Experience of NCO Earthquake and Restart of Kashiwazaki-Kariwa NPP

November 25, 2010

Gaku SATO

Tokyo Electric Power Company

東京電力 TEPCO

Contents

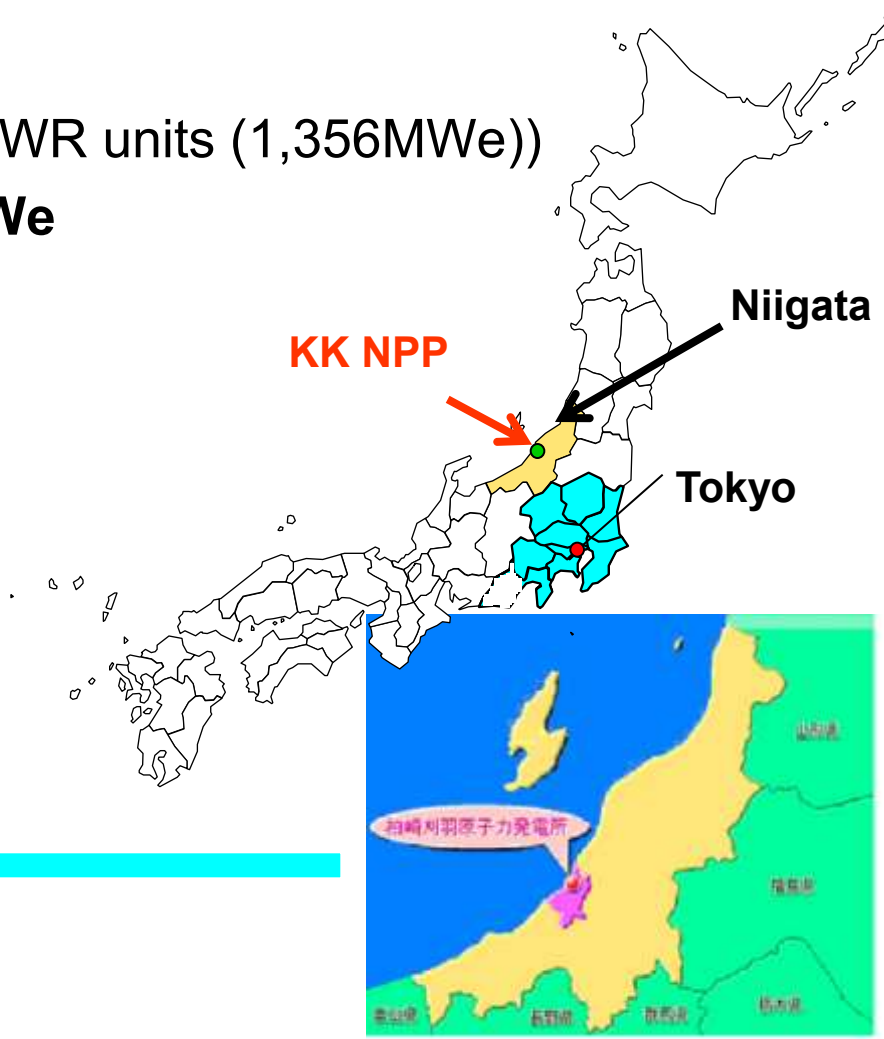
Outline of Niigataken Chuetsu-Oki Earthquake

Outline of Kashiwazaki-Kariwa NPP

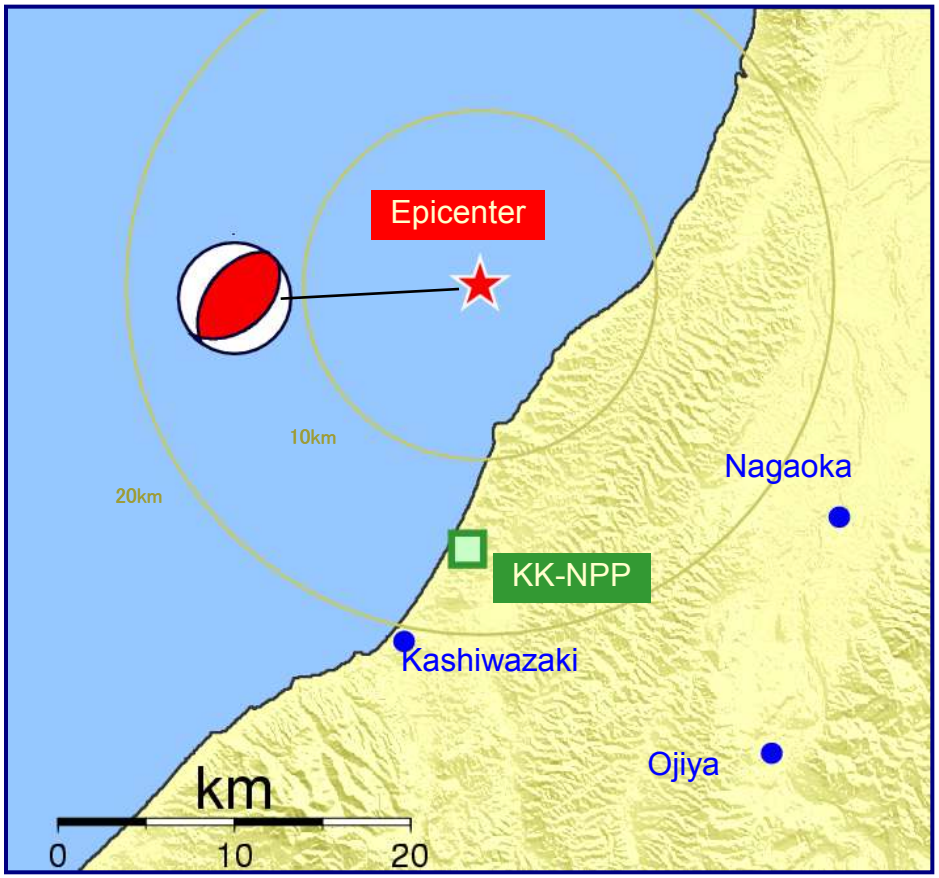
- Located on the border between Kashiwazaki City and Kariwa Village, Niigata Prefecture.
- 7 units.

  (5 BWR-5 units (1,100MWe) & 2 ABWR units (1,356MWe))

  ⇒ the world largest NPP：**8,212 MWe**



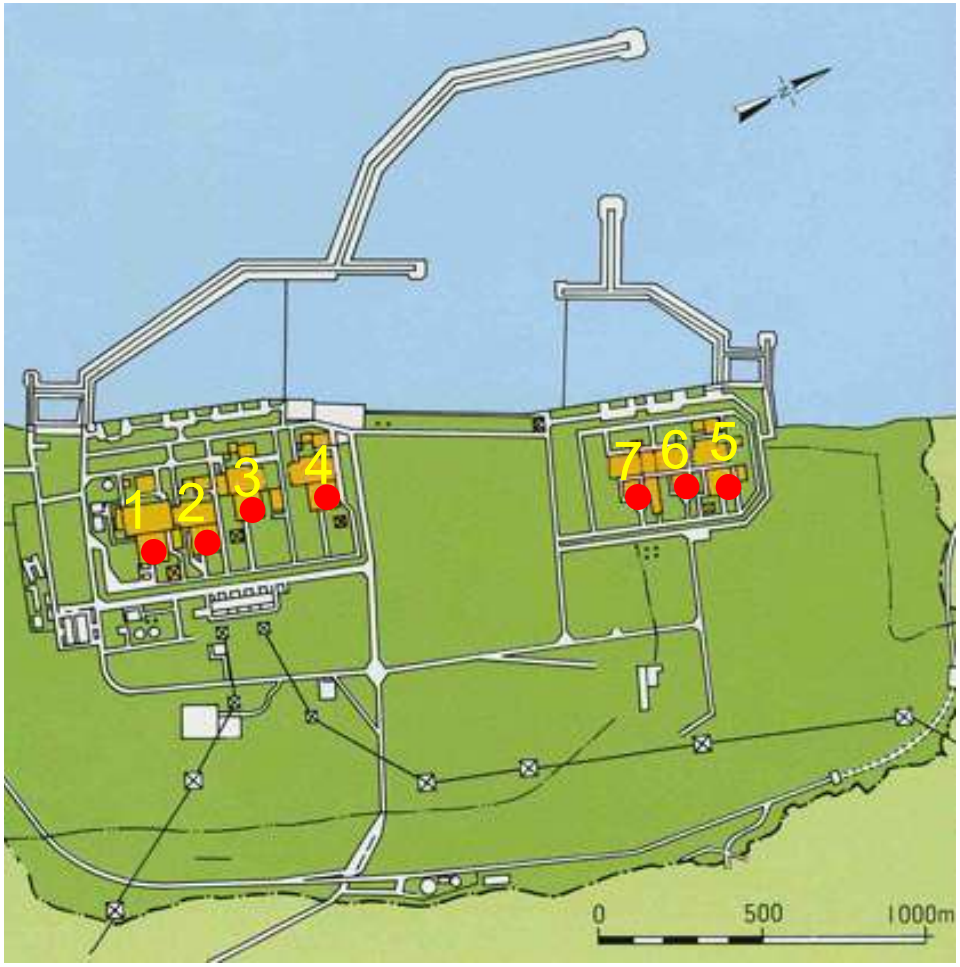
Niigataken Chuetsu-Oki Earthquake (NCO)



- Date & Time: July 16, 2007 10:13 AM JST
- Epicenter: Offshore of Niigata-pref., Lat. 37° 33.4' N. , Long. 138° 36.5'E.
- Depth: 17 km
- Scale: M_{JMA} 6.8 (M_w=6.6)
- Distance from KKNPP: Epicenter -> 16 km, Hypocenter -> 23 km
- Seismic Intensity: 6Upper : Kashiwazaki, Kariwa, Nagaoka
  6Lower : Joetsu, Ojiya, Izumozaki

(JMA: Japan Meteorological Agency)

Observed Seismic Acceleration

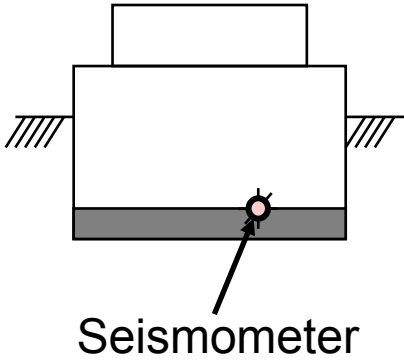


Unit:Gal (cm/s^2), Design Value is in ( )

Unit	Horizontal-NS	Horizontal-EW	Vertical
1	311(274)	680(273)	408(235)
2	304(167)	606(167)	282(235)
3	308(192)	384(193)	311(235)
4	310(193)	492(194)	337(235)
5	277(249)	442(254)	205(235)
6	271(263)	322(263)	488(235)
7	267(263)	356(263)	355(235)

Horizontal static seismic intensity: 3 Ci ＝ 0.48G（470Gal）

Set point to SCRAM
(Automatic Shutdown)
Horizontal : 120 Gal
Vertical : 100 Gal



Plant Status at / after NCO Earthquake

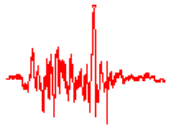
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
At quake	Operation status	Outage	Start-up	Operation	Operation	Outage	Outage	Operation
	Automatic SCRAM	—	Yes	Yes	Yes	—	—	Yes
	Fuels	No fuels	Fuel Bundles Loaded					
	RPV	Open	Closed					
	PCV	Open						
Post-quake	Status	Cold shut down						
	Overflow of spent fuel pool	Yes						
	Radioactive release	No					Minor discharge to sea (Jul. 16)	Minor discharge to air (Jul. 17)
	Fire and major leakage	2000m^3 water into C/B (Jul. 16)	—	Fire of house trans. (Jul. 16)	24m^3 sea water into T/B (Jul. 16)	—	—	—

Essential Nuclear Safety Ensured

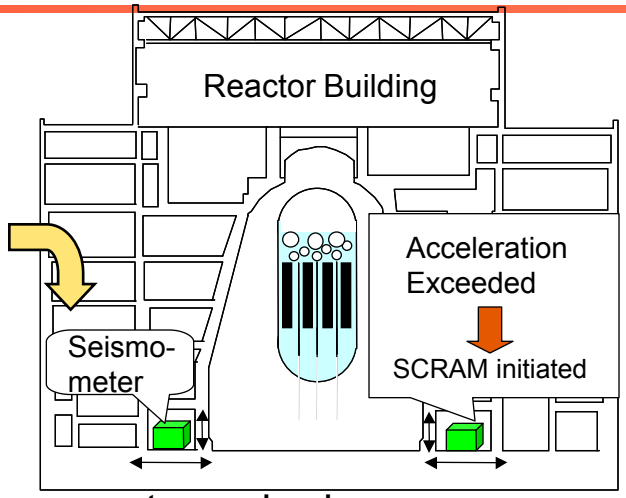
The most important functions for nuclear safety:

