PNC TJ 1409 97-023

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公開資料

ATR「Fugen」Data Base
Design/R&D/ Plant Performance
[Pressure Tube Assembly]

March, 1997

PESCO Co., Ltd.

PNC TJ 1409 97-023
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ATR「Fugen」Data Base Design/R&D/Plant Performance [Pressure Tube Assembly]

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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 perform with 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)

4 "Design/R&D/Plant Performance Data Base" of [Pressure Tube]

(1) Important Information of Pressure Tube after the Design Approval

Important information for hardware, such as components and systems, after the Design Approval, resistance characteristics against their ageing.

In case of the pressure tube, such techical information are obtained in commissioning, operation annual inspection, etc.

Main information is shown as follows:

① Mechanical strength change

② Dimension change, especially inner diameter change

③ Corrosion characteritics

④ Crack initiation and crack growth

⑤ Surveillance test

⑥ Effects of irradiation

(2) "Design/R&D/Plant performance Data Base" of [Pressure Tube]

It would be considered reasonable that the above informations be collected in "Plant Operation/R&D Data Base".

Therfore, Table 3 will be omitted in "Design/R&D/Plant Performance Data Base" of [Pressure Tube].

Contents

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

Item	Design Policy, Design Condition, Design etc.	(R) (T) etc.
1. Design policies/ criteria/guides	1. Design policies/criteria/guides etc.	
(1) Policies on design as a whole	(1) Policies on design as a whole	
(i) Pressure tube	(i) Pressure tube Design the pressure tube based on the characteristics of the Zr-2.5 wt%Nb alloy in accordance with the design criteria for the pressure vessel (class I vessel) of a light water reactor shown in the Notification No.501 of the MITI.	
(ii) Pressure tube rolled joint	(ii) Pressure tube rolled joint In the pressure tube rolled joint, the pressure tube made of the Zr-2.5wt%Nb alloy is sandwiched by high-rigidity Inconel-718 or SUS-50Mod, and the stress and strain of the Zr-2.5wt%Nb alloy are completely dominated by the high-rigidity rolled joint materials; accordingly, confirm the strength (mechanical properties and durability) of the rolled joint by tests. Remarks: The special structure of the rolled joint makes theoretical stress analysis impossible. Therefore, confirm the strength by tests.	
(2) Design policies for each item/ allowable values	(2) Design policies for each item/allowable value	
(i) Wall thickness of pressure tube	(i) Wall thickness of pressure tube (nominalvalue) $\text{(nominal value)} = \dfrac{\text{(effective wall thickness after 30 yrs} + \text{(corrosion allowance)}}{1 - \lvert \text{tolerance of wall thickness} \rvert}$	

(ii) Design allowable stress	(ii)	Design allowable stress The design allowable stress should be the min. value of the following three; 2/3 of yield strength (at room and hign temperatures) 1/3 of tensile strength (at room and hightemperatures) The smaller value of either 80% of minimum creep strength for load acting time or 2/3 of the mean value of the creep rupture strength	
(iii) Allowable creep strain	(iii)	Allowable creep strain Allowable value of membrane strain due to internal pressure strain: 2.5% Remarks: The membrane strain of 2.5% was judged to be equal to or less than the strain that causes the tertiary creep. Evaluate and confirm this by monitoring actual pressure tubes.	
(iv) Corrosion allowance	(iv)	Corrosion allowance Corrosion allowance is the sum of the following: ・Corrosion by water ・Fretting corrosion ・Corrosion by carbon dioxide gas	
(v) Hydrogen absorption	(v)	Hydrogen absorption Adopt the design value for CANDUBLW-250.	
(vi) Brittleness	(vi)	Brittleness Design brittleness is as follows: (Maximum defect length) has adequate safety factor for (limit defect length for maximum defect depth) at the working and room temperatures. (The penetrated defect length of the maximum defect depth) has adequate safety factor for (limit defect depth for the penetrated defect length) at the working temperature. Evaluate in accordance with the ASME Code Sec. Ⅲ Appendix-G, and confirm (stress intensity factor during operation): ×2 < (limit stres intensity factor)	

