P B M R

# *Automation System*

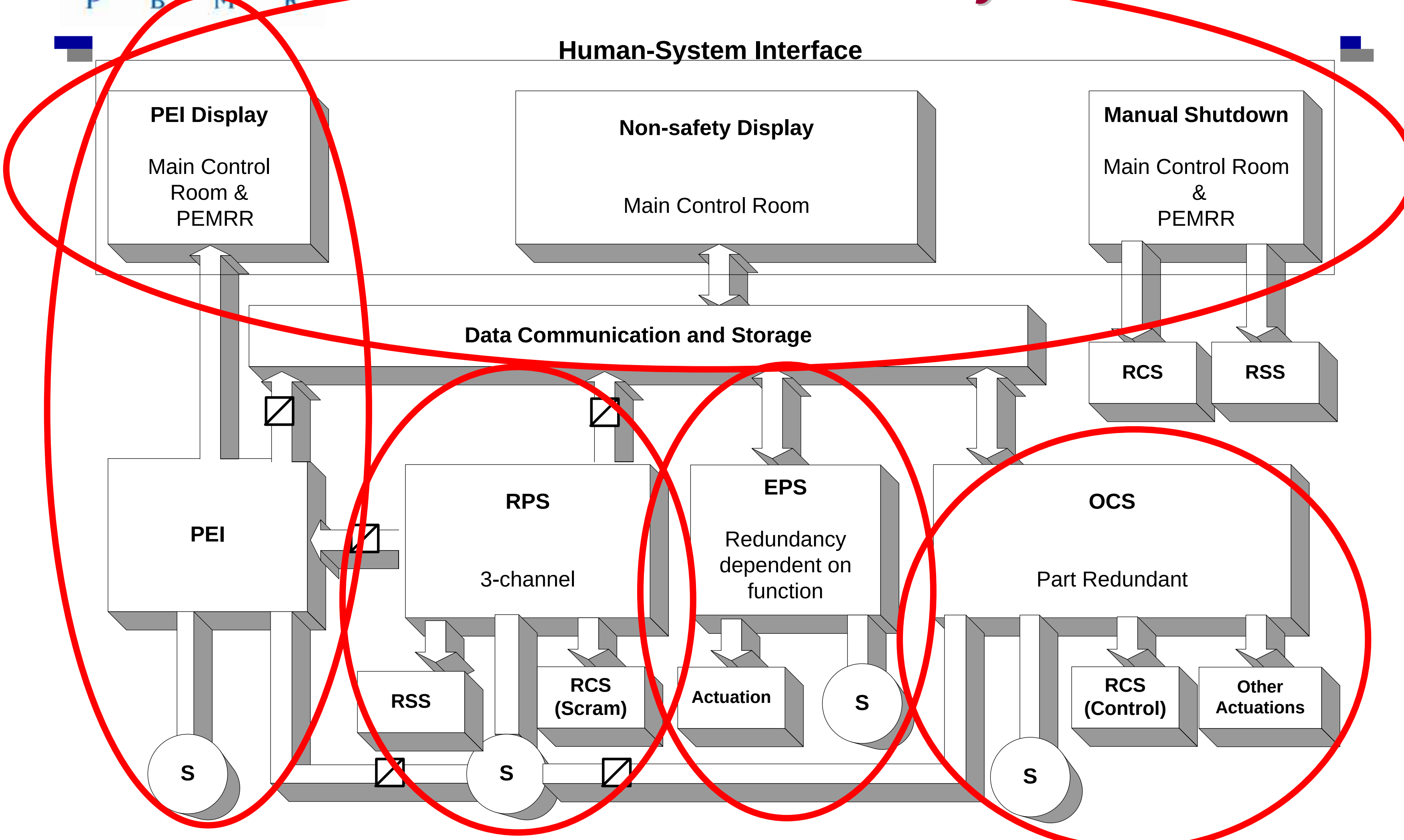
**Dr. Charles L. Kling**

- **Automation System (AS) Overview**
- **Description**
  - **Human-System Interface (HSI)**
    - ***Main Control Room (MCR)***
    - ***Post-Event Monitoring and Recovery Room (PEMRR)***
  - **Post-Event Instrumentation (PEI)**
  - **Operational Control System (OCS)**
  - **Activity Measurement System (AMS)**
  - **Burn-up Measurement System (BUMS)**
  - **Core Instrumentation**
  - **Equipment Protection System (EPS)**
  - **Reactor Protection System (RPS)**

# Automation System Overview

- **Design Bases**
  - Plant shall be controlled within its defined and safe operating envelope.
  - Design shall comply with regulatory requirements.
  - Number of operators shall be minimized.
  - Modern control system technology shall be applied to ensure longer operating life cycle and design for system upgrading as technology develops.
  - System must be of integrated and modular design.
  - Plant reliability and availability shall be enhanced to ensure a single failure does not cause plant shutdown.
  - Effective levels of plant investment protection shall be provided

# System Overview




S = Sensors
EPS = Equipment Protection System
RPS = Reactor Protection System
OCS = Operational Control System
RCS = Reactivity Control System
RSS = Reserve Shutdown System
PEMRR = Post-Event and Recovery Room
⍁ = Isolation

# Human-System Interface

- **Description**
  - Main Control Room (MCR) and Post-Event Monitoring and Recovery Room (PEMRR).
- **Design Basis**
  - The MCR provides a central control area for the operator to:
    - *Monitor the power plant*
    - *Control the power plant*
    - *Perform preventative and corrective maintenance*
    - *Perform calibration and testing*
    - *Perform event recovery*
    - *Perform diagnostic tasks*
    - *Perform routine control room tasks*

