Chemical Engineering 612

Reactor Design and Analysis

Lecture 17

Nuclear Safety

Spiritual Thought

- Sometimes we should express our gratitude for the small and simple things like the scent of the rain, the taste of your favorite macaroni and cheese recipe, the sound of a loved one's voice. Pondering the things we are grateful for is a healing Balm. It helps us get outside ourselves

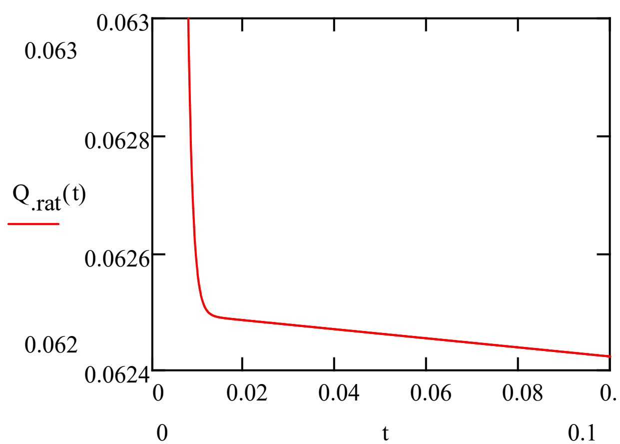
Spiritual Thought

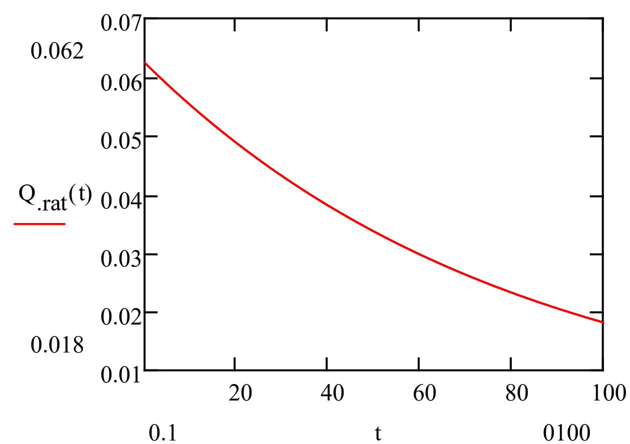
2 Kings 6:16

And he answered, Fear not: for they that be with us are more than they that be with them.

Shutdown Fission Heat

- Even after shutdown heat is produced
  - Fissions
    - Solve kinetic eqns. → large negative reactivity
    - $\phi(t) = \phi_o \left[\frac{\beta}{\beta-\rho} e^{-\gamma_1 t} - \frac{\rho}{\beta-\rho} e^{-\frac{(\beta-\rho)t}{l}}\right]$
      - l = neutron life, t = time after transient initiation, β = total delayed neutron faction, ρ = reactivity change, γ_1= decay constant for longest-lived delayed neutron precursor
      - For ^{235}U, water moderated with ρ = -0.09, (in seconds)





Decay Heat

- Decay of Fission Products
  - Simple approximations:
    - β-energy release rate = $1.4t'^{-1.2}$ MeV/fission·s
    - γ-energy release rate = $1.26t'^{-1.2}$ MeV/fission·s
  - Assuming 200 MeV, 3.1×10^{10} fissions/W
    - $P_\beta = 2.18E11 q_0'''[(\tau-\tau_s)^{-.2} - \tau^{-.2}]$MeV/cm^3 ·s
    - $P_\gamma = 1.95E11 q_0'''[(\tau-\tau_s)^{-.2} - \tau^{-.2}]$MeV/cm^3 ·s
      - $\tau = \text{time since reactor startup}$
      - τ_s = operating time
    - Total Power is thus:
    - $\frac{P}{P_o} = 0.066[(\tau-\tau_s)^{-.2} - \tau^{-.2}]$

