

Water Chemistry of JPDR

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Water Chemistry of JPDR

Summary

The results of various measurements of the chemical aspect of the JPDR have already been described in JAERI No. 1067 on the initial power-up test of this reactor. In order to perform more reliable measurements in the chemical aspect of this reactor, numerous data have been measured since the initial power-up test. The results of these measurements are summarized in this paper. From these results, the release rates of radioiodine and metals such as iron, copper and nickel were estimated and analysed, and the following are concluded: the reliability of the results of the initial power-up test and the excellence of the chemical aspect of this reactor, including the suppression of the release of the radioiodine from the coolant system, the accumulation of corrosion products and the transfer and the deposition of the radioactive nuclides in the coolant system, have been confirmed through these measurements. The chemical aspects of the JPDR with of other BWRs are also compared.

Oct. 1966

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JPDR の 水 化 学

要 旨

JPDR における化学的測定結果の信頼性を高めるために、初回出力試験以来現在にいたるまで、諸種測定、分析を実施して、その結果を蓄積してきた。これらの測定結果をもとに JPDR における放射性ヨウ素と金属腐食生成物の放出率を計算して、その挙動の解析を試みた。初回出力試験の結果の信頼性の高いこと、および特に冷却系外への放射性ヨウ素の放出と冷却系内における金属腐食生成物の蓄積、そして放射性核種の移行と付着の抑制という点において、JPDR の化学的側面の優れた実用性を、これらの測定結果から確認した。そして、JPDR と他の BWR の化学的側面との比較を試みた。

1966 年 10 月

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1. Introduction

Since the initial start-up in October 1963, the JPDR (Japan Power Demonstration Reactor) has operated at approx. 10,000 MWD (thermal). During the operation for three years, a large amounts of the measured data have been obtained in the chemical aspect of the JPDR. Emphasis was on the measurements of the release rates of radiolytic gases, fission products, and radioactivities from the corrosion products and the coolant. These phenomena are unique in water reactors.⁽¹⁾⁽²⁾⁽³⁾⁽⁴⁾⁽⁵⁾⁽⁶⁾⁽⁸⁾⁽⁹⁾ In this paper, the results of measurements of the radiolysis, radioiodine, induced activities and the water qualities of the various systems in the JPDR under the normal operation are reported, and these results and those of other boiling water type reactors are compared and discussed.

2. Flow diagram

The JPDR is a 45 MWt (12.5 MWe) natural circulation, direct single cycle boiling water reactor. The fuel pellets clad with zircaloy are made of 2.6 % enriched uranium dioxide. The pure deionized water (less than $1 \mu\Omega/\text{cm}$ at 25°C) is supplied as the coolant as well as the moderator. The make-up water mixed with the condensate from the turbine is purified by passing through the mixed ion exchange resin beds in the condensate demineralizer, and then is fed to the reactor core after heating with feedwater heaters. Part of the reactor water is continuously withdrawn at the rate of about 4 tons/hour and purified by passing through the mixed ion exchange resin bed in the clean up demineralizer after cooling in the regenerative and the nonregenerative heat exchangers through which the water flows at the rate of about 4 tons per hour. The steam generated in the reactor core flows out to the turbine for generating electricity, and is then condensed in the turbine-condenser by means of sea water cooler; the steam flows at about 70 tons per hour to the turbine in the full power operation. In Fig. 1, a simplified flow diagram of the JPDR is shown. The main structural materials in the JPDR plant are shown in TABLE 1.

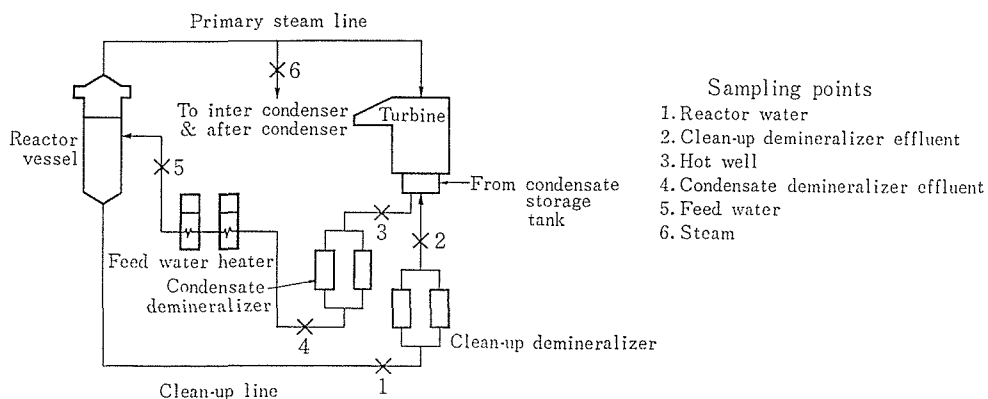


Fig. 1 Simplified flow diagram of primary coolant system of JPDR

TABLE 1 Main structural materials used in JPDR plant

Reactor vessel	304 SS cladding
Fuel element	Zircaloy-2 cladding
Reactor core	(Boron)SS
Control rod	(Boron)SS, Zircaloy-2
Chimney	304 SS
Regenerative heat exchanger	304 SS, SUS 27, STD 38
Non-regenerative heat exchanger	ASTMB 111, SB 42 B
Condenser	BsTF ₂ , SM 41, FC 25, NBsP ₁
Feed water heater 1	ASTM-163-58 T, JIS-SB-46B-SR, JIS-SF-50
" 2	ASTM-B-163, JIS-SB-46B-SR, JIS-SF-50
Primary steam piping	ASTM-A 335-P 22,
Primary piping	304 SS
Turbine	(Cr-Mo)SS, (Ni-Cr-V)SS, Carbon Steel etc.

3. Water Source

The raw water is fed to the JPDR plant from the Kuji river, via Akogigaura lake. The data of chemical analyses of the lake water are shown in TABLE 2. After filtration by the JAERI utility facility, the water is fed to the make up demineralizer of the JPDR. The data of chemical analyses of the JAERI water supply are shown in TABLE 3 and Fig. 2. (These data

TABLE 2 Qualities of water at Akogigaura

Item	Expression			
		Aug. 22, '61	Sep. 19, '61	Jan. 19, '62
Date				
Water temperature	°C	29.0	25.0	9.0
Turbidity		8.5	7.0	3.2
pH		8.5	7.4	6.6
Conductivity	$\mu\text{U}/\text{cm}$	140	125	80
M-alkalinity	as CaCO ₃ ppm	38.0	38.0	25.8
CO ₃ ⁻⁻	as ion ppm	0	0	0
HCO ₃ ⁻⁻	as ion ppm	38.0	38.0	25.8
Dissolved CO ₂	as CO ₂ ppm	0	3.52	2.46
Dissolved oxygen	as O ppm	8.96	7.60	10.6
NH ₄ ⁺	as ion ppm	0.026	trace	trace
NO ₂ ⁻	as ion ppm	<0.02	trace	0.024
NO ₃ ⁻	as ion ppm	0.07	0.33	0.08
Cl ⁻	as ion ppm	11.5	10.5	6.0
SO ₄ ⁻⁻	as ion ppm	6.2	8.2	14.7
Chemical oxygen demand	as ion ppm	2.0	1.10	1.8
Chlorine demand	Cl ppm	1.87	1.49	1.50
Total solid	ppm	156.0	135.0	44.0
Total hardness	as CaCO ₃ ppm	42.2	44.0	20.4
Calcium hardness	as CaCO ₃ ppm	31.8	31.8	11.0
Magnesium hardness	as CaCO ₃ ppm	10.4	12.2	9.4
Total iron	as ion ppm	0.40	0.45	0.45
Fe ⁺⁺	as ion ppm	0.24	0.45	0.20
Silica	as SiO ₂ ppm	13.4	16.9	16.8

TABLE 3 Qualities of water facility (cleaning)

