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BWRX-300 DESIGN

Outline

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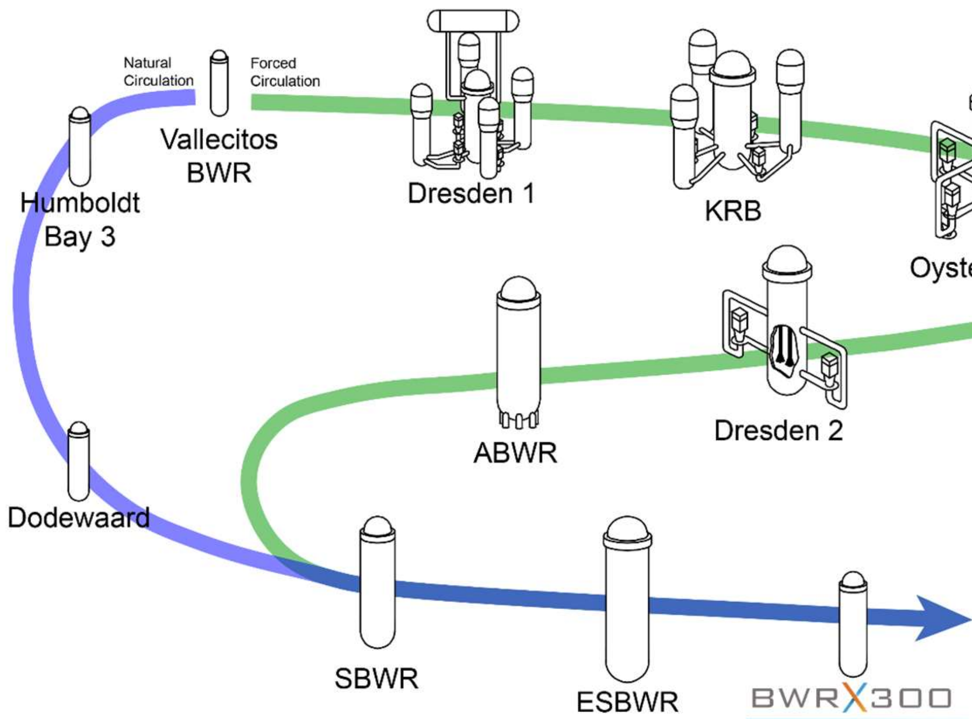
- BWRX-300 Design Overview
- Unique design features for:
  - Reactor Pressure Vessel (RPV)
  - Reactor Isolation Valves (RIVs)
  - Isolation Condenser System (ICS)
  - Passive Containment Cooling System (PCCS)

Boiling Water Reactor (BWR) Innovation



- BWR concept developed in the 1950s
- Continuous evolution in the design
- Main changes related to:
  - Steam cycle
  - Recirculation flow
  - Nuclear fuel
  - Containment

BWRX-300 Design Overview

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Size

~300 MWe gross electrical output

RPV inner diameter ~ 4 meters

RPV height ~ 27 meters

240 bundles of GNF2 fuel

57 control rods

Passive Design

Safety Category 1 functions are not dependent on AC generated sources of power nor operator action to control reactivity, remove heat from the fuel, and confine radioactive material for 72 hours following a design basis accident

Select Key Features

Natural circulation BWR with increased height relative to a forced circulation BWR

RPV contains tall chimney, nozzles are well above Top of Active Fuel (TAF), and RIVs are attached directly to RPV

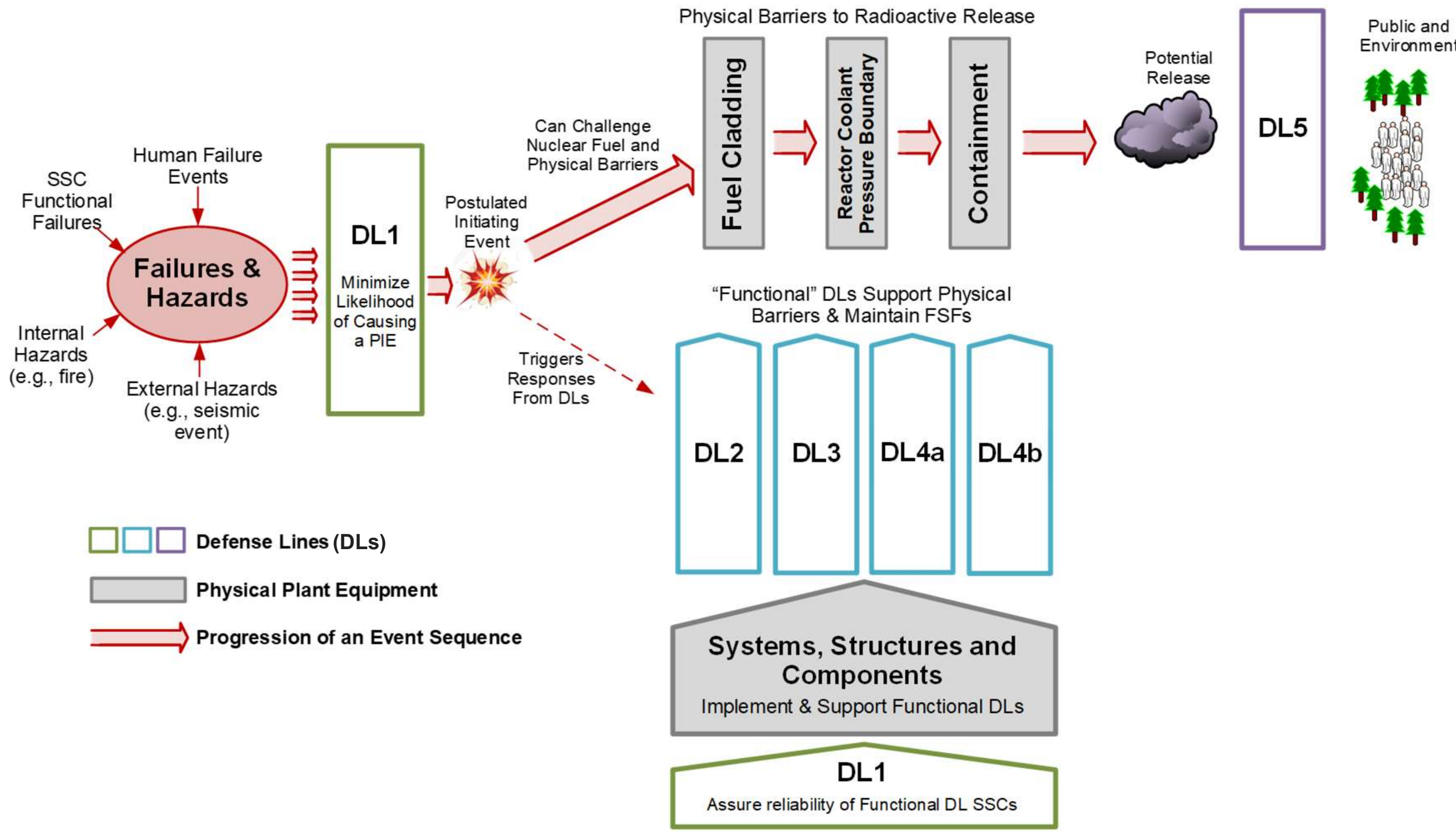
Dry, nitrogen inerted containment, which is cooled passively