	(stress intensity factor during hydraulic test) ×1.5 < (limit stress in tensity factor)	
(vii) Fatigue analysis	(vii) Fatigue analysis Show the fact that the conditions which do not require fatigue analysis specified in Sub-Section 3 of Section 13 of Notification No.501 of the MITI are met, and that the parts required to make fatigue analysis is provided with sufficient fatigue strength.	
(viii) Allowable criteria for rolled joint	(viii) Allowable criteria for rolled joint [License application for specially designed facility p3-(4), Table 4 [Test and inspection items / Allowable criteria]]	
2. Design conditions	2. Design conditions	
(1) Operating conditions of pressure tube	(1) Operating conditions of pressure tube	
(i) Maximum working pressure, etc.	(i) Maximum working pressure, etc. Max. working pressure : 82kg/ cm^2 G Max. working temp. : 296 ℃	(R)PD
(ii) Pressure tube pressure, etc.	(ii) Pressure tube pressure, etc. Lower end pressure of pressure tube: 73.6kg/cm^2 G Lower end temperature of pressure tube: ~280 ℃ Upper end pressure of pressure tube:~71.0kg/ cm^2 G Upper end temperature of pressure tube : ~286℃	(R)THD
(iii) Inside diameter of pressure tube	(iii) Inside diameter of pressure tube (nominal value) : 117.8mm	(R)OP
(iv) Fast neutron flux	(iv) Fast newtron flux (max. in core) : 3.4×10^{13} n/cm^2・s	(R)RPD

(2) Load condition

(i) Combination of loads and allowable stress intensity

(2) Load condition

(i) Combination of loads and allowable stress intensity

	allowable stress intensity			
	1st General	1st	1st+2nd	peak
D_{C1}	S_m	1.5 S_m	–	–
$D_{C1}+S_1$	–	–	$3S_m$	Cumulative factor ≦1

D_{C1}: max. working load=D+ O_D + P_{RO}

O_{C1} : working load= D+ O_P + P_{RO}

S_1 : design seismic load=S_H + P_{RS}

S_m : design allowable stress

D : dead load

O_D : pressure and temperatur at max, working condition

O_P : pressure/temperature during operation

P_{RO}: reation force from piping due to selfweight and heat

P_{RS}: reation force from piping due to design earthquake

S_H : load applied by design earthquake

(ii) Load conditions

(ii) Load conditions

License application special design facility
p2-4-(3) to (4), left lower Table
p2-4-(3) to (4), right Figure of the above Table

(3) Creep strain

(3) Creep strain (ε)

$$\varepsilon = 3.12 \times 10^{-24} \cdot \phi \cdot \frac{P \cdot D}{2 \cdot t} \cdot (T-160) \cdot Tm$$

ϕ : fast neutron flux, 90% average power operation (2.5×10^{13} n/cm^2 ・S)

p : internal pressure, 0.715 kg/mm^2

D : inside dia. of pressure tube, 117.8mm

t : wall thickness of pressure tube, 3.98mm

T : pressure tube temperature, 280 ℃

Tm: operation time, 85% of 30yr (2.24×10^5 hr)

(4) Hydrogen absorption

(4) Hydrogen absorption

Initial stage:25ppm

(5) Brittleness	(5) Btittleness	
(i) Initial defects	(i) Initial defects (Allowable defects at receiving inspection) ×1.1 Defective length : 3.3mm Defective depth : 0.15mm (Detectable minimum defects in in-servic inspection) Defective length : 5.0mm Defective depth : 0.4mm Remarks: Because defects due to pressure tube assembly production, refeuling and fretting are considered to be sufficiently smaller than the one initially postulated, it would not necessary to evaluate these defects.	
(ii) Stress intensity factor	(ii) Stress intensity factor (K) $K=M \cdot \sigma \cdot \sqrt{\pi \cdot F \cdot a}$ M : 1.12 F : 1.0 σ : (design allowable stress)+(wedge effect) a : defective length	
(iii) Fatigue crack	(iii) Fatigue crack propagation rate (dc/dN,d a/dN) $\frac{dc}{dN}\left(\text{or } \frac{da}{dN}\right)=1.7\times10^{-5}(\Delta K)^{2.5}$ K : stress intensity factor, $kg/mm^{3/2}$ $\Delta\sigma$: $18.3kg/mm^2$ $+0.82kg/mm^2$ N : number of normal running stops, 360times a : defective length c : defective depth	
(iv) Calculation of stress intensity fact or in accordance with the ASME Code	(iv) Calculation of stress intensity factor in accordance with the Appendix-G of ASME Code Sec.Ⅲ $K=M \cdot \sigma \cdot \sqrt{\pi \cdot F \cdot a}$ M : 1.12 F :1.0 σ : (membrane stress)+(wedge effect)	

