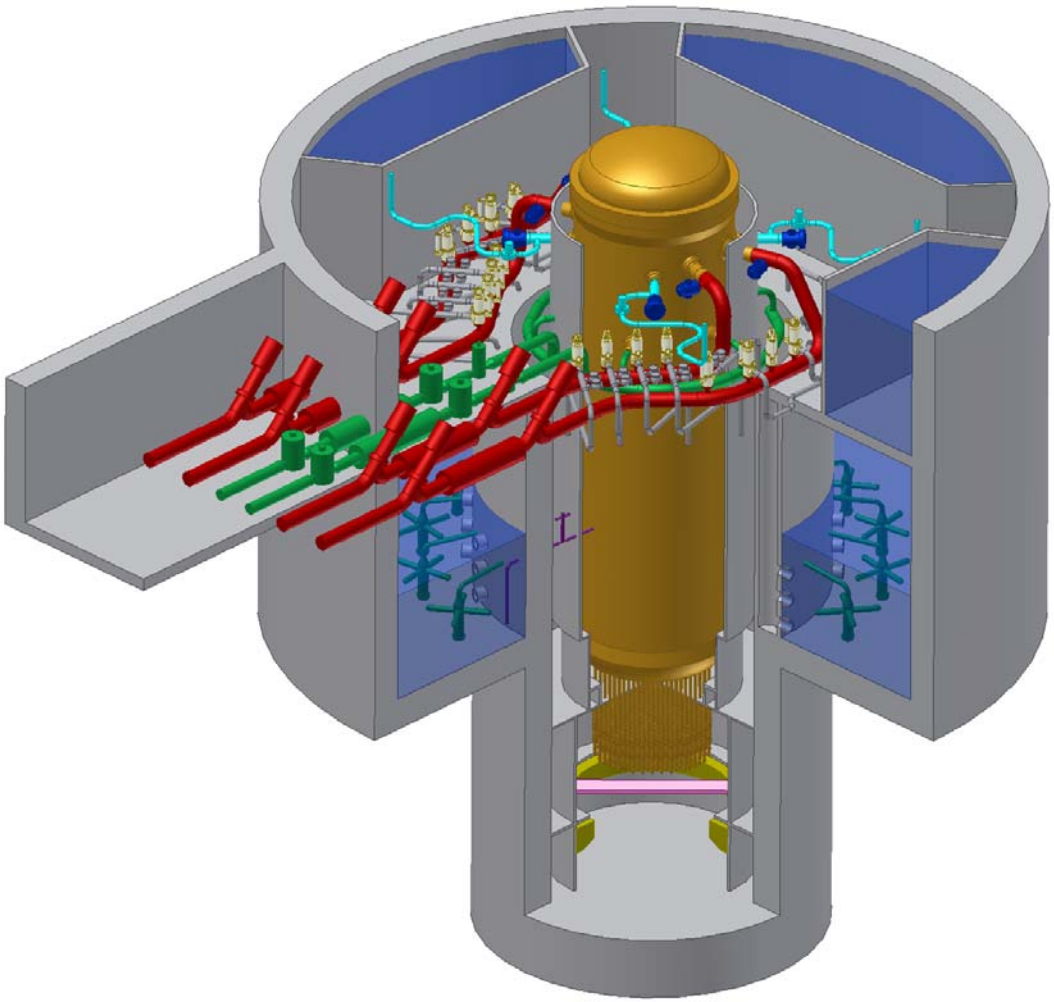
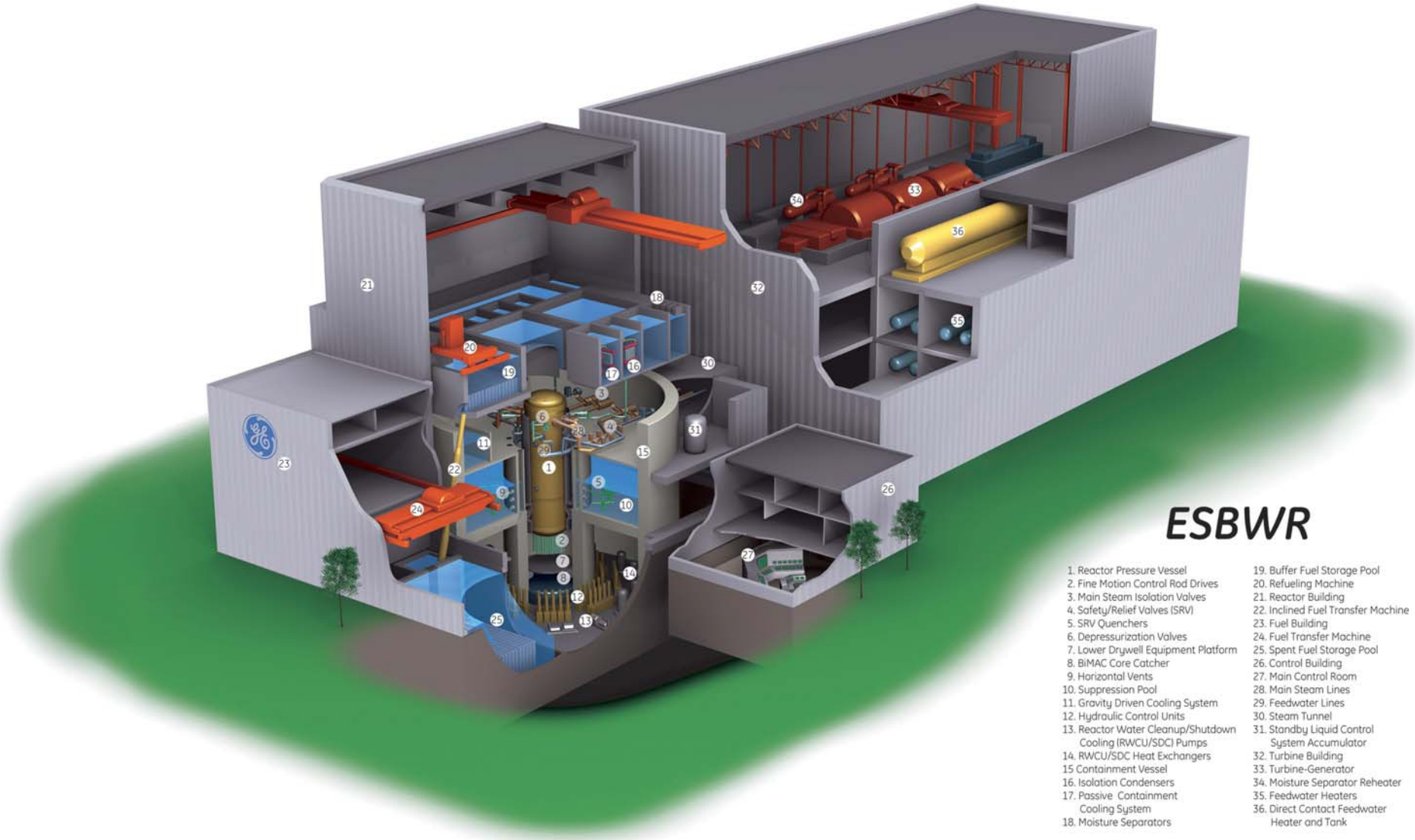
ESBWR Overview



J. Alan Beard

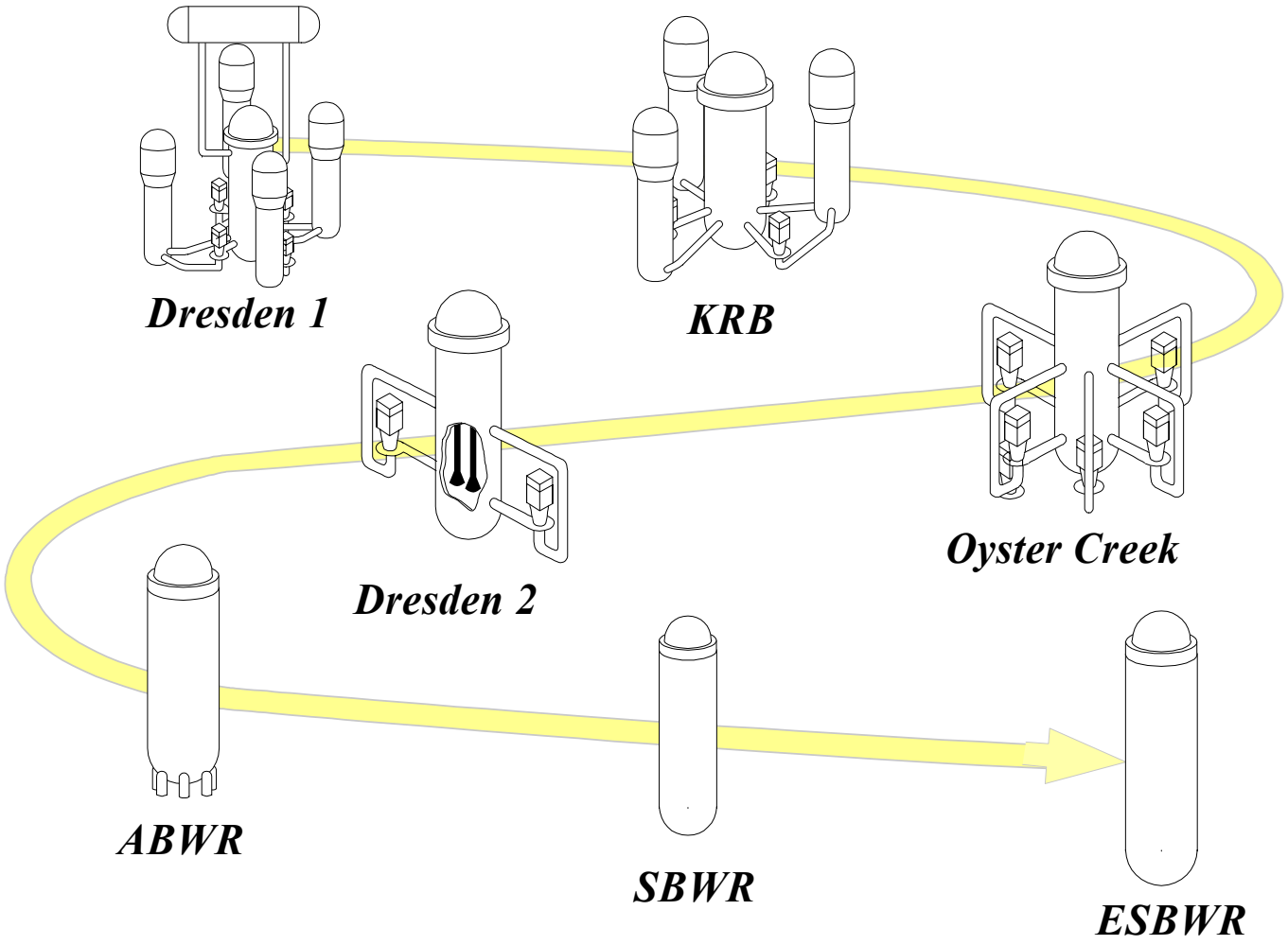
March 23, 2006



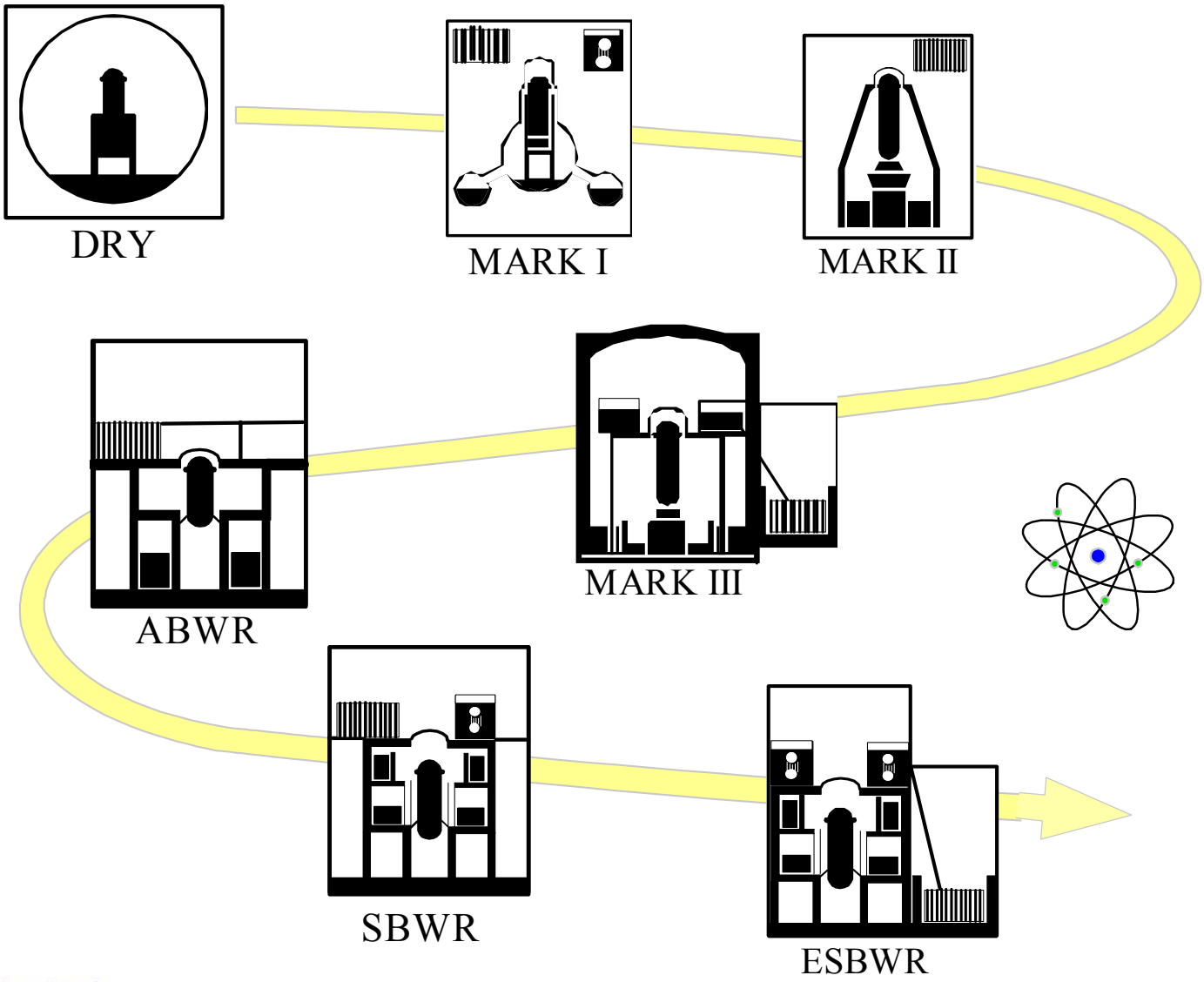
ESBWR

1. Reactor Pressure Vessel
2. Fine Motion Control Rod Drives
3. Main Steam Isolation Valves
4. Safety/Relief Valves (SRV)
5. SRV Quenchers
6. Depressurization Valves
7. Lower Drywell Equipment Platform
8. BiMAC Core Catcher
9. Horizontal Vents
10. Suppression Pool
11. Gravity Driven Cooling System
12. Hydraulic Control Units
13. Reactor Water Cleanup/Shutdown Cooling (RWCU/SDC) Pumps
14. RWCU/SDC Heat Exchangers
15. Containment Vessel
16. Isolation Condensers
17. Passive Containment Cooling System
18. Moisture Separators
19. Buffer Fuel Storage Pool
20. Refueling Machine
21. Reactor Building
22. Inclined Fuel Transfer Machine
23. Fuel Building
24. Fuel Transfer Machine
25. Spent Fuel Storage Pool
26. Control Building
27. Main Control Room
28. Main Steam Lines
29. Feedwater Lines
30. Steam Tunnel
31. Standby Liquid Control System Accumulator
32. Turbine Building
33. Turbine-Generator
34. Moisture Separator Reheater
35. Feedwater Heaters
36. Direct Contact Feedwater Heater and Tank

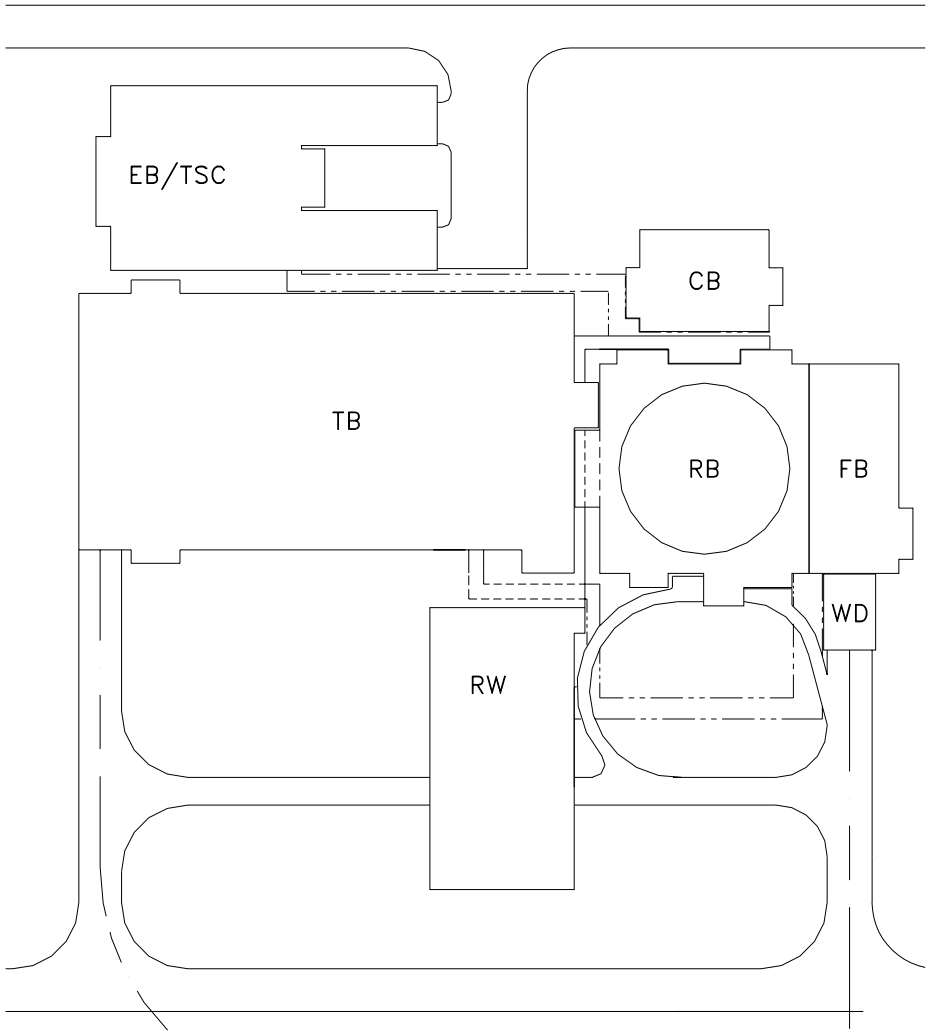
BWR Evolution

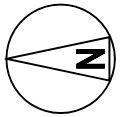


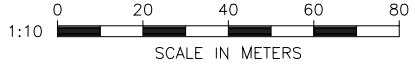
Containment Evolution



Power Block Arrangement

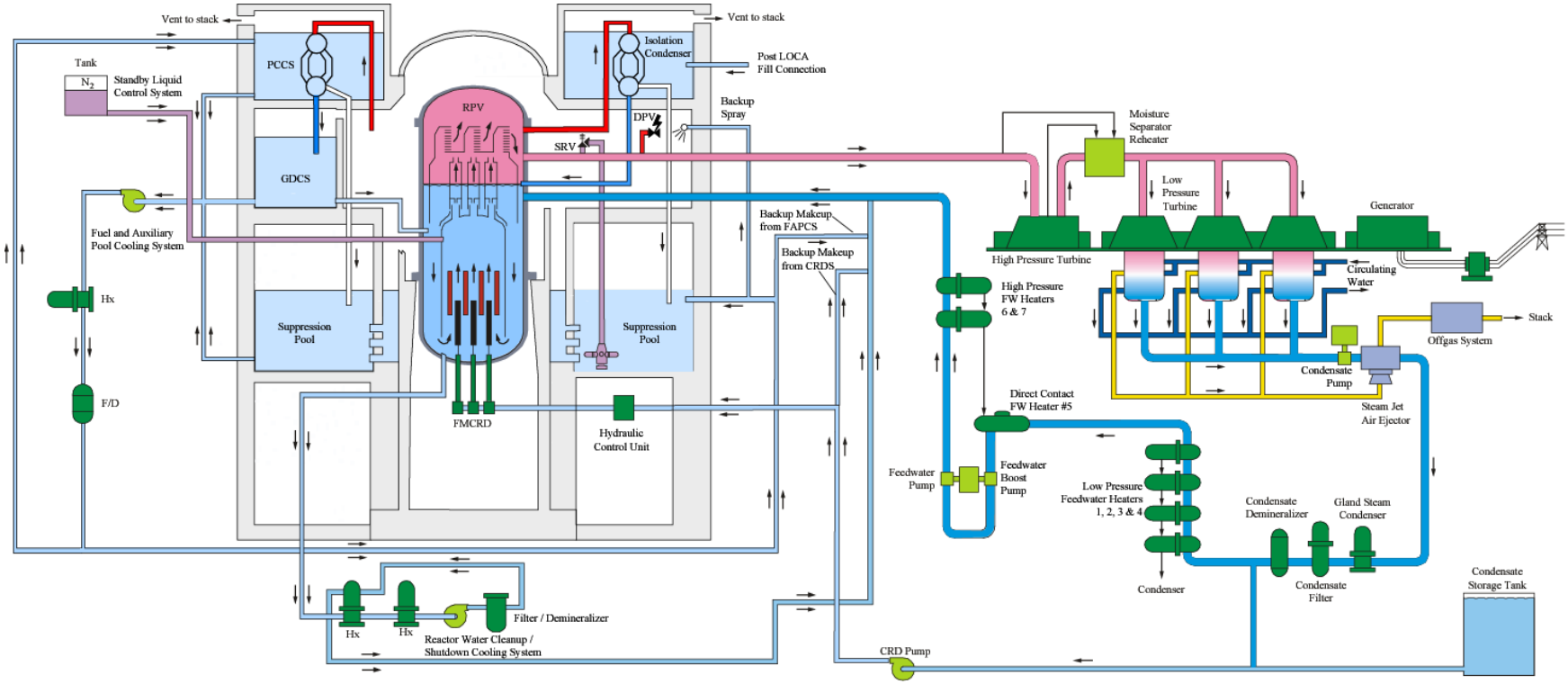






ESBWR Basic Parameters

- 4,500 Megawatt Core Thermal Power
- ~1, 575 to 1,600 Megawatt Electric Gross
  - > Nominal Summer Rating
- Natural Circulation
  - > No recirculation pumps
- Passive Safety Systems
  - > 72 hours passive capability