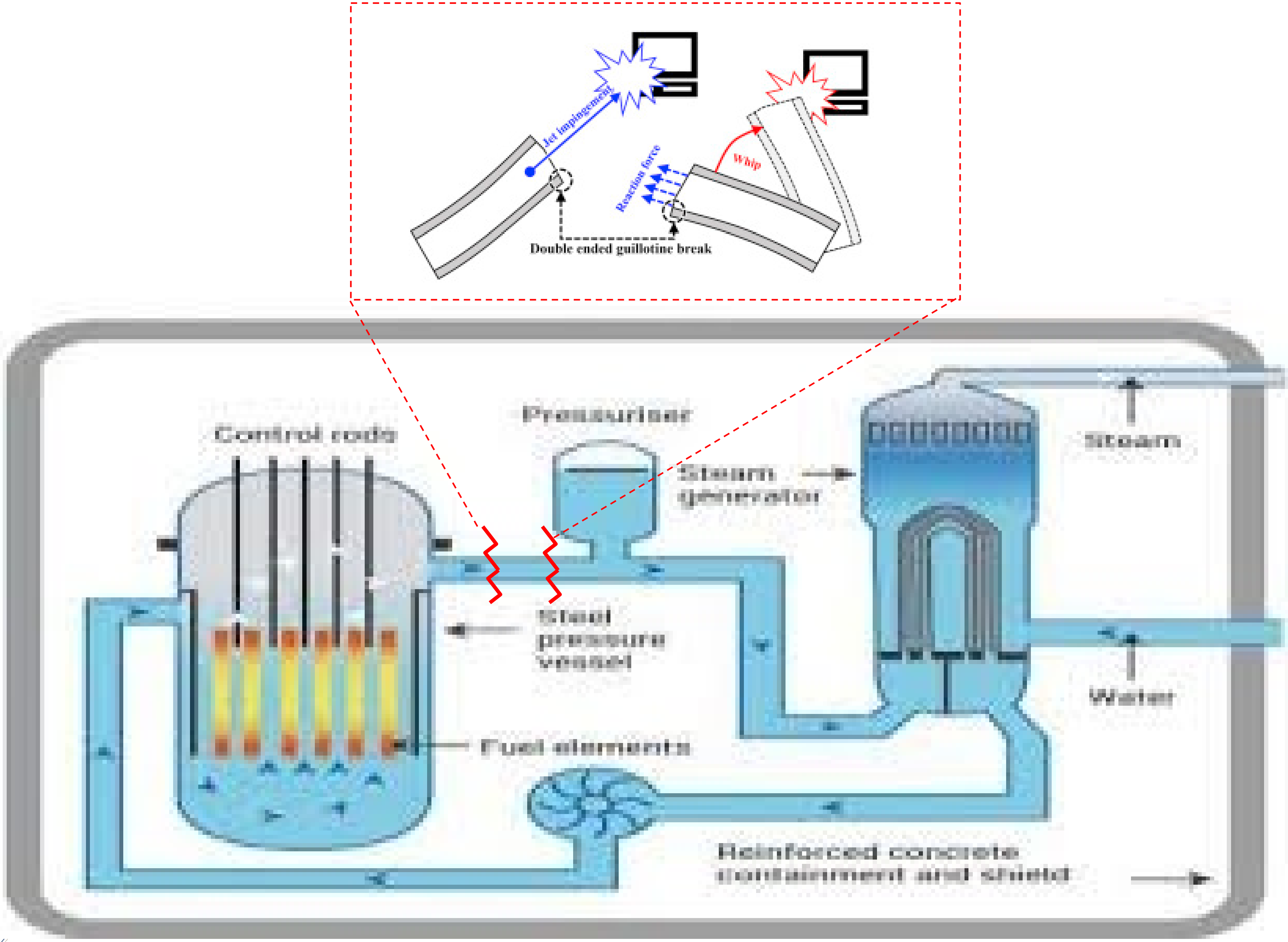
ANS Standard

- Concentrated effort to provide uniform, trustworthy decay heat curve
- Experiments run in 1961
- From 1 to 1E9 seconds
- 235U, 238U, and 239Pu
- Revised experiments (1985) are more accurate
- Given in chapter 3 of the text

Design Basis Accidents (DBA)

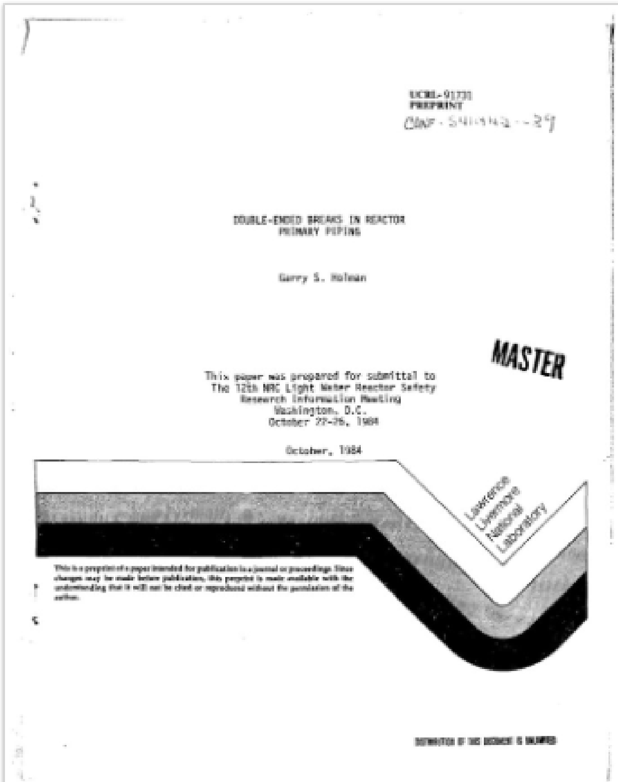
- **Design-basis criticality**: A criticality accident that is the most severe design basis accident of that type applicable to the area under consideration.
- **design-basis earthquake** (DBE): That earthquake for which the safety systems are designed to remain functional both during and after the event, thus assuring the ability to shut down and maintain a safe configuration.
- **Design-basis event** (DBE): A postulated event used in the design to establish the acceptable performance requirements of the structures, systems, and components.
- **Design-basis explosion**: An explosion that is the most severe design basis accident of that type applicable to the area under consideration.
- **Design-basis fire:** A fire that is the most severe design basis accident of this type. In postulating such a fire, failure of automatic and manual fire suppression provisions shall be assumed except for those safety class items or systems that are specifically designed to remain available (structurally or functionally) through the event.
- **Design-basis flood**: A flood that is the most severe design basis accident of that type applicable to the area under consideration.
- **Design-basis tornado (DBT):** A tornado that is the most severe design basis accident of that type applicable to the area under consideration.
- Most Common:
  - LOCA, LOFA, Overpower

LWR CENTRIC (Appendix K)



NRC DBA Debates

Doubled-ended breaks in reactor primary piping. [Guillotine breaks]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DOUBLE-ENDED BREAKS IN REACTOR
PRIMARY PIPING

Garry S. Holman

MASTER

This paper was prepared for submittal to
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October, 1984

Lawrence Livermore National Laboratory

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Description

Results indicate that the probability of double-ended guillotine break (DEGB) in the reactor coolant loop piping of Westinghouse and Combustion Engineering plants is extremely low. It is recommended that the NRC seriously consider eliminating DEGB as a design basis event for reactor coolant loop piping in Westinghouse plants. Pipe whip restraints on reactor coolant loop piping could then be excluded or removed, and the requirement to design supports to withstand asymmetric blowdown loads could be eliminated. It is also recommended that the current requirement to couple safe shutdown earthquake (SSE) and DEGB be eliminated. Recognizing however that seismically induced support ... continued below

