Control Systems of NPP_1

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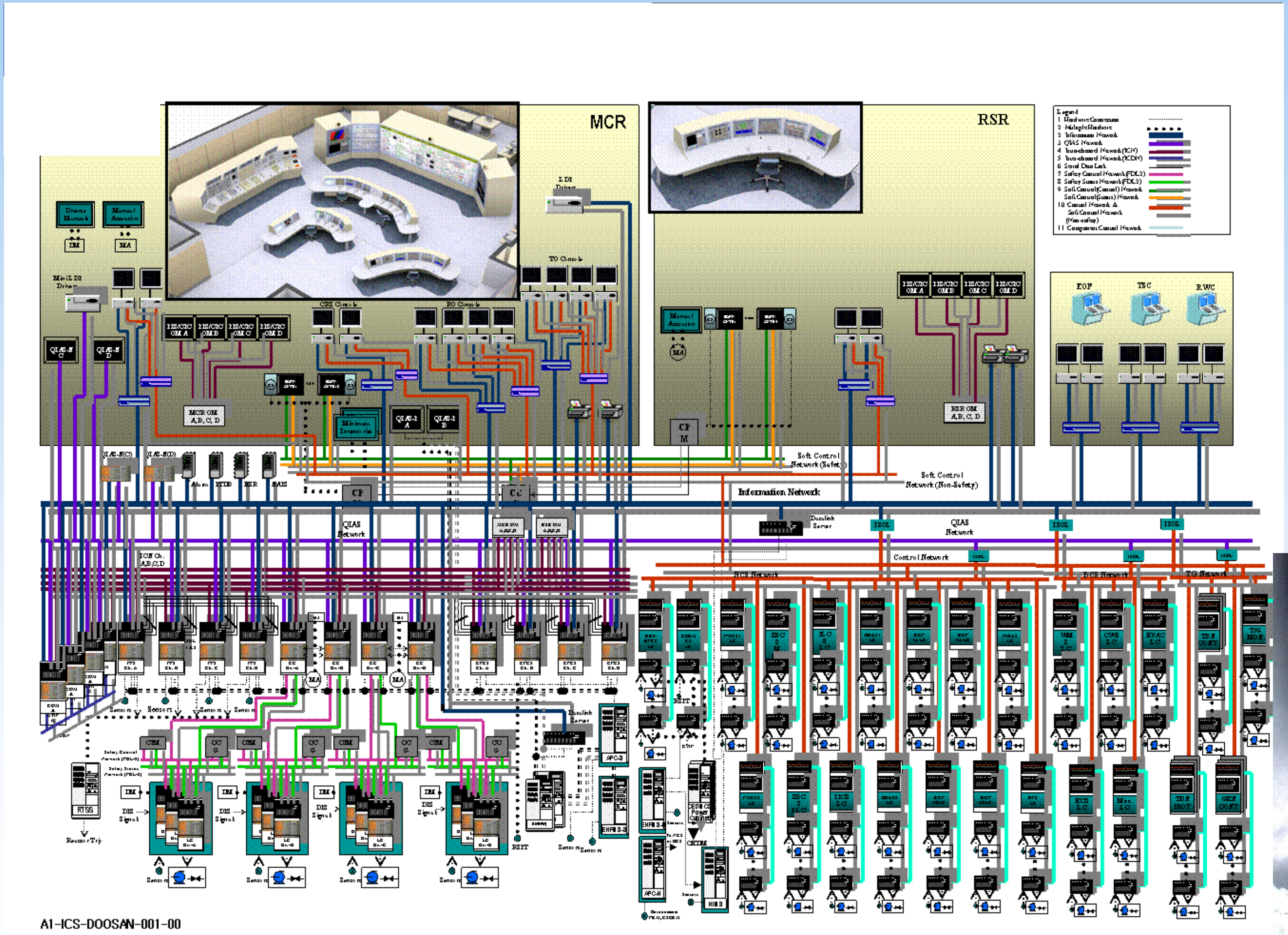
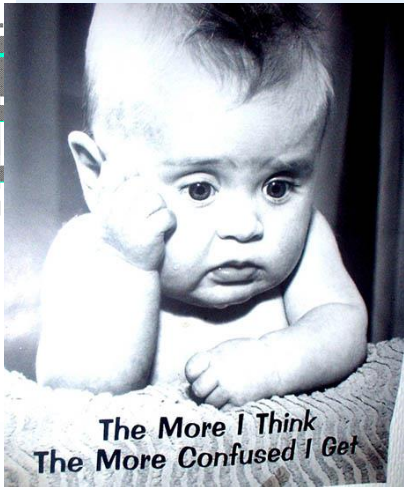
Name : Booh, In Hyoung
E-mail : k307bih@kins.re.kr

한국원자력안전기술원
KOREA INSTITUTE OF NUCLEAR SAFETY

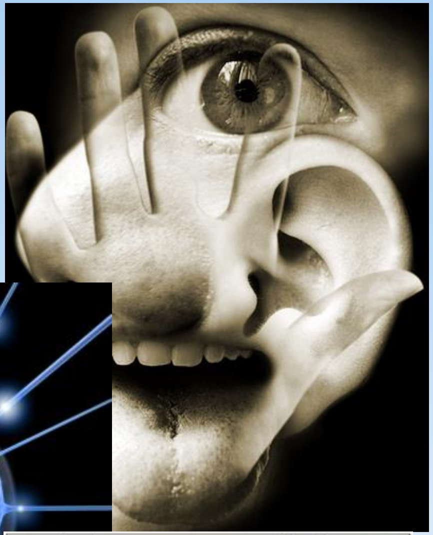
What is "Instrumentation and Control systems" in NPPs?





What is “I&C systems” in NPPs?

- Sensing / Monitoring

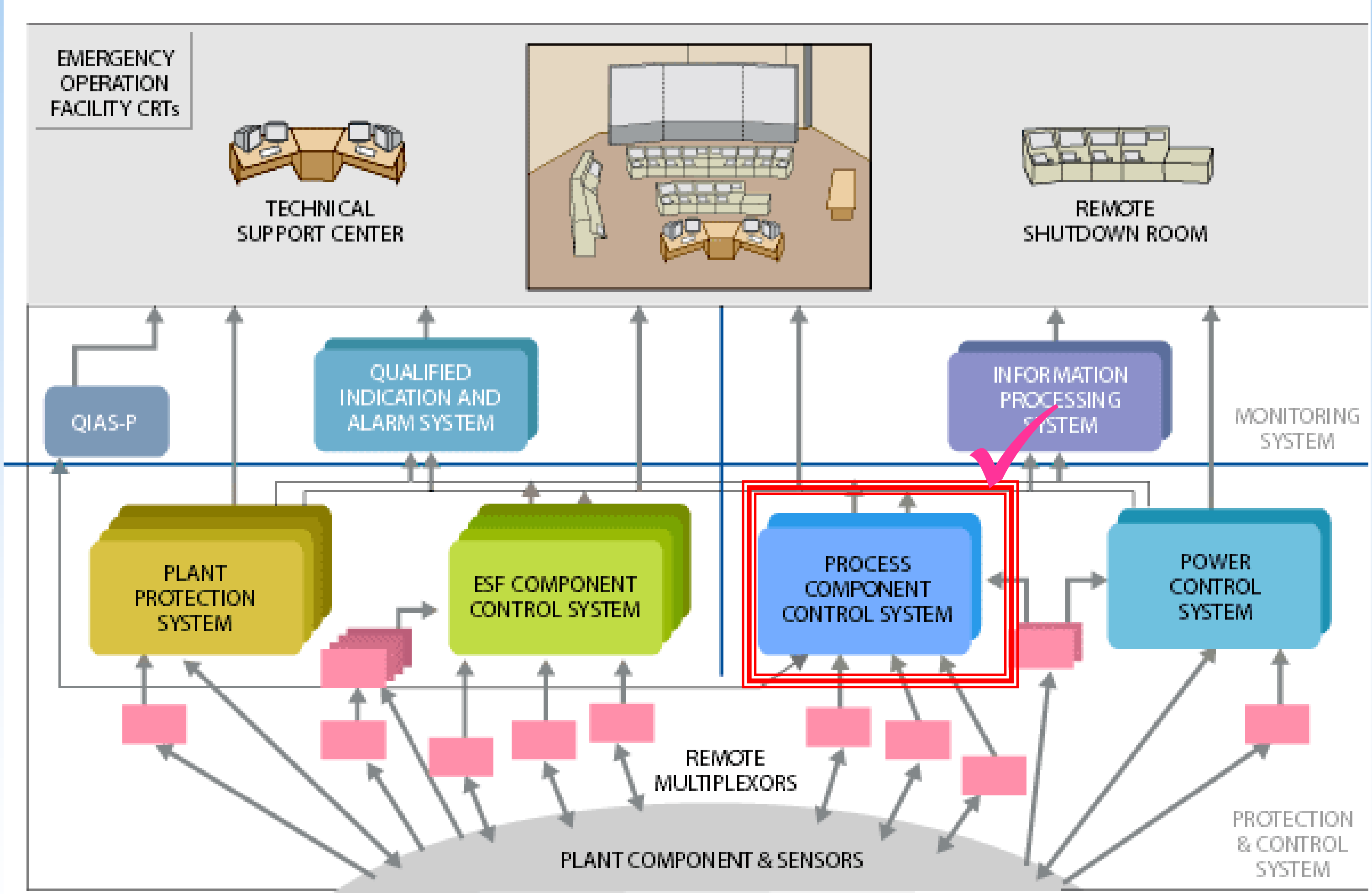


- Determining

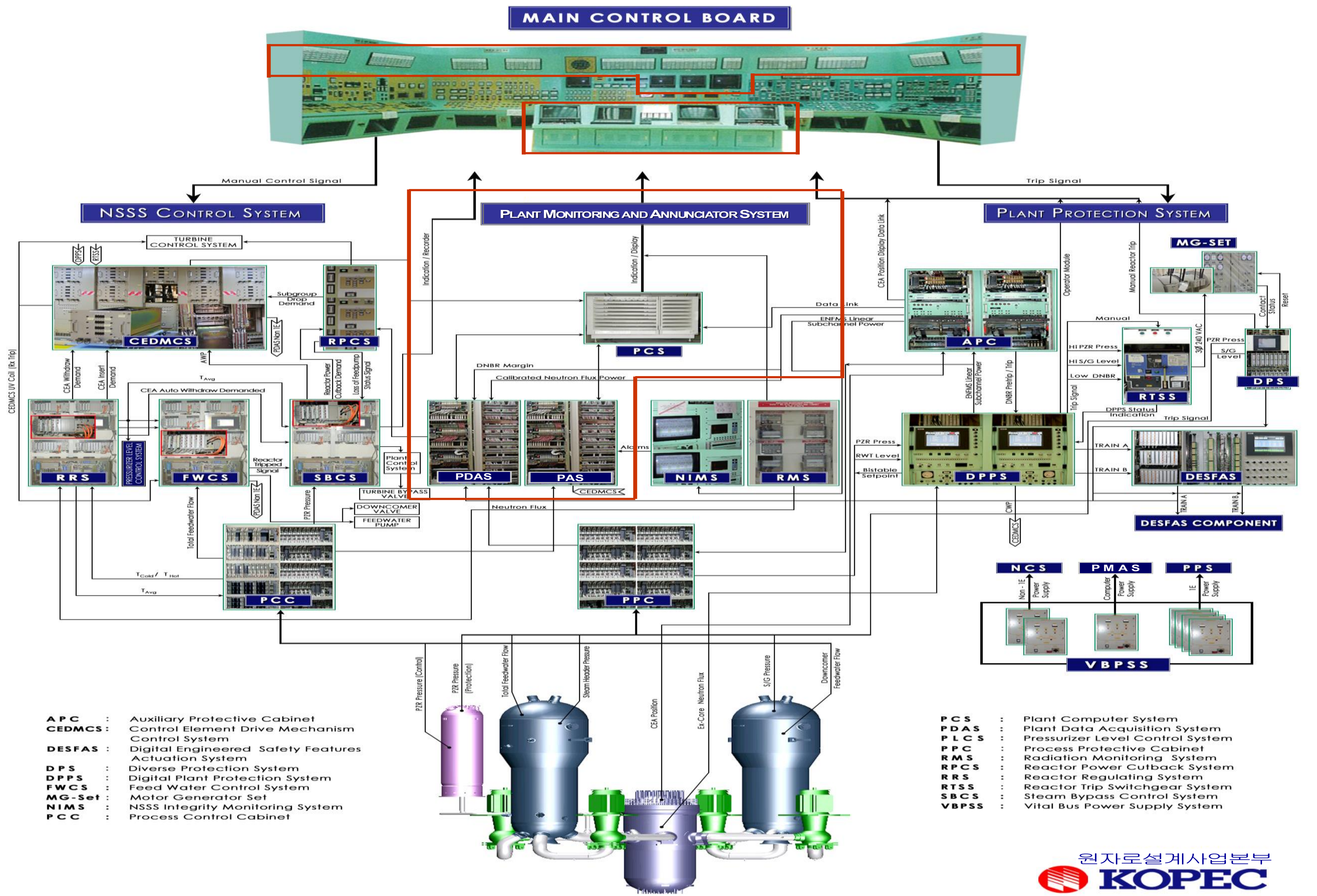
- Controlling to meet required function

This session will cover;

□ Plant Control Systems



NSSS I&C OVERVIEW DIAGRAM FOR SKN 1&2



APC	:	Auxiliary Protective Cabinet
CEDMCS	:	Control Element Drive Mechanism Control System
DESFAS	:	Digital Engineered Safety Features Actuation System
DPS	:	Diverse Protection System
DPPS	:	Digital Plant Protection System
FWCS	:	Feed Water Control System
MG-Set	:	Motor Generator Set
NIMS	:	NSSS Integrity Monitoring System
PCC	:	Process Control Cabinet

PCS	:	Plant Computer System
PDAS	:	Plant Data Acquisition System
PLCS	:	Pressurizer Level Control System
PPC	:	Process Protective Cabinet
RMS	:	Radiation Monitoring System
RPCS	:	Reactor Power Cutback System
RRS	:	Reactor Regulating System
RTSS	:	Reactor Trip Switchgear System
SBCS	:	Steam Bypass Control System
VBPSS	:	Vital Bus Power Supply System

원자로설계사업본부
KOPEC

Agenda – we will have 5 hours to deal with;

- Fundamentals of I&C Systems
- Overview of Plant Control Systems
- Control Systems Design and Requirements;
  - NSSS Control Systems
    - Reactor Regulating System
    - Steam Bypass Control System
    - Feedwater Control System
  - Pressurizer Pressure Control System
  - Pressurizer Level Control System
- Acceptance Criteria for Plant Control Systems

cf.) NSSS : Nuclear Steam Supply System

- **Fundamentals of I&C Systems**

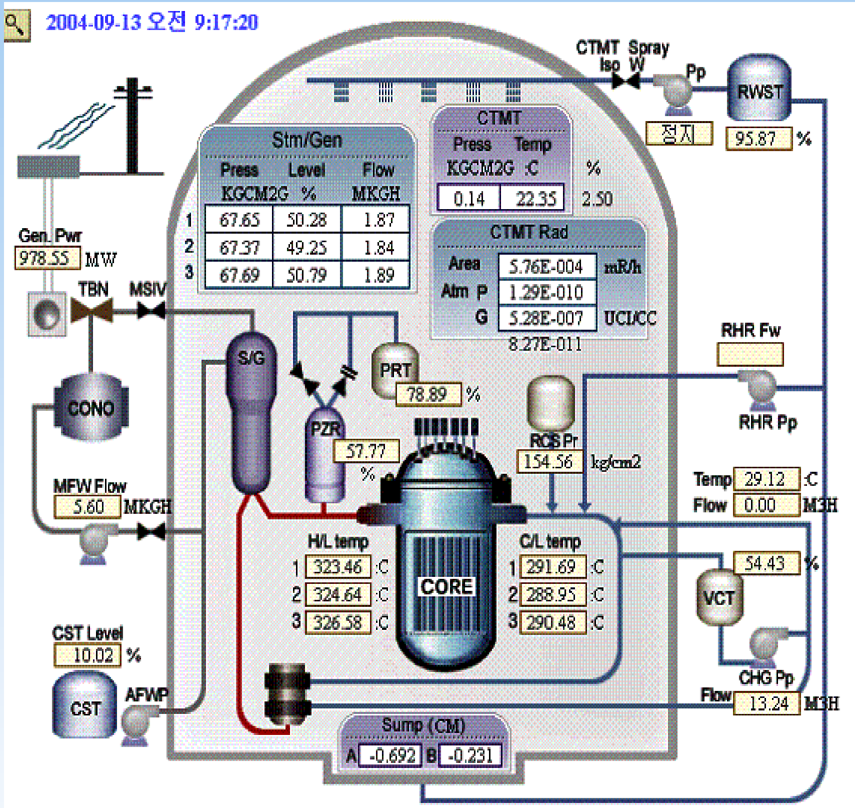
- Overview of Plant Control Systems

- Control Systems Design and Requirements;
  - NSSS Control Systems
  - Pressurizer Pressure Control System
  - Pressurizer Level Control System

- IAEA Safety Standard for Plant Control Systems

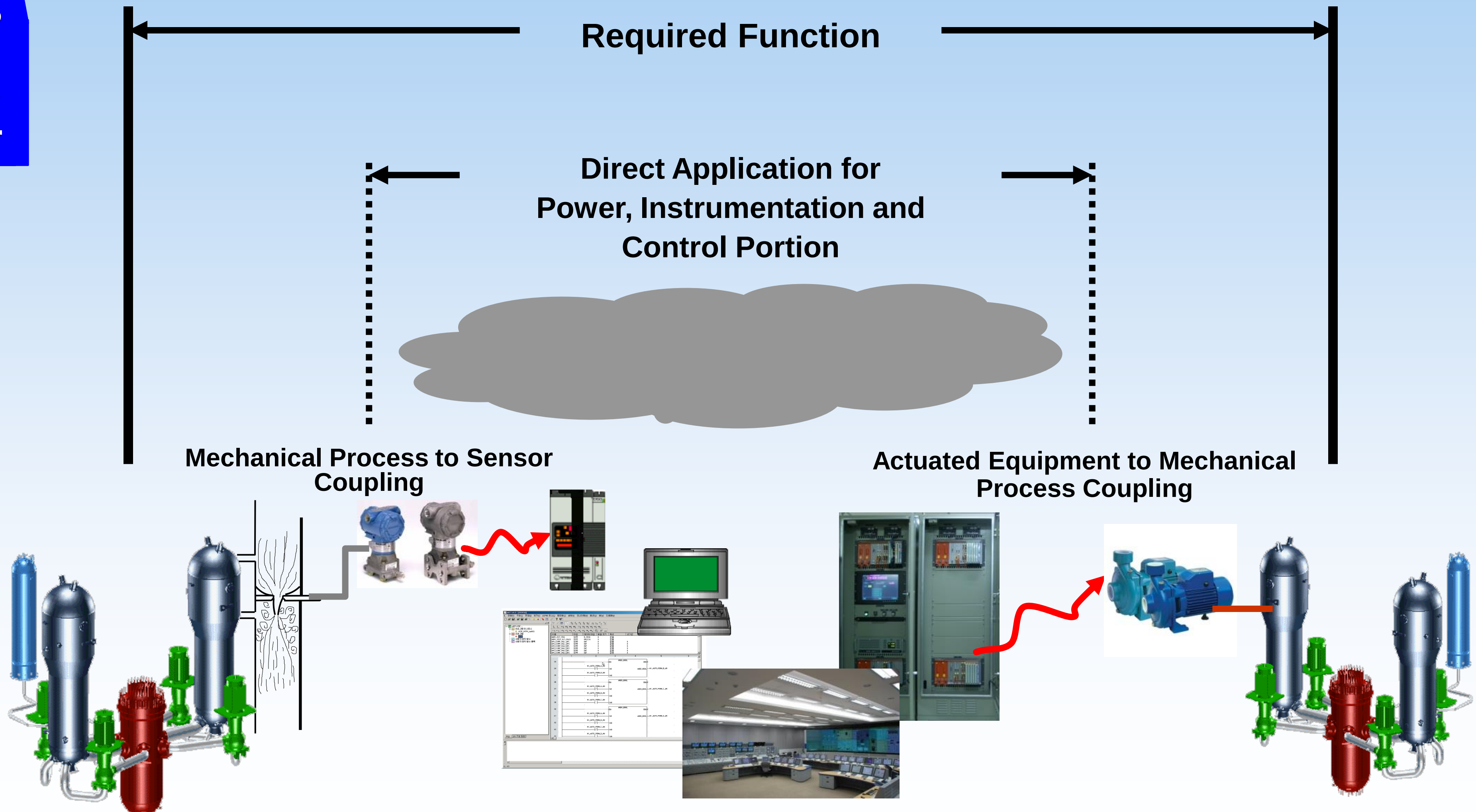
Fundamentals of I&C Systems

- What is "I&C systems" in NPPs?
  - Monitoring the plant parameters
    - Neutron, Temperature, Pressure, Level, Flow, etc.
  - Determining those within design basis
    - Based on DBA
    - Based on operational requirements
  - Protecting the plants in case of abnormal condition or accident
    - Plant Protection Systems
    - Engineered Safety Feature Actuation Systems
    - Diverse Protection Systems, etc.
  - Controlling the components to meet those required function for normal operation
    - Pumps, Valves, etc.
    - NSSS control
    - Turbine control



