Chemical Engineering 612

Reactor Design and Analysis

Lecture 18

Nuclear Safety II

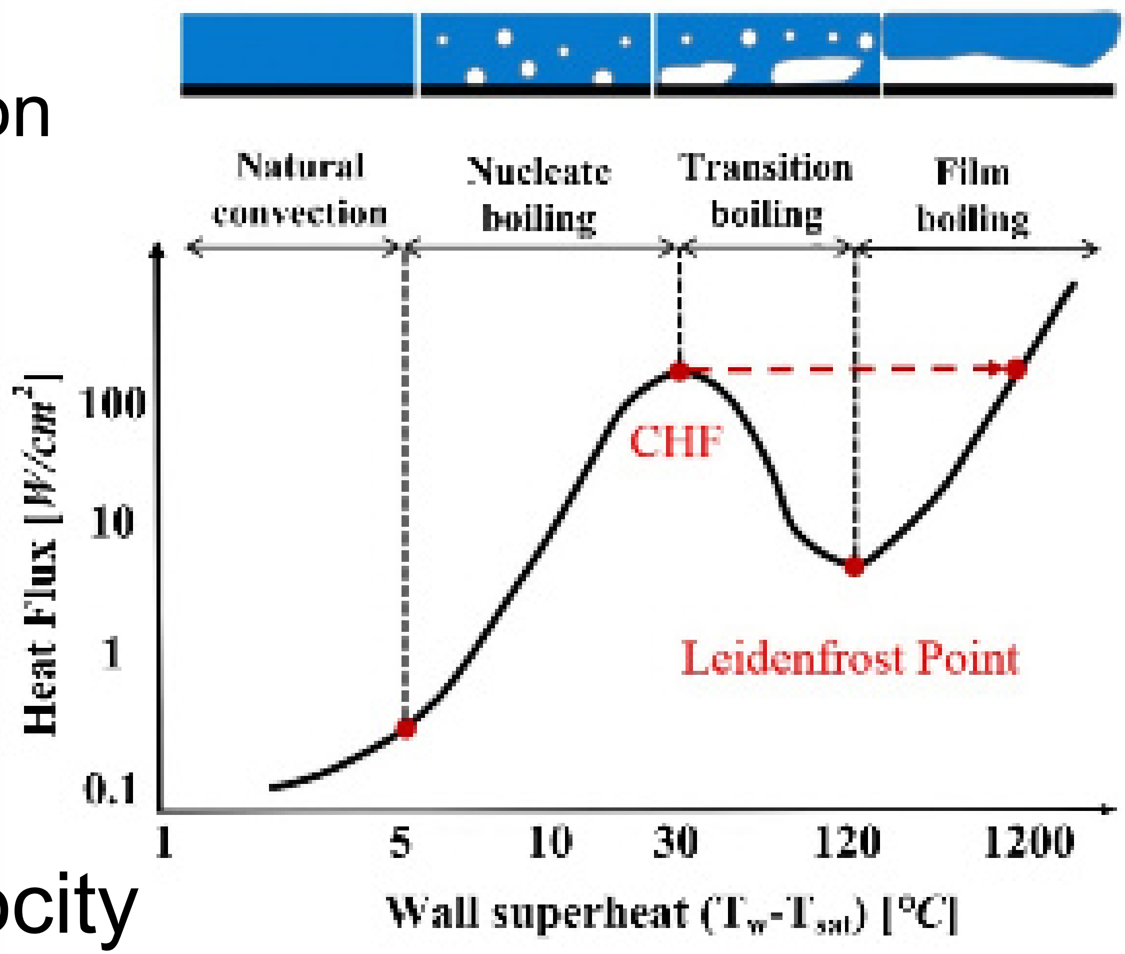
Spiritual Thought

When **He answers yes**, **it** is to give us confidence. When **He answers** no, **it** is to prevent error. When **He** withholds an **answer**, **it** is to have us grow through faith in Him, obedience to His commandments, and a willingness to act on truth.

-Elder Richard G. Scott

PWR Operational Margins

- MDNBR
  - Code evaluation
  - ~2.17
- Pressure Drop
  - 29 psia
- Fuel Temp
  - 2800 ˚C PT
  - 1440 ˚C Avg
- Axial Flow Velocity
  - 7 m/s



PWR Transient Margins

- PCT of 1200 ˚C
- Maximum clad oxidation of less than 17% of the clad thickness
- Hydrogen generation of less than that required for the deflagration limits for containment integrity
- Less than 1% clad strain or a MDNBR of ≤1.0
- 18% overpower limit

BWR Transient Margins

- Linear Heat Generation Rate
  - 25 kW/ft
- Critical Power Ratio
  - 1.06
- Average Planer Linear Heat Generation Rate
- Less than 1% clad strain or a MDNBR of ≤1.0
- 18% overpower limit (16.03 kg/ft)