	a : Defective length Calculation conditions for σ Inside dia. of pressure tube = (nominal value) + (max. tolerance) = (117.8+0.762) mm Wall thickness of pressure tube = (nominal value) − (max. tolerance) − (corrosion allowance) = {4.3 (1−0.075)−0.62} mm Internal pressure = 0.715kg/mm² (during operation) 0.82 kg/mm² (during testing)	
(6) Testing conditions for rolled joint	(6) Testing conditions for rolled joint	
(i) Air tightness test	(i) Air tightness test (Air leak test) Testing pressure 5kg/cm² G Shelt time 0.5hr Testing temperature Room temperature (Helium leak test) Testing pressure 5kg/cm² G (After air leak test) Testing pressure 89kg/cm² G Testing temperature Room temperature	
(ii) Pressure test	(ii) Pressure test Hydraculic test Perform after air tightness test Testing pressure 160kg/cm² G Shelf time 0.5hr Testing temperature Room temperature	
(iii) Thermal cycle test	(iii) Thermal cycle test (after air tightness / pressure tests) (Thermal soak test) Fluid temperature 300℃±5℃ Pressure 92kg/cm² Circulating flow rate 175l/hr Time 144hr Torsional moment 100kg-m	

	(Thermal cycle test) Temperature range for thermal cycle 100℃-300℃ Temperature-rising rate 7℃ / min Temperature-falling rate 7℃ / min Number of thermal cycles 600times Pressure 92kg/cm^2 Circulating flow rate 175l/hr Torsional moment 100kg-m (Thermal shock test) Temperature range for thermal shock 100℃-300℃ Temperature-rising rate 20℃ / min Temperature-falling rate 7℃ / min Number of thermal shocks 60times Pressure 92kg/cm^2 Circulating flow rate 175l/hr Torsional moment 100kg-m	
(iv) Tension test	(iv) Tension test (after air tightness / pressure tests) Testing temperature design temperature (300℃)	
(v) Bending test	(v) Bending test (after air tightness/pressure tests) Testing temperature design temperature Testing load design bending m 2 x (design bending moment rupture strength)	
(vii) Torsional test	(vii) Torsional test Testing temperature design temperature Load conditions design torsional moment 2 x (design torsional moment rupture strength)	
(viii) Repetitive internal pressure test	(viii) Repetitive internal pressure test Testing temperature room temperature Testing pressure 100-180kg/cm^2 Number of cycles 5,000-100,000 Frequency 8～30 cpm	

3. Design (specification)/ safety margin	3. Design (specification) / safety margin	
(1) Main specification of pressure tube	(1) Main specification of pressure tube max. Max. working pressure 82kg/cm² G Max. working temperature 296℃ Inside dia.of pressure tube 117.8mm±0.762mm −0mm Wall thickness of pressure tube 4.3mm± 0.32mm Length of pressure tube about 4.7m Pressure tube material Zr-2.5Wt% Nb alloy	 (T)THD (T)RPD (T)FD (T)FD (T)FD (T)RPD
(2) Main dimensions/ material of pressure tube assembly	(2) Main dimensions/material of pressure tube assembly License application for special design facility Figure for the range of license application of special design facility	(T)RPD (T) THD (T) FD
(3) Design allowable stress	(3) Design allowable stress (18.3kg/mm²) 2/3 of yield strength 26.7kg/mm² 1/3 of tensile strength 18.3kg/mm² Smaller value of either 80% of creep rupture strength or 2/3 of the average 30 kg/mm²	
(4) Creep strain	(4) Creep strain 2.3%/30yr	(T) THD
(5) Corrosion allowance	(5) Corrosion allowance (0.62mm) Corrosion by water 0.31mm Fretting corrosion 0.23mm Corrosion by carbon dioxide gas 0.08mm	
(6) Hydrogen absorption	(6) Hydrogen adsorption Initial stage 2.5ppm After 15yr 118ppm After 30yr 211ppm	
(7) Brittleness	(7) Brittleness License application for special design facility p2-3-(51), Table p2-2-(28), Table2	

