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ATR「Fugen」Data Base
Design/R&D/ Plant Performance
[Nuclear]

March, 1997

PESCO Co., Ltd.

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ATR「Fugen」Data Base
Design/R&D/Plant Performance
[Nuclear]

Hiroshi Takeda*
Sadamu Sawai*
Hitoshi Ishigami*

Abstract

1 Reflecton of R&D Results, Design and Operation Experiences

All knowledge obtained in the project, such as R&D results, design, operation experiences and so on, are to be reflected to following items.

① Improvement of safety and reliability in plant operation
② Design modification of the plant
③ Design of the next plant

2 Basic Standpoint for Data Base Composition

"Design/R&D/Plant Performance Data Base" will be composed as shown in the following, so that the Data Base could be utilized for reflecting them to the above items and for improving the above items, effectively and efficiently.

(1) United Data Bases of Design and R&D

"Design/R&D/Plant Performance Data Base" will be composed by uniting design data base and R&D data base, considering that the R&D of the project is mainly made in order to establish the design engineering and technical basis, such as design policy, design criteria, design conditions, alloable design limits, design verification, etc.

(2) Addition of Initial Plant Performance Data

Design is made with safety factors, however, plants performwith its own characteristics, namely without safety factors.

Therefore, plant performance data, especially initial plant performance data, are to be added in "Design/R&D/Plant Performance Data Base", so as to make following engineering works, effectively, and efficiently.

Work performed by PESCO Co., Ltd. under contract with Power Reactor and Nuclear Fuel Development Corporation
PNC Liaison : Senior Engineer of ATR R&D Group, Reacter Development Project, Kazuteru Naruo
＊ : PESCO Co., Ltd.

① Setting-up of appropriate safety factors, by comparing and evaluating the design and actual plant performance

② Ageing evaluation of components and equipment, coupled with annual inspection data

③ Clarification of reactor characteristics change according to fuel burnup and fuel composition change

④ Upgrading technologies and design, based on the actual plant performance data

3 Compositon of "Design/R&D/Plant Performance Data Base"

Based on the above consideration, "Design/R&D/Plant Performance Data Base" is composed of following items.

①	Design Basic Items	(Table-1)
②	Engineering data on design (Design technology basis)	(Table-2)
③	Plant Performance	(Table-3)

Contents

Table 1
ATR 「Fugen」 Data Base
Design/R&D/Plant Performance
[Nuclear]
Design Basic Items

Item	Design Policy, Design Condition, Design, etc	(T) (R) etc.
1. Design policy / basis / guideline	1. Design policy / basis / guideline	
(1) Reactivities	(1) Reactivities	
(i) Power coefficient	(i) Power coefficient Always negative	
(ii) Coolant system void reactivity	(ii) Coolant system void reactivity worth/layout 0 or negative	
(2) Power distribution	(2) Power distribution Refueling and control rod programs shall be set to obtain power distribution with satisfying following heat removal limit.	
(i) Max. linear heat generation rate	(i) Max. linear heat rate: 17.5 kW/ft	
(ii) Min. critical heat flux ratio	(ii) Min. critical heat flux ratio ≦ 1.9 (Corresponding to "Minimum critical heat flux ratio ≦ 1.5" at design power (120% of rated power))	
(3) Reactor shutdown margin	(3) Reactor shutdown margin (i) 0.02 or more (ii) Shutdown margin shall be assured by control rod in equilibrium core. (iii) Shutdown margin shall be assured by control rod and liquid poison during transition period	

	from initial core to equilibrium core.	
(4) Control rod	(4) Control rod reactivity worth/layout Reactivity worth and layout of control rod shall be determined so that core is kept subcritical with sufficient margin even in status where one control rod with maximum reactivity worth is completely withdrawn.	
(5) Heavy water dump level	(5) Heavy water dump level Subcriticality shall be assured even in initial core without poison at heavy water dump level or less.	
(6) Reactivity control method	(6) Reactivity control method Following methods are adopted. Solid control rod Liquid poison Heavy water dump	
2. Design condition	2. Design condition	
(1) Reactor thermal power	(1) Reactor thermal power	
(i) Electric power	(i) Electric power 165 MWe	(R) HB (R) PD
(ii) Thermal power transmitted to coolant	(ii) Thermal power transferred to coolant 518.7 MWt	(R) PD
(2) Core	(2) Core	
(i) Coolant void distribution (density distribution)	(i) Coolant void distribution (density distribution) (mean value)	(R) THD