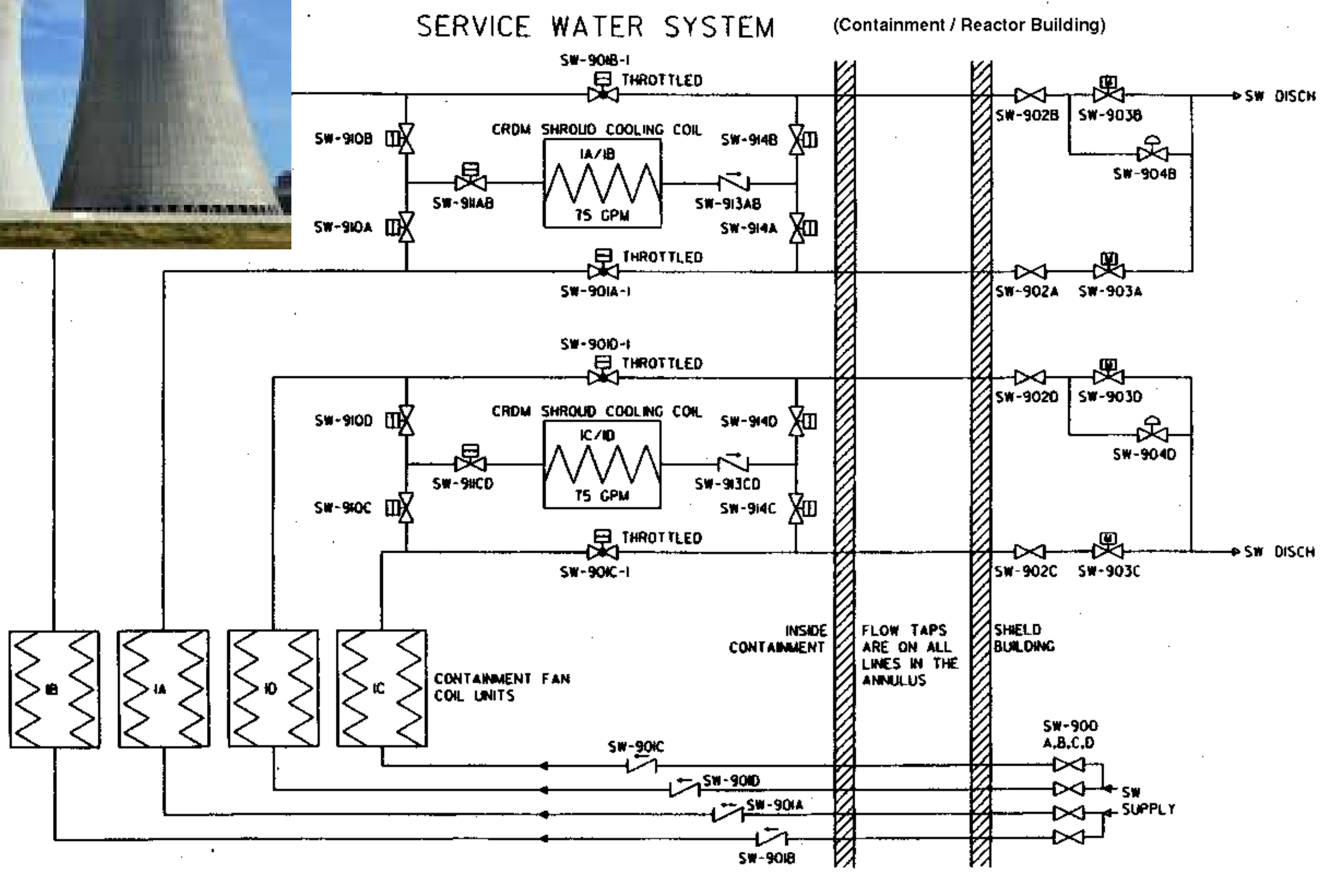
Safety Systems

- Required for licensing
- Prevent Public Dose
- Designed to protect in DBAs
- For BDBAs
  - Provide some credit
  - Inadequate
  - Fukushima
- 7 typical safety systems in PWRs and BWRs

The Reactor Protection System (RPS)

- Control rods
- Safety Injection/Standby liquid control

Essential Service Water System (ESWS)



Emergency Core Cooling System (ECCS)

- High Pressure Safety Injection System (HPSI)
  - Initiated by:
    - Low pressurizer pressure
    - High containment pressure
    - Steam line pressure/flow anomalies
- Automatic Depressurization System
  - 7 SRVs in vessel head
  - Rapidly decrease system pressure
  - Initiated by low level + time delay

ECCS (continued)

- Low Pressure Safety System (HPSI)
  - Only functions after blowdown
    - Larger supply
    - Later in accident
- Containment cooling system
  - Spray system
    - Actuated by high containment pressure/temperuture
- Core Spray System
  - (BWR only)

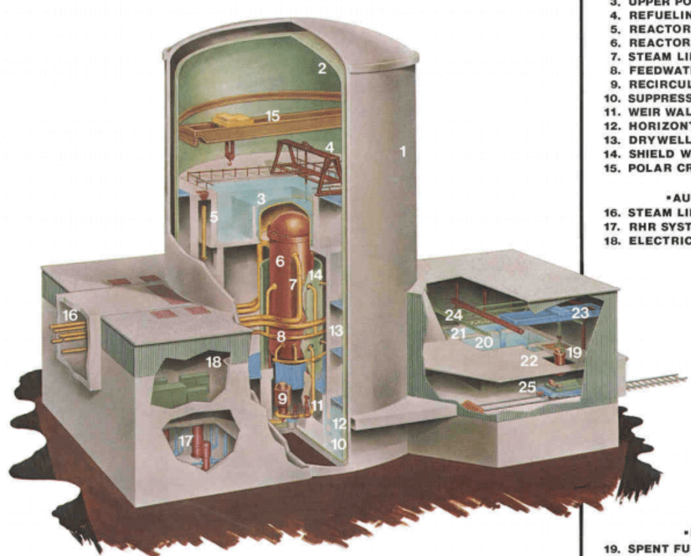
Emergency Electrical Systems (EES)

- Diesel Generators
- Flywheels
- Batteries

Containment Systems

- Clad
- Containment
- Secondary Containment

MARK III CONTAINMENT



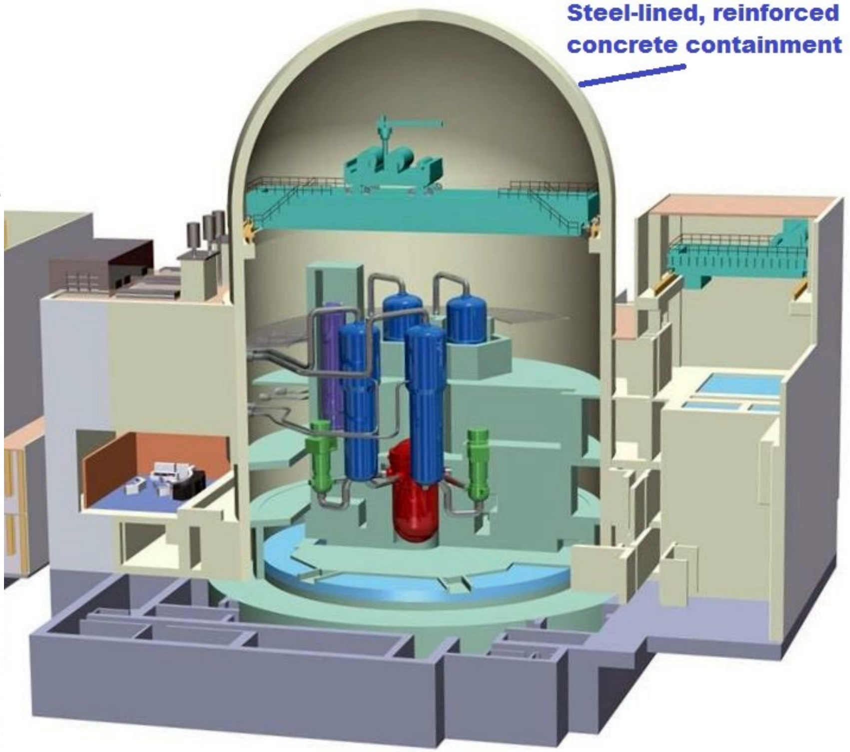
GENERAL ELECTRIC

•REACTOR BUILDING•
1. SHIELD BUILDING
2. FREESTANDING STEEL CONTAINMENT
3. UPPER POOL
4. REFUELING PLATFORM
5. REACTOR WATER CLEANUP
6. REACTOR VESSEL
7. STEAM LINE
8. FEEDWATER LINE
9. RECIRCULATION LOOP
10. SUPPRESSION POOL
11. WEIR WALL
12. HORIZONTAL VENT
13. DRYWELL
14. SHIELD WALL
15. POLAR CRANE

•AUXILIARY BUILDING•
16. STEAM LINE TUNNEL
17. RHR SYSTEM
18. ELECTRICAL EQUIPMENT ROOM

•FUEL BUILDING•
19. SPENT FUEL SHIPPING CASK
20. FUEL STORAGE POOL
21. FUEL TRANSFER POOL
22. CASK LOADING POOL
23. CASK HANDLING CRANE
24. FUEL TRANSFER BRIDGE
25. FUEL CASK SKID ON RAILROAD CAR