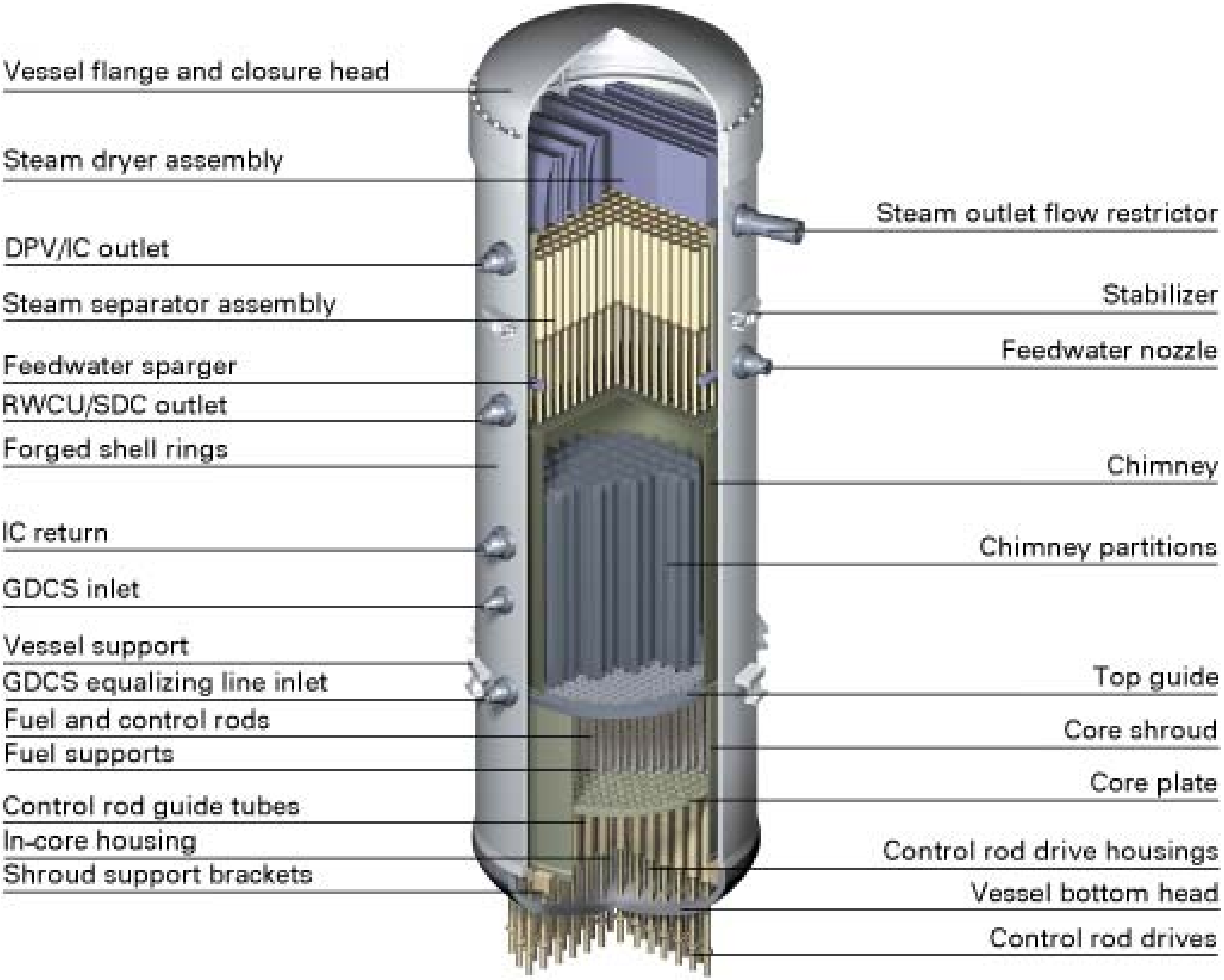


What's different about ESBWR

ABWR	ESBWR
Recirculation System + support systems	Eliminated
HPCF System (2 each)	Eliminated need for ECCS pumps
LPFL (3 each)	Utilize passive and stored energy
Residual Heat Removal (3 each)	Non-safety, combined with cleanup system
Safety Grade Diesel Generators (3 each)	Eliminated – only 2 non-safety grade diesels
RCIC	Replaced with IC heat exchangers
SLC –2 pumps	Replaced pumps with accumulators
Reactor Building Service Water (Safety Grade) And Plant Service Water (Safety Grade)	Made non-safety grade

Optimized Parameters for ESBWR

Parameter	BWR/4-Mk I(Browns Ferry 3)	BWR/6-Mk III (Grand Gulf)	ABWR	ESBWR
Power (MWt/MWe)	3293/1098	3900/1360	3926/1350	4500/1590
Vessel height/dia. (m)	21.9/6.4	21.8/6.4	21.1/7.1	27.7/7.1
Fuel Bundles (number)	764	800	872	1132
Active Fuel Height (m)	3.7	3.7	3.7	3.0
Power density (kw/l)	50	54.2	51	54
Recirculation pumps	2(large)	2(large)	10	zero
Number of CRDs/type	185/LP	193/LP	205/FM	269/FM
Safety system pumps	9	9	18	zero
Safety diesel generator	2	3	3	zero
Core damage freq./yr	1E-5	1E-6	1E-7	3E-8
Safety Bldg Vol (m^3/MWe)	115	150	160	< 130



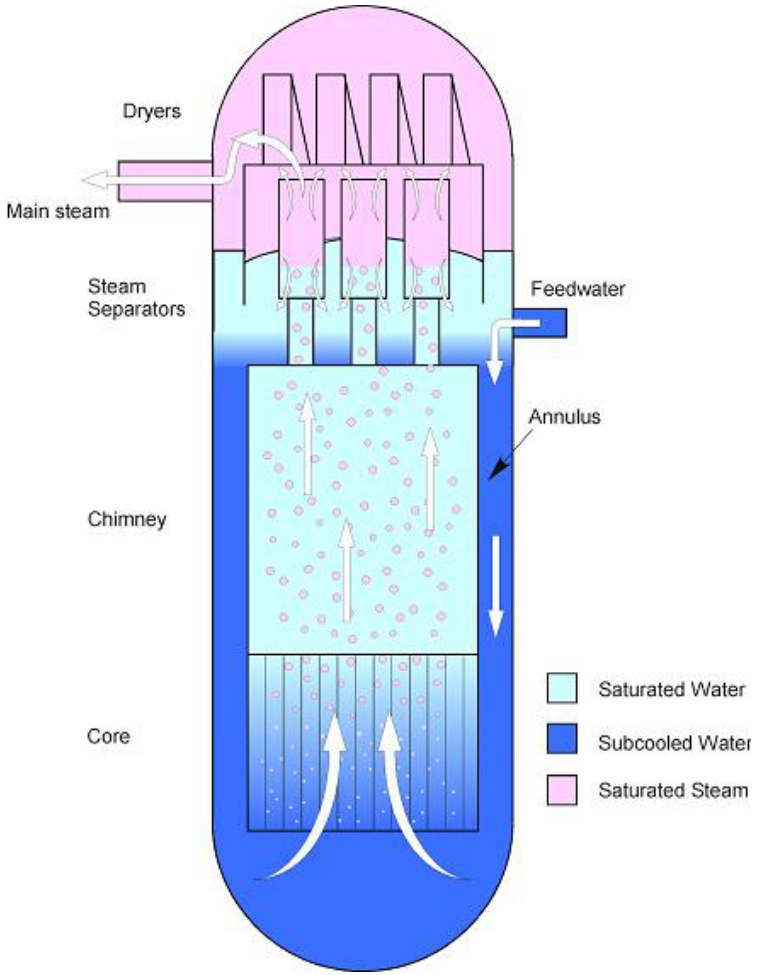
Other Design Improvements

- 110% Steam Bypass
  - > Island Mode of Operation
- Fine Motion Control Rod Drives (FMCRD)
- Shoot-out Steel Eliminated
- Integrated Head Vent Pipe
- Improved Incore Instrumentation
  - > Start-up Range Neutron Monitor (SRNM)
  - > Gamma Thermometer
    - – No Traversing Incore Probe (TIP)

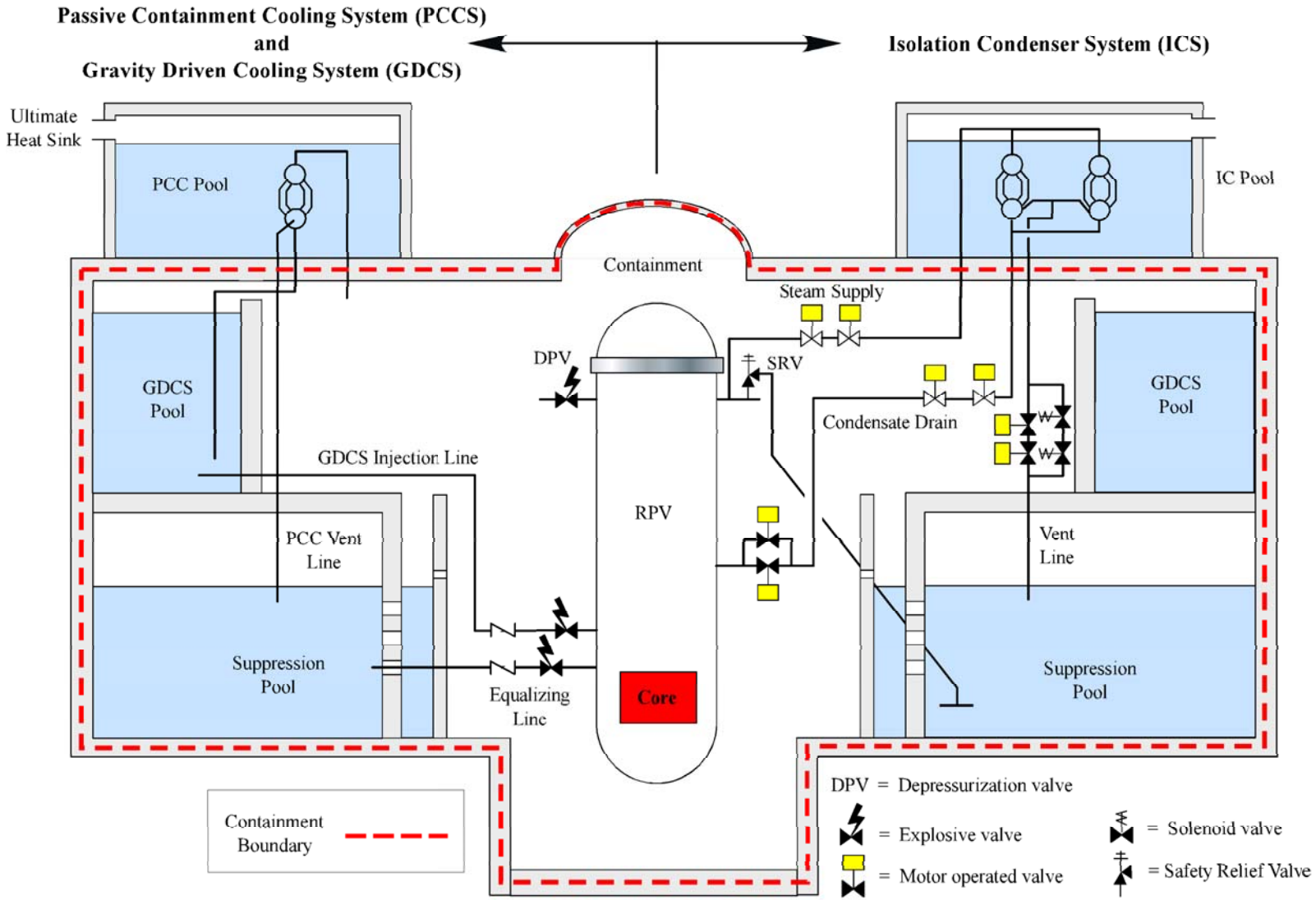
Natural Circulation

Simplification without performance loss ..

- **Passive safety/natural circulation**
  - Increase the volume of water in the vessel
  - Increase driving head
- **Significant reduction in components**
  - Pumps, motors, controls, HXers
- **Power Changes with Control Rod Drives**
  - Minimal impact on maintenance