Item	Expression	Expression		
		Aug. 22, '61	Sep. 19, '61	Jan. 19, '62
Date				
Water temperature	°C	27.0	23.0	7.5
Turbidity		0	0	0
pH		6.7	7.1	6.7
Conductivity	$\mu\text{S}/\text{cm}$	140	160	77
M-alkalinity	as CaCO_3 ppm	25.0	42.0	23.4
CO_3^{--}	as ion ppm	0	0	0
HCO_3^{--}	as ion ppm	25.0	42.0	23.4
Dissolved CO_2	as CO_2 ppm	3.52	5.28	2.82
Dissolved oxygen	as O ppm	7.84	7.20	11.9
NH^+	as ion ppm	trace	trace	0
NO_2^-	as ion ppm	<0.02	trace	0.02
NO_3^-	as ion ppm	trace	0.41	0.14
Cl^-	as ion ppm	11.5	9.5	6.0
SO_4^{--}	as ion ppm	9.0	8.0	22.6
Chemical oxygen demand	as ion ppm	0.90	0.30	1.25
Chlorine demand	Cl ppm	1.22	1.38	2.1
Total solid	ppm	140.0	161.0	30.0
Total hardness	as CaCO_3 ppm	44.0	40.0	22.0
Calcium hardness	as CaCO_2 ppm	30.2	30.2	7.4
Magnesium hardness	as CaCO_3 ppm	13.8	9.8	12.6
Total iron	as ion ppm	trace	trace	0.20
Fe^{++}	as ion ppm	trace	trace	0.1
Silica	as SiO_2 ppm	12.6	14.6	15.2

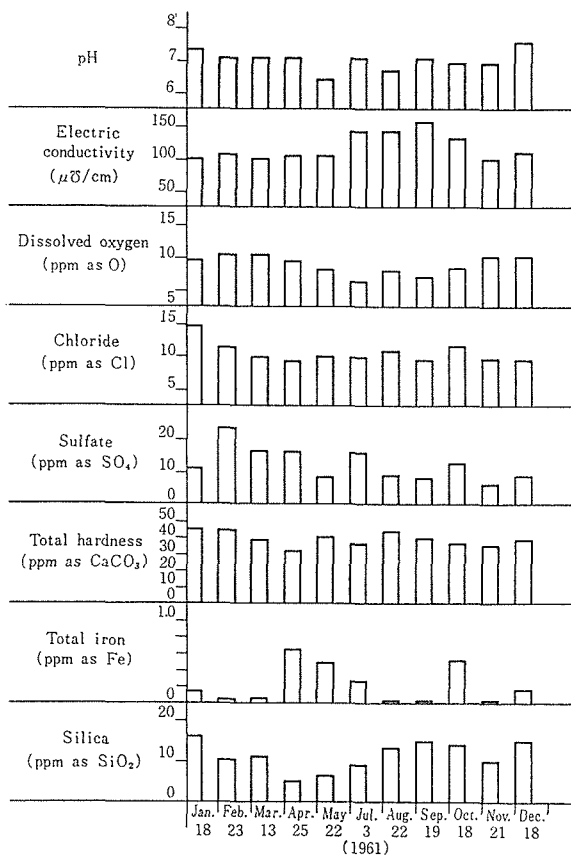


Fig. 2 Water qualities at water facility (cleaning) of JAERI

shown in Fig. 2, TABLES 2 and 3 were transmitted from Kurita Kogyo. Co.)

4. Make up water after the demineralizer

The make up demineralizer consists of a cation exchange resin unit, an anion exchange resin unit and a mixed resin unit. At the present time, the diaion SK1B is used as the cation resin and the diaion SA 10 A is used as the anion resin in this system. About 350 liters of the swelled resins are used respectively. The amount of deionized water which can be taken without regenerating the resin is about 60 tons in the cation unit, about 40 tons in the anion unit and about 1500~2500 tons in the mixed unit. The production of deionized water in each of the cycle is influenced by the quality of the service water, of the cation bed effluent and of the anion bed effluent. The water quality from the mixed bed is normally maintained at less than one $\mu\text{U}/\text{cm}$ at 25°C of the electric conductivity and less than 0.02 ppm of the soluble silica. The pH and the electric conductivity of the mixed bed effluent are continuously measured and recorded in the control panel. The amount of soluble silica in the mixed effluent is determined spectrophotometrically by chemical analysis. The deionized water is transferred to the storage tank by the transfer pump and stored in it.

5. Feedwater

The quality of feedwater is determined by the following three items during the power operation : 1) chemical interactions between the inner-surfaces of the pipes of the system and the water, 2) the state of the condensate demineralizer resins, and 3) the water quality in the hot well. Stainless steel is mainly used for the primary coolant system. Chromium-molybdenum steel is used for the main steam pipe, and the copper-nickel alloy is used for the feedwater heater pipe in the feedwater line. The copper and nickel dissolved in the feedwater from the feedwater heater pipe are the source of major activities induced in the reactor water during the operation. In TABLE 4 are shown the typical amounts of iron, copper and nickel in the reactor water, the clean up demineralizer effluent, the hot well, the condensate demineralizer effluent, the feed water and the steam. About 0.23 m^3 of the anion and about 0.45 m^3 of the cation resin are employed in the condensate demineralizer. The mixed resins are regenerated either when the electric conductivity of the effluent becomes larger than $1\text{ }\mu\text{U}/\text{cm}$ at 25°C or when the pressure difference between the influent and the effluent exceeds $3.0\text{ kg}/\text{cm}^2$. When the resins are replaced, the used resins are generally transferred and reused in the waste demineralizer, after regeneration. The insoluble substances are carried to the condensate demineralizer from the hot well ; they deposit on the demineralizer, as the residual. The major residual is iron oxide, while others are copper oxide, insoluble silica and organic matters such as the decrepited resin. The amount of dissolved oxygen in the feed water is thought to be dependent on the air leakage into the feedwater system from the turbine-condenser, and also on the air leakage at the turbine-condenser. At the start-up of the reactor and during the power-up, the amount of dissolved oxygen in the feed water is usually higher than during the normal power operation of the reactor. The results of determination of the dissolved oxygen in the feedwater and the reactor water as well as the reactor water quality, at the start-up of the reactor, are shown in Fig. 3.

TABLE 4 Results of determinations of iron, nickel and copper in sample water*

Date (1965)	sam- ple Metal	Reactor water			Clean-up effluent			Hot well			Condensate demineralizer effluent			Condensate storage tank			Feed water			Steam		
		Fe	Ni	Cu	Fe	Ni	Cu	Fe	Ni	Cu	Fe	Ni	Cu	Fe	Ni	Cu	Fe	Ni	Cu	Fe	Ni	Cu
9/26 (21MWt)	(F)	(≤1)	16	56	16	3	20	16	5	22	27	4	18	16	(1)	20	10	23	22	42	14	49
	(C)	28	9	15	7	(1)	5	32	2	10	12	2	5	39	2	7	15	2	6	361	7	30
	(T)	²⁸ ~ ²⁹	25	71	23	3~4	25	48	7	32	39	6	23	55	2~3	27	25	25	28	403	21	79
9/27 (42MWt)	(F)	14	17	68	(≤1)	8	11	12	4	23	12	11	97	15	(1)	6	13	7	23	16	6	26
	(C)	95	32	30	10	(1)	5	59	3	7	43	2	5	47	(1)	7	26	2	12	241	10	31
	(T)	109	49	98	¹⁰ ~ ¹¹	8~9	16	71	7	30	55	13	102	62	2	13	39	9	35	257	16	57
10/6 (37MWt)	(F)	25	24	51	14	6	5	15	6	14	23	6	(1)	11	6	28	41	6	13	35	7	17
	(C)	21	5	20	12	(1)	(2)	48	(1)	(4)	12	(1)	(3)	21	(1)	8	7	(1)	5	98	(1)	7
	(T)	46	29	71	26	6~7	5~7	63	6~7	¹⁴ ~ ¹⁸	35	6~7	~4	32	6~7	36	48	6~7	18	133	7~8	24
10/20 (6 MWt)	(F)	6	24	40	18	2	11	13	(1)	9	14	(1)	(3)	14	(1)	20	14	(1)	4	13	(1)	15
	(C)	38	24	23	(2)	2	4	97	9	(1)	7	14	(4)	19	9	(2)	6	14	(2)	7	2	(2)
	(T)	44	48	63	¹⁸ ~ ²⁰	4	15	110	⁹ ~ ¹⁰	⁹ ~ ¹⁰	21	¹⁴ ~ ¹⁵	~7	33	⁹ ~ ¹⁰	²⁰ ~ ²²	20	¹⁴ ~ ¹⁵	4~6	20	2~3	¹⁵ ~ ¹⁷
10/26 (40MWt)	(F)	16	14	52	23	(1)	(1)	11	4	13	11	(1)	(1)	16	(1)	(1)	17	(1)	6	14	(1)	3
	(C)	12	3	7	4	3	(2)	33	3	(3)	26	3	(1)	7	3	7	16	3	7	130	6	17
	(T)	28	17	59	27	3~4	~3	44	7	¹³ ~ ¹⁶	37	3~4	~2	23	3~4	7~8	33	3~4	13	144	6~7	20
10/30 (40MWt)	(F)	8	28	98	9	22	27	8	2	8	8	(1)	(2)	9	(1)	7	8	4	21	5	2	7
	(C)	9	3	8	7	3	(1)	19	3	(2)	26	3	4	10	3	3	5	3	5	7	3	7
	(T)	17	31	106	16	25	²⁷ ~ ²⁸	27	5	⁸ ~ ¹⁰	34	3~4	4~6	19	3~4	10	13	7	26	12	5	14
11/5 (40MWt)	(F)	10	29	99	12	(1)	10	14	(1)	7	10	9	3	10	(1)	13	11	18	18	12	35	6
	(C)	9	3	12	6	3	(1)	26	3	(2)	9	3	5	11	3	6	5	3	8	7	3	6
	(T)	19	32	111	18	3~4	¹⁰ ~ ¹¹	40	3~4	7~9	19	12	8	21	3~4	19	16	21	26	19	38	12