(8) Stress calculation	(8) Stress calculation (i) Stress calculation for the vicinity of rolled joint Lisense application for special design facility p2-4-(16), Table 7 p2-4-(17), Table 8 transient conditions for analysis states 1-4 (p2-4-(15)) p2-4-(18), Table 9 p2-4-(1), left lower Table	
(9) Fatigue analysis	(9) Fatigue analysis	
(i) Fatigue diagram	(i) Fatigue diagram License application for special design facility p2-2-(48), Fig.17	
(ii) Number of cycles of atmospheric pressure - operating pressure	(ii) Number of cycles of atmospheric pressure-operating pressure Allowable number of cycles with the repeated peak pressure of 3Sm = 700times Number of cycles of (start-up/shutdown) +(pressure/leak test) = 415times	
(iii) Allowable double amplitude of pressure fluctuation during load operaztion	(iii) Allowable double amplitude of pressure fluctuation during load operation Repeated peak stress for 10^6 cycles : 7.1kg/mm^2 Pressure fluctuation exceeding the above = (loss of station power) + (turbine trip) Number of the above pressure fluctuation : 320 times Max. pressure fluctuation for the above: 35.6kg/cm^2 Allowable double amplitude of pressure fluctuation for the above:113kg/cm^2	
(iv) Max. allowable temperature difference between 2points	(iv) Max. allowable temperature difference between 2 points Max. allowable temperature difference between 2 points : 604 ℃ Max. allowable temperature difference between	

	2 points during load running : 61.0℃	
(v) Allowable double amplitude of stress due to mechanical load	(v) Allowable double amplitude of stress due to mechanical load Repeated stress for 10^6 cycles : 7.1kg/mm^2 Event exceeding the above: design earthquake number of the above : 50times Repeated peak stress for the above number : 183kg/mm^2	
(10) Results of tests for rolled joint	(10) Results of tests for rolled joint (License application for special design facility p3-(4), Table4)	
(11) Safety margin	(11) Safety margin	
(i) Safety margin for brittleness evaluation	(i) Safety margin for brittleness evaluation Do not take into consideration the number of cycles (in the order of 10^3 - 10^5) of stress change in which an initial notch defect grows into an initial fatigue crack. As to fatigue crack propagation rate, adopt the best fit data in the working range of pressure tubes, whereas analyze and calculate fatigue propagation by using a safety factor which is 20times as high as that for the stress cycle. Calculate stress intensity factor by taking into account the infinite length of surface defect and "wedge effect" due to internal pressure. The stress intensity factors in the longitudinal direction of the defect are smaller than that in the longitudinal end of the defect. However, consider that the longitudinal crack propagation rate is equal to the crack propagation rate toward depth.	

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

Item	Design Engineering and Technical Basis, etc.	(R) (T) etc.
1. Characteristics of pressure tube material	1. Characteristics of pressure tube material	
(1) Composition of Zr-2.5wt% Nb alloy	(1) Composition of Zr-2.5Wt% Nb alloy License application for special design facility p2-2-(3), Table1	(T)RPD
(2) Mechanical properties of Zr-2.5wt%N b alloy	(2) Mechanical properties of Zr-2.5wt% Nn al loy	(T)FD
(i) Yield strength	(i) Yield strength License application for special design facility p2-2-(12), Fig.1 Remarks: BLW-250-TECH NOTE 61, (1964)	
(ii) Tensile strength	(ii) Tensile strength License application for special design facility p2-2-(18), Fig.4 Remarks: BLW-250-TECH NOTE 61, (1961)	
(iii) Creep rupture strength	(iii) Creep rupture strength License application for special design facility p2-2-(18), Fig.14 Remarks: AECL MET-1-58 (1965)	
(iv) Creep rate	(iv) Creep rate Design equation $\dot{\varepsilon}=3.12\times10^{-24}\cdot\phi\cdot\sigma\cdot(T-160)$	

