Redundancy and Reliability of Passive Safety Systems

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INPRO Criteria Evaluated:

- CR 1.1.1 Robustness
  - EP 1.1.1.5 Redundancy of Systems
- CR 1.1.2 Operation
  - EP 1.1.2.2 High Quality of Operation
- CR 1.3.3 Safety Features
  - IN 1.3.3 Reliability of Engineered Safety Features
CR 1.1.1 Robustness

EP 1.1.1.5 Redundancy of Systems

Increased redundancies of systems may reduce the probability of degradation or loss of a function and help to avoid transients (such as those caused by control system actions, trips and set backs).

ESBWR Design Features

• Turbine Island
  • Triplicated Fault Tolerant Digital I&C
    • Turbine Control (Steam Bypass and Pressure Control)
    • 3 element Feedwater Level Control
  • 100% load rejection and transition to island mode without SCRAM
  • Condensate and Feedwater is 4 x 35% for pumps
  • Condensate and Feedwater is N+1 for filters and demineralizers
  • Feedwater heater #4 (direct contact) has ~15 minute volume
  • Standby condensate and feedwater pumps auto start if needed
ESBWR Overall Flowchart

11 fewer major systems
25% fewer components
CR 1.1.1 Robustness (continued)

Nuclear Island

• Isolation Condenser System
  • No loss of coolant on isolation event (no opening of SRVs)
  • 4 x 35% Heat Exchangers
  • Fail-Safe Initiation
  • Parallel Control Valves
    • Operable by 3 of 4 Safety-Related Divisions (Q-DCIS)
    • Operable by Diverse Protection System (DPS)

• High Pressure CRD Makeup
  • Two trains of high pressure pumps
    • 1.96 m³/min per train
  • Each backed by on-site Standby Diesel Generators

• RWCU Shutdown Cooling
  • High pressure decay heat removal
  • 100% capacity 30 minutes after shutdown
CR 1.1.2 Operation

EP 1.1.2.2 High Quality of Operation

One of the options to simplify the reactor design is to reduce the number of components of the cooling system.

ESBWR Design Features

- Nuclear Island
  - Reactor Water Cleanup and Shutdown Cooling Combined into a single system
    - Low Pressure Residual Heat Removal (RHR) not utilized
    - Eliminates a source of Inter-system LOCA (ISLOCA)
  - Utilizing natural circulation eliminates the Recirculation System
    - External recirculation piping and pumps eliminated
  - Favorable water to steam volume ratio
    - Eliminates opening of SRVs for transients and DBAs
ABWR to ESBWR evolution: Nuclear Island

1. Standby Liquid Control System – simplified design
2. Fuel and Aux Pool Cooling – equivalent designs
3. Suppression Pool Cooling & Cleanup System – equivalent capability
4. Residual Heat Removal System – equivalent for shutdown cooling
5. Reactor Water Cleanup System – equivalent designs
6. Hydraulic Control Unit – equivalent design

7. High Pressure Core Flooder – replaced by HP CRD makeup
8. Reactor Core Isolation Cooling – replaced by Isolation Condenser
9. Residual Heat Removal Containment Spray – replaced by PCCS
10. Safety Relief Valves – Diversified by Depressurization Valves

Systems are Equivalent or Simplified
Natural Circulation

It Works in Operating BWRs Today

ESBWR greatly improves this feature

• Passive safety/natural circulation
• Differential water level increased by approximately ~8.2 m (27 feet)
• Greatly increases driving head to increase natural circulation flow
• Simplification removes many risks of forced circulation plants (e.g., pump failure)
• Significant reduction in components
  • Pumps, motors, controls, heat exchangers
MSIV Closure Transient

Limiting Pressure Transient – No SRVs open
CR 1.3.3 Safety Features

IN 1.3.3 Reliability of Engineered Safety Features

Enhanced “reliability of engineered safety features” may be achieved by inclusion of passive systems into the INS design, although other methods can also be effective.

ESBWR Design Features

- Nuclear Island
  - Isolation Condenser System
    - 4 x 35% trains
    - Fail Safe into operation
    - Each train controllable by 3 of 4 Q-DCIS and DPS
    - Valves do not require constant energy or pressure to maintain position
ESBWR Design Features

• **Nuclear Island**
  • Passive Containment Cooling System (PCCS)
    • Entirely passive
  • Gravity Driven Cooling System (GDCS)
    • Each train controllable by 3 of 4 Q-DCIS and DPS
    • Squib circuits are continuously monitored for continuity
    • Squib circuit contacts can be verified without firing
    • **Valves do not require constant energy or pressure to maintain position**
  • **Automatic Depressurization System (ADS)**
    • 10 of 18 SRVs controllable by 3 of 4 Q-DCIS and DPS
      • Are only needed for a short period
    • Depressurization Valves (DPVs)
      • Squib circuits are continuously monitored for continuity
      • Squib circuit contacts can be verified without firing
      • **Valves do not require constant energy or pressure to maintain position**
GDCS Squib Valves

These drawings represent a conceptual design.
per actuator

Typical of OPV solenoids, DPV solenoids, GPC valves, equalizing valves; any one of three equally divided or DPs will open the valve.

Lines with two isolation valves in series use two solenoids per valve; lines with one isolation valve in series with a check valve use your solenoid.

Per division, any one of two AC inputs (voltageless batteries), allows the squib to fire.

Overall scheme allows any division to be taken out of service, incurs a DPA and accepts a single additional failure and still opens all valves.
References

ESBWR

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