* The unit is in parts per billion; the value in the parenthesis means less than the limits of the determination.

(F) : Filtrate; (C) : Crud; (T) : Total

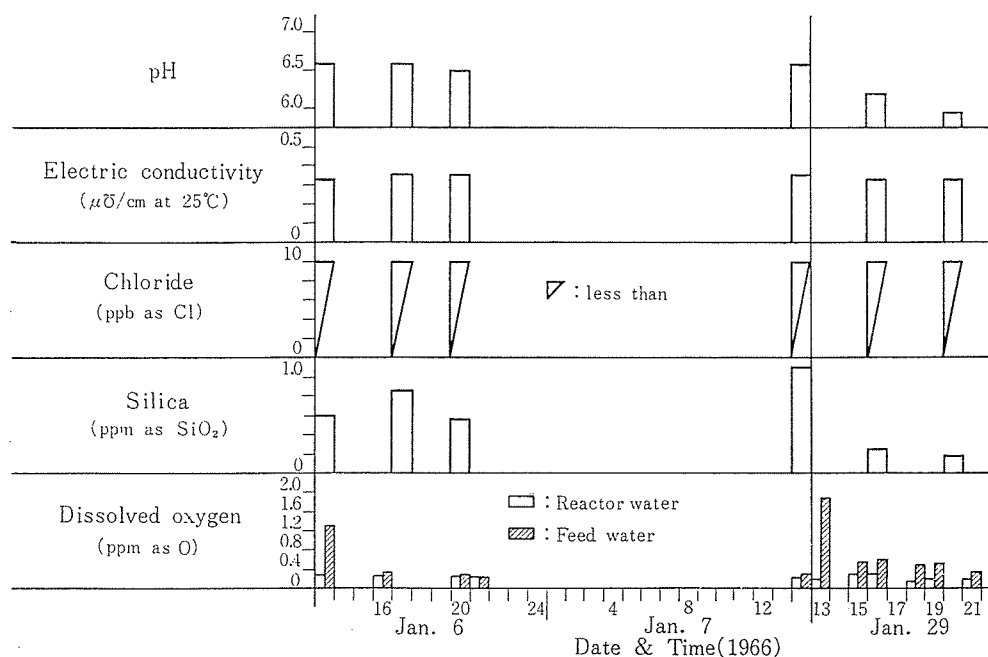


Fig. 3 Variation of reactor water quality and dissolved oxygen in reactor water and feed water at reactor start-up

6. Reactor water

The water quality in the reactor vessel is dependent on the feed water quality. In the full power operation, the coolant water is fed continuously to the reactor at the rate of about 70 tons per hour from the feedwater system and is taken out as the steam into the steam line. In the pressure vessel, the coolant as well as the fuel and other structural materials are under pressure of about 61.4 kg/cm², at 277 °C; the neutron flux is about 1.4×10^{13} neutron/cm²/sec where the radiolytic gas formation, the production and deposition of corrosion products and various induced activities occur. Therefore, the water quality of the reactor coolant is strictly maintained, as follows: electric conductivity <1 μΩ/cm at 25 °C, pH 5.5~7.5, Cl as chloride <100 ppb, silica <1 ppm and boron <1 ppm.

6.1 Induced activities

The corrosion products from the material of the primary coolant system are the major sources of induced radioactive nuclides such as copper-64, manganese-56 and cobalt-58. These nuclides are produced by such nuclear reactions as $^{63}\text{Cu}(n, \gamma)^{64}\text{Cu}$, $^{56}\text{Fe}(n, p)^{56}\text{Mn}$ and $^{58}\text{Ni}(n, p)^{58}\text{Co}$. The nuclides, the sodium-24 and the fluorine-18 also exist. These are produced by $^{23}\text{Na}(n, \gamma)^{24}\text{Na}$ and $^{18}\text{O}(p, n)^{18}\text{F}$, respectively. The condensate demineralizer resin and the coolant are thought to be as the sources of sodium-24 and oxygen-18, respectively. The minor induced radioactive nuclides, such as ^{51}Cr , ^{54}Mn , ^{59}Fe , ^{60}Co , ^{65}Zn , ^{95}Zr , ^{99}Mo , $^{110\text{m}}\text{Ag}$, ^{124}Sb and ^{187}W are also detected in the reactor water of the JPDR. The results of measurements of the radioactive nuclides in the reactor water from 149 EFPH (Equivalence to Full Power Hour) to 3951 EFPH are shown in Figs. 4, 5 and 6. The activity balances of the reactor water under the normal full power operation show that the activity of each nuclide such as ^{64}Cu , ^{56}Mn and ^{18}F