(ii) Coolant temperature at core entrance	(i i) Coolant temperature at core entrance: 277℃	(R) THD
(iii) Coolant temperature at core exit	(iii) Coolant temperature at core exit: 285℃	(R) THD
(iv) Fuel temperature distribution	(i v) Fuel temperature distribution (mean value)	(R) FD
(v) Heavy water temperature	(v) Heavy water temperature (reactor entrance) : 70℃ (reactor exit) : 51℃	(R) PD (R) HB
(vi) Heavy water concentration	(v i) Heavy water concentration: 99.65%	(R) PD
(3) Primary coolant system	(3) Primary coolant system	
(i) Steam drum pressure	(i) Steam drum pressure: 68 kg/cm^2 G	(R) PD
(4) Fuel assembly	(4) Fuel assembly	
(i) Fuel assembly dimension specifications	(i) Fuel assembly dimension specifications Refer fuel design	(R) FD
(ii) Fuel dimension (nominal value)	(i i) Fuel dimension (nominal value) Clad inner diameter: 14.70 mm Clad outer diameter: 16.46 mm Pellet outer diameter: 14.40 mm Pellet density: 95%	(R) OD (R) FD
(iii) Material	(iii) Material Clad: Zry-2 Spacer tie rod: Zry-2	(R) FD

	Spacer: Inconel-718 Tie plate (upper and lower): SUS 13 (SUS 304) Rod spring: Inconel-X	
(5) Pressure tube assembly	(5) Pressure tube assembly	
(i) Pressure tube assembly dimension specifications	(i) Pressure tube assembly dimension specifications Pressure tube assembly design shall be referred to.	(R) PTAD
(ii) Pressure tube dimension (nominal value)	(ii) Pressure tube dimension (nominal value) 117.8 mm	(R) OD
(iii) Material	(iii) Material Pressure tube: Zr-2.5wt%Nb Pressure tube extension: SUS 50 Mod. Pressure tube rolled joint ring: SUS 50 Mod. (lower inner ring) Inconel-718 (upper outer ring)	(R) PTAD
(6) Calandria tube	(6) Calandria tube	
(i) Calandria tube dimension (nominal value)	(i) Calandria tube dimension (nominal value) Calandria tube inner diameter: 156.4 mm Calandria tube wall thickness: 1.9 mm	(R) SD
(ii) Material	(ii) Material Zry-2	(R) SD
3. Design (specifications), safety margin	3. Design (specifications), safety margin	
(1) Core specifications	(1) Core specifications	
(i) Core layout, control rod	(i) Core layout, control rod layout Lattice pitch: 240 mm	(T) SD (T) THD

layout	Control rod pitch: 480 mm	(T) DPA
	Number of fuel assemblies: 124 (UO_2 standard fuel) 96 (MOX standard fuel) 4 (special fuel) Number of control rods : 4 (adjustment rod) 45 (safety rod) (License application for construction modification of prototype ATR, Attached document (complete book) Attached document 8 Fig. 3.2-1, p. 8)	(T) SA
(ii) Core specifications	(ii) Core specifications Effective core height: Approx. 3,700 mm Core equivalent diameter: Approx. 4,050 mm Reflector thickness (Radial direction): 400 mm (Height direction): 400 mm Moderator/fuel volume ratio: 8.24 Coolant/fuel volume ratio: 1.1 Fuel assembly: 28-rod cluster Fuel enrichment U enrichment: 1.5% Puf enrichment: 0.55% + (natural U) (Outer layer) 0.80% + (natural U) (Inter mediate layer) (Inner layer) Mean burnup Initial core: 10,000 MWD/t Equilibrium core: 12,000 MWD/t	(T) SA
(2) Control specifications	(2) Control specifications	
(i) Control rod	(i) Control rod Boron carbide Two-layer cluster	(T) SD