- **Design Basis (cont.)**
  - With the MCR non-functional, the PEMRR provides:
    - *Capability to shut down the reactor*
    - *Seismically qualified instrumentation and controls to*
      - Maintain the unit in a safe condition during shutdown
      - Monitor the reactor in cases where the MCR is not functional
    - *Habitability during and following all DBAs.*
    - *Location in a seismically qualified structure*

# Main Control Room

- **3 individually definable wide display panels**
- **Operator control desk:**
  - Displays all operational information
  - Provides PEI/RPS display panels, hard controls with diverse displays, and plant-wide communication devices
- **Supervisor control desk displays all operational information**

# Control Room

# Post Event Monitoring and Recovery Room

- Control desk for emergency operations
- Facilities to house all necessary procedures and information to support the operator's task during and after an upset event.
- A habitable environment in which the operator can monitor the plant and recover from upset events

# Post-Event Monitoring and Recovery Room

# Post-Event Instrumentation

- **Function**
  - Provides information displays to operators during normal operation, during and following DBAs, to enable them to assess the safety status of the plant
- **Design Basis**
  - Electrically powered from a UPS for 24 h
  - U.S. NRC RG 1.97 used as a guide
  - Provide information to operators in support of manual RS and RSS actuation.
  - Provide system inoperability status indication
  - Provide system bypassed indication
  - Provide information about plant status during and after DBAs

# PEI Functions

| Function | Variables |
| --- | --- |
| Provide system bypassed indication | Battery-powered system supply;<br>RPS, including its execute features; and<br>any other auxiliary or supporting system that effectively renders inoperative the safety functions of the RPS. |
| Provide information about plant status during and after DBAs | RPS status<br>Reactor Cavity Cooling System (RCCS) water level status<br>Pressure relief shaft damper status<br>Variables to indicate reactor shutdown status<br>Variables to indicate the effectiveness of residual heat removal<br>Variables to indicate the status of primary coolant pressure retention<br>Variables to indicate the status of radioactivity containment<br>Variables to indicate the conditions inside the reactor cavity and other areas<br>Variables to indicate the radiological release to the environment |

# Operational Control System

- Closed loop control of plant variables
- Performs non-safety plant protection, control monitoring and data recording
- Diverse platform for the shutdown of the reactor
- Process interlocking
- Display of process and plant information to operators for plant supervision and control
- Execution of operator commands
- Data storage

# OCS Automation Units

| Automation Unit | Plant Area |
|---|---|
| Main Helium Loop | Redundant controllers to control Brayton cycle start-up and continuous plant operation. It includes the control of the reactor, compressors, main turbine-alternator set, and Active Cooling System (ACS). |
| Fuel Handling and Storage System (FHSS) | Non-redundant controller to control all functions related to the fuel handling |
| Helium Inventory Control System (HICS) | Redundant controllers to control all functions related to the helium inventory control |
| Compressor and turbine control | Fast-acting redundant controllers to perform compressor anti-surge control on the turbo-unit compressors and helium blowers |
| Analytical instrumentation interfaces | Handles the special interfaces to analysers and analytical instrumentation. No redundancy is provided. |
| Test and Evaluation | Non-redundant automation unit for the once-off test and evaluation measurements |

# OCS Closed Loop Controls

- **Automatic functions to regulate plant operating conditions within prescribed limits**
  - Reactor Outlet Temperature (ROT)
  - Reactor Inlet Temperature (RIT)
  - Recuperator Inlet Temperature (RECIT)
  - Helium Inventory
  - Reactor neutronic power
  - HPC System pressure
  - Compressor surge margin
  - TGS speed control
  - CCS decay heat control
  - CBCS heat removal control
  - Long-term reactivity control

# Operational Control System

- **Other process controls and tasks**
  - Reactivity shutdown margin monitoring
  - Reactor core neutron flux distribution alarms
  - Reactor approach-to-criticality and start-up operations support
  - Helium Pressure Boundary (HPB) leak alarms
  - Fuel handling / pebble inventory control

# Operational Control System

- **Design Basis**
  - Commercial quality, distributed control system that performs automated plant control, monitoring of plant and process variables, and data storage
  - Redundant networks and controllers prevent plant shutdown due to single sensor or component failure
  - Allows for successive hardware and software upgrades during the productive life of the plant
  - Uses design requirements of IEEE 603-1991 for system independence/shared sensors
  - Implemented on a diverse platform from the RPS

PBMR

# *Activity Measurement System*

- **Description**
  - Wide-range gamma sensitive ionization chamber
  - Check source
- **Function**
  - Measure the dose rate emitted by fuel spheres
  - Categorize the spheres as either fuel or graphite