- **"Shutdown"**

⇒ SCRAM ⇒ Full insertion of all control rods



Earthquake

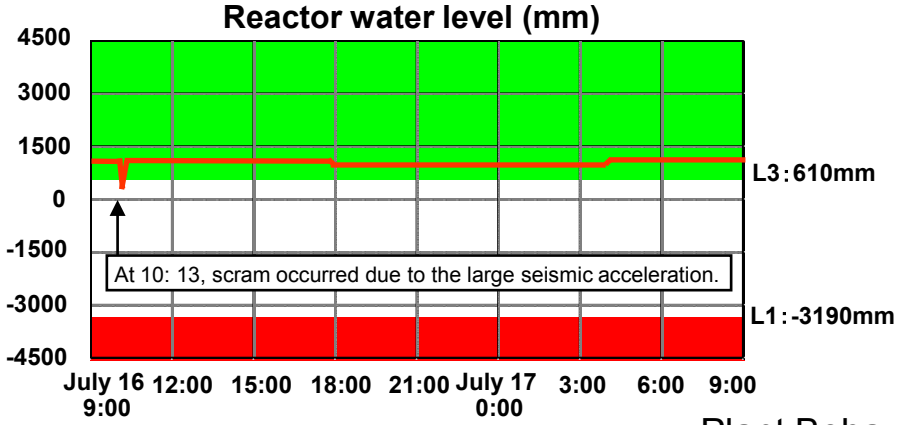


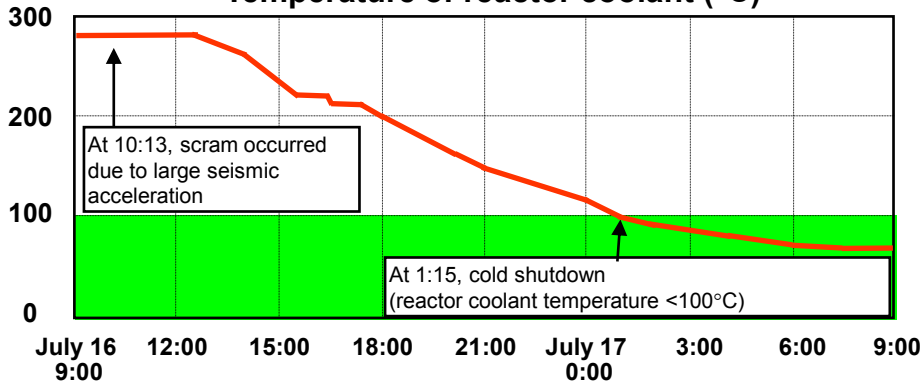
- **"Cooling"**

⇒ Maintain reactor water level

⇒ Reactor coolant temperature: below 100°C, Reactor Pressure: atmospheric pressure

⇒ Cold shutdown





Plant Behavior of Unit 7

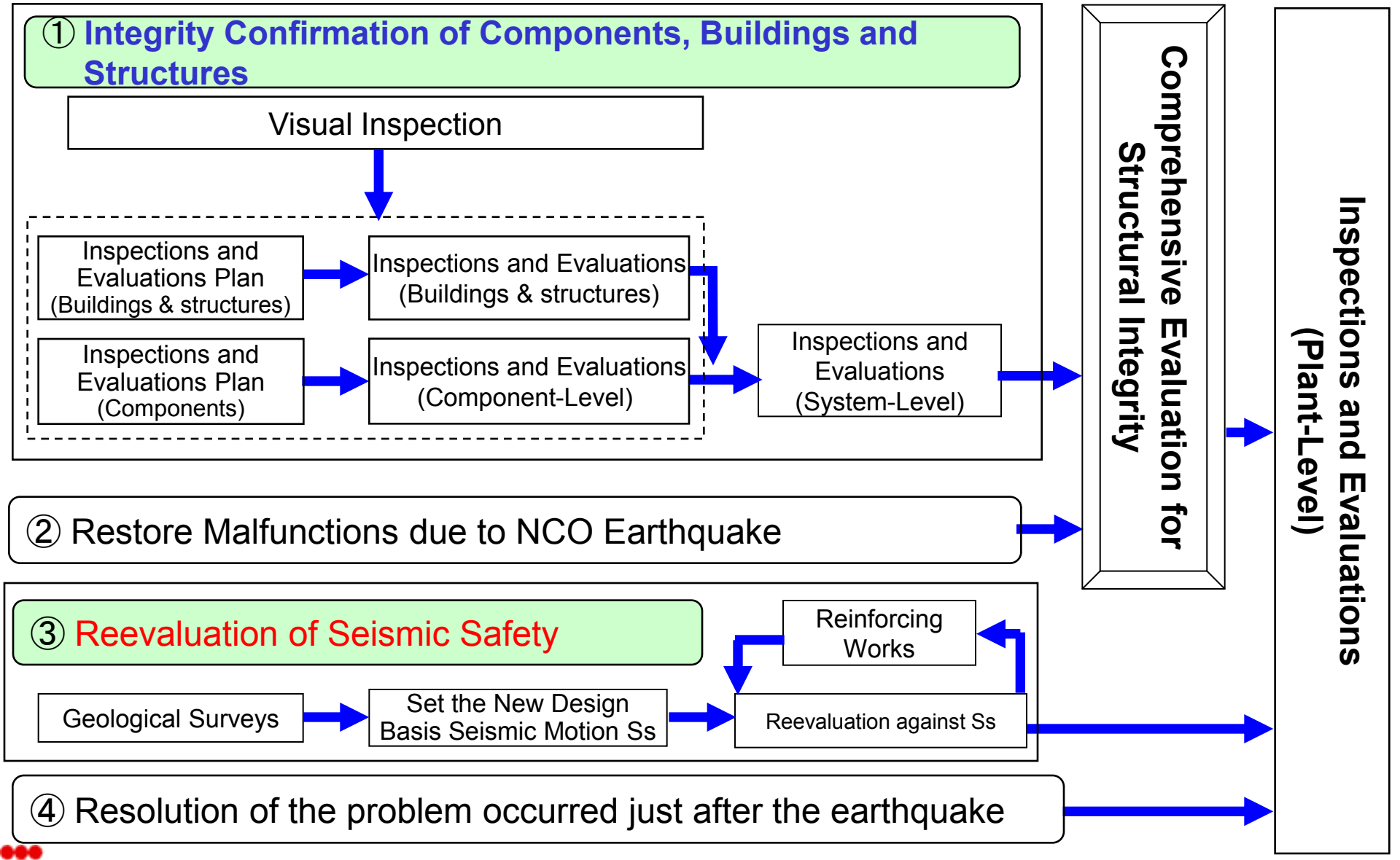
- **"Containment"**

⇒ Fuel Bundles, Cladding Tubes, RPV kept sound ⇒ No environmental impact

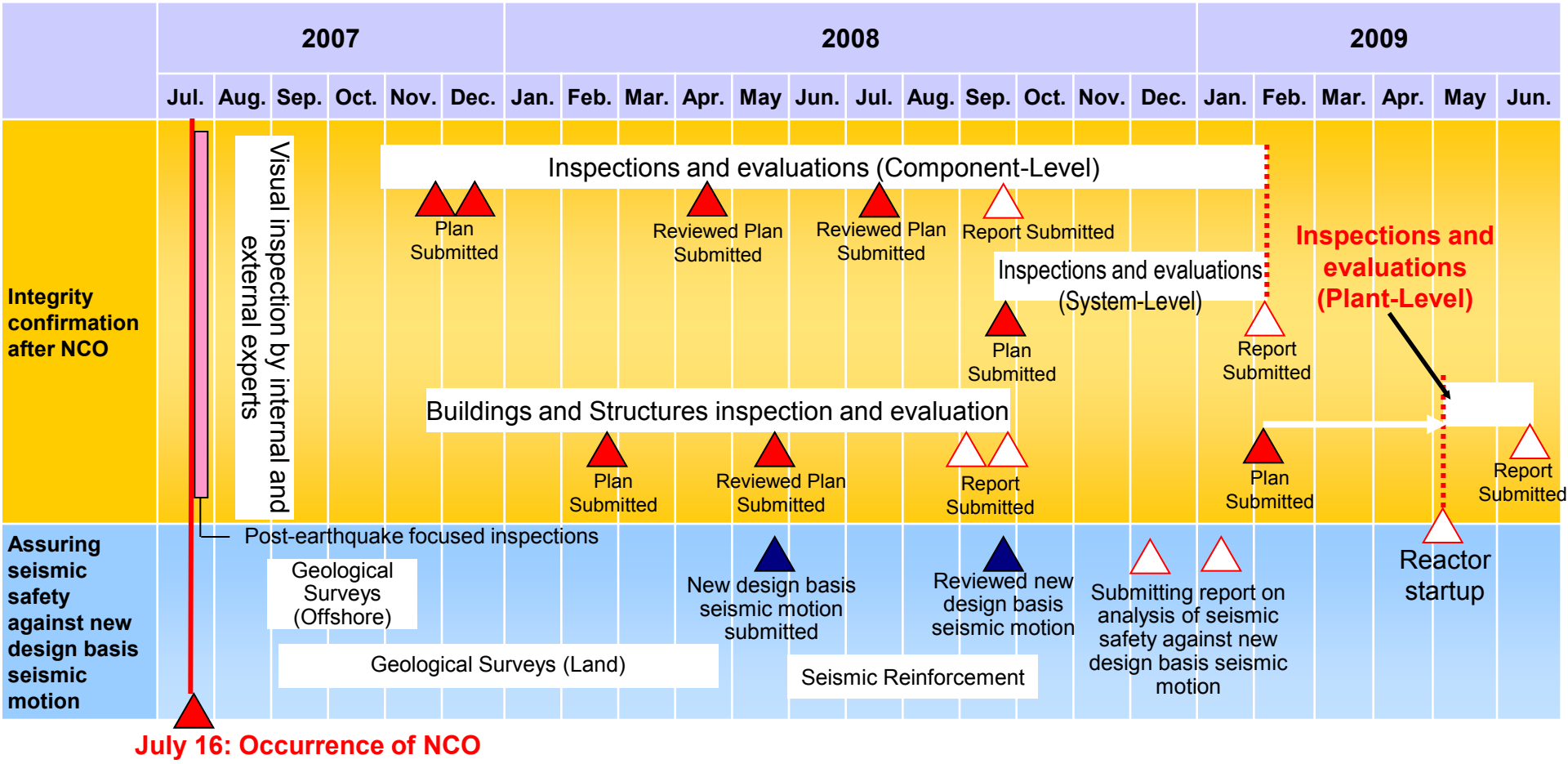
Safety ensured through designed plant behavior and appropriate operators' performance

Post-Earthquake Actions after NCO (Actual Results of Unit 7)

Overview of Post-Earthquake Actions after NCO



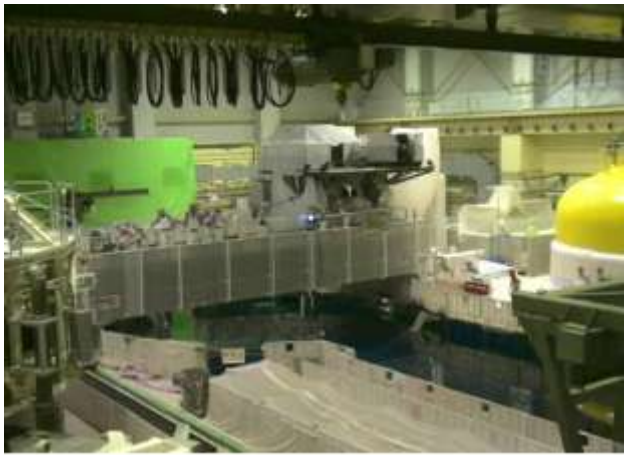
Actual Schedule of Integrity Confirmation (Unit 7)



Visual Inspection by Experts

- Internal and external experts visually inspected the buildings, structures, and components related to “**shutdown**” “**cooling**” and “**containment**.”
- After the Completion of the above, emergency diesel generators and emergency core cooling pumps were confirmed functionally operable