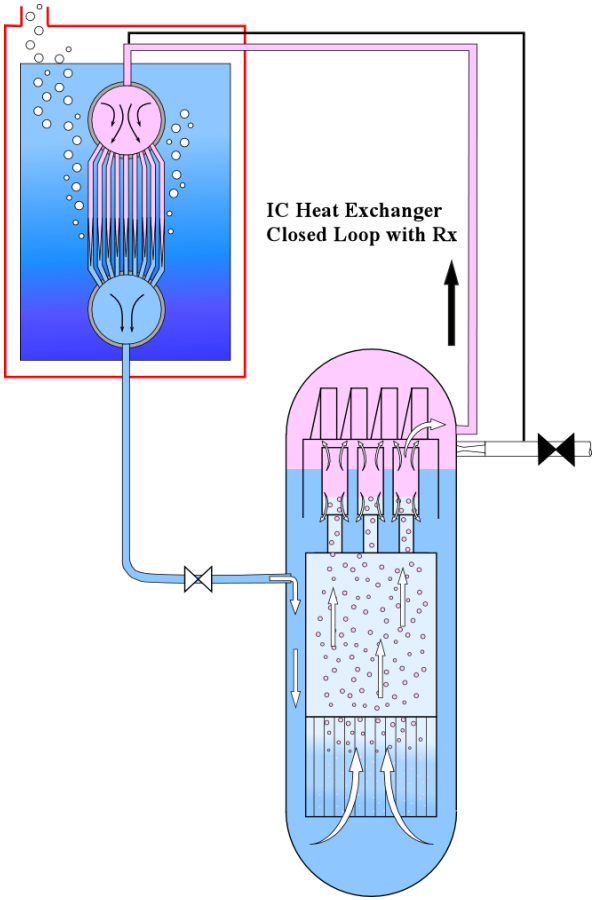
Passive Safety



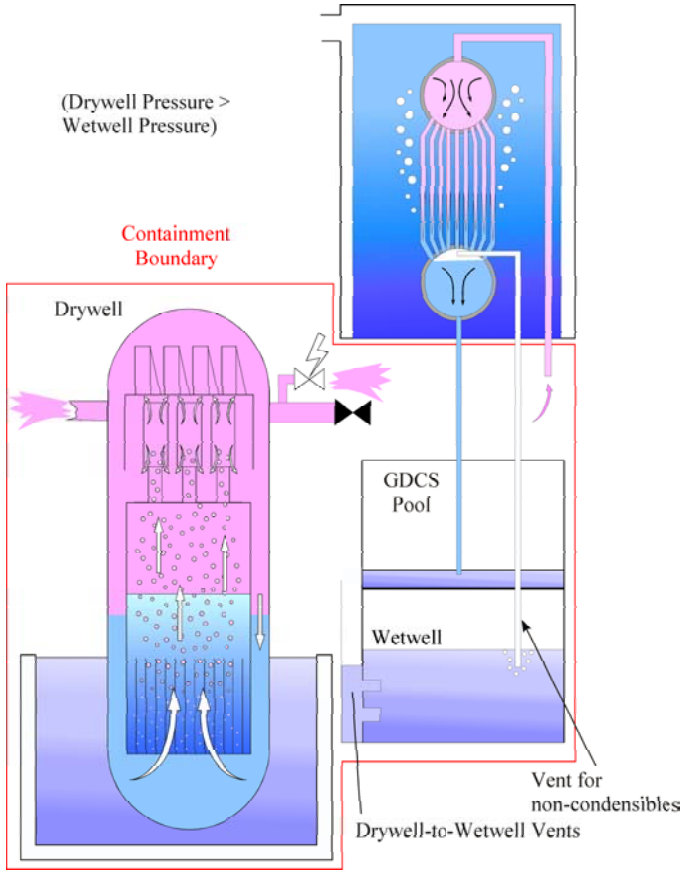
imagination at work

Passive Safety Systems …

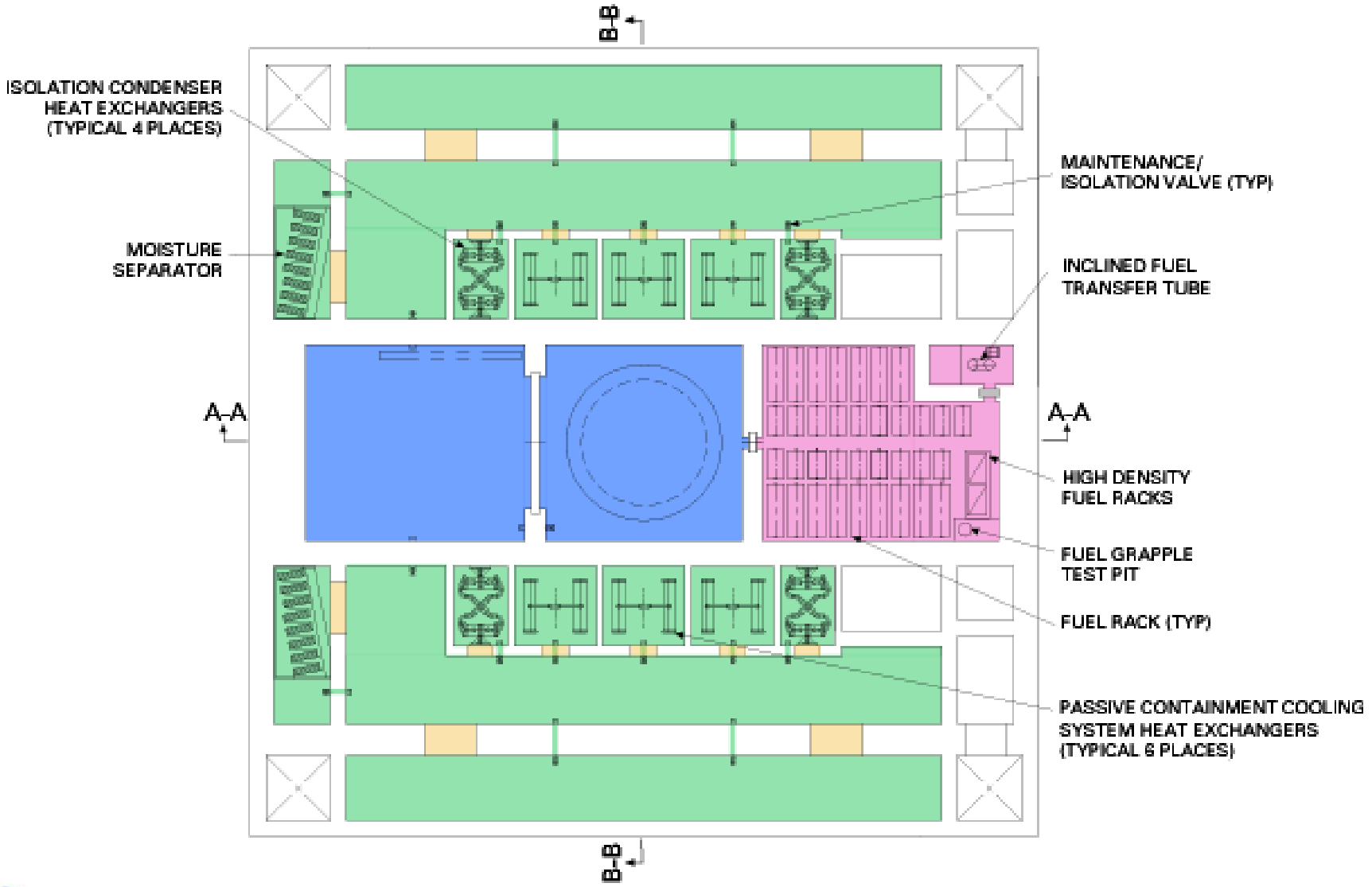
Isolation Condenser System



Passive Containment Cooling



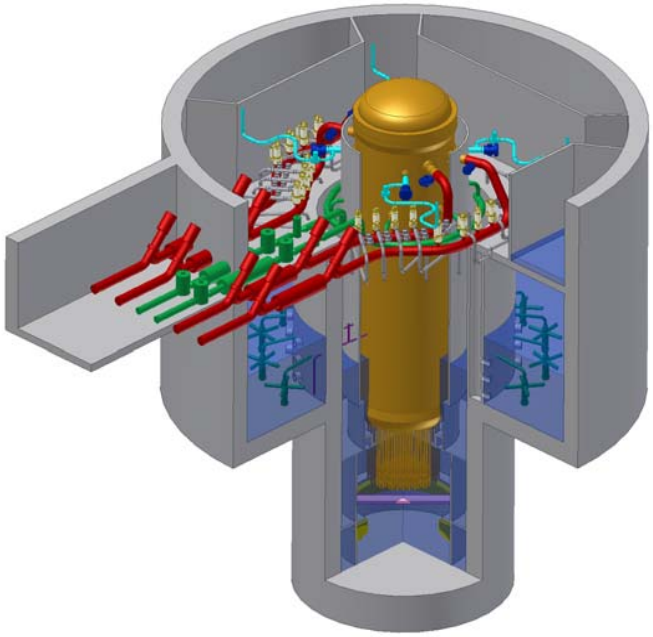
72 Hours Passive Capability

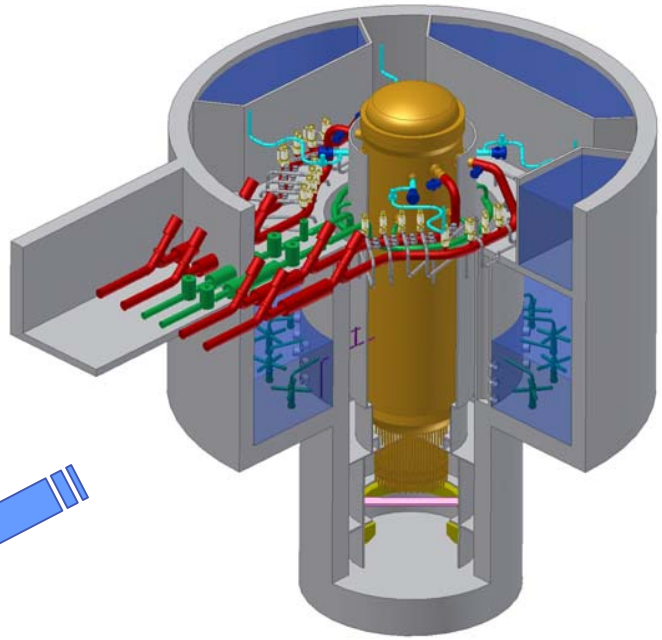


Gravity Driven Cooling System …

Simple design
Simple analyses

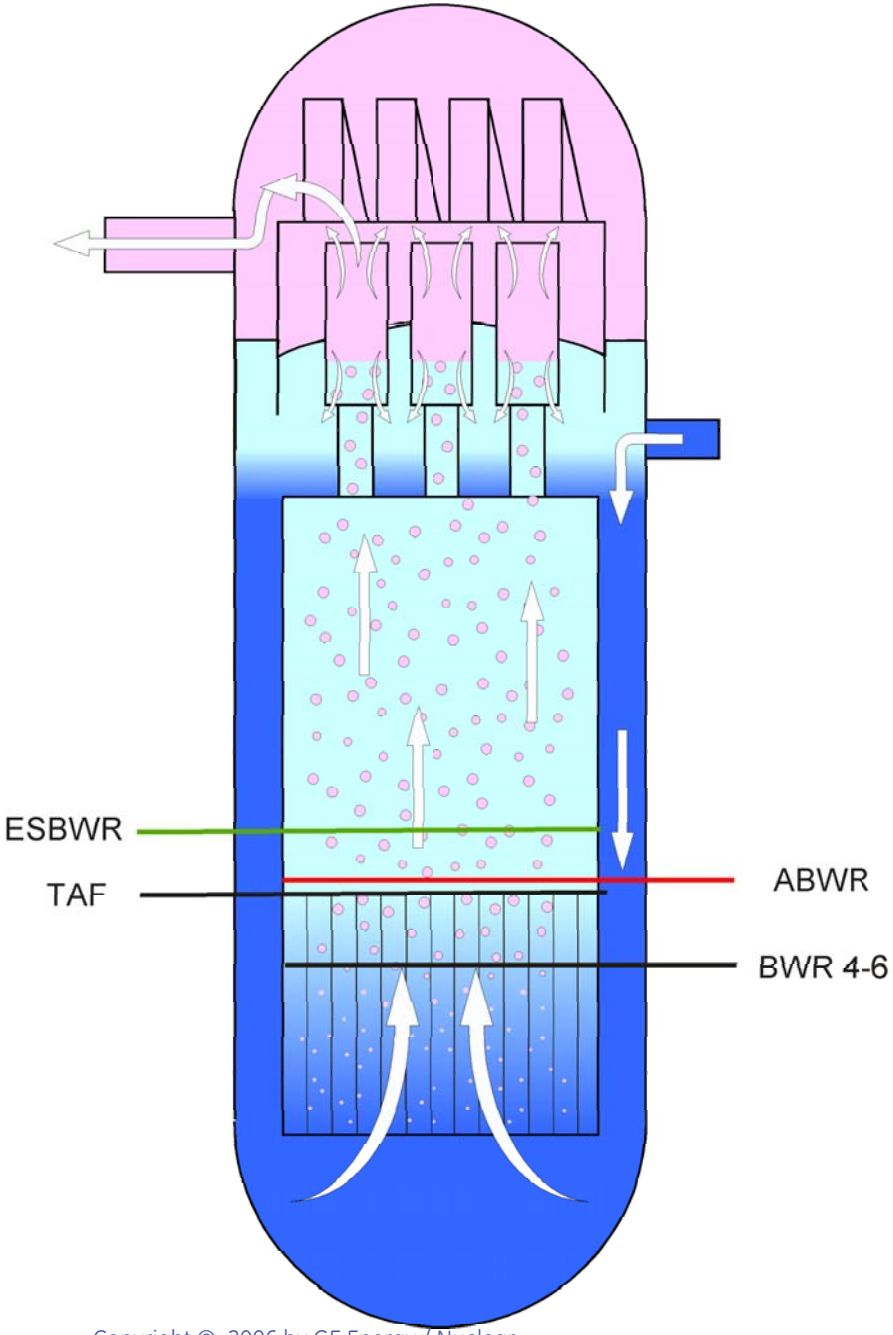
Extensive testing
Large safety margins



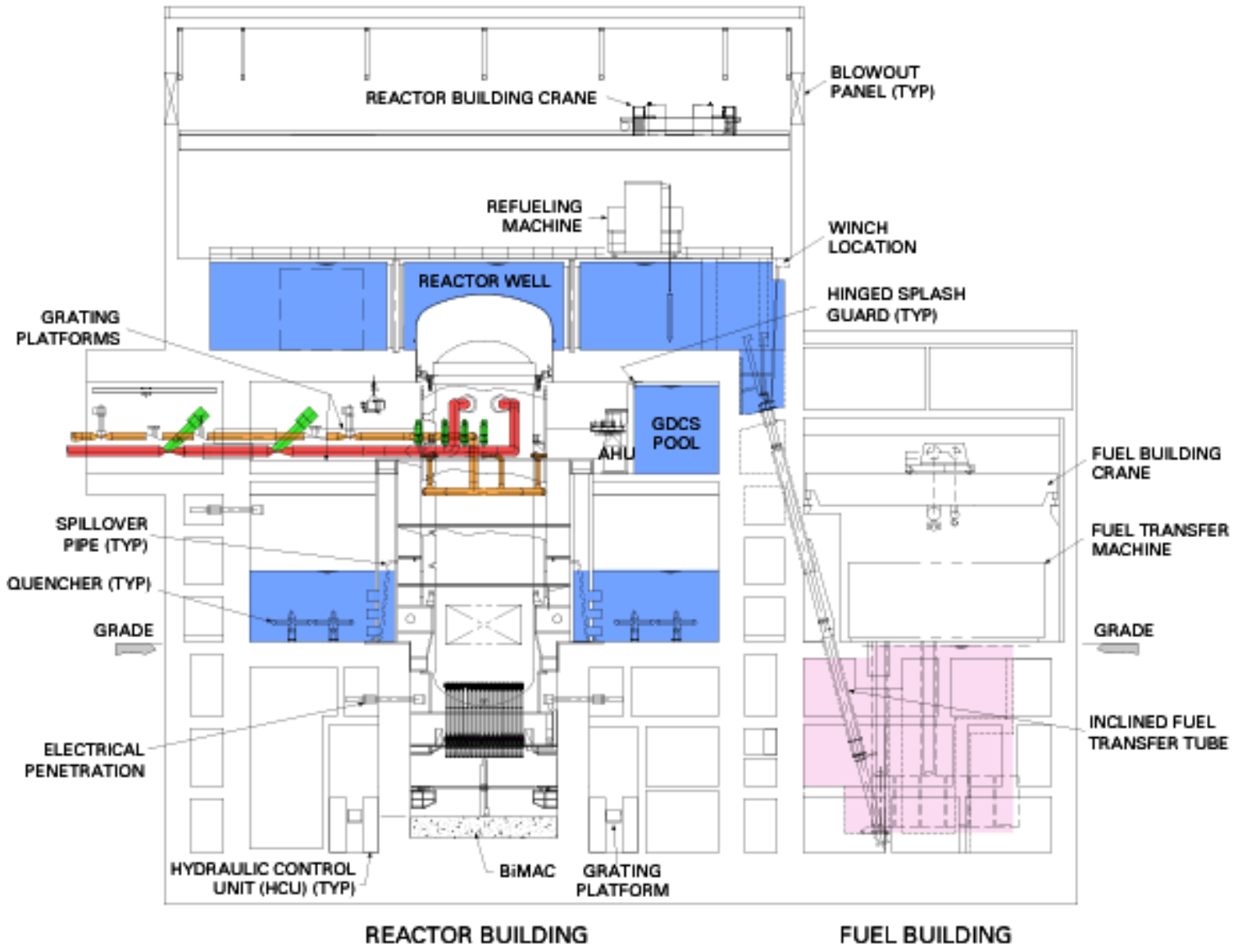


Gravity driven flow keeps core covered

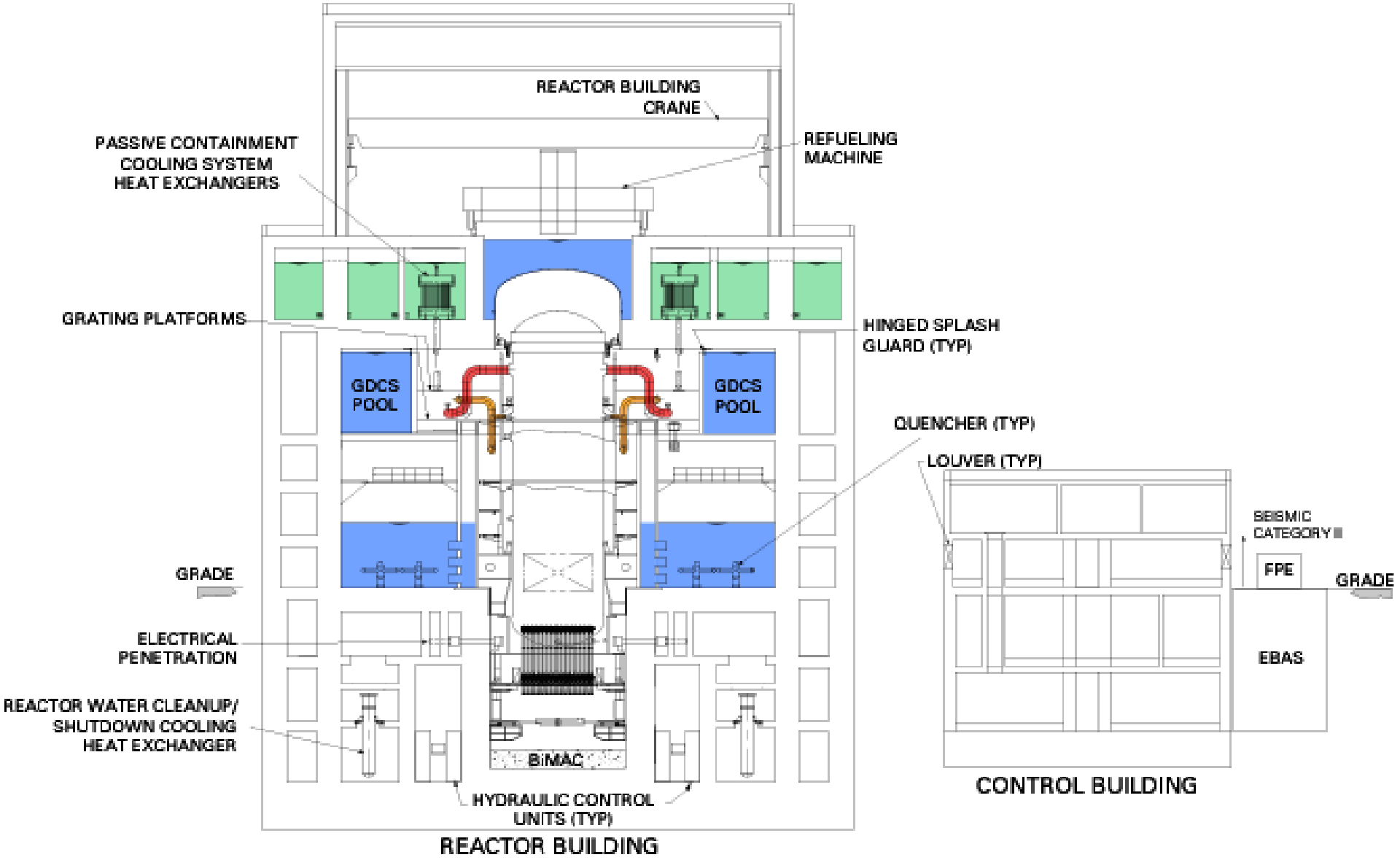
LOCA Water Level Response



Reactor and Fuel Building

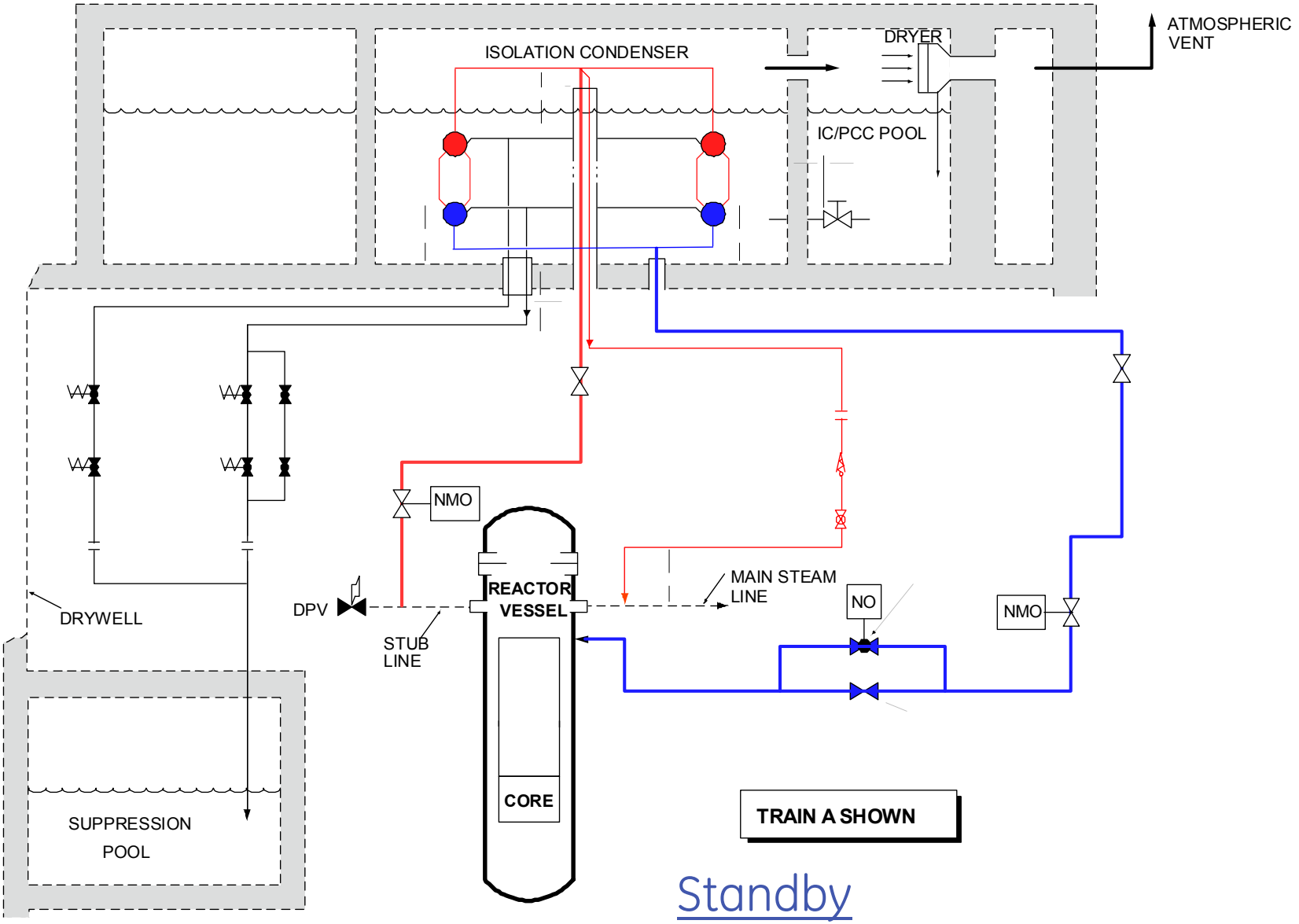


Containment

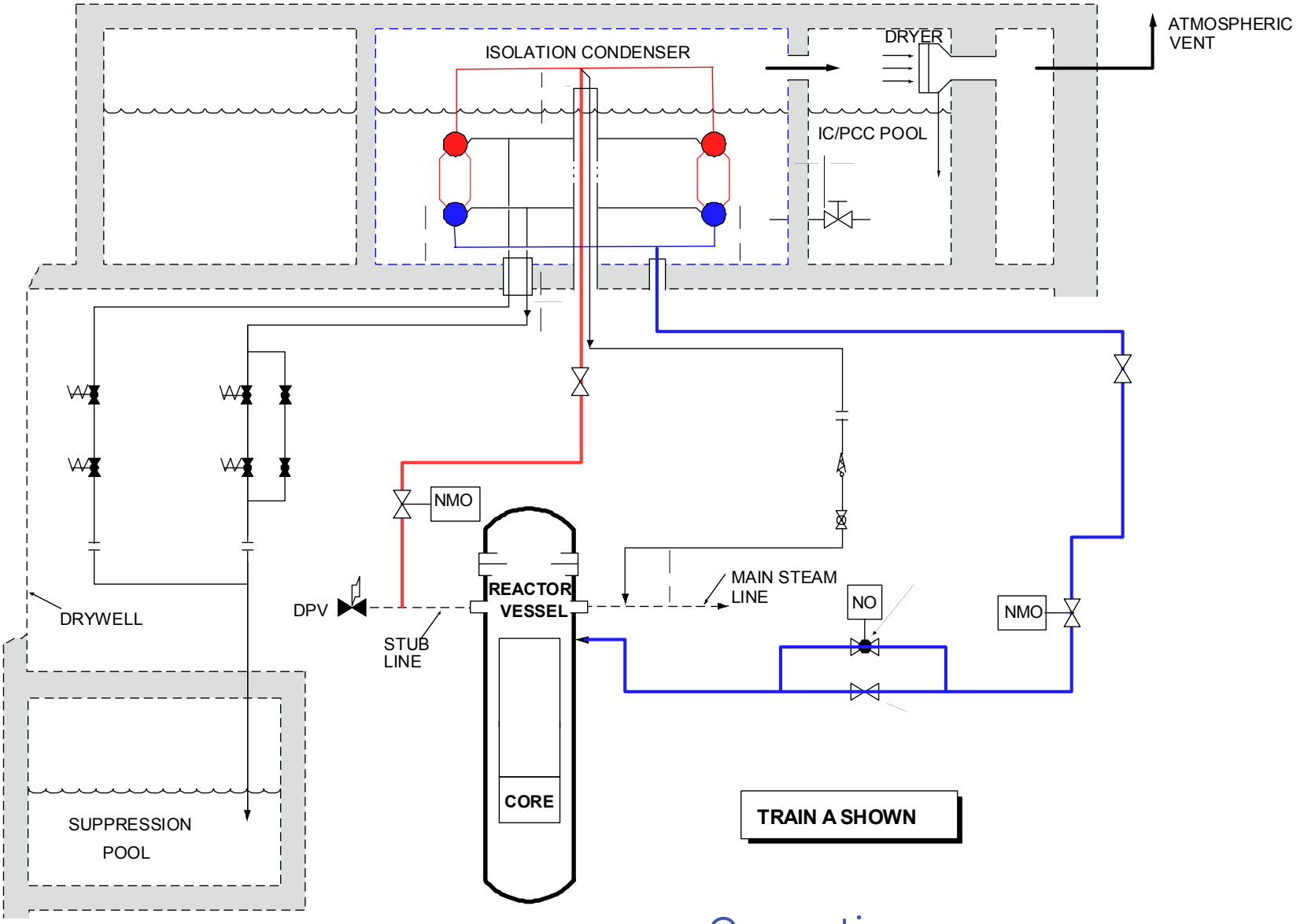


Isolation Condensers

- ICs provide passive decay heat removal
  - > Single Failure Criteria apply
  - > No lift of the Safety Relief Valves (SRVs)
  - > Operates in all Design Basis Conditions except medium and large break LOCAs
  - > ICs transport decay heat direct from NSSS to the Ultimate Heat Sink
    - > No steaming in the primary containment
  - > Rapidly reduces RPV pressure
  - > Redundant Active Components