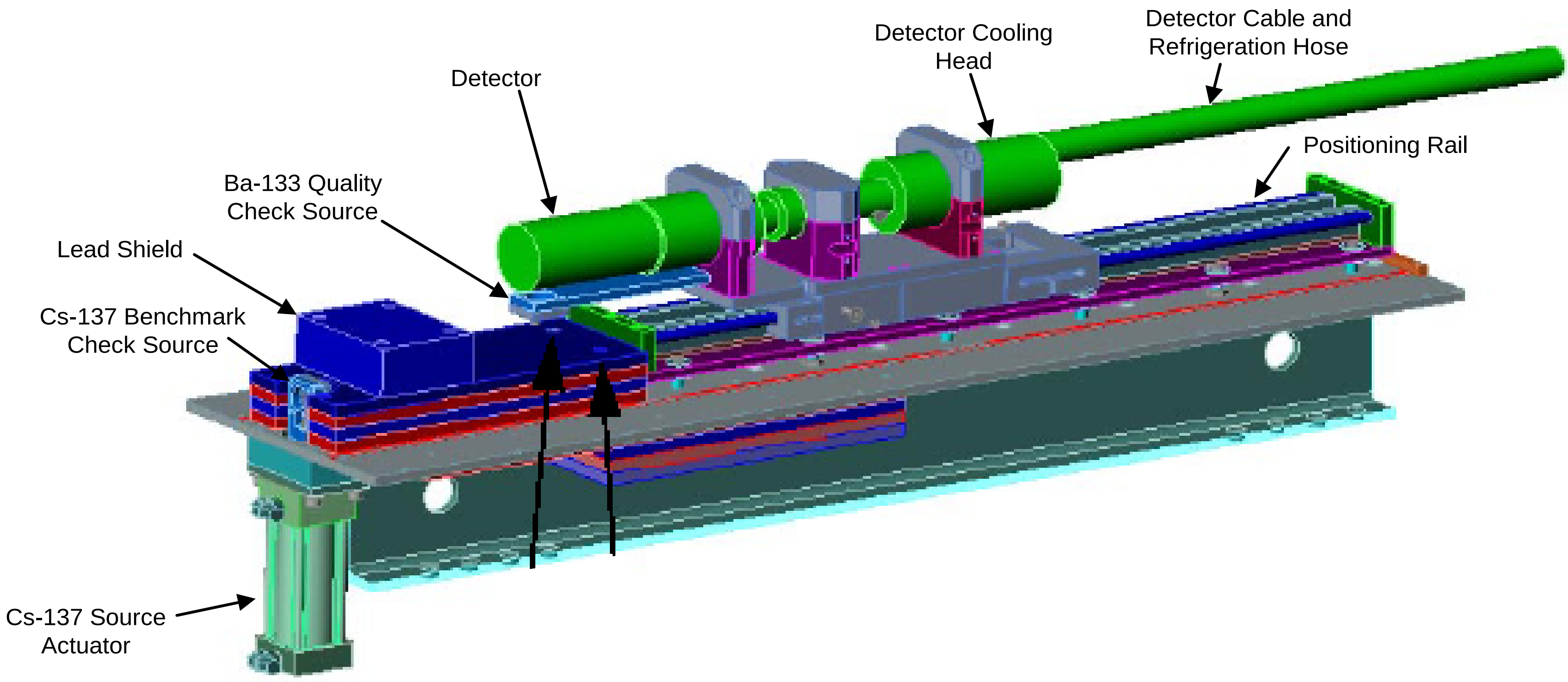
# Burn-up Measurement System

- **Description**
  - Measures the burn-up of PBMR fuel spheres
  - Cryogenic, High Purity Germanium (HPGe) detector assembly
  - Digital Signal Processor (DSP) based burn-up analysis system
  - Photon collimator
- **Description**
  - Classify spheres as:
    - *Used fuel (burn-up < target) or*
    - *Spent fuel (burn-up > target)*
  - Measure target burn-up with fuel sub-criticality delay time as short as 40h
  - Evaluate burn-up of a fuel sphere, based upon the inventory of Cs-137
  - A test irradiated fuel sphere will be used as the calibration source.