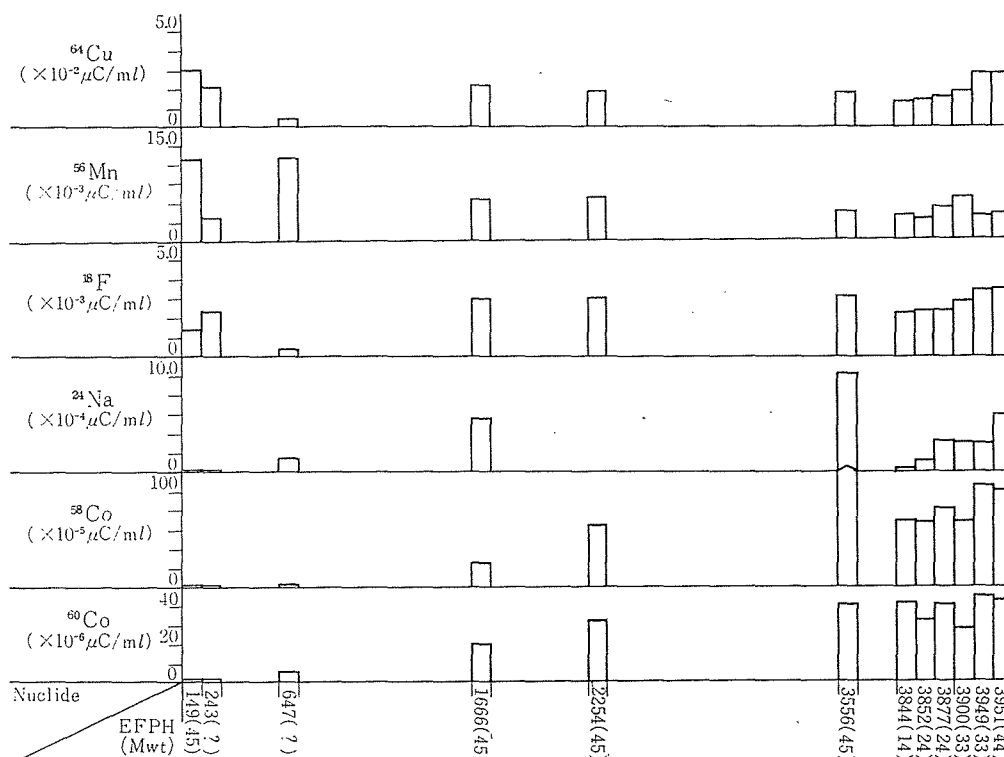


Fig. 4 Activity of Each nuclides in reactor water filtrate at each EFPH

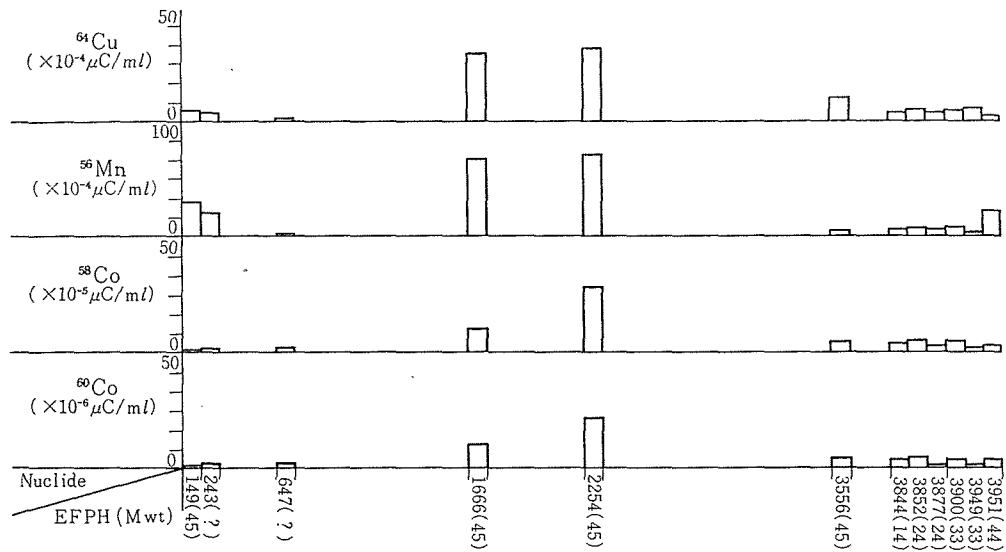


Fig. 5 Activity of each nuclides in reactor water crud at each EFPH

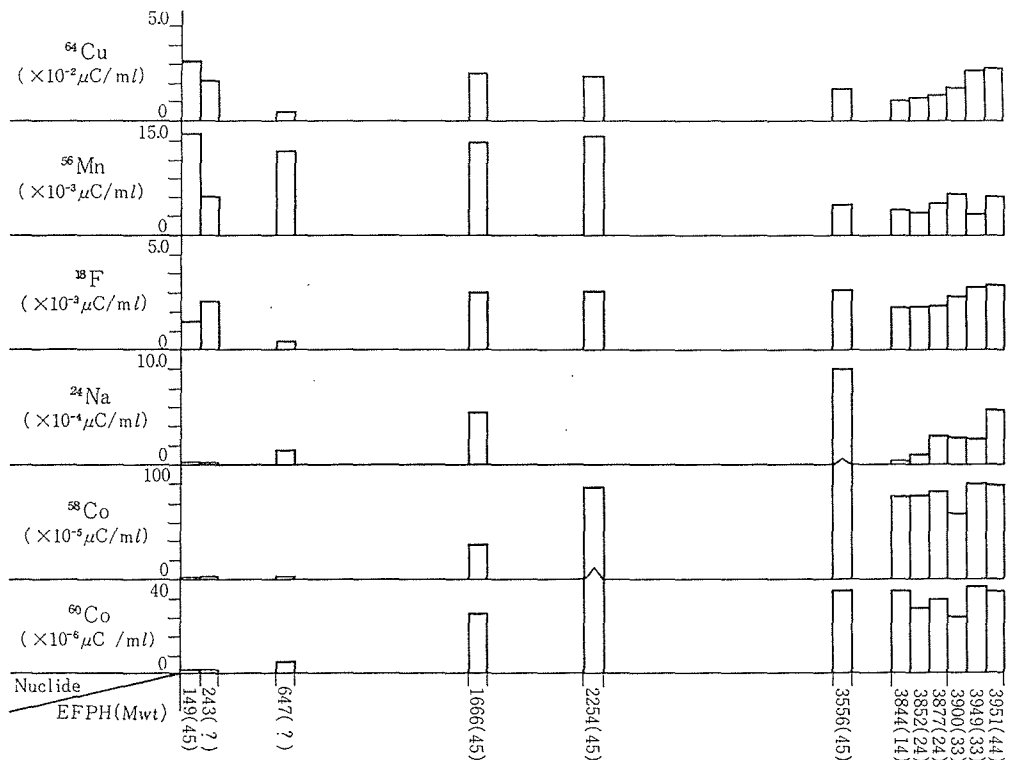


Fig. 6 Activity of each nuclides in reactor water at each EFPH

is in constant ranges at each EFPH and the major nuclides of the activity at full power consist of these three. Each nuclides as described above were measured after chemical separations.⁽¹⁰⁾ In fact, the total gamma activity of the reactor water when 2 hours passed away after sampling has not changed significantly in the normal full power operation of the reactor. The gamma activity of the reactor water due to the three nuclides is about $5 \times 10^{-2} \mu\text{C}$ per ml at maximum, copper-64 and manganese-56 constituting 90 % of the total. About 90 % of the gamma activity in the reactor water, due to radioactive nuclide of half lives longer than about 30 days, is from cobalt-58. About 99 % of the gamma activity in the primary steam due to radioactive nuclides of half lives longer than 10 min. are from nitrogen-13 and fluorine-18.

The sources of these nuclides are explained in the item of 9, steam. The metals in the reactor water are mainly iron, copper and nickel; their amounts are to be ~ 100 ppb, ~ 100 ppb and ~ 50 ppb, respectively, and amounts of chromium, manganese and molybdenum are less than several ppb. The feedwater brings iron, copper and nickel as corrosion products into the reactor water.

6. 2 Behaviors of metal corrosion products

The deposit rates of these metals in the reactor vessel were estimated from the amounts of the metals in the reactor water and feedwater, as follows. The assumptions were first made: 1) the reactor water temperature is approximately the same in the pressure vessel, at any power level during the normal operation, 2) the flow rate of the steam and of the feedwater are proportional to the reactor power level, 3) the carry over of these metals into the steam is negligible, 4) all metals cruds are scavenged in the clean up demineralizer and never returns to the reactor vessel, and 5) the metal concentration of the primary coolant system is in the equilibrium state. By the assumptions, the mass balance in the reactor water of the JPDR may be expressed as

$$\frac{dx}{dt} \cdot V_p = V_F \cdot Y - V_c \cdot x - A \cdot V_p \quad (1)$$

V_p : the mass of the reactor water, g.

V_F : the flow rate of the feed water, g/hr.

V_c : the flow rate in the clean up line, g/hr.

x_0 and x : the concentration of metal in the reactor water, $\mu\text{g/g}$.

Y : the concentration of metal in the feed water, $\mu\text{g/g}$.

A : the deposition rate of the metal in the reactor vessel, $\text{ppb} \cdot \text{hr}^{-1}$.