R/B Walkway, Unit 1

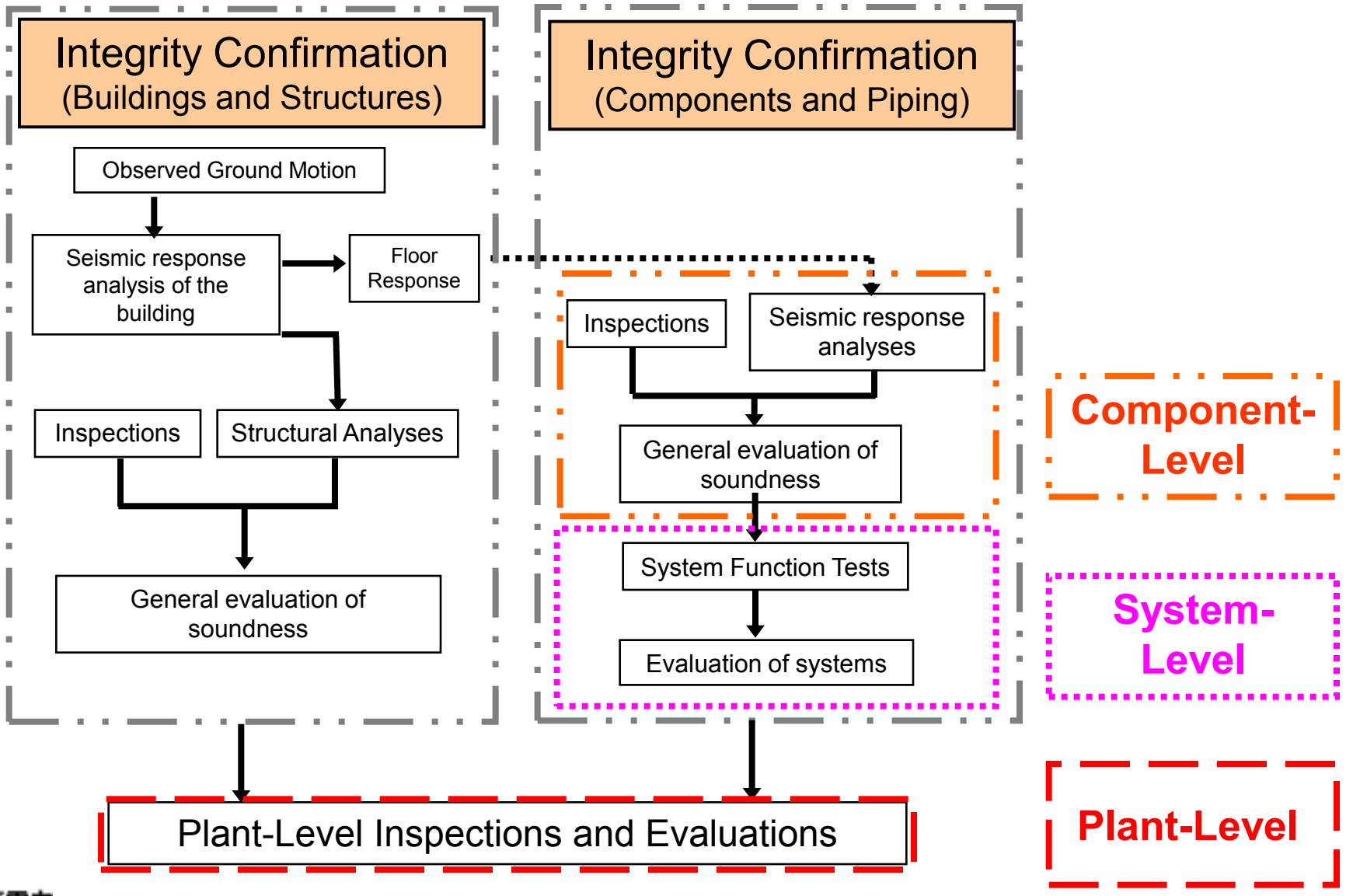


R/B Operating Floor, Unit 1

EDG, Unit 3

No damage that impaired functions was found.

Overall Flow of Integrity Confirmation



Component-Level Inspections and Evaluations

Process of Inspections

1. List intended components and piping systems

- Basically all the components/Piping are to be inspected, and the results of ones important to safety are subject to report to Regulatory Authority.

2. Separate components into categories

- Depending on the sensitivity against seismic motion and the failure modes
- 40 categories for Unit 7

■Dynamic components (Vertical pumps, Fans, etc.)
■Static components (Tanks, Piping, etc)
■Support structures (Piping Support, Foundation, etc.)

3. Select appropriate inspection methods for each category

- Visual Inspection are applied to all the SSCs in principle.
- Inspection methods are chosen so as to detect all the failure modes, considering the working condition / environment.

4. Reflect the inspection methods to the procedures of all the individual components

- Deploy the Inspection methods to the individual SSCs.
- Organize the Inspection Procedures

5. Execute the inspections

6. Evaluate the results

- Judge if each abnormality causes functional impair, and if it is caused by NCO.
- Restore/replace damaged components if necessary

Categorize Components (Example of Unit 7)

Referring to the seismic design technical guideline (JEAG 4601), select components into the following 40 categories depending on the effects due to the earthquake.

Dynamic Components	Static Components	
1) Vertical Pumps	19)Reactor Pressure Vessel	35)Dehumidifiers
2) Horizontal Pumps	20)Reactor Internal Structures	36)Tanks
3) Reciprocating Pumps	21)Pipings	37)Instrumentation Racks
4) Pump-Driving Turbines	22)Fuel Racks	38)Control Panels
5) Electric Motors	23)Heat Exchangers	39)HVAC Duct
6) Fans	24)Condensers, Feed Water Heaters, Moisture Separator/Reheaters	40)Fuel Assemblies
7) Refrigerators	25)Pool Liner	
8) Air compressors	26)Transformers	
9) Valves	27)Batteries	
10)Dampers	28)Breakers	
11)Emergency Diesel Generators	29)Gauges, Relays, Regulators, Detectors, Transducers	
12)Control Rods	30)Primary Containment Vessel	
13)Control Rod Drive Mechanisms	31)Accumulators	
14)Main Turbines	32)Filtration Demineralizers	
15)Generator	33)Strainers / Filters	
16)Internal Pumps	34)Steam Jet Air Ejectors	
17)Fuel Handling Machine		
18)Cranes		

●Buildings and structures such as reactor building etc. are also checked and evaluated to their structural characteristics.

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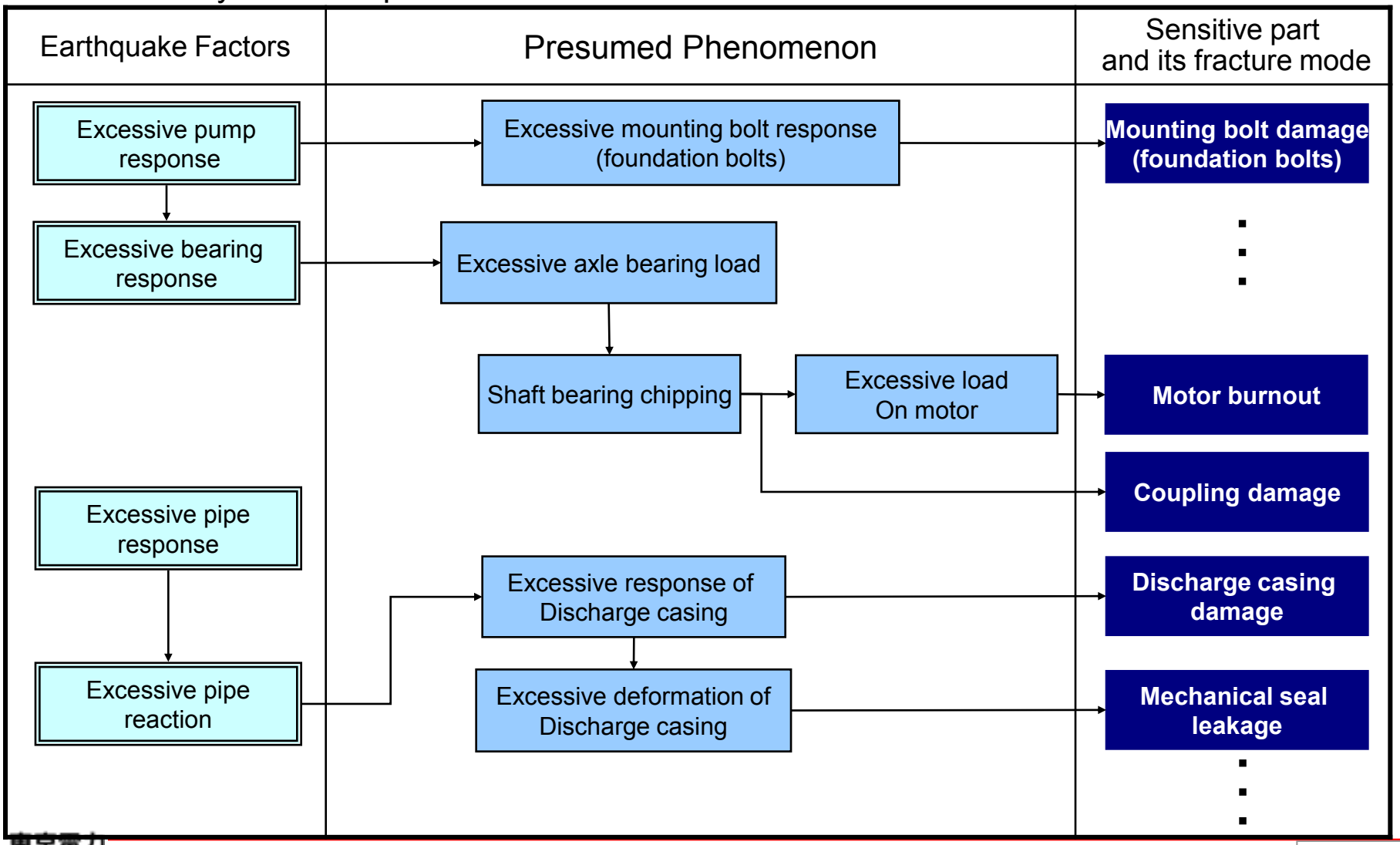
Supposed Fracture Modes of Each Component

Seismically sensitive parts and the fracture mode are listed up referring to the results of tests. The component designers of the vendors also considered the parts and condition to be affected by the earthquake.

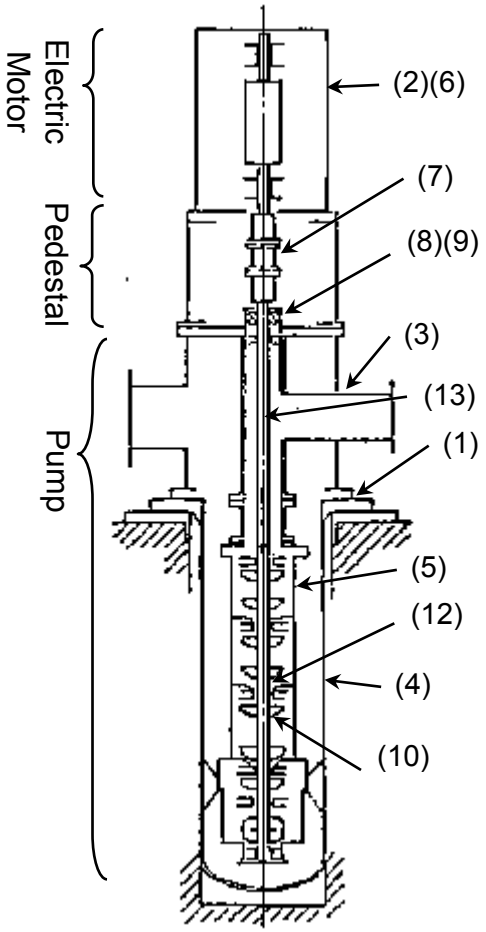


Select Inspection Methods

- Visual inspections and functional tests are performed as the Basic Inspection for vertical pumps, since
  - the pumps are required its functionality,
  - the operational data show the soundness of the pump quantitatively.
- Disassemble Inspection is performed in case any abnormality is found

Sensitive parts and fracture mode	Inspection items		
	Basic Inspection		Additional Inspection
	Visual Inspection	Functional Test	Disassembling Inspection
(1)Mounting bolt damage (foundation bolts)	＊		
(2)Drive function loss		○	
(3)Discharge casing damage	○	○	○
(4)Barrel damage		○	○
(5)Column damage		○	
(6)Electric motor burnout /overload		○	
(7)Coupling damage	○	○	○
(8)Mechanical seal leak		○	
(9)Mechanical seal damage		○	○
(10)Impeller damage		○	○
(11) Bearing Damage		○	○
(12)Liner ring chipping		○	○
(13)Shaft damage		○	○
(14)Coolant water pipe damage	○	○	
(15)Mechanical seal heat exchanger damage	○	○	

＊ Conduct for support structure
○ Detectible



Evaluate the Results of the Inspections

Compare with Pre-Earthquake Data
- Vibration
- Bearing Temperature etc

Compare with Required Specification
- Design Performance

Results of Seismic Response Analyses

Basic Inspections (mainly Visual, Leak And Functional Tests)

Evaluations of Obtained Data
- Equipment performance
- Vibration
- Bearing Temperature etc.