	License application for special design facility p2-2-(22), Table 9 p2-2-(23), Table10 p2-2-(27), Fig.8 p2-2-(28), Fig.9 CRNL-67, (1967); J. of Nuclear Materials, 26, (1968) p2-111; AECL-3365; CNA (1965), P537; CRNL-139, (1968); AECL MET-1-58; Emprical formula $\dot{\varepsilon} = \dot{\varepsilon}_o \cdot f(\phi t) + B \cdot f(A) \cdot \sigma^n \cdot \phi^p \cdot t^{m-1} \cdot f(T) + f(G)$ 1st term:time-dependent creep behavior 2nd term:effect of irradiation on creep 3rd term:irradiation growth (no load) $\dot{\varepsilon}_o$: Out-of-core creep rate ϕ : Fast neutron flux t : Time B : Constant f (A) : Function regarding amisotropy σ : Stress n, p, (m-1) : Indexes, (1,1,0) T : Temperature f (G): Function regarding irradiation gronth, etc. Remarks: J. of Nuclear Materials, 45, (1973) p335-338 and 46, (1973), p281-292; Ross-Ross, JOICE Meeting (1973); p2-2-(29), Eq.(2) in license application for special design facility Empirical formula The 1st term the empirical formula (Ref.1) can be ignored for long-term cerrp, and the 3rd term can be included in the 2nd term. As a result, the following formula can be proposed. $\dot{\varepsilon} = K \cdot \sigma \cdot \phi \cdot \exp(-5500/RT)$ License application for special design facility p2-2-(33), Fig.11	

	K : 5.5×10^{-25} R : Gas constant, 1.985 Kcal/Kmol・^{o}K T : Operating temperature, ^{o}K σ : Stress, MN/m^2 Remarks: Ross-Ross, JUICE Meeting (1973); p2-2-(30), Eg.(3) in license application for special design facility	
(v) Young's modulus	(v) Young's modulus License application for special design facility p2-2-(72), Table28 p2-2-(72), Table29 Remarks: CRNL FD-34-19, (1964) CGE TECH, DATA, No. 75-379 (1966)	
(vi) Poisson's ratio	(vi) Poisson's ratio License application for special design facility p2-2-(73), Table30 Remarks: CGE TECH, DATA, No. 75-379 (1966)	
(vii) Modulus of longitudinal elasticity	(vii) Modulus of longitudinal elasticity License application for special design facility p2-4-(9), Table4	
(3) Thermal characteristics of Zr-2.5wt% Nb alloy	(3) Thermal characteristics of Zr-2.5wt%Nb alloy	(T)THD
(i) Thermal conductivity	(i) Thermal conductivity License application for special design facility p2-2-(75), Fig.27	(T)FD
(ii) Coefficient of thermal expansion	(ii) Coefficient of thermal expansion (Coefficient of linear expansion) License application for special design facility p2-2-(75), Fig.28 p2-2-(75), Table31	