Fundamentals of I&C Systems

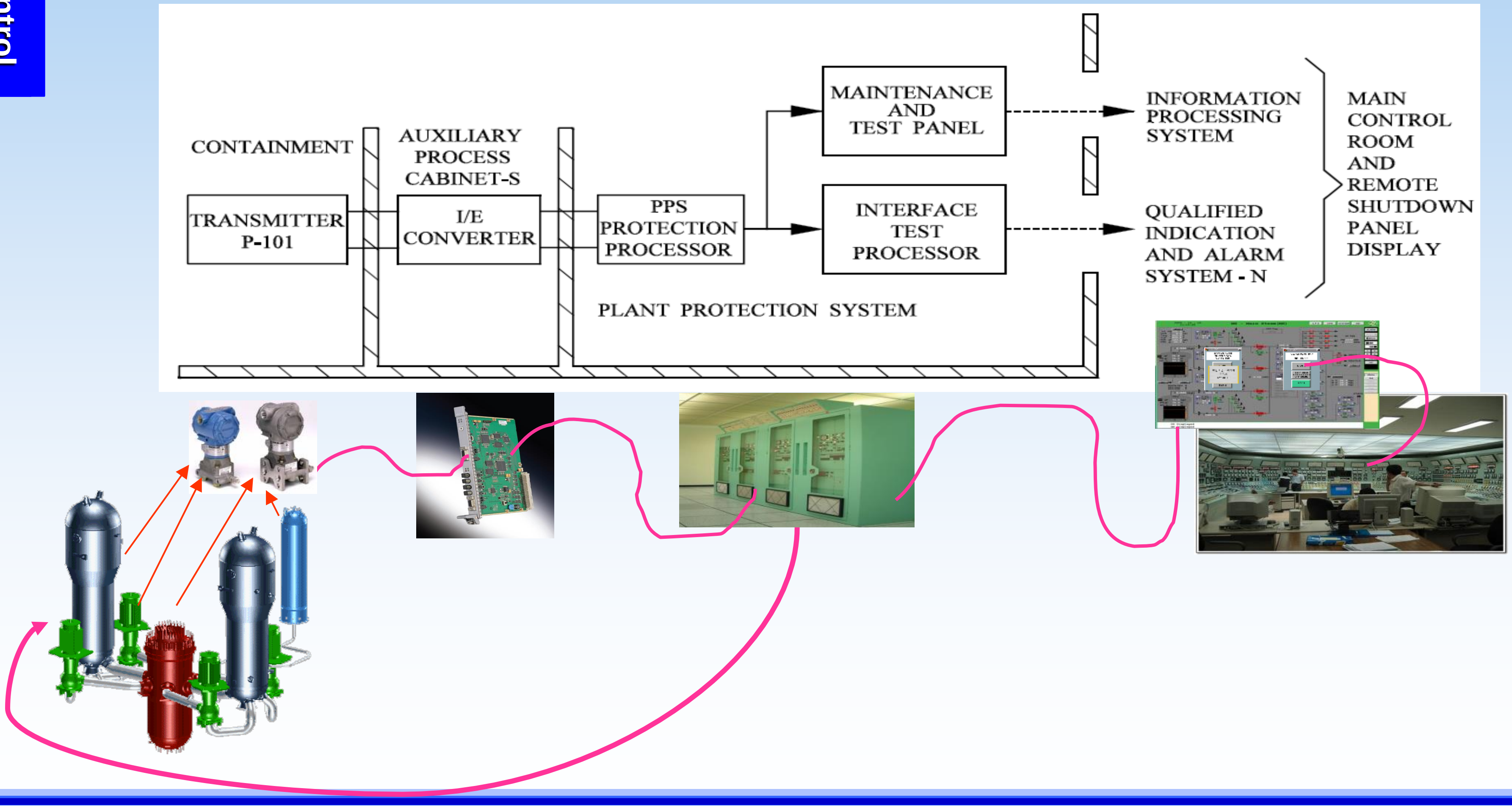
□ Interface scope of I&C systems



Fundamentals of I&C Systems

□ Typical concepts of I&C systems in NPPs

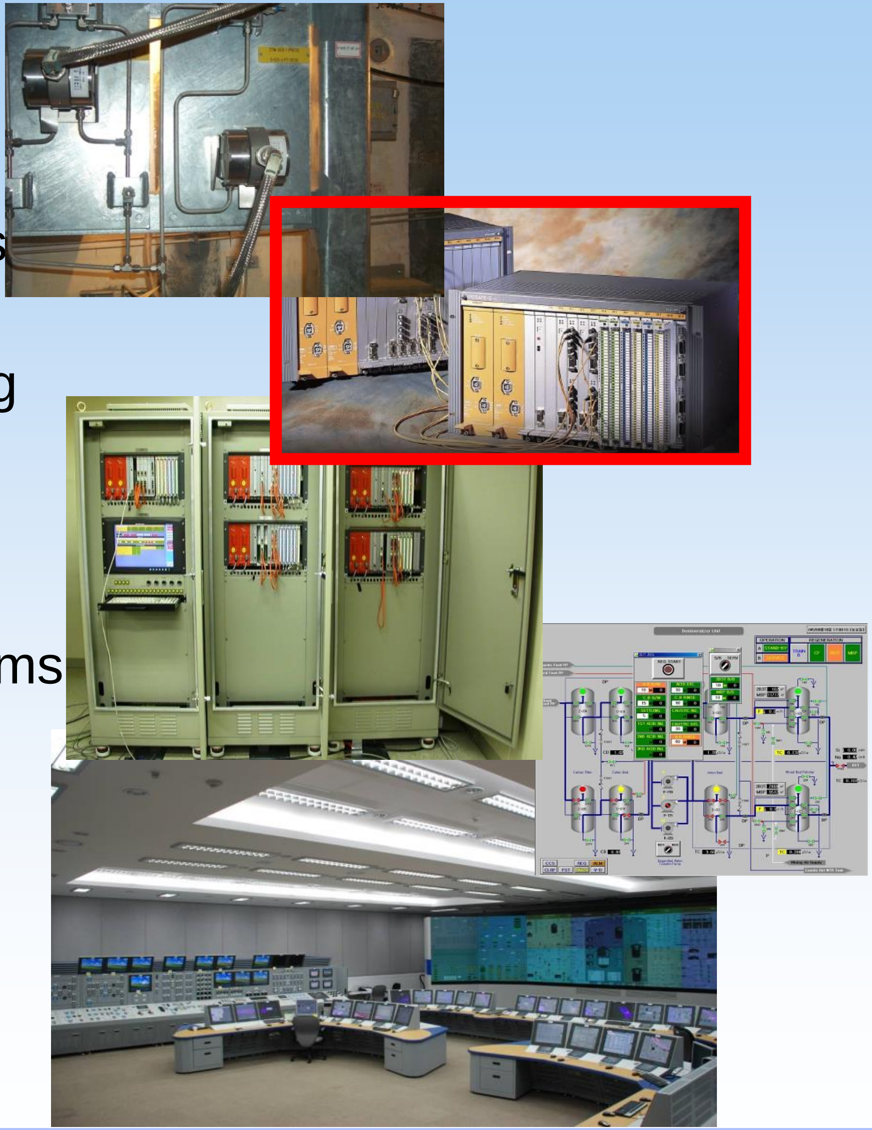
- Example, Plant Protection Systems



Fundamentals of I&C Systems

- I&C Systems consist of
  - Sensors, Transducers, Switch
  - PLCs, micro-controllers,
  - NIC, switch, gateways, servers
  - Motors, valves, pumps,
  - Embeded Real-Time Operating Systems,
  - Fieldbus, Modbus, Profibus, Ethernet,
  - Plant control / protection systems software,
  - Main Control Room, Remote Shutdown Room,
  - HMI

* PLC : Programmable Logic Controller



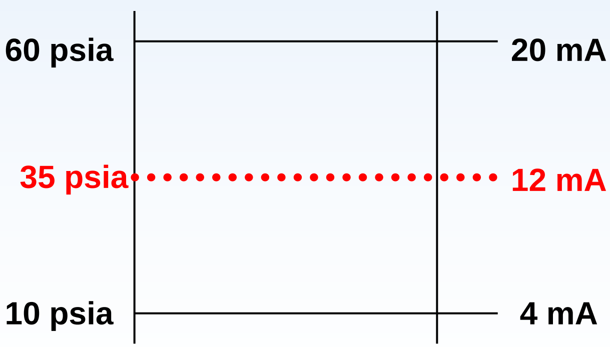
Fundamentals of I&C Systems

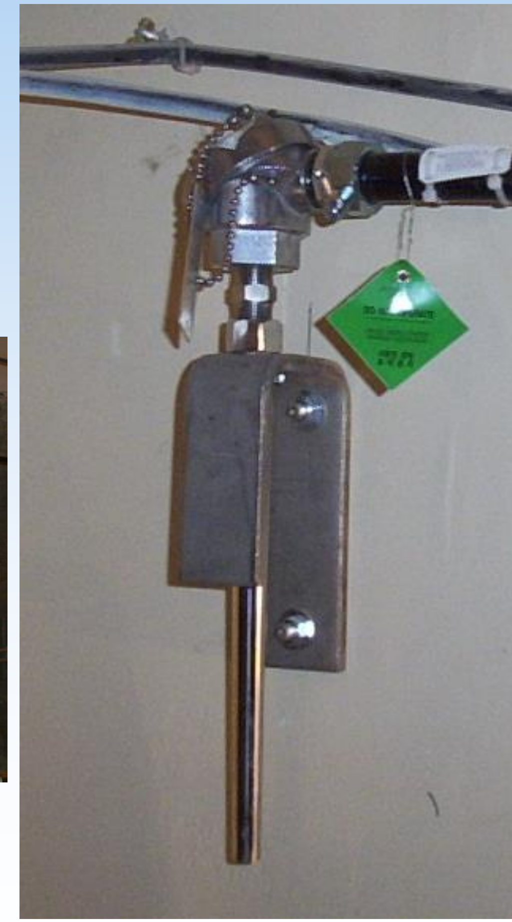
Transmitter?

Sensor + Transducer

□ Transmitters in NPPs

- Physical changes to electric signal (4~20mA)
  - Pressure
  - Differential pressure
  - Temperature
  - Flow
  - Level





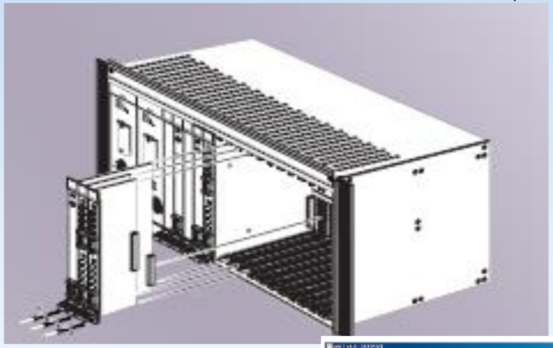
Fundamentals of I&C Systems

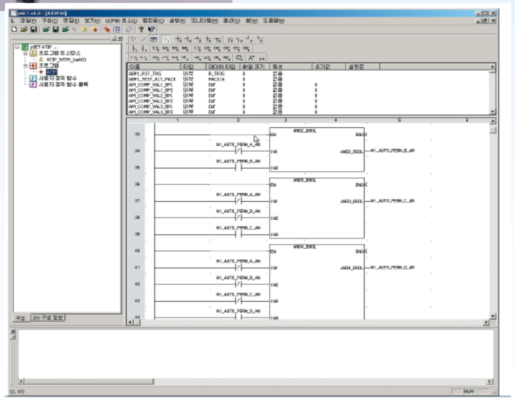
□ PLC (Programmable Logic Controller)

- Industrial Digital Computer
- Control logic for various purposes

482.6 x 281.35 x 294mm
(19 inch Standard)

- Power Supply
- Rack & Backplane Bus
- Processor Module
- Communication Module
- Input/Output Module
  - » Digital Input/Output,
  - » Analog Input/Output,
  - » RTD Input, etc.
- Engineering Workstation

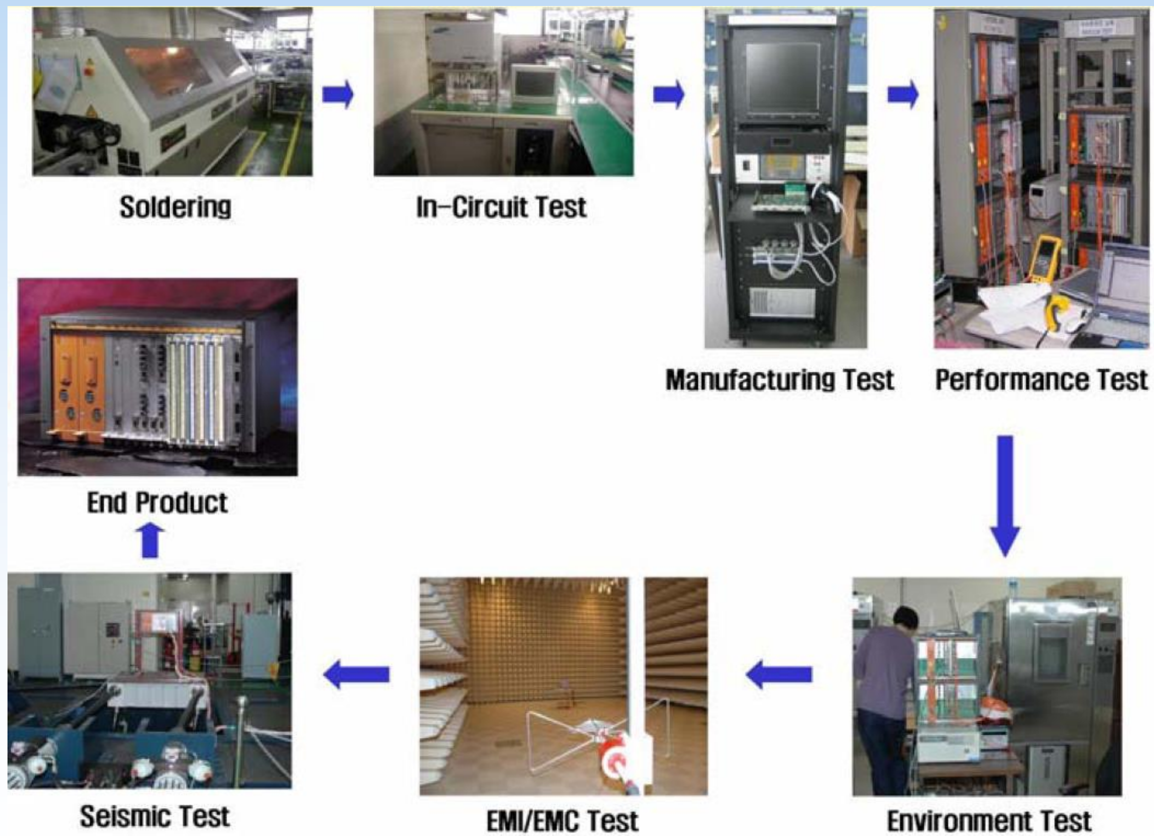




Fundamentals of I&C Systems

- □ I&C systems must be designed, fabricated, installed, and tested to quality standards commensurate with the importance of the functions to be performed.

- □ Hardware design



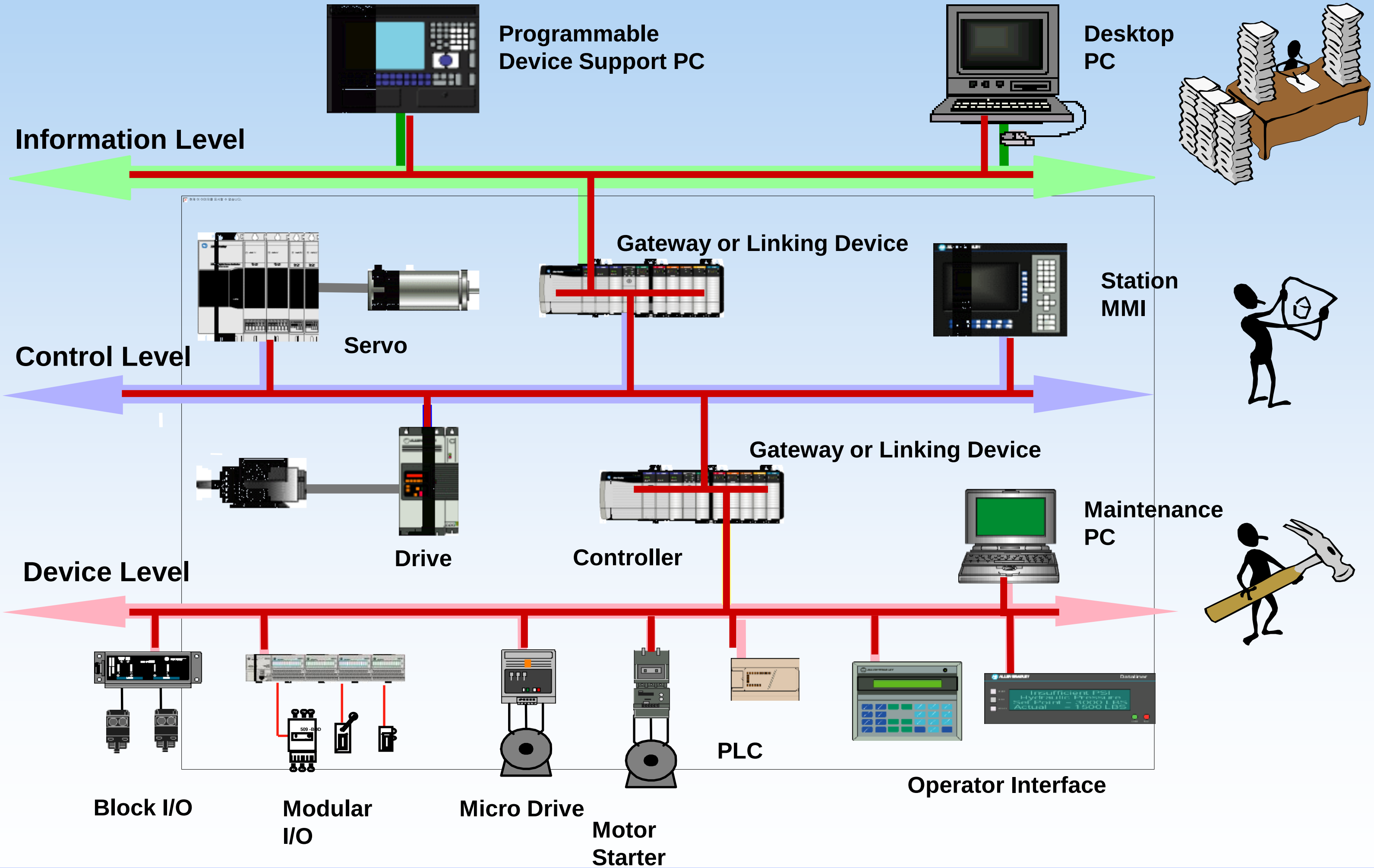
Fundamentals of I&C Systems

□ software design

Life Cycle Activity Groups	Planning Activities	Requirements Activities	Design Activities	Implementation Activities	Integration Activities	Validation Activities	Installation Activities	Operation & Maintenance Activities
Design outputs		Requirements Specification	Design Specification Hardware & Software Architecture	Code Listings	System Build Documents		Operations Manuals Installation Configuration Tables Maintenance Manuals Training Manuals	
Process implementation		Requirements Safety Analysis V&V Requirements Analysis Report CM Requirements Report	Design Safety Analysis V&V Design Analysis Report CM Design Report	Code Safety Analysis V&V Implementation Analysis & Test Report CM Implementation Report	Integration Safety Analysis V&V Integration Analysis & Test Report CM Integration Report	Validation Safety Analysis V&V Validation Analysis & Test Report CM Validation Report	Installation Safety Analysis V&V Installation Analysis & Test Report CM Installation Report	Change Safety Analysis V&V Change Report CM Change Report
Process planning	Software Management Plan Software Development Plan Software QA Plan Integration Plan Installation Plan Maintenance Plan Training Plan Operations Plan Software Safety Plan Software V&V Plan Software CM Plan							