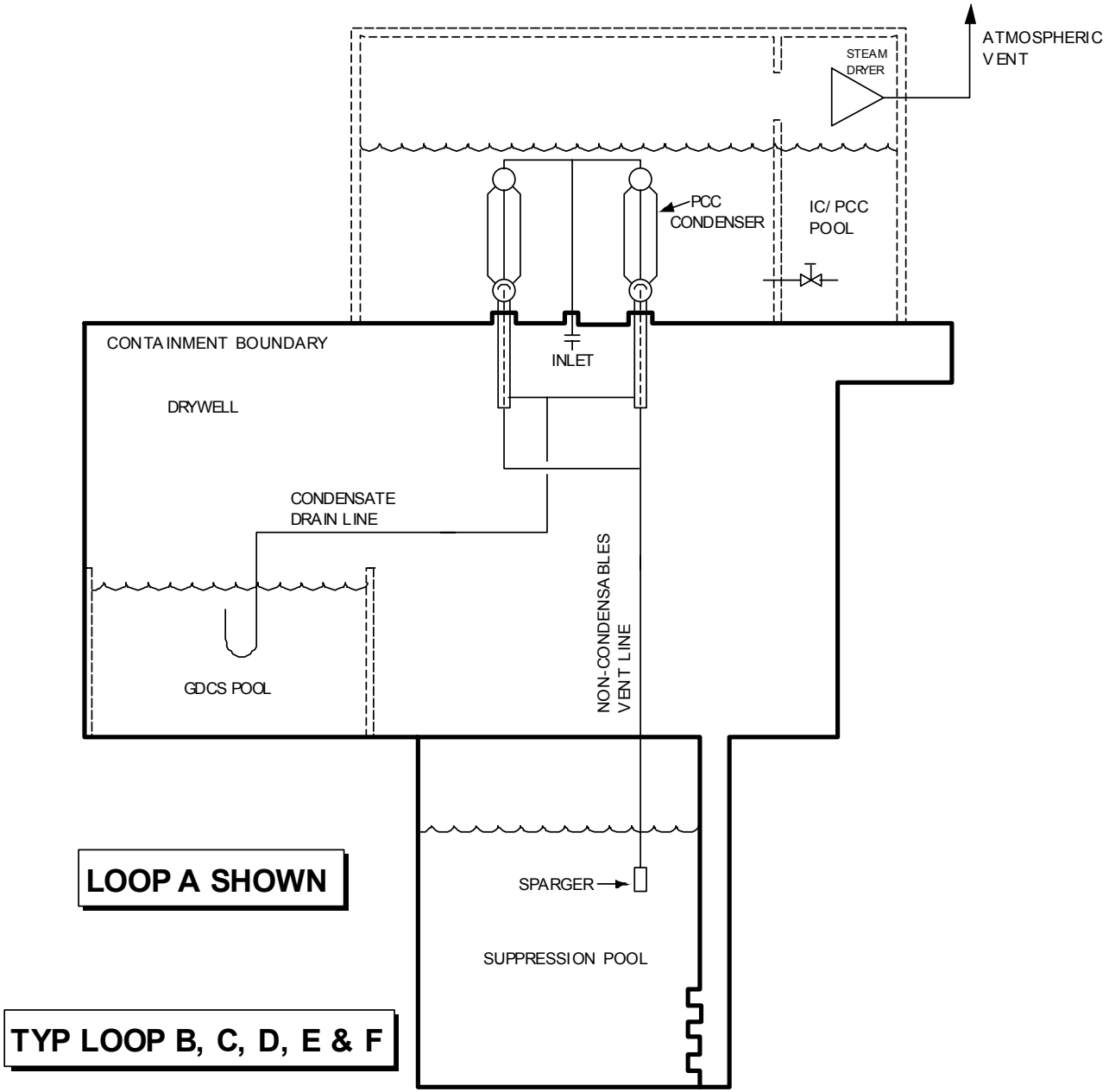
Standby



Operation

Passive Containment Cooling

- PCCs provide passive decay heat removal from the primary containment
  - > Operates in medium and large break LOCAs
  - > Provides backup of ICs if needed
    - – RPV is depressurized using DPVs
  - > Entirely Passive
    - – ~40 hours with demineralized water
  - > PCCs transport decay heat direct from Primary Containment to the Ultimate Heat Sink



imagination at work

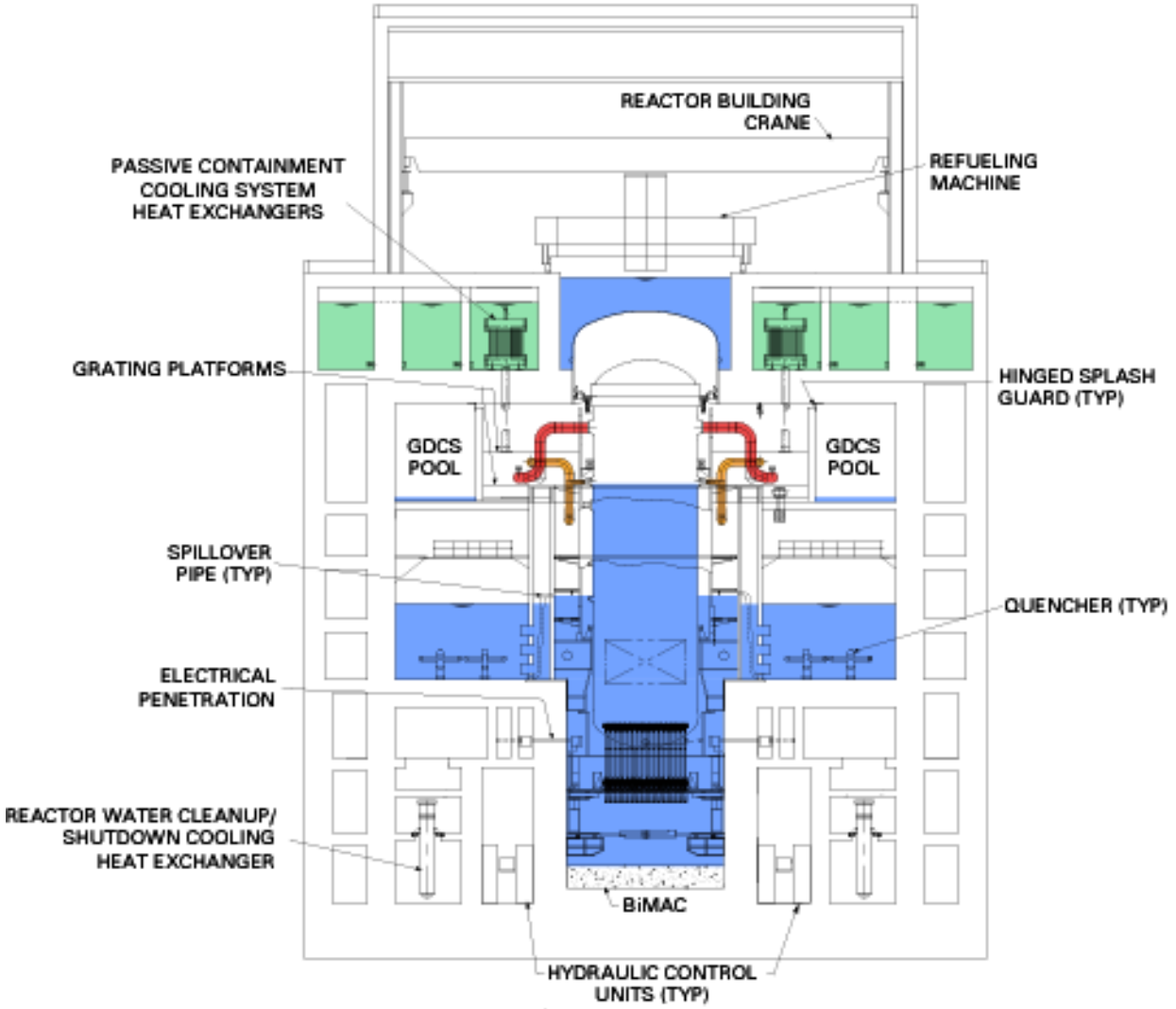
Emergency Core Cooling (ECC)

- Gravity Driven Cooling System (GDCS)
  - Three Pools
  - Four Trains
- Automatic Depressurization System (ADS)
  - 10 of 18 Safety Relief Valves (SRV)
    - Pneumatic actuation
    - No relief mode
  - 8 Depressurization Valves (DPV)
    - Squib actuated
    - Each squib can be fired by 2 divisions

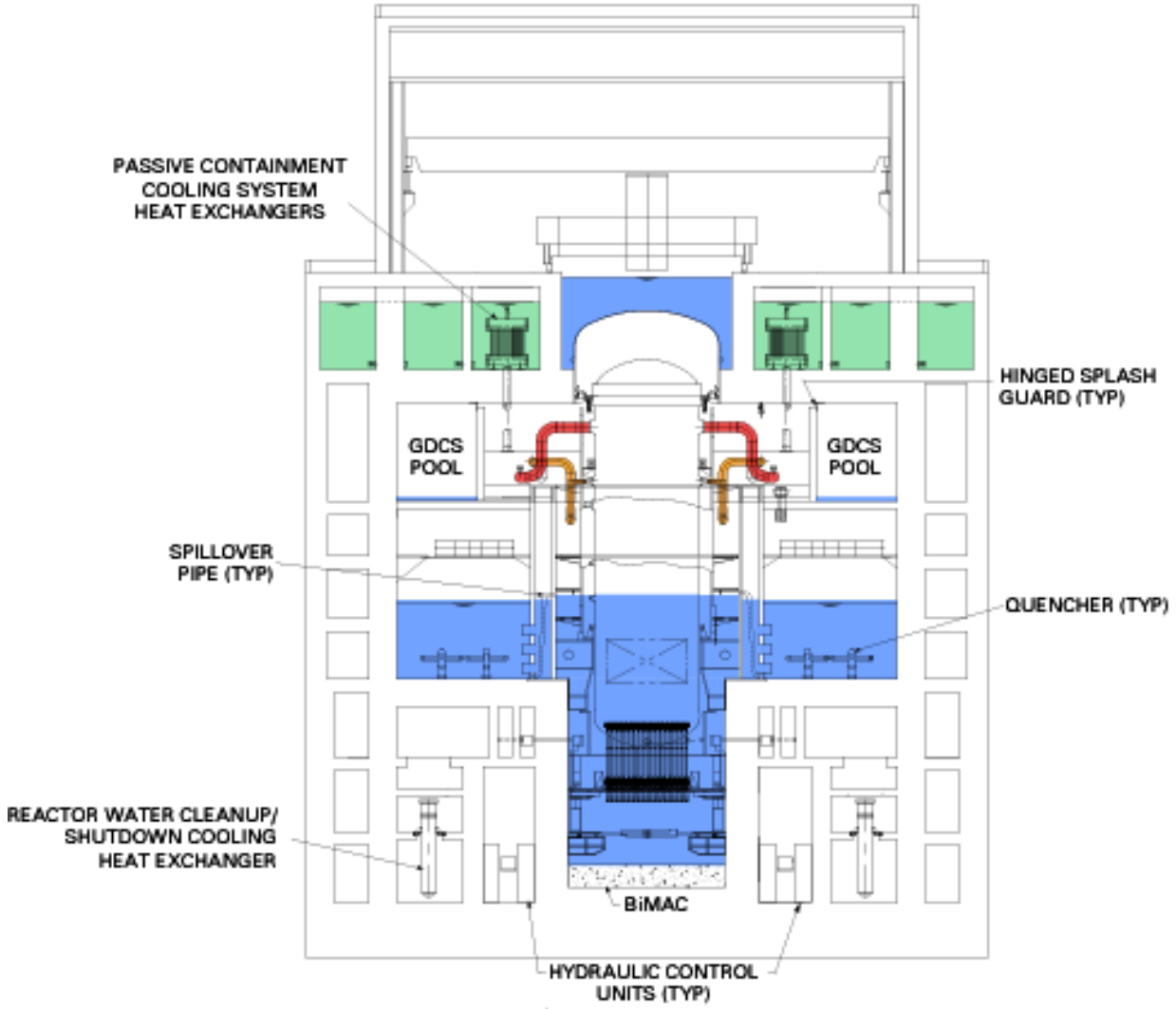
Emergency Core Cooling (cont)

- GDCS lines are squib actuated
- Core remains covered for entire range of Design Basis Accidents
  - > No fuel heat-up
- Complies with 10 CFR 50.46
  - > Codes have been approved by NRC
- Stored water is sufficient to flood containment and RPV to above the top of fuel
  - > 1 meter above TAF or better
    - – All events

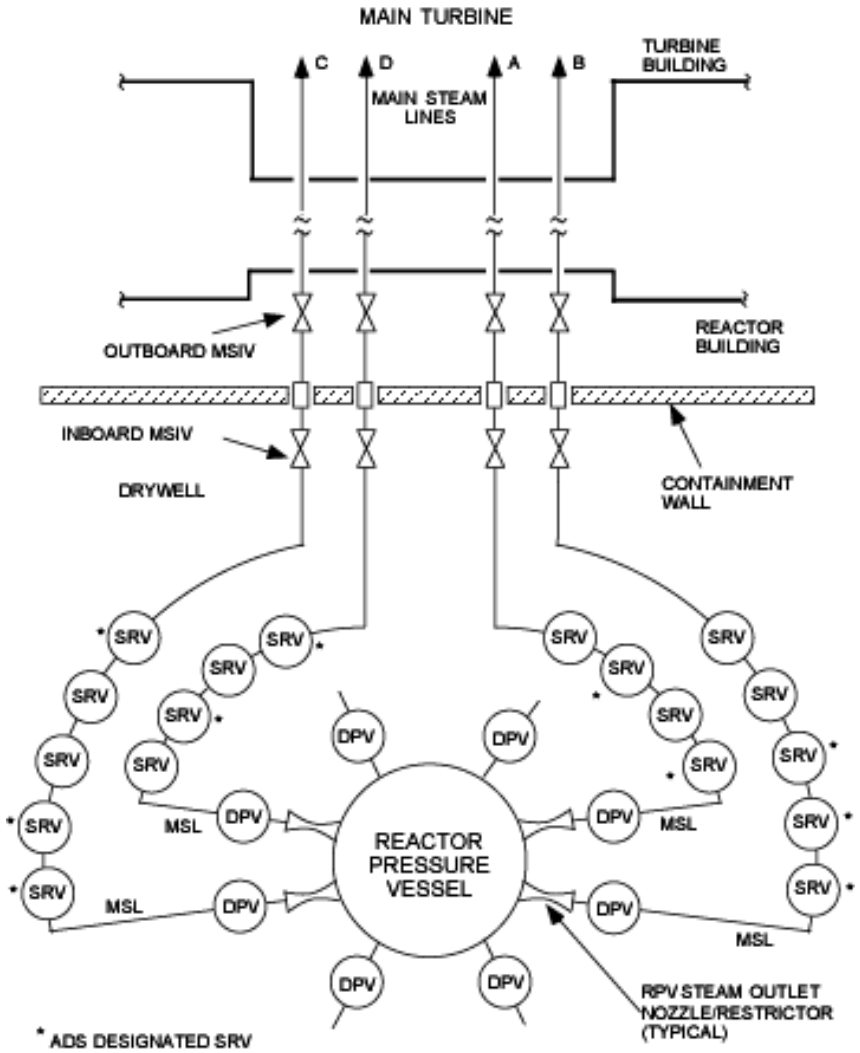
ESBWR Water Level Management – FW Line Break



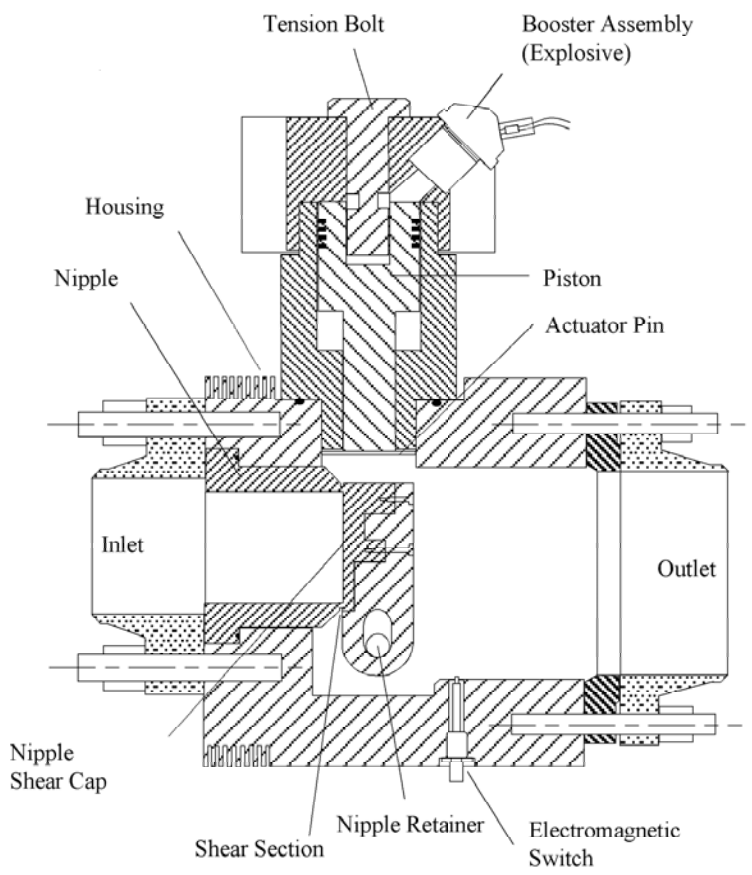
ESBWR Water Level Management – BDL Break



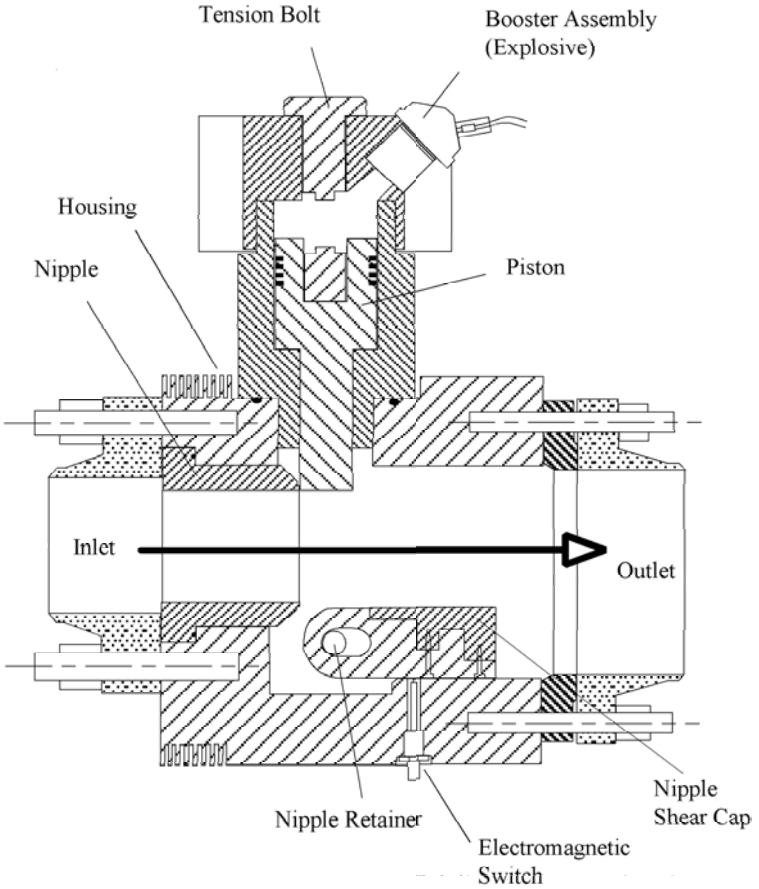
MSIV, SRV and DPV Arrangement



Depressurization Valve (DPV)