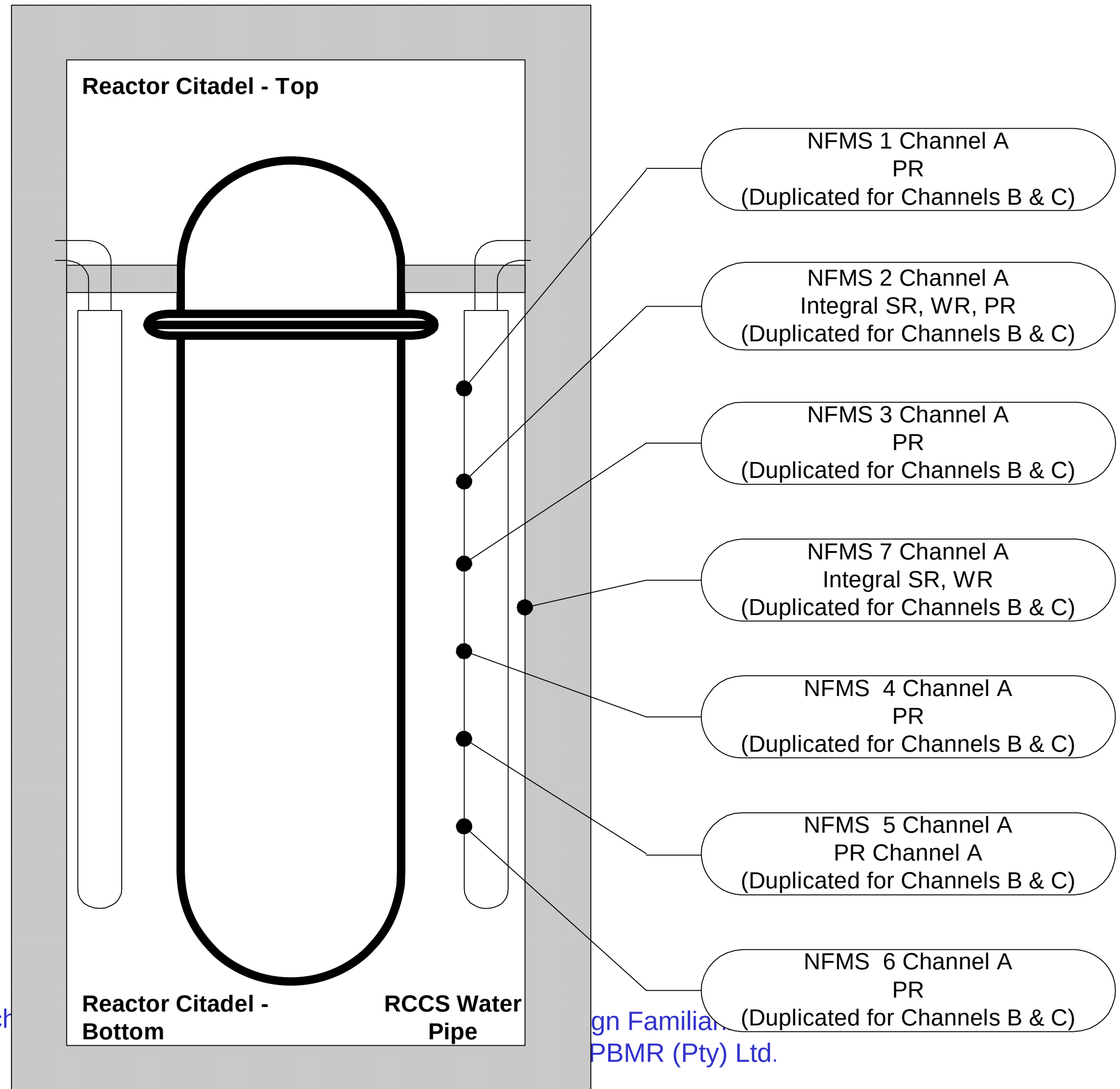
# BUMS Qualification Program

- **Test series using irradiated SAFARI-1 fuel elements proved the measurement principle employed in the BUMS for the PBMR.**
- **PBMR is planning a BUMS test programme to:**
  - Validate burn-up measurement of irradiated fuel similar to PBMR fuel
  - Validate gamma spectrometry methods for fuel of different enrichment
  - Determine the repeatability/statistical distribution in measurement accuracy
  - Determine BUMS sensitivity to misalignment
  - Determine effects of background radiation
  - Provide fuel spheres of known burn-up to develop an accurate burn-up measure
  - Generate calibration irradiated fuel spheres for BUMS