Fundamentals of I&C Systems

□ General structures of I&C Systems

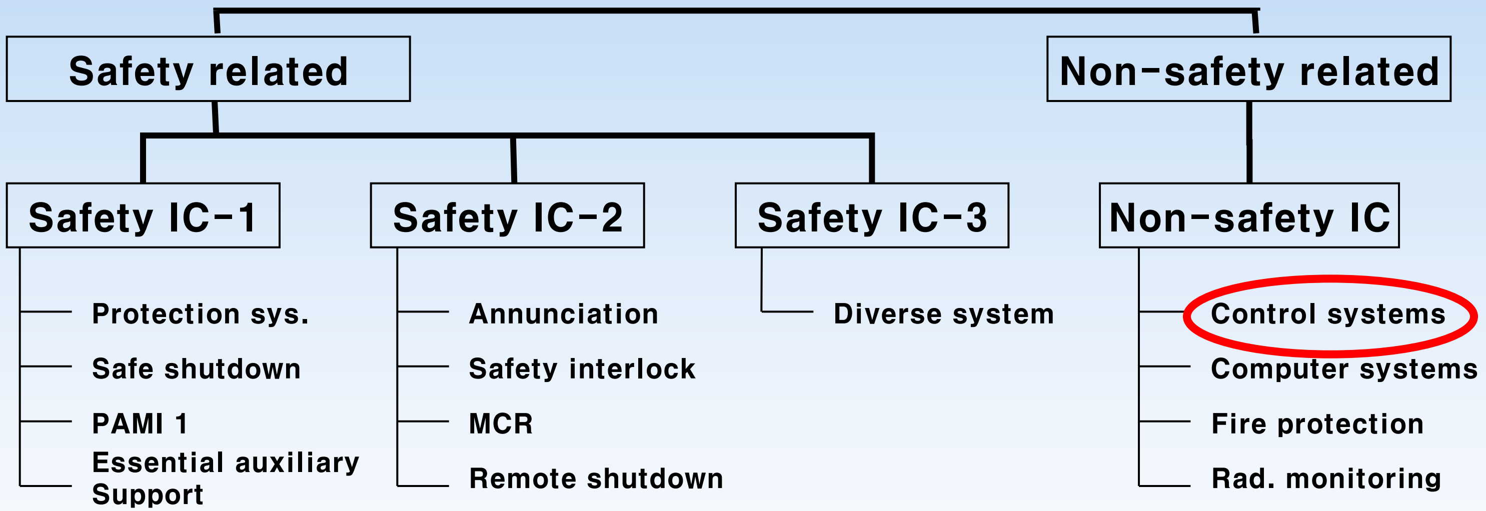


- Fundamentals of I&C Systems
- **Overview of Plant Control Systems**
- Control Systems Design and Requirements;
  - NSSS Control Systems
  - Pressurizer Pressure Control System
  - Pressurizer Level Control System
- IAEA Safety Standard for Plant Control Systems

Plant Control Systems

□ Classification of I&C Systems

- Classification that commensurate with the function to be performed



Plant Control Systems

□ Classification of I&C Systems

- Software Classification

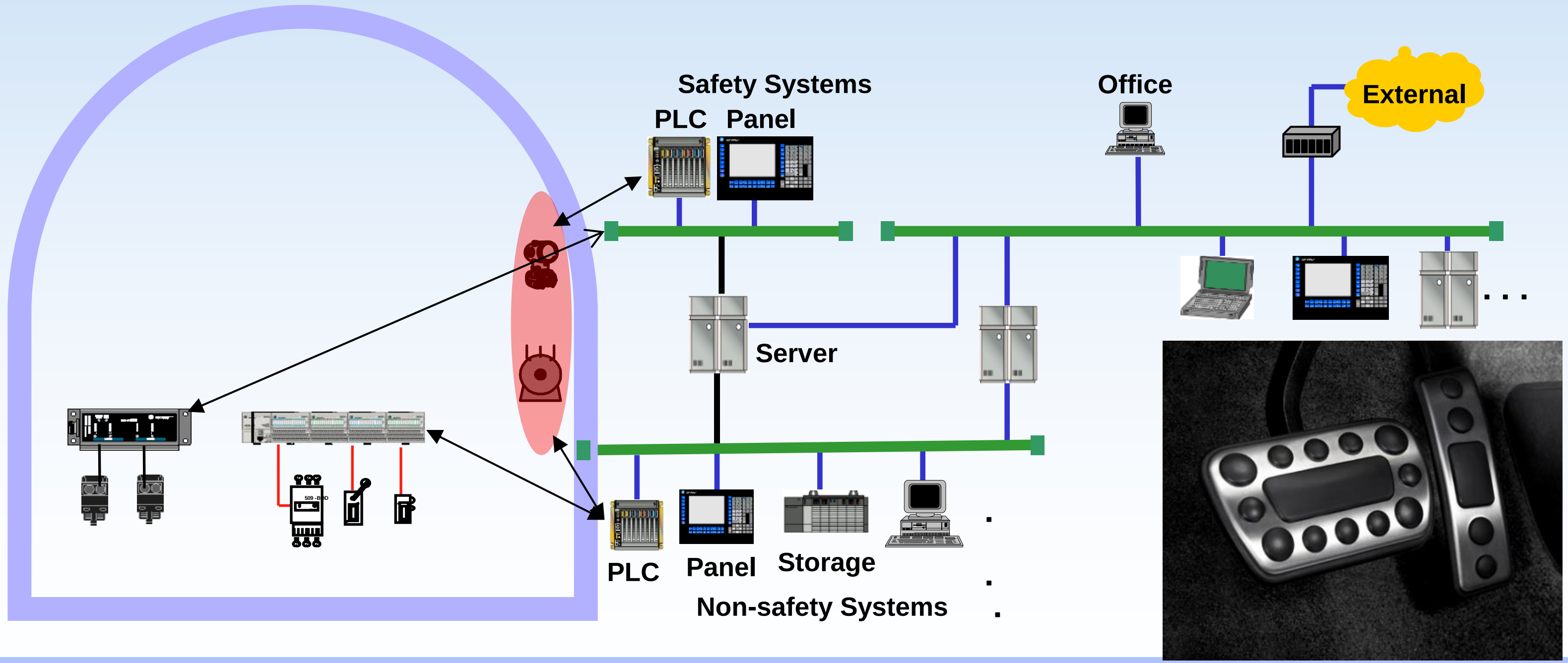
IEEE 1012	SIL 4	SIL 3	SIL 2	SIL 1
IAEA	Important to safety			Not important to safety
	Safety	Safety related		
IEC 61226	Category A	Category B	Category C	Unclassified
KINS	Safety-Critical	Safety-Related		Non Safety
W	Protection (Safety critical)	Important to safety	Important to availability	General purpose (Non safety)

cf.) SIL (Software Integrity Level)

Plant Control Systems

□ Plant Control Systems

- Not essential for the safety, but essential for the normal operation of plant
- Still, control system failure or inadvertent operation can affect to the performance of critical safety functions.



Plant Control Systems

- Typical control systems
  - Functional grouping & segmentation (ref. EPRI)

Reactivity Control	Automatic and manual control and monitoring of rod positions and manual control and monitoring of boron concentrations and neutron flux
S/G Control	Control and monitoring of main feedwater flow, main feed pumps and steam generator inventory
Turbine Steam Demand Control	Control and monitoring of turbine throttle valves and bypass valves
Pressurizer Pressure Control	Control and monitoring of the pressurizer heaters and spray and reactor coolant system pressure
Reactor Coolant System Inventory Control	Control and monitoring of makeup and letdown, reactor coolant system inventory and CVCS inventory

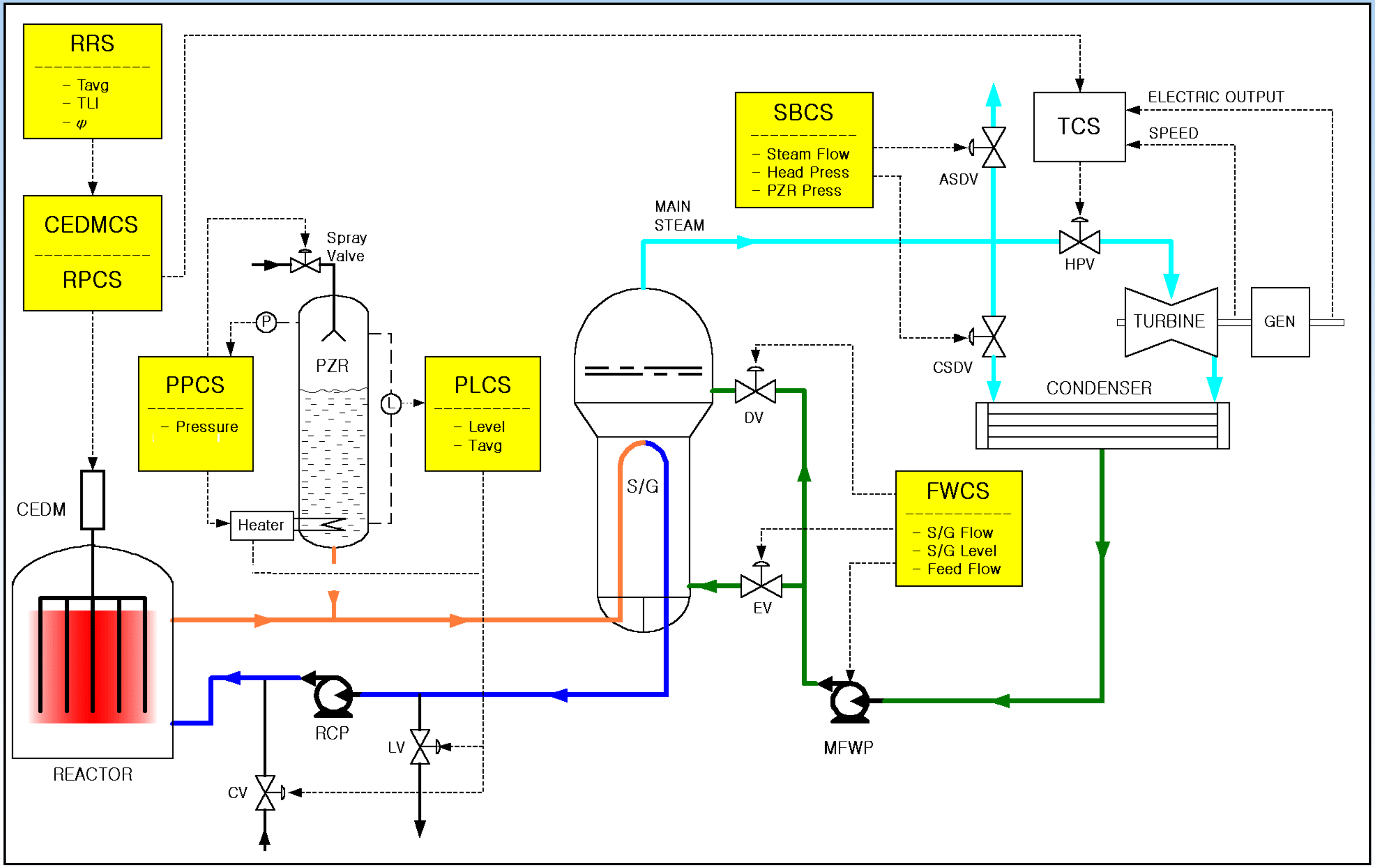
Plant Control Systems

- Typical control systems
  - For the pressurized water reactor systems

✓	Reactivity Control System
	Boron Control System
✓	Reactor Power Cutback System
✓	Pressurizer Pressure and Level Control System
✓	Feedwater Control System
	Steam Generator Water Level Control System
	Steam Dump Control System.
✓	Steam Bypass Control System
	Safety System and Sensing Line Environmental Control

Plant Control Systems

- Typical control systems for Nuclear Steam Supply



Plant Control Systems

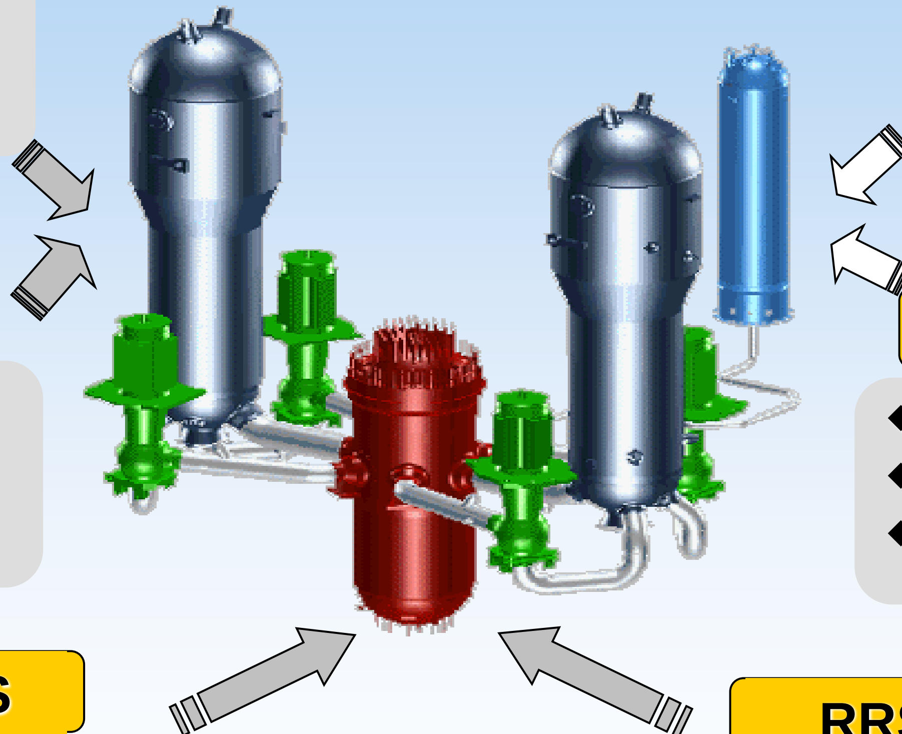
□ Typical control systems

SBCS

- PI Control
- SG Press. Control
- TBV

FWCS

- PI Control
- SG Level Control
- DFWCV, EFWCV, MFWP Speed



PPCS

- P Control
- PZR Press.
- Spray Valve, Heaters

PLCS

- PI Control
- PZR Level
- Charging Valve, Letdown Isolation Valves

RPCS

- Rx Power
- CEA Group 5 or 4+5, TCV

RRS

- T_{AVG}
- CEA Group

- □ Fundamentals of I&C Systems
- □ Overview of Plant Control Systems
- □ **Control Systems Design and Requirements;**
  - **NSSS Control Systems**
  - Pressurizer Pressure Control System
  - Pressurizer Level Control System
- □ IAEA Safety Standard for Plant Control Systems

NSSS Control Systems

□ NSSS Control Systems

- Load Follow Operation
  - Reactivity feedback properties of the NSSS will inherently cause reactor power to match the total NSSS load

    → turbine load

- Load Follow Control
  - The ability of NSSS to follow turbine load changes is dependent on the ability of control systems / operator to adjust;
    - reactivity,
    - feedwater flow,
    - turbine bypass steam flow,
    - reactor coolant inventory,
    - energy content of pressurizer.

NSSS Control Systems

□ NSSS Control Systems

- Provide capability to automatically follow limited load changes
- Provide capability to accommodate load rejections of any magnitude or the loss of one of two operating feedwater pumps without a reactor trip or lifting any safety valves.

Control System	Controlling Components	Controlled Parameter
Reactor Regulating System	Regulating CEA Position	Reactor Coolant Temperature
Steam Bypass Control System	Steam bypass valves	Secondary Pressure
Feedwater Control System	Downcomer & Economizer Feeewater Control Valves Feedwater pumps (speed)	Steam Generator Level

NSSS Control Systems - RRS ✓

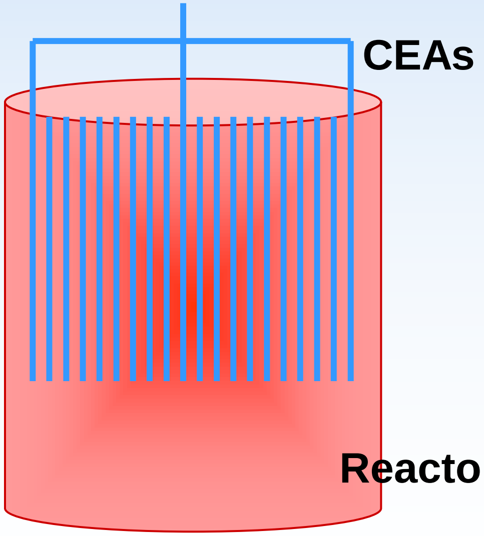
□ Reactor's reactivity is controlled by

- adjustments of CEAs by rapid reactivity changes
- Adjustment of boric acid concentration for slow changes
  - suitable, or easy to control

- CEAs can either be controlled manually or automatically to maintain the programmed reactor coolant temperature and power level within the limits of CEA travel.