Steel-Plate Composite Containment Vessel (SCCV)

Emergency Cooling System is made up of ICS and RIVs

Overpressure protection is provided via ICS and reactor scram function

Defense In Depth … Built Into The Design From The Start



NRC Approved Licensing Topical Reports (LTRs) for BWRX-300

NEDC-33910P-A, BWRX-300 RPV Isolation and Overpressure Protection (NRC Final Safety Evaluation Report (SER) Issued 11/18/2020)

Describes design requirements, acceptance criteria, and regulatory basis for RPV isolation and overpressure protection design functions for mitigation of loss-of-coolant accidents (LOCAs) and RPV overpressure events. LTR established ECCS for BWRX-300 as ICS and RIVs, and established overpressure protection to be made up of reactor scram and ICS functions. This allowed for the elimination of an automatic depressurization system, suppression pool, additional water inventory source, relief valves, and safety valves.

NEDC-33911P-A, BWRX-300 Containment Performance (NRC Final SER Issued 3/12/2021)

Addresses physical design requirements for new dry, inerted containment design (including containment vessel, containment penetrations and PCCS), and acceptance criteria requirements (design basis pressures and temperatures) for containment performance following the specified design basis accidents.

NEDC-33912P-A, BWRX-300 Reactivity Control (NRC Final SER Issued 1/12/2021)

Describes design requirements, acceptance criteria, and regulatory basis for reactivity control functions for shutting down the reactor following anticipated operational occurrences and design basis accidents. Allows removal of safety-related standby liquid control system from design, as one is not needed to comply with NRC Anticipated Transient Without Scram (ATWS) regulations.

NRC Approved LTRs for BWRX-300

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NEDC-33922P-A, BWRX-300 Containment Evaluation Method (NRC Final SER Issued 4/27/2022)

Addresses development of and qualification of analytical methods for determining containment response (calculated containment pressures and temperatures over time) after a design basis accident for comparison with acceptance criteria of NEDC-33911P-A.

NEDO-33914-A, BWRX-300 Advanced Civil Construction and Design Approach (NRC Final SER Issued 4/27/2022)

Describes regulatory basis, analytical methods, design and inspection requirements, acceptance criteria and guidelines specific to the innovative approaches implemented for design and construction of the BWRX-300 Reactor Building vertical shaft design.

Applicable Limitations and Conditions (L&Cs) from previously approved LTRs are addressed in TVA PSAR

BWRX-300 LTRs Currently Under NRC Review

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NEDC-33926P, BWRX-300 Steel-Plate Composite Containment Vessel (SCCV) and Reactor Building (RB) Structural Design (Initially Submitted to NRC 5/4/2023)

