed:

- Intentional power maneuver
- Single Pump Trip
- Recirc Pump Operating Limiter
  - Loss on Feed/Cond Pump and < Level 4
- Recirc Pump Minimum Speed Limiter
  - <20% feedwater flow
  - Level 3
  - Discharge valve not full open
- Dual Pump Trip
  - ATWS RPT: 1120 psig, Level 2
  - EOC-RPT: Turbine Trip when > 30% power

Which are survivable at 100%?

Speed Limiters



- Minimum Speed Limiter - 30% Runback
- Operational Limiter - 45% Runback

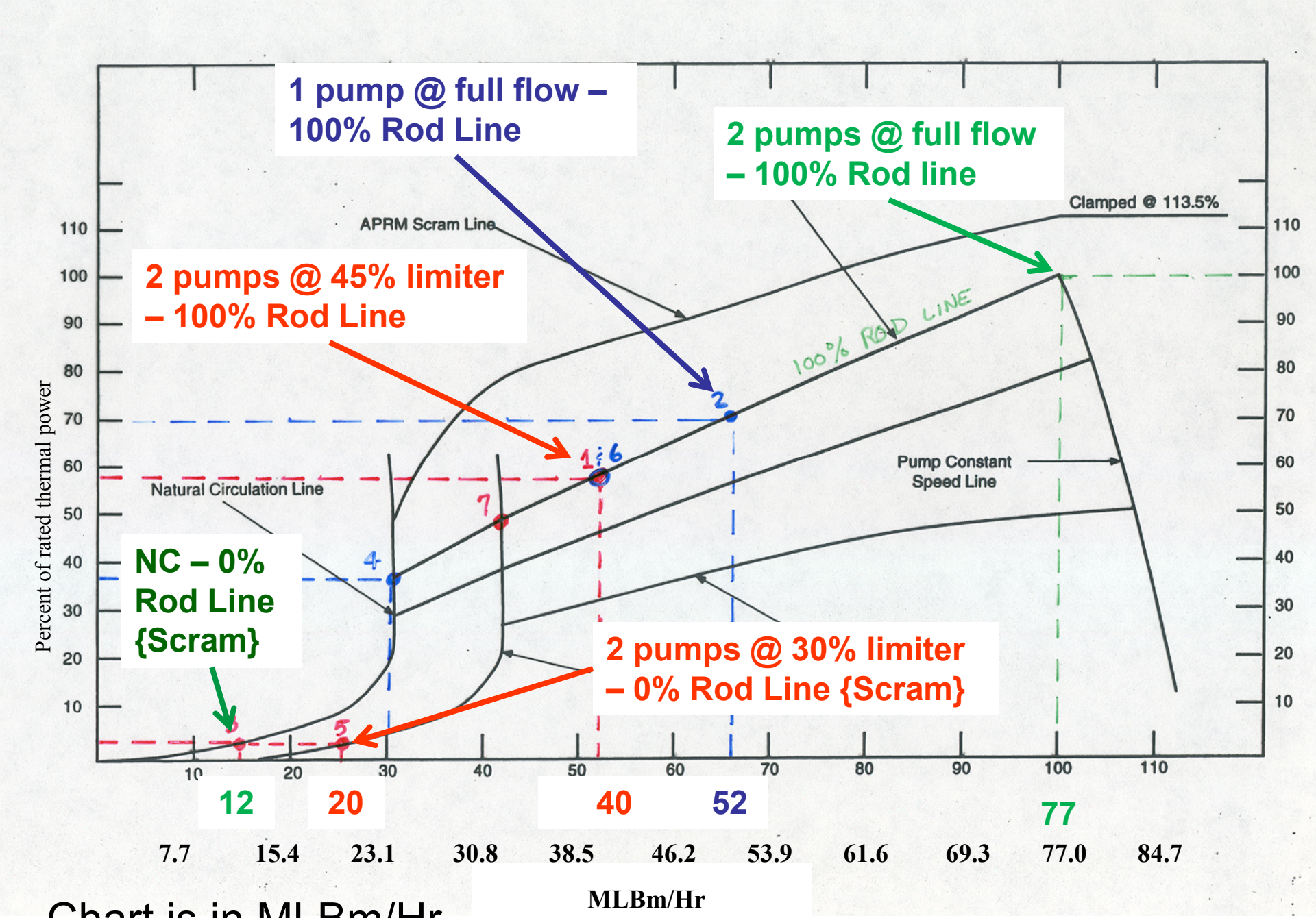
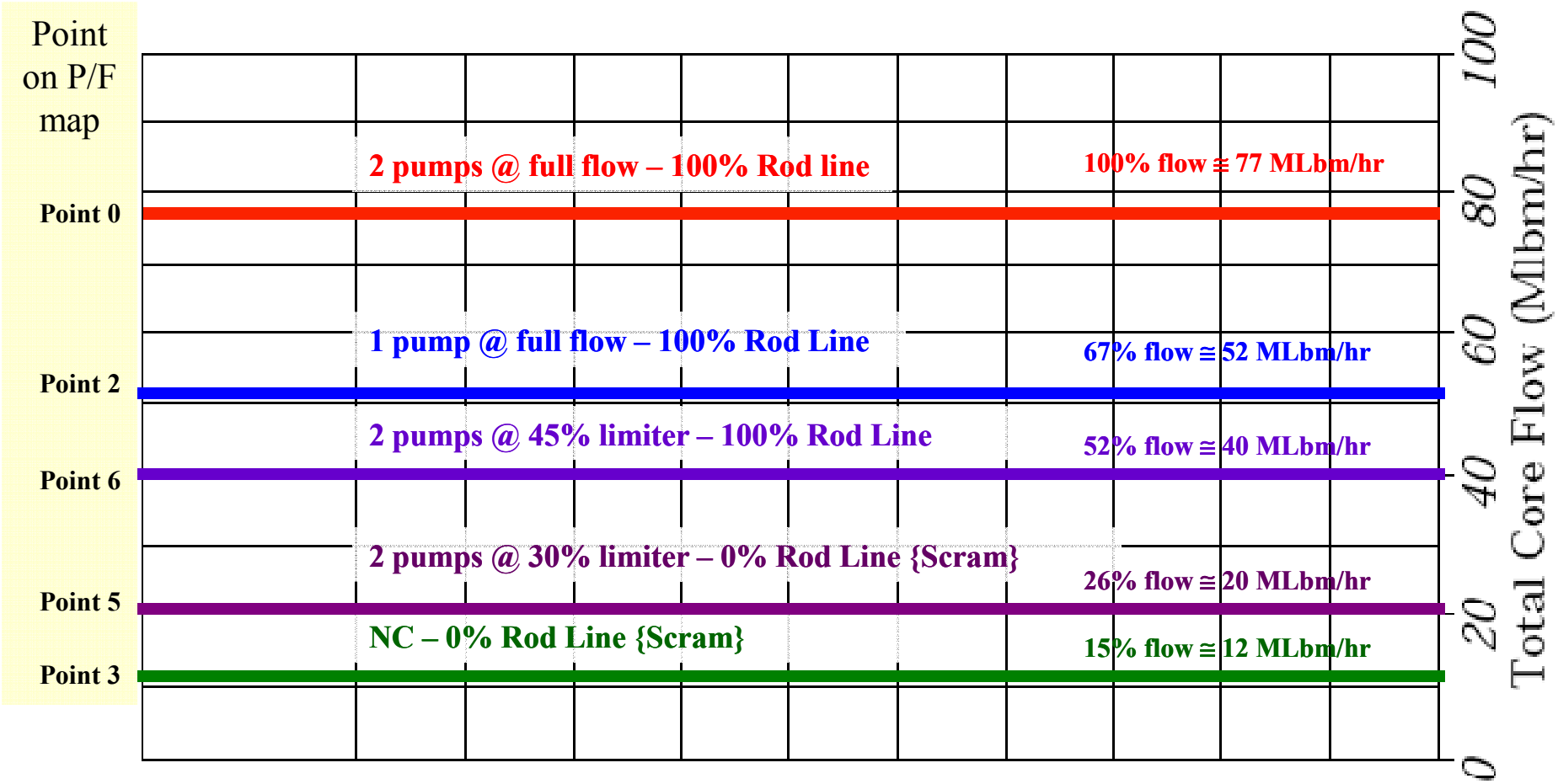
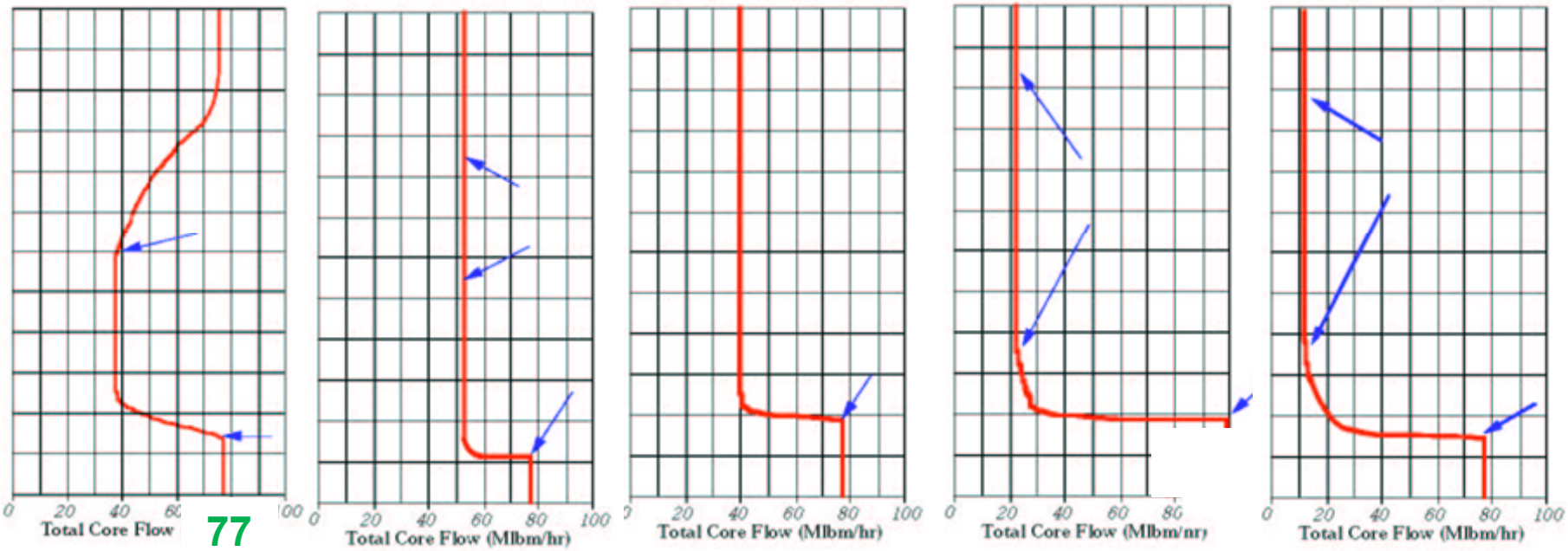