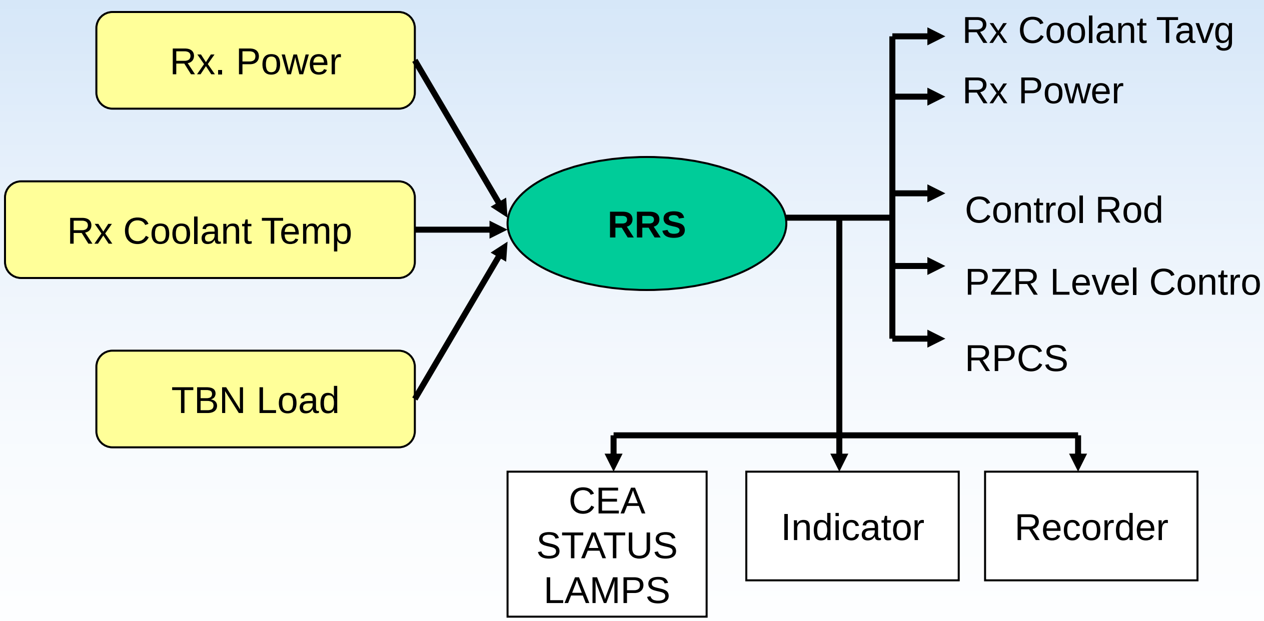
  → Reactor Regulating System

Control Element Assembly



NSSS Control Systems - RRS

- Reactor Regulating System (RRS)
  - Automatic adjustment of reactor power
    - and reactor coolant temperature using TBN Load Index
  - Provides CEA movement (withdrawal, insertion & hold) and rate signals to CEDMCS to adjust reactor power



NSSS Control Systems - RRS

- Function of RRS
  - Provides a programmed T_ref as a function of turbine load
  - Provides CEA movement to the CEDMCS
    - to reposition the regulating CEAs to maintain the reactor coolant T_avg within a deadband of the programmed reference temperature
  - Provides automatic control of the reactor coolant T_avg and reactor power,
    - for each of the following plant conditions during plant operation between 15% and 100% power:
      - Loss of one out of two (1/2) operating feedwater pumps
      - 10% step change in NSSS load
      - 5%/min ramp changes in NSSS load
      - Steady-state conditions

NSSS Control Systems - RRS

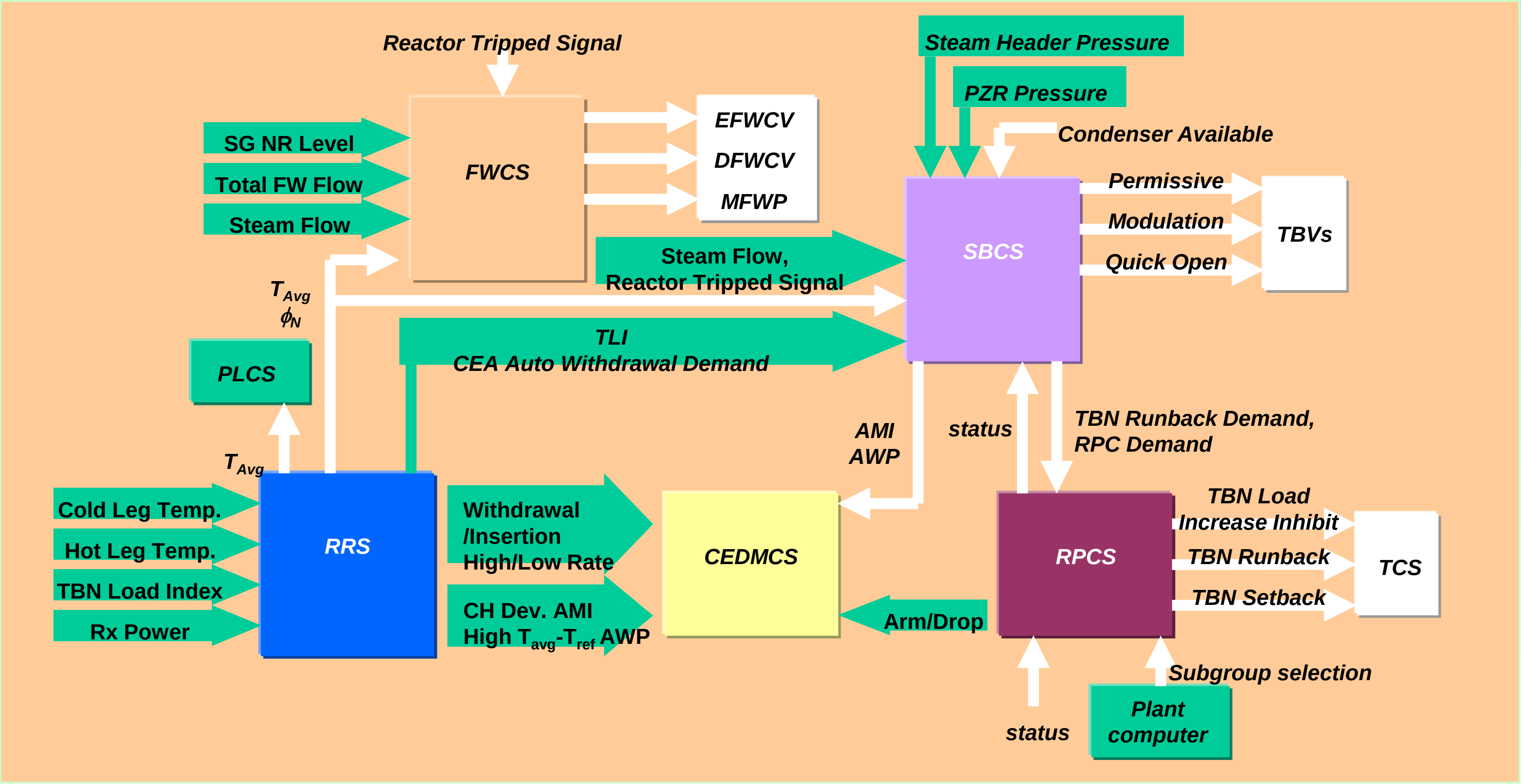
□ Function of RRS

- Provides an Automatic Withdrawal Prohibit (AWP) signal to the CEDMCS
  - to stop CEA withdrawal on a high deviation of reactor coolant Tavg from reactor coolant T_ref

- Provides an Automatic Motion Inhibit (AMI) signal to the CEDMCS
  - to stop CEA motion on an input channel deviation

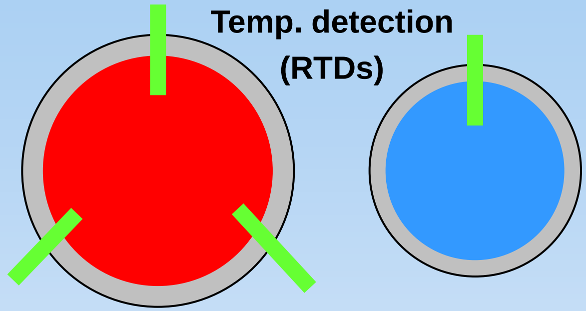
NSSS Control Systems - RRS

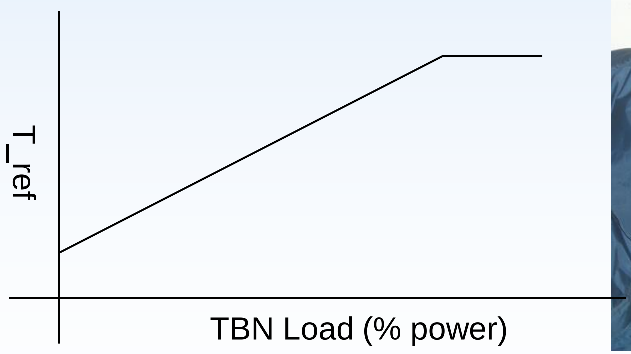
- Function of RRS – system interface
  - Provides signal interface to PLCS, SBCS and FWCS
  - Provides indication to the operator on MCB & PDAS

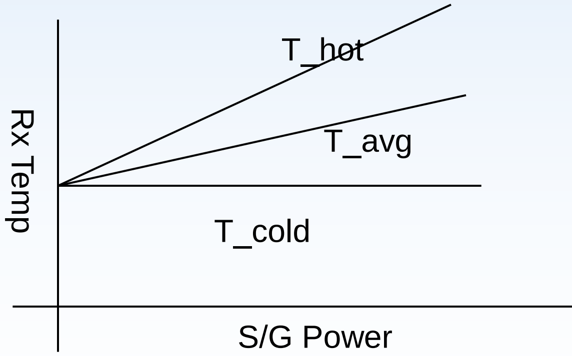


NSSS Control Systems - RRS

- Input signals to RRS
  - Reactor Coolant Cold leg Temp.
  - Reactor Coolant Hot leg Temp.
  - Turbine Load Index
    - impulse turbine pressure, which is linear to the turbine load, to determine T_ref of reactor coolant system
  - Reactor Power
    - From control channels of the Excore Neutron Flux Monitoring System







NSSS Control Systems - RRS

□ Output signals from RRS

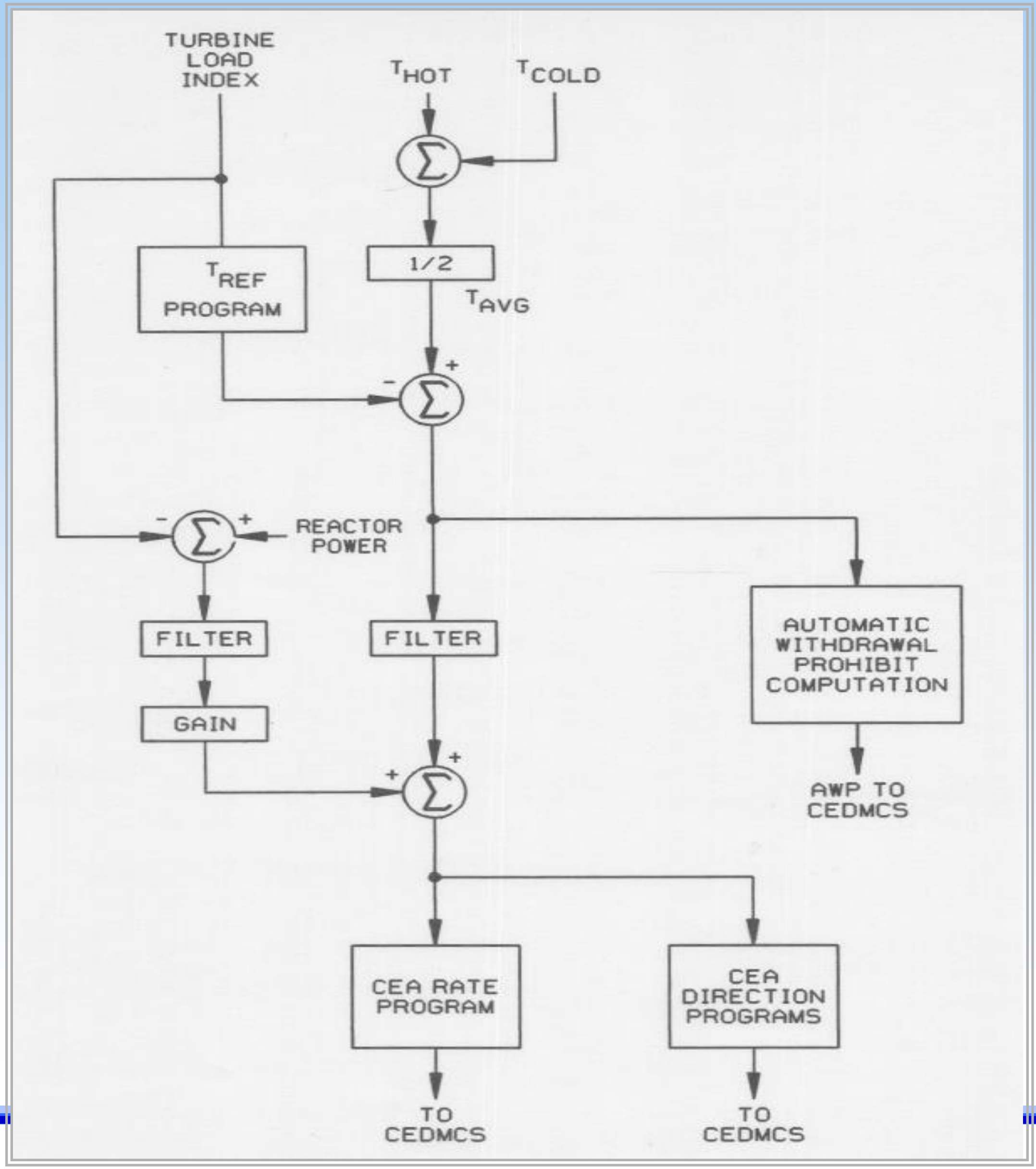
- CEA Automatic Withdrawal / Insertion Demand signal
- CEA Rate Demand signal
- High T_{avg}-T_{ref} Alarm
- High T_{avg}-T_{ref} AWP signal
- Low T_{avg}-T_{ref} Alarm
- RRS input Channel Deviation Alarm signal
- CEA Motion Demand

- Signal to SBCS, FWCS, PLCS,…

- Information to PDAS, computer systems,..

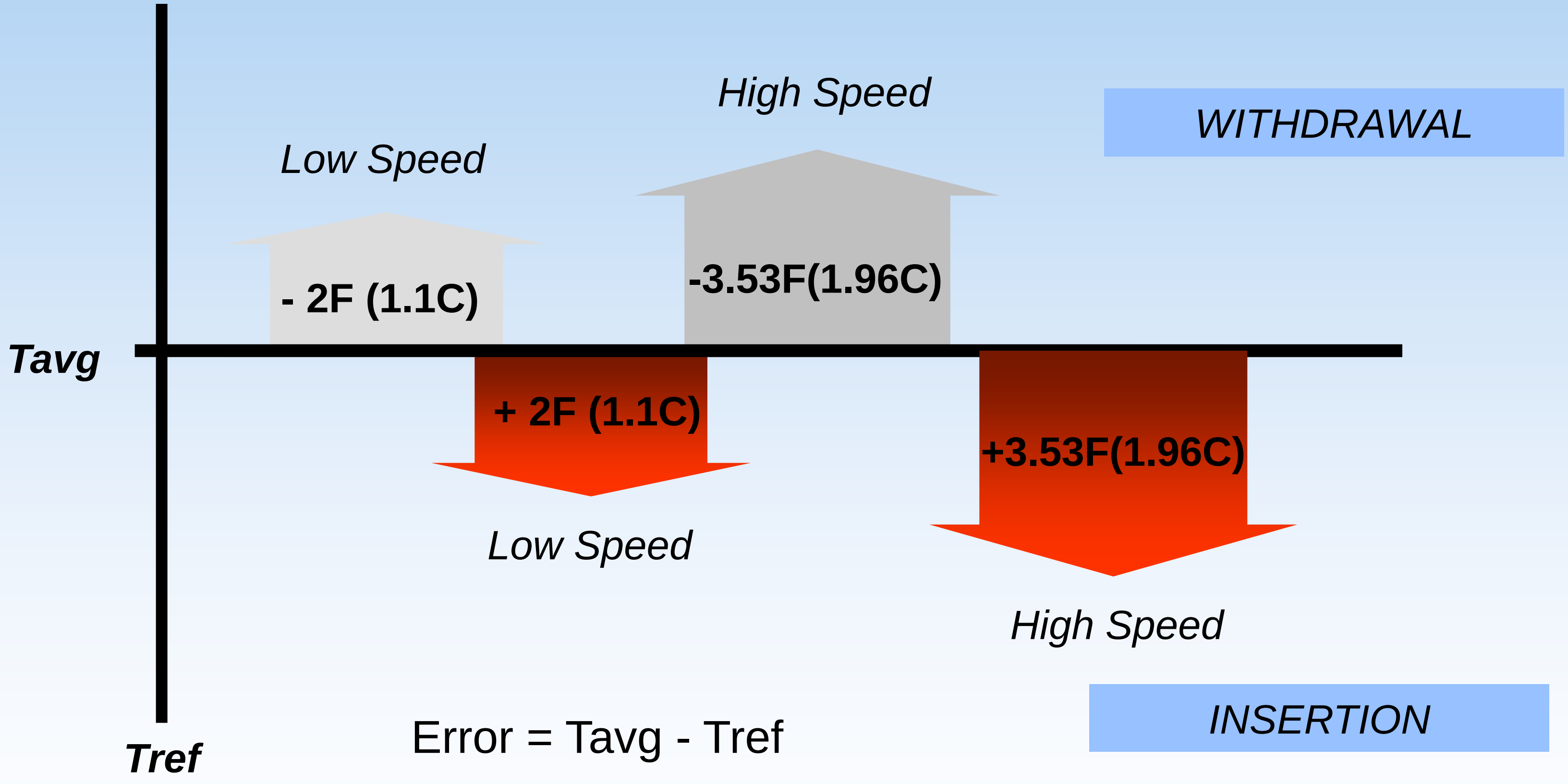
NSSS Control Systems - RRS

- Conceptual diagram of RRS



NSSS Control Systems - RRS

- RRS
  - CEA Insertion / Withdrawal



NSSS Control Systems - SBCS ✓

- RRS is designed to cover 10% step change and 5% ramp change of reactor power without tripping.
  - What about to a large load rejection, without tripping?

- Steam Bypass Control System
  - to increase the load following capability of the NSSS
    - to include load rejections of any magnitude turbine trip from 100% power without tripping the reactor or lifting pressurizer or main steam safety valves
  - dissipates excessive energy in the NSSS to maximize plant availability by regulating Turbine Bypass Valves
  - prevent unnecessary opening of primary or secondary side safety valves

Down shifting?

NSSS Control Systems - SBCS

- Steam Bypass Control System

Best Normal Condition of Plant

NSSS Power = T/G Power

Plant Abnormal Status

NSSS Power > T/G Power

Control of Excess Load of NSSS

RPCS

ADVs

Steam Dump

RPCS : Reactor Power Cutback System

ADVs : Atmospheric Steam Dump Valves

NSSS Control Systems - SBCS

□ Function of SBCS

- 55% load rejection
- Maintain steam header pressure in the following transients without reactor trip or lifting PZR or main steam safety valve
  - Load rejection of any magnitude
  - Loss of one feedwater pump during three pumps operation
- Initiate Reactor Power Cutback System (RPCS) whenever the magnitude of load rejection exceeds turbine bypass capacity
- Provide a means of manually controlling the RCS temperature during plant heatup and cooldown

NSSS Control Systems - SBCS

□ Function of SBCS

- Operate the eight turbine bypass valves in a sequential manner
- CEA AMI signal to CEDMCS
  - Whenever reactor power falls below 15% or the reactor & turbine power falls below predetermined thresholds
- AWP signal to CEDMCS
  - Whenever turbine bypass demand exists
- Automatic or Manual Control capability

NSSS Control Systems - SBCS

□ Major Input/Output of SBCS

- Input
  - Steam flow
  - Steam header pressure
  - Pressurizer pressure

- Output
  - Steam bypass valves modulation & quick open demand
  - CEA AMI
  - Reactor Power Cutback demand generation