Physical Description

25

2

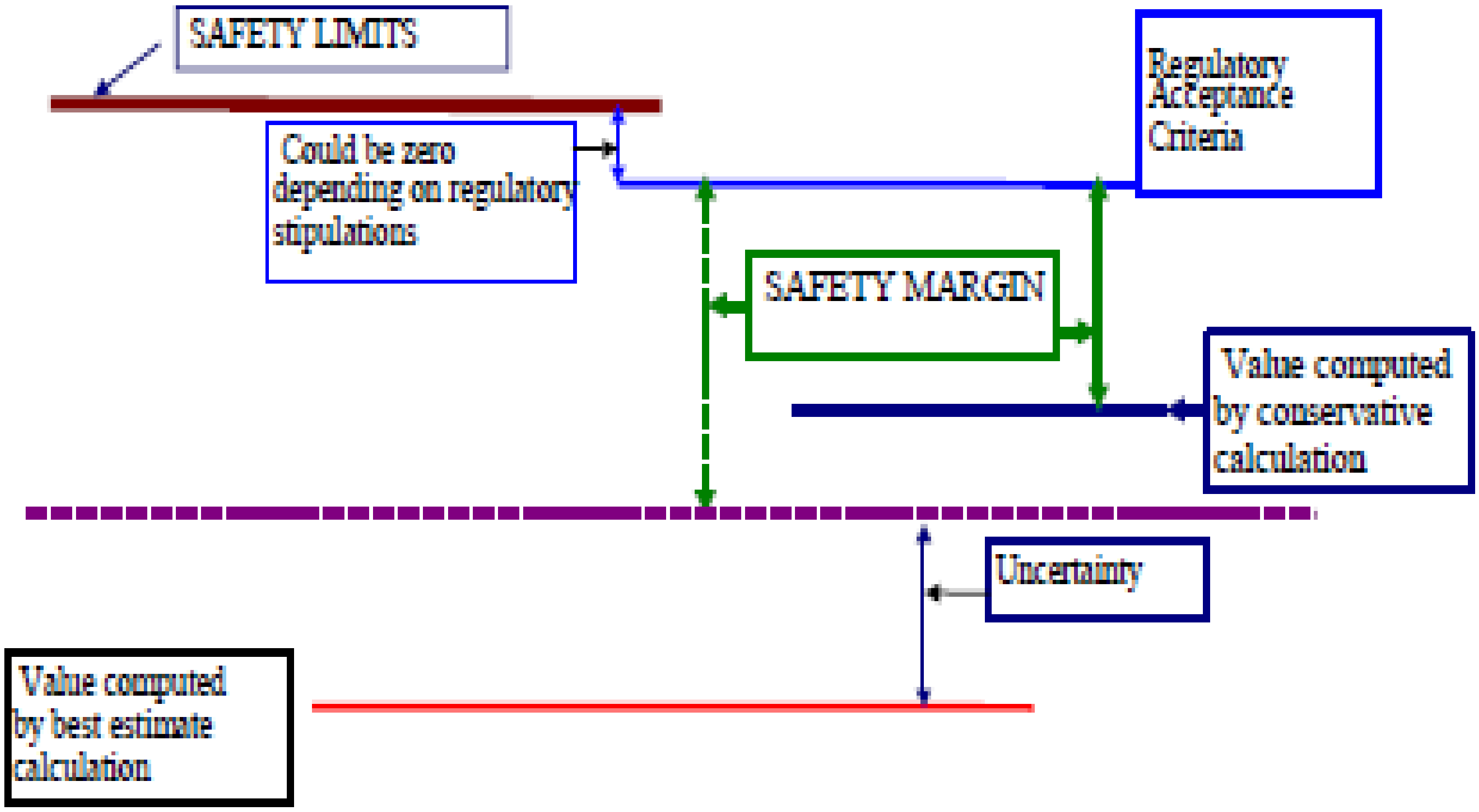
Beyond Design Basis Accidents (BDBA)

- Beyond scope of design
  - Unlikely events
  - Extreme conditions
- Extremely severe
- Station Blackout
  - Fukushima
  - Significant focus

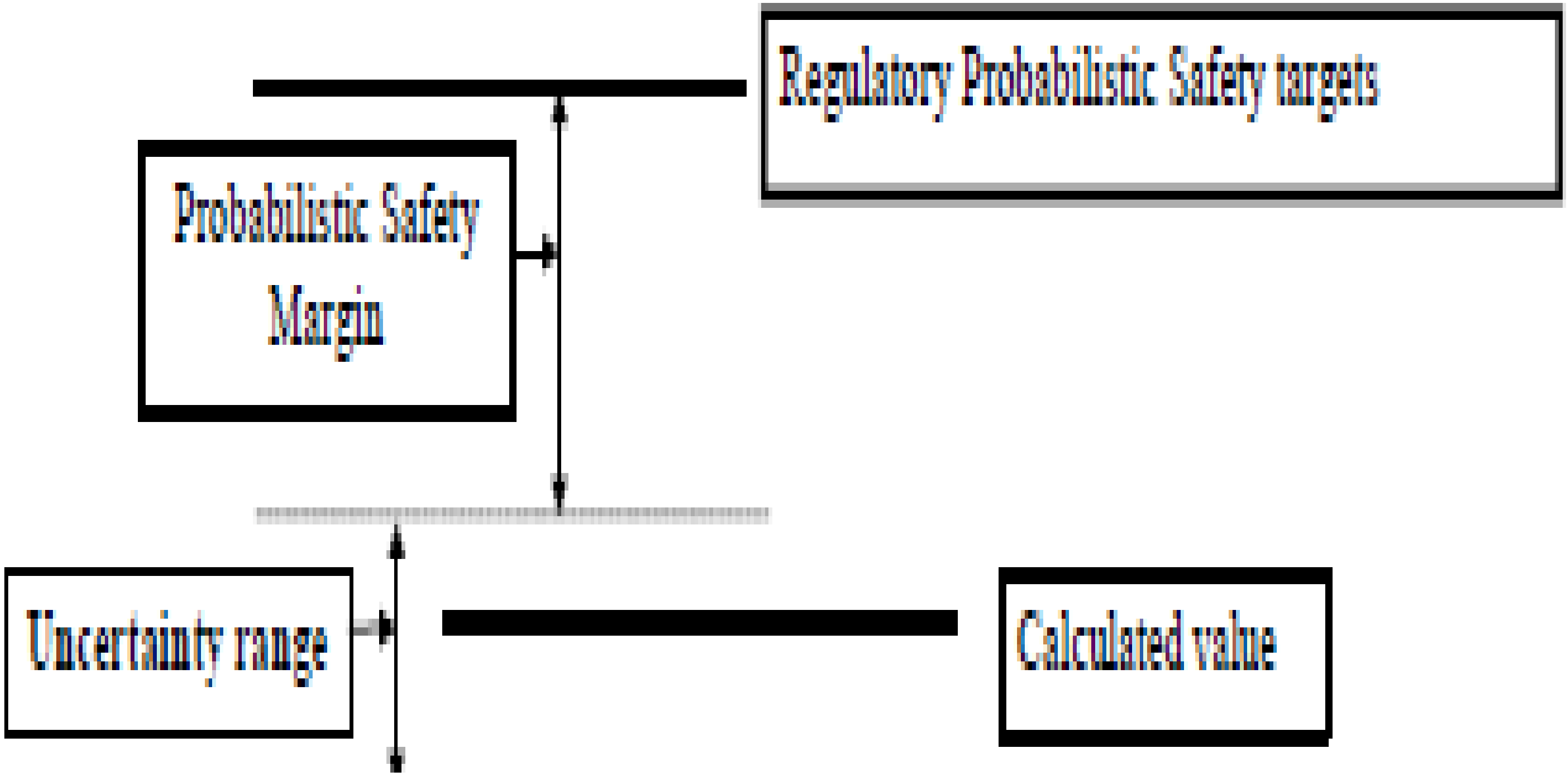
10 CFR 50 - Accidents and Safety

- “steady state” or operational margins
  – Designed to prevent failures during operation
  – Based upon best estimate calcs
  – Technical Specifications – operation to avoid
- “transient” margins
  – Accident based margins
  – Defined in licensing
  – Transient calculations to test limits
  – Prevent public exposure during accidents