	Ref.: HW-60903, (1959)	
(iii) Specific heat	(iii) Specific heat License application for specfic design facility p2-2-(76), Fig.29 p2-2-(76), Table32 Ref.: BMI-1644, (1963); J. of Nuclear Materials, 18, (1966), p233	
(iv) Density	(iv) Density 0.238lb/in^3=6.6g/cm^3 License application for specific design facility p2-2-(74)	
(4) Fatigue characteristics	(4) Fatigue characteristics (design fatigue diagram) License application for special design facility p2-2-(54), Fig.22 Ref.: TRG/AECL NEWSLETTER-14, (1965) JAERI-memo 4604, (1971)	
(5) Corrosion characteristics	(5) Corrosion characteristics Design corrosion allowance for neutral water design fretting corrosion allowance design corrosion allowance for carbon for carbon dioxide gas License application for special design facility p2-2-(63), Table1 (except central portion) Ref.: BLW-250-NOTE- MET.5 (1966)	(T)FD
(6) hydrogen absorption characteristics	(6) Hydrogen absorption characteristics License application for special design facility p2-2-(70), Table27 p2-2-(70), Table26 Ref.:BLW-250-TBCH NOTE 61, (1966); AECL MET-1-58, (1965) Basis for evaluating the hydrogen absorption amount to be 211ppm after 30yr : Design hydrogen absorption of a pressure tube given by BLW-250=110ppm for 10yr, wall thickness …0.095" p2-2-(70), Table27	(T)FD

	Design hydrogen absorption of the pressure tube of "Fugen"= (110ppm) $\cdot \frac{0.095}{(4.3/25.4)''} \cdot \frac{30yr}{10yr}$ =186ppm Initial hydrogen content 25ppm Hydrogen content after 30yr 25ppm + 186ppm= 211ppm	
(7) Brittleness	(7) Brittleness	
(i) Crack propagation characteristics	(i) Crack propagation characteristics License application for special design facility p2-3-(29), Fig.15 (at room tempera ture) p2-3-(30), Fig.16 (at 300 ℃)	
(ii) Fatigue crack initiation characteristics	(ii) Fatigue crack initiation characteristics License application for special design facility p2-3-(28), Fig.14	
(iii) Fracture toughness	(iii) Fracture toughness License application for special design facility p2-3-(31), Fig.17 (effects of hydrogen content) p2-3-(32), Fig.18 (effects of temp rature	
(v) Limit defect	(v) Limit defect License application for special design facility p2-3-(34), Fig.20 (at room temperature) p2-3-(35), Fig.21 (at 300 ℃) p2-3-(37), Fig.23 (250ppm H_2)	
(e) LBB test	(vi) LBB test License application for special design facility p2-1-(32), Table1	

2. Material characteristics of pressure tube extension (1) Composition of SUS50Mod. (2) Mechanical properties of SUS50Mod. (3) Impact transition characteristics of SUS50Mod.	2. Material characteristics of pressure tube extension (1) Composition of SUS50Mod. (Results of development of "Fugen" p79, Table2, 3 and 11) (2) Mechanical properties of SUS50Mod. (Results of development of "Fugen" p79, Table2, 3 and 11) (3) Impact transition characteristics of SUS 50Mod. (Results of development of "Fugen" p80, Fig.s 2, 3 and 24)	
3. Load conditions for stress calculation for pressure tube (1) Stress calculati on point (2) Design load conditions (i) Dead load (ii) Pressure / temperature under max. working conditions (iii) Pressure/temperature under plant operation	3. Load conditions for stress calculation for pressure tube (1) Stress calculation point (near lower rolled joint) (License application for special design facility p2-4-(1), Fig.1) (2) Design load conditions (i) Dead load (D) Upper extended tube 101kg Pressure tube 56kg Total 157kg (ii) Pressure/temperature under max. working conditions (O_D) Max. working pressure 82.0kg/cm^2 G Max. working temperature 296℃ (iii) Pressure/temperature under plant operation (O_P) (License application for special design facility p2-4-(3) to (4), Fig.2)	