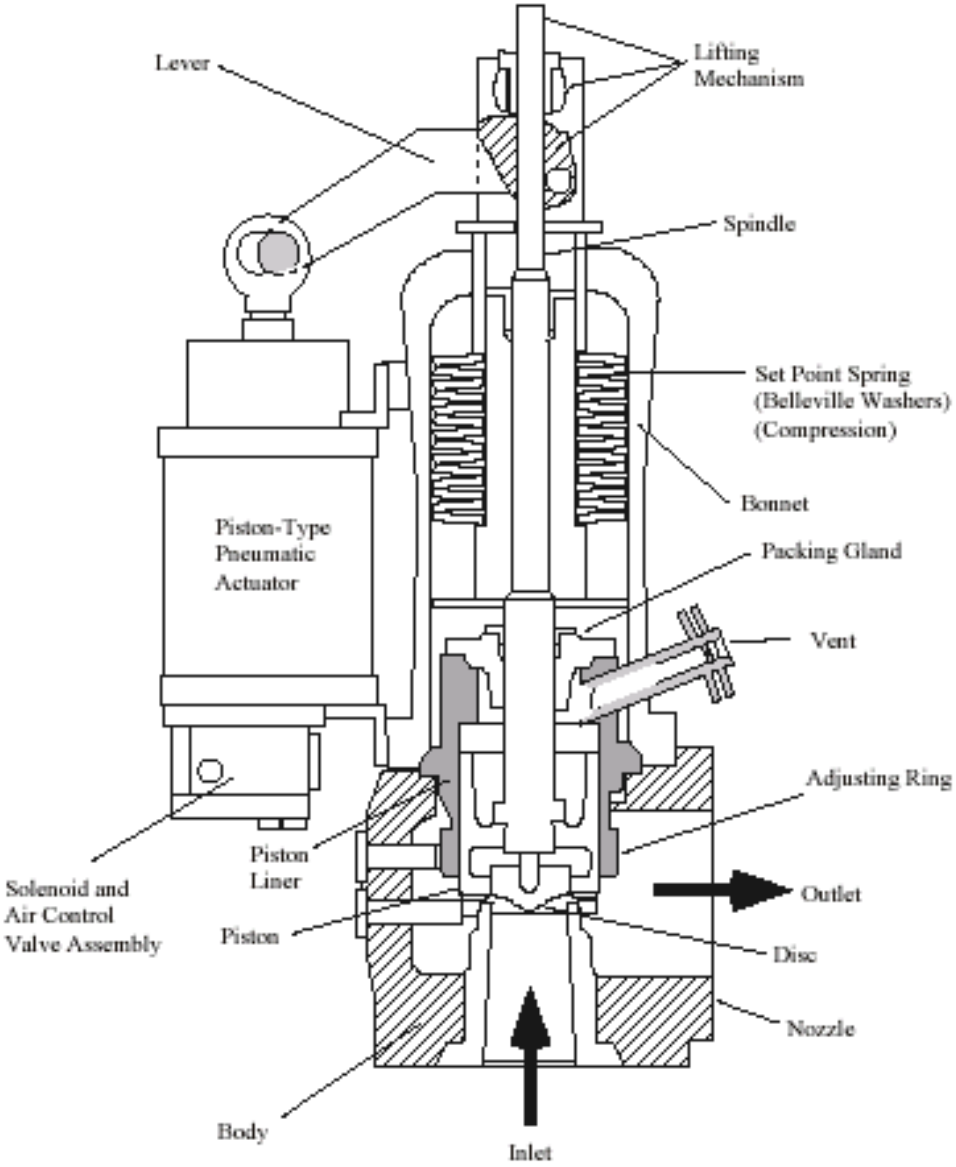


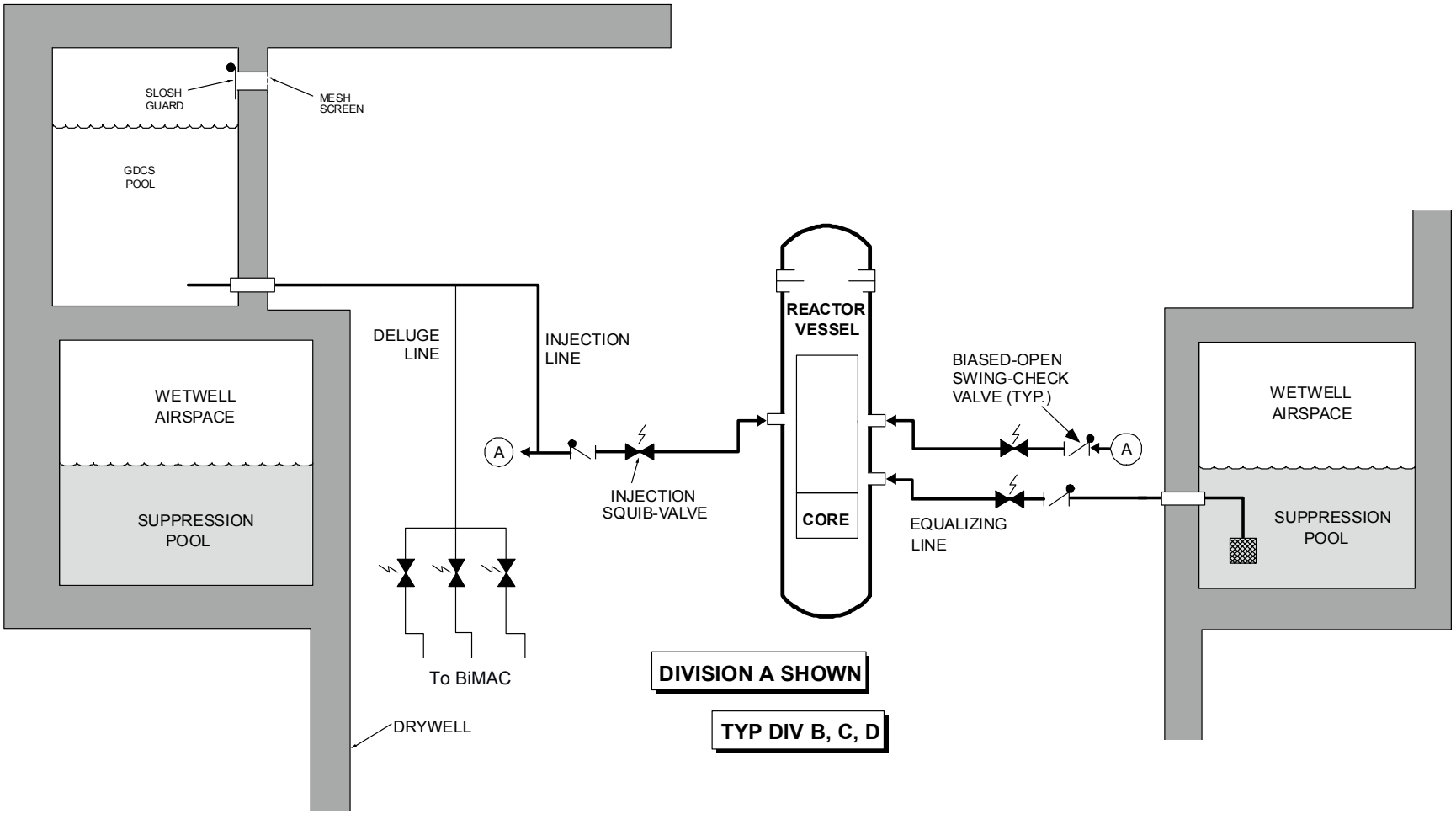
Unfired - Closed



Fired - Open

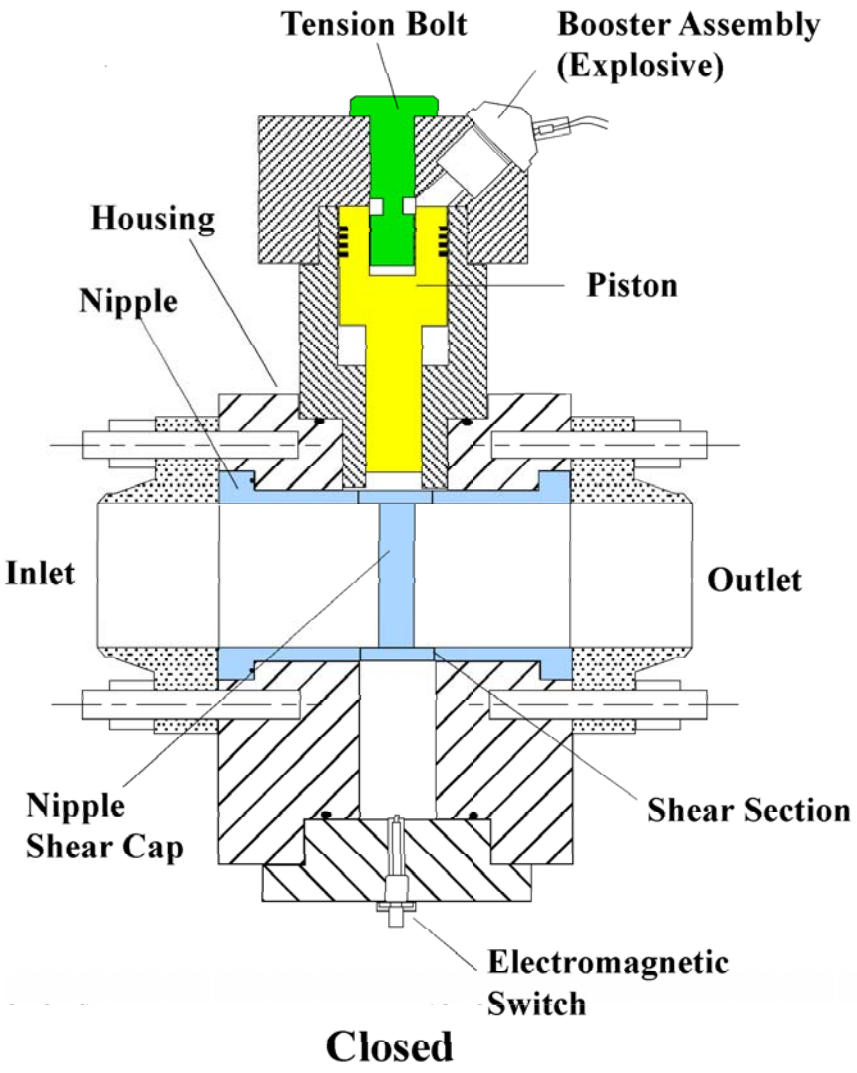
Depressurization Valve
Cross Section

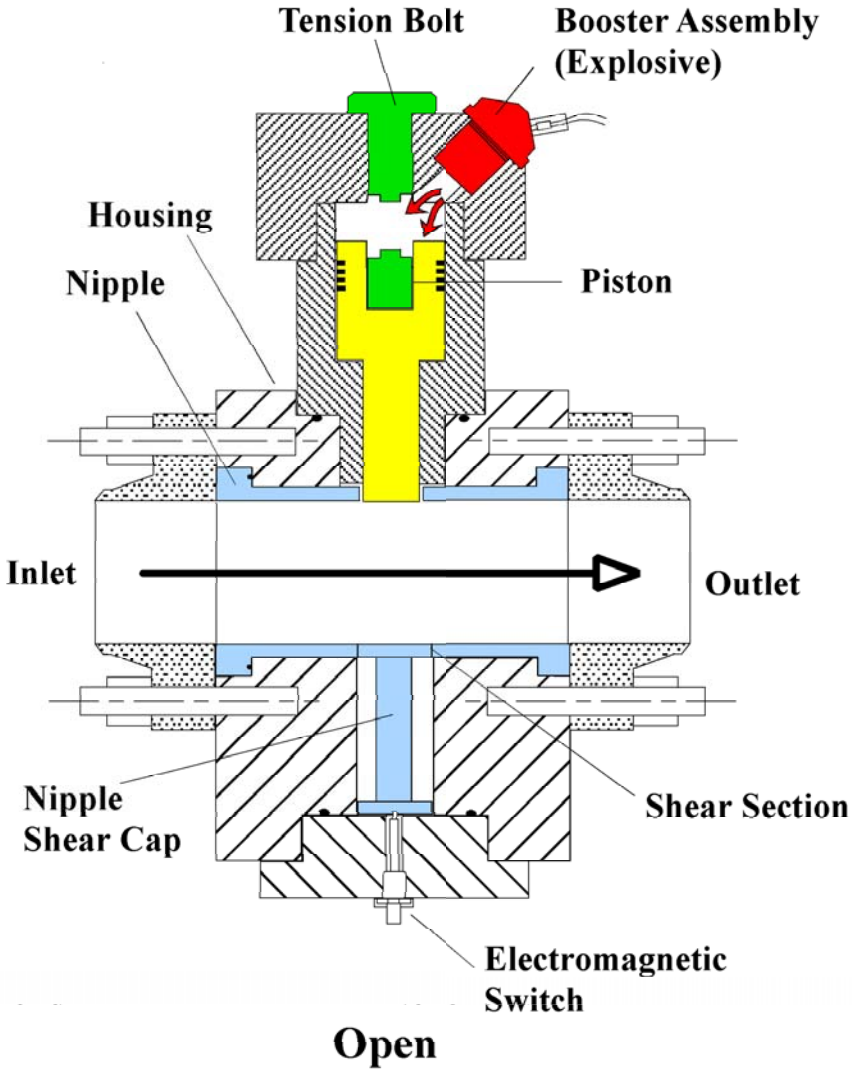




Gravity-Driven Cooling System

imagination at work





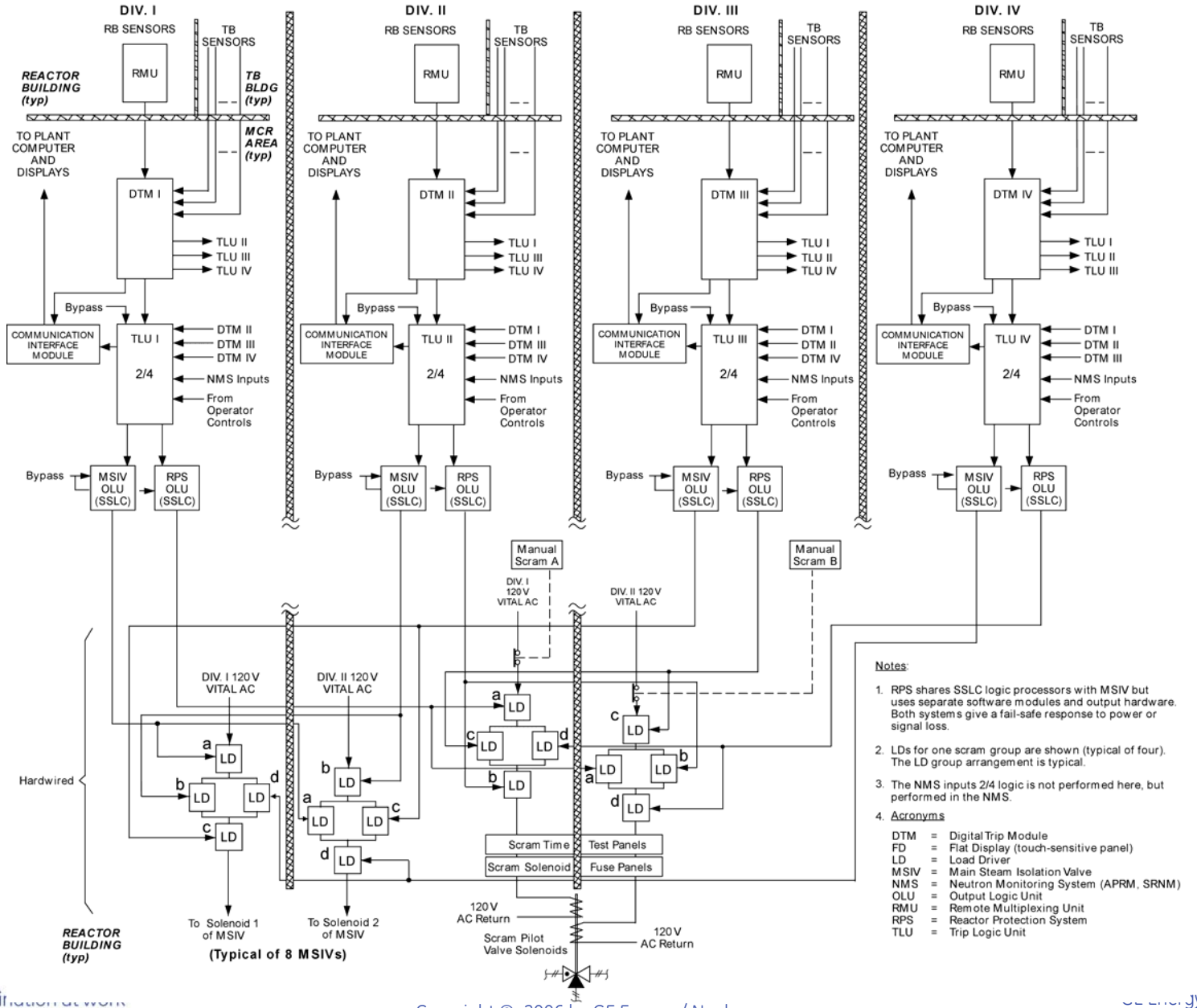
Other Safety-Related Passive Systems

- Digital Instrumentation and Control
  - > Reactor Trip and Isolation
  - > Engineered Safety Features
- Standby Liquid Control (SLC)
  - > Two Pressurized Tanks of Boron
- Emergency Breathing Air System
  - > Main Control Room Habitability
- Vacuum Breakers
- BiMAC

ESBWR Safety System Logic Control (SSLC) Framework

Reactor Protection System

- Based on ABWR design
  - 2/4 logic
  - Fail safe
  - Deterministic
  - Diverse from ECCS
- Any two unbypassed same parameters exceeding limits always cause a scram with:
  - Any single logic failure
  - Any division of sensors bypass status
  - Any division of logic bypass status (independent from sensor bypass)
  - Any single power failure
  - Any possible main control room RPS control configuration
- Each division makes a per parameter trip decision
- Each division informs other divisions of its trip data (via communication module and isolated fiber optics)
- Each division makes a 2/4 per parameter decision to scram
- Two divisions of load drivers – each driven by four divisional trip outputs – control HCU scram solenoids



Notes:

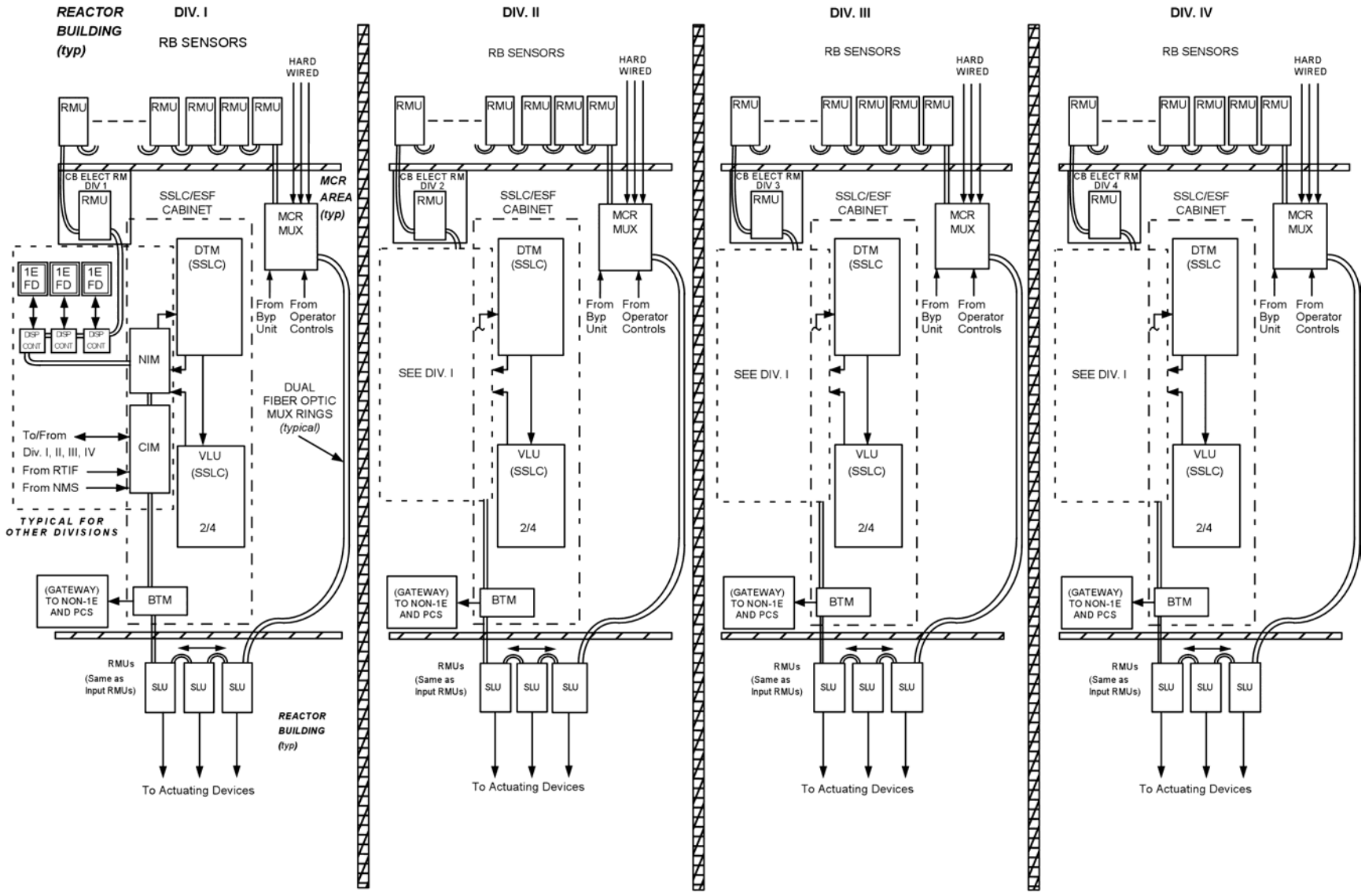
1. RPS shares SSLC logic processors with MSIV but uses separate software modules and output hardware. Both systems give a fail-safe response to power or signal loss.
2. LDs for one scram group are shown (typical of four). The LD group arrangement is typical.
3. The NMS inputs 2/4 logic is not performed here, but performed in the NMS.
4. Acronyms