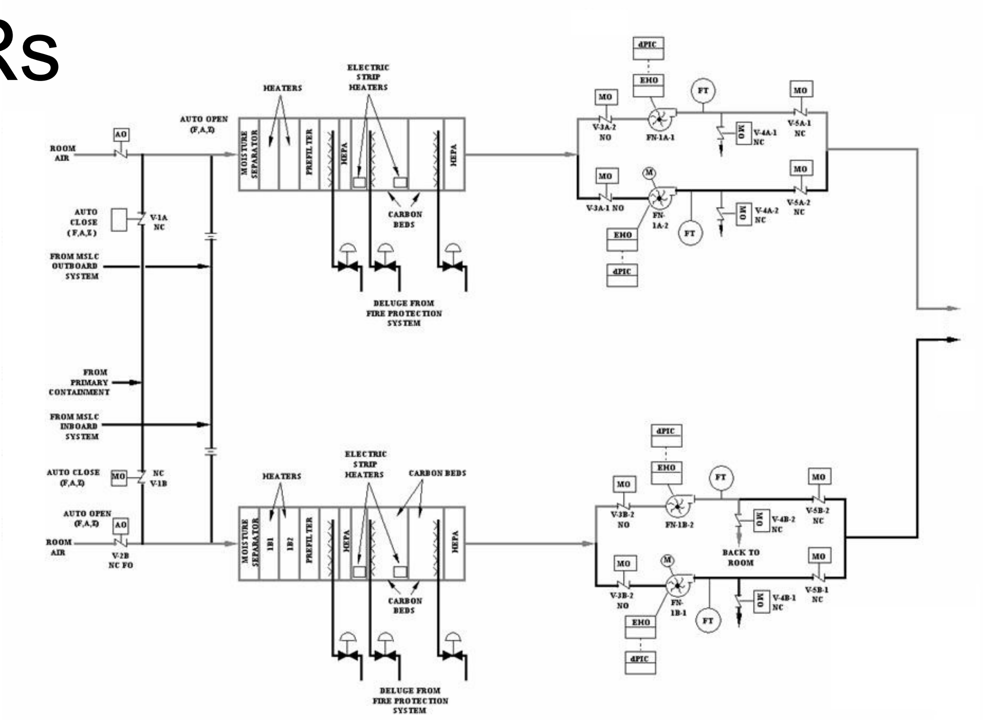
Typical Pressurized Water Reactor



Source: U.S. Nuclear Regulatory Commission

Standby Gas Treatment Systems (SBGT)

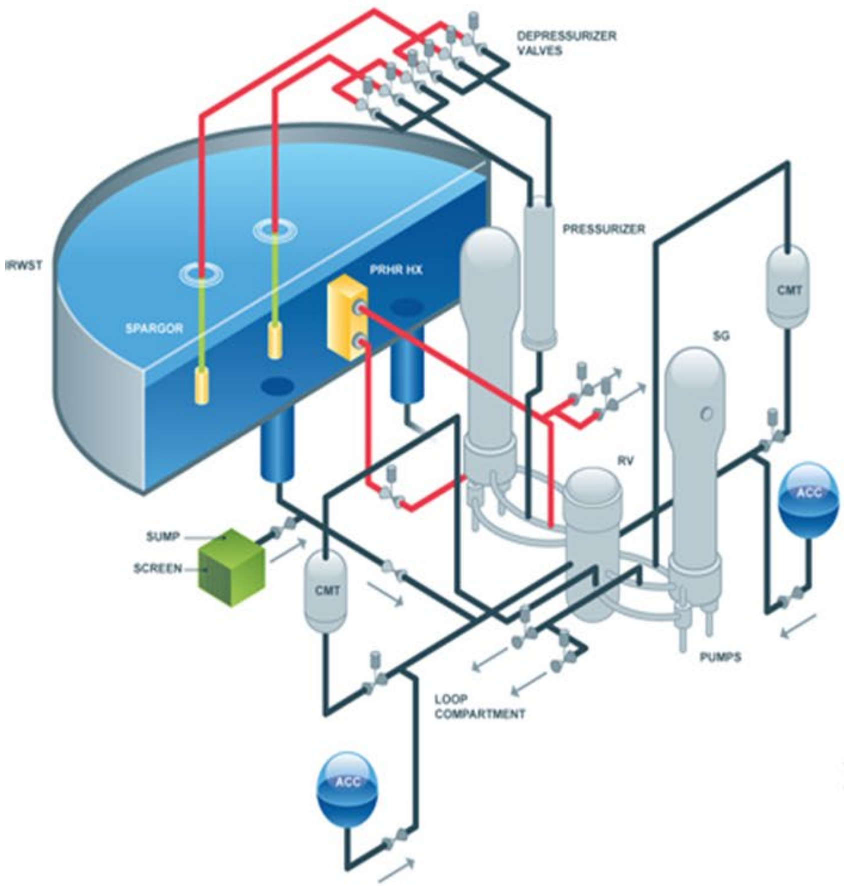
- Secondary Containment
  - Maintain negative pressures
  - (pull air in, rather than release radioactivity)
- Primarily for BWRs