Margins

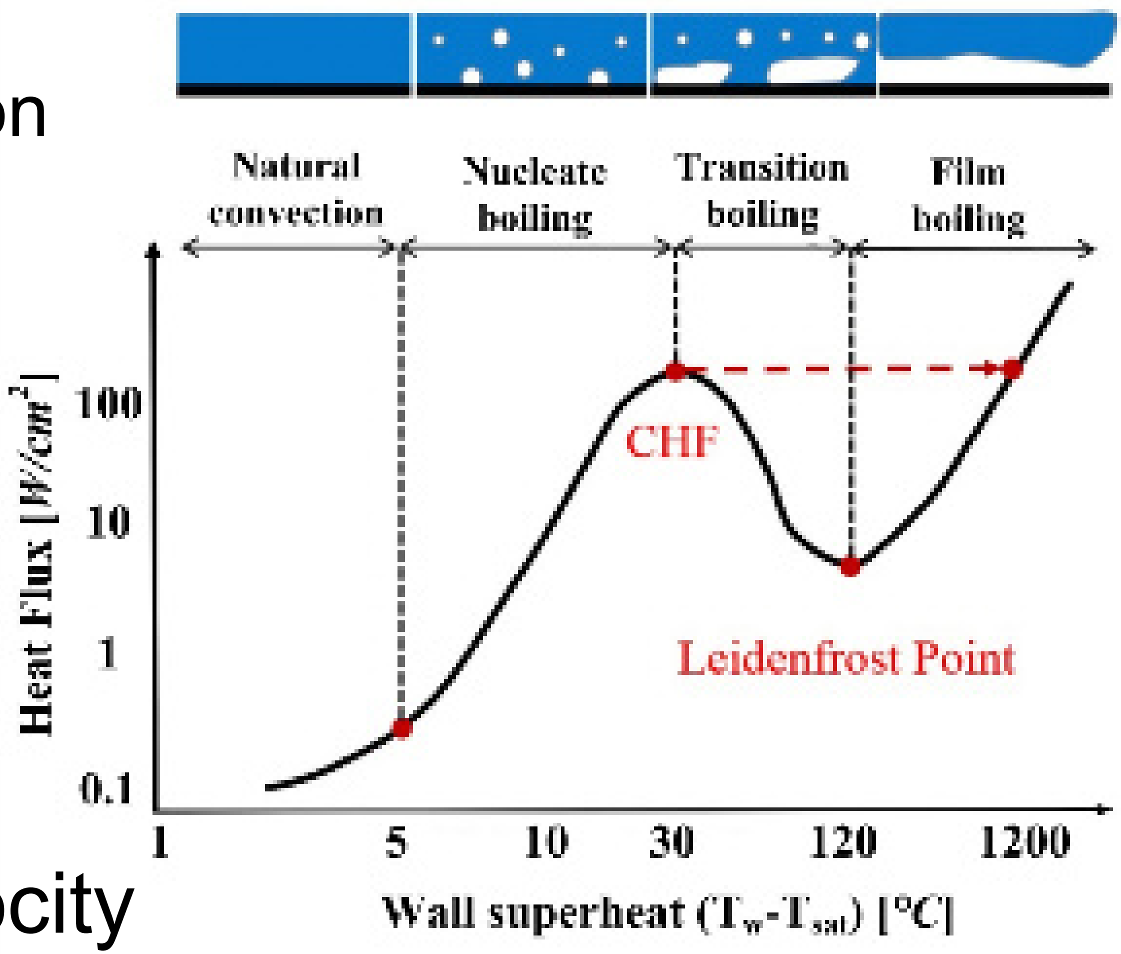

SAFETY LIMITS
Could be zero depending on regulatory stipulations
Regulatory Acceptance Criteria
SAFETY MARGIN
Value computed by conservative calculation
Uncertainty
Value computed by best estimate calculation

PRA Margins


Regulatory Probabilistic Safety targets
Probabilistic Safety Margin
Uncertainty range
Calculated value

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)

