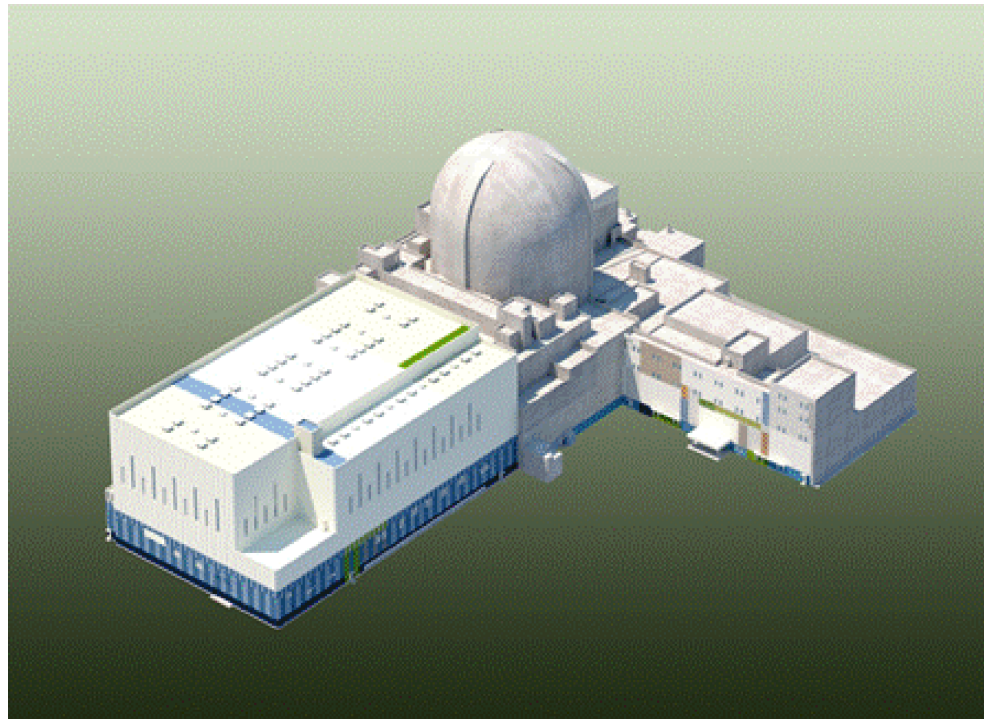


APR1400 Structural Analysis for Reactor Coolant System



KEPCO/KHNP
Apr. 20~21. 2016

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- Conclusion

Design concept of the reactor coolant system (RCS)

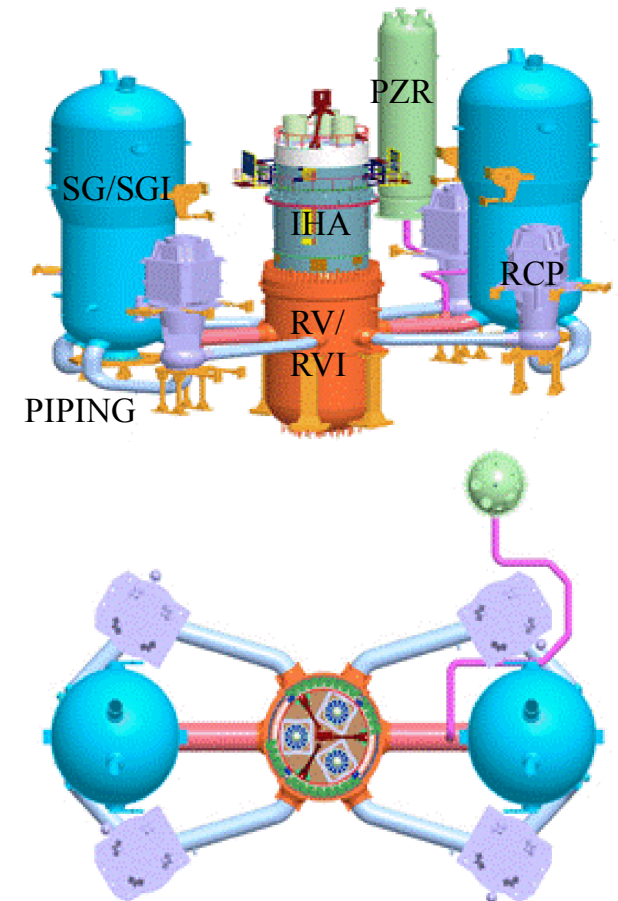
- ❑ Function of the RCS:
 - Transfer heat energy from the reactor core to the secondary system, via the steam generators, by means of the pressurized water circulating in the system
- ❑ The RCS shall be designed to withstand the combined effects of earthquakes, postulated pipe breaks, IRWST discharge 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 :