(ii) Liquid poison	(ii) Liquid poison Poison: D_3BO_3 ^{10}B concentration in heavy water: 11 ppm (initial core)	(T) SD
(iii) Heavy water dump	(iii) Heavy water dump Heavy water dump level: 1,200 mm	(T) SD
(3) Refueling program	(3) Refueling program On-power refueling (1 fuel rod/2 to 4 days) On-power refueling shall be kept pending until measures against fuel densification and BWR fuel failure are made clear (after installation modification licence was received).	
(4) Power distribution	(4) Power distribution	
(i) Design channel power distribution	(i) Design channel power distribution Licence application for construction modification of prototype ATR, Attached document (complete book) Attached document 8 Fig. 15.2-1, p. 62	(T) THD (T) FD (T) DPA (T) SA
(ii) Design power peaking facter	(ii) Design power peaking facter Channel power peaking facter: 1.58 Axial power peaking facter: 1.35 Local power peaking facter: 1.22 Engineering are taken into account in these values.	(T) SA
(5) Reactivity balance	(5) Reactivity balance	
(i) Shutdown margin	(i) Shutdown margin 0.03	(T) DPA (T) SA

<table>
<tr>
<td>(ii) Reactivities</td>
<td>(i i) Reactivities (ΔK/K)
<table>
<tr><th></th><th>(Initial core)</th><th>(Equilibrium core)</th></tr>
<tr><td>Burnup</td><td>0.15</td><td></td></tr>
<tr><td>From low to high temperature</td><td>0.03</td><td>0.03</td></tr>
<tr><td>Accumulation of Xe and Sm</td><td>0.04</td><td>0.04</td></tr>
<tr><td>Area power control
Power leveling
Burnup margin</td><td>0.03</td><td>0.02</td></tr>
<tr><td>Total</td><td>0.25</td><td>0.09</td></tr>
</table>
</td>
<td>(T) SA</td>
</tr>
<tr>
<td>(iii) Control capacity</td>
<td>(iii) Control capacity (ΔK/K)
<table>
<tr><th></th><th>(Initial core)</th><th>(Equilibrium core)</th></tr>
<tr><td>Control rod</td><td>0.12</td><td>0.12</td></tr>
<tr><td>Liquid poison</td><td>0.16</td><td>----</td></tr>
<tr><td>Total</td><td>0.28</td><td>0.12</td></tr>
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</td>
<td>(T) SA</td>
</tr>
<tr>
<td>(iv) Control rod worth having maximum reactivity</td>
<td>(i v) Control rod worth having maximum reactivity (ΔK/K)
<table>
<tr><th>(Initial core)</th><th>(Equilibrium core)</th></tr>
<tr><td>0.01</td><td>0.01</td></tr>
</table>
</td>
<td>(T) SA</td>
</tr>
<tr>
<td>(v) Other reactivity</td>
<td>(v) Other reactivity (ΔK/K)
Coolant void reactivity
(License application for construction modification of prototype ATR, Attached document (complete book) Attached document 8 Fig, 15.1-1, p. 60)
Moderator temperature reactivity
(License application for construction modification of prototype ATR, Attached document (complete book) Attached document 8 Fig, 15.1-2, p. 61)</td>
<td>(T) SA</td>
</tr>
<tr>
<td>(6) Reactivity coefficients</td>
<td>(6) Reactivity coefficients (rated power)</td>
<td></td>
</tr>
</table>

	(Initial core) / (Equilibrium core)	
(i) Power coefficient	(i) Power coefficient -8.1×10^{-3} Δ k/k/Δ p/p / -8.6×10^{-3} Δ k/k Δ p/p	(T) DPA
(ii) Fuel temperature coefficient	(ii) Fuel temperature coefficient -1.6×10^{-5} Δ k/k/℃ / -1.6×10^{-5} Δ k/k/℃	(T) SA
(iii) Coolant void coefficient	(iii) Coolant void coefficient -2.0×10^{-4} Δ k/k/%void / -1.4×10^{-4} Δ k/k/%void	(T) SA
(iv) Coolant temperature coefficient	(iv) Coolant temperature coefficient -4.0×10^{-5} Δ k/k/℃ / -1.1×10^{-5} Δ k/k/℃	(T) SA
(v) Moderator temperature coefficient	(v) Moderator temperature coefficient -1.1×10^{-4} Δ k/k/℃ / -4.2×10^{-4} Δ k/k/℃	(T) SA
(7) Heating of heavy water, etc. by γ ray, neutron, etc.	(7) Heating of heavy water, etc. by γ ray, neutron, etc.	
(i) Reactor thermal power	(i) Reactor thermal power : 557 MWt	(T) SA (T) HB
(ii) Thermal power transmitted to coolant	(ii) Thermal power transferred to coolant : 518.7 MWt	(T) PD (T) THD
(iii) Heat generated in heavy water	(iii) Heat generated in heavy water: 35.1 MWt	(T) SD (T) DPA
(iv) Heat generated in shield	(iv) Heat generated in shield: 3.2 MWt	(T) SD