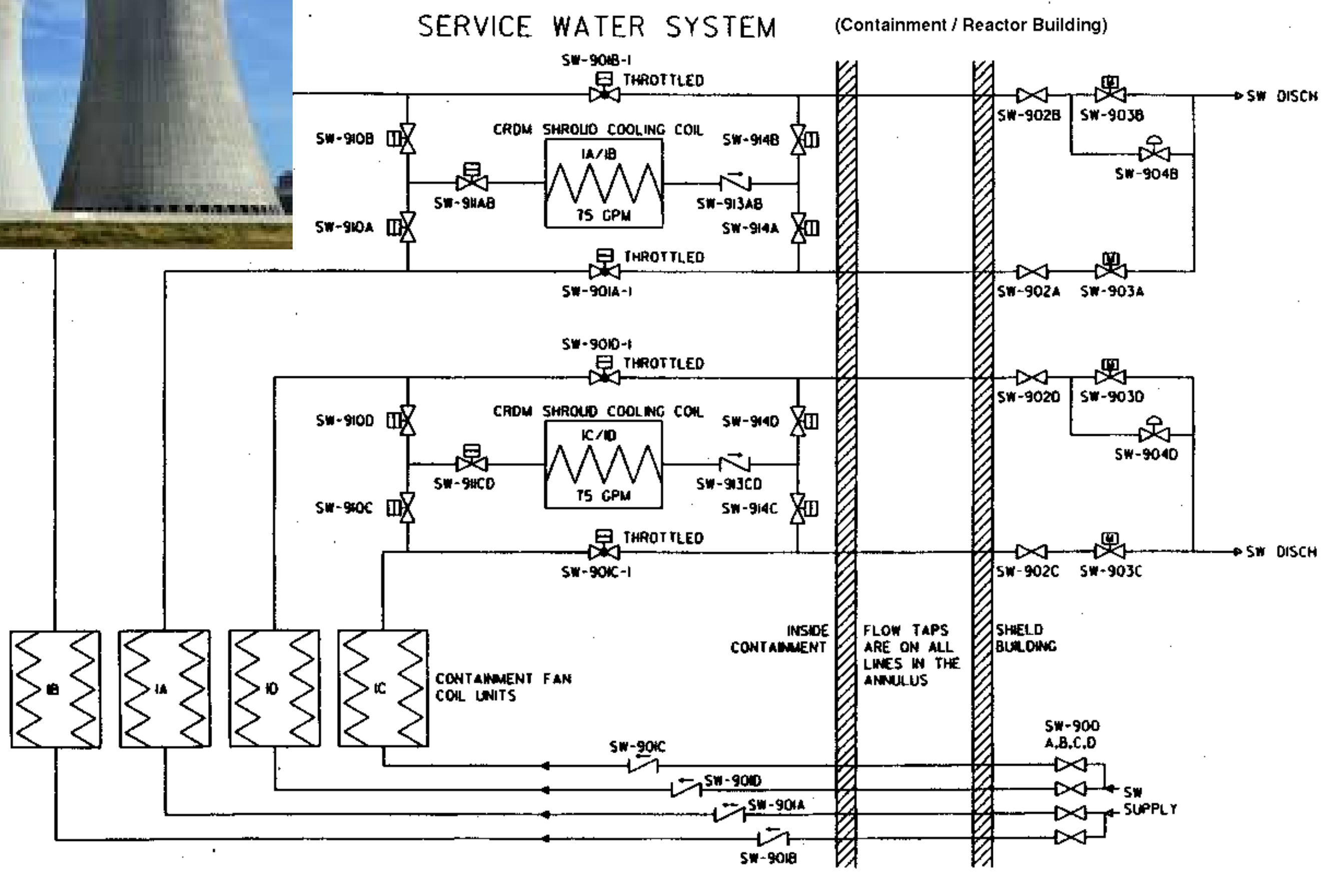
Safety Systems

- 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)

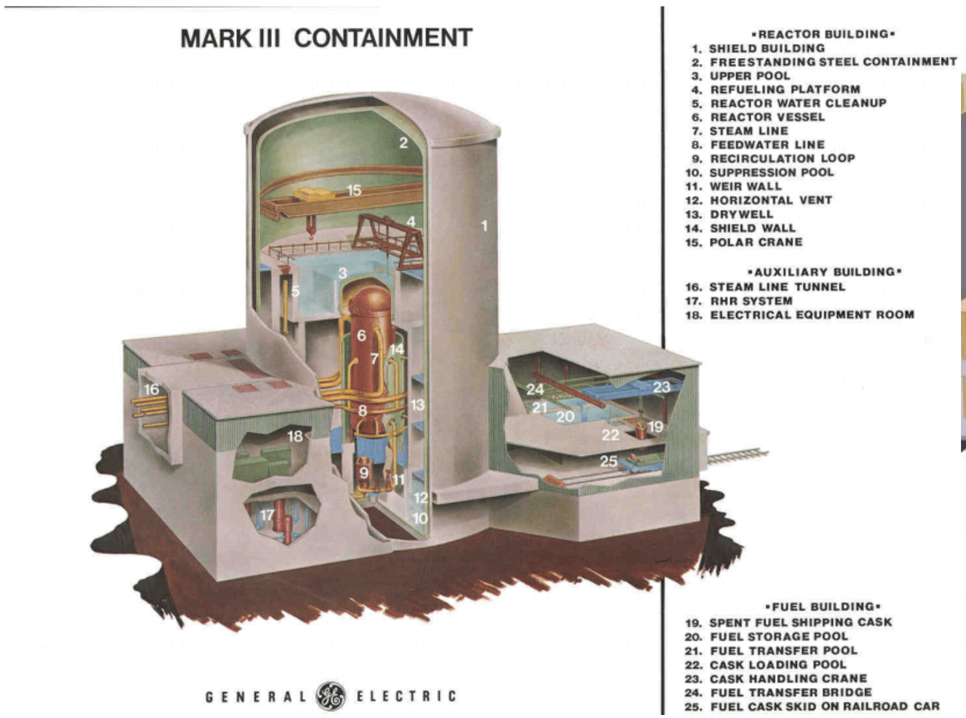
- Low Pressure Safety System (HPSI)
  - Only functions after blowdown
    - Larger supply
    - Later in accident
- Containment cooling system
  - Spray system
    - Actuated by high containment pressure/temperuture
- Core Spray System
  - (BWR only)

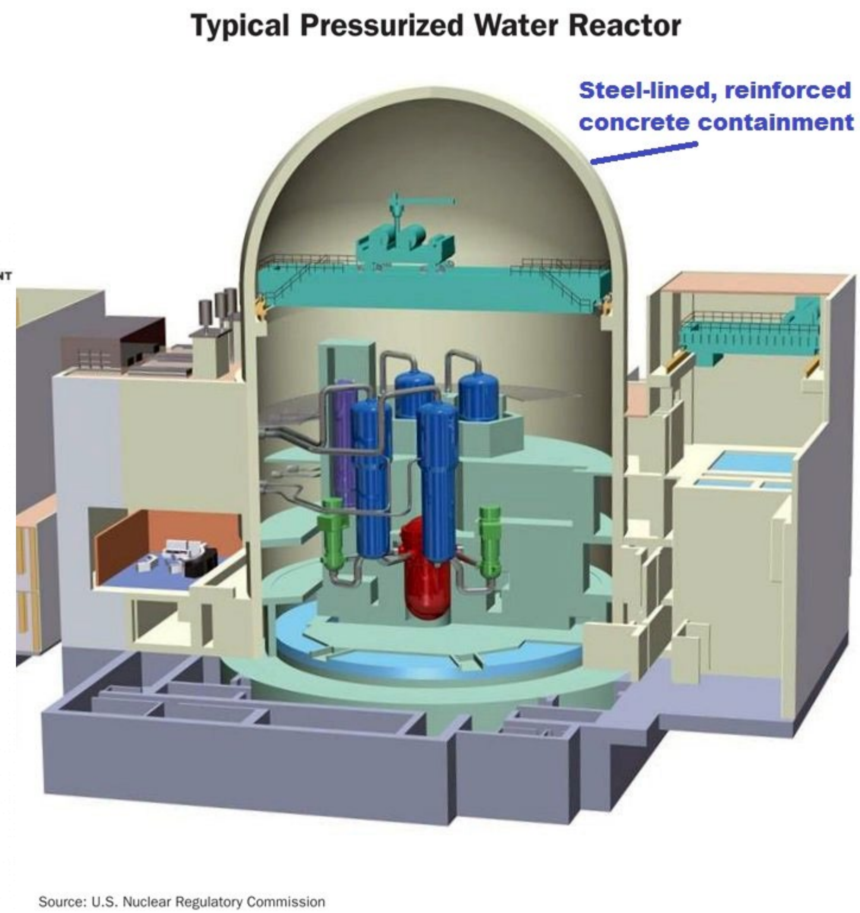
Emergency Electrical Systems (EES)