# Burn-up Measurement System



# Ex-Core Neutron Detector Arrangement

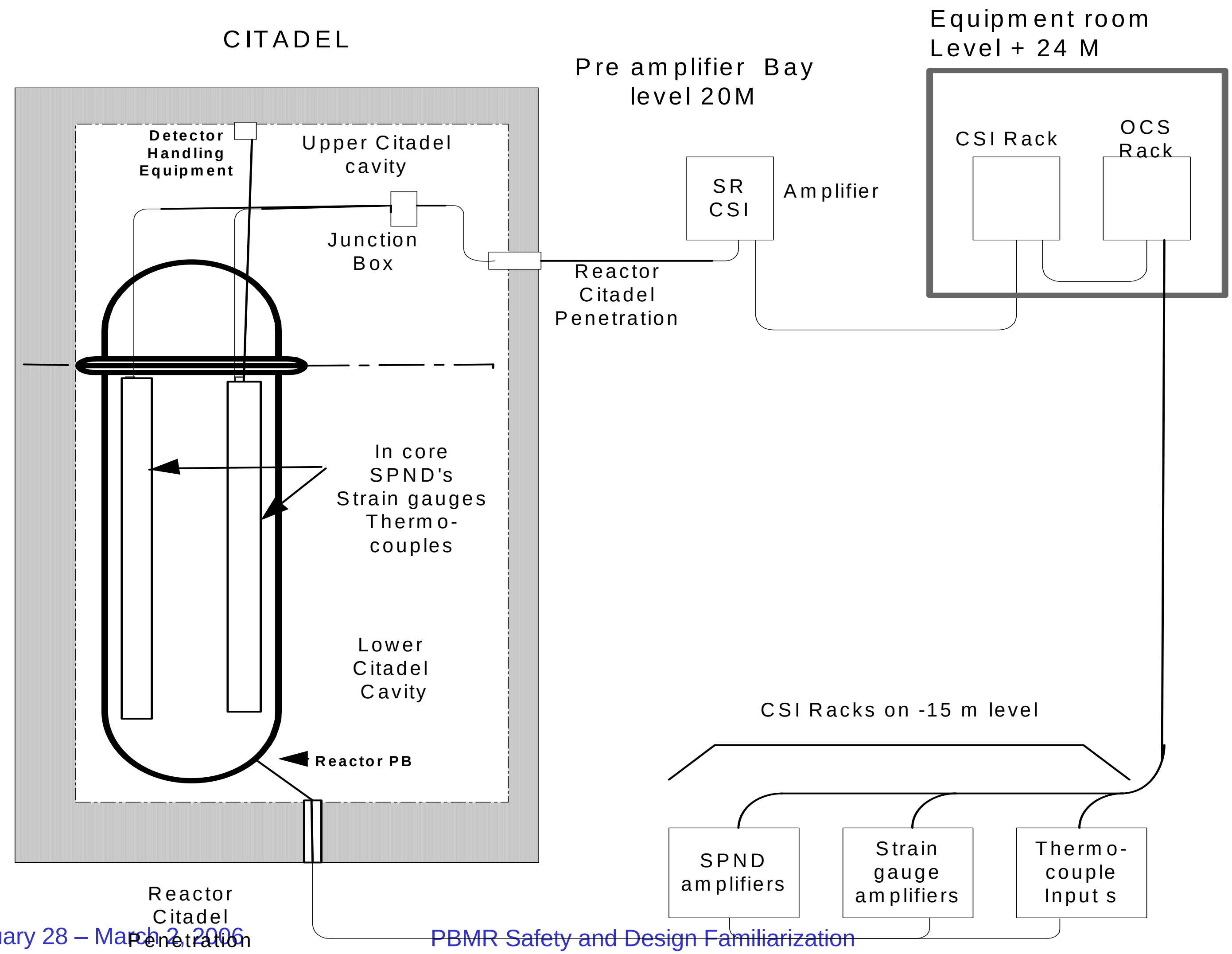


# DPP Core Structures Instrumentation (CSI) Functions

## Primary function of CSI is for validation

- In Core Source Range flux measurement for approach to criticality and initial start-up
- In Core measurement of neutron flux distribution
- In Core measurement of temperature distribution in graphite structures and core barrel
- Measurement of stresses in the Core Barrel (CB) and Core Barrel Support Structures (CBSS)
- Displacement measurement of CB top plate and CBSS

# Scope Of Special DPP CSI



# Special DPP Detector Location

| | | | |
|---|---|---|---|
| Source Range Detectors | | 3 Arranged symmetrically at 120º | Side Reflector (SR) |
| Self-Powered Neutron Detectors (SPND) | 30 | 3 Symmetrical Banks of 2 X 5 elevations @ 120º | 15 Inner SR<br>15 Outer SR |
| Thermo-couples | 15 | 3 Symmetrical Banks of 5 | Central Reflector |
| | 15 | 3 Symmetrical Banks of 10 | Inner SR |
| | 15 | 3 Symmetrical Banks of 10 | Outer SR |
| | 39 | 3 Symmetrical Banks of 12<br>At 7 heights + other locations on 0º azimuth | Bottom Reflector |
| | 30 | 3 Symmetrical Banks of 10 | Top Reflector |

# Equipment Protection System (EPS)

- **Function**
  - Protects systems and equipment identified as significant owner investment due to OCS failure
- **Description**
  - Monitors the equipment and initiates plant shutdown when the established limits are exceeded
  - For the PCU this entails initiation of a MPS shutdown (i.e., termination of the Brayton cycle by opening gas cycle bypass valves, and insertion of the control rods).
  - Overrides all OCS command to the control rods and bypass valves until the operator issues a reset command

# EPS Protective Functions

| SSC Protected | Protective Function | |
|---|---|---|
| Turbo Generator Set | Overspeed | MPS shutdown when overspeed is detected |
| | Vibration | MPS shutdown when excessive vibration is detected |
| | Axial displacement | MPS shutdown when excessive axial displacement is detected |
| | Bearing status | MPS shutdown when bearing failure, or conditions indicative of bearing failure progression is detected |
| | Bearing oil supply failure | MPS shutdown when a failure in bearing oil supply is detected |
| | Turbine high inlet temperature | MPS shutdown when a high turbine inlet temperature is detected |
| | Turbine high exhaust temperature | MPS shutdown when high turbine exhaust temperature is detected |
| | Blade path temperature spread | TBD |
| | Dry gas seal | MPS shutdown when failure of the primary or secondary dry gas seal is detected |
| | Electrical system trip | MPS shutdown when an electrical system trip is detected.<br>Note: The trip system is generated by the EPS. |
| | Slow acceleration during run-up | MPS shutdown when the speed in critical regions exceed predefined set points |

# EPS Protective Functions

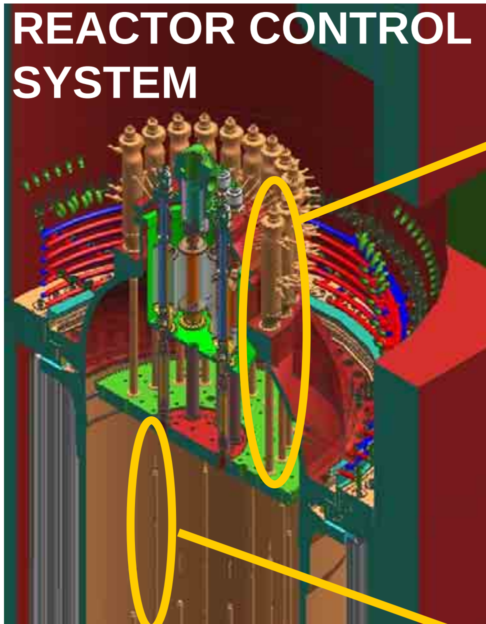
| SSC Protected | Protective Function | |
|---|---|---|
| High Pressure Compressor (HPC) | HPC surge | MPS shutdown when predefined surge margin limits are exceeded |
| | HPC high inlet temperature | MPS shutdown when high HPC inlet temperature is detected |
| Low Pressure Compressor (LPC) | LPC surge | MPS shutdown when predefined surge margin limits are exceeded |
| | HP compressor high inlet temperature | MPS shutdown when high LPC inlet temperature is detected |
| Recuperator | High inlet temperature | Later |
| Reactor | High reactor inlet temperature | Later |
| | High reactor temperature differential | Later |
| Operational Control System (OCS) | Failure of MPS controllers | Later |
| Operator | Manual MPS shutdown | MPS shutdown when the operator command is received |

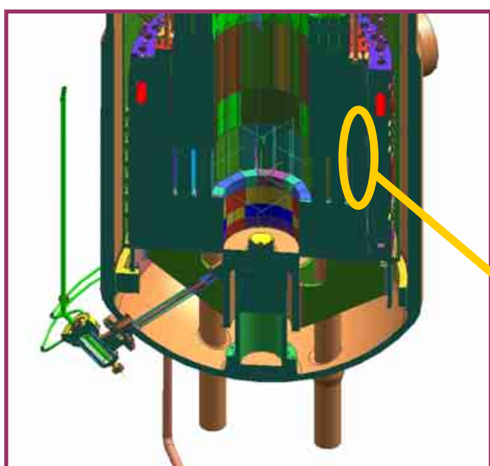
- **Design Basis**
  - IEC 61508 and ISA Standard S84 are used as a guideline for allocating integrity level to each function.
  - Redundant networks and controllers are provided to prevent plant shutdown due to single sensor or component failure.