Table 2
ATR「Fugen」 Data Base
Design/R&D/Plant Performance
[Nuclear]
Engineering Data on Nuclear Design

Item	Design Engineering and Technical basis, etc.	(T) (R) etc.
1. Selection of optimum lattice	1. Selection of optimum lattice	
(1) Optimum calculation technique	(1) Optimum calculation technique	
(i) Optimum calculation flow sheet	(i) Optimum calculation flow sheet [Committee 105, Reference paper Fig. 8.1-6, p. 8-12]	
(ii) Price of major structures, etc.	(ii) Price of major structures, etc. Based on USAEC Report DP-1007	
(2) Optimum calculation condition	(2) Optimum calculation condition	
(i) Plant condition	(i) Plant condition Thermal power: 1590 MWt Electric power: 500 MWt Core pressure: 72.5 kg/cm^2 G Fuel: Pu enriched natural U Initial core shall be started from U core. Pressure tube material: Zr-2.5wt%Nb Calandria tube material: Zry-2	
(ii) Major parameters	(ii) Major parameters Fuel rod diameter Lattice pitch Number of cluster fuel rods	
(iii) Major control condition	(iii) Major control condition Minimum gap between fuel rods: 2.0 mm	

	Minimum pitch between lattices: 240 mm $\dfrac{\text{Coolant void reactivity (entire core)}}{\text{Number of loops}} : 0.8\,\beta$	
(3) Optimum calculation result	(3) Optimum calculation result (Committee 105, Reference paper Fig. 8.1-7, p. 8-13) In case of 28-rod cluster (selected)	
(4) Modification from selected lattice	(4) Modification from selected lattice Minimum gap between fuel rods: 2.0 mm → 2.1 mm Gap between fuel and pressure tube: 2.285 mm →3.1 mm Calandria tube inner diameter: 149.8 mm → 156.4 mm	
2. Nuclear characteristics (1) Initial core characteristics	2. Nuclear characteristics (1) Initial core characteristics	
(i) Coolant void reactivity	(i) Coolant void reactivity (Committee 82, Reference paper Fig. 6.2-1, p 78 Fig. 6.3-1, p 81) Fig. 6.3-1, p. 81	(T) DPA (T) SA
(ii) Moderator temperature reactivity	(ii) Moderator temperature reactivity (Committee 82, Reference paper Fig. 6.2-2, p 79)	(T) SA
(iii) Power distribution	(iii) Power distribution Written with burnup core characteristics in (2.(2)(iii))	

(iv) Change in reactivity when light water mixes into heavy water	(iv) Reactivity change when light water mixes into heavy water (Committee 63, Reference paper Fig. 7.5-1, p 123)	(T) DPA (T) SA
(v) Change in reactivity when heavy water level is fluctuated	(v) Reactivity change when heavy water level is fluctuated (Committee 63, Reference paper Fig. 7.10-1, p. 148 Table 7.10-2, p. 148)	(T) SA
(2) Burnup core characteristics	(2) Burnup core characteristics	
(i) Coolant void reactivity	(i) Coolant void reactivity (equilibrium core) Written with initial core characteristics in (2.(1)(i))	
(ii) Moderator temperature reactivity	(ii) Moderator temperature reactivity (equilibrium core) Written with initial core characteristics in (2.(1)(i))	
(iii) Change in power	(iii) Change in power distribution Change in axial power distribution in axial direction (Committee 82, Reference paper Fig. 6.6-1, p 90 Fig. 6.6-2, p. 91) Change in channel power distribution (Committee 82, Reference paper Fig. 6.6-3, p 92 Fig. 6.6-4, p 93 Fig. 6.6-5, p. 94)	(T) THD (T) FD (T) DPA (T) SD
(iv) Reactivity change	(iv) Reactivity change (initial core) (Committee 63, Reference paper Fig. 7.2-1, p 117)	(T) DPA (T) SA