- Diesel Generators
- Flywheels
- Batteries

Containment Systems

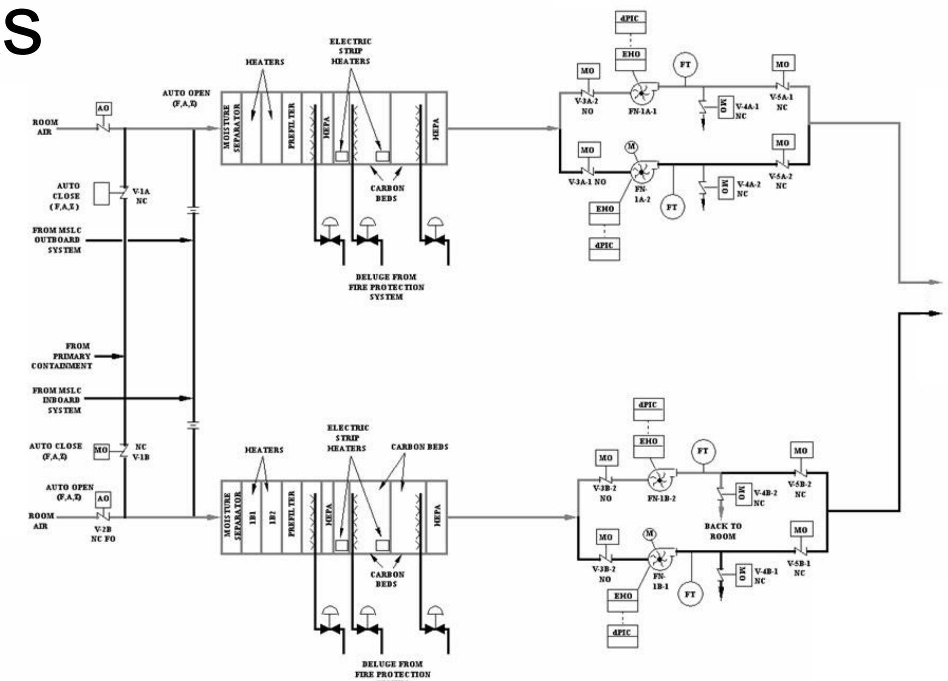
- Clad
- Containment
- Secondary Containment





Standby Gas Treatment Systems (SBGT)

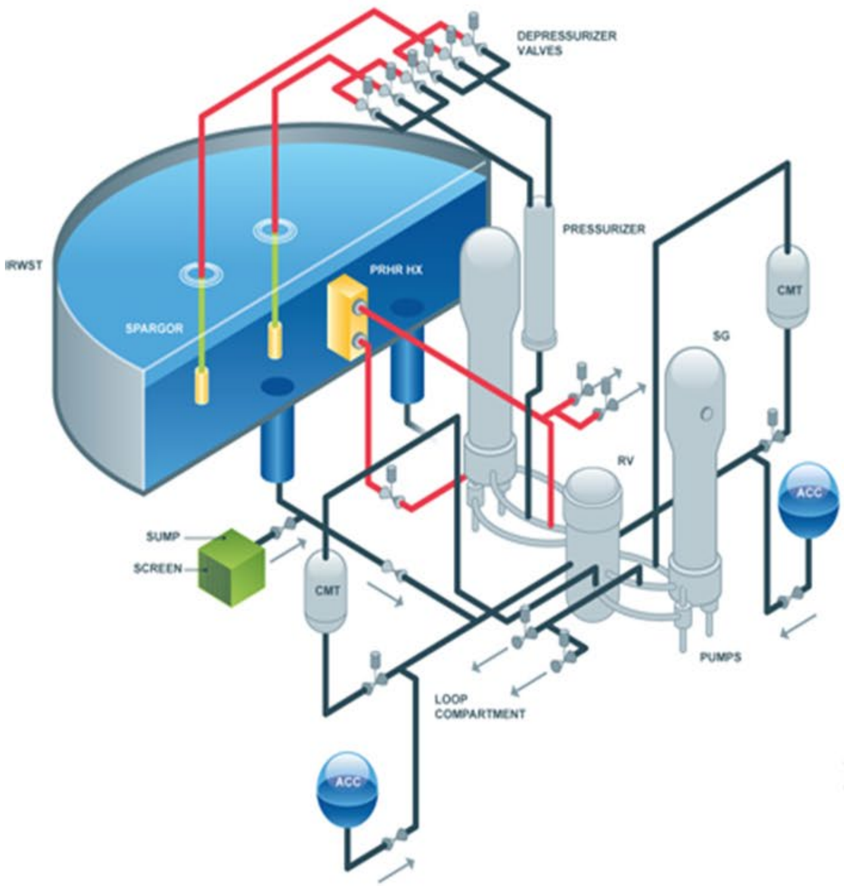
- Secondary Containment
  - Maintain negative pressures
  - (pull air in, rather than release radioactivity)
- Primarily for BWRs