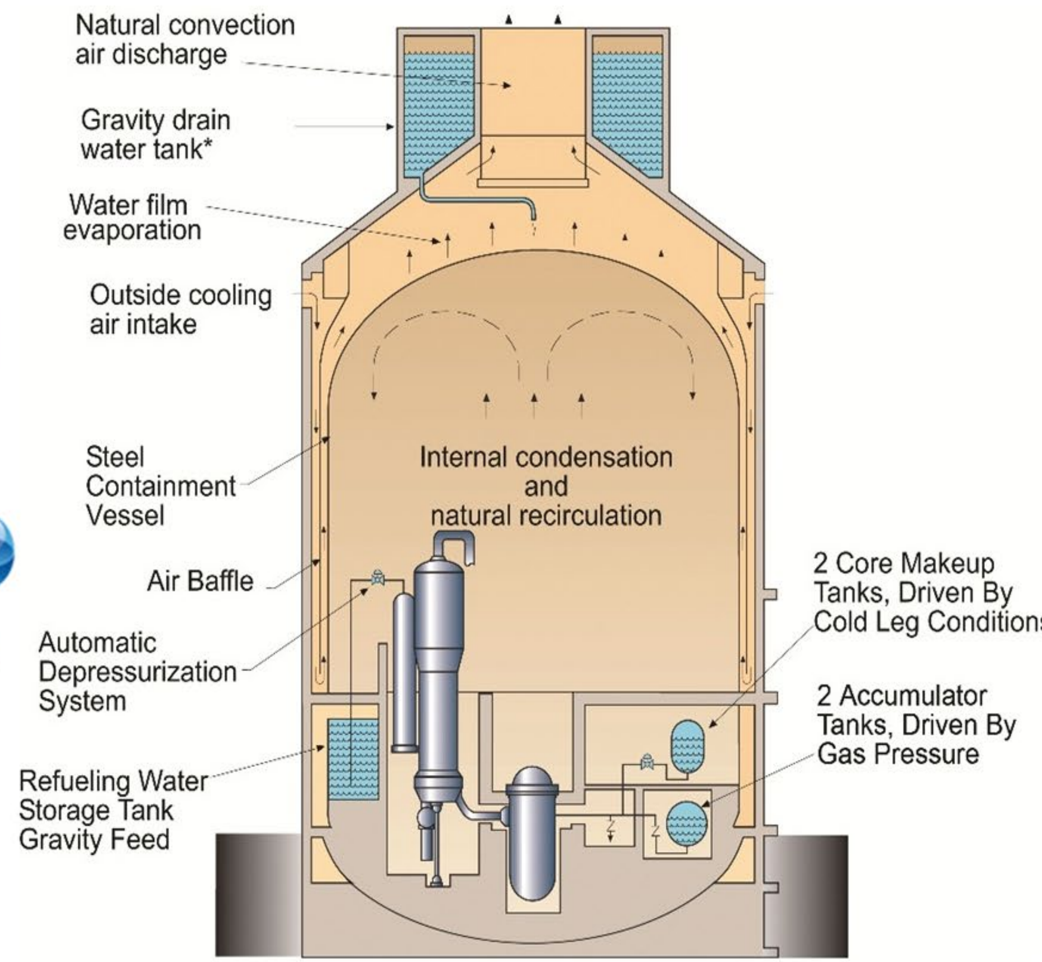


Ventilation and Radiation Protection Systems

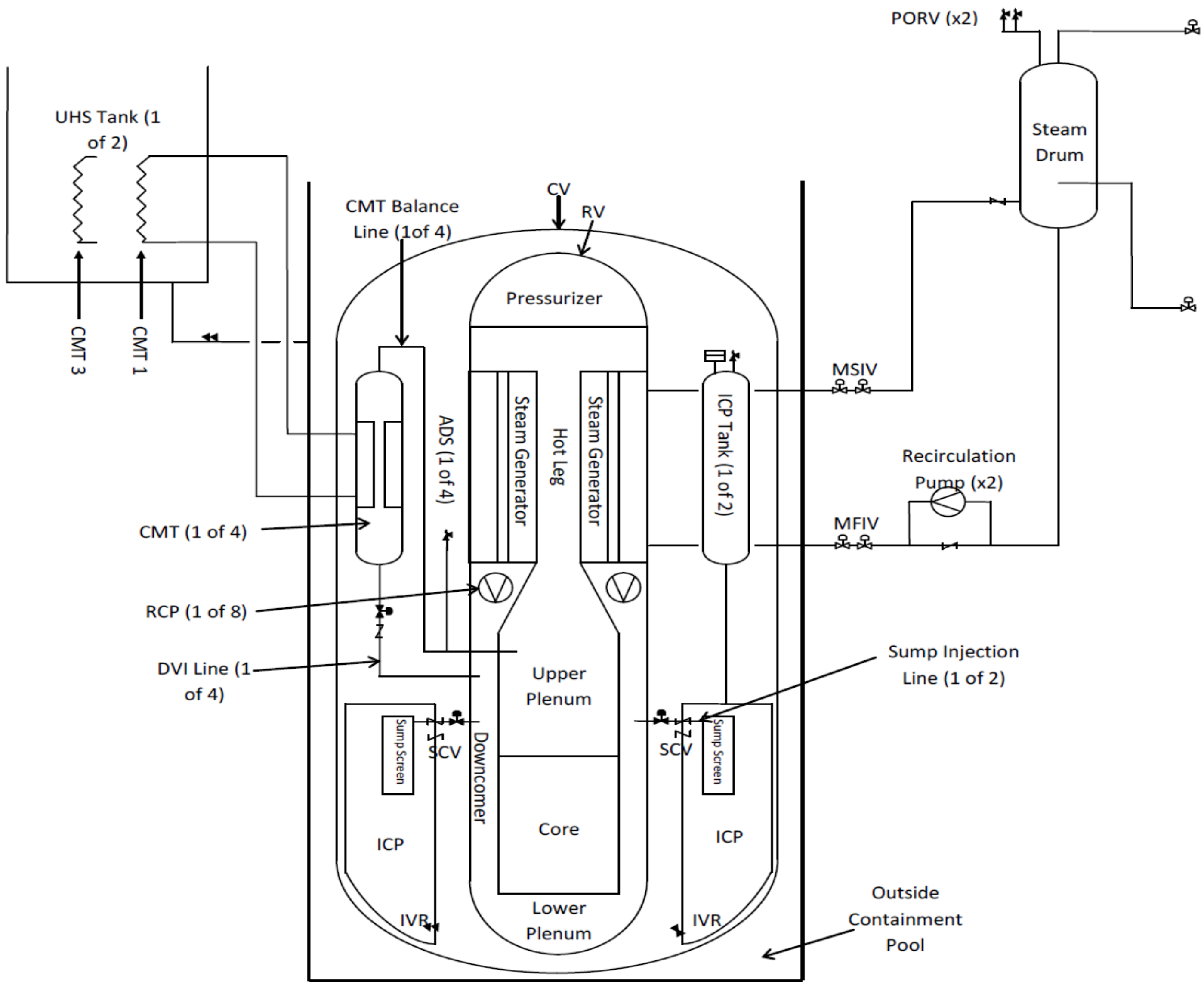
- Prevention of radiation gas release
  - Auxiliary Building
  - Shield Building
  - Reactor Building
  - Turbine Building
  - Radwaste Building
  - Control Room
  - Screenhouse
- Vent, Filter, Blowers

AP1000


DEPRESSURIZER VALVES
PRESSURIZER
IRWST
PRHR HX
SPARGOR
CMT
SG
RV
SUMP
SCREEN
CMT
ACC
PUMPS
LOOP COMPARTMENT
ACC


Natural convection air discharge
Gravity drain water tank*
Water film evaporation
Outside cooling air intake
Steel Containment Vessel
Internal condensation and natural recirculation
Air Baffle
Automatic Depressurization System
2 Core Makeup Tanks, Driven By Cold Leg Conditions
2 Accumulator Tanks, Driven By Gas Pressure
Refueling Water Storage Tank Gravity Feed

Westinghouse SMR Safety Systems



AP1000 vs. SMR

Function	AP1000	Westinghouse SMR
Short Term Reactivity Controls	Control Rods	Control Rods
Long-Term Reactivity Controls	2 CMTs	4 CMTs
Decay Heat Removal	1 PRHR / PCS	4 CMTs w/ integral heat exchangers
Long-Term Makeup Water Supply	1 iRWST / Sump	2 ICP Tanks / Sump
Ultimate Heat Sink	PCS (72 hours)	2 UHS Tanks (72 hours each)