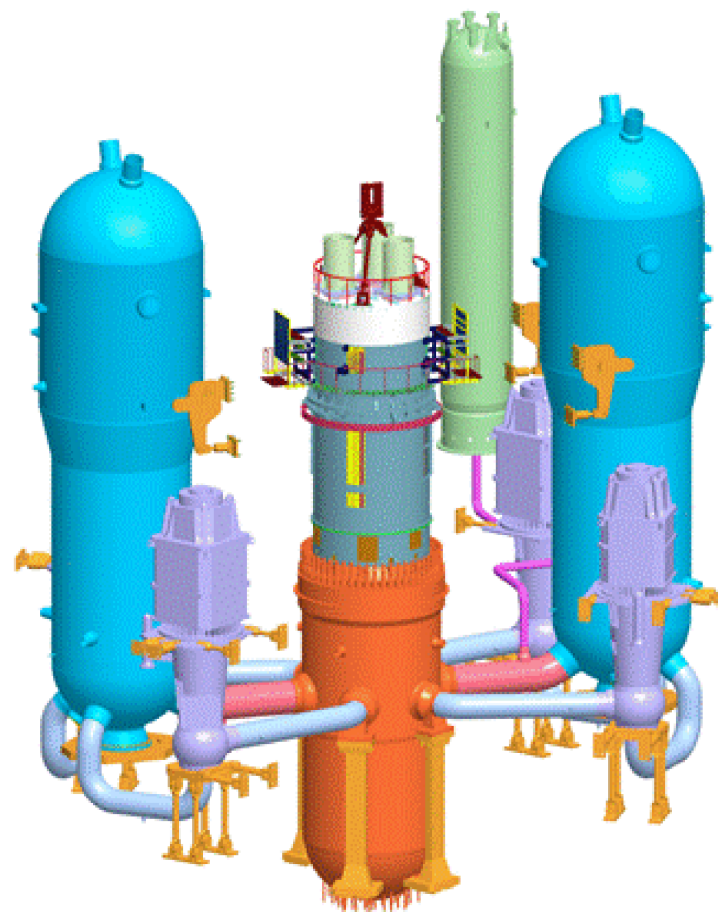
- **R**eactor **V**essel (RV)
- **S**team **G**enerator (SG)
- **R**eactor **C**oolant **P**ump (RCP)
- **R**CS **P**iping
 - Hot Leg
 - Cold Leg
 - Crossover Leg
- **P**ressurizer (PZR)



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
- In-Containment **Refueling Water Storage Tank (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:

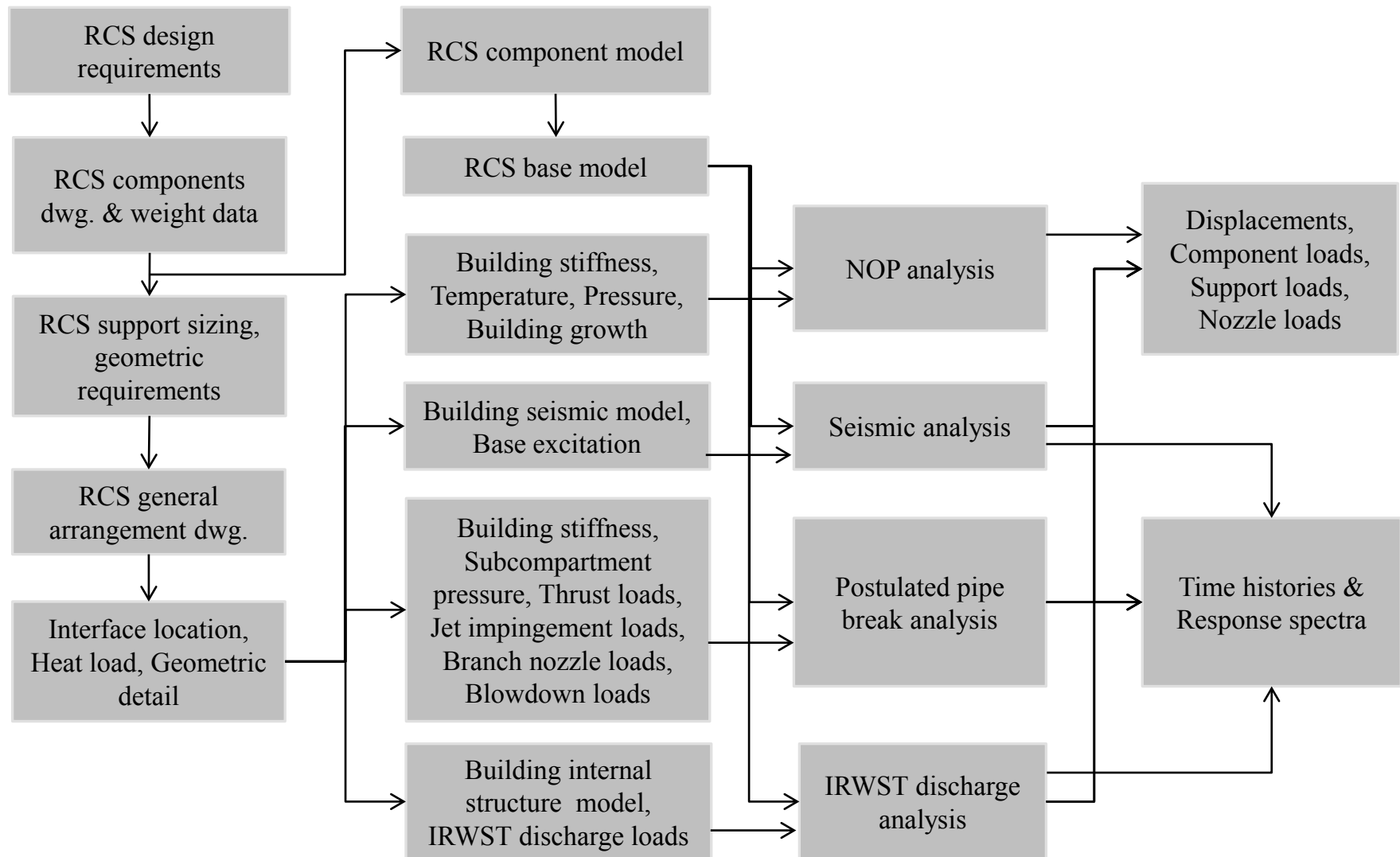
- Forces and moments
- Displacements
- Time histories
- Response spectra