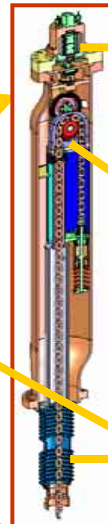
# Reactor Protection System (RPS)

- **Description**
  - Comprised of three redundant channels
  - CRS → Gravitational insertion of 12 control rods
  - RS → Gravitational insertion of 12 control and 12 shutdown rods
  - RSS → Reserve Shutdown System
- **Design Basis**
  - Maintain reactor heat production within safety limits by automatically shutting down the reactor and assuring long-term sub-criticality for all DBAs
  - Designed and qualified for the full range of environmental conditions during all DBAs, including an SSE
  - Class 1-E COMMON Q PLATFORM
  - Electrically powered from an Uninterruptible Power Supply (UPS)
  - Uses the requirements of IEEE 603-1991 and IEEE ANSI 7-4.3.2
  - Software development guidance provided by RG 1.168, Rev. 1, RG 1.169, RG 1.170, RG 1.171, RG 1.172 and RG 1.173

# Reactivity Control and Shutdown System





**RCS Drive Motor**

The main function is to keep the RCS rods in position, move the rods up and down and allow insertion during power failure.

**Control Rod Drive Mechanism (CRDM)**

Transfer rotational movement of the RCS motor into linear movement of the control rods.

**RCS Guide Tube**

Connects the CRDM housing and the Core Structures and serves as guide for the rod between the CRDM and the Core.

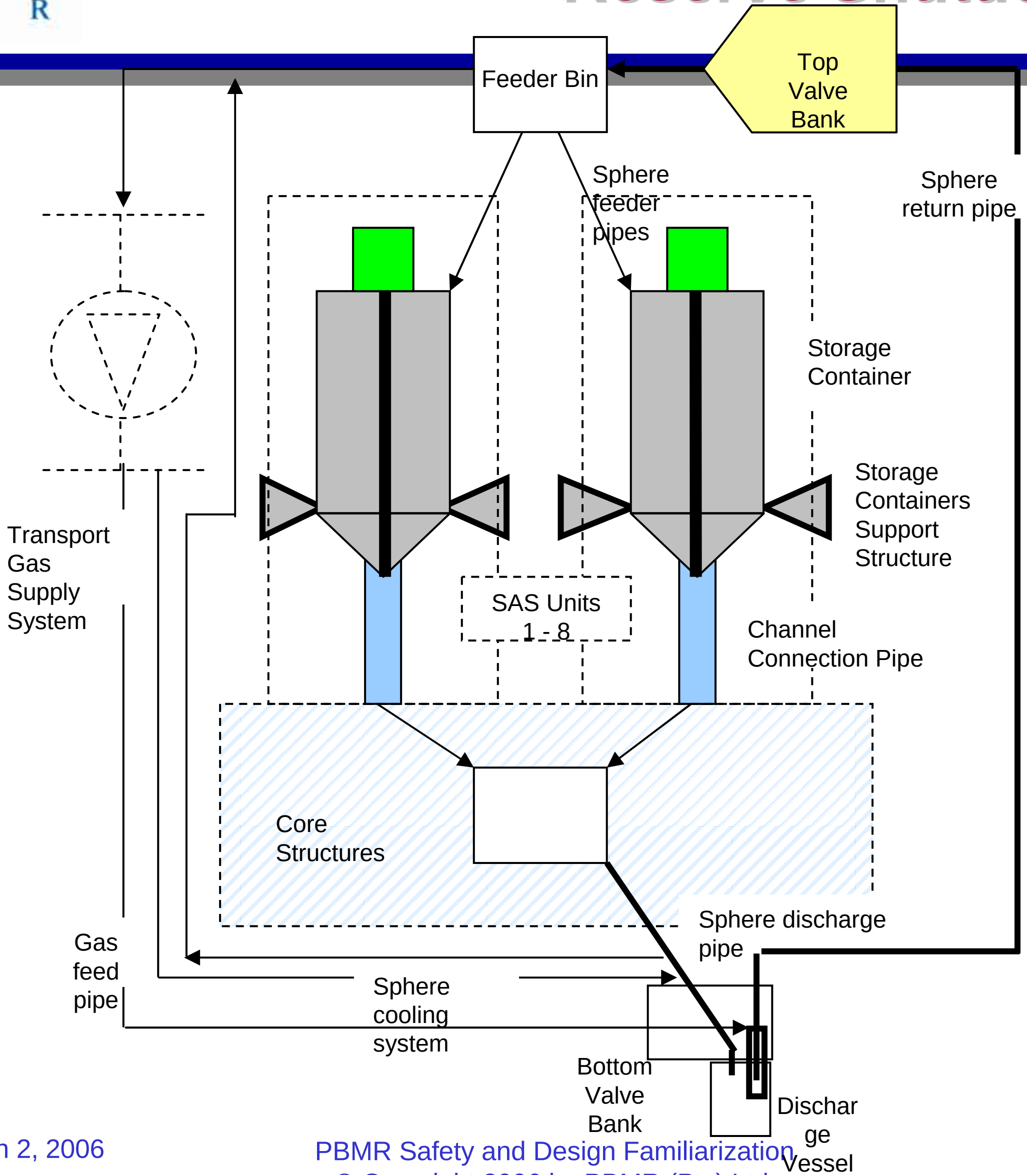
**Control Rod & Chain**

The function of the Control Rod is to absorb neutrons inside the core whereas the chain connects the CRDM and the Control Rod.