Evaluate the Soundness

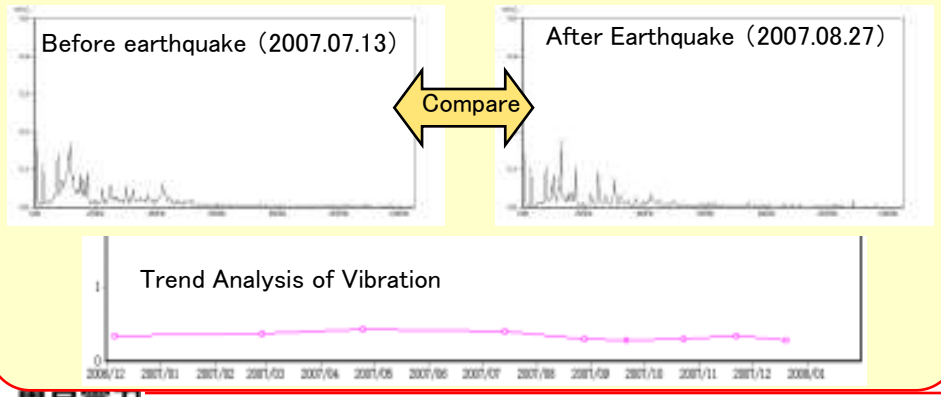
Found Abnormality by basic inspections

Additional Inspections

Pre-Planned Additional Inspections

Results of Additional Inspections
- Visual Inspection of Bearing
- Visual Inspection and PT of Shaft and Impeller
- Visual Inspection of Barrel etc.

Application of Condition-Based Maintenance Technology
(Vibration Diagnosis)



Main flow of inspections and Evaluations

Flow of the Data for Evaluation

Results of Component-Level Confirmation

- Confirmed the soundness of the integrity/functionality of components and piping systems through the completion of all the activities prior to the start-up.

- Seismic Classes A/As: No serious damage found
- Seismic Classes B/C: Functionally damaged in some components

Inspected during post-seismic outage

- Components: ~1,700
- Instruments: ~5,600
- Panels: ~1,300
- Valves: ~12,000
  (Total: approx. 20,600)

- Pipe: ~31,000
  (Total length: 155,000m)
- Supports: ~44,000

x2.3

Inspected during previous outage (usual outage)

- Components: ~ 900
- Instruments: ~4,800
- Panels: ~ 700
- Valves: ~2,600
  (Total: approx. 9,000)

Actual Inspection Works

Suppression Chamber

ECCS Suction Strainer (Underwater)

RHR Valve

R/B Ceiling Crane

Damage of Seismic Classes B/C Equipment

Damage by High Acceleration

- Service Water Tank
  - Side Wall Buckling
  - Anchorage Bolts Break

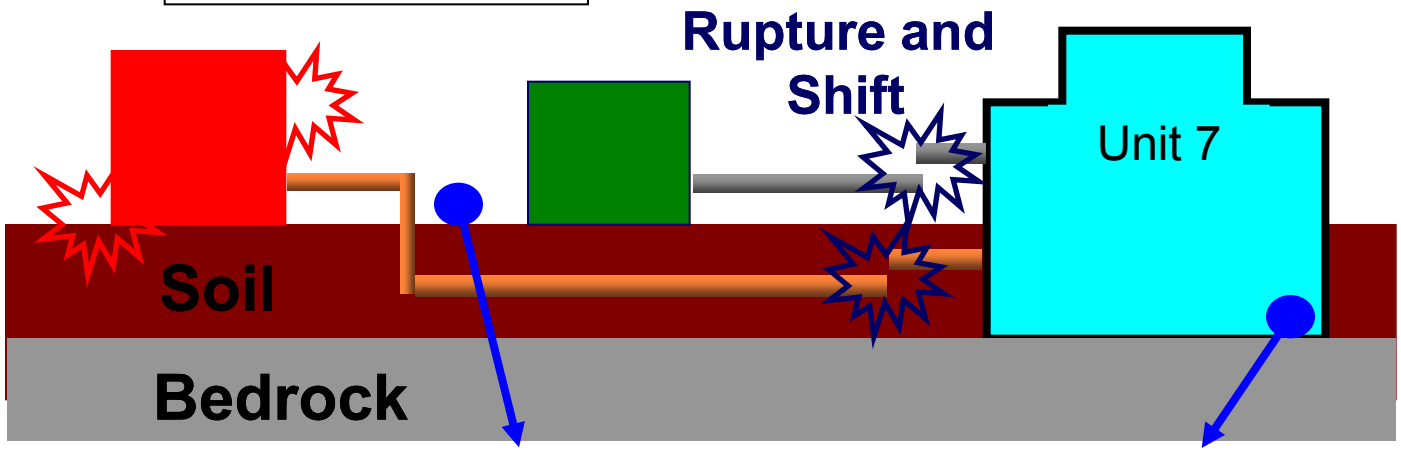
Damage by Subsidence and Displacement

- Transformer Connecting Bus Bar Shift
- Fire Protection Piping Rupture

No or Minor Damage in the Building

Classes As,A

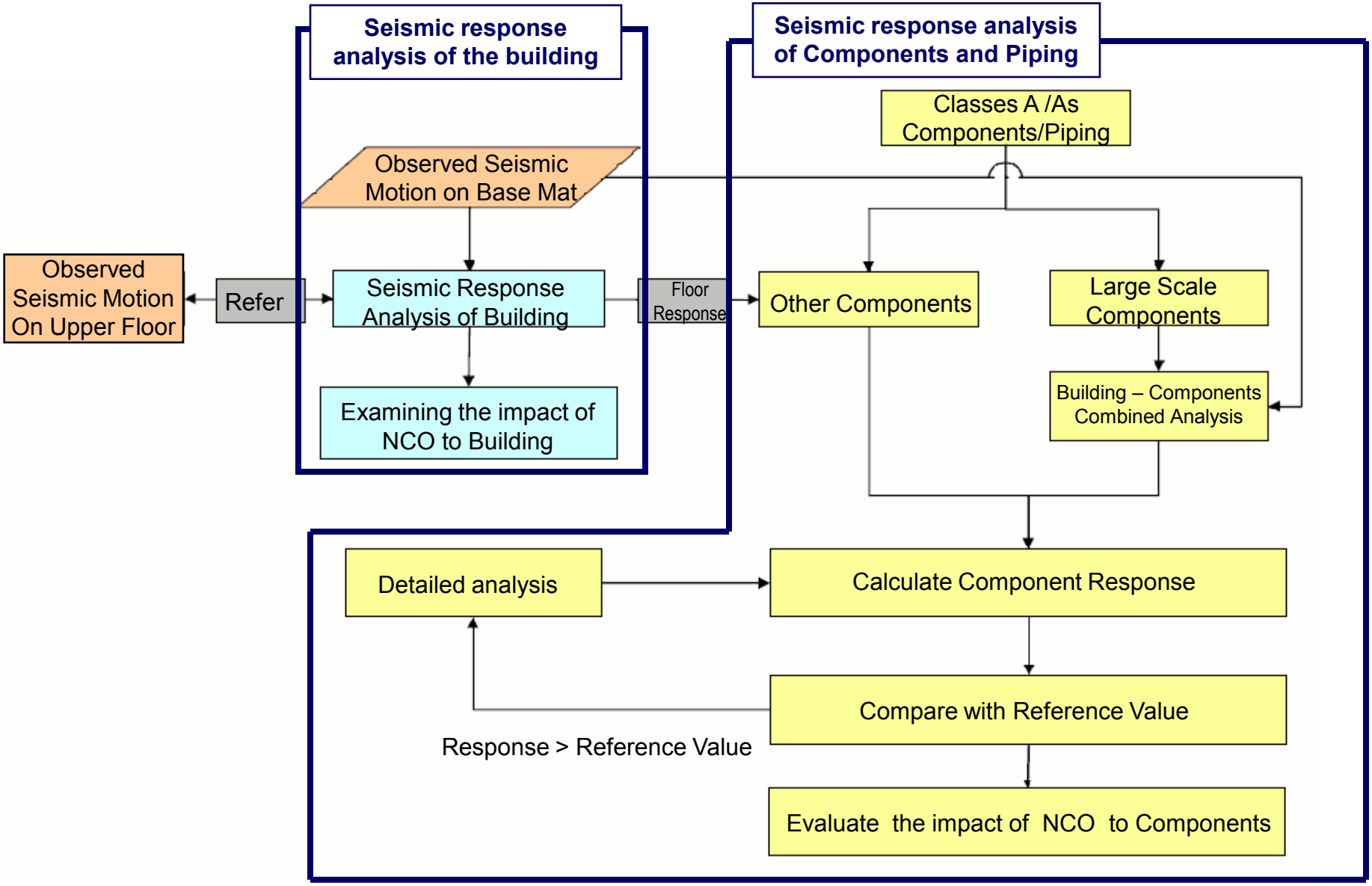
Classes B/C



Ground Surface : Max. 1223 gal

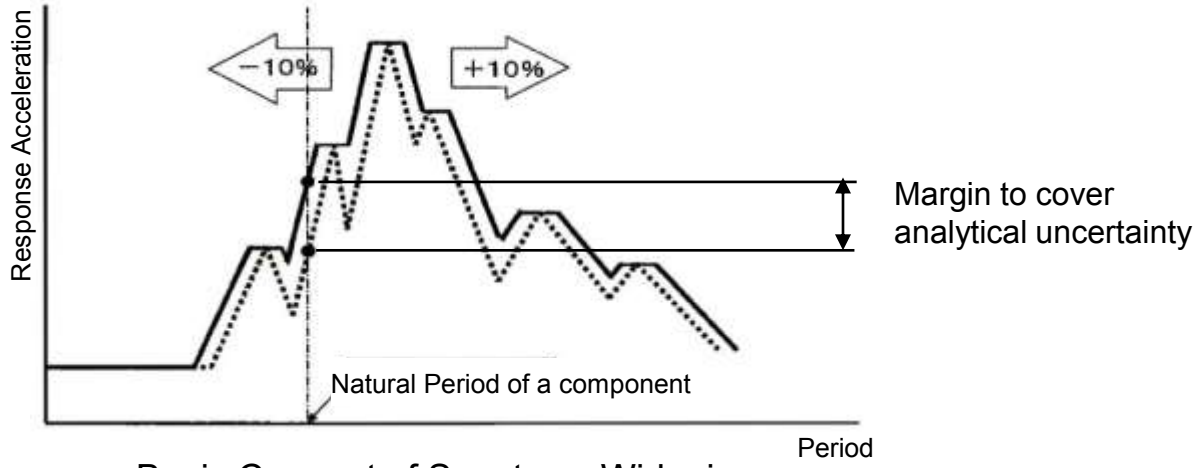
R/B Foundation : Max. 356 gal

Overview of Seismic Response Analyses



Floor Responses Used for the Seismic Response Analyses

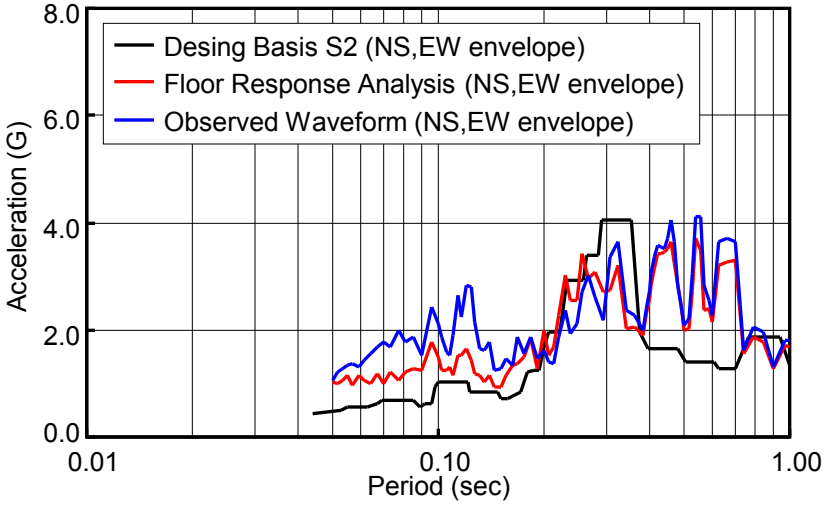
- Floor Response on the Seismic Response Analyses of Components
  - Observed seismic motions are used if the waveforms recorded.
  - Other than the above, the calculated floor responses are used.
- Floor Response Spectra for the design
  - NCO Waveform as recorded or the response acceleration as obtained by the building response analysis
  - No widening of spectra, since the recorded waveforms never contain analytical uncertainties in such as Soil Characteristics, Building Stiffness, Formula/Damping factors of Soil Spring Constants, Phase property of Simulated Ground Motion, etc.