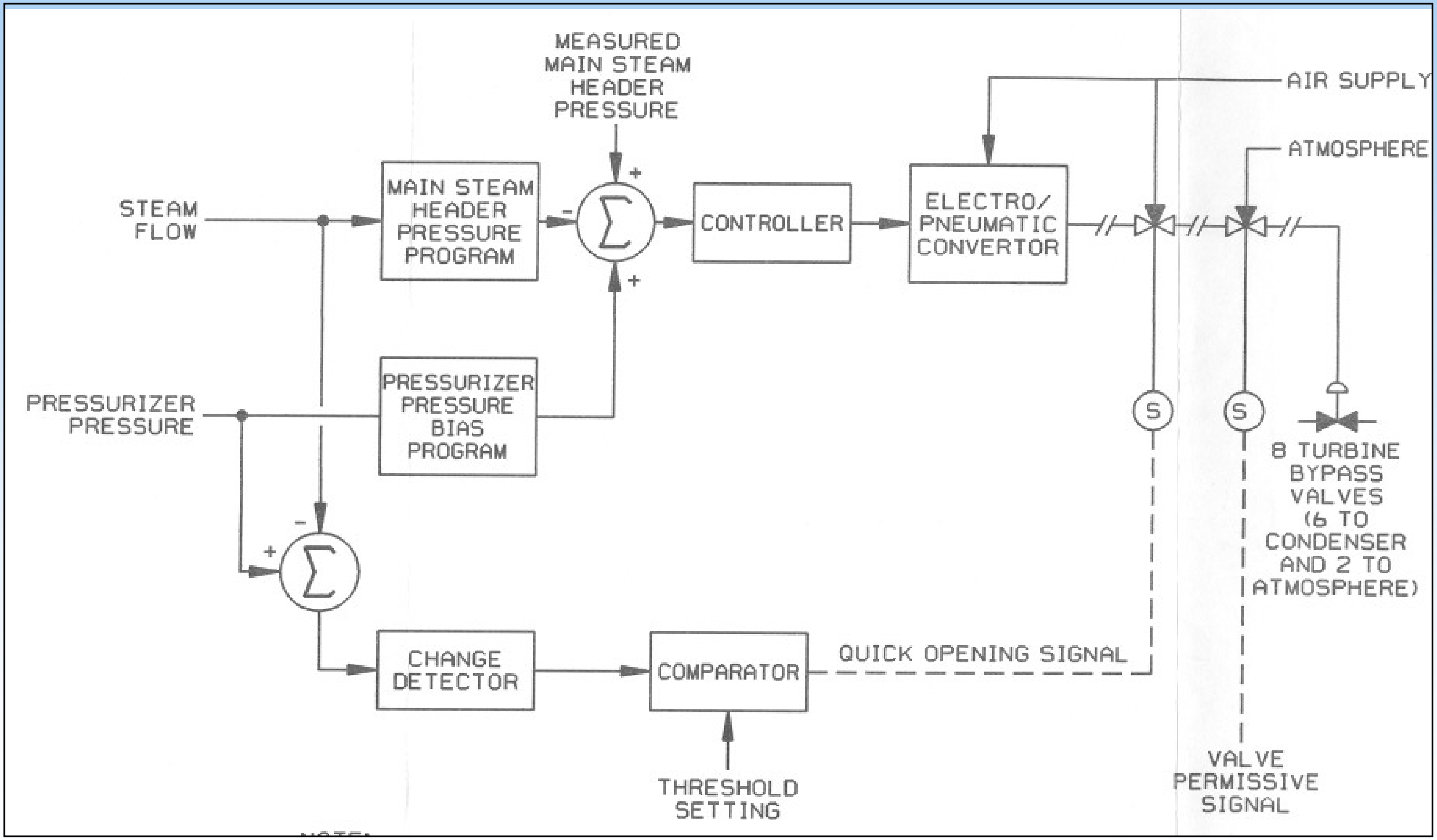
NSSS Control Systems - SBCS

□ Design basis of SBCS

- Accommodate load rejections of any magnitude without tripping the reactor or lifting the pressurizer or steam generator safety valves
- Maintain reactor power at a desired level following a turbine trip or load rejection
- Manually limit reactor coolant heat-up rate during startup
- Provide a mean of manually removing energy during plant cooldown

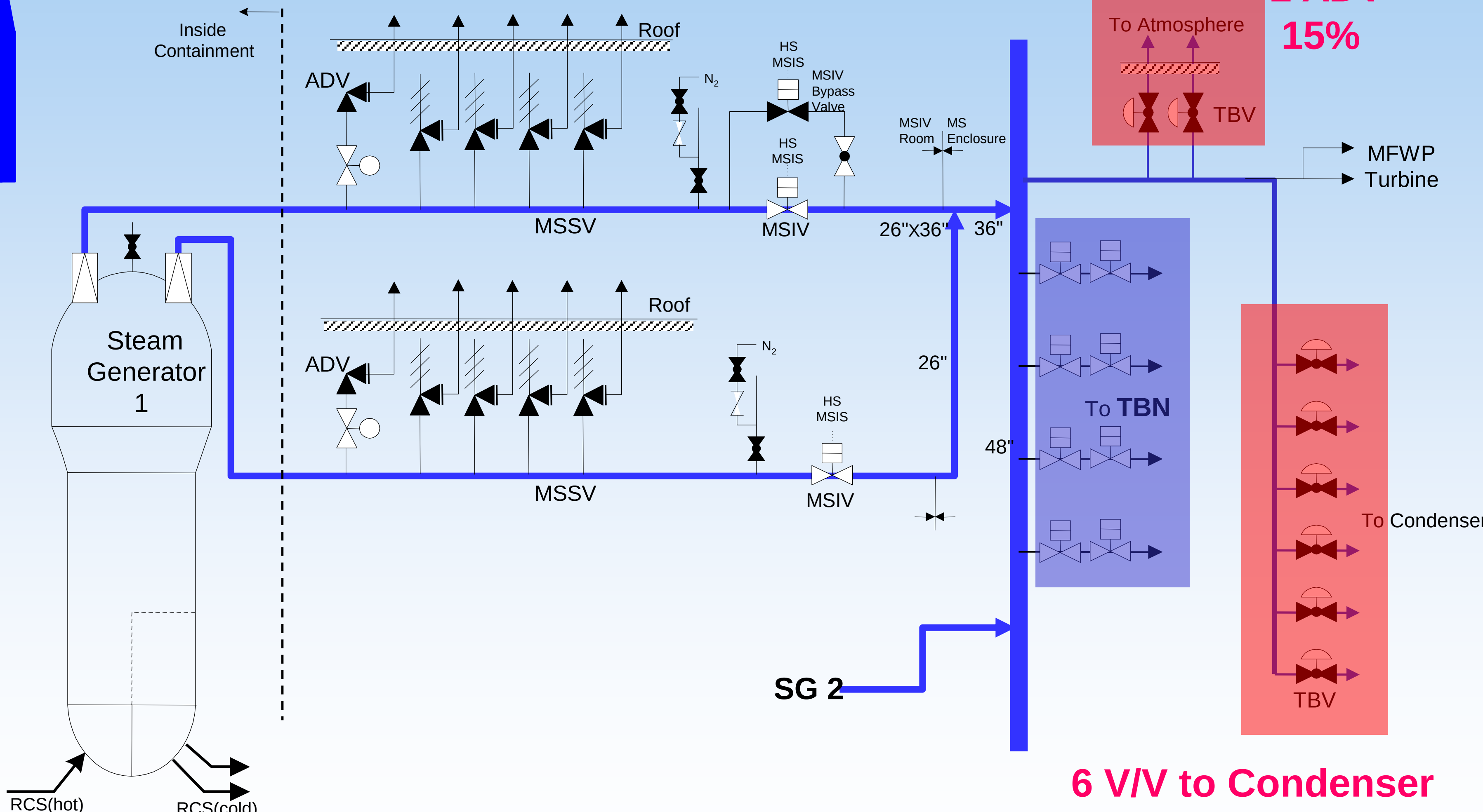
NSSS Control Systems - SBCS

□ Diagram of SBCS



NSSS Control Systems - SBCS

□ Diagram of SBCS



2 ADV
15%

6 V/V to Condenser
40%

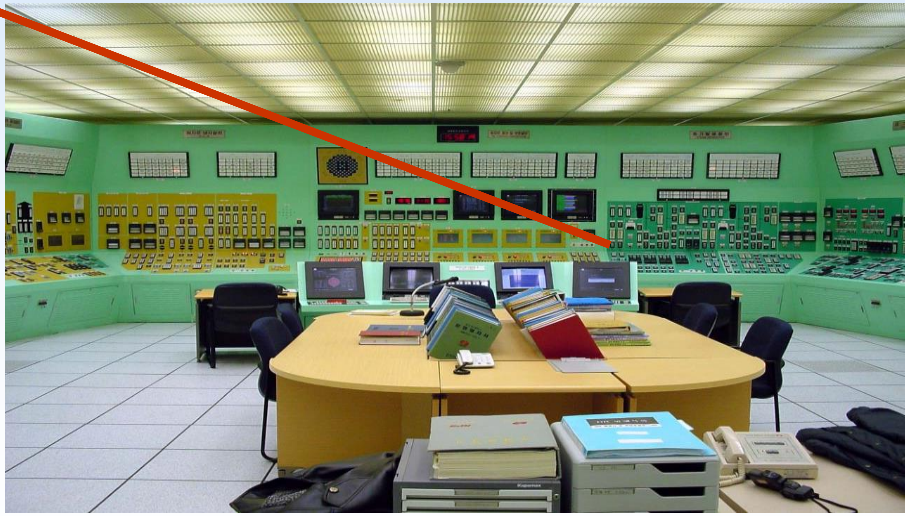
NSSS Control Systems - SBCS

□ Operations of SBCS

- During the normal operation
  - Automatic Control
    - » Valve is automatically controlled by SBCS
  - Master Controller Manual Control
    - » Valve is controlled by the operator when the Automatic Modulation Permissive signal is present in SBCS
  - Individual Manual Control
    - » Valve is controlled by the operator from its M/A Controller when the Automatic Modulation Permissive signal is present in SBCS
- Abnormal conditions
  - SBCS automatically controls excess energy in the NSSS due to load rejection including a turbine trip from 100% power by regulating the flow of steam through turbine bypass valves in conjunction with RPCS

NSSS Control Systems - SBCS

- □ Manual control in MCR



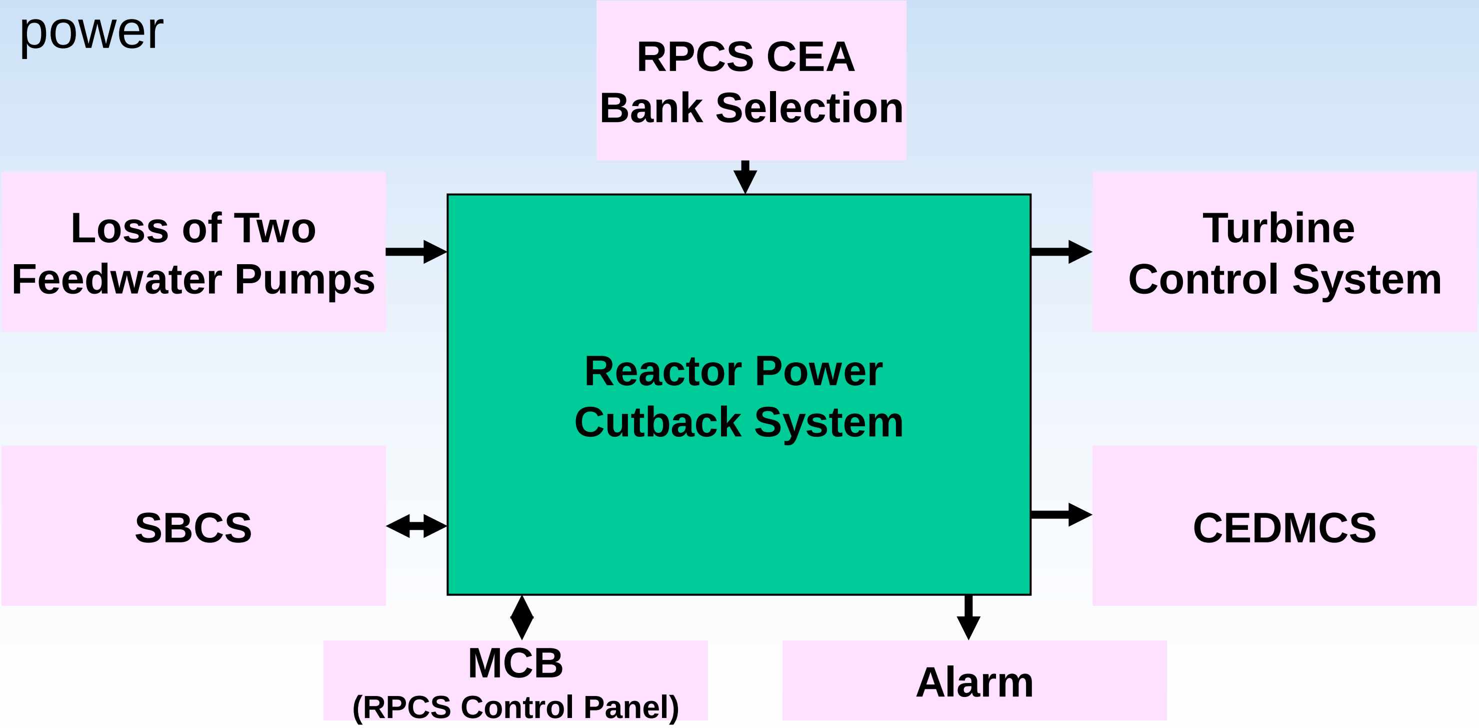
NSSS Control Systems - RPCS ✓

□ Reactor Power Cutback System

- NSSS normally operates with minor perturbations in power and flow.
  - Can be handled by SBCS and RRS
- However, large plant imbalances can occur,
  - Turbine trip
  - Loss of one of two operating main feedwater pumps
- How to maintain the NSSS within the control band ranges is accomplished by a rapid reduction of NSSS power?

NSSS Control Systems - RPCS

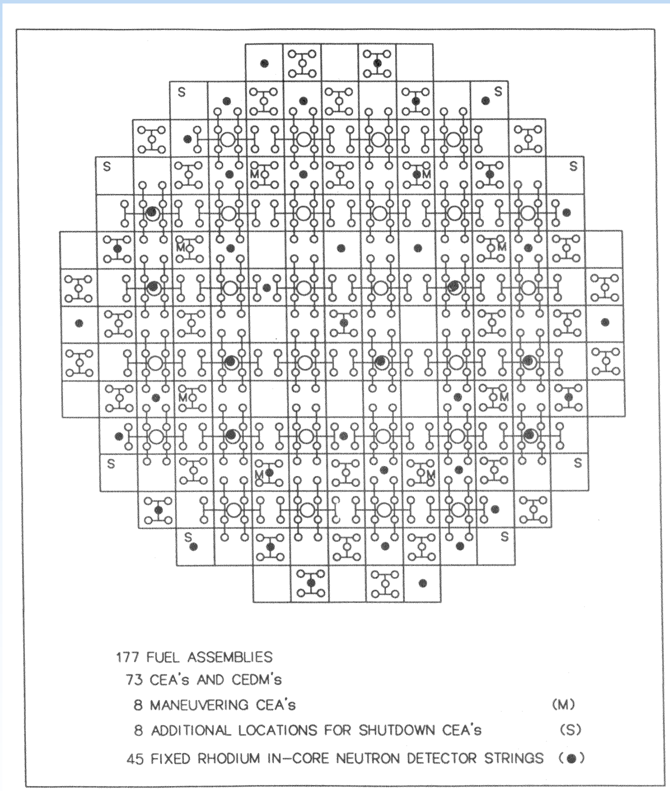
- Reactor Power Cutback System
  - 20 ~ 75% load rejection by,
    - simultaneous dropping of 1 or more pre-selected groups of full-length regulating CEAs into the core
    - Control signal to Turbine to rebalance turbine and reactor power



NSSS Control Systems - RPCS

□ Reactor Power Cutback System

- CEA selection by manual or automatic (from plant computer)

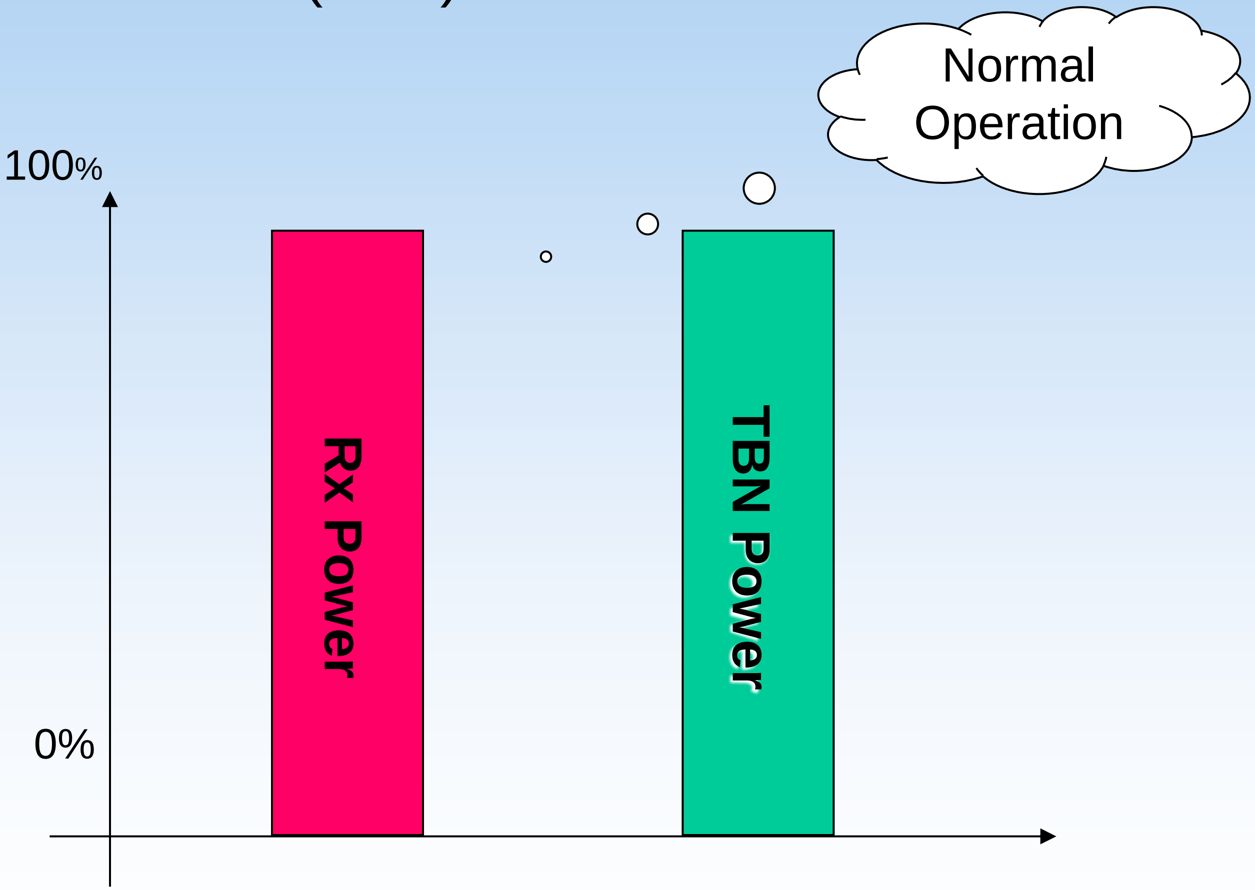


CONTROL GROUP	SUBGROUP	CEA
Shutdown group A	2 3 5	6, 8, 10, 12 7, 9, 11, 13 18, 19, 20, 21
Shutdown group B	6 7 9 10	22, 24, 26, 28 23, 25, 27, 29 34, 36, 38, 40 35, 37, 39, 41
Reaulating group 1	1 14 15	2, 3, 4, 5 54, 57, 60, 63 56, 59, 62, 65
Reaulating group 2	12 13	46, 48, 50, 52 47, 49, 51, 53
Reaulating group 3	11 16	42, 43, 44, 45 55, 58, 61, 64
Reaulating group 4	8	30, 31, 32, 33, 1
Reaulating group 5	4	14, 15, 16, 17
Part Strength Group	17 18	66, 68, 70, 72 67, 69, 71, 73

NSSS Control Systems - SBCS

□ SBCS Operation Scenario

- Loss of Small Load(20%)