**Secondary Shock**

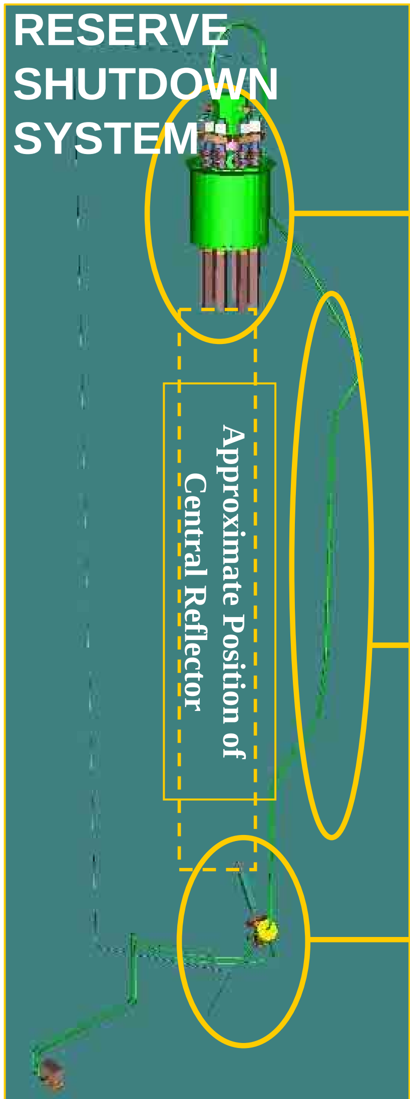
The function of the Secondary Shock Absorber is to prevent damage on the Rod and the Graphite Core Sleeve in the inadvertent event of a rod drop.

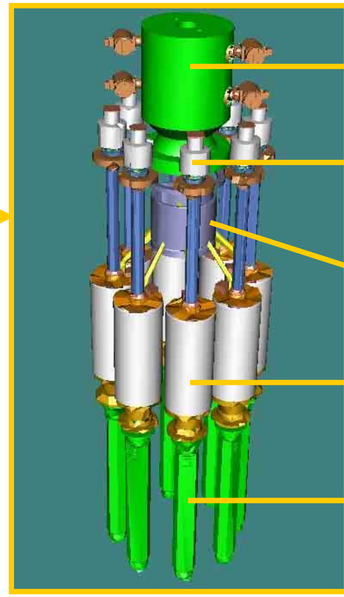
# Reserve Shutdown System

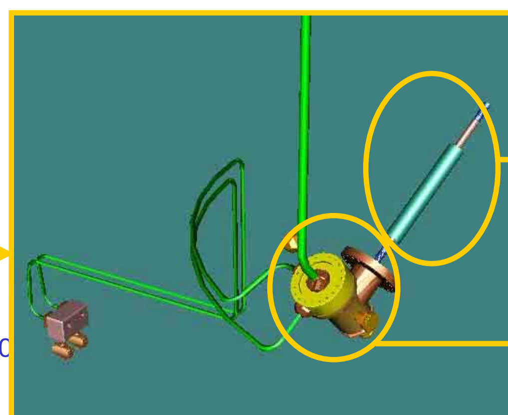


PBMR

# Reserve Shutdown System





- **RSS Valve** → **Responsible for separating SAS from conveying gas stream.**
- **Valve Actuator Ass.** → **Responsible for insertion of SAS into borings. Designed fail-to-safe.**
- **Feeder Bin** → **Responsible for overfill and distribution of SAS to containers.**
- **SAS Container** → **Stores $B_4C$ SAS ready for insertion into borings. 8 containers, 400,000 SAS ea.**
- **SAS Guide Tube** → Coaxial tube connecting SAS container to core barrel top plate. Responsible for guiding SAS into borings inside central reflector
- SAS Return Pipe → **Coaxial pipe fixed to outside of RPV for pneumatic conveying of SAS to the top of the reactor**
- **SAS Discharge** → Coaxial tube responsible for guiding SAS from the borings inside central reflector to the Discharge Vessel
- **Discharge Vessel** → Vessel situated on RPV responsible for stopping SAS flow from the borings and fluidizing SAS for conveying to the top of the reactor

# RPS System Functions

| TRIP FUNCTION | TYPE | SETPOINT* |
|---|---|---|
| Reactor overpower | CRS | ~105% |
| | RS | ~110% |
| | CRS | ~103% integrated over 8 hrs. |
| Primary coolant over-temperature | CRS | ~925ºC |
| | RS | ~935ºC |
| Excessive reactor power increase | CRS | Excessive power increase rate |
| Loss of forced cooling | CRS | Time delay following ΔP loss across reactor |
| Loss of primary coolant | RS | Time delay following pressure loss |
| Earthquake detected | RS | Following SSE |
| | RSS | Following SSE |

*Setpoint values are representative and may change

# Manual Diverse Shutdown System

- **Description**
  - Hardwired, relay logic-based system directly connected to the reactor trip switchgear
  - Enables operators to manually initiate reactor trip functions from both the MCR and PEMRR.
  - 3 redundant channels physically and electrically separated from each other.
  - Trip functions include control/shutdown rod and small absorber sphere insertion respectively.