(v) Reactivity worth of new fuel	(v) Reactivity worth of new fuel (Committee 63, reference paper Fig. 7.4-1, p 121) (During on-power operation)	(T) SA
(vi) Change in power peaking coefficient distribution	(vi) Change in power peaking coefficient (Committee 105, reference paper Fig. 8.1-5 (1), p 8-7 Fig. 8.1-5 (2), p 8-8) (During on-power operation)	(T) SA
3. Nuclear design analysis code system (omitted)	3. Nuclear design analysis code system (omitted) Following shall be written from design analysis code system. (1) List-up of nuclear design analysis codes for each nuclear design item and analysis flow (2) Accuracy of nuclear design analysis code	
4. Technical information related to nuclear design (others)	4. Technical information related to nuclear design (others)	
(1) Core material	(1) Core material	
(i) Fuel pellet impurity	(i) Fuel pellet impurity (Application for approval of initial load fuel design Attached document [I] Table III-2, p. 11)	(R) FD
(ii) Zry-2 composition	(ii) Zry-2 composition (Application for approval of initial load fuel design p. 2, ditto, Attached document [I] Table III-3, p. 12)	(R) FD

(iii) SUS 304 composition	(iii) SUS 304 (SUS-13) composition (Application for approval of initial load fuel design, p. 3)	(R) FD
(iv) Inconel-718 composition	(iv) Inconel-718 composition (Application for approval of initial load fuel design, pp. 4 and 5)	(R) FD
(v) Inconel-X composition	(v) Inconel-X composition (Application for approval of initial load fuel design, p. 4)	(R) FD
(vi) SUS 630 composition	(vi) SUS 630 composition (Application for approval of initial load fuel design, p. 6)	(R) FD
(vii) SUS 50Mod. composition	(vii) SUS 50Mod. composition "Fugen" development Table 2.3-11, p. 79	(R) PSD
(viii) Zr-2.5wt%Nb composition	(viii) Zr-2.5wt%Nb composition Application for approval of special design facility Table 1, p. 2-2-(3)	(R) PSD
(2) Control rod	(2) Control rod	
(i) General drawing	(i) General drawing Licence application for installation modification of prototype ATR, Attached document (complete book) Attached document 8 Fig. 3.5-1, p. 15	(R) SA
(ii) Specifications	(ii) Specifications Poison: B_4C Poison tube Material: SUS 304	(R) SA

	Outer diameter: 4.8 mm Inner diameter: 3.5 mm Layout: 81 rods, two-layer cluster Effective poison length: 3,700 mm Poison charging degree: 1.75 g/cm^3 (vibration charging)	
(3) Comparison of nuclear calculation with experiments and actual results	(3) Comparison of nuclear calculation with experiments and actual results Refer to nuclear design analysis code system	

Table 3
ATR 「Fugen」 Date Base
Design／R&D／Plant Performance
[Nuclear]
Engineering Data on Plant Characteristics

Item	Plant Performance	Remarks
1 Fuel loading	1 Fuel loading	
(1) Fuels loaded	(1) Fuels loaded Standard U fuels :124 Assemblies Standard MOX fuels : 96 Assemblies Special fuels : 4 Assemblies	
(2) Fuel specifications	(2) Fuel specifications Table-1.1 : Fuel specificarions [Commissioning test report, P-17, & 18]	
(3) Fuel arrangement	(3) Fuel arrangement Fig.1.3 : Fuel arrangement [Commissioning test report, P-20]	
2 Initial criticality	2 Initial criticality	
(1) Summary of criticality test	(1) Summary of Criticality tests Table-2.1 : Reactor core configuration for critical tests [Commissioning tets report, P-25]	
(2) Min. criticality	(2) Min. criticality (i) Min. No. of fuels for criticality 22 assemblies (ii) Core Configuration for min. criticality Fig.2.2 : Fuel arragement for min. criticality [Commissioning test report, P-28]	

(3) Core with 100 assemblies for criticality test (4) Full core fuel loading for criticality test	(iii) Inverse mulitiplication factor Fig.2.3 : Inverse multiplication factor [Commissioning test report, P-29] (3) Core with 100 assemblies for criticality test (Adjusted with boron concentration) (i) Core configuration with 100 fuel assemblies Fig.2.4 : Fuel arrangement for criticality test [Commissioning test report, P-29] (ii) Inverse multiplication factor Fig.2.5 : Inverse multiplication factor [Commissioning test report, P-30] (4) Full core fuel loading for criticality test (Adjusted with boron concentration) (i) Arrangement of full core fuel loading [Commissioning test report, P-30] (ii) Inverse multiplication factor Fig.2.7 : Inverse multiplication factor [Commissioning test report, P-30]	
3 Control rod reactivity worth (1) Test method	3 Control rod reactivity worth (1) Test method (i) Fuel loading Full core (ii) Measurement method of control rod reactivity worth Reactor period method	