Basic Concept of Spectrum-Widening

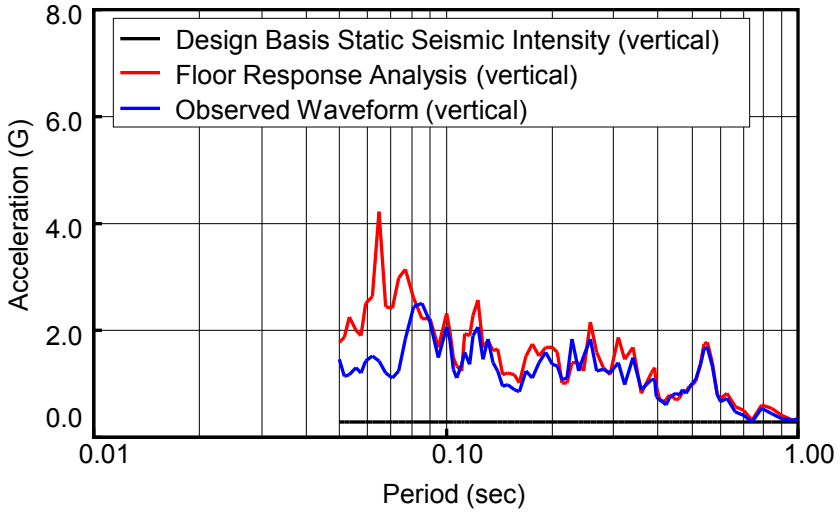
Floor Response Spectra

(Horizontal)

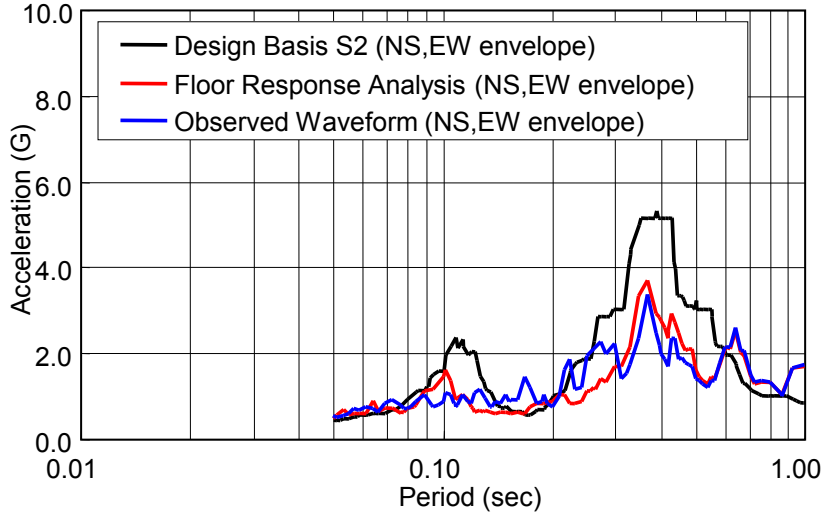


Unit-1 R/B TMSL 12.8m Floor Response Spectrum (Damping: 1.0%)

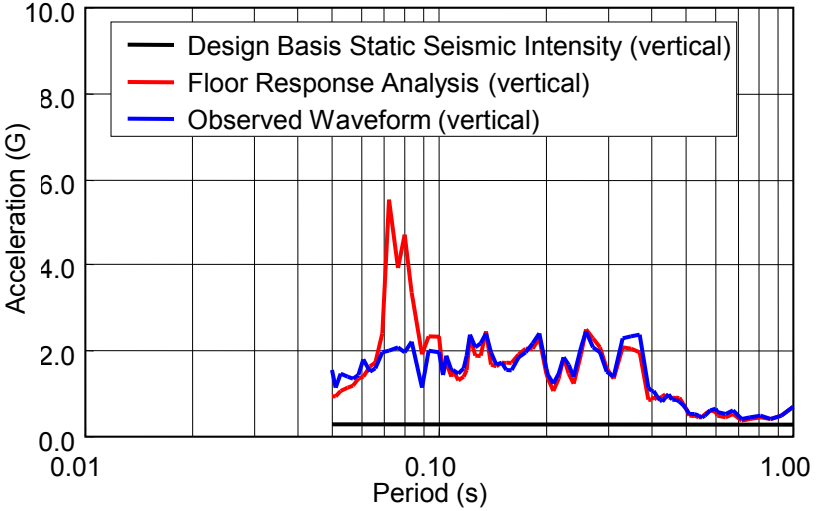
(Vertical)



Unit-1 R/B TMSL 12.8m Response Spectrum (Damping: 1.0%)



Unit-7 R/B TMSL 23.5m Floor Response Spectrum (Damping: 1.0%)



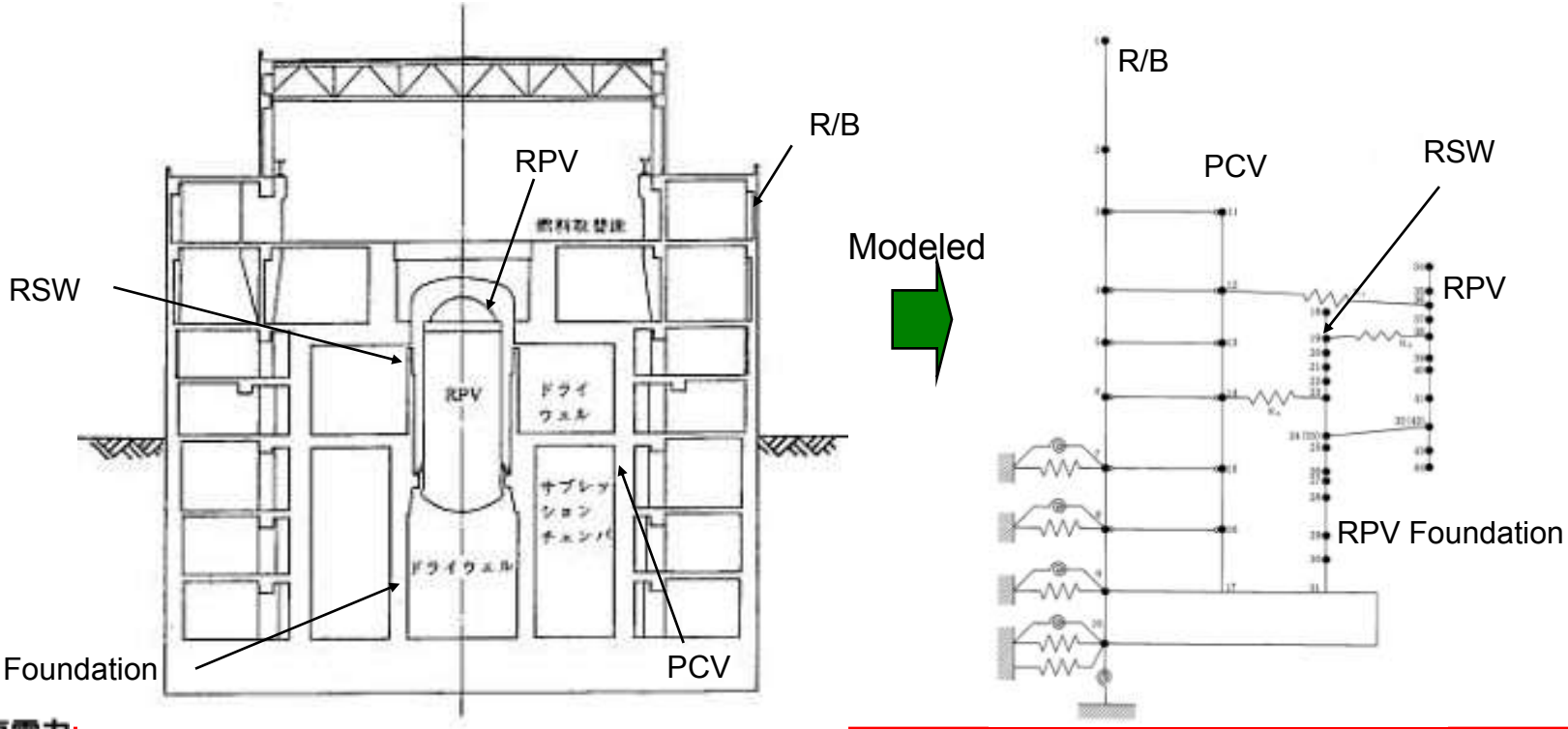
Unit-7 R/B TMSL 23.5m Floor Response Spectrum (Damping: 1.0%)

Seismic Response Analyses for Components and Piping

- Structural Integrity
  - Reference Values: The allowable stress condition III_AS (JEAG 4601), or engineering-based values (design values, values proven through tests, etc.)
  - Supporting Structures (Foundation Bolts, Legs, etc)
  - Parts with relatively small design margins
- Dynamic Functionality
  - Comparison between the response acceleration and the functionality-confirmed acceleration
  - Reference Value
    - ✓JEAG4601 (1991 addendum)
    - ✓Test-proven Value

Analytical Model of Large Scale Components

- Calculate the responses of Large Scale Components (such as RPV, PCV, etc.) using Building-Component Combined Model
  - Based on the Models of the Construction Permit Applications
    - ✓ Real strength applied for Young Modulus of concrete instead of Specified Concrete Strength
    - ✓ Allow Auxiliary Walls into Building Stiffness in addition to Shear Walls
  - PCV- RPV Analytical Model
    - ✓ Modeling the Reactor Shield Wall (RSW), RPV Foundation, RPV



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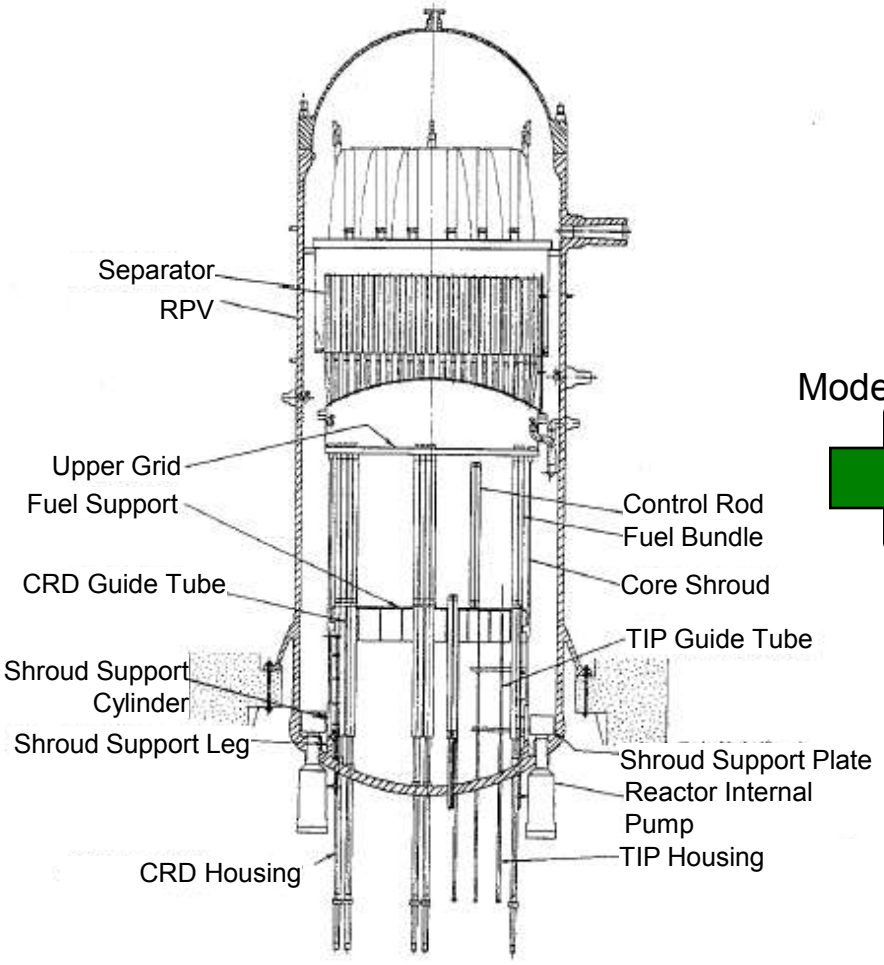
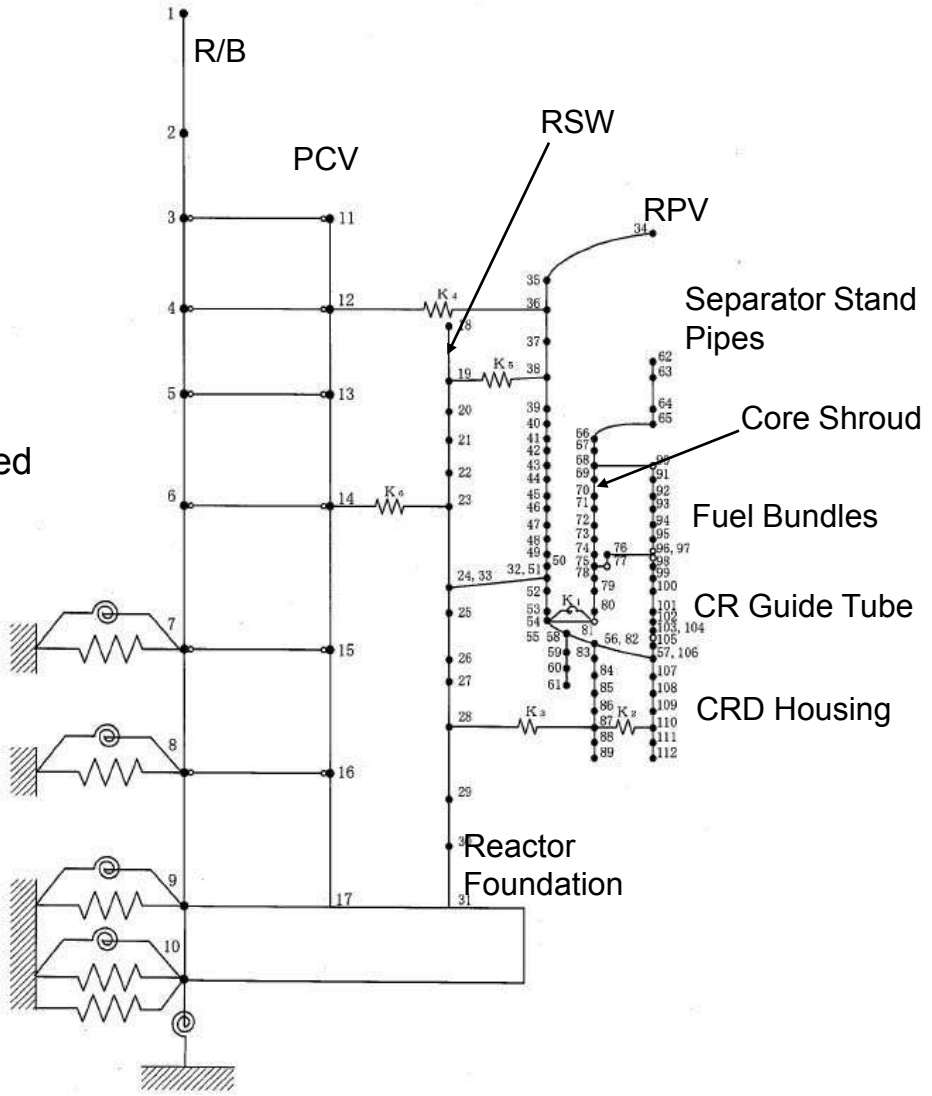
Analytical Model of Large Scale Components