DTM	=	Digital Trip Module
FD	=	Flat Display (touch-sensitive panel)
LD	=	Load Driver
MSIV	=	Main Steam Isolation Valve
NMS	=	Neutron Monitoring System (APRM, SRNM)
OLU	=	Output Logic Unit
RMU	=	Remote Multiplexing Unit
RPS	=	Reactor Protection System
TLU	=	Trip Logic Unit

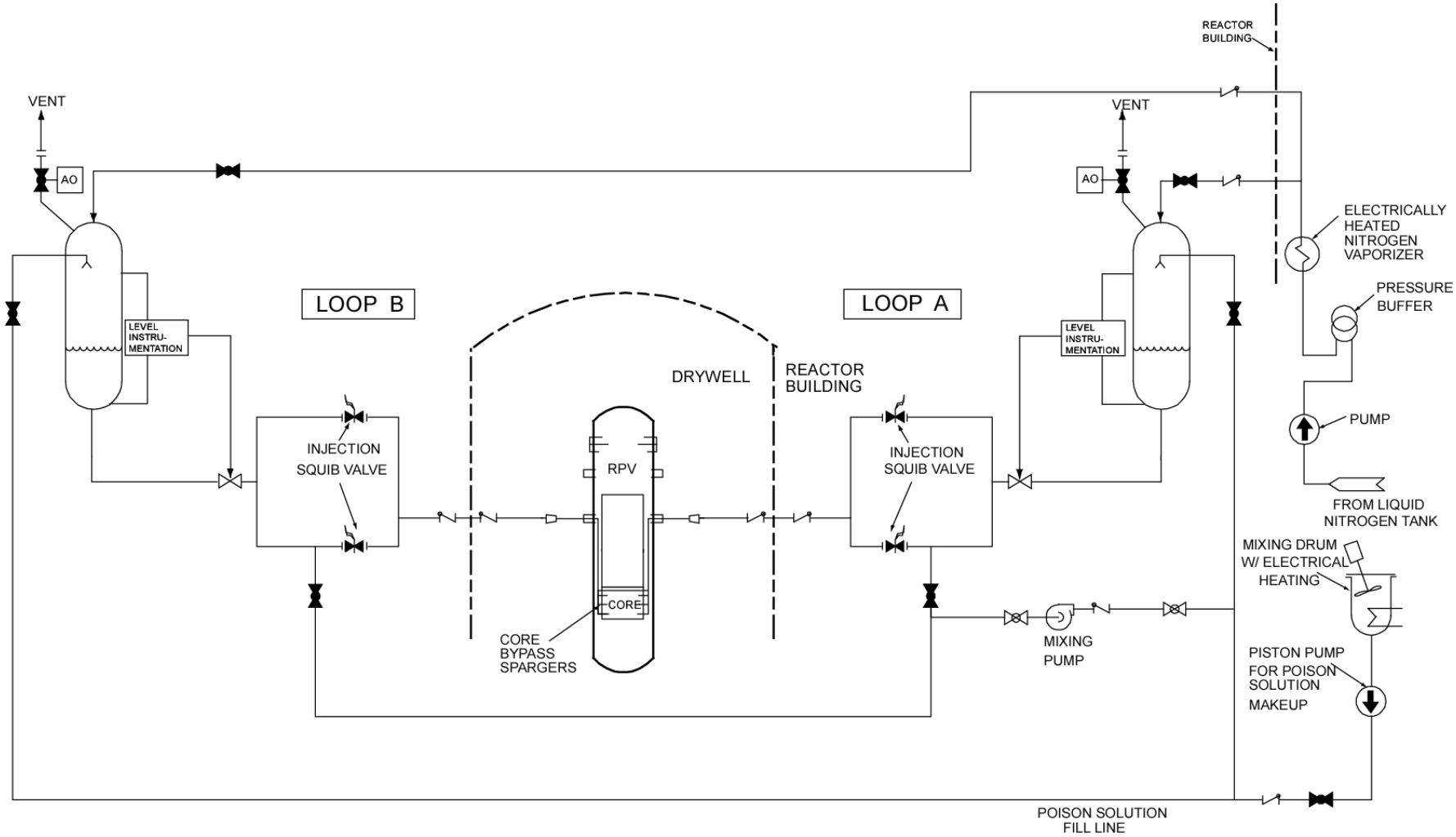
ESBWR Safety System Logic Control (SSLC) Framework

Engineering Safety Features Logics (SSLC/ESF)

- Based on ABWR design
  - 2/4 logic
  - Fail As-Is
  - Deterministic
  - Diverse from RPS
- Any two unbypassed same parameters exceeding limits always initiate ECCS with:
  - Any single logic failure
  - Any division of sensors bypass status
  - Any single power failure
- Each division makes a per parameter trip decision
- Each division makes a dual 2/4 per parameter decision to initiate
- Each division informs other divisions of its trip data (via communication module and isolated fiber optics)
- Each divisional redundant 2/4 logic drives an output load driver
- Redundant load drivers per division wired in series
- Design is single failure proof (logic and power) to actuate when required
- Design is single failure proof to prevent inadvertent actuation
- Any one of two power divisions can actuate one of the two actuators (squib valve or SRV solenoid) and open the valve



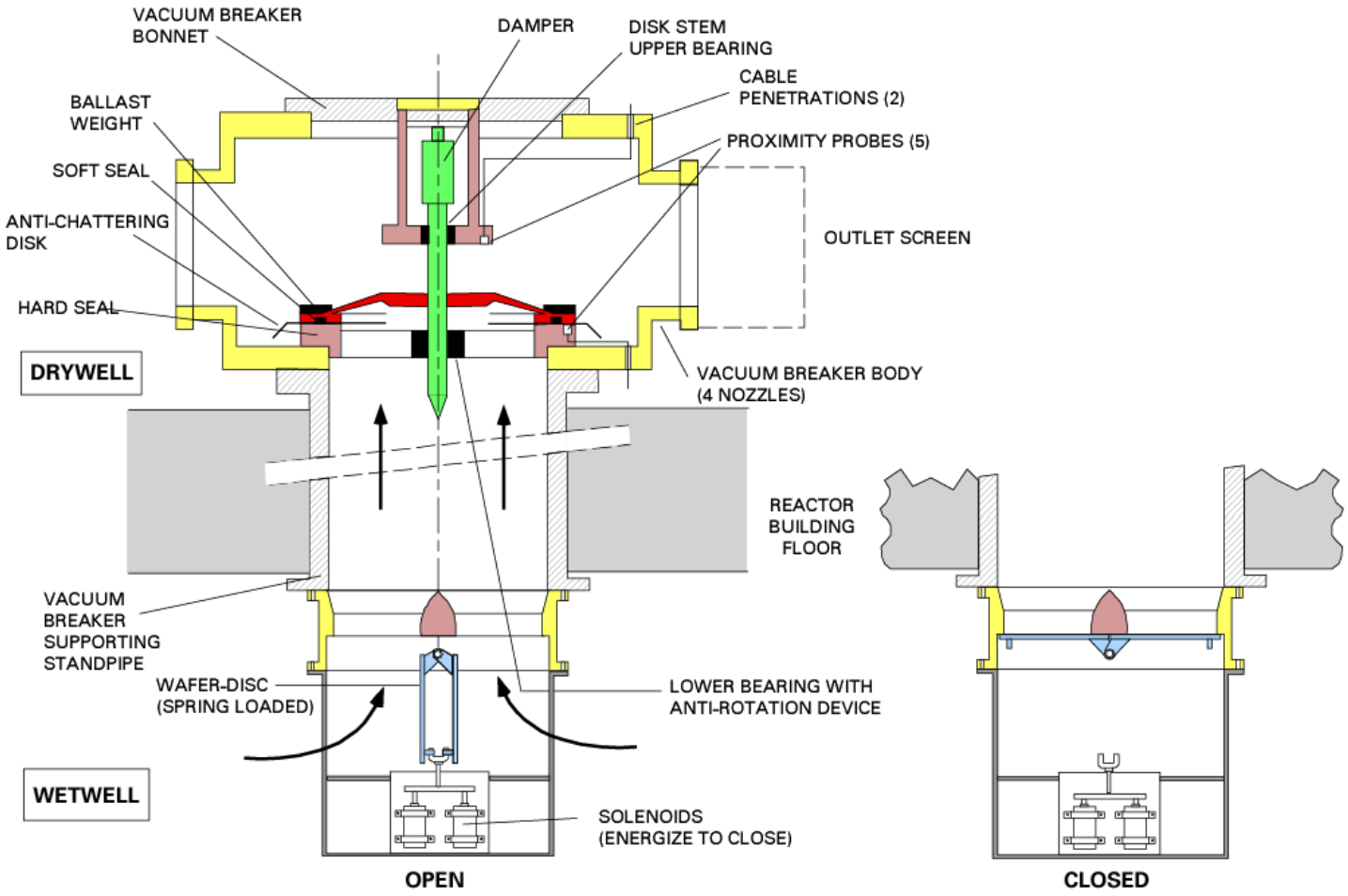
Standby Liquid Control



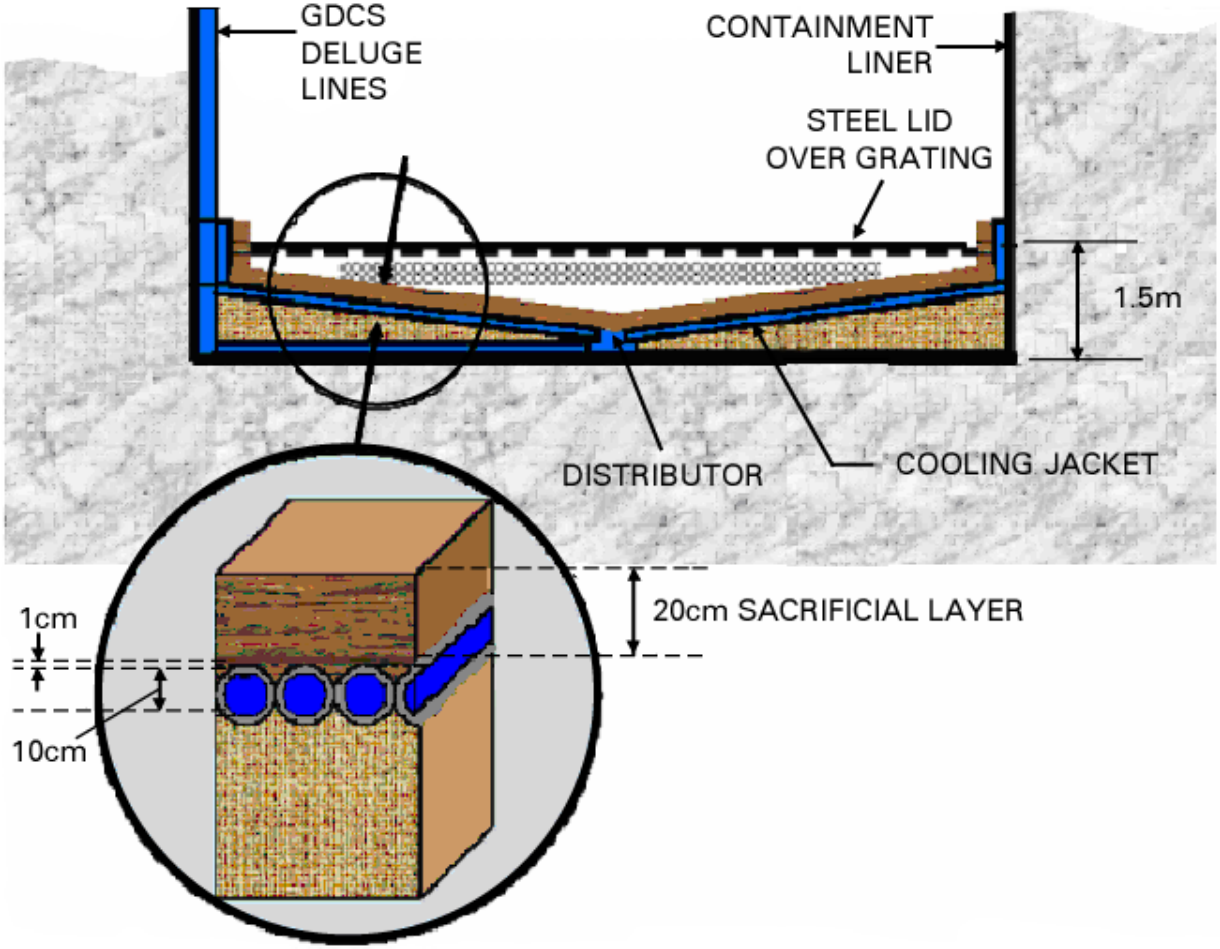
Emergency Breathing Air System

- Main Control Room Habitability
  - > Pressurized space 1/8 inch water gauge
    - – 100 CFM
  - > EBAS safety-related
    - – Single Failure Proof
    - – 72 hour passive capability
  - > MCR HVAC non-safety related
    - – With AC power availble
    - – 2 x 100% trains
    - – HEPA and Charcoal filtration

Vacuum Breaker



Basemat Internal Melt Arrest Coolability BiMAC



Fine Motion Control Rod Drives (FMCRD)

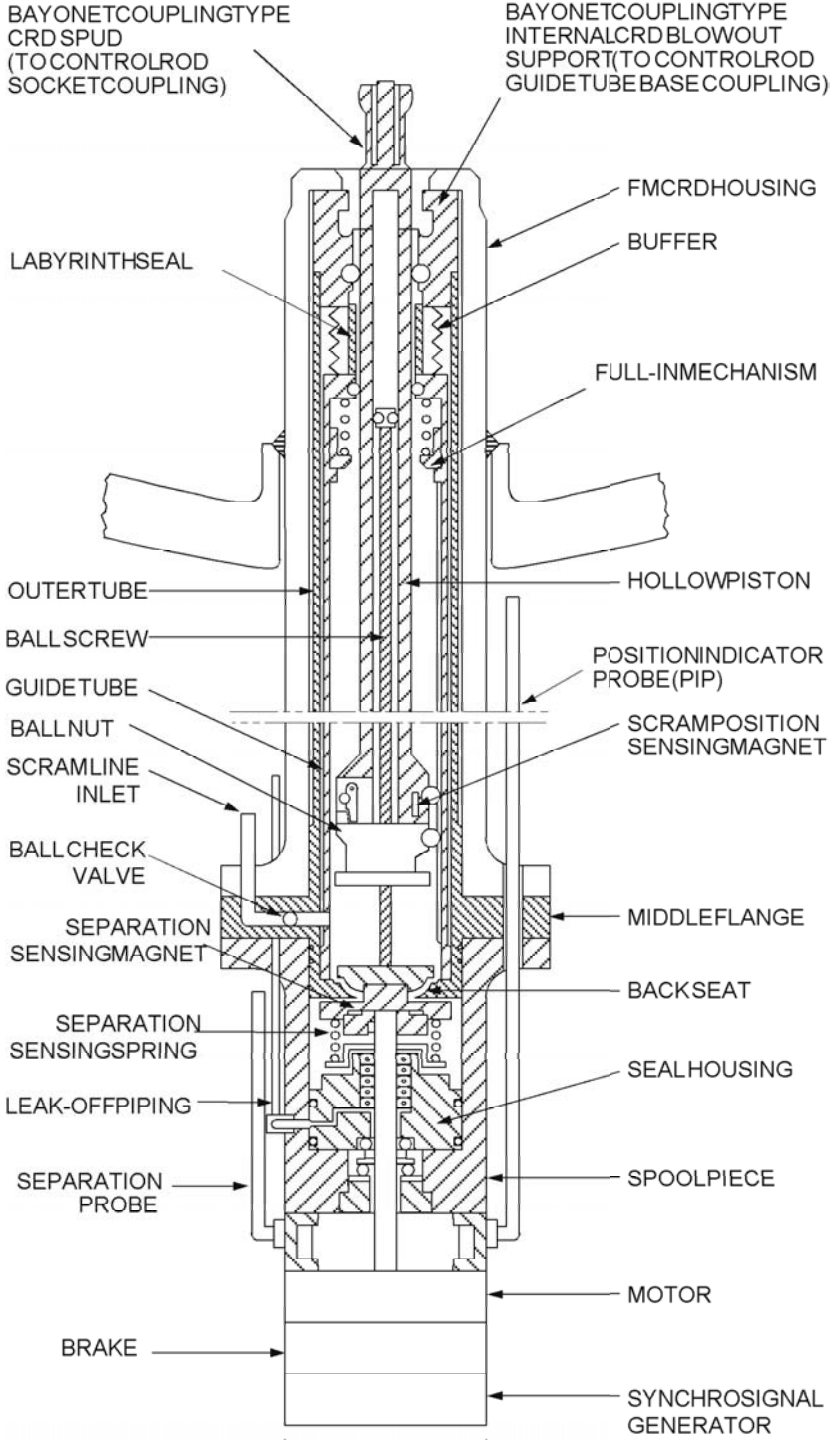
- 269 Control Rods
- Hydraulic Scram
  - > 1 HCU for 2 FMCRDs
  - > FMCRDs for 1 HCU are separated in core
  - > No Scram Discharge Volume
    - – Qualified to insert at ATWS pressures
  - > Rapid Insertion
    - – ~1.1 seconds full out to full in
  - > Reduced maintenance
- Shoot-out Steel is eliminated
  - > Self arresting

FMCRD (cont)

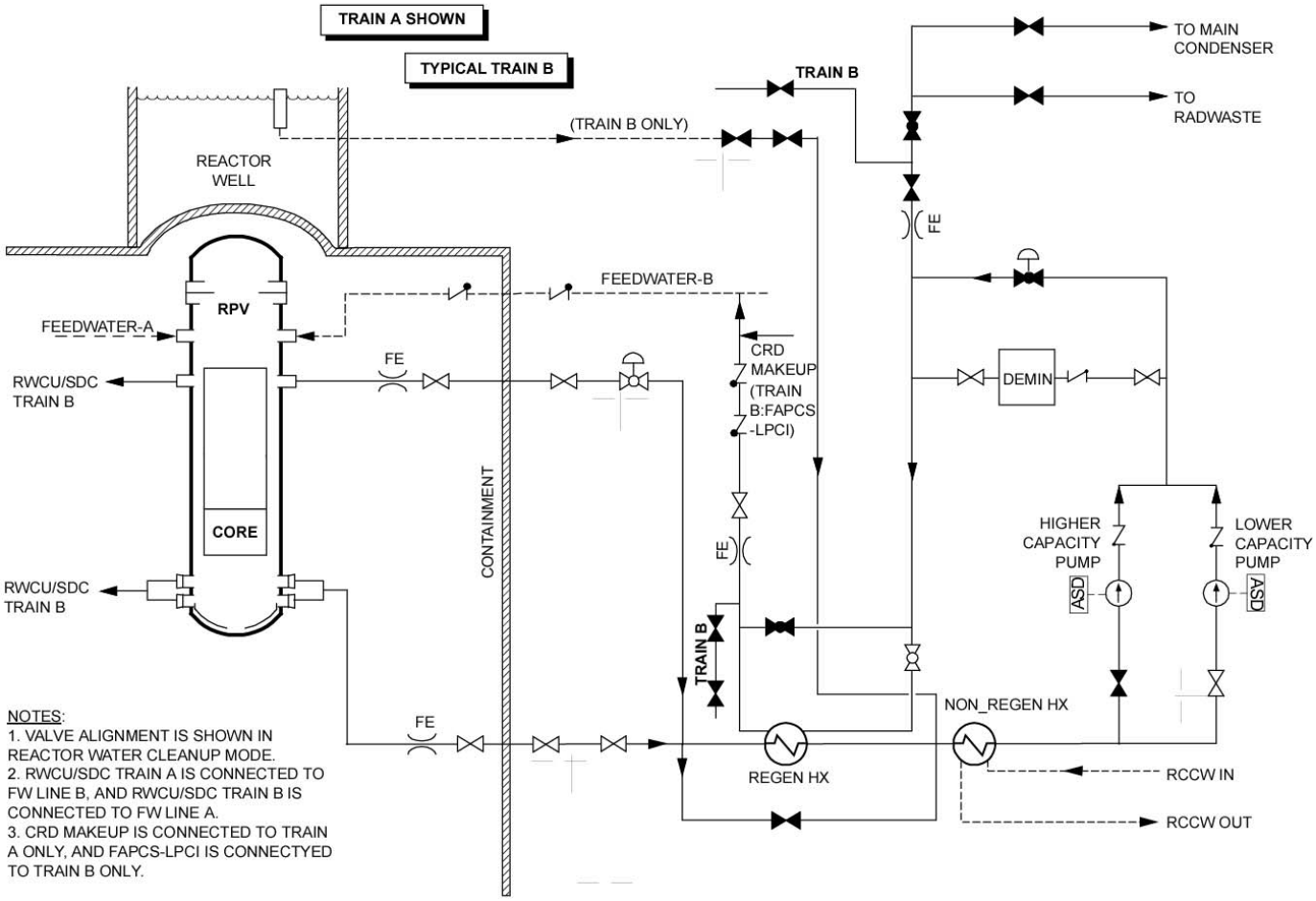
- Insertion and Withdrawl by Electric Motor
  - > No overshoot
  - > Can be ganged in groups as large as 26
  - > Positioning Increments of ~3 inches
  - > Rod Control and Information System (RCIS)
- Rod Drop Accident is no longer Credible
  - > Detection of blade failure to follow drive
  - > Check of blade to drive coupling integrity