(2) Control rod reactivity worth (3) Integrated reactivity of control rod	(2) Control rod reactivity worth Fig.3.1 : Control rod reactivity worth measurement [Commissioning test result, P-35] (3) Integrated reactivity of control rod Fig.3.1 : Integrated reactivity of contorl rod [Commissioning test report, P-36]	
4 Reactivity worth of liquid poison (1) Test method (2) Reactivity worth of liquid poison	4 Reactivity worth of liquid poison (1) Test method (i) Full core fuel loading (ii) All control rods, except one, are withdrawn, and criticality is achieved with adjusting poison concentration. (iii) Poison reactivity worth is evaluated with comparing poison concentration change and control rod movement. (2) Reactivity worth of liquid poison Table-4.1 : Reactivity worth measurement of liquid poison [Commissioning test report, P-38]	
5 Shutdown margin (1) Test method	5 Shutdown margin (1) Test method (i) Shutdown margin varidation test-1 Make full core fuel loading with all control rods inserted into the core. Adjust boron concentration to the value at the commencement of nuclear heating.	

	Confirm sub-criticality with withdrawing the control rod of max. reactivity worth. (ii) Shutdown margin varidation test-2 Make full core fuel loading with all control rods inserted into the core. Adjust boron concentration to the value at the commencement of nuclear heating. Confirm sub-criticality with with- drawing 4 control rods. (iii) Min. boron concentration varidation test for shutdown Make full core fuel loading with the max. controd rod withdrawn. Confirm the min. boron concentration to keep 1%/ Δ k/k of shutdown margin in the cold shutdown.	
(2) Shutdown margin	(2) Shutdown margin (i) Shutdown margin Table-5.1 : Shutdown margin Measurement [Commissioning test report, P-40] (ii) Inverse multiplication factor in shutdown margin measurement for min. boron concentration Fig.5.1 : Inverse multiplication factor curve [Commissioning test report, P-40]	
6 Shutdown by heavy water dump	6 Shutdown by heavy water dump	
(1) Test method	(1) Test method (i) Make full core fuel loading. Adjust boron concentration to the value at the commencement of nuclear heating.	

	(i i) Confirm sub-criticality with making heavy water dump.	
(2) Shutdown by heavy water dump	(2) Shutdown by heavy water dump (i) Shutdown by heavy water dump Table-6.1 : Shutdown confirmation by lowering heavy water level [Commissioning test report, P-42] (i i) Inverse multiplication factor in lowering heavy water level Fig.6.2 : Inverse multiplication factor in lowering heavy water level [Commissioning test report, P-43]	
7 Coolant temp. coefficient of reactivity	7 Coolant temp. coefficient of reactivity	
(1) Test method	(1) Test method (i) Set coolant temperature at 40 ℃, 120℃,160℃,220℃, respectively. (i i) At each coolant temperature, give 10℃ of temperature change, and evaluate the reactivity change.	
(2) Coolant temp. coefficient of reactivity	(2) Coolant temp. reactivity coefficient Table-10.1 : Coolant temp. reactivity coefficient measurement [Commissioning test report, P-64] Fig.10.1 : Coolant temp. reactivity coefficient measurement [Commissioning test report, P-64]	

8 Power coefficient of reactivity	8 Power coefficient of reactivity	
(1) Test method	(1) Test method (i) Keep power at the set point. (ii) Change the power by inserting the control rod whose reactivity worth is known. Evaluate power coefficient of reactivity.	
(2) Power coefficient of reactivity	(2) Power coefficient of reactivity (i) Electric power : 25%, 50%, 75%, 100% (ii) Power coefficient of reactivity Table-18.1 : Power coefficient of reacivity measurement [Commissioning test report, P-122] Fig.18.1 : Relationship between thermal power and powercoefficient of reactivity [Commissioning test report, P-123]	
9 Neutron flux distribution in core	9 Neutron flux distribution in core	
(1) Test method	(1) Test method Measure neutorn flux distribution with movable neutron flux monitors	
(2) Arrangement of neutron flux monitors	(2) Arrangement of neutorn flux monitors (i) Arrangement of PCM (Power Callibration Monitor) Fig.15.1 : Arrangement of PCM [Commissioning test report, P-105]	

