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

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

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
[Thermal/Hydraulic]
Design Basic Items

Item	Design Policy, Design Condition, Design, etc.	(T)(R) etc.
1. Design policy/ basis/guideline	1. Design policy/basis/guideline	
(1) Applicable design policy/ basis/guideline	(1) Applicable design policy/basis/guideline (i) Thermal-hydraulic design policy/basis of light reactor (ii) Safety review guideline for emergency core cooling system of light reactor	
(2) Heat removal limit	(2) Heat removal limit Following shall be satisfied in design power.	
(i) Design heat removal limit	(i) Heat flux of fuel rod shall keep appropriate margin against critical heat flux at max. channel power in design power distribution. Minimum critical heat flux ratio (MCHFR) >= 1.5 (120% power)	
(ii) Design linear heat generation rate	(ii) 21.0 kW/ft (120% power) 17.5 kW/ft (100% power)	
(iii) Fuel center temperature	(iii) Fuel fusion point or less	
(iv) Design power	(iv) 120% power	
(3) Hydraulic stability	(3) Hydraulic stability Reduction width ratio <= 0.25	
(4) Heat removal limit in overpower transient	(4) Heat removal limit in overpower transient Specific overpower transients or incidents shall be analyzed to confirm following.	

	(i) Min. critical heat flux ratio ≧ 1.0 (ii) Fuel temperature < Fuel fusion point (iii) Analysis/evaluation event Turbine generator trip Loss of recirculation pump power supply Cool water event, Others	
2. Design condition	2. Design condition	
(1) Reactor thermal output	(1) Reactor thermal output	
(i) Reactor thermal output	(i) 557 MWt	(R)HB
(ii) Thermal output transferred to coolant	(ii) 518.7 MWt	(R)HB
(iii) Heat generated in heavy water	(iii) 35.1 MWt	(R)HB (R)RPD
(iv) Heat generated in shield	(iv) 3.2 MWt	(R) HB (R) RPD
(2) Reactor design power and design power distribution	(2) Reactor design power and design power distribution	
(i) Design power	(i) 120% power	
(ii) Design power distribution (at channel with maximum power)	(ii) License application for construction modification of prototype ATR, Attached document (complete book), Attached document 8 Fig. 15.2-1, p. 62	(R) RPD

(iii) Design power peaking factor	(iii) Channel power peaking factor: 1.58 Axial power peaking factor: 1.35 Local power peaking factor: 1.22	(R) RPD (R) RPD (R) RPD
(3) Primary coolant system	(3) Primary cooling system	(R)PD
(i) Steam drum pressure	(i) 68 kg/cm^3 G	
(ii) Steam drum steam flow	(ii) 910 t/hr	
(4) Fuel assembly	(4) Fuel assembly	(R)FD
(i) Fuel assembly size specifications	(i) Refer to fuel design	
(ii) Fabrication tolerance	(ii) Clad inner diameter: 14.70 ± 0.05 mm Clad outer diameter: $16.46^{+0}_{-0.08mm}$ Clad wall thickness: 0.8 mm Pellet outer diameter: 14.40 ± 0.03 mm (UO₂) Pellet outer diameter: 14.40 ± 0.05 mm (MOX) Pellet density: 95 ± 1.5 % (UO₂) Pellet density: $95^{+1.5\%}_{-2\%}$ (MOX) U enrichment: 1.5 % (UO₂) Puf enrichment: 0.55 % (Outer layer) Puf enrichment: 0.80 % (Inner layer, Medium layer)	
(5) Pressure tube assembly	(5) Pressure tube assembly	(R)PTAD
(i) Pressure tube size specifications	(i) Refer to pressure tube assembly design	
(ii) Manufacture tolerance	(ii) Pressure tube inner diameter: $117.8^{+0.762mm}_{-0mm}$	

3. Design (specifications) and safety margin	3. Design (specifications) and safety margin	
(1) Thermal -hydraulic characteristics of core with design power	(1) Thermal-hydraulic characteristics of core with design power	
(i) Design power	(i) 120% power	(R)RPD
(ii) Channel power	(ii) 4.7 MWt	(T)RPD (T)FD
(iii) Channel flow rate	(iii) 8.7 kg/s	
(iv) Max. heat flux	(iv) 1.15 x 10^{6} kcal/hr・m^{2}	(T)FD
(v) Critical heat flux ratio distribution Heat flux distribution (at channel with design power)	(v) License application for construction modification of prototype ATR, Attached document (complete book), Attached document 8 Fig. 15.2-1, p. 62 Committee 82, Reference paper Fig. 8.5-2, p. 87	(T) SA (T) FD (T)FD (T) SA
(vi) Steam weight ratio (at channel with design power)	(vi) License application for construction modification of prototype ATR, Attached document (complete book), Attached document 8 Fig. 15.2-1, p. 62 Committee 82, Reference paper Fig. 6.5-2, p. 87	(T) FD (T) SA (T) FD (T) RPD
(vii) Min. critical heat flux ratio	(vii) 1. 5	
(viii) Max. pellet temperature	(viii) 2,740℃	