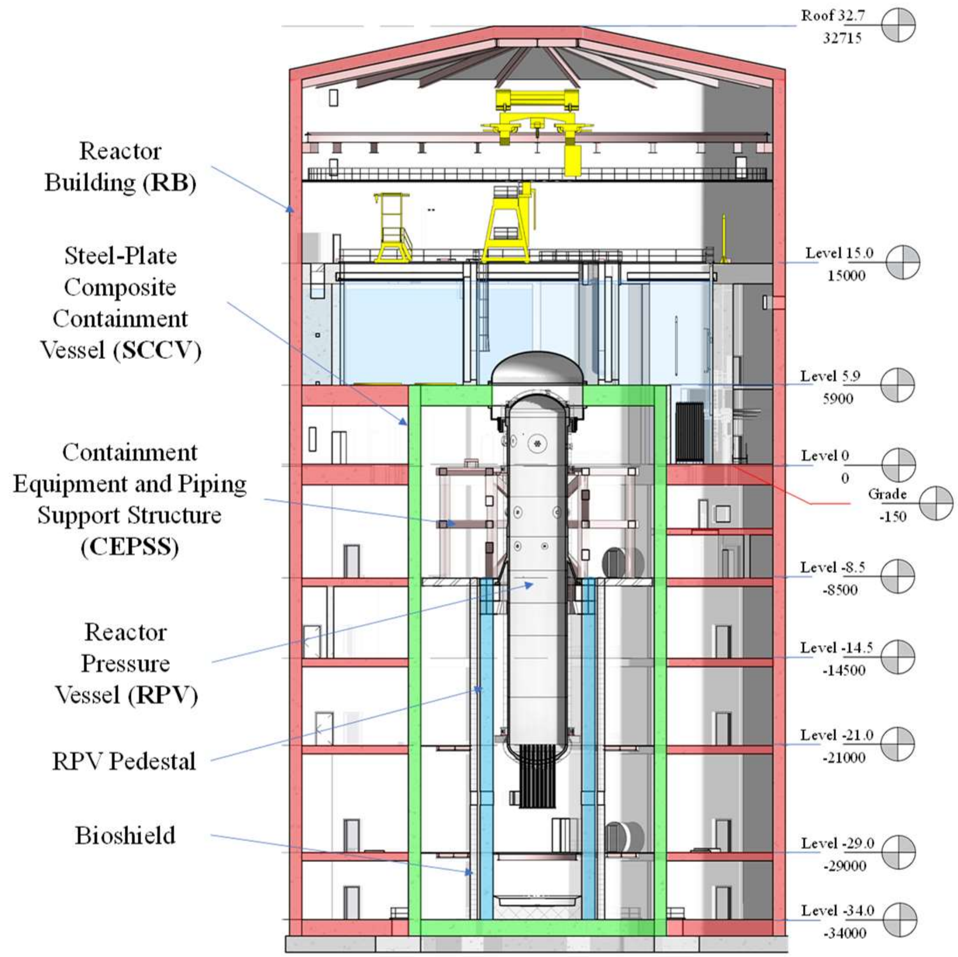
Seeks NRC approval for

(1) The design approach and methodology of Diaphragm Plate Steel-Plate Composite (DP-SC) structural elements for the Seismic Category I SCCV and RB structures,

(2) Requirements for the material, fabrication, construction, inspection, examination and testing of the DP-SC modules for the SCCV and RB structures,

(3) Proposed criteria and requirements for materials, design, fabrication, construction, inspection, examination, and testing for the SCCV adapted from specific Section III requirements, and

(4) Modified criteria and requirements for material, design, analysis, fabrication, construction, inspection, examination, and testing of non-containment Seismic Category I structural members, including slabs and curved walls, built using DP-SC modules



BWRX-300 LTRs Currently Under NRC Review

NEDC-33934P, BWRX-300 Safety Strategy (Initially Submitted to NRC 3/8/2024)

The BWRX-300 Safety Strategy applies a Defense-in-Depth design approach to achieve an internationally deployable design with an inherent high level of safety. NEDC-33934P describes the use of DL functions to mitigate design basis and beyond design basis events, and the resulting Structures, Systems, and Components (SSC) classification and seismic categorization.

NEDC-33934P, Rev. 1, seeks the following NRC approvals:

(1) BWRX-300 Safety Class 1 (SC1) SSCs are equivalent to the "safety-related SSCs" definition in 10 CFR 50.2

(2) The LTR identifies the correct set of SSCs that are applicable to GDCs involving "important to safety" or "protection system"

(3) Safety Strategy event categorization process is acceptable

(4) The LTR identifies the correct set of SSCs that are applicable to Technical Specifications Limiting Conditions for Operation Criteria

(5) Identification of Regulatory Treatment of Non-Safety Systems (RTNSS) SSCs is not necessary, as the Safety Strategy already classifies such SSCs as Safety Class 3 (SC3) or higher.

BWRX-300 LTRs Currently Under NRC Review

NEDC-34270P, BWRX-300 Stability Analysis (Initially Submitted to NRC 3/31/2025)

The BWRX-300 Stability Analysis LTR supports an applicant fulfilling L&C 5.3 from NEDC-33912P-A, *BWRX-300 Reactivity Control*, thereby conforming to NUREG-0800 Standard Review Plan (SRP) 15.9, *Boiling Water Reactor Stability*, and demonstrating compliance to the acceptance criteria provided therein. NEDC-34270P requests NRC approval of the BWRX-300 stability analysis, which utilizes implicit numerical integration for channel components and a nominal core wide Decay Ratio acceptance criterion of ≤ 0.80.

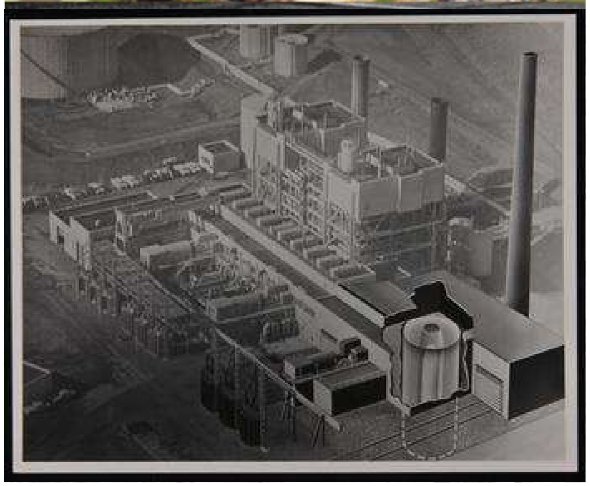
Design concepts for LTRs currently under NRC review are not expanded in this presentation, since these LTRs will get their own ACRS meeting, if required.

