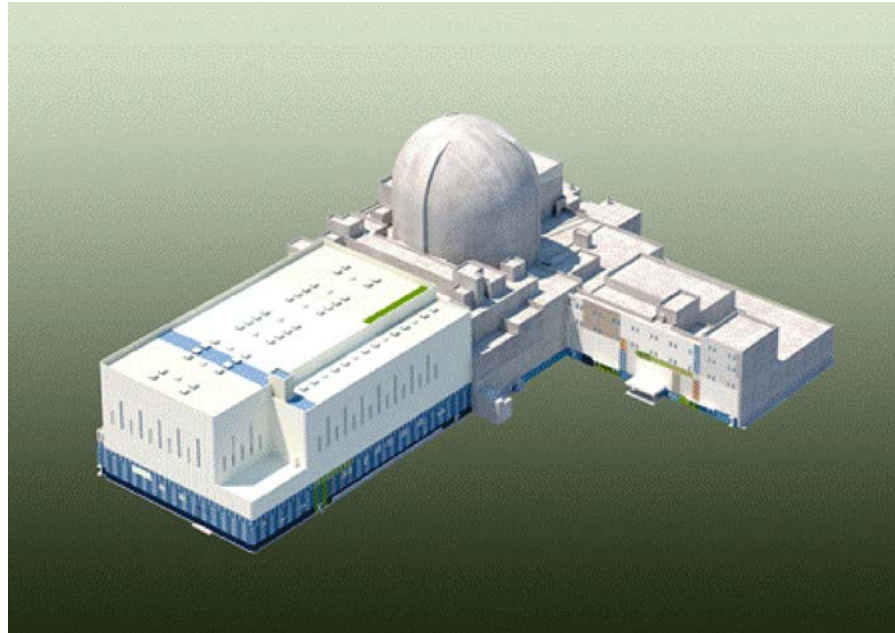


Structural Analysis for the Reactor Coolant System



KEPCO/KHNP
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Contents

- Design concept of the **R**actor **C**oolant **S**ystem (RCS)
- Regulatory bases
- Design requirements of the RCS components
- Design acceptance for the RCS components
- Design control document description
- Conclusion

Design concept of the reactor coolant system (RCS)

- ❑ Function of the RCS:
 - Transfer heat energy from the reactor core to the secondary system, via the steam generators, by means of the pressurized water circulating in the system

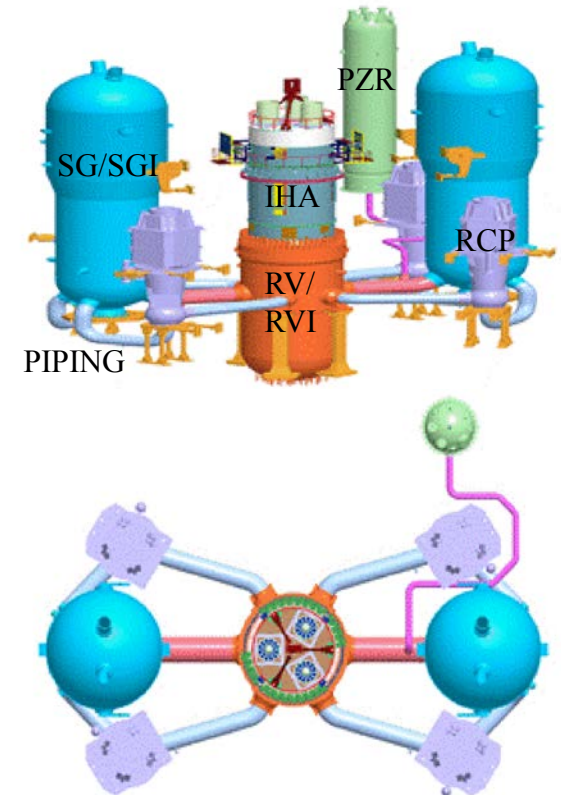
- ❑ The RCS shall be designed to withstand the combined effects of earthquakes, postulated pipe breaks, **In-Containment Refueling Water Storage Tank (IRWST)** discharge and the loads from the normal operation condition.