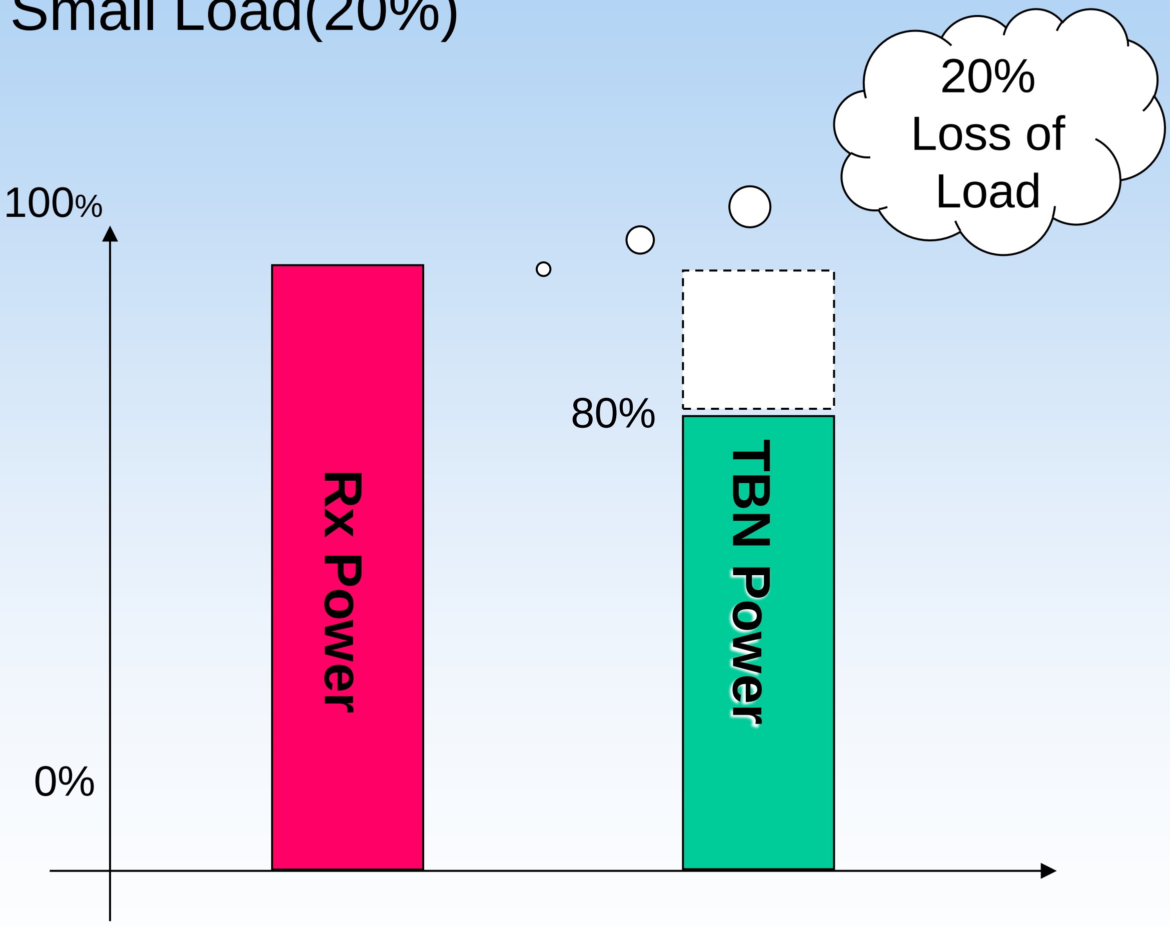


Rx power = TBN Power

NSSS Control Systems - SBCS

□ SBCS Operation Scenario

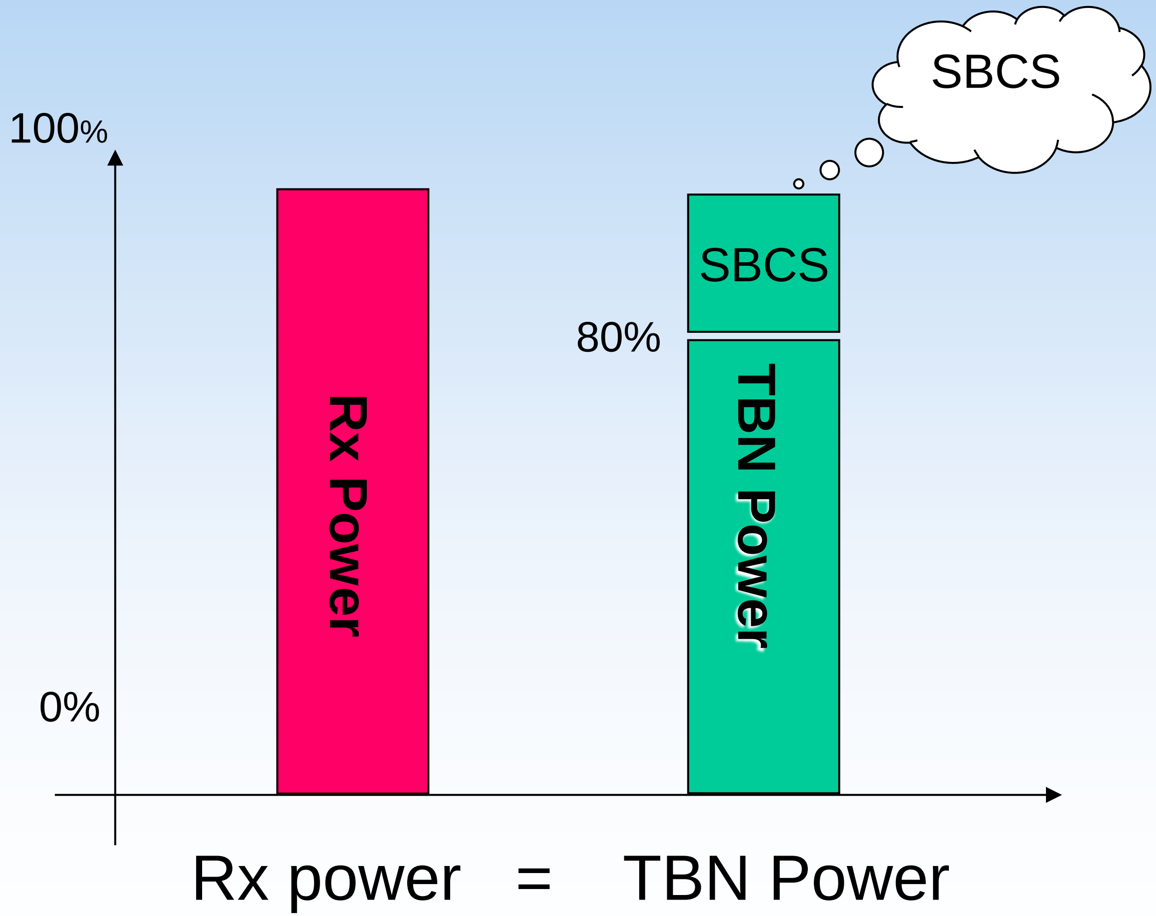
- Loss of Small Load(20%)



Rx power > TBN Power

NSSS Control Systems - SBCS

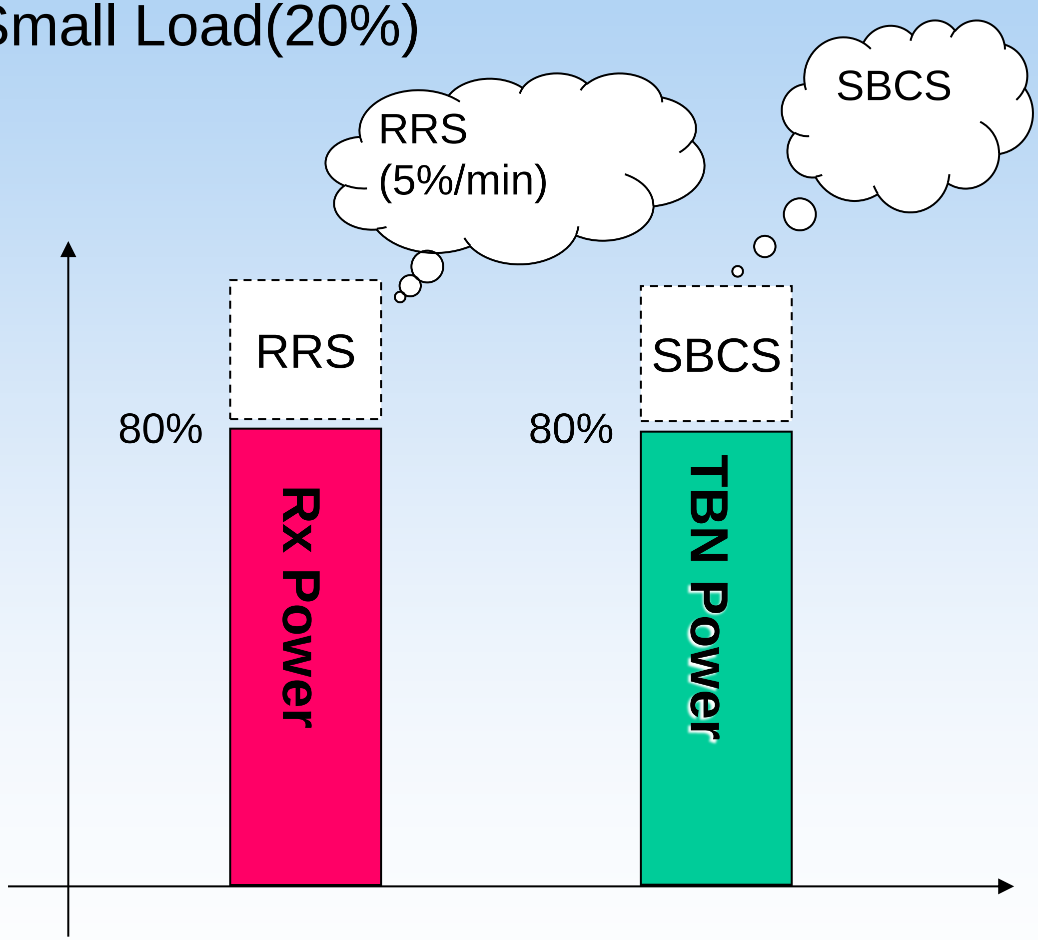
- SBCS Operation Scenario
  - Loss of Small Load(20%)



NSSS Control Systems - SBCS

□ SBCS Operation Scenario

- Loss of Small Load(20%)

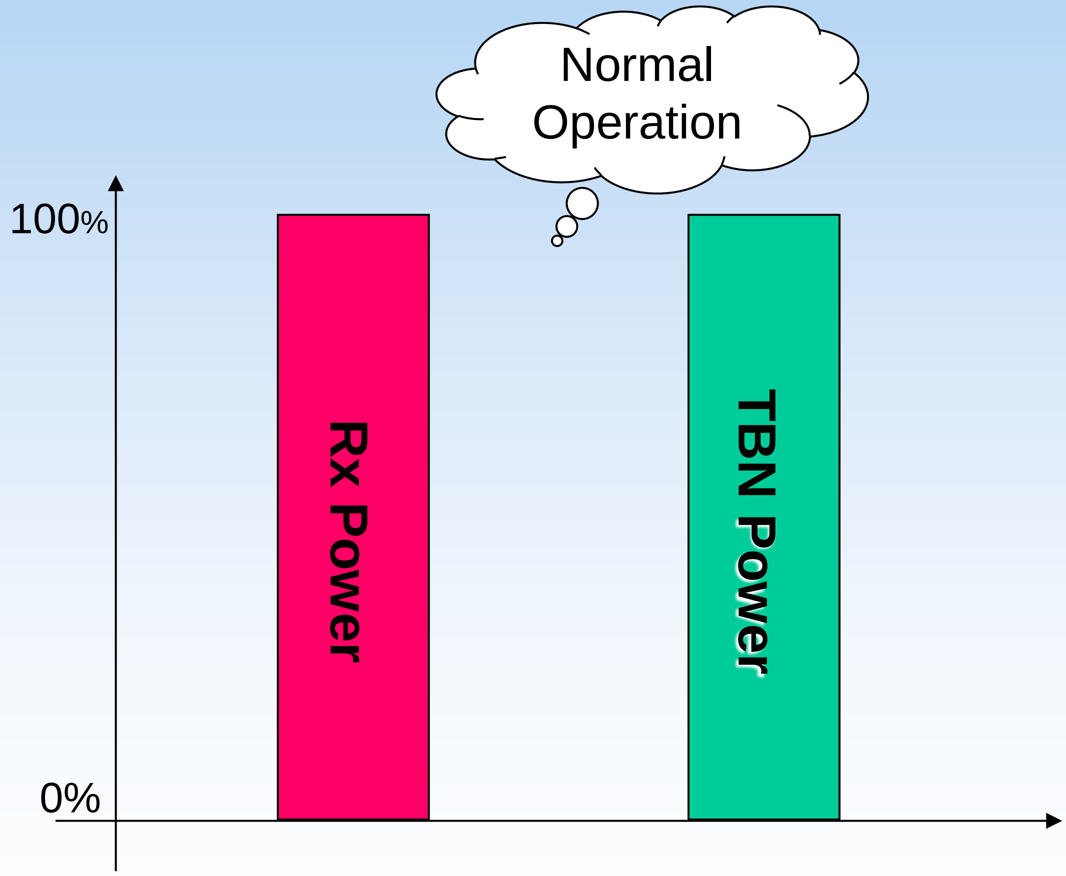


Rx power = TBN Power

NSSS Control Systems - SBCS

□ SBCS Operation Scenario

- Loss of Small Load(20%)

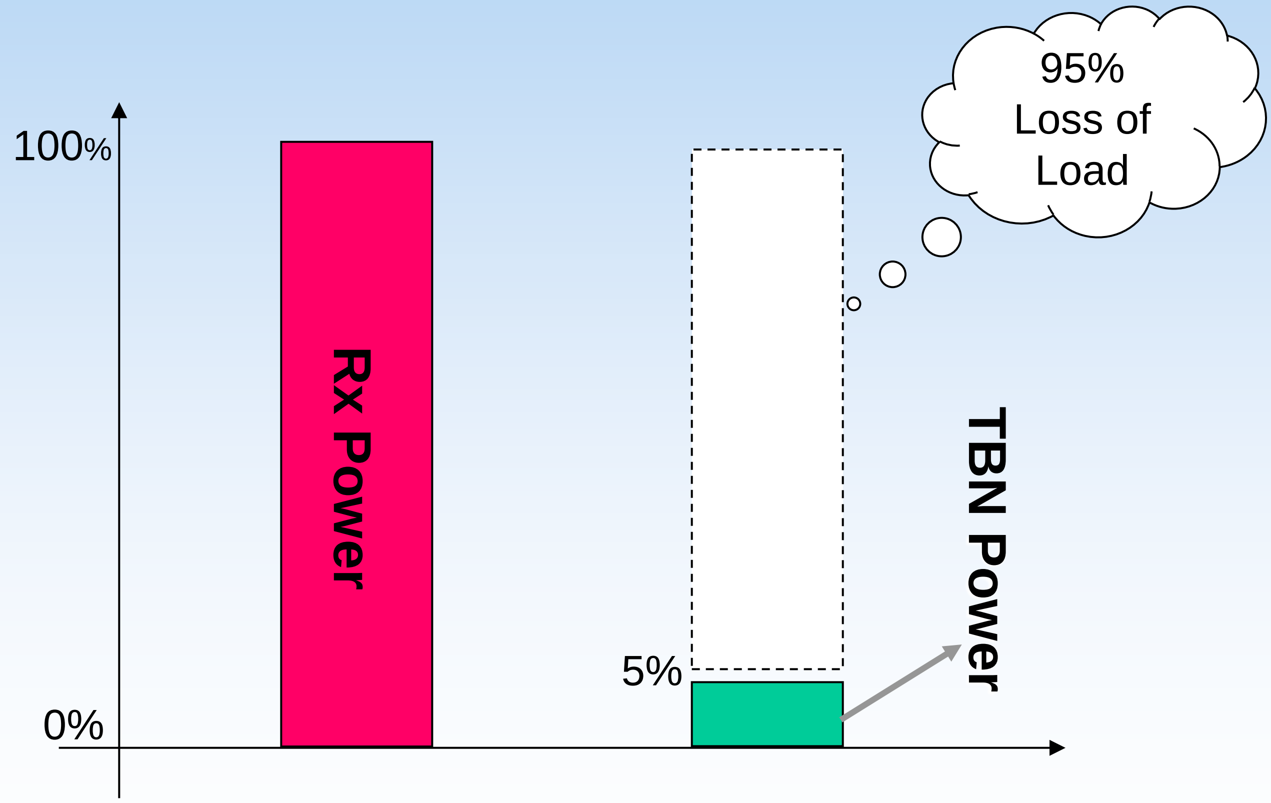


Rx power = TBN Power

NSSS Control Systems - SBCS

□ SBCS + RPCS Operation Scenario

- Loss of Large Load(95%)

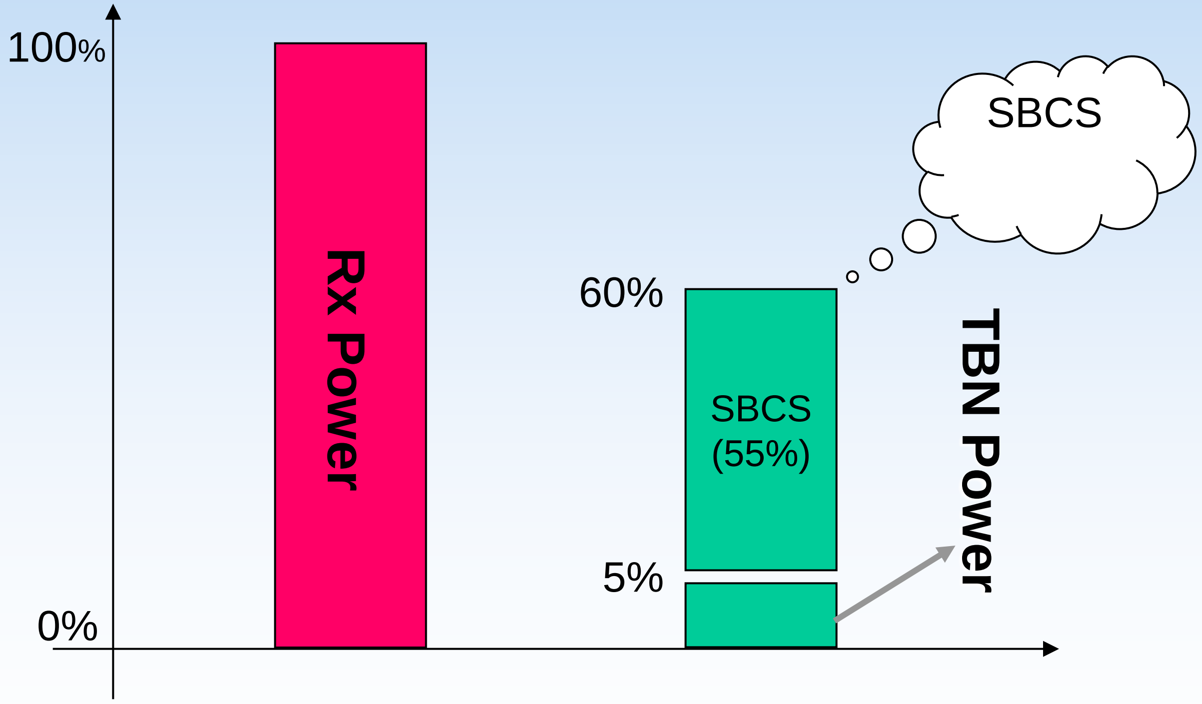


Rx power >> TBN Power

NSSS Control Systems - SBCS

□ SBCS + RPCS Operation Scenario

- Loss of Large Load(95%)

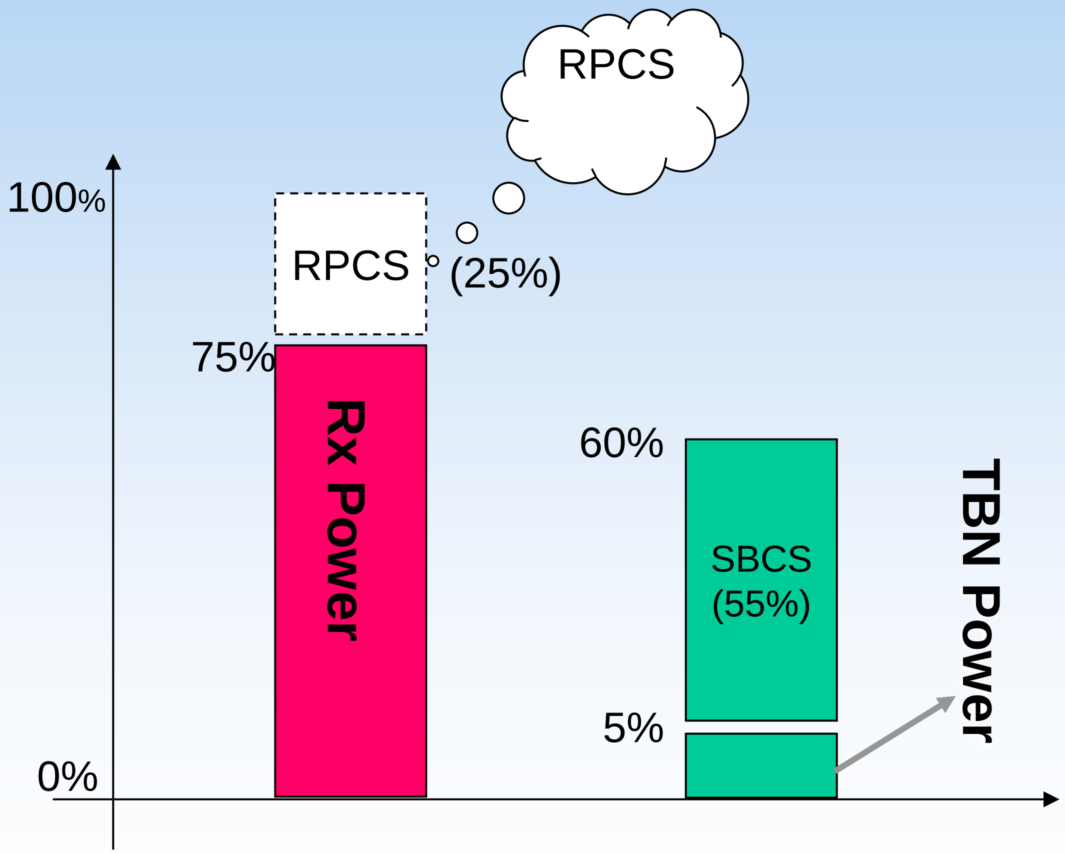


Rx power > TBN Power

NSSS Control Systems - SBCS

□ SBCS + RPCS Operation Scenario

- Loss of Large Load(95%)