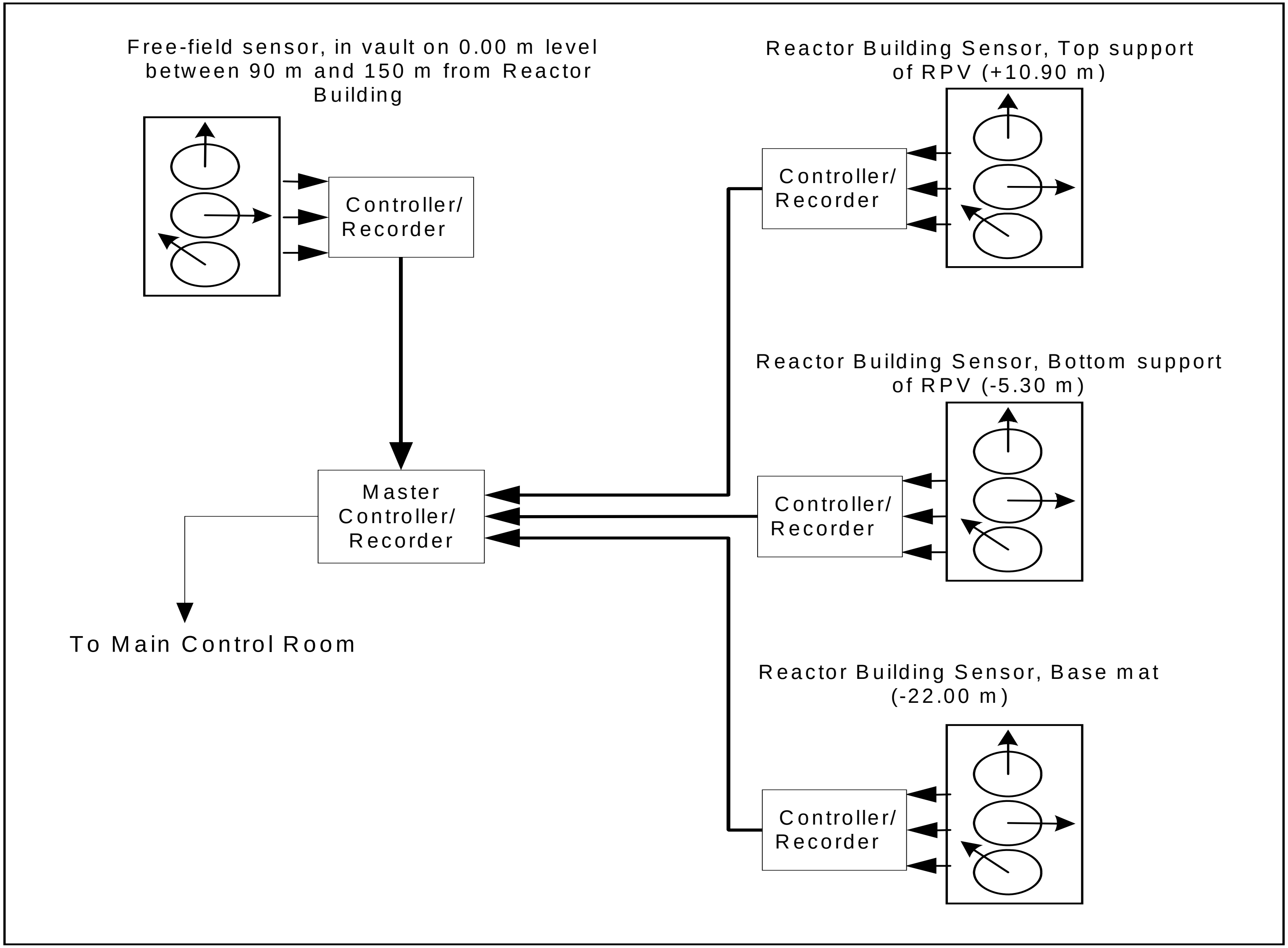
# Manual Diverse Shutdown System

- **Design Basis**
  - Use Class 1-E requirements of IEEE 603-1991
  - Use environmental qualification requirements of IEEE 323-1983
  - Use seismic qualification requirements of IEEE 344-1987
  - Provide DiD for:
    - *Digital Common Cause Failure (DCCF) per NUREG/CR-6303*
    - *Fires/External events*

## Seismic Monitoring System

- Triaxial acceleration sensors in their respective positions
- 4 recording devices are linked to the central recording facilities via network communication cables.
- Each of the sensor/controller systems is supplied with a UPS as well as a battery back-up.
- Position of the sensors in the Reactor Building was chosen to represent positions as indicated in RG 1.12.

# Seismic Monitoring System



# DiD – Reactor Shutdown

| System | Operational Control System | Reactor Protection System | Reactor Manual Shutdown System | |
|---|---|---|---|---|
| Actuation | Automatic runback of control rods | Automatically actuates control rod insertion | Manual control rod insertion | Manual small absorber sphere insertion |
| Mechanism | Provides new setpoints to Control Rod Drive (CRD) system to insert the control rods | Disconnects power by opening trip breakers | Disconnects power by opening trip breakers | Disconnects power by opening trip breakers |