Chart is in MLBm/Hr

Comparison of recirculation pump operating conditions



Total Core Flow



77

Intentional - Gradual change, can end up at any flow

Single Pump Trip

52

Operational Limiter

40

Minimum Speed Limiter

20

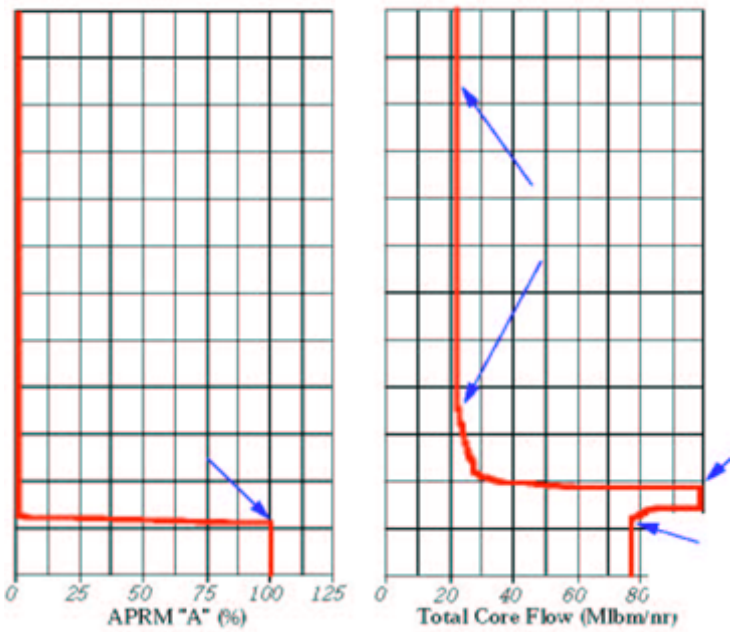
Dual Pump Trip

12

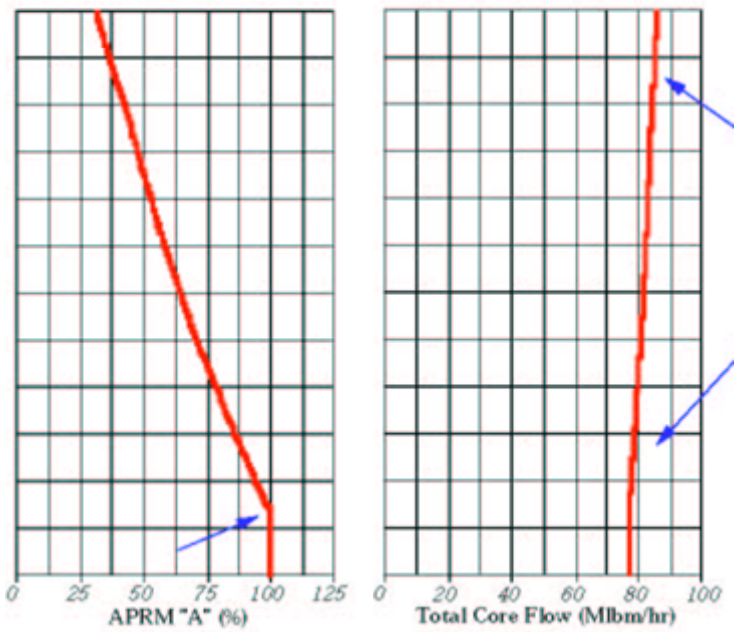
Total Core Flow

<u>Core Flow Change from Change in Flow Resistance</u>:

– Power reduction, (especially scram), reduces (collapses) voids, lowering 2-phase flow resistance, increases core flow at same recirc pump speed