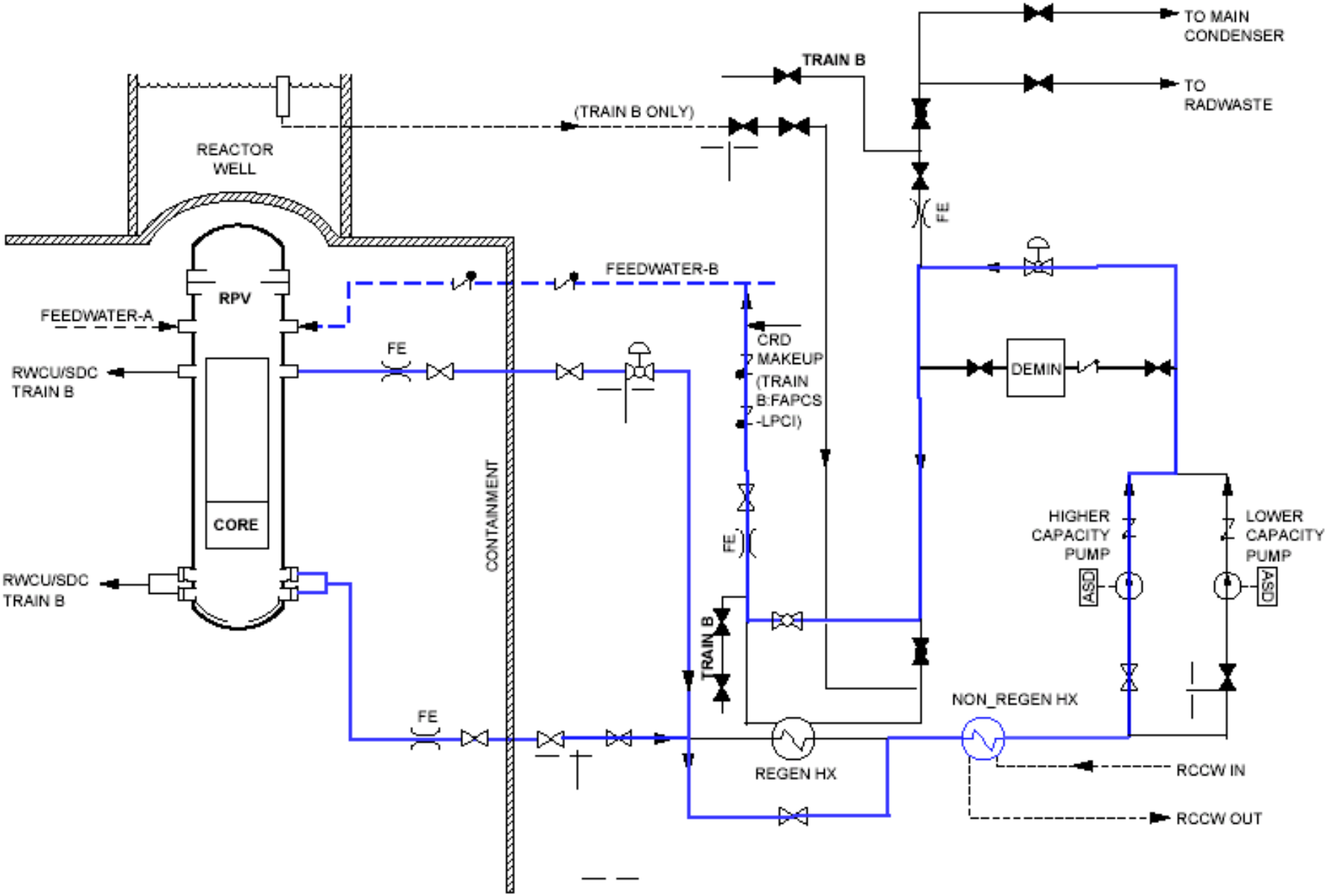
FMCRD (cont)

- Power adjustments are made with rod movement
  - > Select Control Rod Rapid Insertion (SCRRI), provides a means for rapid power reduction
  - > Simultaneously moves all rods to pre-programmed target position
- Maintenance
  - > Hydraulic portions surveillance primarily
  - > Electrical requires no break of pressure boundary


BAYONETCOUPLINGTYPE
CRD SPUD
(TO CONTROLROD
SOCKETCOUPLING)
BAYONETCOUPLINGTYPE
INTERNALCRD BLOWOUT
SUPPORT(TO CONTROLROD
GUIDETUBE BASE COUPLING)
FMCRDHOUSING
BUFFER
LABYRINTHSEAL
FULL-INMECHANISM
OUTERTUBE
HOLLOWPISTON
BALLSCREW
POSITIONINDICATOR
PROBE(PIP)
GUIDETUBE
BALLNUT
SCRAMPOSITION
SENSINGMAGNET
SCRAMLINE
INLET
BALLCHECK
VALVE
MIDDLEFLANGE
SEPARATION
SENSINGMAGNET
BACKSEAT
SEPARATION
SENSINGSPRING
SEALHOUSING
LEAK-OFFPIPING
SEPARATION
PROBE
SPOOLPIECE
MOTOR
BRAKE
SYNCHROSIGNAL
GENERATOR

Reactor Water Cleanup (RWCU)





Shutdown Cooling

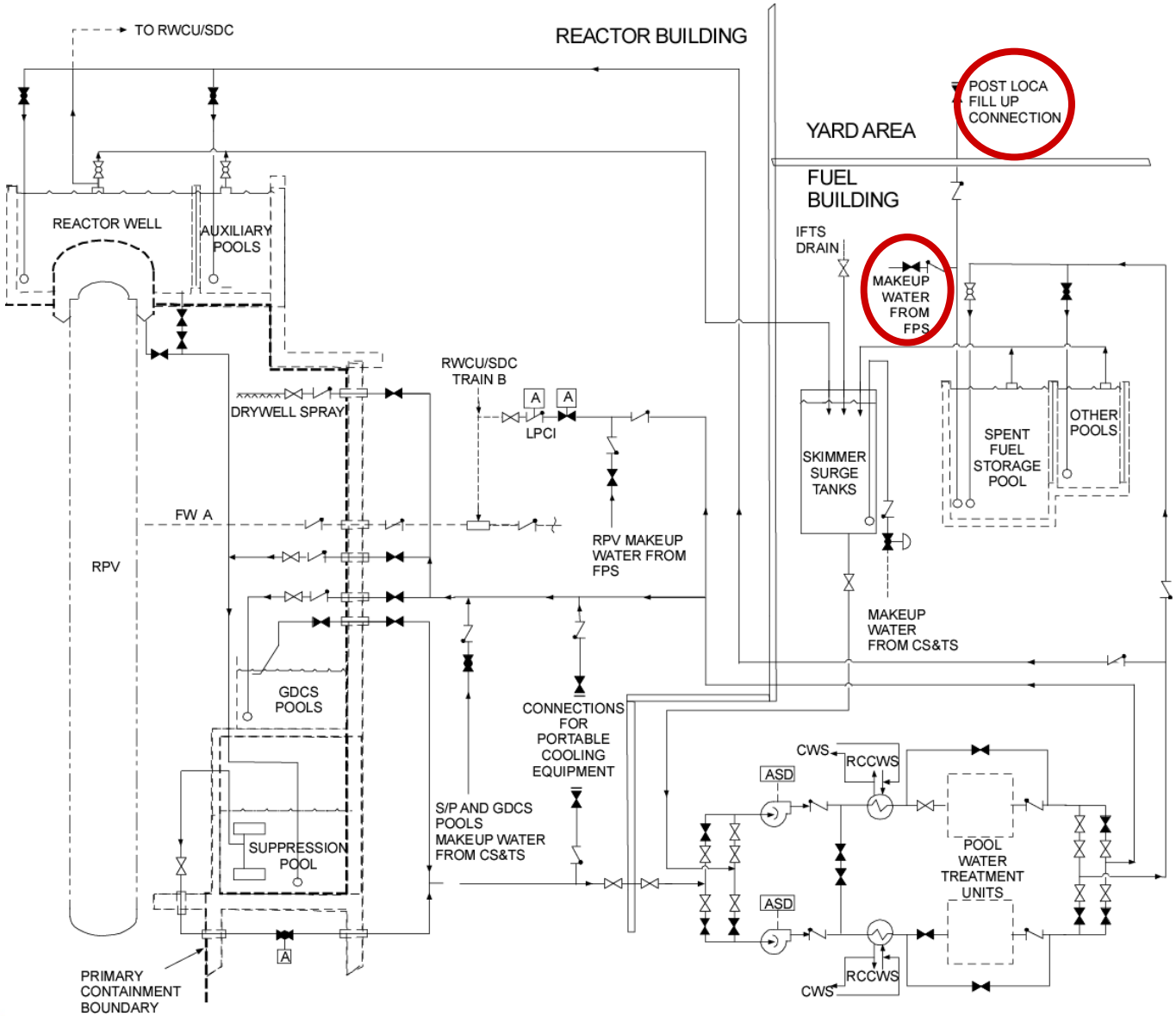
Fuel and Auxiliary Pool Cooling and Cleanup (FAPCS)

- 2 Subsystems
  - > Main
    - – 2 trains, nominally 100%
  - > ICC and PCC Pool
- Normal Operating Modes
  - > Spent Fuel Pool Cleaning and Cleanup
  - > IC/PCCS Pool Cooling and Cleanup
  - > GDCS Pool Cooling and Cleanup
  - > Suppression Pool Cooling and Cleanup

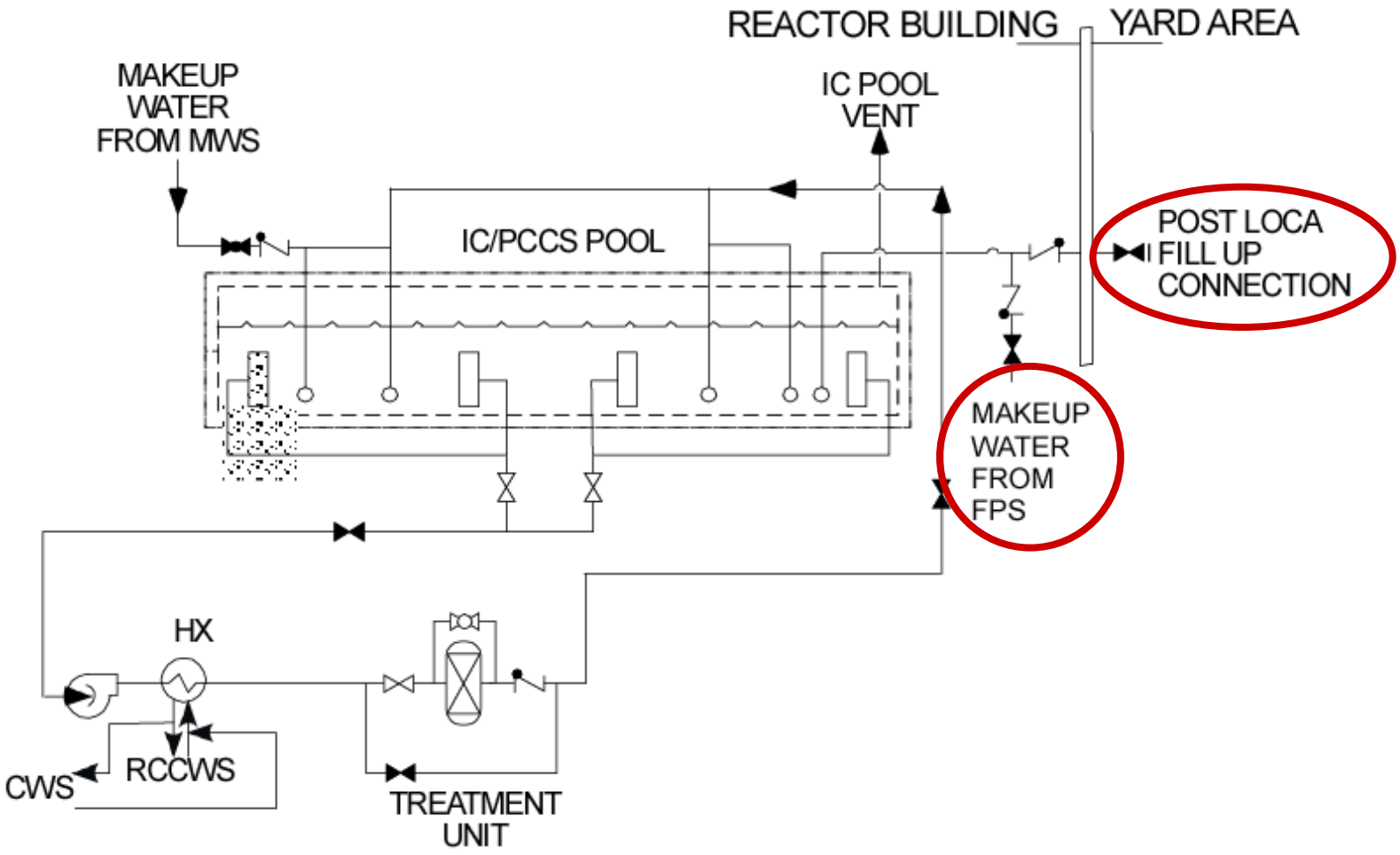
FAPCS (cont)

- FAPCS may be operated in the following modes for post-accident recovery following an accident:
  - > Spent Fuel Pool Cooling
  - > Low Pressure Coolant Injection (LPCI)
  - > Suppression Pool Cooling (SPC)
  - > Drywell Spray
  - > Alternate Shutdown Cooling (ASDC)
  - > FAPCS piping can also be used to provide makeup water to IC/PCCS pools and Spent Fuel Pool from offsite emergency water supply or Fire Protection system following a DBA

FAPCS



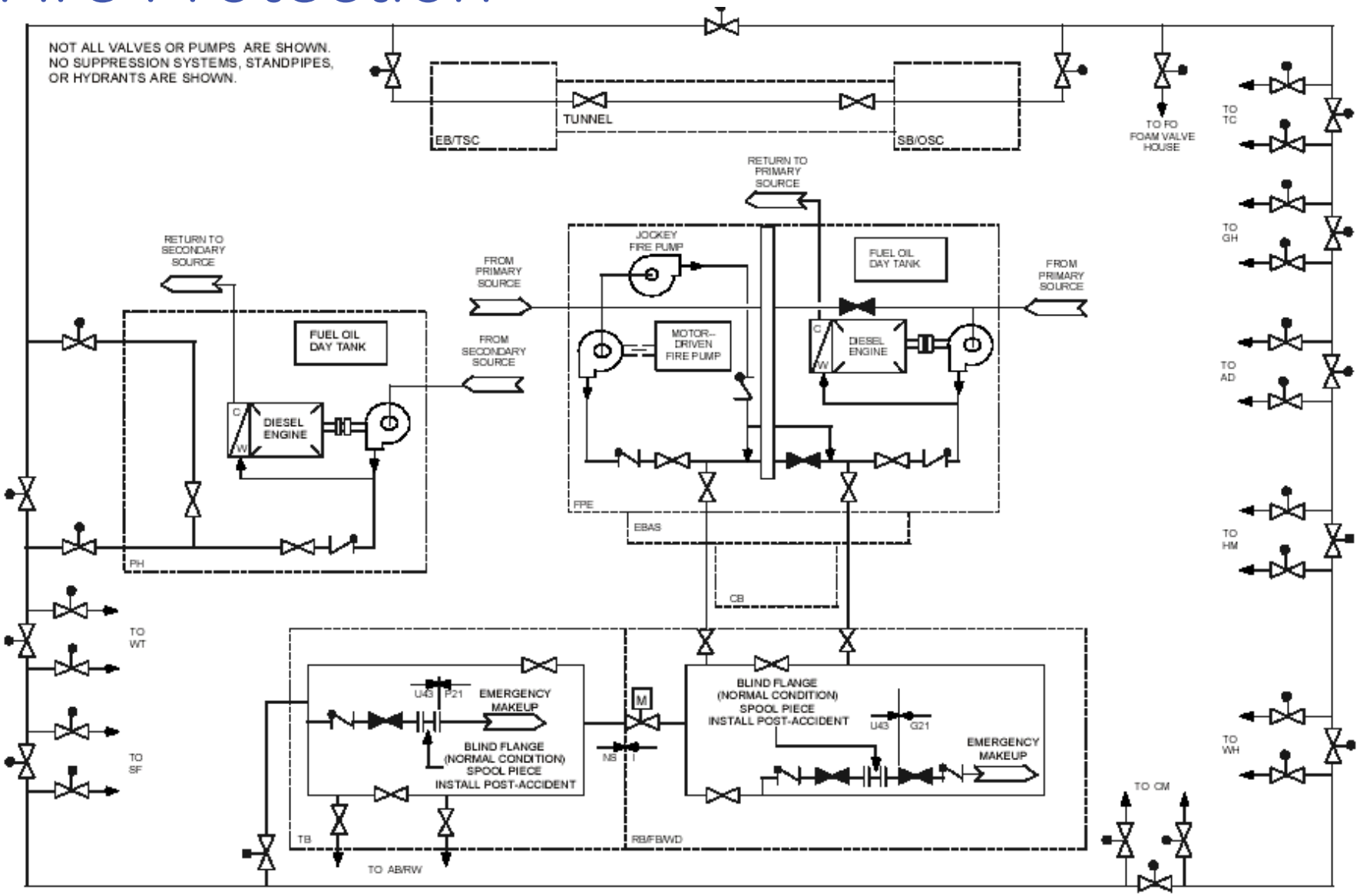
FAPCS (ICC &PCC Pool Subsystem)



Fire Protection

- One of Two RTNSS systems
  - > RTNSS applies to limited portion of system
    - Diesel driven pump and piping to FAPCS
    - Seismically analyzed but not Category I
    - Primary mission is 72 hours through 7 days
    - Secondary missions
      - Low pressure makeup
      - Makeup to IC/PCC pools if valves fail

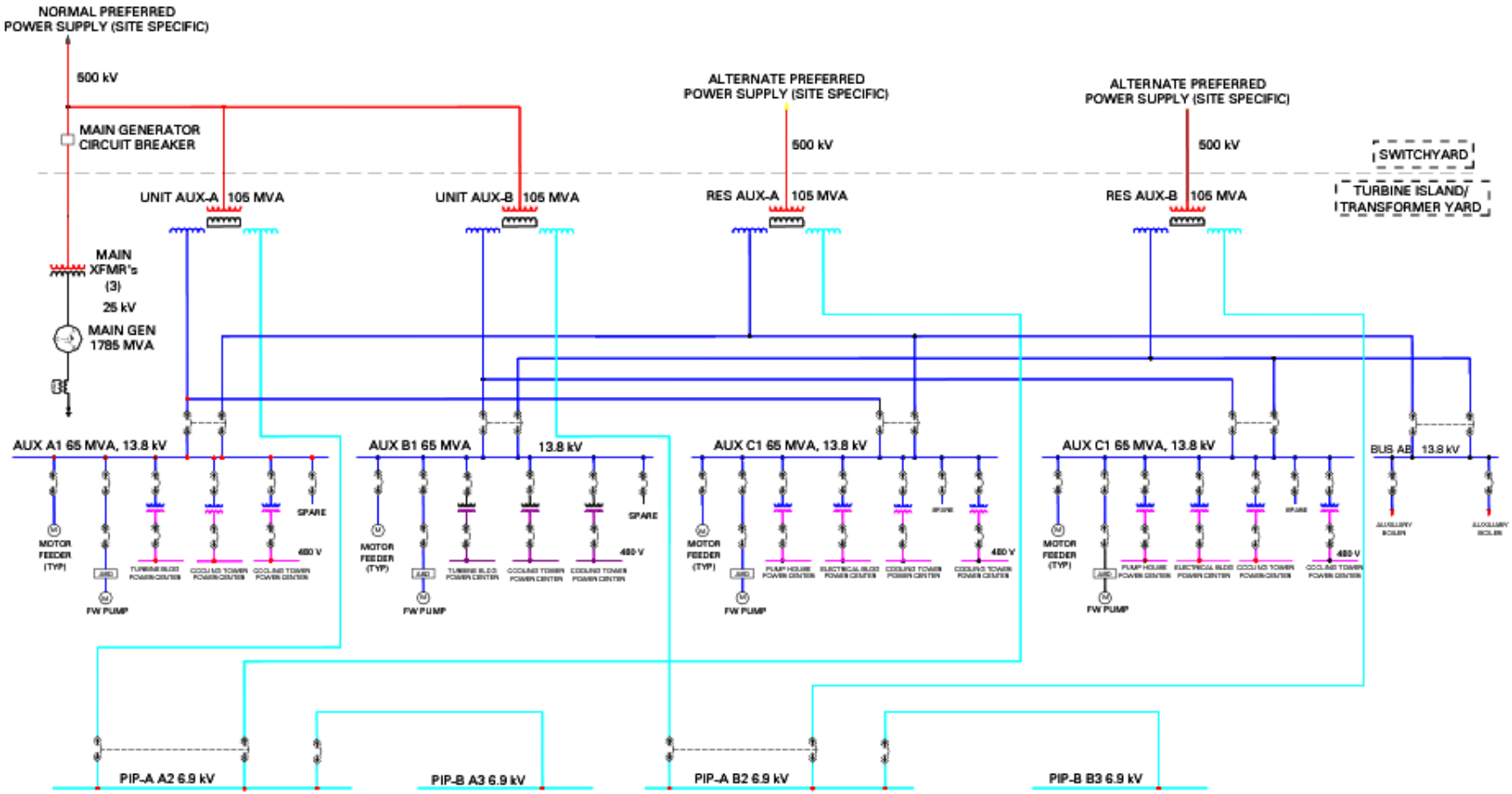
Fire Protection



Electrical System

- Designed for 100% load rejection
  - > No Scram
  - > 110% rated bypass system
    - – Short term capability
    - – SCRRI rapidly reduces power
  - > Hotel load operation
  - > Fast transfer available between UAT and RAT
  - > UAT and RAT are both triple winding design
    - – UAT and RAT are identically sized