Here, Y represents $1/2 \cdot (Y_1 + Y_2)$ or $1/2 \cdot (Y_2 + Y_3)$ and dt is counted in the unit of 24 hours. The suffix to Y is the measuring order number. And $dx/dt \equiv (x - x_0)/24$ ($\mu\text{g/ml/hour}$). V_p and V_c are 1.5×10^7 g and 3.2×10^6 g/hr, respectively, at room temperature and atmospheric

TABLE 5 Values of x , x_0 , mean Y and calculated values of " A/x " and " A'/x " for Cu filtrate at each MWt

MWt	series No.	x $\mu\text{g/ml}$	x_0 $\mu\text{g/ml}$	Y $\mu\text{g/ml}$	A/x hr^{-1}	A'/x hr^{-1}
14	1	29.3×10^{-3}				
	2	37.7×10^{-3}	29.3×10^{-3}	4.8×10^{-3}	-0.02	-0.01
	3	29.5×10^{-3}	37.7×10^{-3}	6.4×10^{-3}	0.14	0.13
	Av				0.06	0.06
24	1	44.0×10^{-3}				
	2	26.7×10^{-3}	44.0×10^{-3}	4.2×10^{-3}	0.13	0.10
	3	30.0×10^{-3}	26.7×10^{-3}	4.2×10^{-3}	0.05	0.06
	Av				0.09	0.08
33	1	10.8×10^{-3}				
	2	30.3×10^{-3}	10.8×10^{-3}	3.0×10^{-3}	0.12	0.14
	3	16.1×10^{-3}	30.3×10^{-3}	6.3×10^{-3}	1.2	1.2
	Av				0.66	0.67
44	1	36.2×10^{-3}				
	2	30.2×10^{-3}	36.2×10^{-3}	9.8×10^{-3}	1.4	1.4

TABLE 6 Values of x , x_0 , mean Y and calculated values of " A/x " and " A'/x " for Cu crud at each MWt

MWt	series No.	x $\mu\text{g/ml}$	x_0 $\mu\text{g/ml}$	Y $\mu\text{g/ml}$	A/x hr^{-1}	A'/x hr^{-1}
14	1	4.6×10^{-3}				
	2	3.2×10^{-3}	4.6×10^{-3}	7.6×10^{-3}	3.4	3.4
	3	9.2×10^{-3}	3.2×10^{-3}	6.9×10^{-3}	0.9	1.0
	Av				2.2	2.2
24	1	$\leq 2.0 \times 10^{-3}$				
	2	5.1×10^{-3}	$\leq 2.0 \times 10^{-3}$	2.8×10^{-3}	1.0	1.0
	3	11.5×10^{-3}	5.1×10^{-3}	4.0×10^{-3}	0.51	0.54
	Av				0.75	0.77
33	1	$\leq 2.0 \times 10^{-3}$				
	2	15.6×10^{-3}	$\leq 2.0 \times 10^{-3}$	7.2×10^{-3}	1.4	1.4
	3	2.1×10^{-3}	15.6×10^{-3}	7.2×10^{-3}	12.0	11.5
	Av				6.7	6.5
44	1	3.0×10^{-3}				
	2	2.0×10^{-3}	3.0×10^{-3}	2.2×10^{-3}	5.2	5.2

TABLE 7 Values of x , x_0 , mean Y and calculated values of " A/x " and " A'/x " for Fe filtrate at each MWt

MWt	serie No.	x $\mu\text{g/ml}$	x_0 $\mu\text{g/ml}$	Y $\mu\text{g/ml}$	A/x hr^{-1}	A'/x hr^{-1}
14	1	7.3×10^{-3}				
	2	5.7×10^{-3}	7.3×10^{-3}	6.4×10^{-3}	1.5	1.5
	3	11.2×10^{-3}	5.7×10^{-3}	5.4×10^{-3}	0.6	0.5
	Av				1.2	1.2
24	1	5.7×10^{-3}				
	2	5.5×10^{-3}	5.7×10^{-3}	3.4×10^{-3}	1.2	1.2
	3	3.7×10^{-3}	5.5×10^{-3}	3.5×10^{-3}	2.0	2.0
	Av				1.6	1.6
33	1	9.0×10^{-3}				
	2	13.5×10^{-3}	9.0×10^{-3}	7.5×10^{-3}	1.7	1.7
	3	9.0×10^{-3}	13.5×10^{-3}	7.5×10^{-3}	3.2	2.7
	Av				2.5	2.2
44	1	6.4×10^{-3}				
	2	6.4×10^{-3}	6.4×10^{-3}	6.9×10^{-3}	5.1	5.1

pressure. V_F is read from the recorder in the control room. The estimated deposition rates of iron, copper and nickel are given, as examples, in TABLES 5, 6, 7, 8, 9 and 10. When the primary coolant system is in the equilibrium state, dx/dt should be approximately equal to zero in the equation (1). When $dx/dt=0$, the deposition rate A' , of a metal in the reactor vessel, can be calculated. The measured values of x and Y shown in TABLES 5, 6, 7, 8, 9 and 10 appear to be relatively low, within the reproducibility of measurements. In fact, it has been nearly impossible to expect both the perfect equilibrium state of the primary coolant system at various MWt level and the statistically ideal distribution of the metal concentration all over in the primary coolant. Therefore, the measurements of x and Y seem to be difficult, which are

TABLE 8 Values of x , x_0 , mean Y and calculated values of " A/x " and " A'/x " for Fe crud at each MWt

MWt	series No.	x $\mu\text{g/ml}$	x_0 $\mu\text{g/ml}$	Y $\mu\text{g/ml}$	A/x hr^{-1}	A'/x hr^{-1}
14	1	7.3×10^{-3}				
	2	6.3×10^{-3}	7.3×10^{-3}	5.8×10^{-3}	1.1	1.1
	3	8.3×10^{-3}	6.3×10^{-3}	5.3×10^{-3}	0.8	0.7
	Av				1.0	0.9
24	1	3.0×10^{-3}				
	2	5.3×10^{-3}	3.0×10^{-3}	8.3×10^{-3}	3.4	3.4
	3	51.7×10^{-3}	5.3×10^{-3}	14.8×10^{-3}	0.4	0.4
	Av				1.9	1.9
33	1	14.0×10^{-3}				
	2	10.0×10^{-3}	14.0×10^{-3}	6.5×10^{-3}	2.0	2.0
	3	6.3×10^{-3}	10.0×10^{-3}	6.9×10^{-3}	3.6	3.6
	Av				2.8	2.8
44	1	$\leq 2.0 \times 10^{-3}$				
	2	40.8×10^{-3}	$\leq 2.0 \times 10^{-3}$	3.2×10^{-3}	0.2	0.25

TABLE 9 Values of x , x_0 , mean Y and calculated values of " A/x " and " A'/x " for Ni filtrate at each MWt

MWt	series No.	x $\mu\text{g/ml}$	x_0 $\mu\text{g/ml}$	Y $\mu\text{g/ml}$	A/x hr^{-1}	A'/x hr^{-1}
14	1	8.4×10^{-3}				
	2	2.7×10^{-3}	8.4×10^{-3}	6.5×10^{-3}	3.6	3.5
	3	4.8×10^{-3}	2.7×10^{-3}	7.1×10^{-3}	2.1	2.0
	Av				2.8	2.8
24	1	13.2×10^{-3}				
	2	26.4×10^{-3}	13.2×10^{-3}	1.4×10^{-3}	-0.2	-0.2
	3	18.6×10^{-3}	26.4×10^{-3}	2.9×10^{-3}	0.2	0.2
	Av				0~	0~
33	1	1.5×10^{-3}				
	2	3.6×10^{-3}	1.5×10^{-3}	1.0×10^{-3}	0.8	0.8
	3	$\leq 1.0 \times 10^{-3}$	3.6×10^{-3}	1.3×10^{-3}	4.4	4.3
	Av				2.6	2.6
44	1	5.3×10^{-3}				
	2	4.4×10^{-3}	5.3×10^{-3}	2.7×10^{-3}	2.8	2.8

reliable and reproducible and from which the relationship between A , x or Y , and the thermal power may be derived. But as the ranges of x and Y in the normal power operation can be determined by chemical analysis⁽⁷⁾, the range of A should be derived from the results of measurements of x and Y and from the equation (1); then the apparent deposition (or release) rates of the metals in the reactor vessel can be calculated. The apparent corrosion rate of the feedwater heater pipe calculated from the apparent deposition rate of the copper in the reactor vessel almost agree with that calculated from the copper concentration in the feedwater, in the unit of $\mu\text{g/cm}^2/\text{hr}$ at full power. The calculated apparent deposition rate of the copper and nickel is about $1.5 \mu\text{g/cm}^2/\text{hr}$, and the value from the copper and nickel in the feedwater

TABLE 10 Values of x , x_0 , mean Y and calculated values of " A/x " and " A'/x " for Ni crud crud at each MWt

MWt	series No.	x $\mu\text{g/ml}$	x_0 $\mu\text{g/ml}$	Y $\mu\text{g/ml}$	A/x hr^{-1}	A'/x hr^{-1}
14	1	2.1×10^{-3}				
	2	16.0×10^{-3}	2.1×10^{-3}	4.4×10^{-3}	0.2	0.2
	3	7.4×10^{-3}	16.0×10^{-3}	5.2×10^{-3}	0.9	0.9
	Av	-	-	-	0.6	0.6
24	1	7.4×10^{-3}				
	2	9.0×10^{-3}	7.4×10^{-3}	2.7×10^{-3}	0.4	0.4
	3	9.0×10^{-3}	9.0×10^{-3}	1.6×10^{-3}	0.1	0.1
	Av	-	-	-	0.3	0.3
33	1	$\leq 1.0 \times 10^{-3}$				
	2	$\leq 1.0 \times 10^{-3}$	$\leq 1.0 \times 10^{-3}$	3.4×10^{-3}	11.6	11.6
	3	$\leq 1.0 \times 10^{-3}$	$\leq 1.0 \times 10^{-3}$	4.0×10^{-3}	13.7	13.7
	Av	-	-	-	12.6	12.6
44	1	2.0×10^{-3}				
	2	$\leq 1.0 \times 10^{-3}$	2.0×10^{-3}	1.0×10^{-3}	4.7	4.7

is about $1 \mu\text{g/cm}_2/\text{hr}$. The difference between two values seems to be due to stainless steel of the pressure vessel.