Power Flow



Power Flow

Reactor Pressure

- Normally Pressure follows power, controlled by EHC:

  Power ↑, Voids ↑ , Steam production > removal, Pressure ↑, EHC opens CVs to match turbine load

  Power ↓, Voids ↓, Steam production < removal, Pressure ↓, EHC closes CVs to match turbine load

- Transients can directly impact pressure:

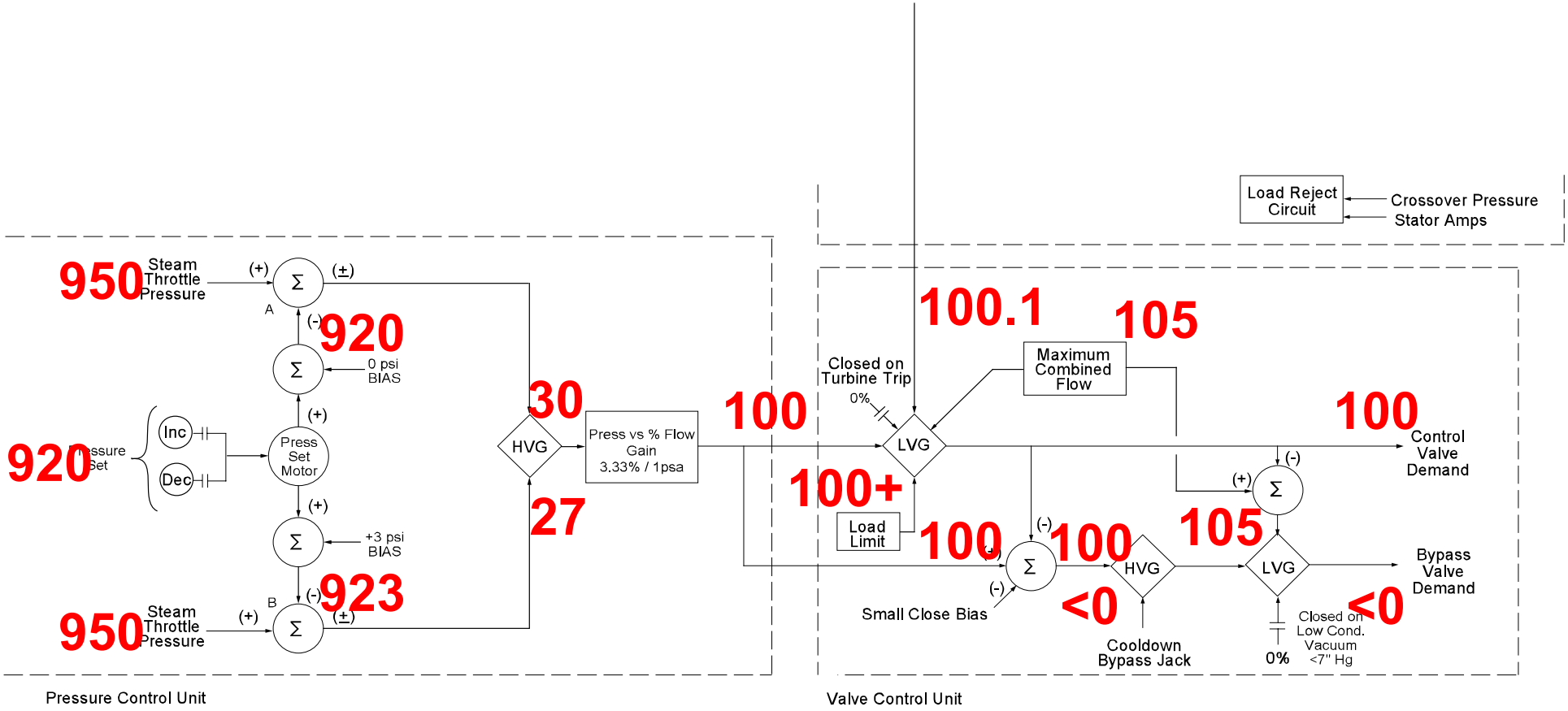
  <u>High pressure</u>: MSIV Closure, Turbine Trip

  <u>Lower</u>: SRV open, ADS

- EHC Pressure Controller Failure:

  Fails low, BU Controller picks up (slight increase)

  Fails high, steam flow exceeds production, pressure goes down.



Pressure

Valve positioning

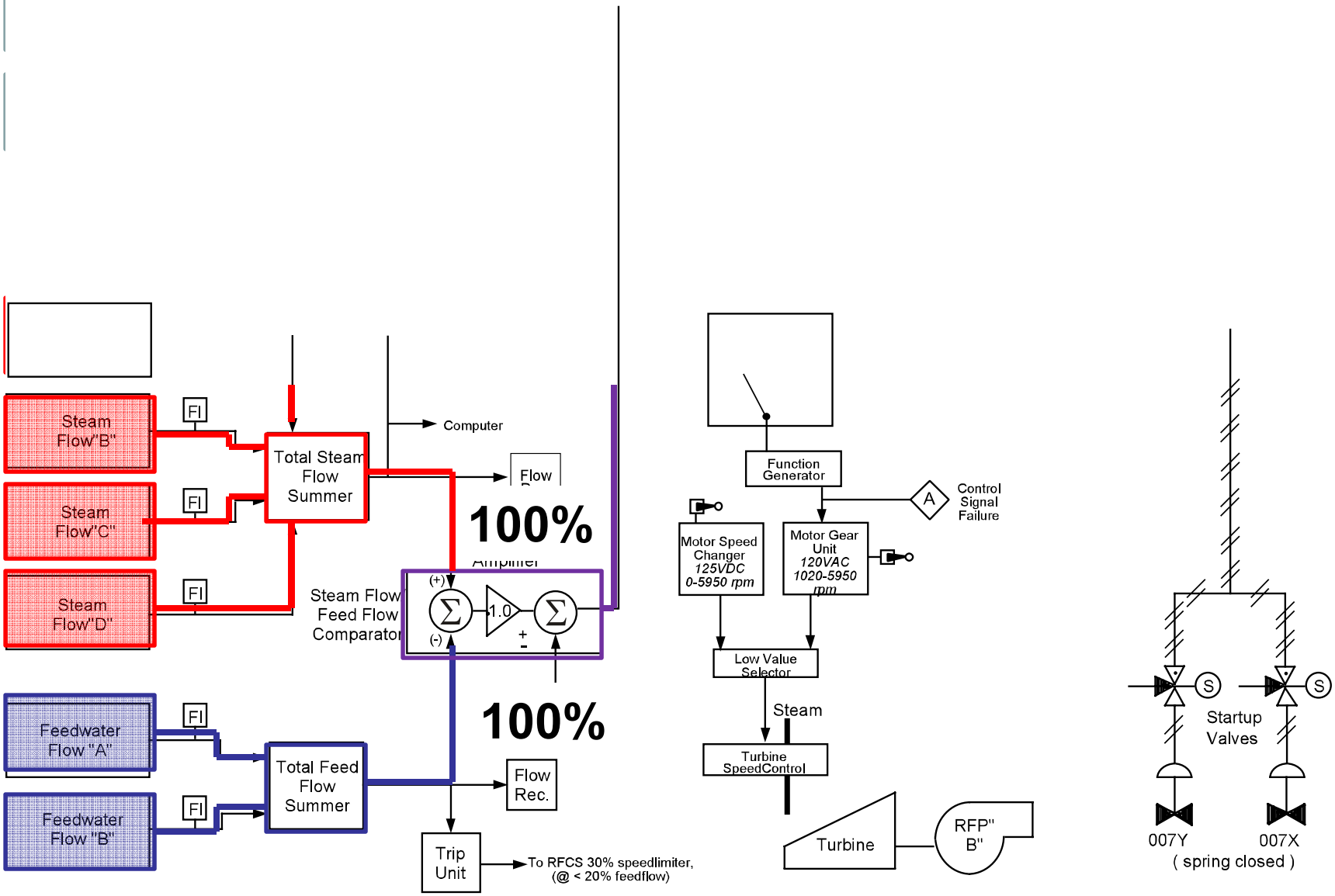
Vessel Level

Normal Operation:

- Normally level controlled by FWLC based on Feed Flow (FF), Steam Flow (SF) and Level

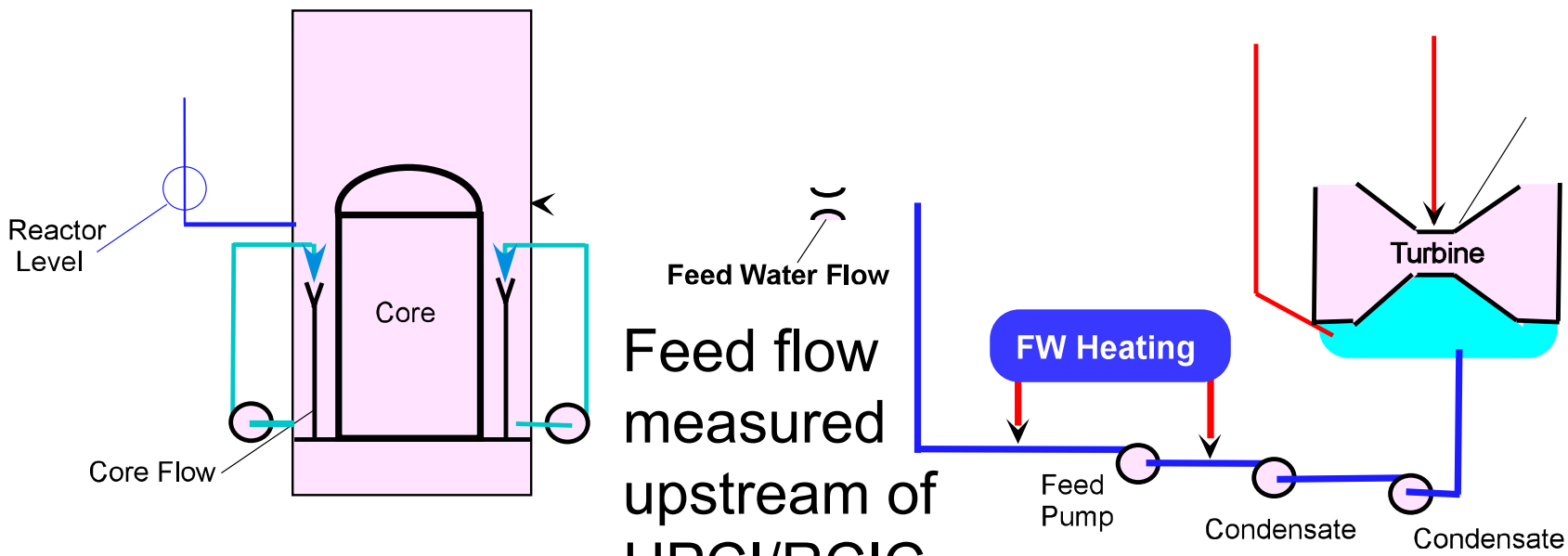
  Steam Demand (SF) ↑, Level lowers, FWLC increases Feed Flow (level and SF/FF mismatch), Level restored

  Steam Demand (SF) ↓, Level rises, FWLC decreases Feed Flow (level and SF/FF mismatch), Level restored


Steam Flow"B"
Steam Flow"C"
Steam Flow"D"
FI
Total Steam Flow Summer
Computer
Flow
100%
Steam Flow Feed Flow Comparator
(+)
(-)
1.0
+
-
Feedwater Flow "A"
Feedwater Flow "B"
Total Feed Flow Summer
Flow Rec.
Trip Unit
To RFCS 30% speedlimiter, (@ < 20% feedflow)
Function Generator
A
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"
S
Startup Valves
007Y
007X
(spring closed)

FWLC impacted by where

Steam flow measured downstream of SRVs



Feed flow measured upstream of HPCI/RCIC

If final stable level is higher or lower than initial:

- FWLC instrument failure,
- SRV is open or
- HPCI/RCIC initiated

Vessel Level

<u>Initial Level change greatly impacted by change in VOIDS</u>

WR and NR level are measured in the annulus.

The weight of the water in the annulus adds to the total driving head for flow.

When resistance to flow increases, level will have to increase for the same flow.

Initial Level changes during transients are based on the amount of **voiding** in the core (the amount of head loss or resistance to flow)