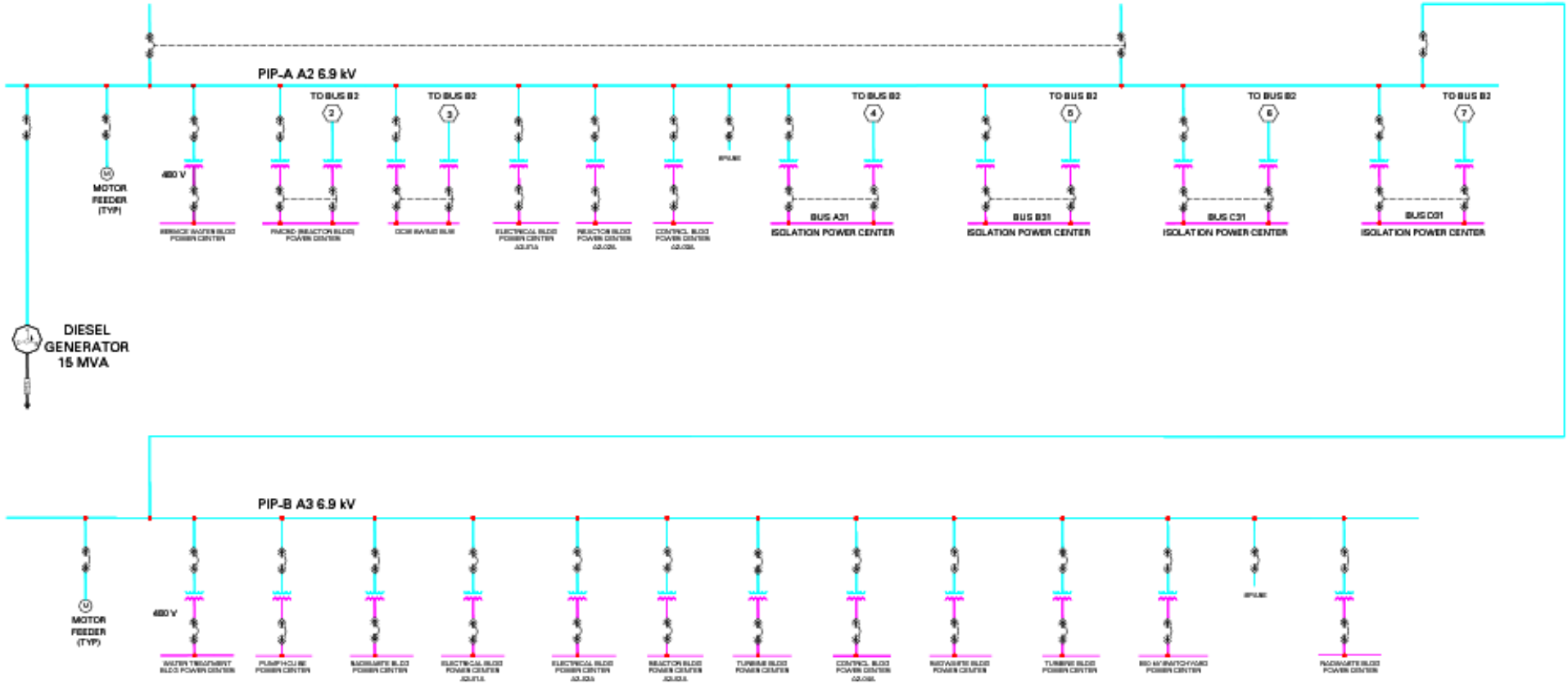
Electrical Main Single Line Diagram



Plant Investment Protection

- Backed by 2 non-safety on-site diesel generators
- Investment Protection
  - > Turbine Lube Oil
- Plant Availability
  - > Chilled Water
  - > HVAC
- Defense in Depth
  - > FAPCS and RWCU
    - – Service Water and Closed Cooling Water

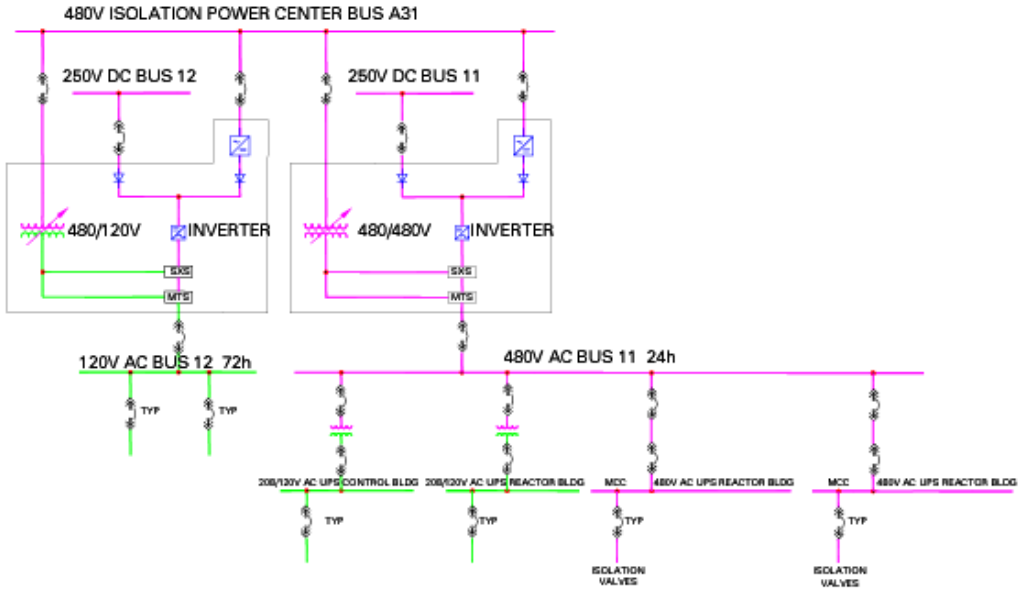
Plant Investment Protection Busses



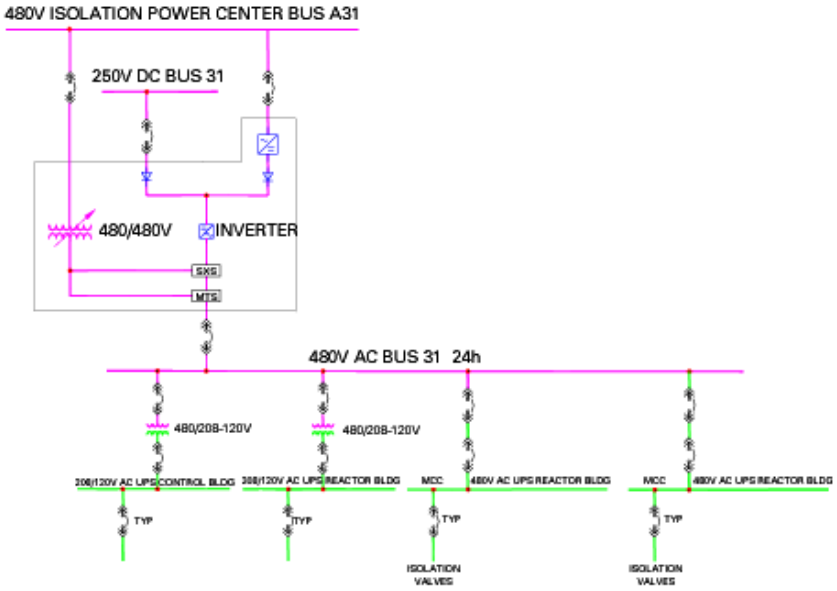
Safety Related (1E) Electrical System

- Four Divisions Safety-Related
  - > DC (battery) Backed
    - – Inverted power for AC loads
    - – 4 Divisions with 24 hours Capability
      - Monitor
      - Control
    - – 2 divisions with 72 hours Capability
      - Monitor

ESBWR Class 1E Uninterruptable Power

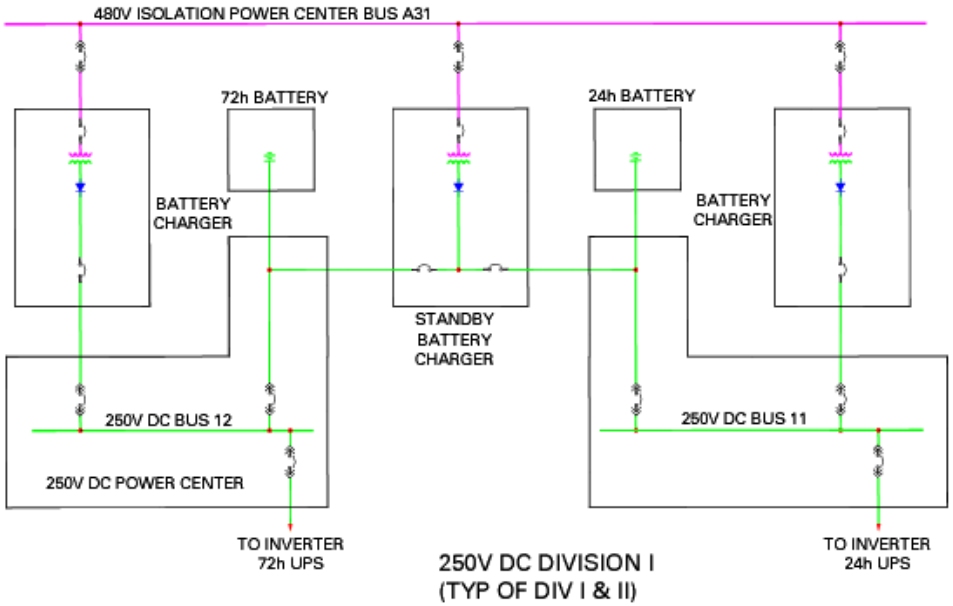


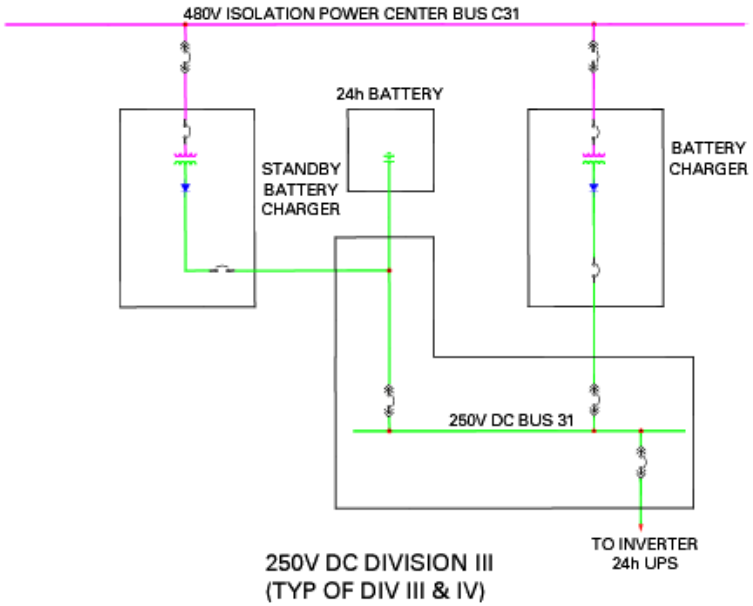
CLASS 1E UNINTERRUPTABLE POWER SUPPLY DIVISION I
(TYP OF DIV I & II)



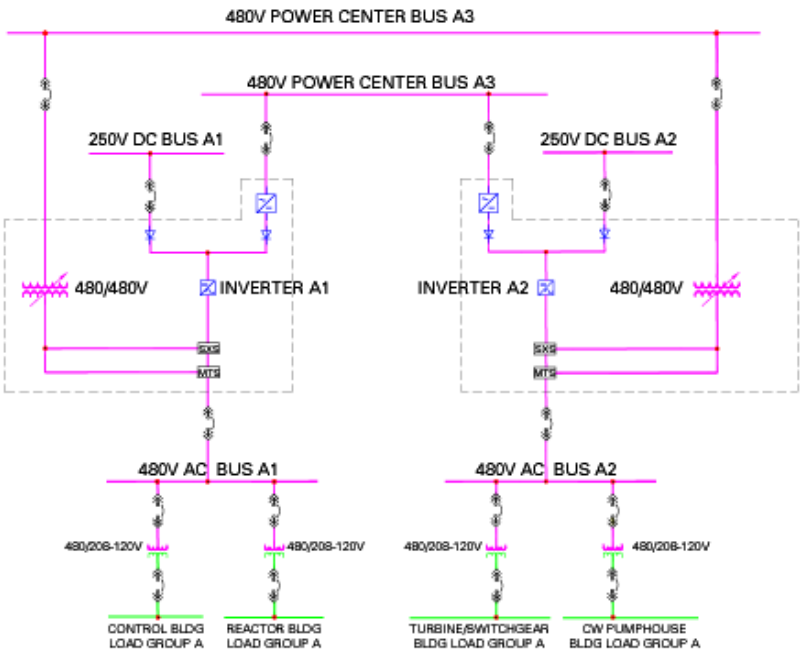
CLASS 1E UNINTERRUPTABLE POWER SUPPLY DIVISION III
(TYP OF DIV III & IV)

ESBWR Class 1E DC Power

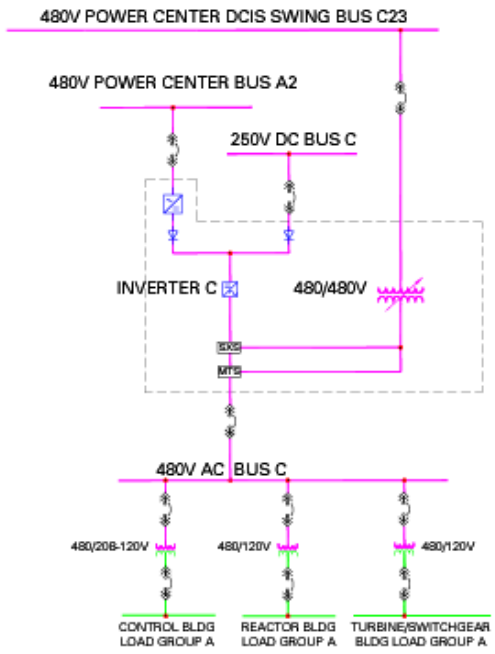




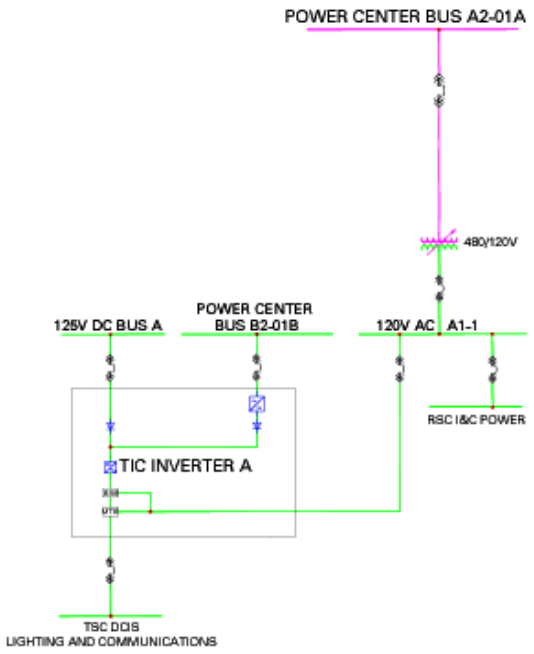
ESBWR Non-Class 1E Uninterruptable Power



NON CLASS 1E UNINTERRUPTABLE POWER SUPPLY (TYP OF BUS A3 & B3)

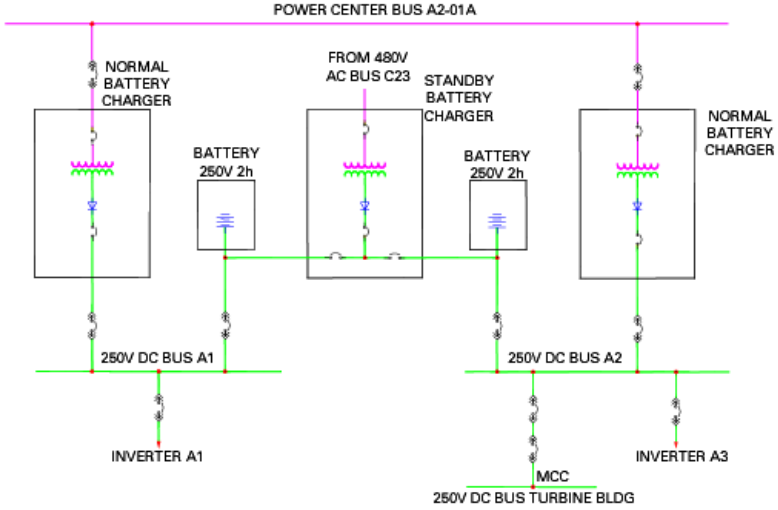


NON CLASS 1E UNINTERRUPTABLE POWER SUPPLY (SWING BUS)

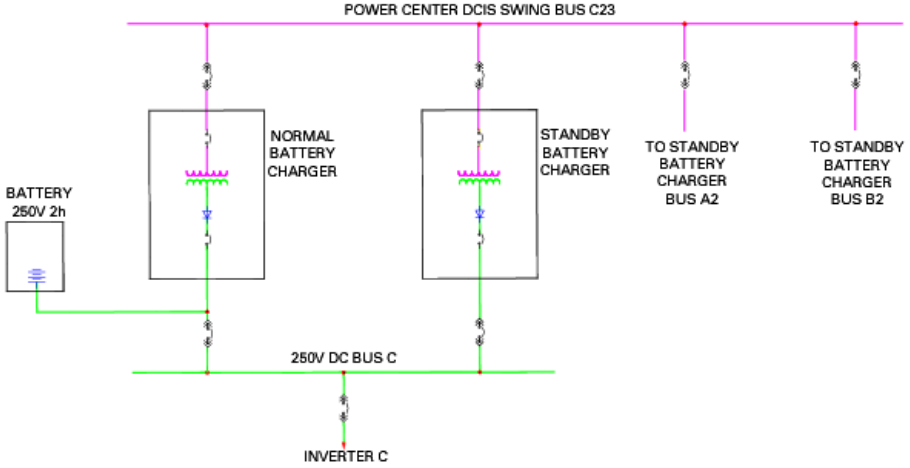


NON CLASS 1E UNINTERRUPTABLE TSC SYSTEM (TYP OF A2 AND B2)

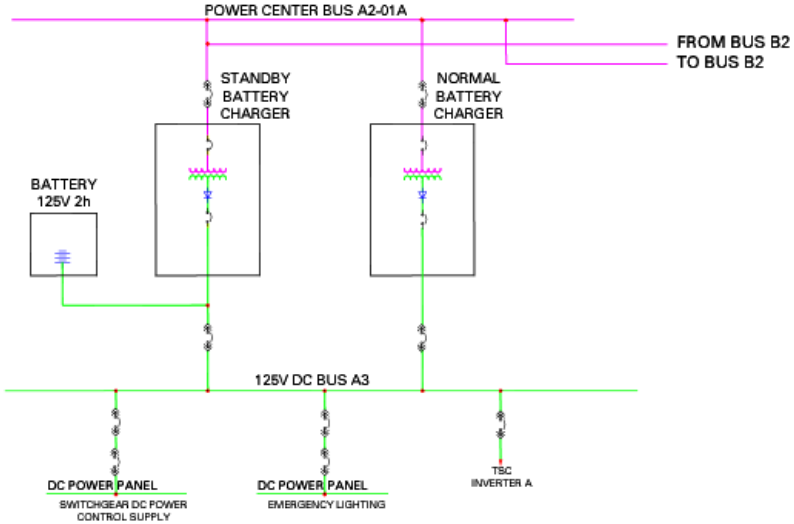
ESBWR Non-Class 1E DC Power



NON-CLASS 1E 250V DC POWER SYSTEM (TYP OF BUS A2 & B2)



NON-CLASS 1E 250V DC POWER SYSTEM DCIS SWING BUS



NON-CLASS 1E 125V DC POWER SYSTEM(TYP OF BUS A2 & B2)