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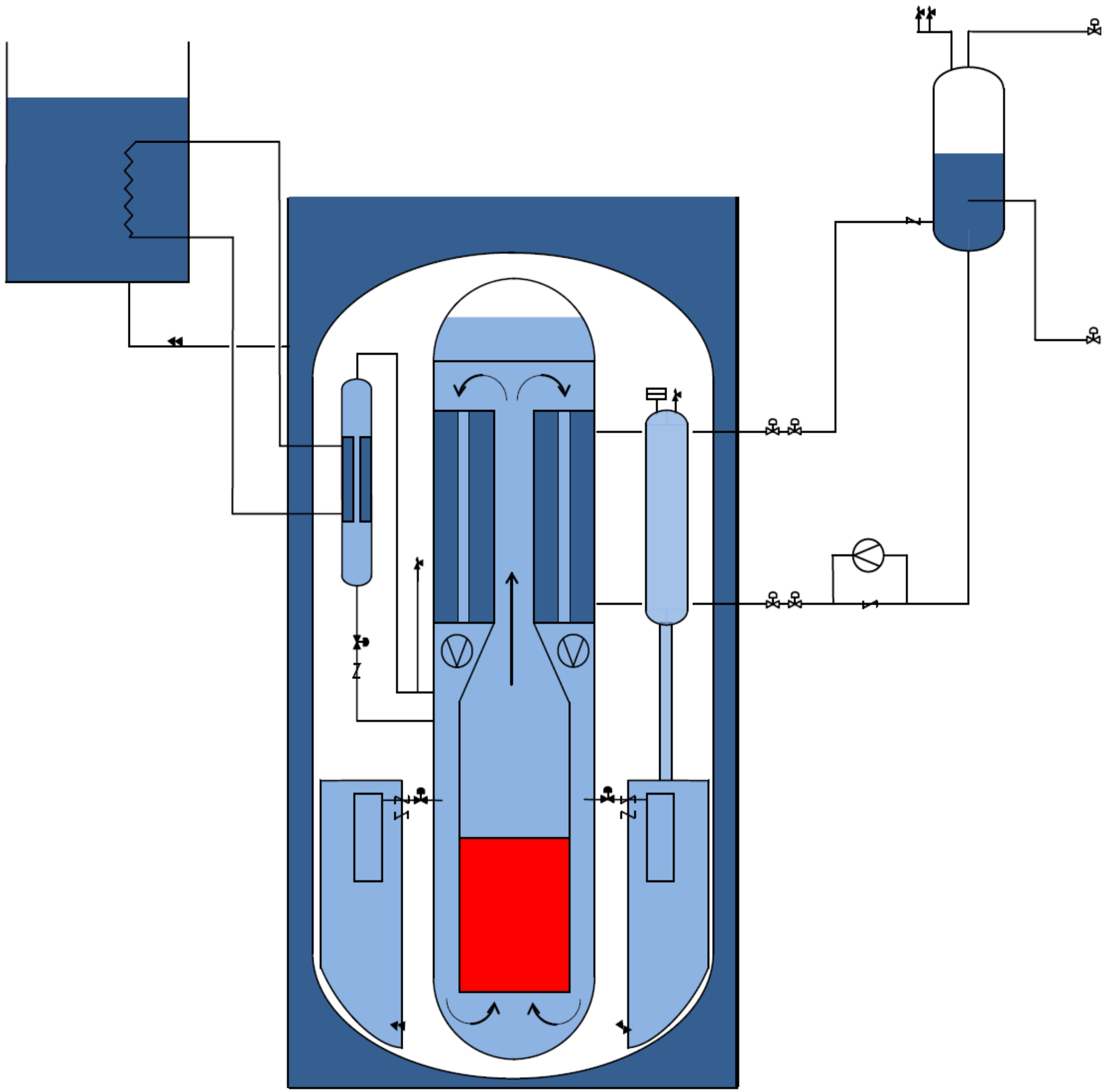
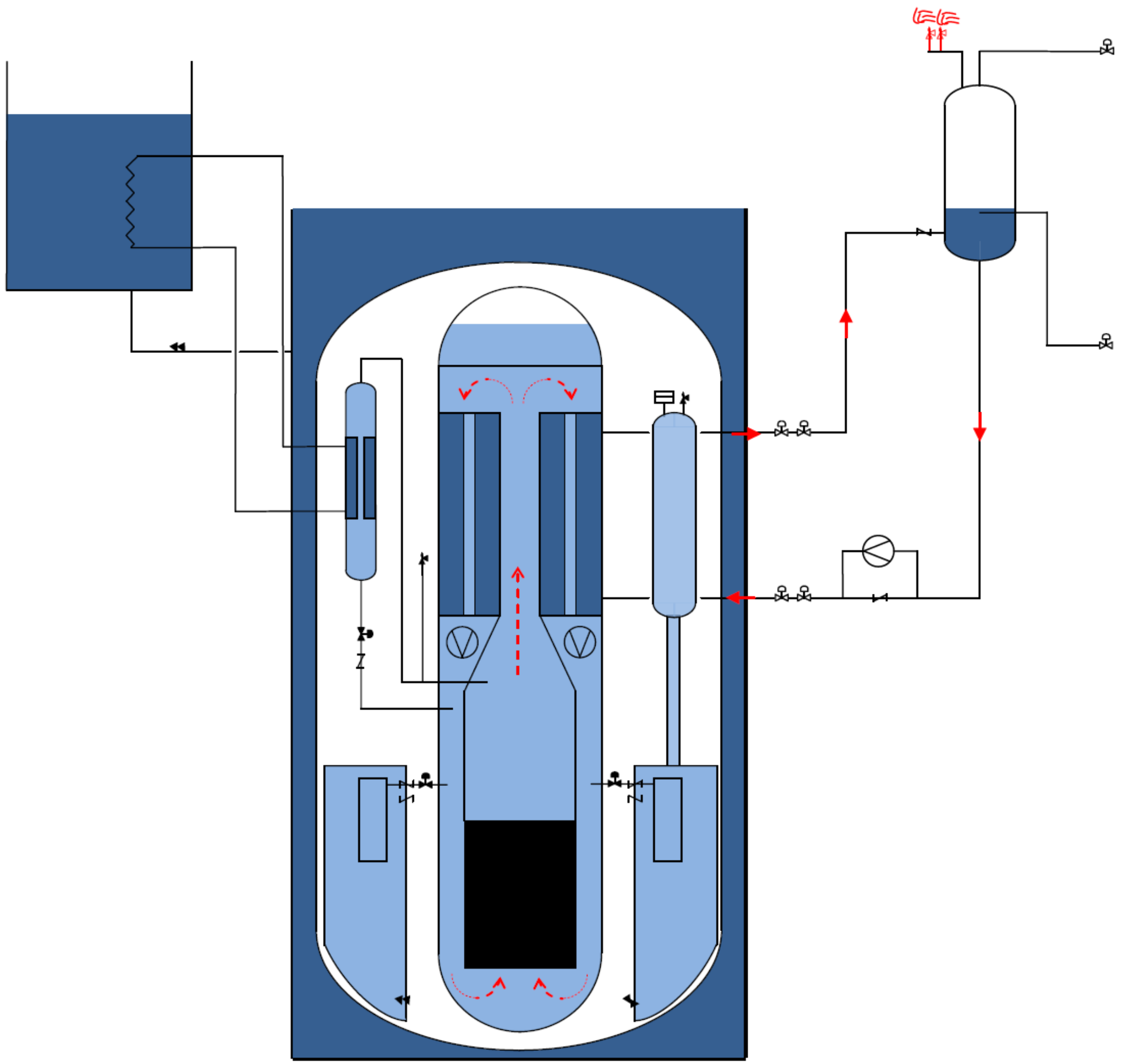
Safety Analysis Steps