Unique Design Features

- Because GVH has utilized LTRs extensively for new or unique design features, ACRS has previously reviewed associated BWRX-300 design phenomena
- However, it’s been several years since ACRS has seen some of these LTRs
- Presentation will focus on the following design features:
  - RPV
  - RIVs
  - ICS
  - PCCS

Natural Circulation – Background & Overview

- Proven effective operating power reactor technology
  - EBWR (20→100 MWt), Chicago
  - Dodewaard reactor (163 MWt), Netherlands
  - Humbolt Bay 3 (215 MWt), California
- Operating BWR data gathered from Stability tests under Natural Circulation and from Recirc Pump trip events benchmarks flow at higher power (> 1000 MWt)
- Chimney two phase flow testing conducted
- Startup characteristics testing performed
- TRACG code qualification includes above data – predicts natural circulation flow well at power when flows are much higher and at decay heat powers when flows are very low.
- Core power density/size and RPV configuration to support natural circulation flow are designed to ensure thermohydraulic stability



BWRX-300 Reactor Pressure Vessel (RPV) and Internals

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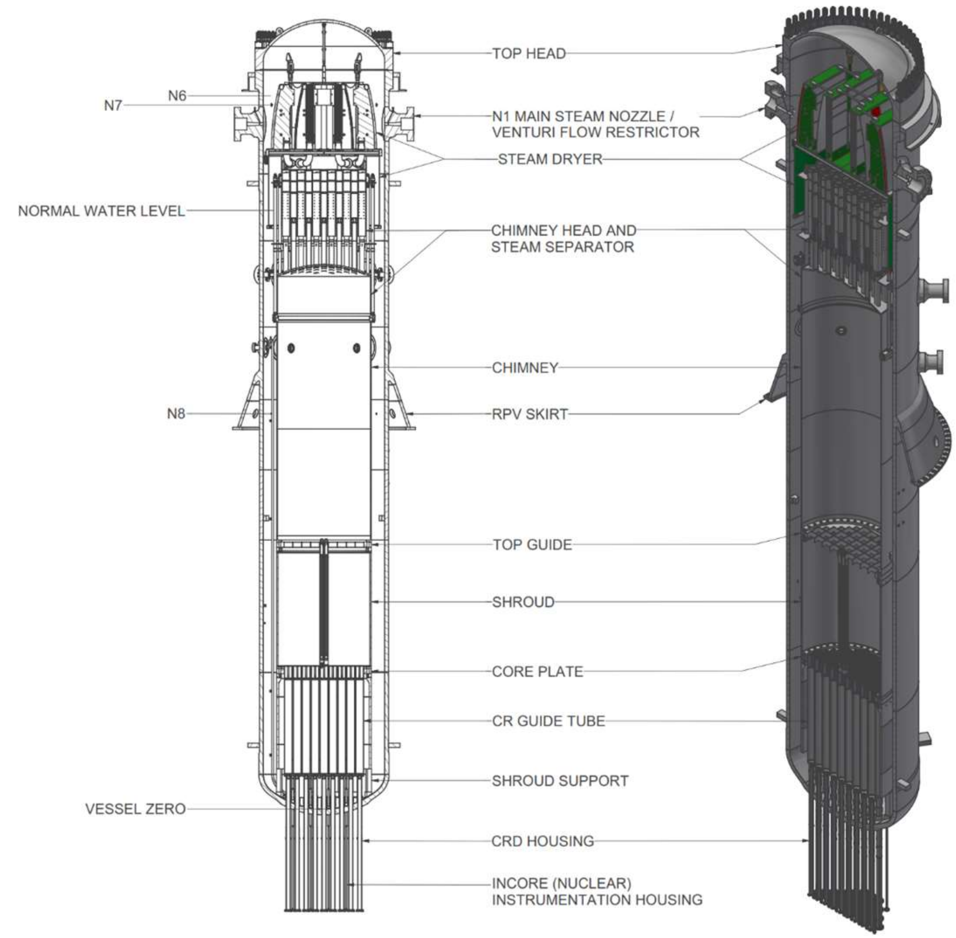
Proven Components with Operational Experience

- **RPV** same material and fabrication processes as ABWR and much of the operating BWR fleet
- **RPV** diameter and fuel assembly arrangement similar to Kernkraftwerk Mühleberg (KKM)
- **Partitionless Chimney** drives core flow.
- **Steam Dryer** has same features as ABWR and replacement dryers in operating BWRs
- **Steam Separator** is same as in BWR/6s and ABWR
- **GNF2 Fuel** is widely used
- **Control Rods** essentially same technology used in operating BWRs
- **Fine Motion Control Rod Drives (FMCRDs)** essentially same as ABWR



BWRX-300 Fine Motion Control Rod Drives (FMCRD)

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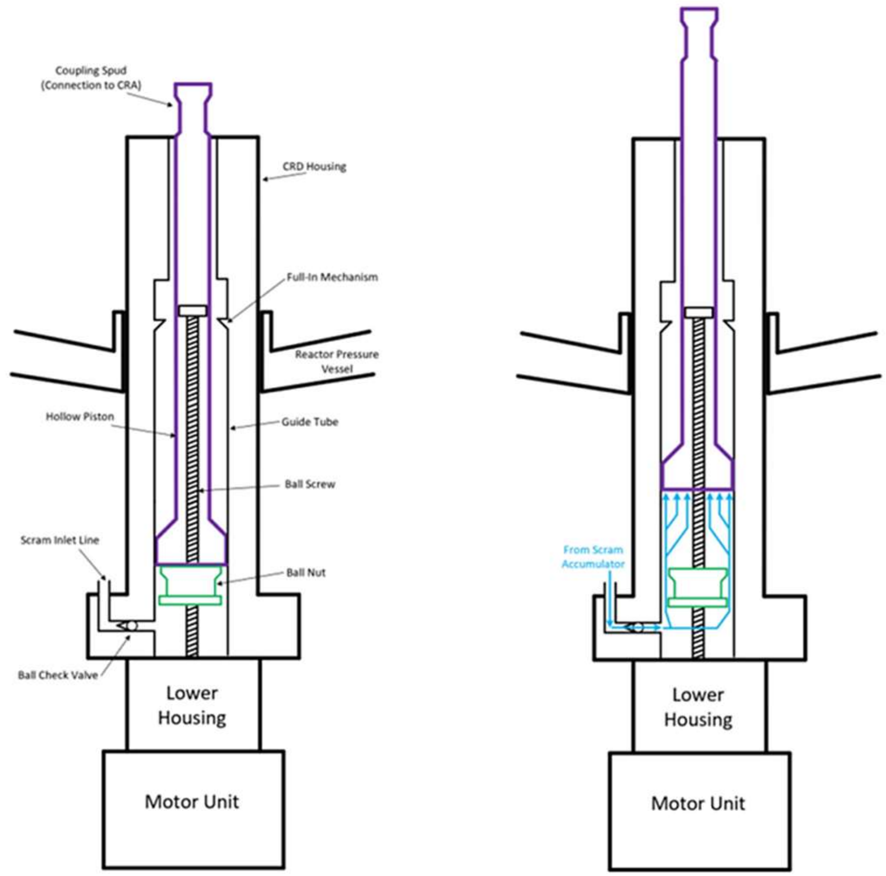
- Positive insertion means of controlling reactivity include:
  - Hydraulic scram control rod insertion function using the hydraulic control units and control rods
  - Motor-driven control rod run-in insertion function using the FMCRDs and control rods