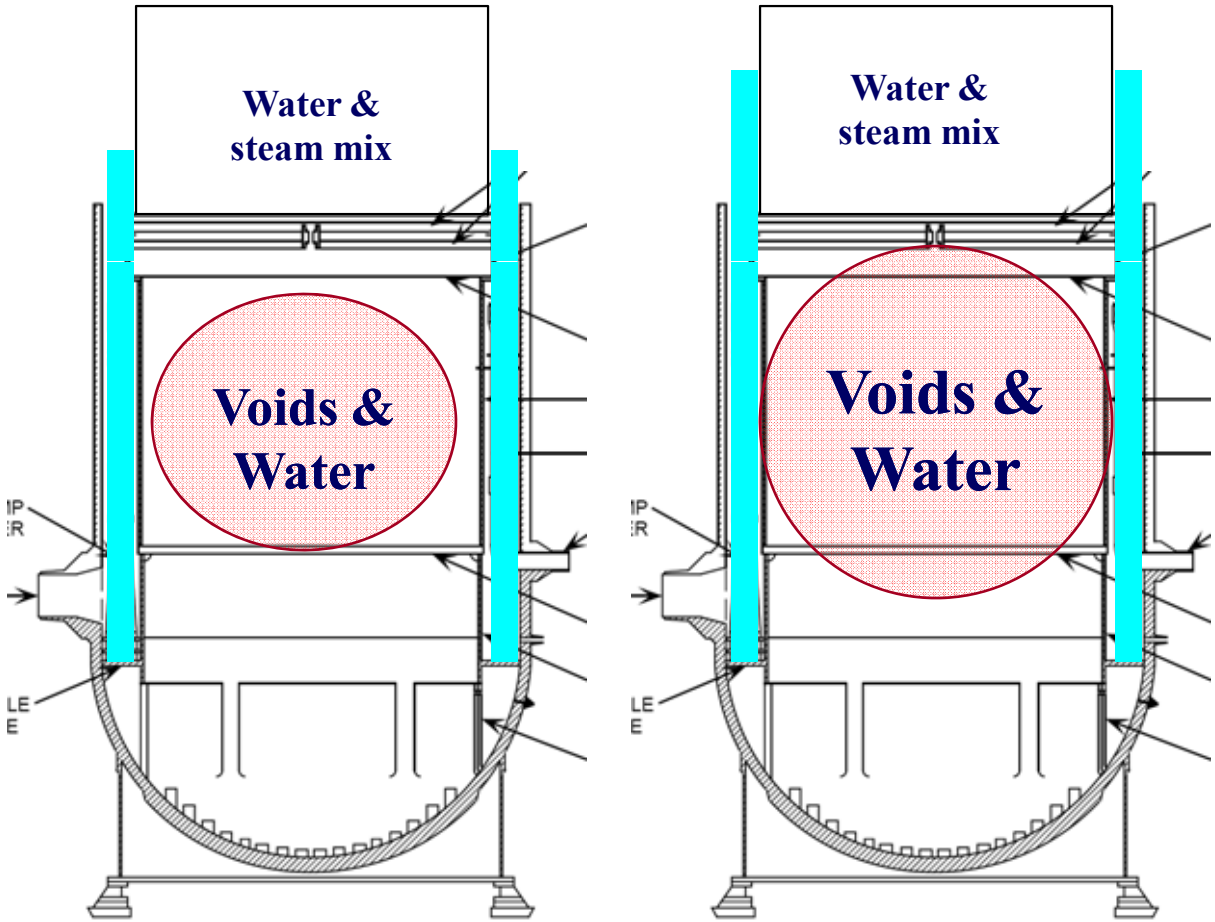
Voids ↑, Resistance to flow ↑, Level ↑

Voids ↓, Resistance to flow ↓, Level ↓

NR and WR level are measured in the annulus.

Voids go up, “forces water out of shroud into annulus”, level goes up

Voids go down, “water rushes in from the annulus to fill the space”, level goes down



Vessel Level Changes vs Void Changes

Scram: Voids collapse, Level goes down

Recirc Flow (until RX catches up):

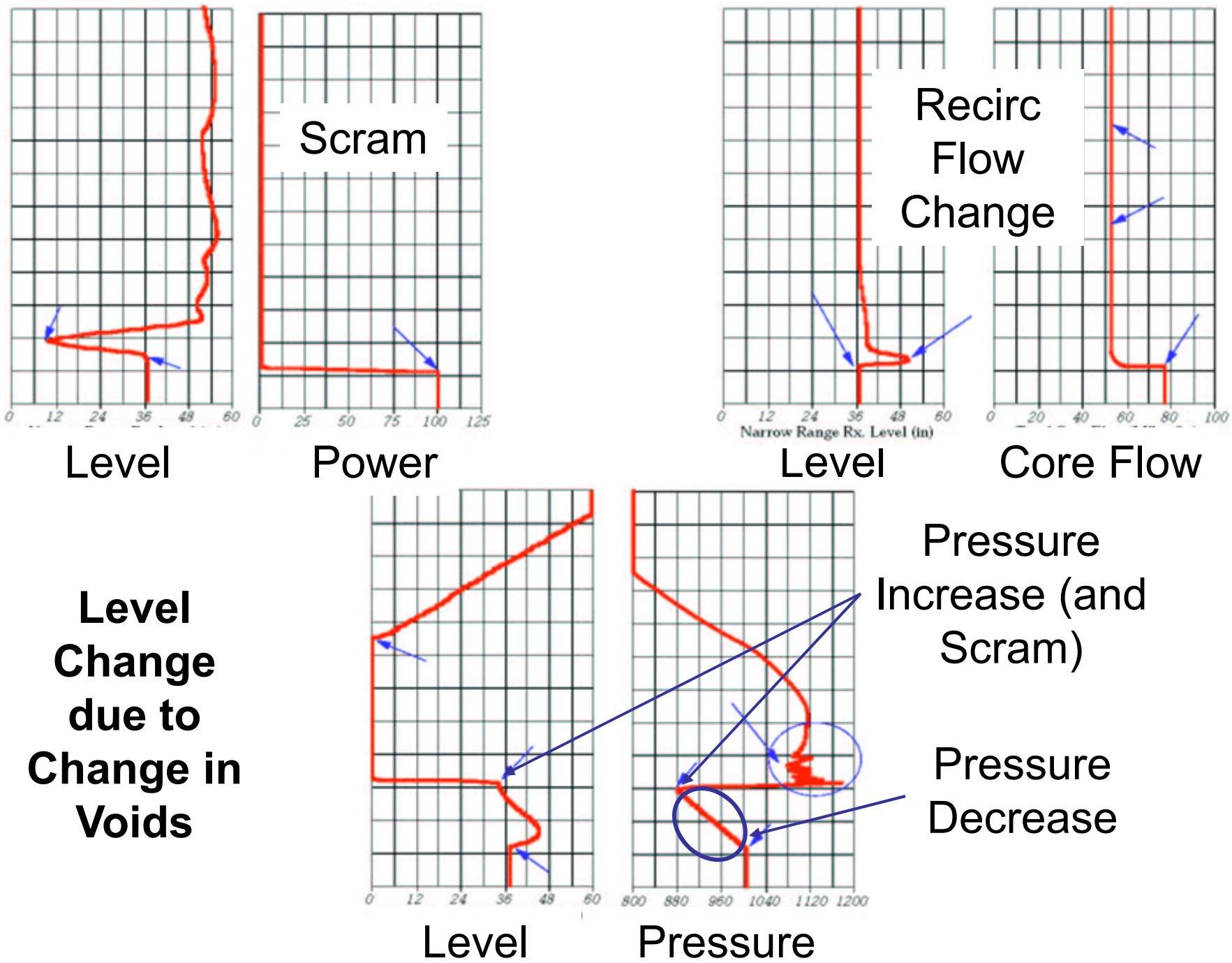
Recirc Flow (Core Flow) ↑, draw more from annulus and water has less contact time with fuel, less voids (initially), both cause level to go down

Recirc Flow (Core Flow) ↓, draw less water from annulus and water has more contact time with fuel, more voids (initially), both cause level to go up

Pressure :

Increase: Voids collapse, Level goes down

Drop: Voids get bigger, Level goes up


Scram
Recirc
Flow
Change
Narrow Range Rx. Level (in)
Level
Power
Level
Core Flow
Level Change due to Change in Voids
Pressure Increase (and Scram)
Pressure Decrease
Level
Pressure

Vessel Level

When analyzing level response:

- Greatly impacted by changes in voids (Scram, MSIV closure, turbine trip, Recirc pump trip, etc..) both initially and during the transient (effects often compete).
- Then FWLC should respond to restore level to program