Reactor Internal (RIN)

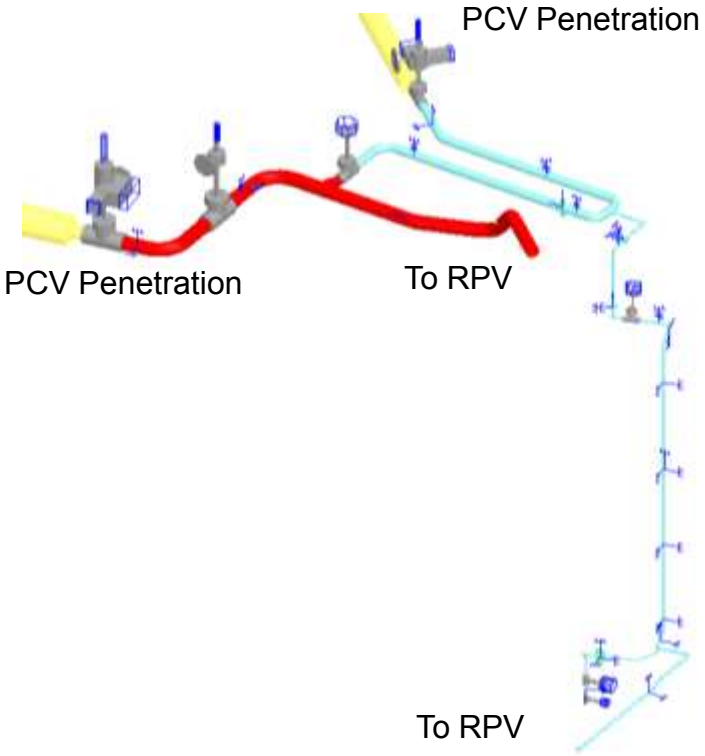


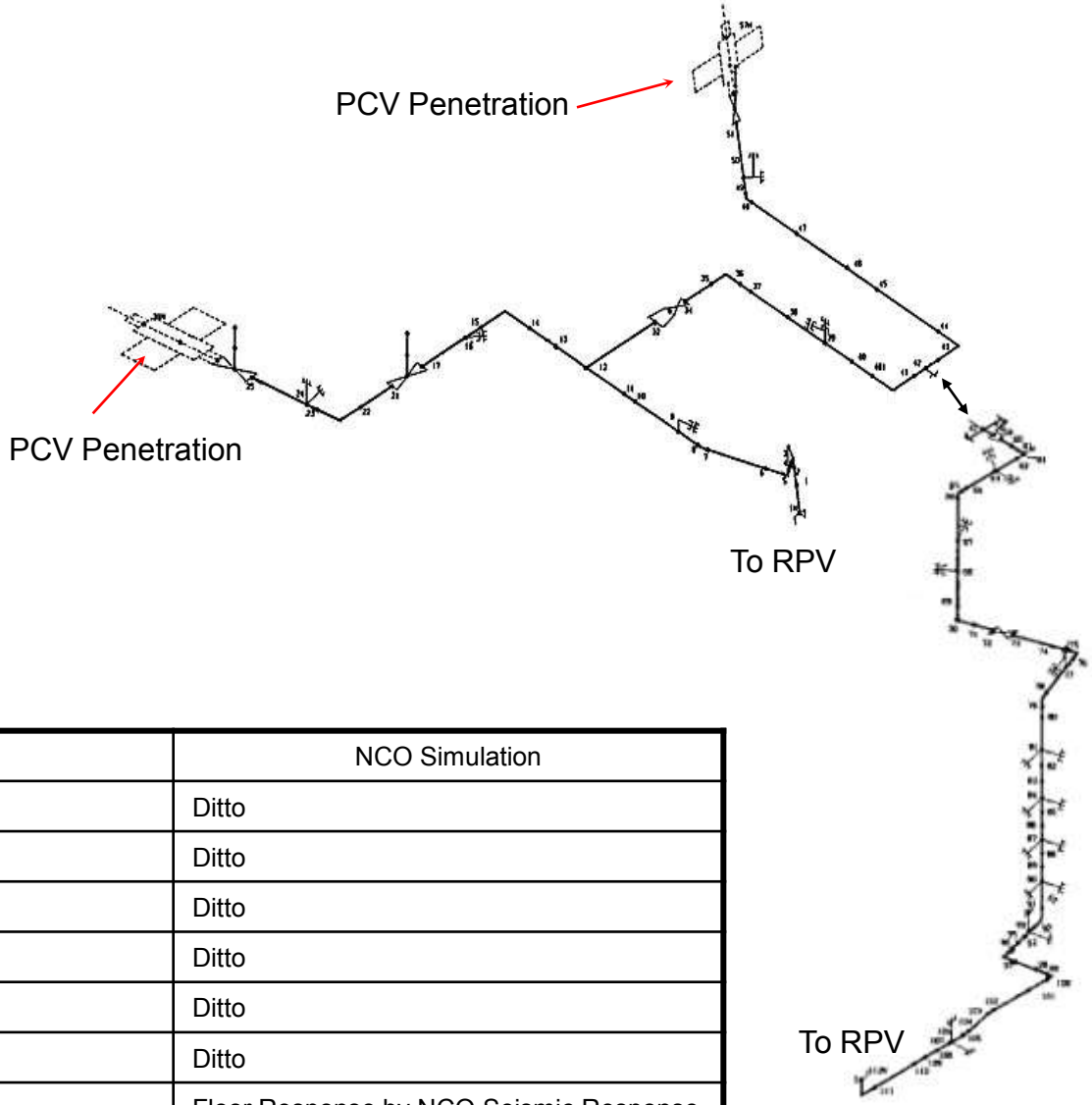
Modeled



RIN Horizontal Analytical Model (NS)

Analysis of Piping (RHR of Unit 7)

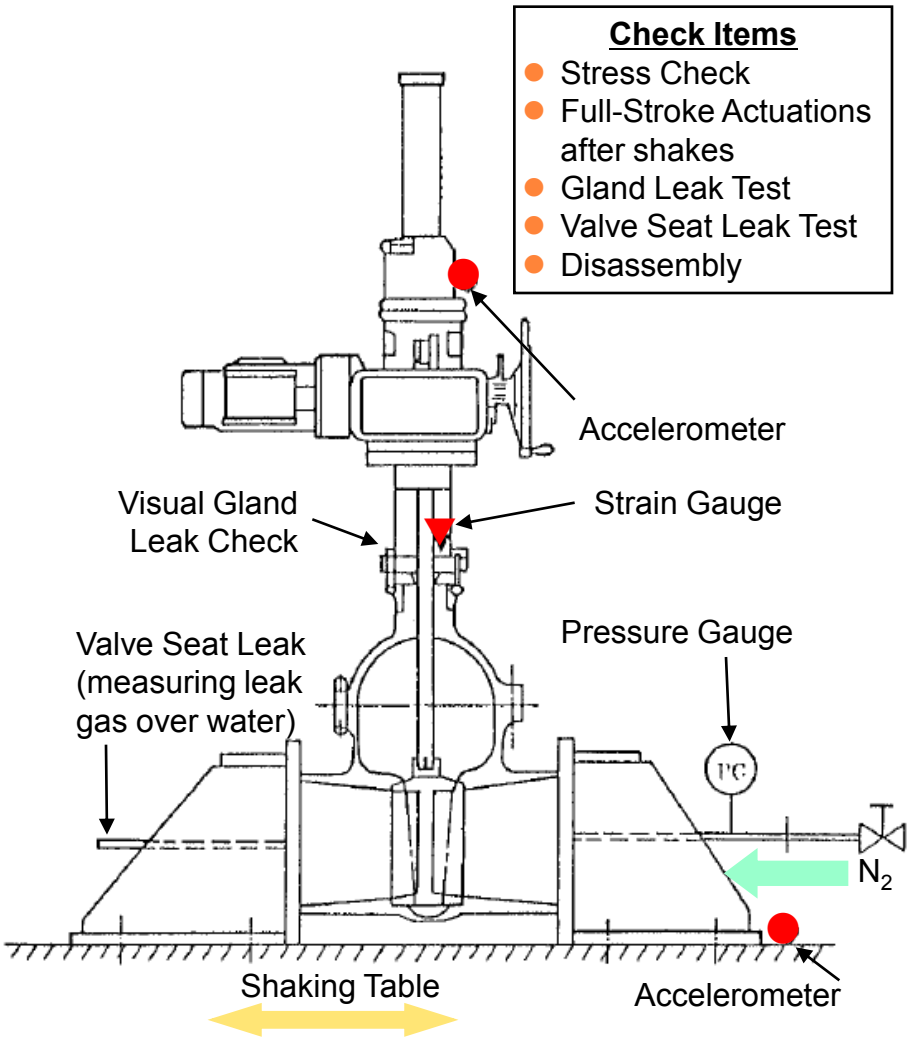




	Design	NCO Simulation
Pressure	87.90 kg/cm^2	Ditto
Temperature	302 Degree Celsius	Ditto
Outer Diameter	216.30 mm	Ditto
Thickness	15.10 mm	Ditto
Material	STS410 (STS42)	Ditto
Damping Coeff.	2.0%	Ditto
Inputs	Static and Dynamic Design Basis Motion	Floor Response by NCO Seismic Response Analysis

Dynamic Functionality Confirmation

- Screen intended dynamic components by comparing the Response Acceleration with the Reference Value based on the accumulated findings such as ones through shaking tests.
- If the Response is equal to or below the Reference, the Dynamic Functionality is judged confirmed
- In case the Response exceeded the Reference, detailed analysis is executed
- Even if the Response exceeded the Reference, it does not immediately mean safety problems



Overview of Test Facility for Motor-Operated Gate Valves

Results of Seismic Response Analyses

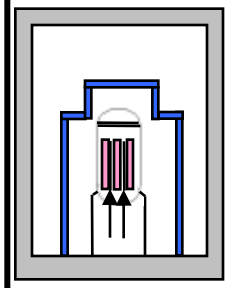
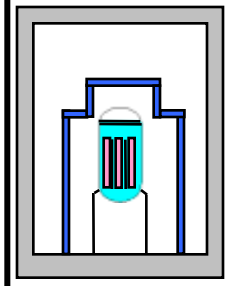
- Safety-Related Components and Piping are subject to the Seismic Response Analyses, which include Structural Integrity Evaluation and Dynamic Functionality Evaluation.

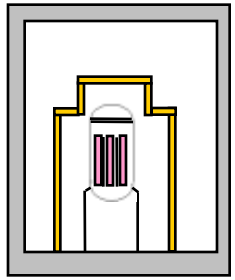
- The calculated values against NCO are below the corresponding Reference Values with a few exceptions.
  - Most of the Components and Piping were confirmed sound immediately by the results.
  - The Calculated values of some components exceeded the Reference Values
    - Those components were additionally inspected in detail and no abnormality was found, same as the results of the basic inspections
    - The results of more realistic analyses are within the Reference Values.
  - The those results show:
    - Those components are sound
    - The results of the Seismic Response Analyses contains safety margins, especially in the methodology, the damping factors, the stress coefficient, reference values, etc.

System-Level Inspections and Evaluations

Conducted System Function Tests (ex. Unit 7)

- The results of 23 System Functional Tests shows that all the tested systems are sound and comply with the Regulatory Requirements and our Tech. Spec.
- The Functional Tests vary depending on the plant design.