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

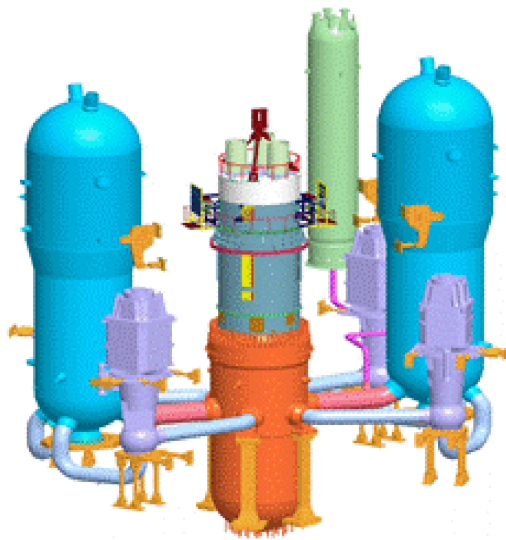
□ Procedure of the RCS structural analysis



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

TS

RCS base model

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

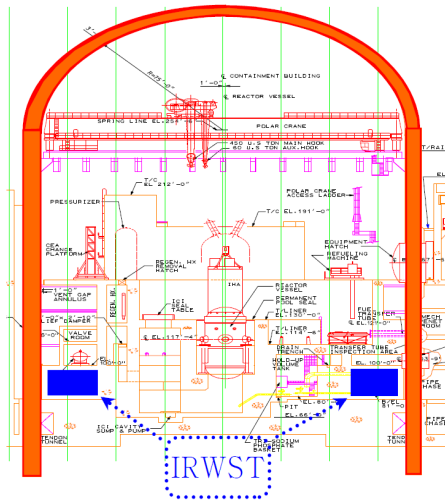
❑ RCS postulated pipe break analysis

- 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



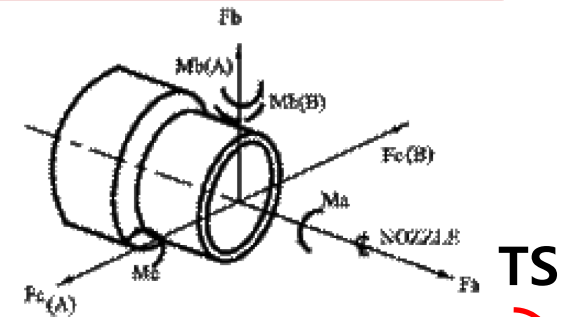
Location of IRWST



RCS IRWST discharge analysis model

Design requirements of the RCS components

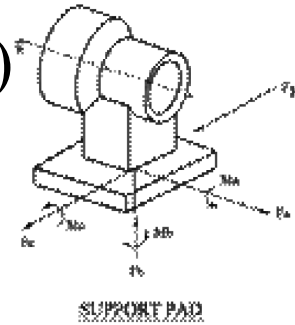
- Design loads of the RCS components
 - Reactor vessel inlet nozzle loads



Design requirements of the RCS components

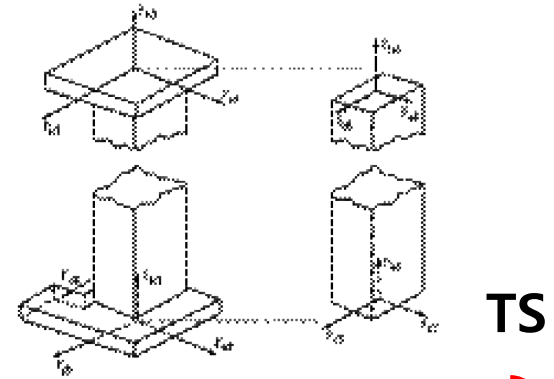
□ Design loads of the RCS components (cont'd)

- Reactor vessel support loads



Design requirements of the RCS components

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



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)

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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

TS

Design certification 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 summary of the reactor vessel

☐ Reactor vessel

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Stress summary of the reactor vessel

☐ Reactor vessel support structure

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Stress summary of the steam generator

☐ Steam generator

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Stress summary of the steam generator

☐ Steam generator supports

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Stress summary of the reactor coolant pump

☐ Reactor coolant pump supports

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Stress summary of the reactor coolant main piping

❑ Reactor coolant main piping

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Stress summary of the pressurizer

☐ Pressurizer

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