Normal Configuration
(Hollow Piston resting on Ball Nut)

Hydraulic Scram
(Hollow Piston lifted from Ball Nut)

BWRX-300 Simplified View of FMCRD with Hydraulic Scram

Reactor Core Monitoring Instrumentation

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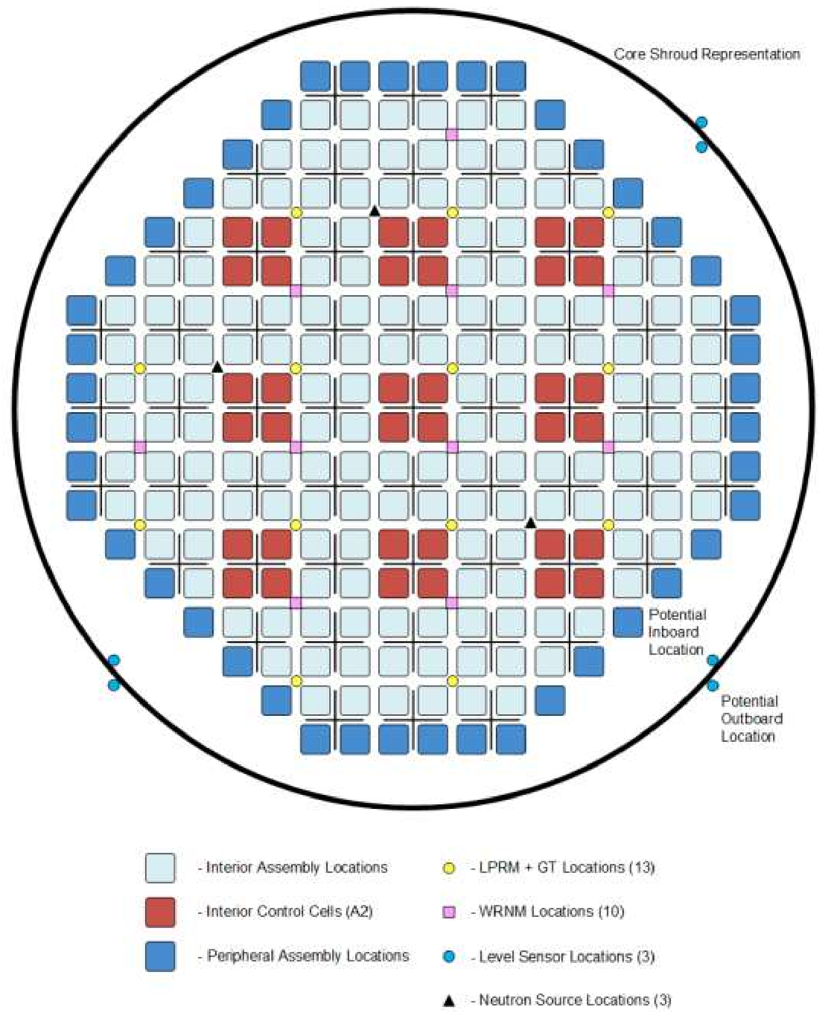
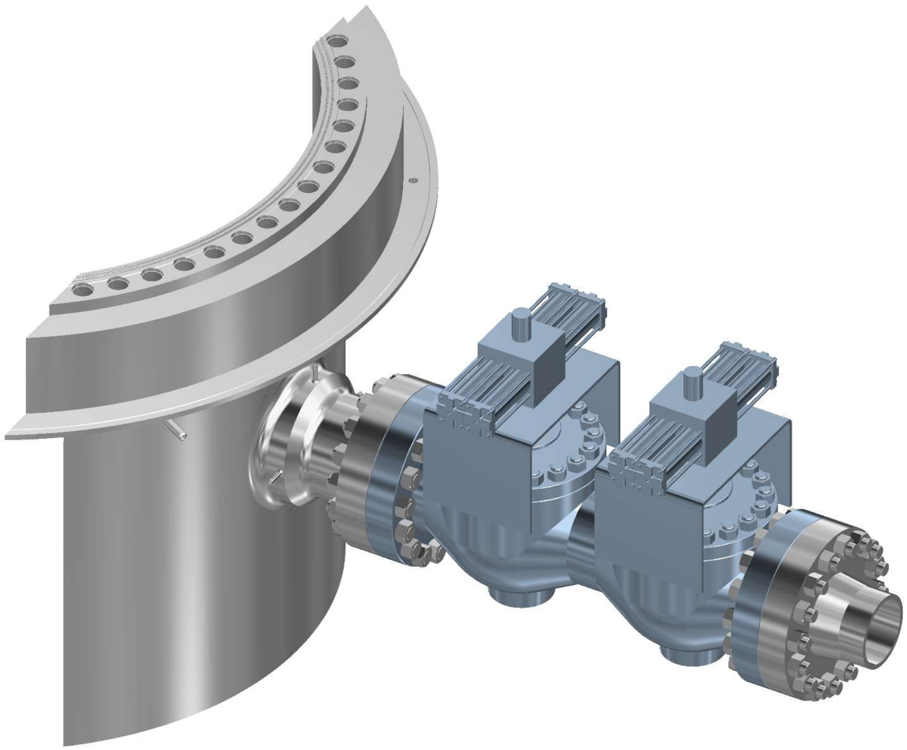
- Local Power Range Monitors (LPRMs) and Wide Range Neutron Monitors (WRNMs) are distributed across the core to measure neutron flux
  - Each LPRM detector provide neutron monitoring sensitivity from ~10% core thermal power to greater than 100% reactor thermal power
  - Each WRNM detector is sensitive to neutrons from below criticality to power operation
- Fixed, in-core Gamma Thermometers (GTs) convert local gamma flux to an electrical signal, providing a diverse means of detecting core thermal power
  - GTs are used for neutron instrument calibration
  - Fixed, in-core GTs were also used in ESBWR