1. Identify Initiating events
2. Step through follow-on events
   a) Code simulations
   b) Interpretation of codes
3. Identify weaknesses/shortcomings
4. Develop system to overcome weakness
5. Re-simulate to assure performance
6. Develop trip/actuation logic
7. Validate codes/simulations with experiments

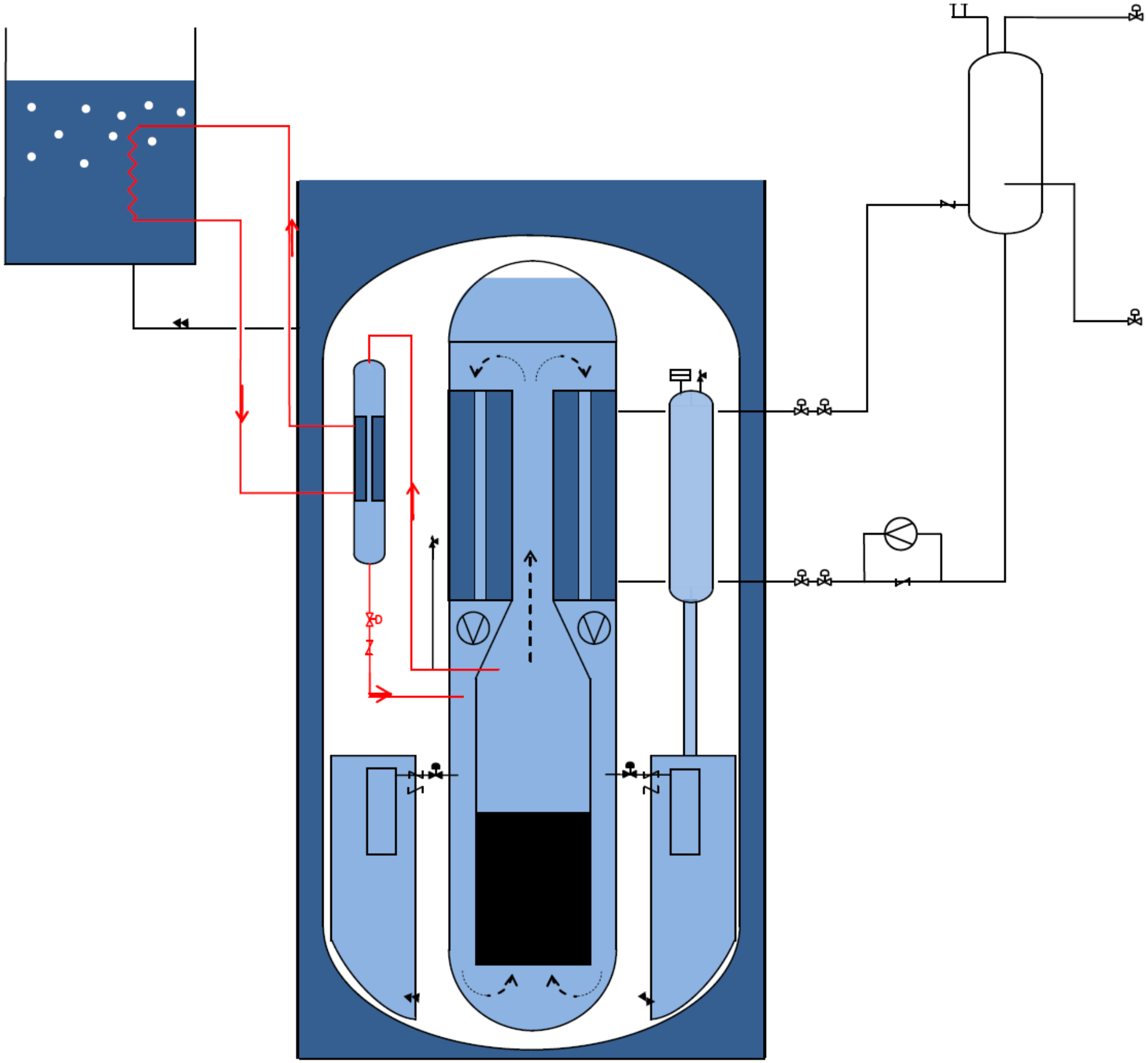
Station Blackout (I)



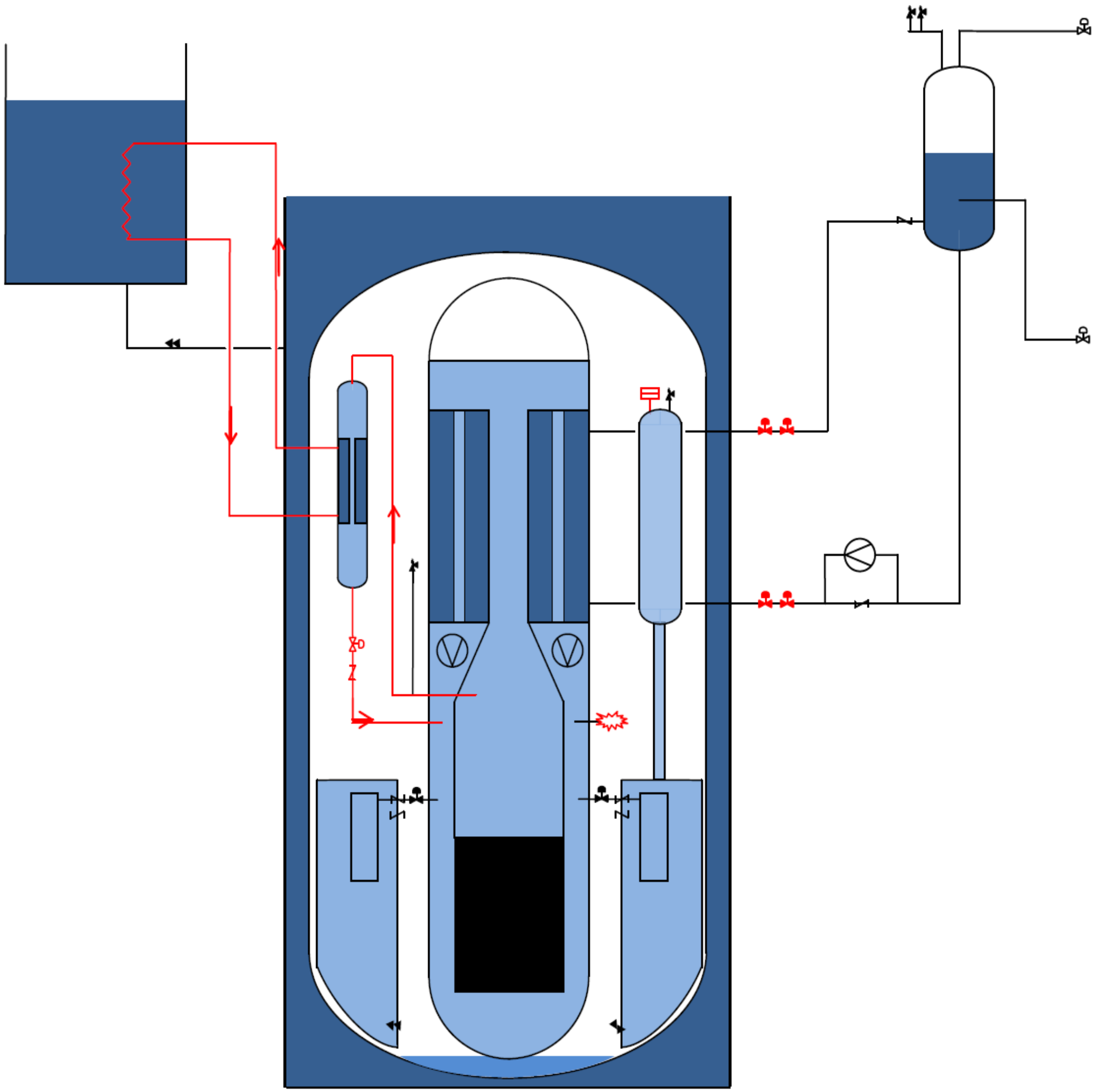
Station Blackout (II)