(2) Thermal -hydraulic characteristics with rated power	(2) Thermal-hydraulic characteristics with rated power	
(i) Channel power	(i) 3.9 MWt	(R) RPD (T) RPD
(ii) Channel flow rate	(ii) 8.9 kg/s	(T) FD
(iii) Min. critical heat flux ratio	(iii) 1.9	
(3) Thermal -hydraulic characteristics with rated power	(3) Thermal-hydraulic characteristics with rated power	
(i) Reactor thermal output	(i) 557 MWt	(T) RPD
(ii) Steam flow rate	(ii) 910 t/hr	(T) RPD
(iii) Coolant flow	(iii) 7,600 t/hr	(T) FD
(iv) Coolant temperature at core inlet	(iv) 277℃	(T) Ditto
(v) Coolant temperature at core outlet	(v) 285℃	(T) Ditto
(vi) Mean steam quality at core outlet	(vi) 14%	(T) RPD
(vii) Core mean void fraction	(vii) 37%	

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

Item	Design Engineering and Technical Basis, etc.	(T)(R) etc.
1. Heat removal characteristics (1) Equation for heat removal limit	1. Heat removal characteristics (1) Equation for heat removal limit $q_c = (2.2 - 3.0\ \chi)$ q_c: Critical heat flux (10^6 kcal/hr・m^2) χ : Steam quality (i) Method to determine equation for heat removal limit Critical heat flux is affected by factors such as steam quality, power distribution, spacer interval, fuel layout, flow rate, etc. Based on test and evaluation related to effects of each of these factors, full scale heat removal test was done in order to determine equation for heat removal limit in the following, by evaluating test results 〔Comitee 105, Reference paper Fig. 8.3-8, p. 8-41〕 〔Comitee 82, Reference paper Fig. 6.5-1, p. 86〕 Effects of major factors on critical heat flux are as follows. (ii) Effects of local power distribution 〔Comitee 105, Reference paper Fig. 8.2-11, p. 8-25〕 (iii) Effects of axial power distribution 〔Comitee 105, Reference paper Fig. 8.2-14, p. 8-27〕	(T) FD (T) SA

	(iv) Effects of spacer interval Comittee 105, Reference paper Fig. 8.2-12, p. 8-25 Fig. 8.3-5, p. 8-38 (v) Effects of fuel layout and spacer structure Comittee 105, Reference paper Fig. 8.2-13, p. 8-26 (vi) Effects of abnormal layout of fuel rods Comittee 105, Reference paper Fig. 8.4-1, p. 8-46 Fig. 8.4-5, p. 8-50 Fig. 8.4-6, p. 8-51 Fig. 8.4-16, p. 8-61 (vii) Effects of eccentricity of fuel assembly Comittee 105, Reference paper Figs. 8.5-8 to 8.5-10, pp. 8-72 to 8-74 (viii) Effects of contact between fuel rods Nuclear Engineering and Design: Vol. 42, No. 2, 1997 Fig. -4.6, p. 239 Fig. -12, p. 241 Figs. -13 and 14, p. 242	
(2) Equation for heat transfer characteristics	(2) Equation for heat transfer characteristics (i) Forced convection heat transfer coefficient $Nu = 0.023 Re^{0.8} \cdot Pr^{0.4}$ Nu: Nusselt number Re: Reynolds number Pr: Prandtl number (ii) Boiling heat transfer coefficient $h = 1.22 q^{3/4} \exp (p / 63.3)$	

	h: Heat transfer coefficient (kcal/hr · m^2 ℃) q: Heat flux (kcal/hr · m^2) p: Coolant pressure (kg/cm^2)	
	(iii) Heat transfer coefficient for clearance between clad and pellet 1,000 Btu/hr · ft^2 · °F (4,882 kcal/hr · m^2℃)	(R) FD
	(iv) Pellet thermal conductivity $K=\frac{38.24}{T+402.4}+6.125\times10^{-13}(T+273)^3$ K: Thermal conductivity (w/cm · ℃) T: Pellet temperature (℃)	(R) FD
	(v) Thermal conductivity of Clad 0.014 w/cm · ℃ (Adhesion rate: 0.01 mm/year)	(R) FD
	(vi) Thermal conductivity of Oxide film 0.014 w/cm · ℃ (Adhesion rate: 0.01 mm/year)	(R) FD
	(vii) Thermal conductivity of clad $K=0.016(7.71+6.10\times10^{-13}T+2.9\times10^{-6}T^2)$ K: Thermal conductivity (w/cm · ℃) T: Clad temperature (℃)	(R) FD
2. Flow characteristics (1) Equation for pressure loss characteristics in single-phase flow	2. Flow characteristics (1) Equation for pressure loss in single-phase flow (i) Straight pipe (Nikuradse's equation) $\Delta P=\lambda\cdot\frac{L}{D}\cdot\frac{\gamma\cdot V^2}{2g}$ $\lambda=0.0032+\frac{0.221}{Re^{0.237}}$	(T) FD (T) SA