(iv) Load applied at the time of design earthquake	(iv) Load applied at the time of design earthquake (S_H) Horizontal seismic force Bending moment 1.55×10^5kg・mm Shear force 148kg Vertical seismic force 45kg	
(v) Stress from piping due to its self-weight	(v) Stress from piping due to its self-weight and heat (P_{RO}) Bending moment 1.0×10^3kg・mm Axial force 31kg Forsional moment 1.3×10^4kg・mm (License application for special design facility p2-4-(6), Table1)	
(vi) Reaction from piping due to design earthquake	(vi) Reaction from piping due to design earthquake (P_{RS}) Moment 3.0×10^3kg・mm Axial force 73kg Forsional moment 6.6×10^4kg・mm (License application for special design facility p2-4-(8), Table2)	
(3) Temperature distribution (i) Evaluation point for temperature distribution	(3) Temperature distribution (i) Evaluation point for temperature distribution (License application for special design facility p2-4-(11), Fig.3)	
(ii) Change in temperature distribution	(ii) Change in temperature distribution (License application for special design facility p2-4-(12), Fig.4-1 p2-4-(13), Fig.4-2 p2-4-(14), Fig.4-3)	
4. Rolled joint tests (1) Summary of rolled joint tests (i) Upper rolled joint test for short pressure tube	4. Rolled joint tests (1) Summary of rolled joint tests (i) Upper rolled joint test for short pressure tube (License application for special design facility p3-(2), Table1)	

(ii) Lower rolled joint test for short pressure tube	(ii) Lower rolled joint test for short pressure tube License application for special design facility p3-(2), Table2	
(iii) Test for full-scale pressure tube assembly	(iii) Test for full-scale pressure tube assembly License application for special design facility p3-(3), Table3	
(2) Summary of results of rolled joint tests	(2) Summary of results of rolled joint tests License application for special design facility p3-(4), Table4	
(3) Results of upper rolled joint tests fors hort pressure tube	(3) Results of upper rolled joint tests for short pressure tube License application for special design facility p3-(25), Table 5 p3-(27), Table 6 p3-(29), Table 7	
(4) Results of lower rolled joint tests fors hort pressure tube	(4) Results of lower rolled joint tests for short pressure tube License application for special design facility p3-(31), Table 8 p3-(33), Table 9 p3-(35), Table 10	
(5) Results of full-scale pressure tube assembly	(5) Results of full-scale pressure tube assembly License application for special design facility p3-(45), Table11	
5. Pressure tube mon itoring (1) Pressure tube monitoring plan	5. Pressure tube monitoring (1) Pressure tube monitoring plan Application for construction modification permit of ATR prototype reactor, attached documents, (final documents) Attached document8, supplement6, p109 Attached papers 2, p2-1-(10) to (10)	(T)PD

	Follow-up pressure tube inspection Inspection item : creep strain Number of pressure tubes for inspection : 4 tubes In-service inspection Inspection item : defect inspection using ultrasonic wave observation of inside surface with ITV Number of pressure tubes for inspection : 10% pressure tubes for 10yr	
(2) Monitoring using monitoring test pieces	(2) Monitoring using monitoring test pieces	(T)PD
(i) Kind of monitoring test pieces	(i) Kind of monitoring test pieces Application for construction modification permit of ATR prototype reactor, Attached documents (final documents), Attached documents8, supplement 2, p.93 ditto, Fig.3.3-3, p11 Tension test piece Bending test piece Corrosion test piece	
(ii) Monitoring test piece withdrawal plan	(ii) Monitoring test piece withdrawal plan Application for construction modification permit of ATR prototype reactor, (final documents) Attached documents8, supplements 5, p103, Table	
(iii) Monitoring using CO_2 gas system	(iii) Monitoring using CO_2 gas system Monitor by detecting the moisture content at the outlet of the CO_2 gas system.	(T)PD

References

(1) Application for construction modification permit of ATR prototype reactor, Attached document 8 (June, 1976)

(2) Application for construction modification permit of ATR prototype reactor, Committee 63, Reference paper, (November, 1970)

(3) Application for construction modification permit of ATR prototype reactor, Committee 82, Reference paper, (January, 1972)

(4) Application for construction modification permit of ATR prototype reactor, Committee 105, Reference paper,(September, 1974)

(5) Application for fuel assembly design approval for initial core loading of ATR protptype reactor, Tsuruga works, (November, 1974)

(6) Application for specially designed facility approval based upon nuclea power station engineering standards, (February, 1974)

(7) "Fugen", reseach and development, PNC, (June, 1991)

(8) "Fugen" Commissioning Tests, PNC SN 79-11, (September, 1979)