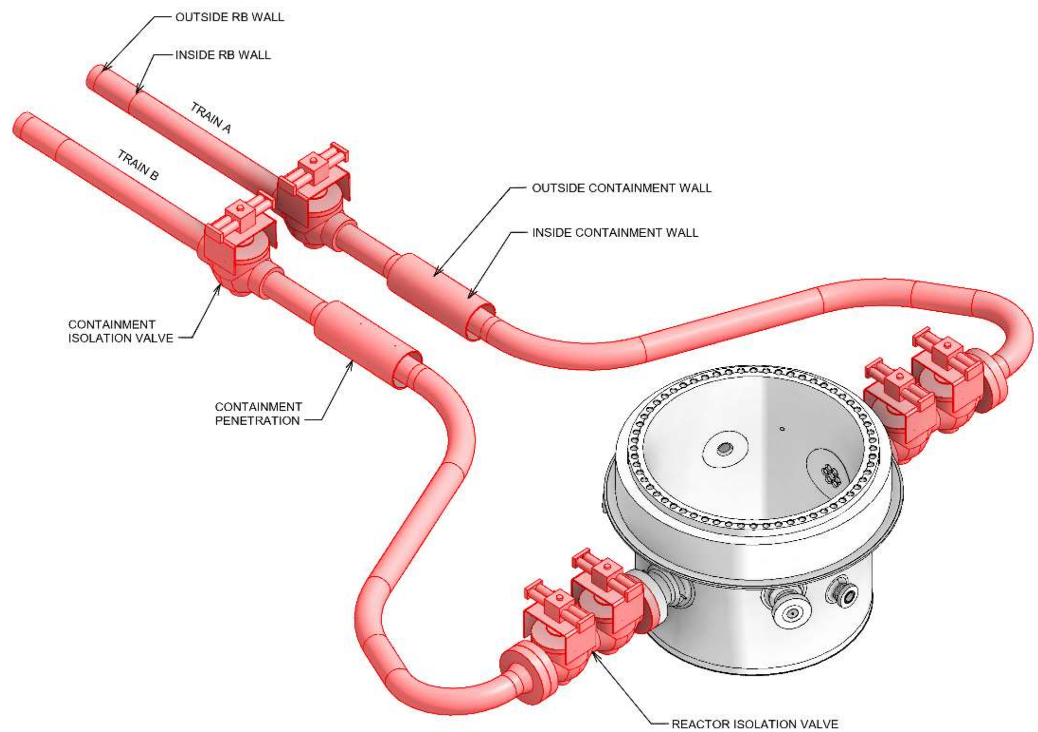
Reactor Isolation Valves (RIVs)



- All large RPV penetrations have two integral RIVs (excludes instrumentation lines)
  - Valves are installed directly on the RPV nozzles via flanged connections
  - Design consists of two valves in a single body
- RIVs are part of the reactor coolant pressure boundary and are ASME Class 1 components

Reactor Isolation Valves (RIVs)

- RIVs effectively mitigate large pipe breaks
  - Coolant loss is limited by one of two RIV closure for large breaks
- RIVs are also part of the containment isolation function (i.e., are the containment isolation valve inside containment)



Isolation Condenser System (ICS)

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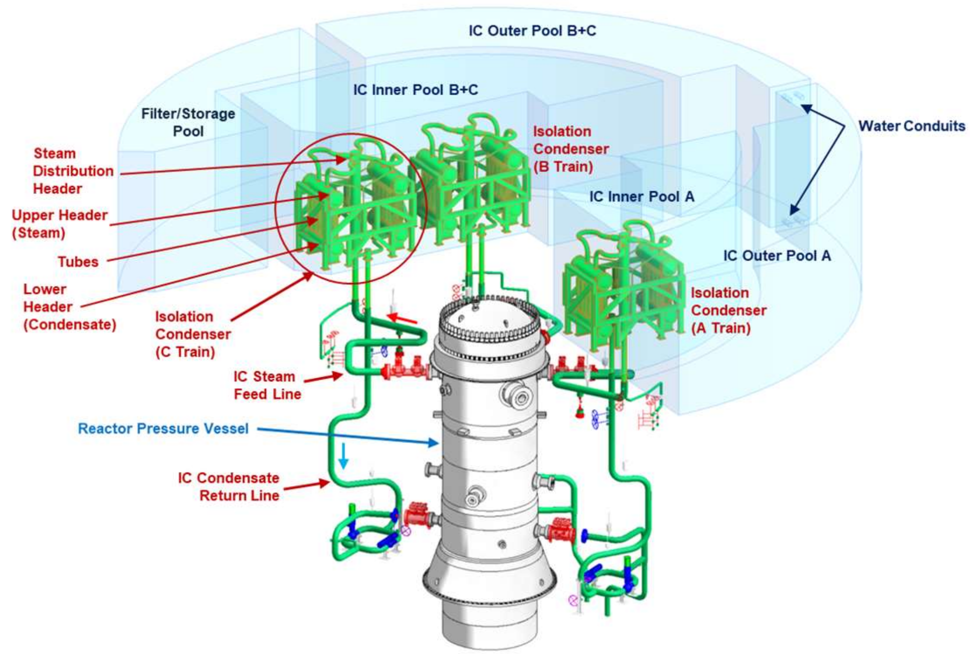
- Isolation Condenser System (three trains) provides heat removal/pressure control
- Mild transient response due to large steam volume in RPV
- No need for safety relief valves – ICS along with scram function provides overpressure protection
- Only one Isolation Condenser (IC) train required to respond to the transient.
- Seven-day coping time for station blackout and with passive system response to transients and design basis accidents
- Simple actions of adding water using installed systems or FLEX after seven days to increase time indefinitely