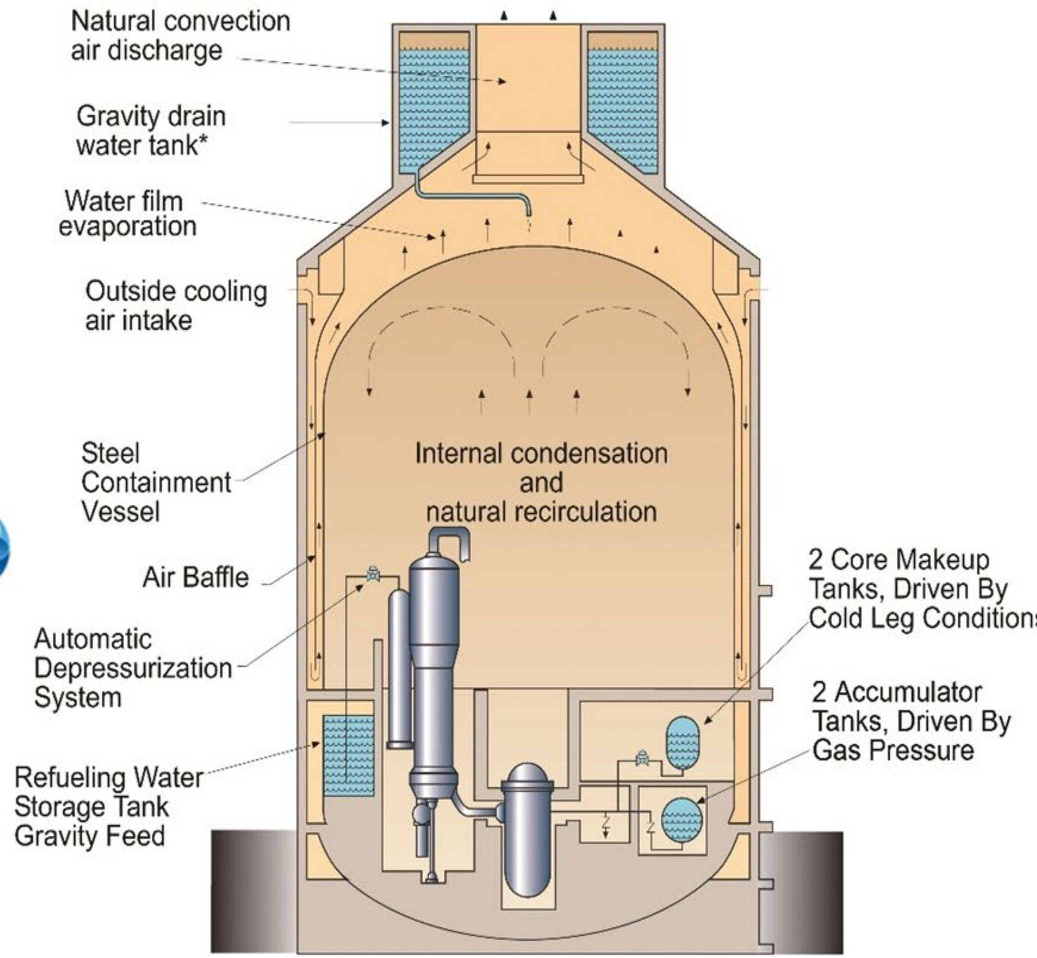


Ventilation and Radiation Protection Systems

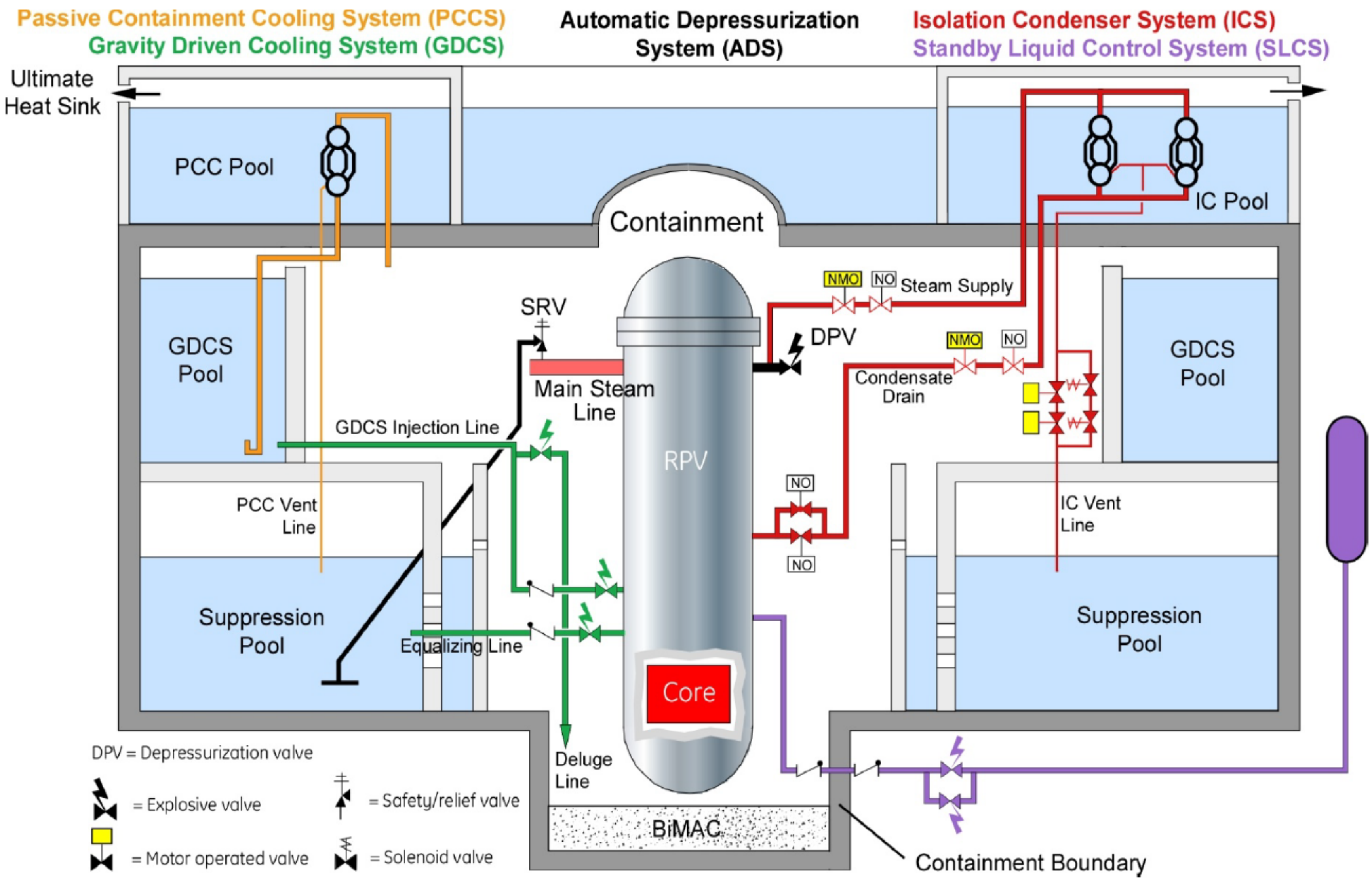
- Prevention of radiation gas release
  - Auxiliary Building
  - Shield Building
  - Reactor Building
  - Turbine Building
  - Radwaste Building
  - Control Room
  - Screenhouse
- Vent, Filter, Blowers