  Feed and steam rate and level deviation from setpoint

  - If final level stable and offset, look for HPCI/SRV

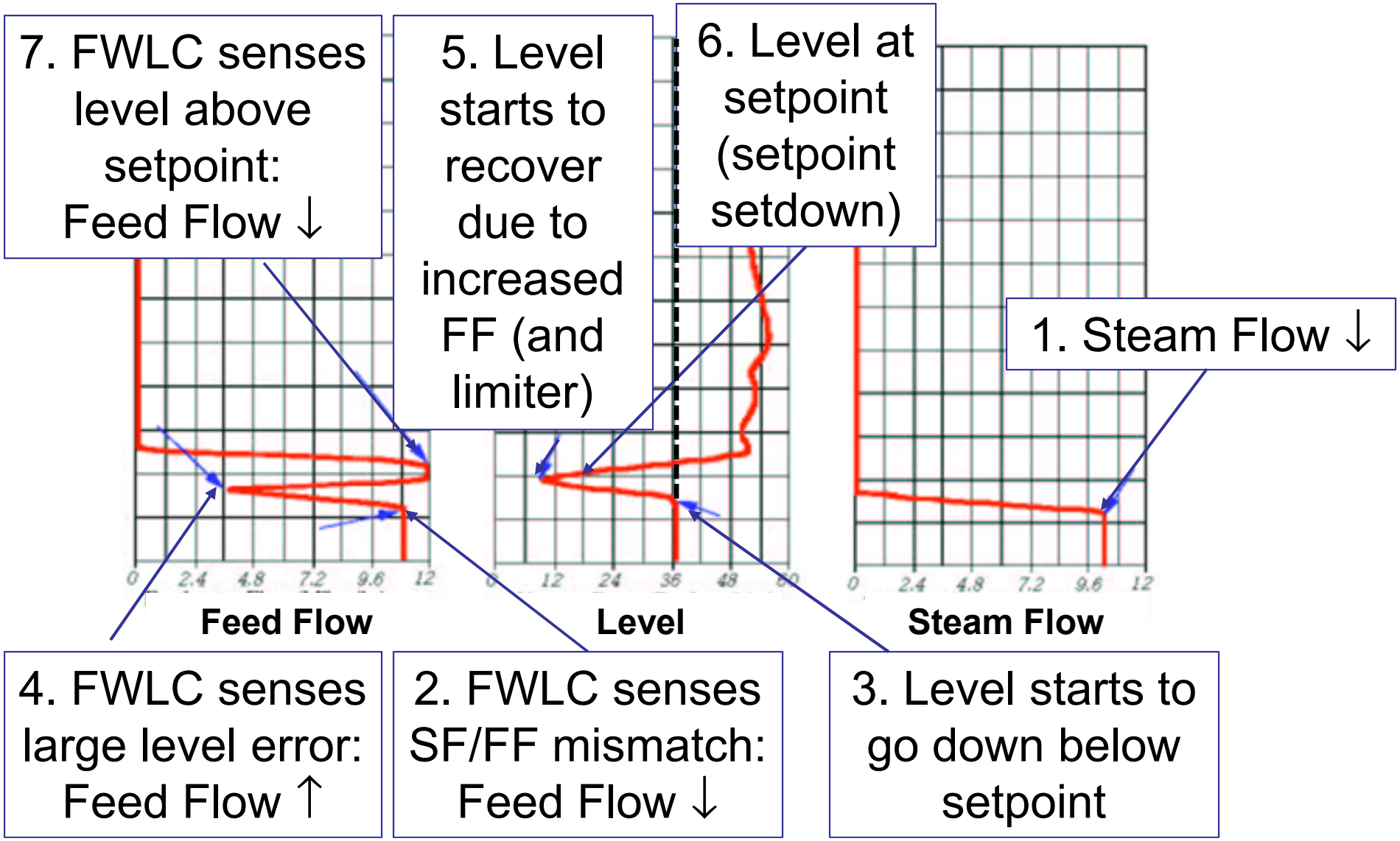
Other injection sources later:

- CRD
- HPCI/RCIC if Level 2
- CBP if pressure < 600#

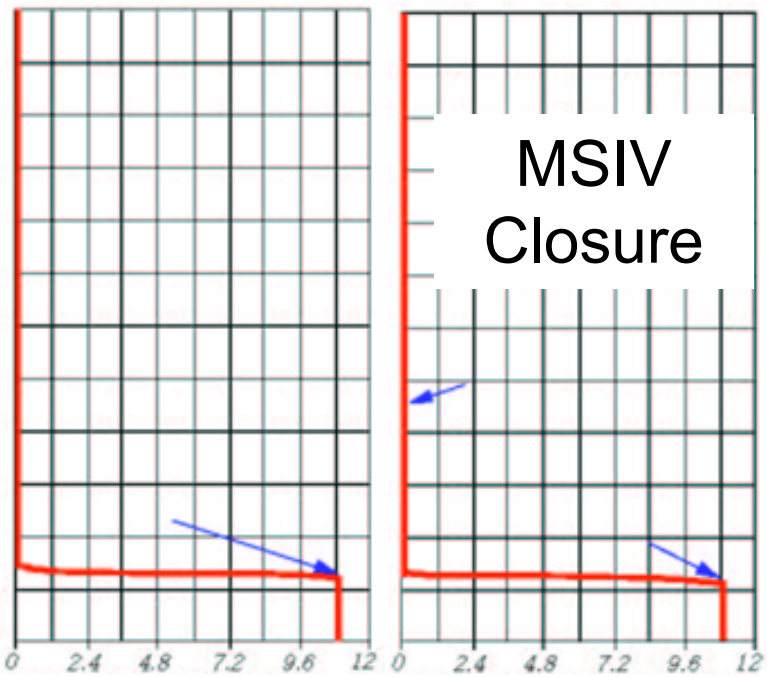
Feed Flow

- Normally level controlled by FWLC based on Feed Flow (FF), Steam Flow (SF) and Level

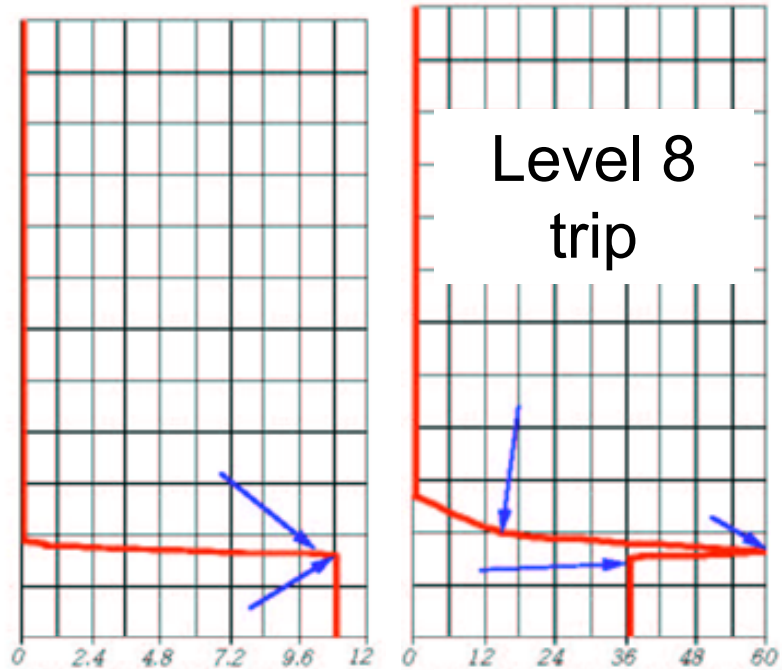
  Steam Demand (SF) ↑, Level lowers, FWLC increases Feed Flow (level and SF/FF mismatch), Level restored
- Feed Pump Trips (Feed Flow goes to zero):
  - Level 8
  - Low Vacuum (20”)
  - No steam (MSIV closure)
- FWCS won’t see HPCI flow, FF will decrease as level ↑
- Late: Will see CBP flow if pressure low enough (600#)



Feed Flow change based on FWLC



Feed Flow Rx Stm Flow



Feed Flow Level

Feed Pump Trips

Turbine Steam Flow

- Controlled by EHC from <u>steam line</u> pressure:

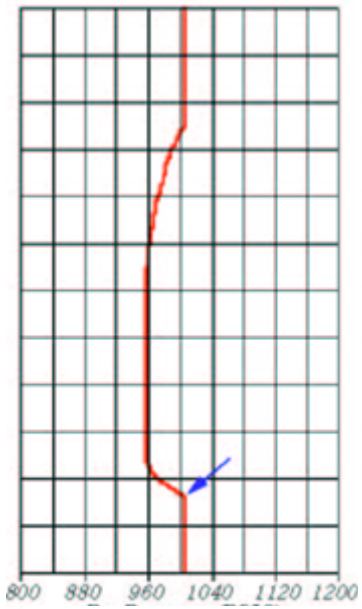
  Pressure ↑, EHC opens CVs, Turb Stm Flow ↑

  Pressure ↓, EHC closes CVs, Turb Stm Flow ↓
- Scram: Rapidly goes to zero as pressure drops
- Turbine Trip: Immediately goes to zero
- ADS, HPCI or SRV will lower sensed pressure – Flow ↓
- BPV fails open: CVs close to maintain pressure
- EHC Pressure Controller Failure:

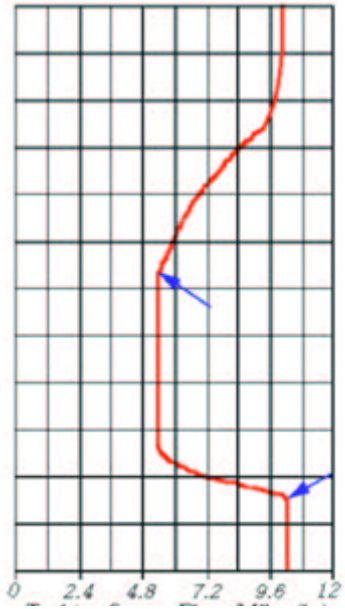
  Fails low, BU Controller picks up (init. lower flow)

  Fails high, EHC calls for 105%, BPV open /CVs full open

Turbine Steam Flow

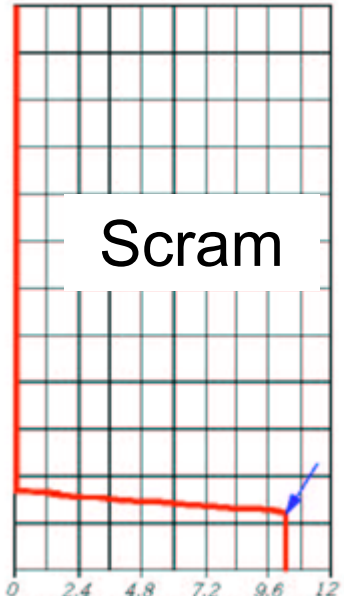


Pressure

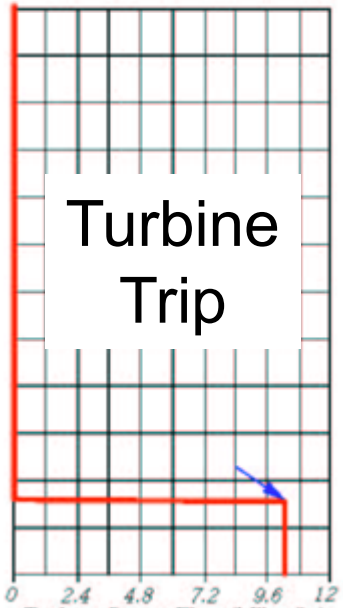


Turb Stm Flow

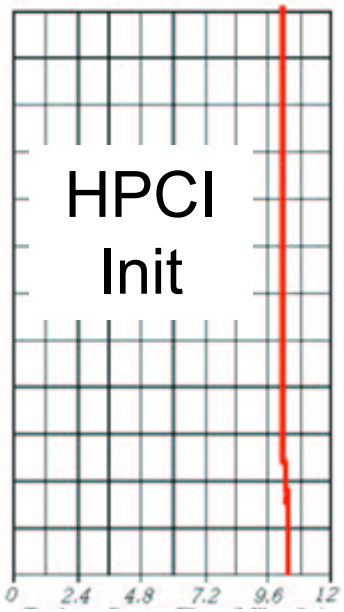
<u>Normal Operation</u>: EHC senses pressure and adjusts CV position to match turbine load with Rx power



Turb Stm Flow



Turb Stm Flow



Turb Stm Flow

Reactor Steam Flow

Turbine Steam Flow + BPV + House Loads

Follows Turb Stm Flow as controlled by EHC

Will <u>only</u> go to Zero post-trip if MSIVs close

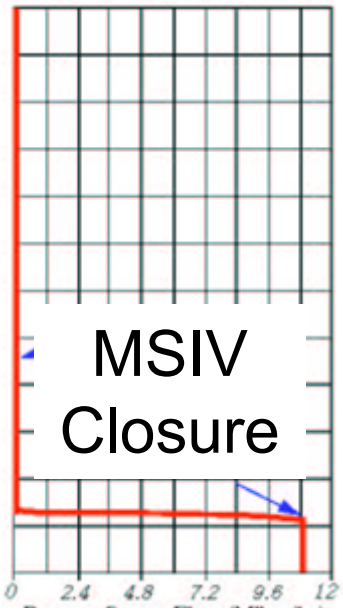
Post-trip: house loads and BPV (920#)

EHC Pressure Controller Failure:

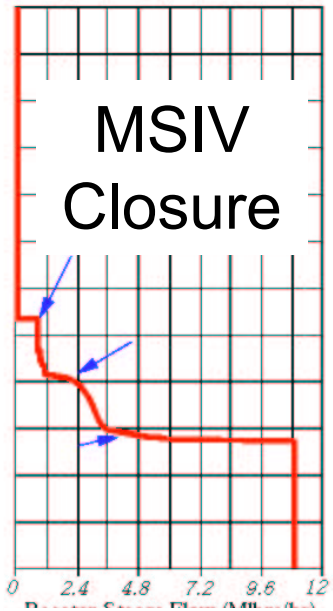
- Fails low, BU Controller picks up (follows turbine)
- Fails high, inc. as EHC calls for 105% and BPV open

Reactor Steam Flow

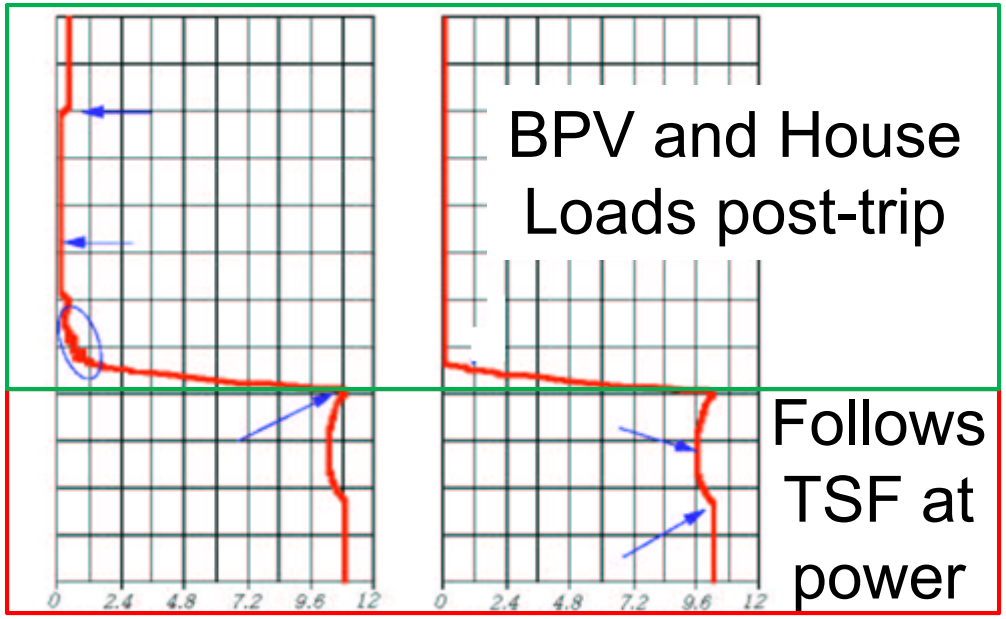
Turbine Steam Flow
+
Bypass Valves
+
House Loads