Design concept of the reactor coolant system (RCS)

□ Description of the RCS

■ Two loops are symmetric and composed of :

- **R**actor **V**essel (RV)
- **S**team **G**enerator (SG)
- **R**actor **C**oolant **P**ump (RCP)
- RCS Piping
 - Hot Leg
 - Cold Leg
 - Crossover Leg
- Pressurizer (PZR)

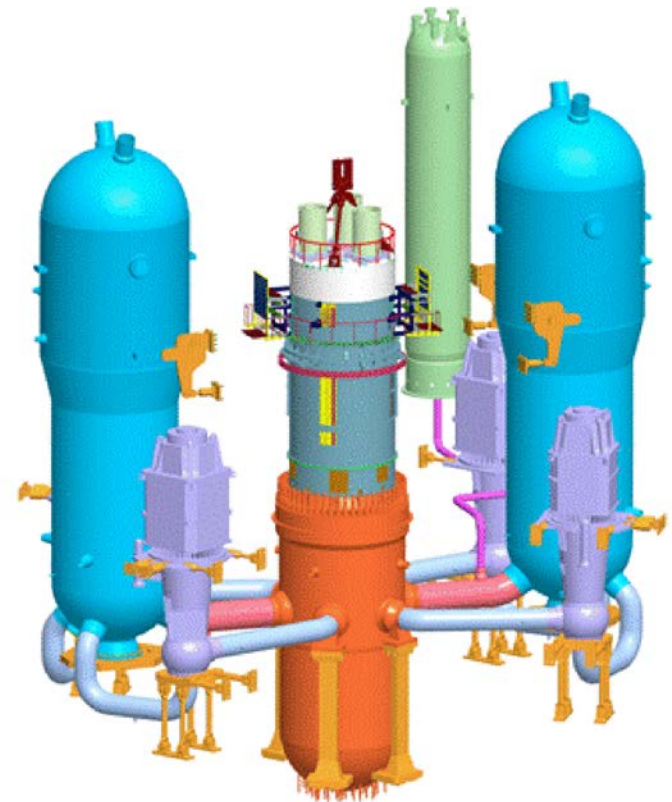


Design concept of the reactor coolant system (RCS)

❑ Description of the RCS (cont'd)

■ The RCS component supports

- Vertical supports
 - Support columns (RV and RCP)
 - Support skirts (SG, PZR)
- Horizontal supports
 - Upper support (RV)
 - Hydraulic snubbers (SG, RCP)
 - Lateral support columns (RCP)
 - Keys (RV, SG, PZR)



Regulatory bases

❑ Regulations

- 10 CFR Part 50, Appendix A GDC 2,

- “Design Bases for Protection against Natural Phenomena”

- Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as **earthquakes**, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions.

- 10 CFR Part 50, Appendix A GDC 4,

- “Environmental and Dynamic Effects Design Bases”

- Structures, systems, and components important to safety shall be designed to accommodate the effects of and to be compatible with the environmental conditions associated with **normal operation**, maintenance, testing, and **postulated accidents, including loss-of-coolant accidents.**

Design requirements of the RCS components

□ Structural analysis overview

■ Purpose

- Determine the responses of the RCS due to the seismic loads, postulated pipe break loads and the loads from the normal operation condition

■ Models

- Finite element models built from the drawings and data of the RCS components

■ Loads

- Weight
- Pressure
- Thermal load
- Seismic load
- Postulated pipe break load
- IRWST discharge load

Design requirements of the RCS components

❑ Structural analysis overview (cont'd)

■ Methods

- Static analyses for pressure, weight and thermal load
- Time-history analyses for seismic, postulated pipe break and IRWST discharge load

■ Results:

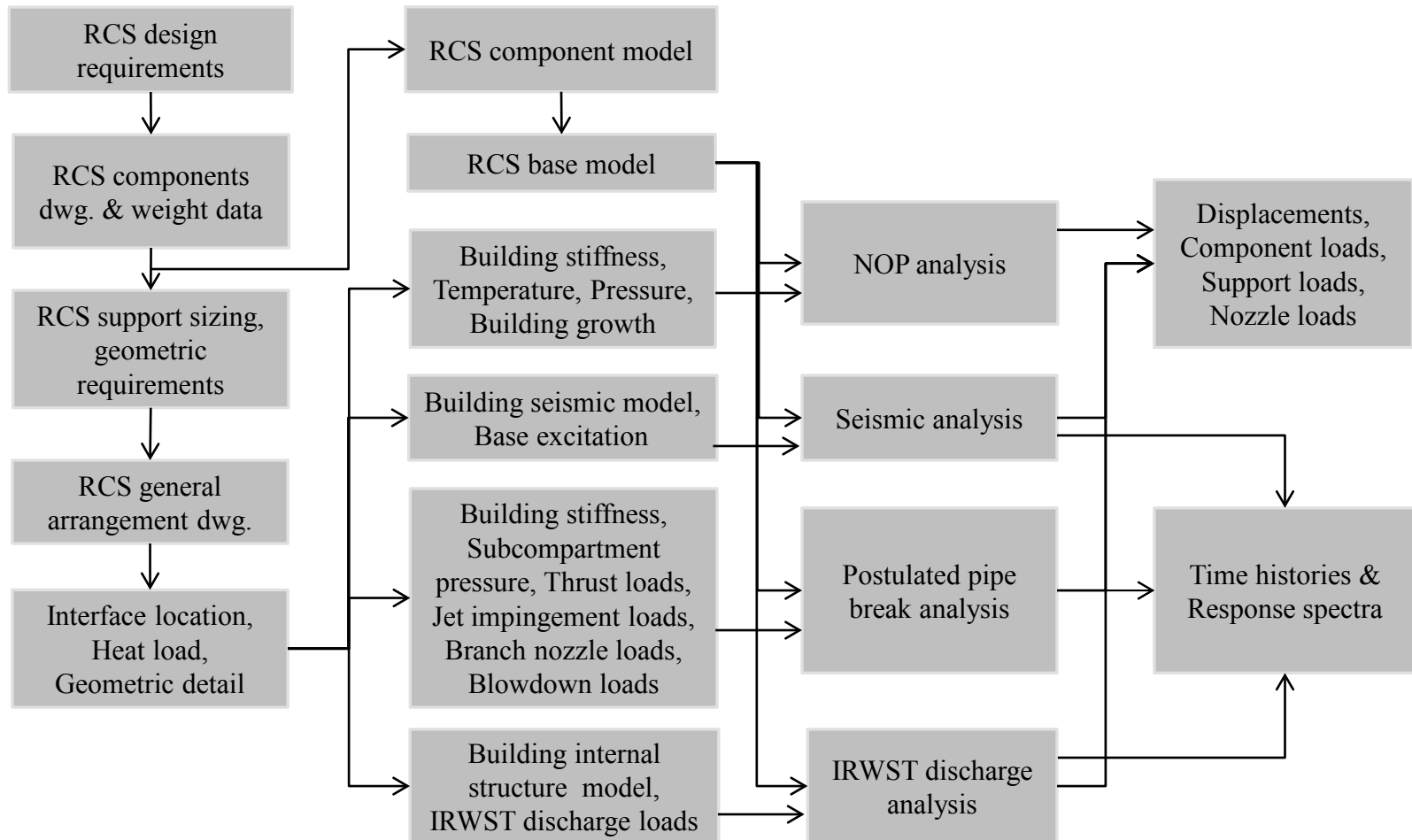
- Forces and moments
- Displacements
- Time histories
- Response spectra

Design requirements of the RCS components

- ❑ Structural analysis for the RCS
 - RCS base model
 - Normal **O**peration(NOP) analysis for the RCS
 - Seismic analysis for the RCS
 - Postulated pipe break analysis for the RCS
 - IRWST discharge analysis for the RCS

Design requirements of the RCS components

□ Procedure of the RCS structural analysis



Design requirements of the RCS components

❑ RCS base model

- 3D lumped mass beam model
- Local stiffness for certain entities by finite element analysis
 - Shell - Keys & Lugs
 - RV Nozzles



Reactor coolant system



RCS base model

TS

Design requirements of the RCS components

❑ RCS NOP Analysis

- Deadweight, normal operation, hot standby and transient analyses for the reactor coolant system
- To calculate the forces, moments and displacements of RCS due to the effects of deadweight, pressure and thermal expansion and contraction
- NOP analysis model
 - Addition of nodes and elements to RCS base model
 - Change of support boundary conditions
 - Other changes
 - Addition of building stiffness
 - Change of material properties based on the operation conditions
- Linear static analysis
- Analysis code : ANSYS

Design requirements of the RCS components

❑ RCS seismic analysis

- Seismic analysis model
 - Nuclear Island (NI) building-coupled RCS model
- Excitation
 - Safe shutdown earthquake motion at the free-field ground surface
- Complex frequency response analysis
- Analysis code : ACS-SASSI

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Seismic analysis model

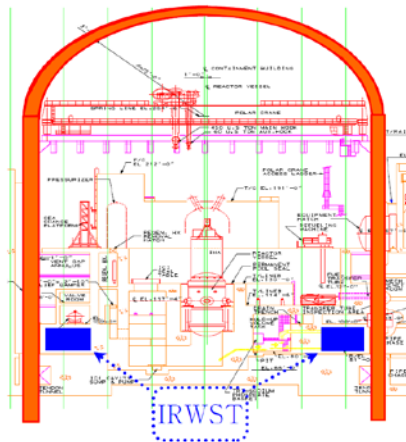
Design requirements of the RCS components

- ❑ RCS postulated pipe break analysis
 - Structural analysis for the RCS due to the pipe break
 - Breaks of the pipe lines to which **Leak-Before-Break** (LBB) concept is not applied
 - Postulated pipe break analysis model
 - Addition of nodes and elements to RCS base model
 - Consideration of the geometric gaps at the RCS supports
 - Postulated pipe break loads
 - Thrust force
 - Branch nozzle load
 - Jet impingement force
 - Subcompartment pressurization load
 - Blowdown load
 - Non-Linear time history analyses
 - Analysis code : ANSYS