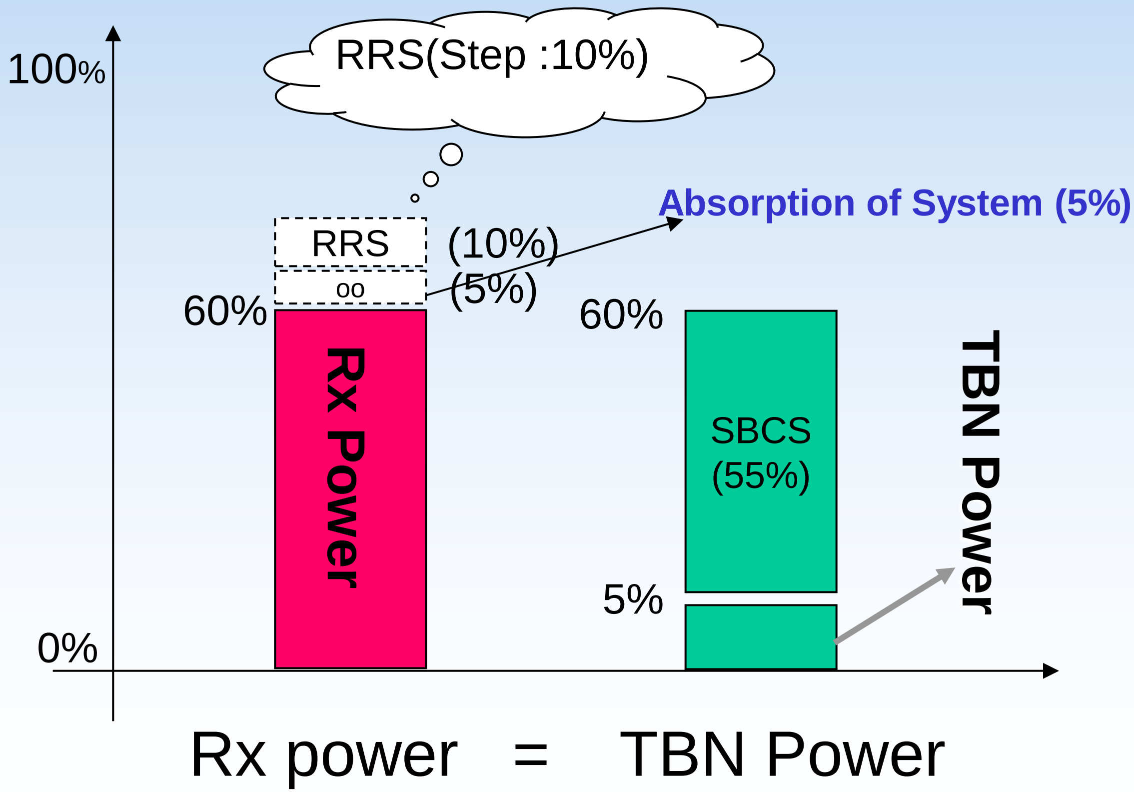


Rx power > TBN Power

NSSS Control Systems - SBCS

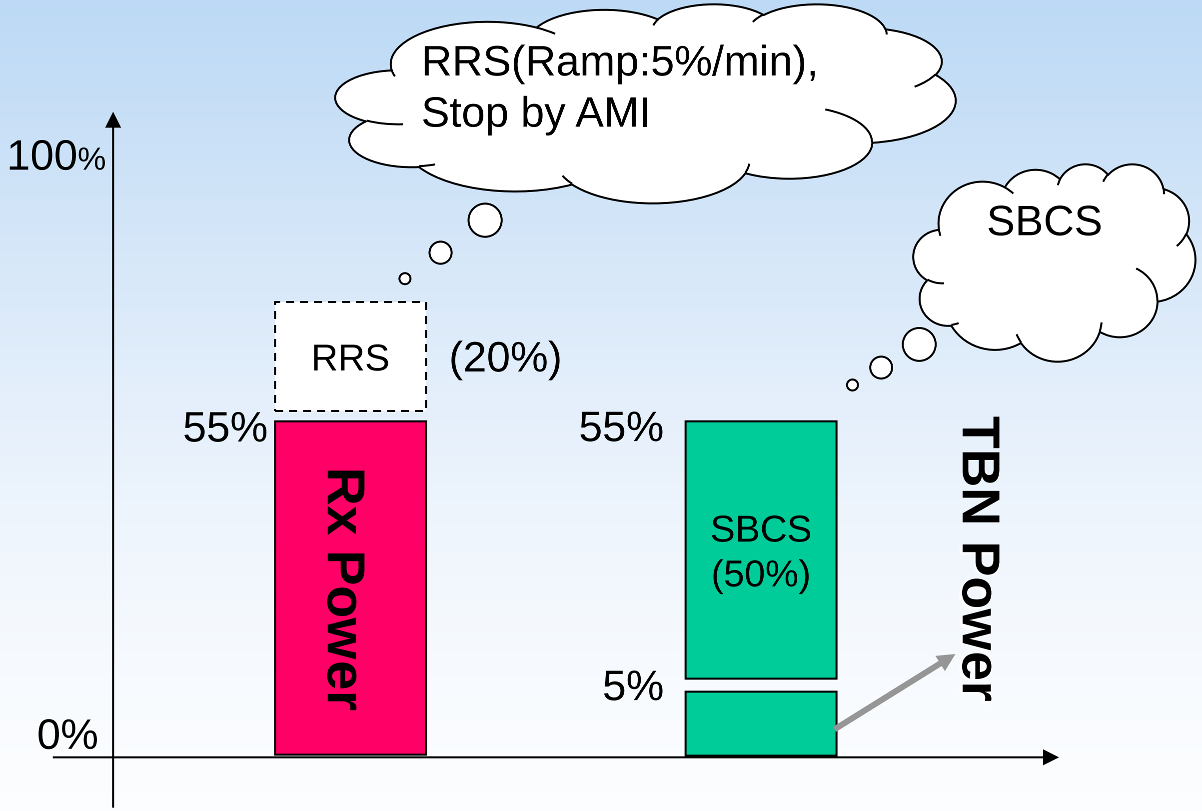
SBCS + RPCS Operation Scenario

- Loss of Large Load(95%)



NSSS Control Systems - SBCS

- SBCS + RPCS Operation Scenario
  - Loss of Large Load(95%)

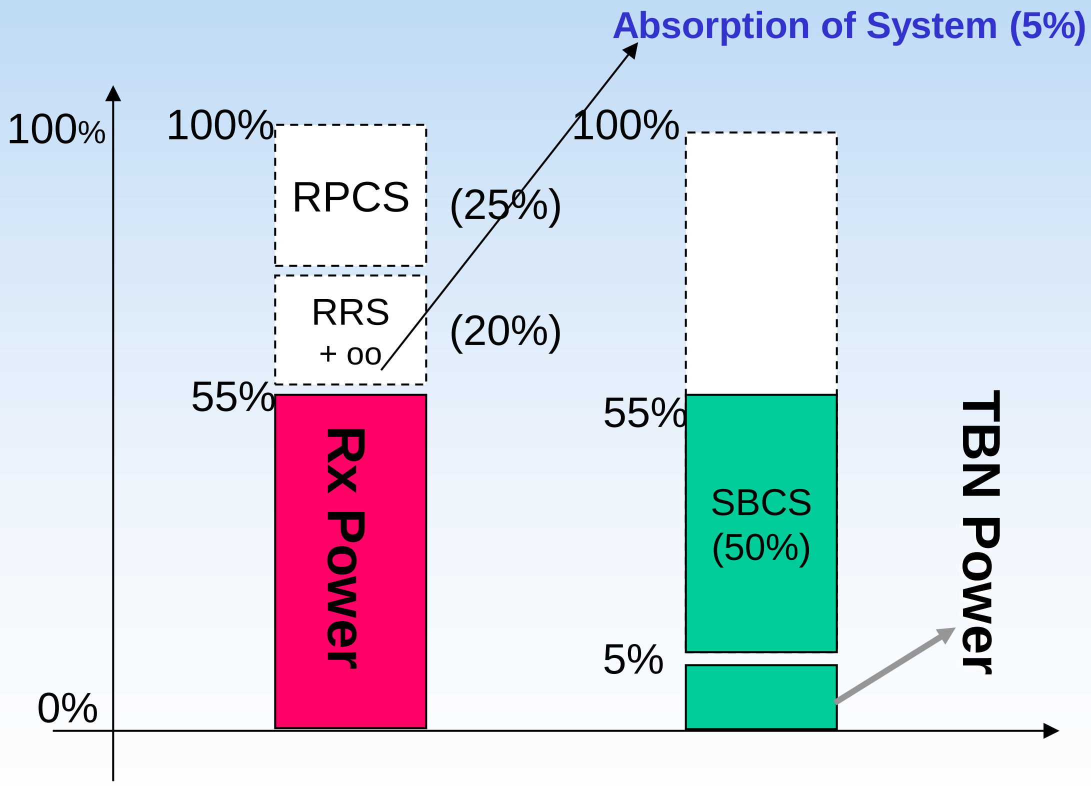


Rx power = TBN Power

NSSS Control Systems - SBCS

□ SBCS + RPCS Operation Scenario

- Loss of Large Load(95%)

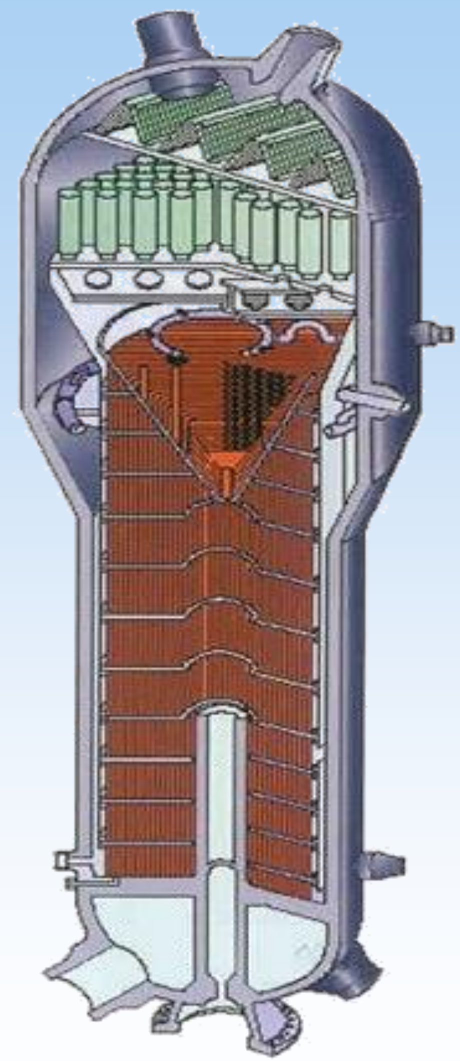


Rx power = TBN Power

NSSS Control Systems - FWCS ✓

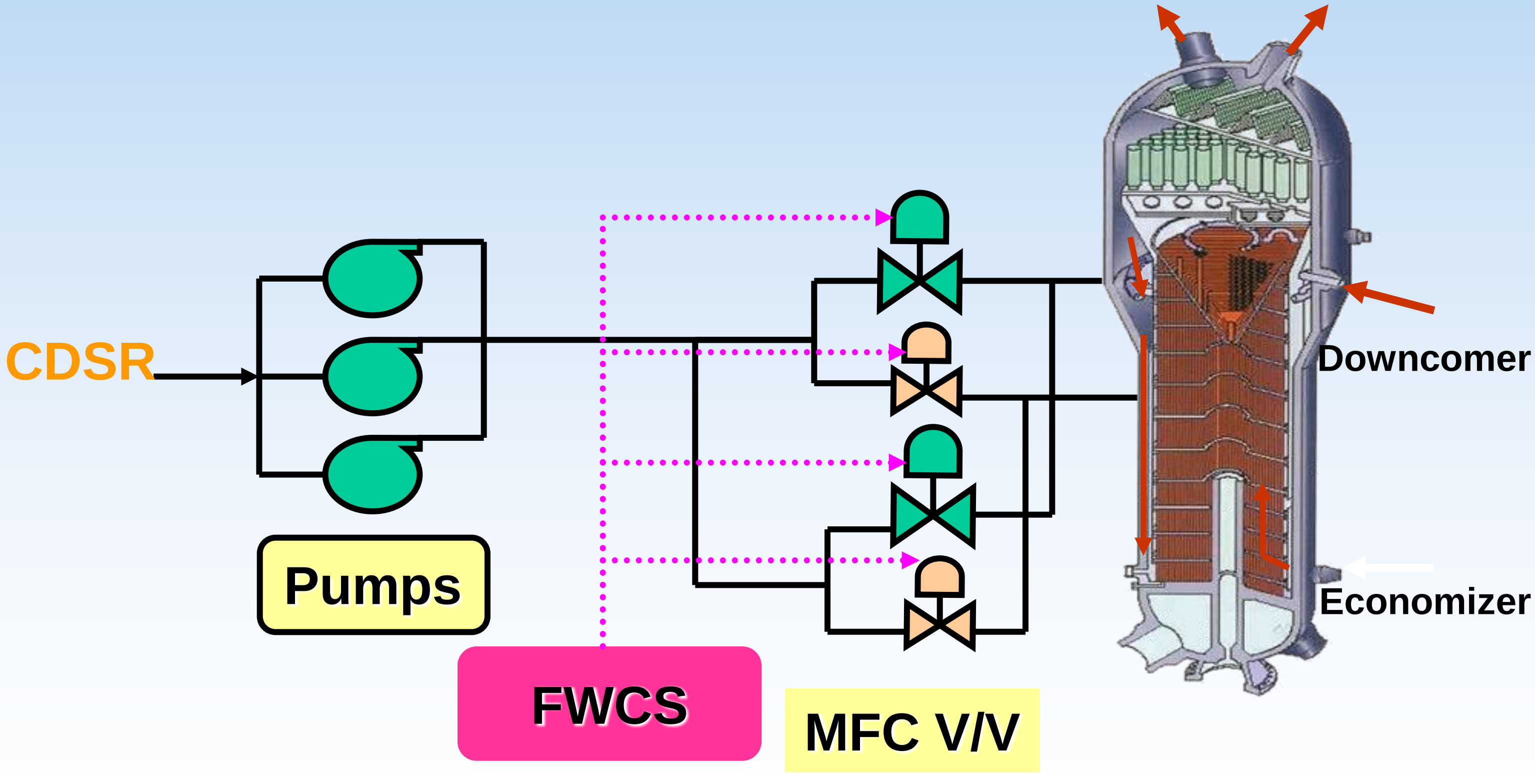
□ Feedwater Control System

- Regulating feedwater flow rate to its corresponding steam generator
  - by adjusting the position of feedwater control valves
    - Economizer
    - Downcomer
- Regulating the speed of operating feedwater pumps
  - by transmitting speed setpoint demand signal to the feedwater pump speed control system
- 1 FWCS is provided for the control of each S/G water level



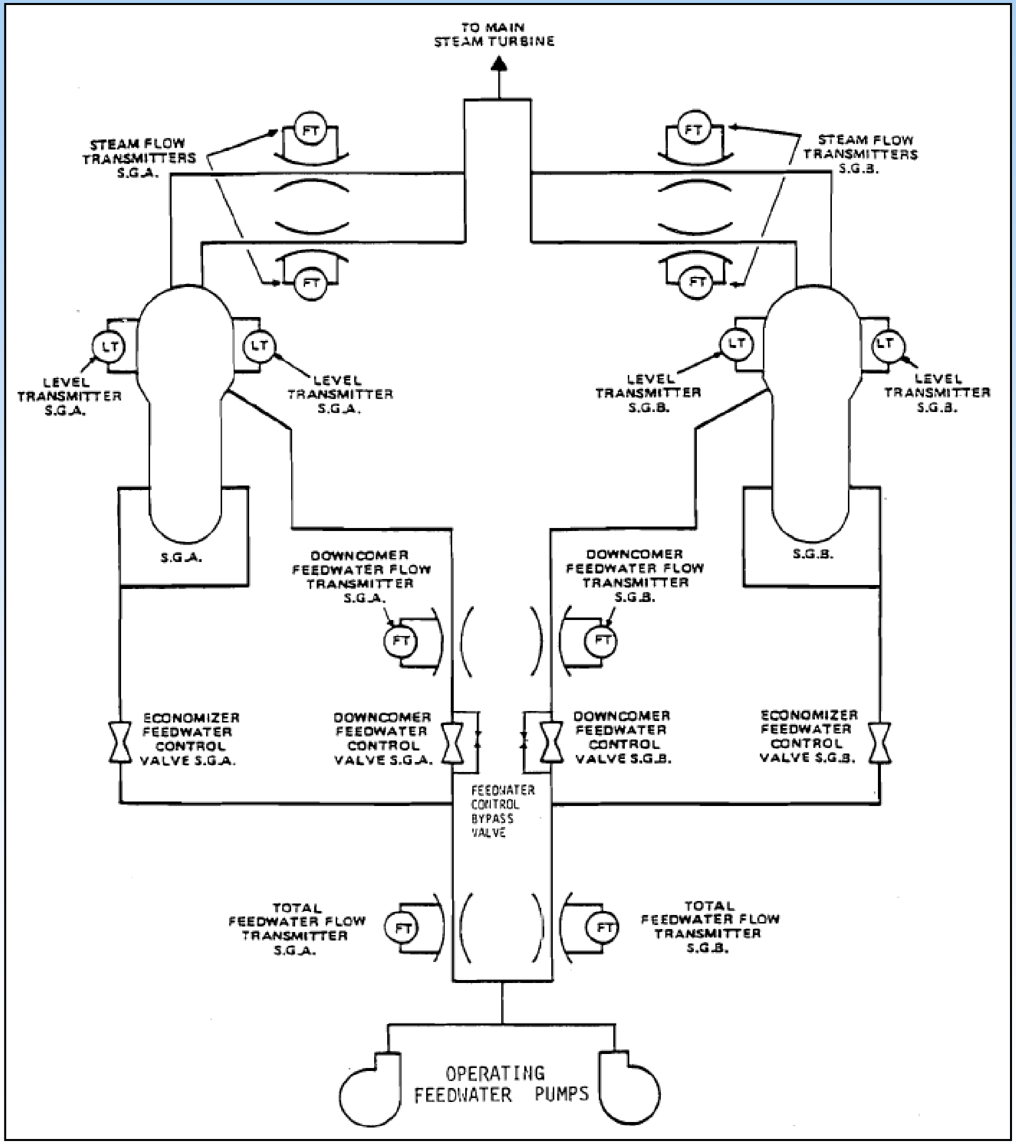
NSSS Control Systems - FWCS

- Feedwater Control System
  - Maintain steam generator level by regulating the feedwater flow rate



NSSS Control Systems - FWCS

- FWCS block diagram



NSSS Control Systems - FWCS

□ Design requirements

- Three Element Control
  - Reactor power > 15%
  - Input signal :
    - » S/G Level,
    - » Total Steam Flow,
    - » Total Feedwater Flow
- Single Element Control
  - Reactor power : between 5% and 15%
  - Input signal :
    - » S/G Level
- Feedwater Flow Control after Reactor Trip
  - Input signal :
    - » TAVG