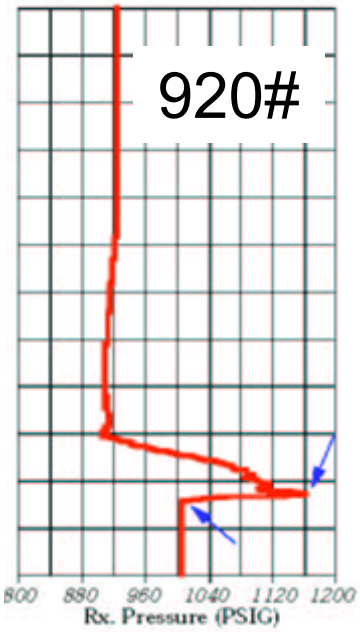
Rx Stm Flow



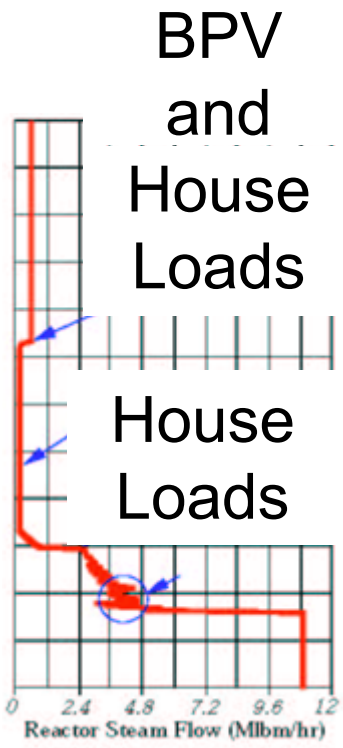
Rx Stm Flow



Rx Stm Flow **Turb Stm Flow**



Pressure



Rx Stm Flow

Fundamental Rules

1. Do NOT try and identify the initiating event first!!!!
2. Start with the parameter you know the best.
3. Stay in the same time frame (i.e. do not continue on the same parameter trying to identify all the points prior to going to the next parameter).
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.

Fundamental Rules

6. If you are not sure, continue down the list.
7. Go to the next parameter that is affected by or cause of the one you have chosen (i.e. power effects pressure, pressure effects steam flow).
8. If you have done everything correctly you will end up with the initiating event.
9. Move to the next time frame and continue the process until all of the points are identified.
10. Test to see if all points agree with the initiating event.

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

Power:

- Rods (Scram)
- Recirc Flow
- SLC
- FW Temperature (Steady state change in FF, HPCI, FW HTR)
- Short term: Pressure and Fuel Time Constant

If scram: What could cause it?

- Manual or other (Hi DW Press, Hi Flux, SDV, MS Line Hi Rad)
- Turbine Trip (manual, Hi Level 56.5”, Lo Vac 22.5”, other)
- Low Level (12.5”)
- Hi Pressure (1043#)
- MSIV Closure (manual, Low pressure 825#, Lo Vacuum 8.5”)

No scram: Check Recirc flow, Feedwater heating effects, Pressure effects

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

<u>Pressure</u>:

- Normally follows power controlled by EHC
- Hi pressure events:
  - Turbine Trip,
  - MSIV Closure
- Low Pressure events:
  - SRV/ADS
- EHC Pressure controller
  - Fails low: slight increase in pressure
  - Fails high: pressure drops
- Later: HPCI can lower pressure if Level 2

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

<u>Flow:</u>

- Recirc Pump speed change/trip:
  - Intentional (gradual)
  - Single Pump trip (52 Mlbm/hr)
  - Operational Limiter (40 Mlbs/hr) [Loss of RFP, <L4]
  - Minimum Speed Limiter (20 Mlbm/hr) [20% FF, L3]
  - Dual Pump Trip (12 Mlbm/hr) [ATWS: 1120#, L2, EOC:TT]
- Change in Flow Resistance (voids w/ no speed change):
  - Scram, Voids collapse, flow goes up
  - Power decrease (w/o recirc speed change – Rods or SLC), flow goes up

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

<u>Level:</u>

- Level decrease (**decrease in voids**):
  - Scram
  - Pressure Increase
- Level increase (**increase in voids**):
  - Press drop
  - Recirc Pump Limiter or Trip
- Should respond to FWLC (Level and/or SF/FF Mismatch)
- Later injection sources:
  - CRD
  - HPCI/RCIC if Level 2
  - CBP if low pressure

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

<u>Feed Flow:</u>

- Normally should respond to FWLC (level change and/or steam flow change)
- Feed Pump trips:
  - Level 8
  - Low Vacuum
  - MSIV Closure
- Decrease with HPCI injection at power
- Later: Will show CBP flow if pressure low enough (600#)

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

Turbine Steam Flow:

- Controlled by EHC based on Pressure sensed at MS Line:
  - Will drop on SRV or HPCI
  - EHC will close CVs on BPV open
- Immediately to zero with turbine trip
- Rapidly to zero on Scram

Reactor Steam Flow:

- Turbine steam flow + BPV + House Loads:
  - At power: Follows Turbine steam flow
  - Shutdown: house loads + BPVs to control pressure at 920#
- Only goes to Zero on MSIV closure (manual, 825# or Lo Vac 8.5”)

One Approach (Use what works for you)

Start with Power

1. **Immediate trip (any parameter change before the trip)?**
   a) **Power/Pressure spike?**
   b) **Turbine trip or MSIV closure?**
   c) **If TT, did MSIVs close later in the event (vacuum)?**
2. **Subsequent trip**
   a) **What caused trip (Lo lvl, Hi press, Lo press[MSIV], Hi lvl [TT])?**
   b) **If high level, did pressure recover?**
3. **Continuous decrease in power:**
4. **Power changed but stable**
   a) **Recirc flow change gradual?**
   b) **Due to change in Recirc flow (Operational limiter or single recirc pump)**
   c) **No change in Recirc Flow: Feedwater temp (HPCI or loss of FW Heating)**
5. **No change in <u>final</u> power – look at pressure impact on power**
   a) **Reactor Pressure increase (EHC fails low)**
   b) **Reactor Pressure drop (SRV or BPV)**

Go to Initiating parameter and identify all parameter changes at that time.

Use your “list” for each parameter to explain changes

Go to next subsequent (higher) parameter change (arrow)

Major changes (Recirc pump trip, MSIV Closure) will effect multiple parameters