6. 3 Radiolytic gas

During the power operation of the JPDR, the radiolytic gases are released from the reactor core, mixed with the steam. Supposing the radiolysis of the reactor water proceeds stoichiometrically and the ratio of the absorbed oxygen (ppm) vs it's saturation solubility (ppm) is equal to the ratio of the absorbed hydrogen (ppm) vs it's solubility (ppm), in the condensed steam at sampling, the experimental expression for the release rate of radiolytic gas at JPDR, R is described as

$$R = \left\{ K \left(1 - \frac{P_{\text{H}_2\text{O}}}{P_A} \right) (2S_{\text{H}_2} + S_{\text{O}_2}) + \frac{V_g}{V_1} \right\} W_s \quad (2)$$

where,

K : the correction factor for the free gas absorbed in the condensed steam at the sampling line when the measurement is made,

P_A : the atmospheric pressure under which the measurement is made,

$P_{\text{H}_2\text{O}}$: the saturation steam pressure at room temperature, mmHg,

S_{H_2} : the solubility of hydrogen gas in the water (V/V) at room temperature and atmospheric pressure 760 mmHg,

S_{O_2} : the solubility of oxygen gas in the water (V/V) at room temperature and atmospheric pressure 760 mmHg,

V_g : the flow rate of free gas in the steam, through the sampling line (STP),

V_1 : the flow rate of condensate through the sampling line,

W_s : the flow rate of main steam, in the volume at room temperature and atmospheric pressure, and not in the mass.

To estimate K in the equation (2), it is necessary to measure the temperature of sample condensate and the dissolved oxygen in the condensate. The gas chromatographic analysis shows that the radiolysis in the reactor core is apparently of a stoichiometric reaction. For

the JPDR, K is approximately 0.10~0.15. The measured apparent release rates of the radiolytic gas are shown in TABLE 11 together with the results of other BWR's. The fluctuations

TABLE 11 Radiolytic gas release rate

Reactor	MWt	Release rate (l/min)	Release rate/MWt
JPDR	14	25.5 Av. of 5 samples	1.8
	24	33.5 "	1.4
	33	51.4 "	1.6
	44	75.3 "	1.7
			Av. 1.6
EBWR ¹⁾	20*		Av. 1.8
VBWR ²⁾	20**		Av. 1.75
Dresden ³⁾			Av. 1.6
SENN ⁹⁾			Av. 1.5
* 600 P. S. I.		** 1000 P. S. I.	
JPDR	22.5***	33.3 Av. of 3 samples	1.5
	22.5****	29.7 "	1.3†
	22.5****	28.3 Av. of 2 samples	1.3†
*** Feed Water Temperature, 108°C			
**** Feed Water Temperature, 59°C			

† Release rate $\frac{1}{2}$ Rated power at 50% neutron flux

of the release rates of JPDR for 1 MWt are due to the method of sampling, and also to the variation in the main steam flow rate. When the neutron flux and the feedwater flow rate are constant and the feedwater temperature becomes lower than it in the normal power operation, the release rates of the radiolytic gas apparently decrease because of the decrease in main steam flow rate (See † in TABLE 11).

6. 4 Release of radioiodine

According to the results of the routine gamma counting of radioiodine in the reactor water, the leakage of the fission products from the fuel into the coolant appears to be only slight, although it actually occurred in March, '65 (See Fig. 7). In December '64 an abnormally high level of off-gas activities was observed. The gamma activity due to radioiodine was measured when 2 hours passed away after sampling. Iodine-131 mostly appears among the iodine radioisotopes when the reactor is started up after several days of shut down; iodine-133 and-135 increased as operation proceeds. While the control rod withdrawal pattern is kept approximately constant during the normal power operation, it can be presumed that the variation of the radioiodine concentration in the reactor water should approximately correspond to the variation of the apparent release rate of radioiodine from the fuel into the reactor water. When the power level is not changed, the release rate of radioiodine for the JPDR is expressed as

$$V_p \cdot \frac{dx}{dt} = R - S \cdot F_s \cdot x - a \cdot F_c \cdot x - \lambda \cdot V_p \cdot x \quad (3)$$

R : the release rate of radioiodine from the fuel, atoms/sec,

V_p : the amount of reactor water, g,

S : the carry-over coefficient of the total radioiodine,

a : the clean up coefficient of the total radioiodine, l,

F_s : the flow rate of main steam, g/sec,

F_c : the flow rate through the clean up line, g/sec,

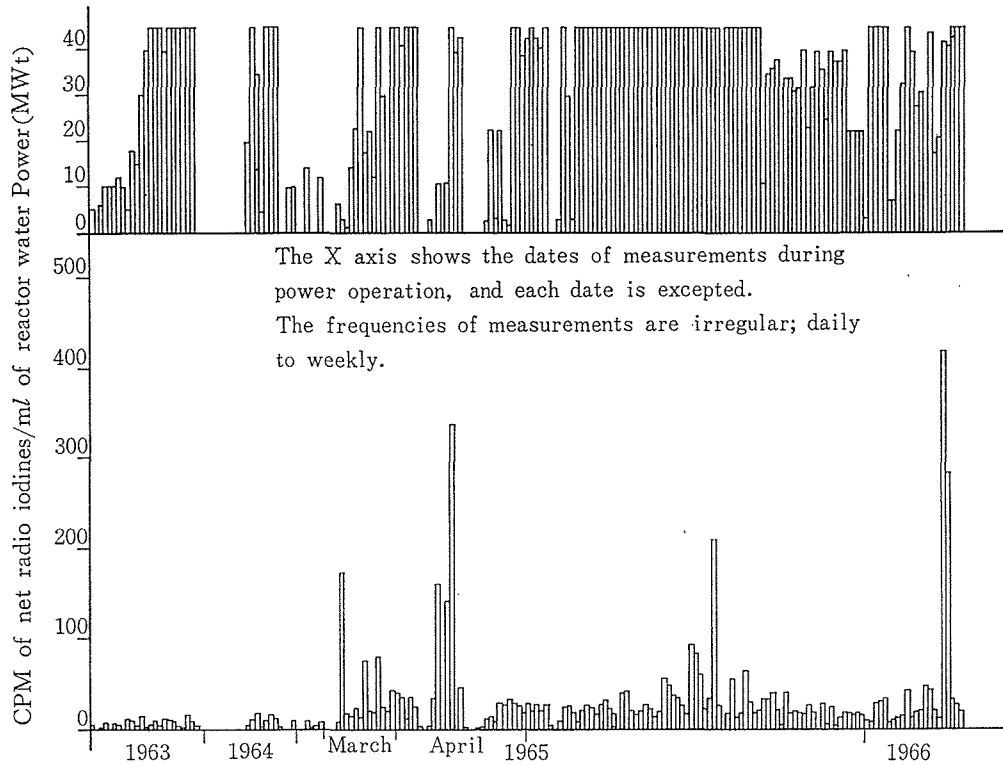


Fig. 7 Radio iodine in JPDR reactor water

TABLE 12 Ratio of apparent formation rate vs measured release rate of iodine-133

Sampled Date, Time	Apparent formation rate (Atoms per sec)	Measured release rate (Atoms per sec)	Ratio ($\times 10^3$)
Apr. 27, 1330~1400	1.1×10^{10}	18.2×10^7	0.6
" , 1400~1430	1.5×10^{10}	9.9×10^7	1.5
" , 1430~1500	1.0×10^{10}	9.0×10^7	1.1
" , 1500~1530	0.6×10^{10}	2.1×10^7	2.8
" , 1530~1600	1.0×10^{10}	9.2×10^7	1.1
" , 1600~1630	1.2×10^{10}	7.5×10^7	1.6
" , 1630~1700	1.0×10^{10}	8.1×10^7	1.3
May. 06, 930~950	2.7×10^{10}	-0.3×10^7	90
" , 950~1010	2.8×10^{10}	6.3×10^7	4.4
" , 1010~1030	2.9×10^{10}	-4.5×10^7	6.4
" , 1030~1050	3.8×10^{10}	18.5×10^7	2.0
" , 1050~1110	2.2×10^{10}	-5.0×10^7	4.6
" , 1110~1130	2.6×10^{10}	4.2×10^7	6.2