	(ii) Arrangement of LPM (Local Power Monitor] Fig.19.1 : Arrangement of neutron flux monitors [Commissioning test report, P-126]	
(3) Neutron flux distribution	(3) Neutron flux distribution (i) Electric power : 25%, 50%, 75%, 100% (ii) Axial neutron flux distribution Fig.15.1 : Axial neutron flux distribution (Location : 18-72) [Commissioning test report, P-106] (iii) Axial neutron flux distribution Fig.15.2 : Axial neutron flux distribution (Location : 26-64) [Commissioning test report, P-106]	
10 Power distribution in core (1) Calculation flow of power distribution	10 Power distribution in core (1) Calculation flow of power distribution Fig.16.1 : Calculation flow of power distribution and heat removal limit [Commissioning test report, P-111]	
(2) Power distribution in core	(2) Power distribution in core (i) Electric Power : 50%, 75%, 100% (ii) Radial power distribution Fig.16.7 : Radial power distribution [Commissioning test report, P-114] (iii) Aixial power distribution Fig.16.8 : Axial power distribution [Commissioning test report, P-114]	

	(iv) Power distribution in core Fig.16.9 : Power distibution in core (100% power) [Commissioning test report, P-116]	
11 Thermal-hydraulic characteristics in core	11 Thermal-hydraulic Characteristics in core	
(1) Test method	(1) Test method (i) Flow distribution in reactor inlet pipes Measure differential pressure between lower header and drain collection pipe. (Refer to Fig.24.2) Measure flow in reactor inlet pipes with channel flow meter installed. Measure flow in reactor inlet pipes with ultrasonic flow meter. (ii) Recirculation flow characteristics Measure recirculation flow with flow meters installed in primary coolant system.	
(2) Thermal-hydraulic characteristics	(2) Thermal-hydraulic characteristics (i) Flow distribution characteristics in reactor inlet pipes Fig.23.5 : Flow distribution in reactor inlet pipes (Room temperature) [Commissioning test report, P-149] (ii) Recirculation flow characteristics (Room temperature) 2394 t/hr : at low recirculation flow 4393 t/hr : at high recirculation flow (Relationship between reactor power and recirculation flow) Fig.23.9 : Relationship between reactor power and	

	recirculation flow [Commissioning test report, P-152] (iii) Natural convection characteristics in reactor inlet pipes after scram (Recirculation pumps are stopped) Fig.23.8 : Flow in reactor inlet pipes after reactor shutdown (Natural convection) [Commissioning test report, P-151]	
12 Characteristics of recirculation flow change (1) Low flow==> High flow	12 Characteristics of recirculation flow change (1) Low flow==>High flow (i) Test conditions Electric power : 35%, 40% Automatic power control : worked Manual feed water control : worked Table-39.2 : Conditions of recirculation flow change [Commissioning test report, P-217] (ii) List of plant data affected Recirculation flow Steam drum water level and pressure Steam flow Neutron flux Generator power (iii) Response characteristics in recirculation flow change-1 Fig.39.2 : Response characteristics in recirculation flow change [Commissioning test report, P-219] (iv) Response characteristics in recirculation flow change-2 Fig.39.3 : Response characteristics in recirculation flow change	

	[Commissioning test report, P-221]	
(2) High flow==> Low flow	(2) High flow==> Low flow	
	(i) Response characteristics in recirculation flow change-1 Fig.39.4 : Response characteristics in recirculation flow change [Commissioning test report, P-223]	
	(ii) Response characteristics in recirculation flow change-2 Fig.39.5 : Response characteristics in recirculation flow change [Commissioning test report, P-225]	
13 Response characteristics of recirculation pump trip	13 Response characteristics of recirculation pump trip	
(1) Recirculation pump trip conditions	(1) Recirculation pump trip conditions Table-40.1 : List of recirculation pump trip conditions [Commissioning test report, P-230]	
(2) Test conditions	(2) Test conditions Electric power : 50%, 100% Number of pumps tripped : 2	
(3) Response characteristics of recirculation pump trip	(3) Response characteristics of recirculation pump trip	
	(i) Plant data change Table-40.3 : Plant data change [Commissioning test report, P-230]	
	(ii) Response characteristics of recirculation pump trip-1 Table-40.2 : Test result of recirculation pump trip [Commissioning test report, P-230]	