AP1000

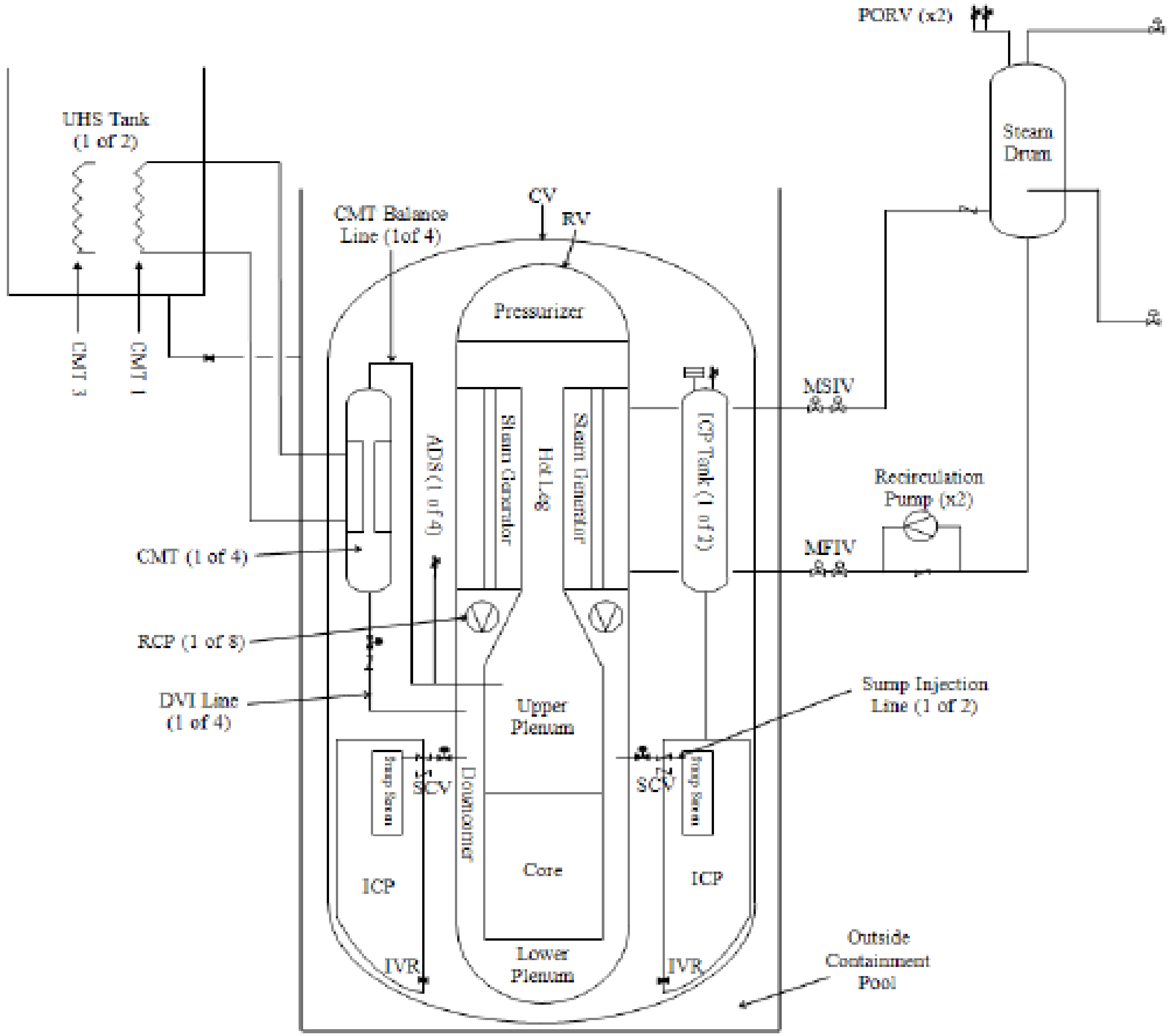

DEPRESSURIZER
VALVES
PRESSURIZER
IRWST
PRHR HX
SPARGOR
CMT
SG
RV
ACC
SUMP
SCREEN
CMT
PUMPS
LOOP
COMPARTMENT
ACC


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
Refueling Water
Storage Tank
Gravity Feed
2 Core Makeup
Tanks, Driven By
Cold Leg Conditions
2 Accumulator
Tanks, Driven By
Gas Pressure

ESBWR


Passive Containment Cooling System (PCCS)
Gravity Driven Cooling System (GDCS)
Automatic Depressurization System (ADS)
Isolation Condenser System (ICS)
Standby Liquid Control System (SLCS)
Ultimate Heat Sink
PCC Pool
Containment
IC Pool
NMO
NO
Steam Supply
SRV
DPV
Condensate Drain
GDCS Pool
GDCS Pool
Main Steam Line
GDCS Injection Line
RPV
PCC Vent Line
IC Vent Line
Suppression Pool
Suppression Pool
Equalizing Line
Core
Deluge Line
BiMAC
Containment Boundary
DPV = Depressurization valve
= Explosive valve
= Safety/relief valve
= Motor operated valve
= Solenoid valve

Westinghouse SMR



What's the Worry?

- Frequency?
- Immediate Deaths?
- Radiation?
- Land Impact?
- Cost?
- Cancer?
- Public Stress?
- Nuclear power has infrequent, but SEVERE social impact due to accidents!

Annual Death rates per TW*hr		
Source	Deaths	US Electricity Percentage
Coal	161	39%
Oil	36	1%
Natural Gas	4	27%
Biofuel/Biomass	12	1.70%
Solar	0.83	0.40%
Wind	0.15	4.40%
Hydro	1.4	6%
Nuclear	0.04	20%

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