SEVEN DAYS COPING TIME

Isolation Condenser System (ICS) Functions

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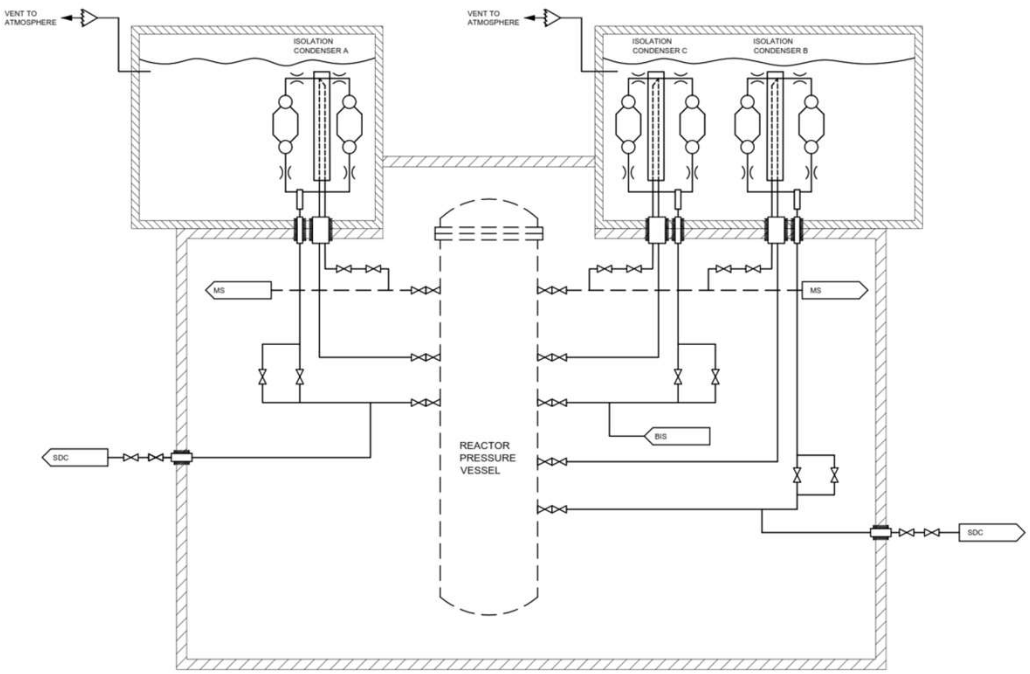
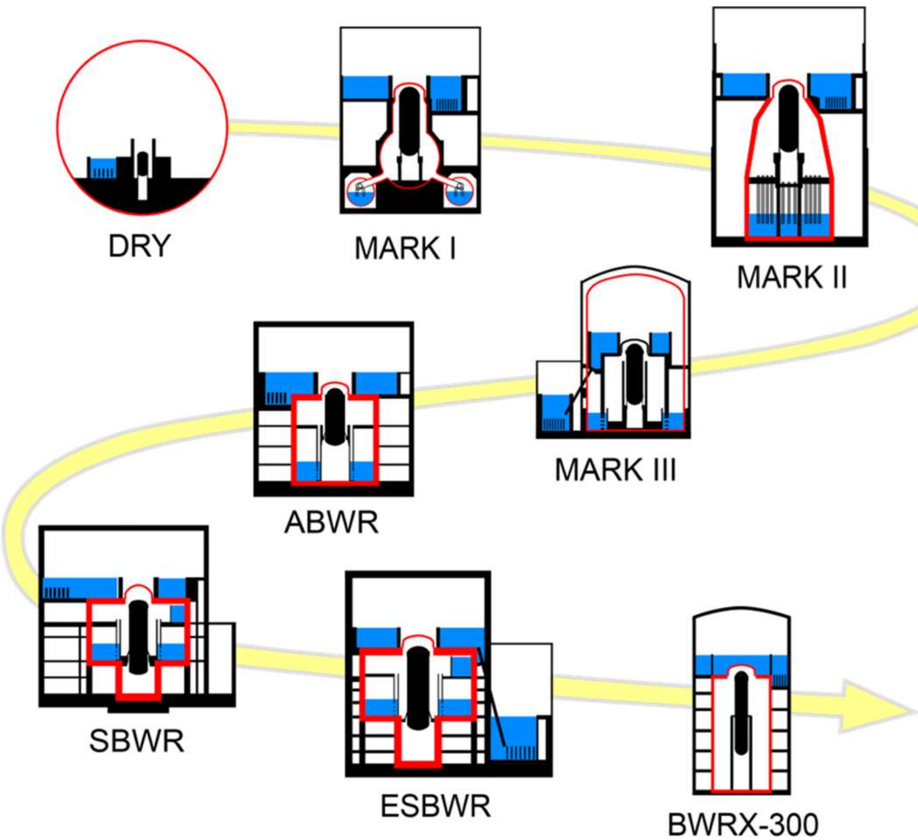