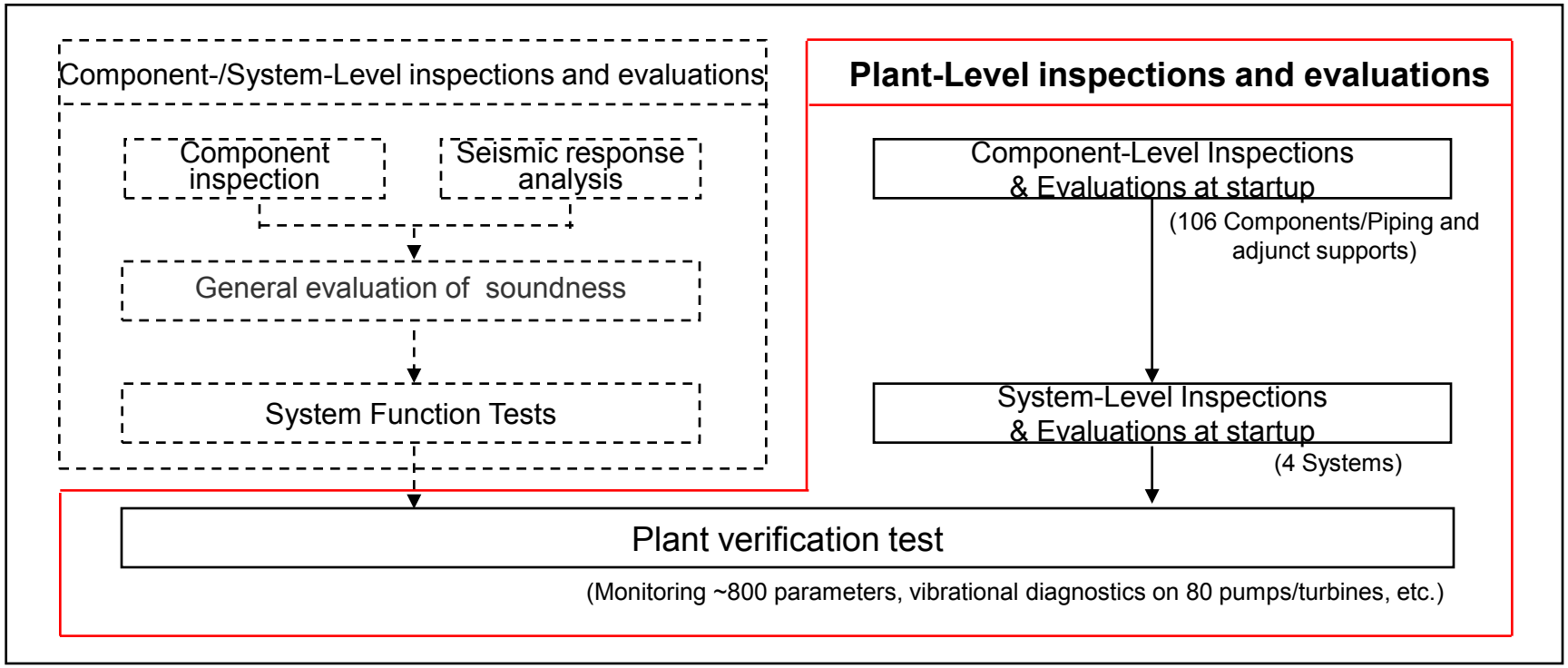
Function	System function tests
Shutdown 	Reactor Shutdown Margin Test
	Control Rod Drive System Function Test
	Control Rod Drive Mechanisms Function Test
	Selected Control Rod Run-In Function Test
	Standby Liquid Control System Function Test
	Reactor Protection System Interlock Function Test
Cooling 	Turbine Bypass Valves Function Test
	Feed Water Pumps Function Test
	Emergency Diesel Generators Rated Capacity Confirmation Test
	Automatic Depressurization System Function Test
	Emergency Diesel Generator, High-Pressure Core Flooder , Low-Pressure Core Flooder and R/B Cooling Water System Function Test

Function	System function tests
Containment 	Main Steam Isolation Valves Function Test
	Primary Containment Vessel Isolation Valves Function Test
	PCV Spray System Function Test
	Stand-by Gas Treatment System Function Test
	Reactor Building Leakage Test
	PCV Integrated Leak Rate Test
	Flammability Control System Function Test
Other	R/B Ceiling Crane Function Test
	Main Control Room Emergency Circulation Function Test
	Liquid Waste Storage/Treatment Facilities Interlock Function Test
	Instrument Air System Function Test
	Direct-Current Power Supply System Function Test

Plant-Level Inspections and Evaluations

Plant-Level Inspections and Evaluations

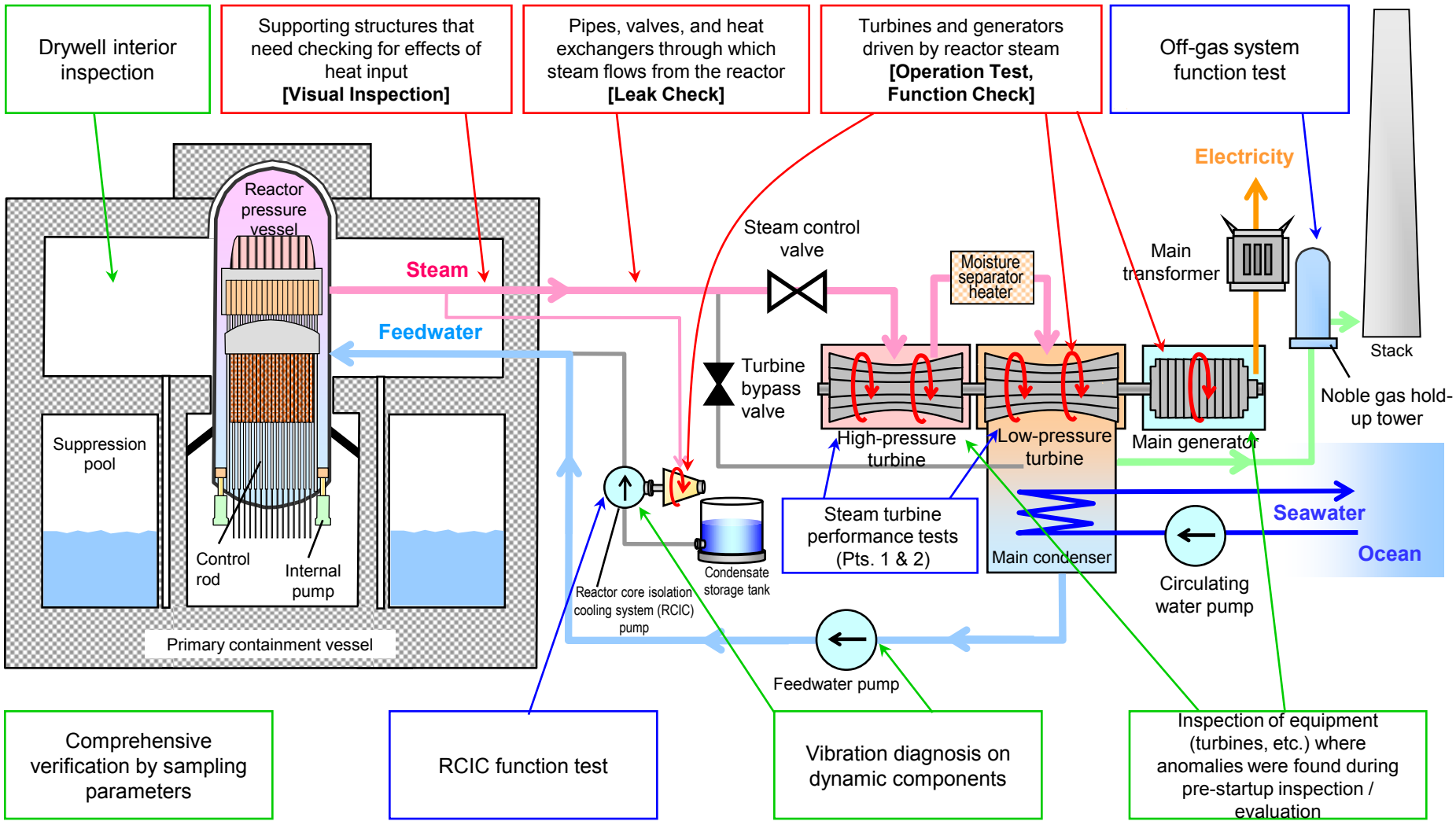
- The **Plant-Level Inspections and Evaluations** are performed to examine the seismic influences on Components and Piping, and to confirm that continued operation is possible.



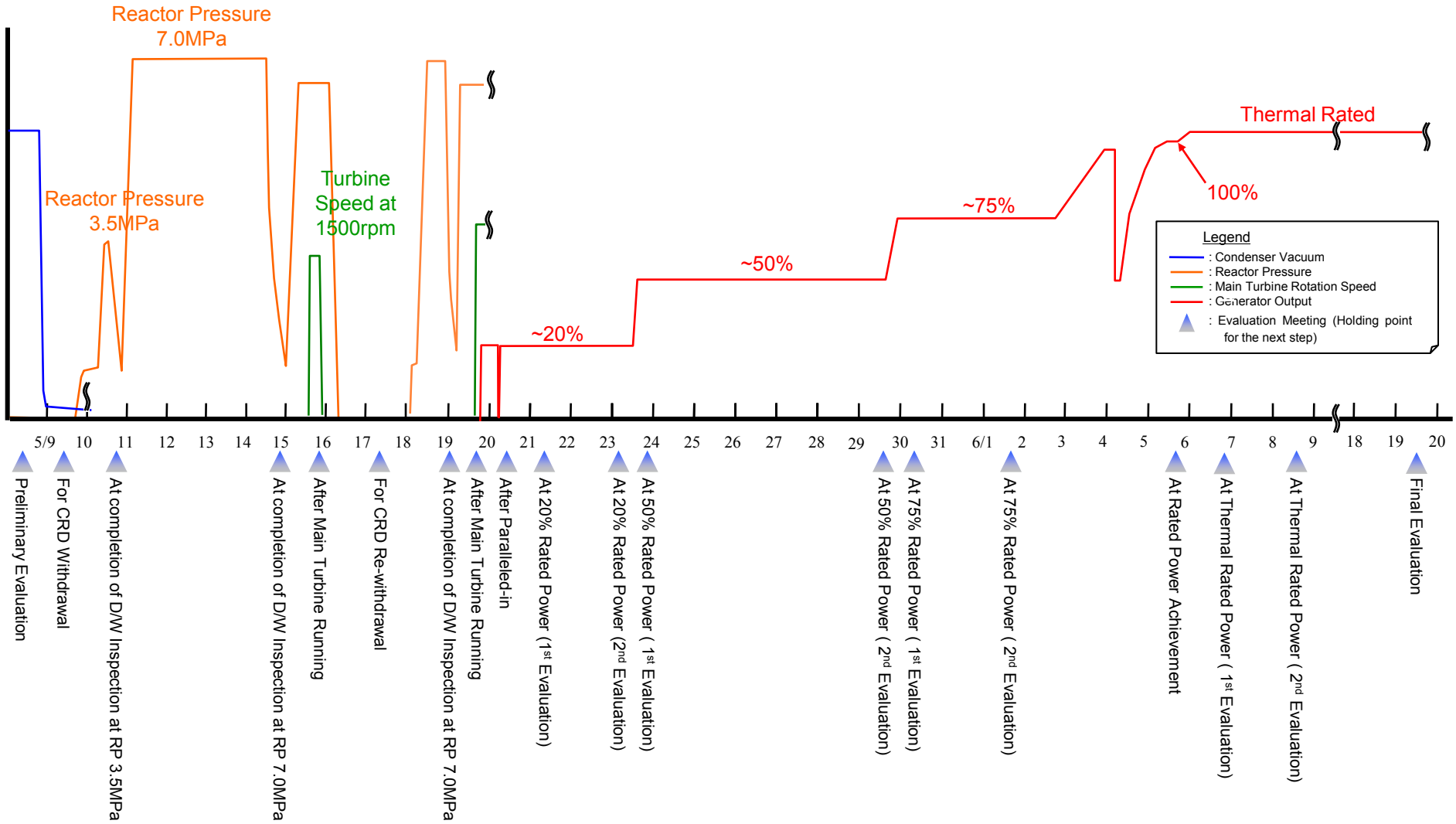
Plant-Level Inspections and Evaluations (cont'd)

- Component-Level Inspections at Start-up (106 components)
  - Integrity confirmation through the actuation and leak tests that need the plant operation
- System-Level Inspections at Start-up (4 Systems)
  - System function tests that need the plant operation
- Plant Verification Test
  - Verify the plant integrated performance through monitoring the plant operational parameters and components' status