Design requirements of the RCS components

❑ RCS IRWST discharge analysis

- RCS coupled model with reactor containment building internal structures
- IRWST discharge load
 - Pressure time histories for air bubble oscillation and steam discharge
 - Applied to IRWST inner wall
- Linear time history analysis using direct integration method
- Analysis code : ANSYS



Location of IRWST

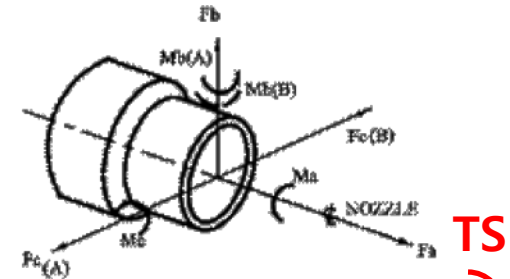


RCS IRWST discharge analysis model

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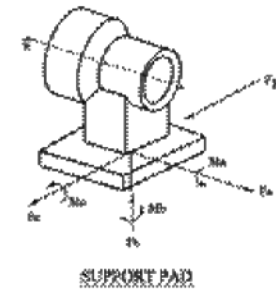
Design requirements of the RCS components

- ❑ Design loads of the RCS components
 - Reactor vessel inlet nozzle loads



Design requirements of the RCS components

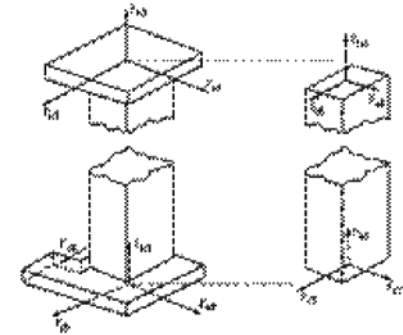
- ❑ Design loads of the RCS components (cont'd)
 - Reactor vessel support loads



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Design requirements of the RCS components

- ❑ Design loads of the RCS components (cont'd)
 - Reactor vessel support structure loads



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Design requirements of the RCS components

- ❑ Design loads of the RCS components (cont'd)
 - Reactor vessel support structure loads (cont'd)

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Design requirements of the RCS components

- ❑ Transient condition and number of occurrence for the RV design
 - Normal events (Level A)

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Design requirements of the RCS components

- ❑ Transient condition and number of occurrence for the RV design
 - Upset events (Level B)

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Design requirements of the RCS components

- ❑ Transient condition and number of occurrence for the RV design
 - Faulted events (Level D)

TS

Design requirements of the RCS components

- ❑ Transient condition and number of occurrence for the RV design
 - Test events

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- Reactor Coolant Gas Vent System (RCGVS) Transients

Design acceptance for the RCS components

❑ Acceptance criteria

- ASME Boiler & Pressure Vessel Code 2007 Edition, 2008 Addenda
 - RCS components : ASME Section III NB
 - RCS component supports : ASME Section III NF

Design acceptance for the RCS components

- ❑ Design acceptance
 - Reactor vessel inlet nozzle

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Design acceptance for the RCS components

- ❑ Design acceptance (cont'd)
 - Reactor vessel support structure

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Design control document description

- ❑ 3.9 Mechanical system and components
 - 3.9.1 Special topics for mechanical components
 - 3.9.1.1 Design transients
 - 3.9.3 ASME code class 1, 2, and 3 components, component supports, and class CS core support structures
 - 3.9.3.1 Loading combinations, Design transients, and Stress limits
 - Appendix 3.9 B - Reactor coolant system analysis

Conclusion

- ❑ The APR1400 structural analyses for the reactor coolant system are performed according to the regulations and guides, and codes and standards of U.S.
- ❑ All of the RCS components and their supports of the APR1400 meet the requirement of ASME Boiler & Pressure Vessel Code 2007 Edition, 2008 Addenda.

Thank You!

Appendix

Stress summary of the RCS components and RCS component supports

Stress evaluation summary of the RV

☐ Reactor vessel

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Stress evaluation summary of the RV

- ☐ Reactor vessel support structure

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Stress evaluation summary of the SG

☐ Steam generator

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Stress evaluation summary of the SG

- ☐ Steam generator supports

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Stress evaluation summary of the RCP

- ☐ Reactor coolant pump supports

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Stress evaluation summary of the RC main piping

☐ Reactor coolant main piping

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Stress evaluation summary of the pressurizer

☐ Pressurizer

TS