NSSS Control Systems - FWCS

□ Design requirements

- Provides automatic control of S/G level during plant operation : 5%~100% power
  - ±1% step and ±1%/min ramp changes (5%~15% power)
  - ±10% step and ±5%/min ramp changes (15%~15% power)
  - Load rejection of any magnitude

- Provide automatic control of S/G level during abnormal plant operation
  - Reactor Trip
  - Loss of one feedwater pump during three pumps operation
  - S/G High Level

NSSS Control Systems - FWCS

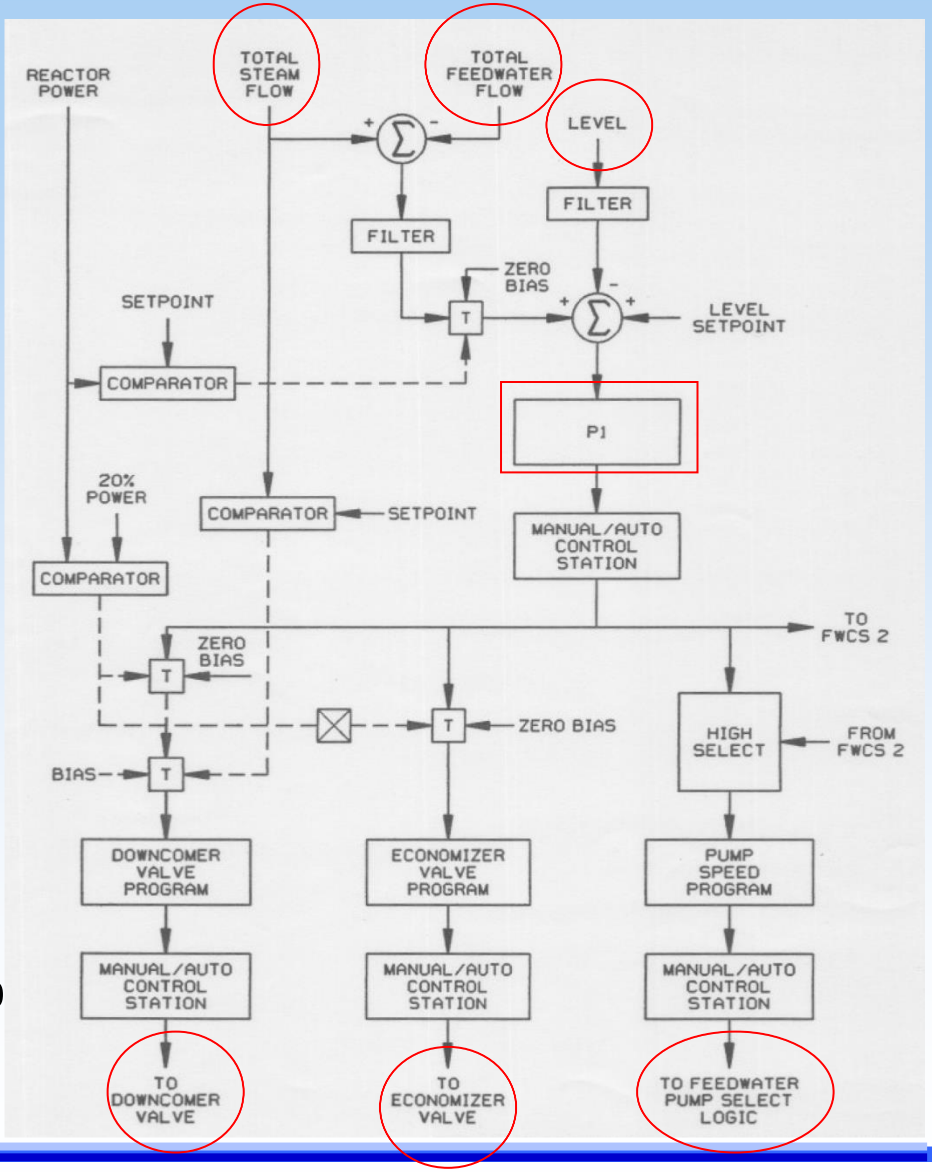
□ Controlled components

- Output Signals for Feedwater Control
  - Economizer Valve position Demand Signal
  - Downcomer Valve Position Demand Signal
  - Feedwater Pump Speed Demand Signal

- Automatic / Manual Control Capability

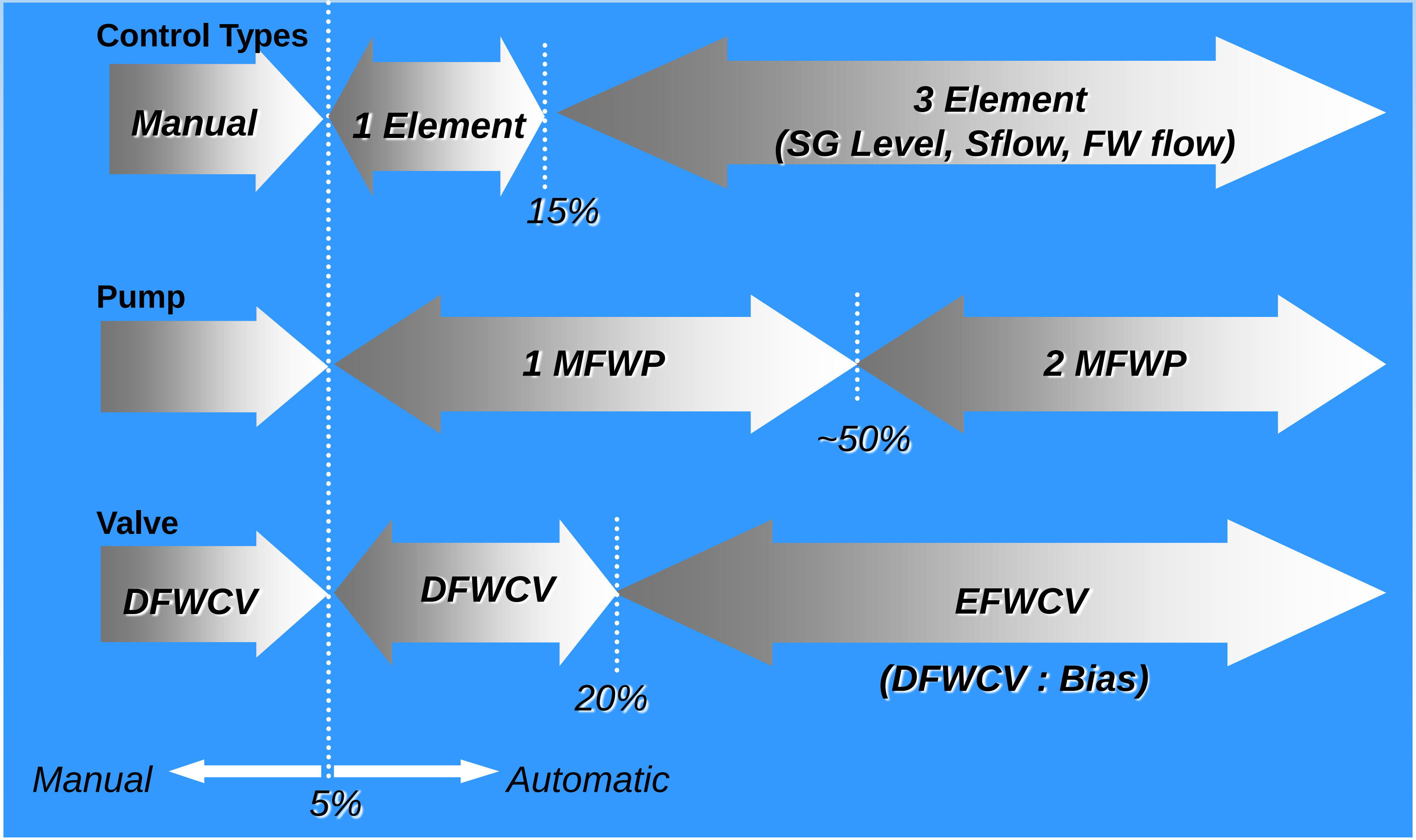
NSSS Control Systems - FWCS

- Block Diagram of FWCS
  - Input
    - S/G level
    - Total steam flow
    - Total feedwater flow
  - PI Controller
  - Output
    - Control downcomer v/v
    - Control ecomizer v/v
    - Control feedwater pump



NSSS Control Systems - FWCS

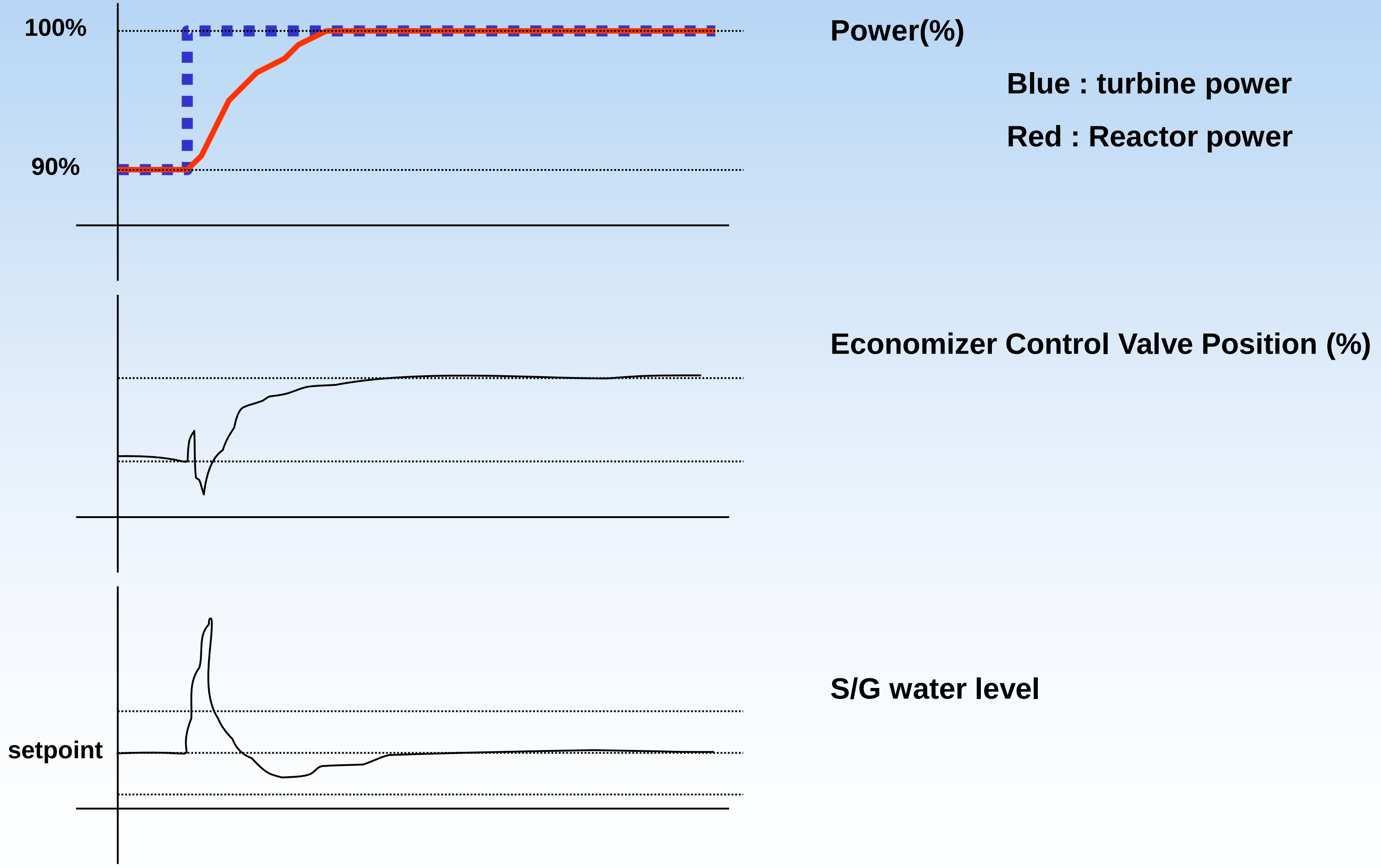
□ Feedwater Control Types Depending on Power



NSSS Control Systems - FWCS

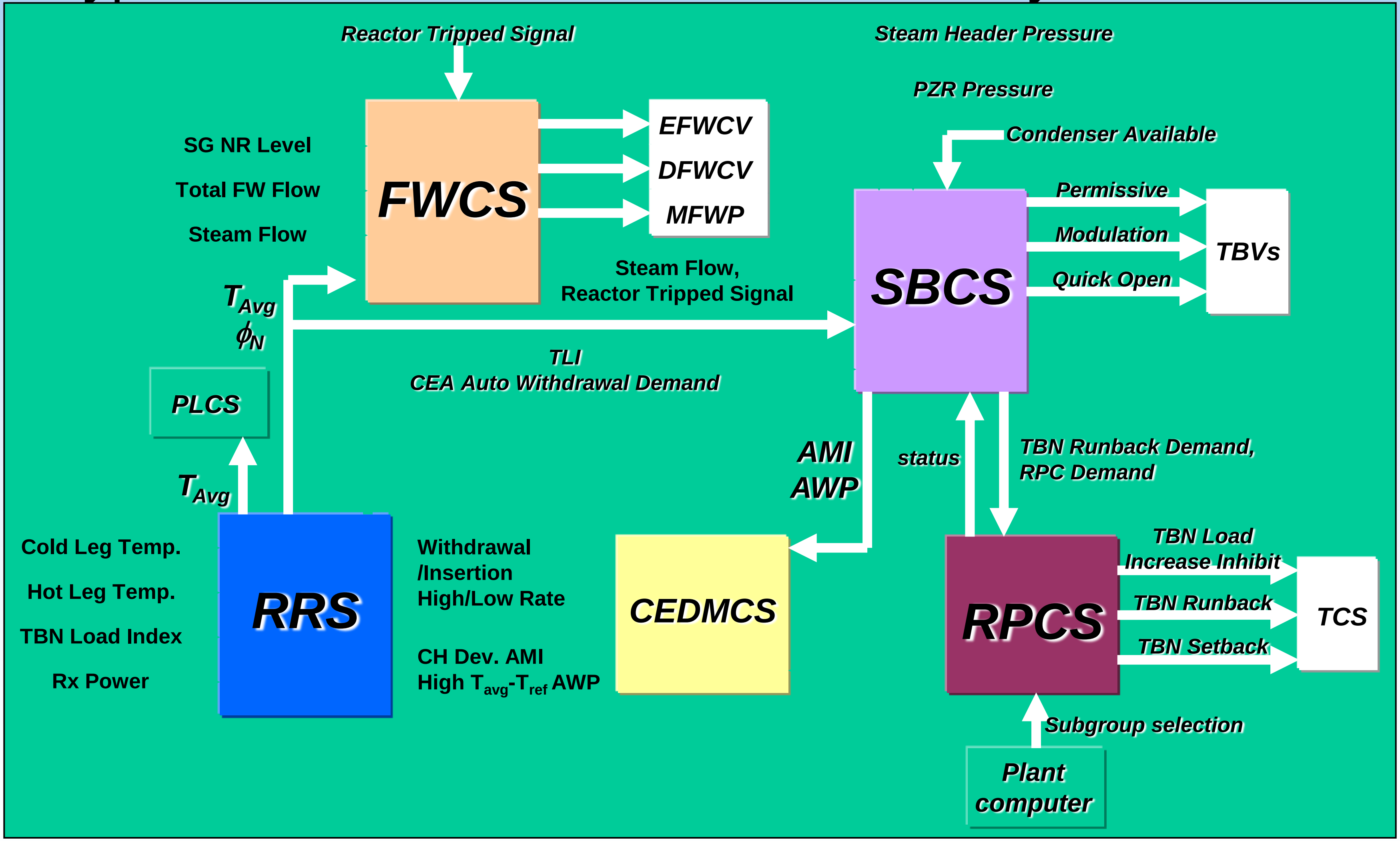
□ Design requirements

- 10% step changes



NSSS Control Systems - interface

□ Typical Interface within NSSS Control System



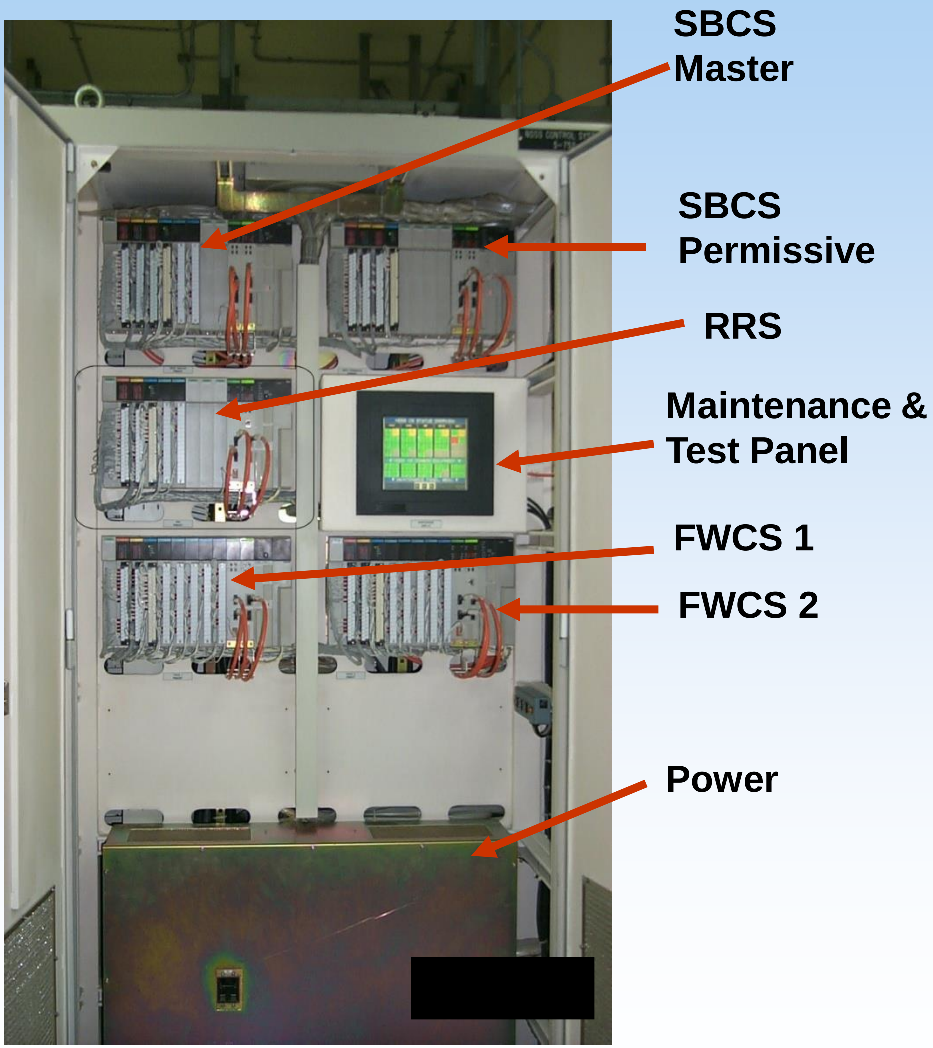
NSSS Control Systems - FWCS

□ Operation

- Low Power Operation
  - Single Element Control by Master PI Controller
  - Reactor power : between 5% and 15%
  - Input signal : S/G Level
- Normal Operation
  - Three element control by Mater PI Controller
  - Reactor power > 15%
  - Input signal : S/G Level, Total Steam Flow, Total Feedwater Flow
- After Reactor Trip
  - After the reactor is tripped, the feedwater flow rate is controlled by using the primary coolant loop average temperature (TAVG) signal
  - Flow demand signal is generated by PI function, its input is compensated TAVG signal

NSSS Control Systems

- Component of NSSS Control systems
  - PLC
    - Process control logic of each sub-system
    - Switching function if a component fails
    - Field I/O modules
    - Networking
  - IBM Compatable PCs
    - Drive FPD
  - FPD (Flat Panel Display)
    - Test & Maintenance
    - Display & Indication
    - 10.4” Color Touch Screen



Always we keep watching
our Atomic Power

Name : Booh, In Hyoung
E-mail : k307bih@kins.re.kr

Thank You

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