Ratio of apparent formation rate vs measured release rate of iodine-135

Apr. 27, 1330~1400	2.2×10^9	11.0×10^7	0.2
" , 1400~1430	3.4×10^9	8.4×10^7	0.4
" , 1430~1500	2.3×10^9	7.5×10^7	0.3
" , 1500~1530	2.0×10^9	3.5×10^7	0.6
" , 1530~1600	3.3×10^9	-2.1×10^7	1.6
" , 1600~1630	2.8×10^9	16.7×10^7	0.17
" , 1630~1700	1.9×10^9	6.9×10^7	0.3

λ : the decay constant of the nuclide, sec^{-1} ,
 x : the radioiodine concentration in the reactor water, atoms/g.

In the expression (3), V_p , F_s , and F_c are approximately constant under the above condition, and S , a , x and dx/dt can be experimentally measured. The measured results of R in the second 1000-hour continuous run in 1966 are given in TABLE 12. In this table, are shown the ratio of the apparent formation rate of iodine-133, as well as of-135, estimated from the apparent release rate of the xenon-133 (and-135) into the off gas, vs. the apparent release rate of the iodine-133 (and-135) measured in the reactor water. These ratios are of the magnitude of 10^2 and 10, respectively. These values are probably due to the retention and deposition of

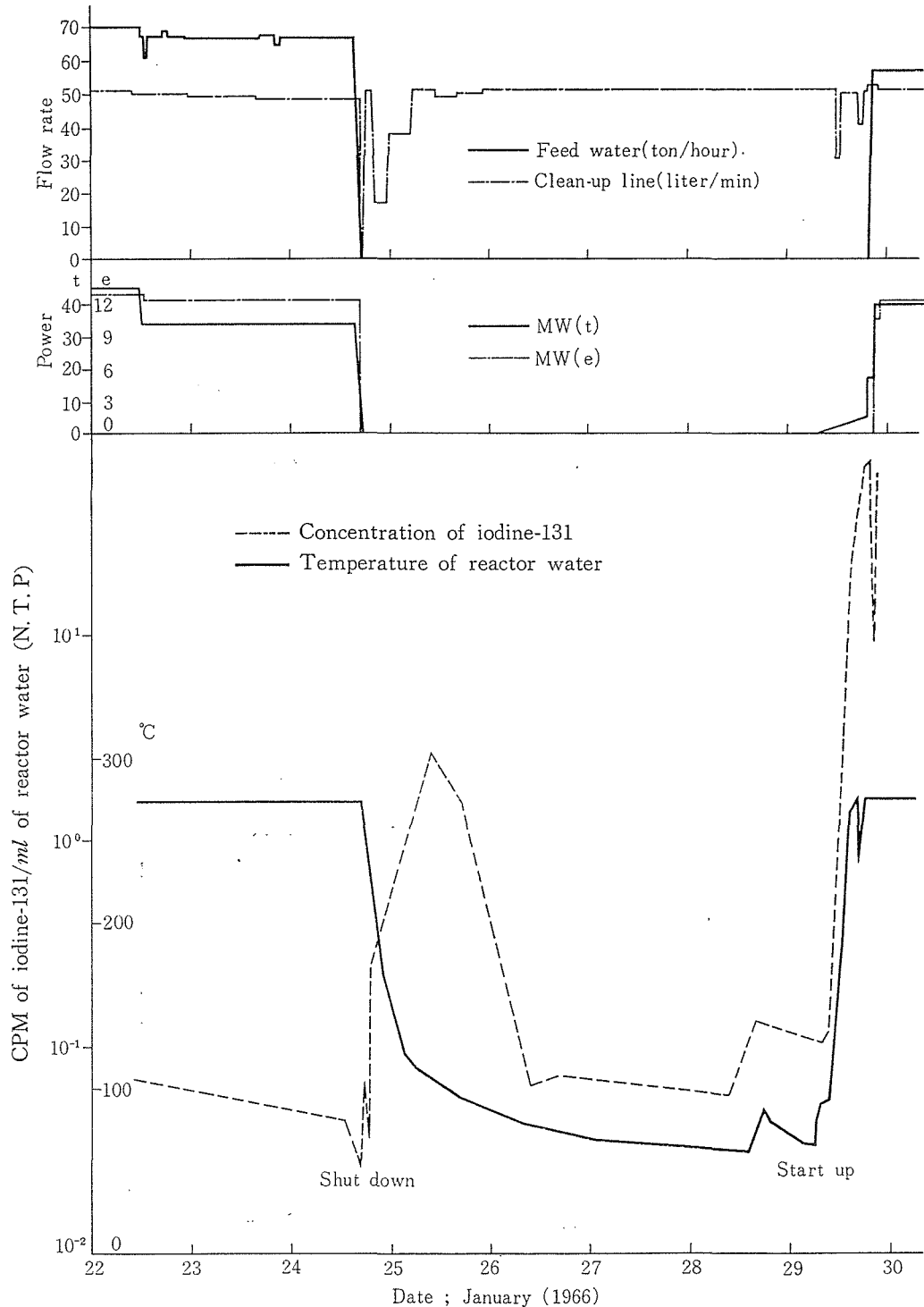


Fig. 8 Release of iodine-131 at shut down and start up of JPDR

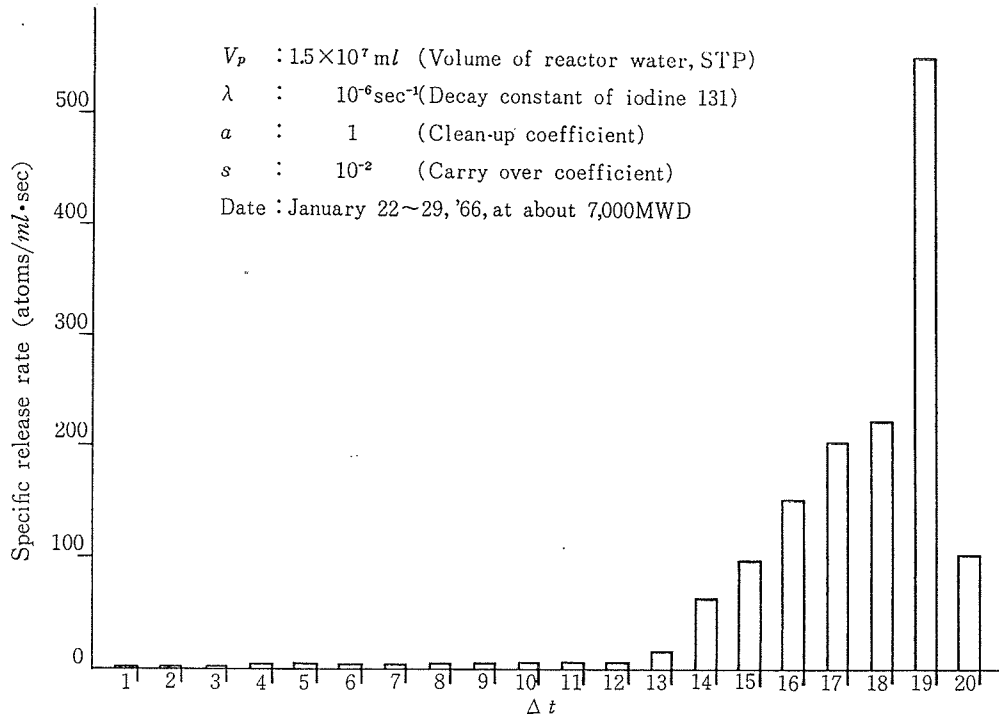


Fig. 9 Release rate of iodine-131 at reactor start-up

the released radioiodine in the reactor vessel. At the constant power level during the normal operation, the value R was measured to fluctuate for once every several tens of minutes. This fluctuation in R seems to be due to the mechanism of release of radioiodine into the reactor coolant or the primary coolant system. The analogic phenomenon as above is also recorded for other fission gases, in the continuous measurement of the off-gas activities. Since the release of radioiodine into the reactor water is low at the present time, the distribution of radioiodine from the plant to the atmosphere is negligible. This phenomenon is found also by other measurements. During the rapid power-up to 45 MWt after the five days shut-down, the release rate of radioiodine into the coolant was found to be about 10^3 times as large as during the normal power operation (See Figs. 8 and 9). It is not possible to determine the chemical forms of radioiodine released from the fuel, because of very low concentrations of radioiodine in the reactor water; but it may be present in the water, as iodide, iodate or elemental iodine and little or nothing about organic compounds.

7. Clean up demineralizer water

During the operation, part of the reactor water is transferred to the hot well, through the regenerative heat exchanger, non-regenerative heat exchanger and clean up demineralizer, in order, by natural circulation. About 60 liters of anion resin and about 120 liters of cation resin are employed in the demineralizer. The quality of effluent from this mixed polisher is normally maintained at less than $0.4 \mu\Omega/\text{cm}$ at 25°C of electric conductivity, less than 10 ppb of Cl as the chloride and pH 5.5~7. Not only the ionic substances but also the non-ionic substances can be removed by means of this mixed bed. In TABLE 13 are shown the typical measured apparent scavenging coefficients for the metallic corrosion products including iron, copper and nickel. The apparent scavenging coefficient is defined as

TABLE 13 Scavenging coefficient of the demineralizer
(Clean-up demineralizer) (in 1965)

Sampled Date	MWt	Fe			Ni			Cu		
		Kc	Kf	Kt	Kc	Kf	Kt	Kc	Kf	Kt
Sept. 26	21	4.0	~0.06	1.3	9.0	5.3	6.3	3.0	2.8	2.8
" 27	42	9.5	14.0~	10.0	32.0	2.1	5.4	6.0	6.2	6.1
Oct. 6	37	1.75	1.8	1.8	5.0	4.0	4.1	10.0	10.2	10.1
" 20	6	19.0	0.33	2.2	12.0	12.0	12.0	5.8	3.6	4.2
" 26	40	3.0	0.7	1.0	1.0	14.0	4.3	3.5	52.0	19.7
" 30	40	1.3	0.9	1.1	1.0	1.3	1.2	8.0	3.6	3.8
Nov. 5	40	1.5	0.8	1.1	1.0	29.0	8.0	12.0	9.9	10.1
Average		5.7	2.7	2.6	8.7	9.7	5.9	6.9	12.6	8.1

(Condensate demineralizer-continued) (in 1965)

Sept. 26	21	2.7	0.6	1.0	1.0	1.3	1.2	2.0	1.2	1.4
" 27	42	1.4	1.0	1.3	1.5	0.4	0.5	1.4	0.2	0.3
Oct. 6	37	4.0	0.7	1.8	1.0	1.0	1.0	1.3	14.0	4.5
" 20	6	13.9	0.9	5.2	0.6	1.0	0.7	0.3	3.0	1.4
" 26	40	1.3	1.0	1.2	1.0	4.0	1.8	3.0	13.0	8.0
" 30	40	0.7	1.0	0.8	1.0	2.0	1.3	0.5	4.0	1.7
Nov. 5	40	2.9	1.4	2.1	1.0	0.1	0.3	0.4	2.3	1.1