Overview of Plant Level Inspections and Evaluations

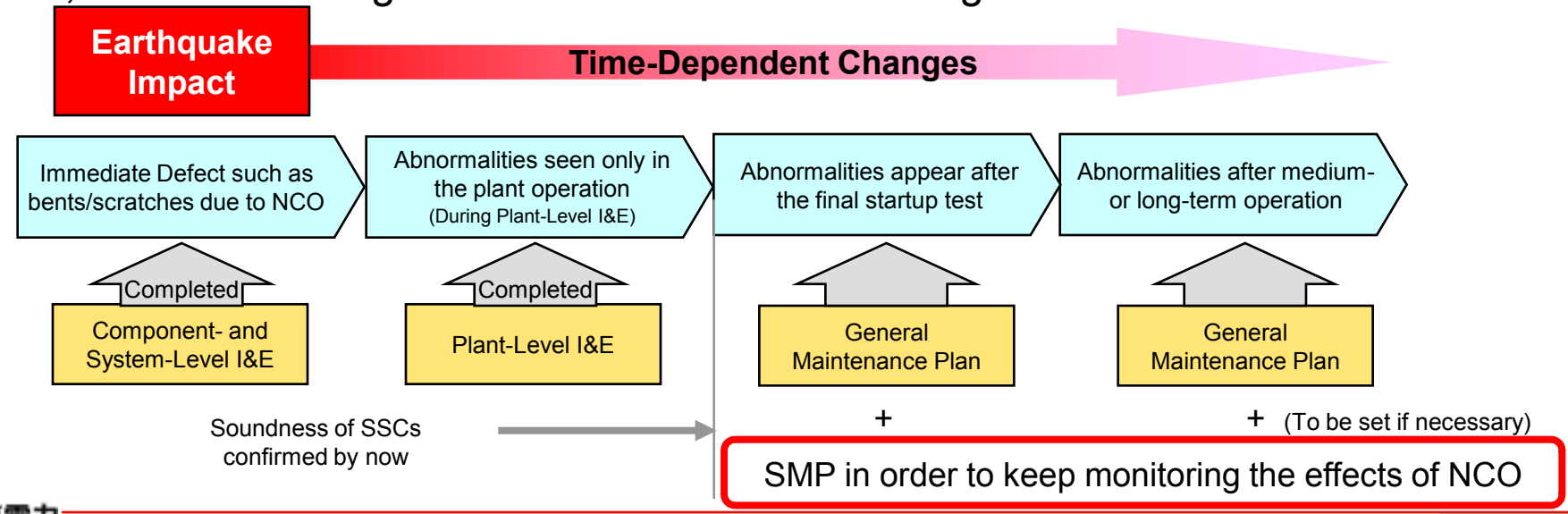


Plant-Level Inspections & Evaluations (Unit 7)



Maintenance Plan during Commercial Operation

- After the completion of Plant-Level I&E, compile an additional maintenance plan as “Special Maintenance Plan” (SMP) to keep monitoring the effects of NCO
- The plan shall be compiled to monitor the effect of time-dependent changes to confirmed abnormalities.
  - During Operation after the completion of Plant-Level I&E.
  - During the next outage
  - After the completion of the next outage (if necessary)
- Components those conditions are not the same as they were before NCO are especially cared.
- While the routinized items in the SMP are being reflected to General Maintenance Plan, medium- to long-term evaluation are also being considered.



Maintenance Plan during Commercial Operation (Unit 7)

Operation after the completion of Plant-Level I&E

- Data Collection and following trend checks for Important Plant Parameters are executed as a part of plant condition monitoring.
- Although no abnormality was found in all the parameters, the parameters not within the past data which the effects of NCO reach are continuously monitored and collected periodically.

The next outage

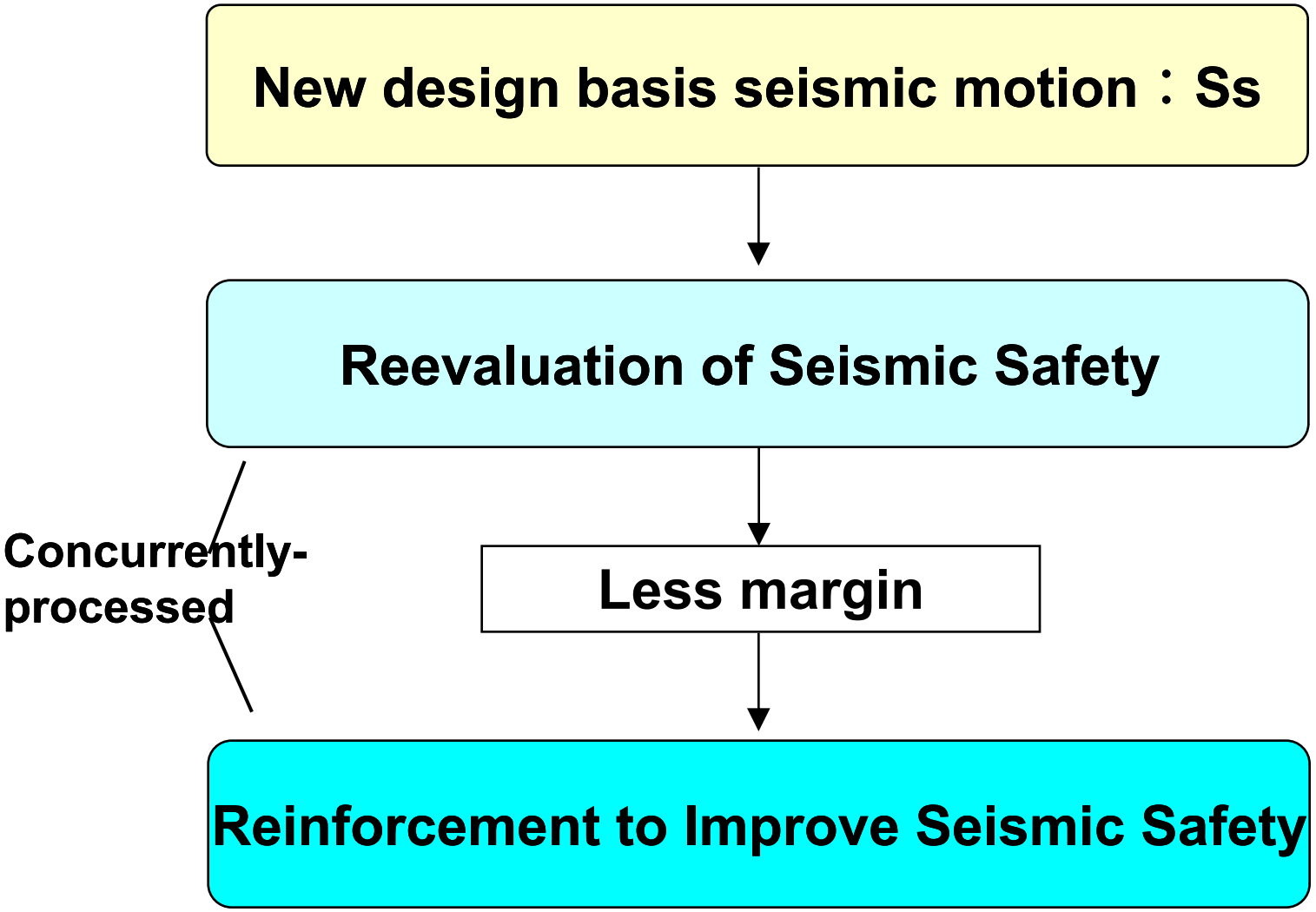
- As the results of Component-Level I&E, SSCs restituted without restoration (such as repair, replacement and reinforce) of damage are to be inspected and evaluated if any kind of effects are seen
- Although there is no influence of fatigue to the soundness of relatively fatigue-sensitive piping, the combination effect of NCO and the operation is evaluated through

After the completion of the next outage

- Conduct further monitoring/inspections depending on the results of the above
- In case any abnormality observed, evaluate if it is caused by NCO.
- For the continuous monitoring, the evaluation may be done as a part of Periodic Safety Reviews and/or Aging Management Assessment Reports

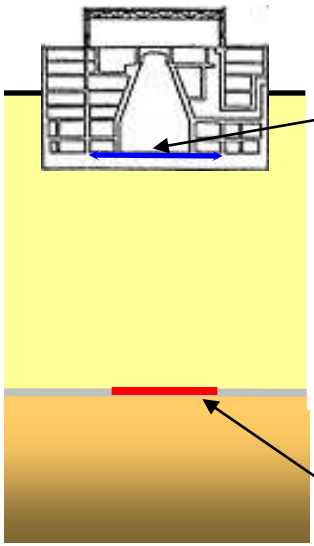
Reevaluation of Seismic Safety against New Design Basis Seismic Motion Ss and Seismic Reinforcement

Assuring Seismic Safety and Seismic Reinforcement



Seismic Ground Motion

1,000 gal Seismic Motion was set for the Seismic Reinforcement (NCO observed wave at Unit 1 R/B Foundation×1.5).



Unit: gal

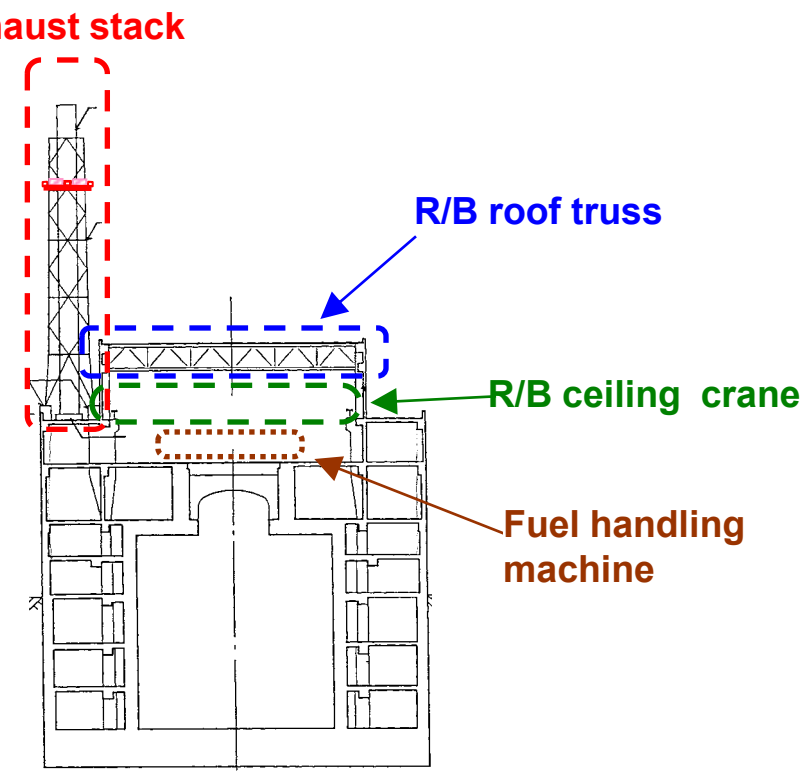
Horizontal ZPA on Reactor building Foundation	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
The NCO Earthquake (observed values)	680	606	384	492	442	322	356
Maximum Response by new Design-Basis Seismic Motions Ss-1~5*	873 (Ss-1)	809	761	704	601 (Ss-2)	728 (Ss-2)	740 (Ss-2)
Seismic motion for Reinforcement	**1,000**						

* : The values for Unit 2 through 4 are tentative.

On the Free surface of base stratum	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Maximum new Design-Basis Seismic Ground Motion Ss	2,300				1,209		

Seismic Reinforcement Work (Example: Unit 7)

- Most of the Seismic Class S (Classes A/As in the Previous Guidelines) Components and Piping Systems meet the reference value without reinforcement works.
- Reinforcement works were performed on:
  - Piping Systems
    Additional Supports
  - Reactor Building Roof Truss
    Additional Braces and Beams
  - Exhaust Stack
    Vibration Control Damper Installed
  - Reactor Building Ceiling Crane
    Improved Derailment Prevention Fitting
  - Fuel handling Machine
    Improved Derailment Prevention Fitting



Unit 7 Reactor Building Cross Section

Seismic Reinforcement Work (Piping Supports)

Supports were added / reinforced to piping systems and other components (including conduits, cable trays, and air-conditioning ducts)

Unit 7 support reinforcement work: **approx. 3,100 locations**

- Piping and air-conditioning ducts (Class S)
  Snubbers / restraints added: **approx. 1,520 locations**
  Snubbers / restraints reinforced: **approx. 700 locations**
- Conduits and cable trays (Class S)
  U-bolts / members added: **approx. 680 locations**
- Other (*): **approx. 200 locations**

* Pipes (non-Class S) and instrumentation pipes

Snubbers were added to reduce piping vibration

Supports were reinforced and modified into secure structures

Conclusion

Conclusion

- Component-, System- and Plant-Level Inspections and Evaluations have basically been executed in series in each unit.
  - As of today, No significant damage was found on Seismic Classes A/As components
- Seismic Reinforcement has been done depending on the results of Safety Re-evaluation against new Design Seismic Motion Ss
- Units 1/6/7 have already been back in commercial operation and Plant-Level Inspections and Evaluations of Unit 5 is currently underway.
- Integrity Confirmation by the Inspections & Analyses is being continued at Units 2 through 4.
- TEPCO is going to keep sharing the information with the nuclear industry worldwide through our English website at http://www.tepco.co.jp/en/index-e.html, and to make any effort to obtain the better understanding of local residents.