	(iii) Response characteristics of recirculation pump trip-2 Fig.40.2 : Test result of recirculation pump trip [Commissioning test report, P-231]	
14 Response characteristics of power set point change	14 Response characteristics of power set point change	
(1) Test conditions	(1) Test conditions Electric power : 50%, 75%, 100% Set point change : 5%～10% Input gain : 100 Dead zone : 0.4 sec. ON time : 0.3 sec. OFF time : 0.2 sec. Delay time : 0.6 sec.	
(2) Response characteristics of power set point change	(2) Response charcteristics of power set point change (i) Response characteristics of power set point change-1 Table-41.1 : Test result of power set point change [Commissioning test report, P-238] (ii) Response characteristics of power set point change-2 Table-41.2 : Test result of power set point change [Commissioning test report, P-239] Table-41.3 : Test result of power set point change [Commissioning test report, P-239] (iii) Response characteristics of power set point change-3 Fig.41.2 : Test result of power set point change [Commissioning test report, P-243] Fig.41.3 : Test result of power set point change [Commissioning test report, P-240]	

15 Response characteristics of main steam pressuure set point change	15 Response characteristics of main steam pressure set point change	
(1) Test conditions	(1) Test conditions Electric power : 25%, 50%, 75%, 100% Pressure set point change : -0.5 kg/cm2	
(2) Response of main steam pressuure set point change	(2) Response of main steam pressure set point change	
	(i) Plant data change Fig.44.1 : Test result of main steam pressure set point change [Commissioning test report, P-265] Table-44.2 : Plant data change [Commissioning test report, P-265]	
	(ii) Response characteristics of main steam pressure set point change Fig.44.2 : Test result of main steam pressure set point change [Commissioning test report, P-266]	
(3) Performance of back-up pressure controller	(3) Performance of back-up pressure controller	
	(i) Plant data change Table-44.3 : Plant data change [Commissioning test report, P-265]	
	(ii) Performance of back-up pressure controller Fig.44.3 : Test result of back-up pressure controller [Commissioning test report, P-267]	

16 Response characteristics of steam drum level set point change	16 Response characteristics of steam drum level set point change	
(1) Test conditions	(1) Test conditions Up to 25% power : 1 element control with low feed water flow control valve 25%～100% Power : 3 element control with feed water flow control valve Level change : 20mm (1 element control) 50mm (3 element control) Low feed water flow control valve Gain constant : 5 Reset time : 450 sec. Feed water flow control valve Gain constant : 0.45 Reset time : 450 sec.	
(2) Response characteristics of steam drum level set point change-1	(2) Response characteristics of steam drum level set point change-1 (1 element control with low feed water flow control valve) (i) Plant data change Table-47.2 : Plant data change [Commissioning test report, P-284] (ii) Response characteristics of steam drum level set point change Fig.47.2 : Test result of stea drum level set point change [Commissioning test report, P-285]	
(3) Response characteristics of steam drum level set point change-2	(3) Response of steam drum level set point change-2 (3 element control with feed water flow control valve)	

	(i) Plant data change Table-47.4 : Plant data change [Commissioning test report, P-286] (ii) Reponse characteristics of steam drum level set point change Fig.47.3 : Response characteristics of steam drum level set point change [Commissioning test report, P-287]	
17 Response characteristics of disturbance in automatic control system	17 Response of disturbance in automatic control system	
(1) Test conditions	(1) Test conditions Thermal Power : 50% Partial insertion of control rod (-1.5 ¢)	
(2) Response characteristics of disturbance in automatic control system-1	(2) Response characteristics of disturbance in automatic control system-1 (i) Response characteristics-1 Fig.41.4 : Response characteristics of disturbance in automatic control system [Commissioning test report, P-241] (ii) Response characteristics-2 Neutron flux : 0.7% is lowered Settled within 30 sec Steam flow : 10 t/hr is lowered tentatively Generator power : 1 MWe is lowered	

18 Power response characteristics of feeding feeding poison	18 Power response characteristics of feeding poison	
(1) Test conditions	(1) Test conditons Electric power : 35% Core status : Xe is saturated	
(2) Power response characteristics	(2) Power response characteristics (i) Power response characteristics-1 (at removing poison) Fig.13.5 : Power response characteristics at removing poison [Commissioning test report, P-90] (ii) Power response characteristics-2 (at poison feeding) Fig.13.6 : Power response characteristics at feeding poison [Commissioning test report, P-90]	
19 Control rod drop time	19 Control rod drop time	
(1) Control rod arrangement	(1) Control rod arrangement Fig.25.1 : Control rods arrangement in core [Commissioning test report, P-160]	
(2) Control rod drop time	(2) Control rod drop time Table-25.2 : Test result of control rod drop time [Commissioning test report, P-159]	

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