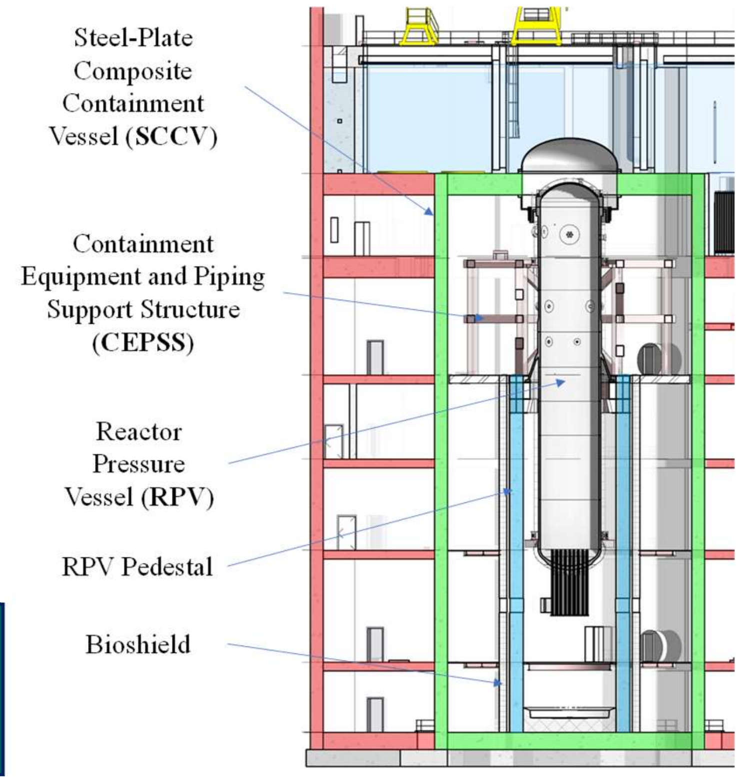
- ICS along with RIVs perform ECCS function since inventory is being retained and decay heat is being removed
- ICS in conjunction with reactor scram provides reactor pressure boundary overpressure protection when system is isolated
- ICS provides isolation capability to maintain Primary Containment integrity
- ICS returns condensate to the chimney in the RPV
- ICS provides heat removal in all modes when the RPV head is in place
- ICS mitigates pressurization transients, provides decay heat removal for isolation events, and provides pressure reduction in LOCA events to limit coolant loss

BWR Containment Design Evolution

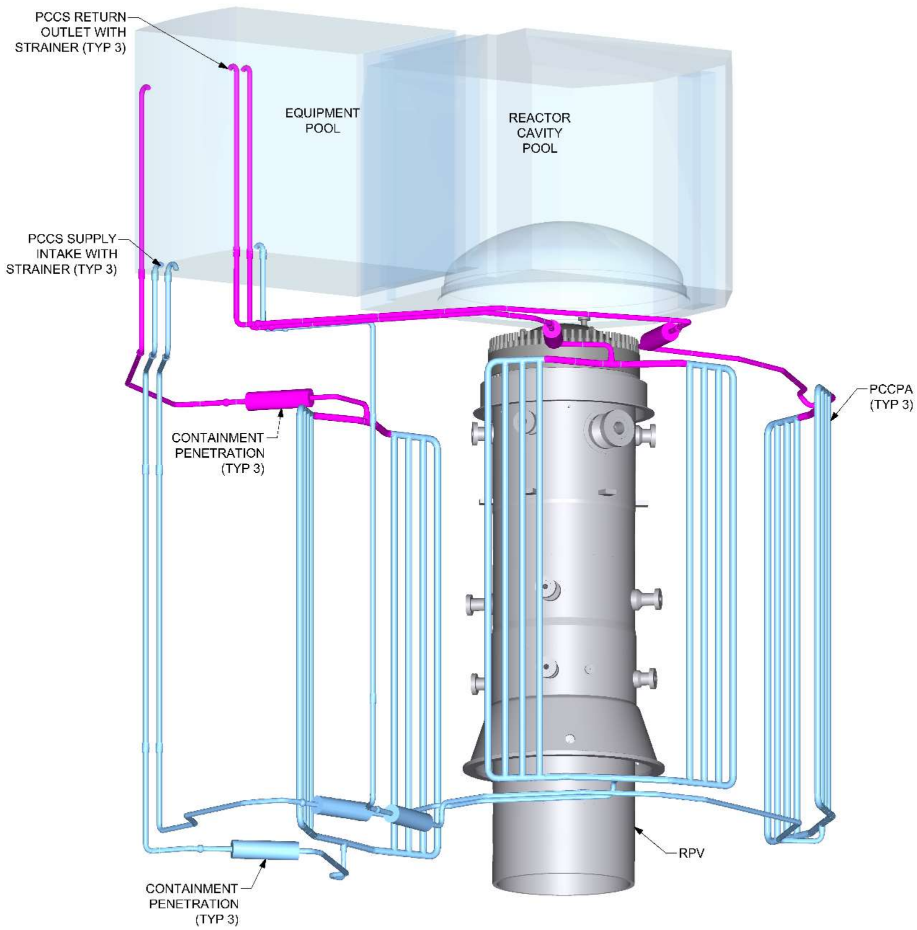


Simpler
Smaller
Faster to Build
Less Expensive

BWRX-300 has a dry containment like the earliest BWRs



Passive Containment Cooling System (PCCS)



- During normal operation heat is removed from the containment by active cooling
- Following an accident, PCCS provides containment heat removal using passive natural circulation flow
- Heat is also removed from Containment naturally through the containment head
- PCCS is always in service unless portions are manually isolated (i.e., no active components or actuation signals required to initiate or maintain function)
- Equipment pool provides the cooling source for the PCCS heat exchangers
- Three independent trains each with a Passive Containment Cooling Pipe Array (PCCPA)
- Mounted to interior of Primary Containment wall
- Piping to and from the Equipment Pool