	(ii) Flow path expanded / contracted $\Delta P = \lambda \cdot \frac{\gamma \cdot V^2}{2g}$ (iii) Curved pipe (Secondary concept design document (Vol. 1) 6454-Revision (11), Fig. 1-33)	
(2) Equation for pressure loss characteristics in two-phase flow	(2) Equation for pressure loss in two-phase flow (i) Straight pipe (Martinelli-Nelson's equation) $\Delta P = (\Delta P)_L \cdot \phi^2$ $(\Delta P)_L$: Pressure loss in single-phase flow ϕ^2: Multiplication coefficient in two-phase flow (ii) Flow path expanded/Contracted (Romie's equation) $\Delta P = (\rho_l / 2g) V_0^2 (2\sigma) \cdot [\chi^2(\rho_l/\rho_g)(1/\alpha_1 - \sigma/\alpha_2) + (1-\chi)^2 \left\{ \frac{1}{(1-\alpha_1)} - \frac{1}{(1-\alpha_2)} \right\}$ σ: Cross Comittee ratio V_0: Flow rate without void ρ_l: Water density ρ_g: Steam density α_1: Void fraction just before cross Comittee is changed α_2: Void fraction just after cross Comittee is changed χ: Steam quality (iii) Flow path contracted (Richardson's equation) $\Delta P = \frac{\rho_1}{2g} (1 - \alpha) V_e^2 (1 + K \cdot \sigma^2)$ Ve: Flow rate after cross Comittee is changed K: $0.2 (1 - \sigma^2)$ $(0.125 \leqq \sigma < 0.5)$	

(3) Equation for slip ratio	σ : Cross Comittee ratio (iv) Acceleration loss $\triangle P = \frac{\rho_1}{2g} \cdot V_e^2 \cdot [(1-\chi_e + S \cdot \chi_e) \cdot (1-\chi_e + \frac{\rho_1}{\rho_g}\chi_e) - 1]$ S : Slip ratio xe : Steam quality at outlet of heating portion (3) Equation for slip ratio $S = \frac{1-\alpha}{K-\alpha+(1-K)\alpha^r}$ $S = \frac{\chi}{1-\chi} \cdot \frac{1-\alpha}{\alpha} \cdot \frac{\rho_1}{\rho_g}$ $K = 0.71 + \frac{0.29}{0.32062} P x 10^{-4}$ $r = 3.53125 - 0.1875\left(\frac{P}{1000}\right) + 0.58594\left(\frac{P}{1000}\right)^2$ P : Coolant pressure (psia) x : Steam quality α: Coolant void fraction (KAPL-2170 shall be referred to.)	
3. Technical information related to thermal -hydraulic design (1) Change in thermal-hydraulic characteristics accompanied by burnup/fuel exchange	3. Technical information related to thermal-hydraulic design (1) Change in thermal-hydraulic characteristics affected by fuel burnup (i) Change in axial power distribution affected by fuel burnup (Comittee 82, Reference paper Figs. 6.6-1 and 6.6-2, pp 90 and 91)	(R) RPD

	(ii) Change in core power distribution and flow rate distribution affected by fuel burnup (Comittee 82, Reference paper Figs. 6.6-3 to 6.6-5, pp 92 to 94)	(R) RPD (T) RPD
	(iii) Change in local power peaking factor affected by fuel burnup (Comittee 105, Reference paper Figs. 8.1-4, p. 8-5)	(R) RPD
	(iv) Change in gross power peaking factor affected by fuel burnup (Comittee 105, Reference paper Figs. 8.1-5 and 8.1-6, pp 8-7 and 8-8)	(R) RPD
(2) Technical basis of thermal-hydraulic design (others)	(2) Technical basis of thermal-hydraulic design (others)	
	(i) Thermal-hydraulic characteristics of channel with design power Axial heat flux distribution Axial critical heat flux ratio distribution Axial steam quality distribution (Comittee 82, Reference paper Fig. 6.5-2, p 87) (Application for permission of installation modification (complete book) Attached document 8 Fig. 15.2-1, p. 62)	(T) FD (T) SA (T) RPD
	(ii) Pressure loss characteristics (design power) (PNC ZJ302 74-11 Fig. 4-4, p. 4-6)	(T) Ditto
	(iii) Pressure loss characteristics (rated power) (PNC ZJ302 74-11 Fig. 4-7, p. 4-10 Table pp. 4-11 and 4-12)	(T) Ditto

Table 3
ATR 「Fugen」 Date Base
Design／R&D／Plant Performance
[Thermal／Hydraulic]
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]	

	(iii) Inverse mulitiplication factor Fig.2.3 : Inverse multiplication factor [Commissioning test report, P-29]	
(3) Core with 100 assemblies for criticality test	(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	(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. (i i) 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] (i i) 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.	

	(ii) 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] (ii) 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. (ii) 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	10 Power distribution in core	
(1) Calculation flow of power distribution	(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 (1) Test conditions (2) Response characteristics of disturbance in automatic control system-1	17 Response of disturbance in automatic control system (1) Test conditions Thermal Power : 50% Partial insertion of control rod (-1.5 ¢) (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 (1) Test cond itions	18 Power response characteristics of feeding poison (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 (1) Control rod arrangement	19 Control rod drop time (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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