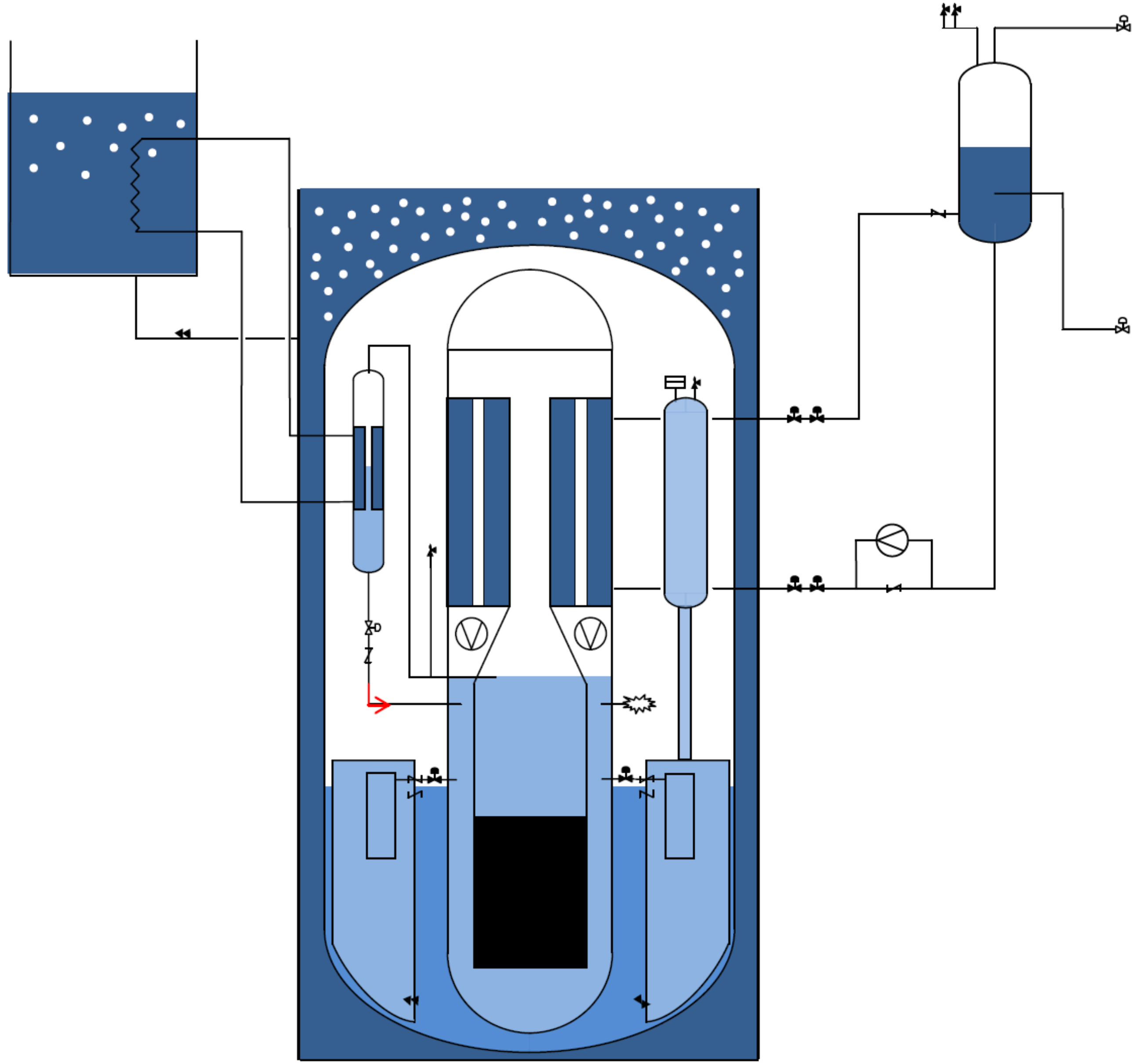
Station Blackout (III)



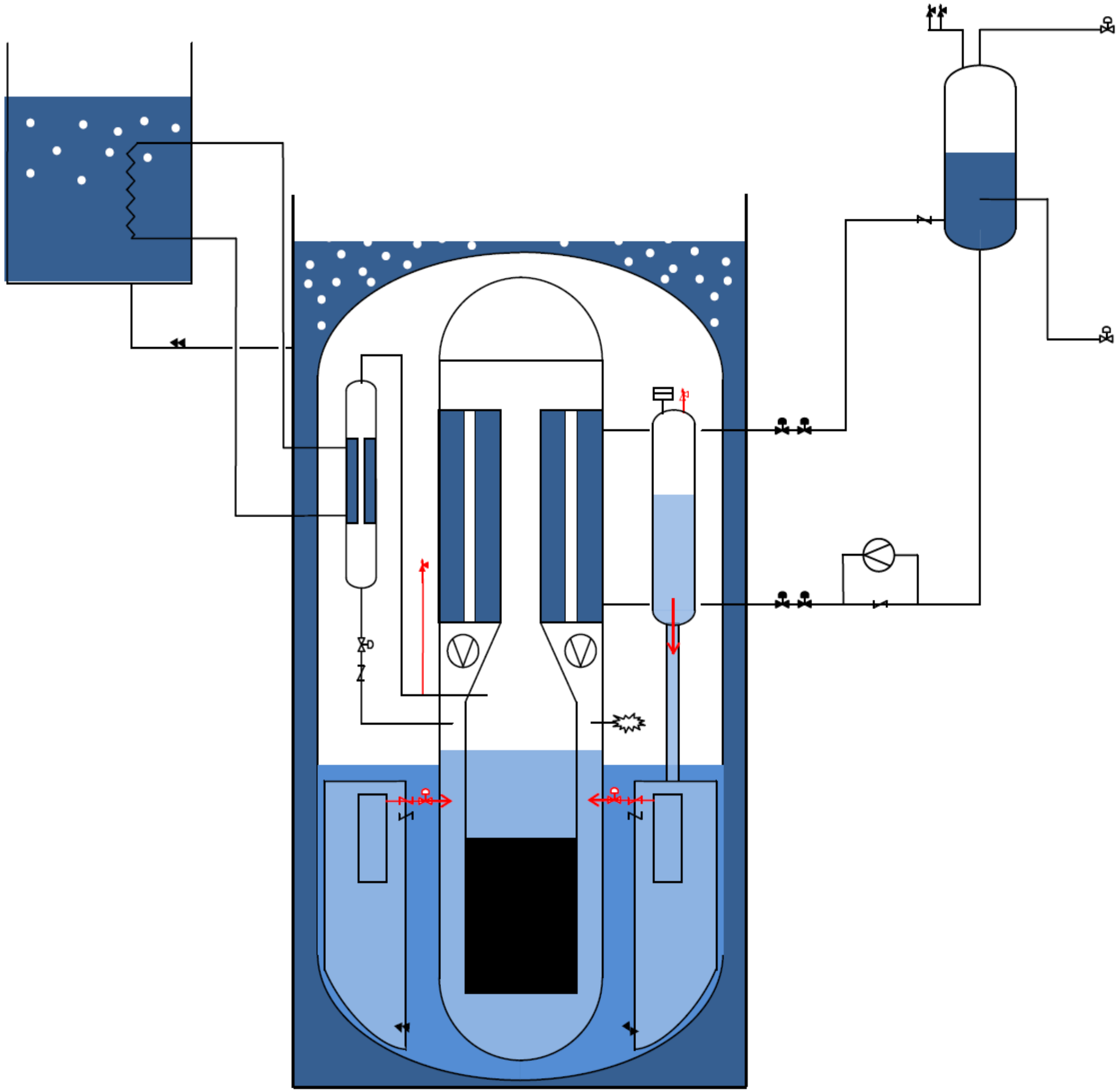
Station Blackout (IV)



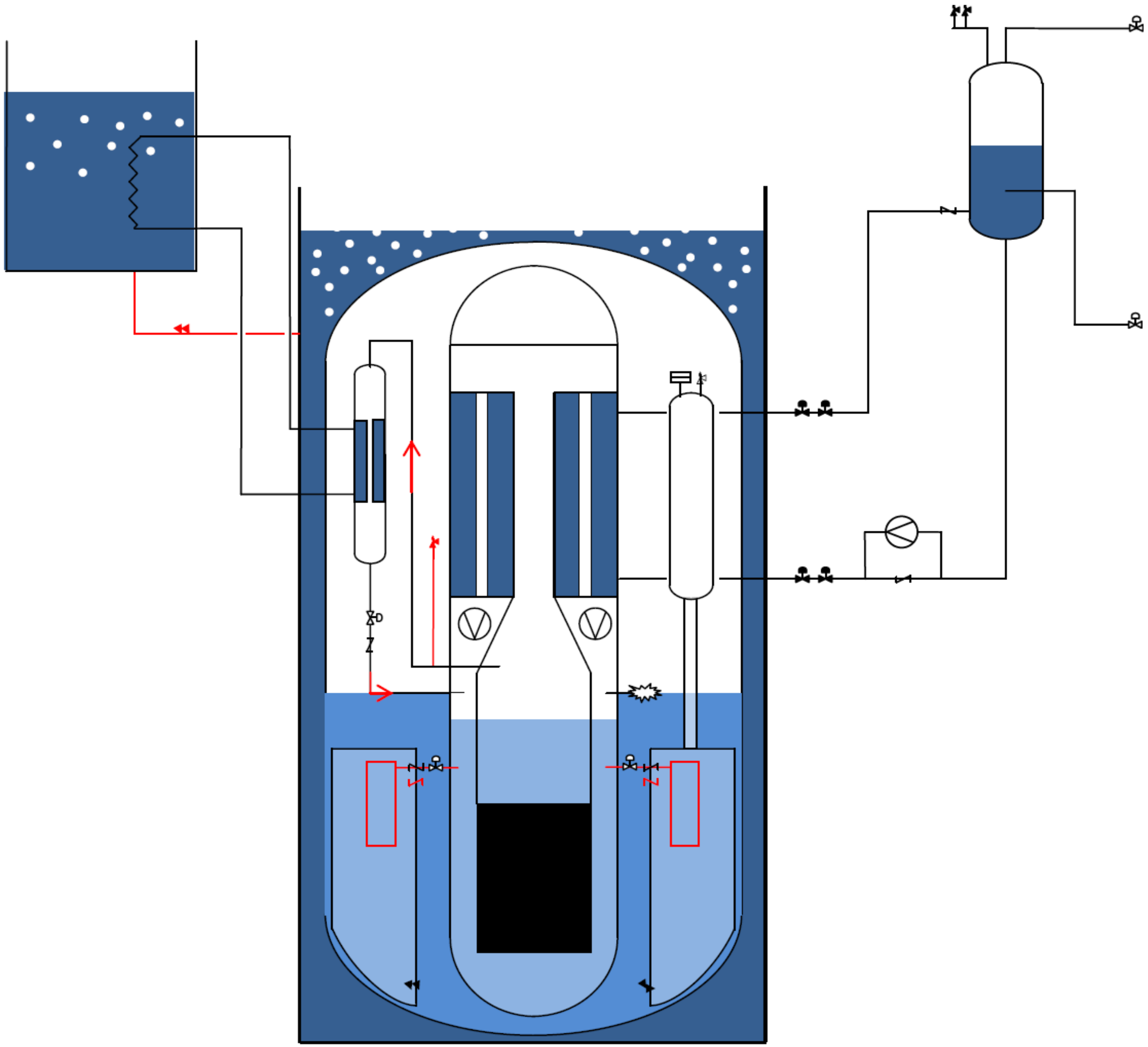
Station Blackout (V)



Station Blackout (VI)



Station Blackout (VII)



Passive Safety System Failure

- Passive systems similar to active (PRA)
- Similar approach, though PRA in design is important
- Failures modes must be understood
- Reliability calculated from failure modes
- Several possible failure modes postulated

Failure Modes

- Inadvertent Actuation
- Boron Concentration Shift
- Through-Wall Cracks/Ruptures
- Flange Leaks
- Flow Reversal
- Thermal Stratification
- Valve Failures

Passivity Levels

Category	Characterized by:
A	No Signal inputs of 'intelligence' No external power sources or forces no moving mechanical parts no moving working fluid
B	No Signal inputs of 'intelligence' No external power sources or forces no moving mechanical parts
C	No Signal inputs of 'intelligence' No external power sources or forces
D	requires signals or inputs of 'intelligence' energy required to initiate processes active components No manual initiation required