Average		3.9	0.9	1.9	1.0	1.4	1.0	1.3	5.4	2.6

$$K_c = \frac{\text{Crud* (Fe, Ni or Cu) in Reactor water}}{\text{Crud* (Fe, Ni or Cu) in Clean up demineralizer effluent}}$$

$$K_f = \frac{\text{Filtrate (Fe, Ni or Cu) in Reactor water}}{\text{Filtrate (Fe, Ni or Cu) in Clean up demineralizer effluent}}$$

$$K_t = \frac{\text{(Crud* + Filtrate) (Fe, Ni or Cu) in Reactor water}}{\text{(Crud* + Filtrate) (Fe, Ni or Cu) in Clean up demineralizer effluent}}$$

(* the residual after filtration of sample water by millipore filter HA.)

The results give the apparent scavenging effects of the clean up demineralizer for the copper, nickel and iron as about 90 %, about 80 % and about 60 %, on the average, respectively. In the case of the condensate demineralizer, the apparent scavenging effects for the copper, nickel and iron are about 60 %, 0~% and 50 %, on the average, respectively. The decontamination factors for the copper-64, manganese-56, fluorine-18, radioiodine, cobalt-58 and cobalt-60 of the clean up demineralizer are given in TABLE 14. The decontamination factor (DF) of the clean up demineralizer is defined as

TABLE 14 Decontamination factor of radioactive nuclide

Nuclide	Decontamination factor
Fluorine -18	1×10^3
Manganese -56	$(4 \sim 5) \times 10^2$
Cobalt -58 (-60)	about 10^2 in average
Copper -64	$(1 \sim 2) \times 10^3$
Radio Iodine	about 10^2 in average

$$DF = \frac{\text{The radioactive nuclide in the reactor water}^*}{\text{The radioactive nuclide in the clean up demineralizer effluent}^*}$$

(* counts per min. per ml in unit is corrected to the time of sampling)

Where the cpm/ml values are used in the sampling of all radioactive nuclides except the total radioiodine; the cpm/ml is employed for the total radioiodine passed away 2 hours after sampling. In the clean up demineralizer of the JPDR, the apparent scavenging coefficients for the metallic corrosion products are usually lower than the apparent DF of the induced radioactive nuclides from their corrosion products, by a factor of about 10^2 for the copper. This difference of about 10^2 seems to be caused by the following. The scavenging coefficient measured by chemical analyses is equivalent to the ratio between the sum of the element of the ionic and the non-ionic states in the demineralizer influent, and that in the demineralizer effluent, in the normal operation. Among the elements measured by chemical analyses, the copper in the non-ionic state is the major one. The DF measured by gamma counting is the ratio between the sum of the gamma activities of the nuclide in the ionic and non-ionic states in the demineralizer influent, and that in the demineralizer effluent, in the normal operation, and the major part of the element measured by gamma counting is the ionic one. In the case of manganese, the amount in the coolant is very little, and the major part of it appears to be the deposit on the iron crud. And the source of the cobalt-58 is the nickel. The latter two elements in the clean up demineralizer system are too little to determine. The behaviors of other metallic elements are unknown because of the microamounts of the radioactive and non-radioactive nuclides, including ^{51}Cr , ^{59}Fe and ^{187}W , and Cr and W in the coolant.

8. Hot well water

In the power operation, the condensate is dumped into the hot well, and then transferred to the feedwater line by condensate pumps. To maintain the water level in the hot well at preset value during the power operation, water which is within the tentative quality limitation in the condensate storage tank is transferred appropriately to the hot well by a transfer pump. If necessary, water from the waste disposal system is used for this purpose via the condensate storage tank. The tentative quality limitations of these waters are shown in TABLE 15. The

TABLE 15 Tentative limitation of water quality

	Hot well,	waste water to return for use
pH	5.5~7.5	5.5~7.5
Electric conductivity ($\mu\text{S}/\text{cm}$)	< 1	< 1.2
Cl (ppb)	< 10	< 10
SiO ₂ (ppm)		< 0.1
B (ppm)		< 0.2
Turbidity (ppm)		< 1.0
Gross β activity ($\mu\text{C}/\text{ml}$)		< 10^{-3}

waste water is checked by chemical analyses. The leak of sea water from the condenser cooling pipe into the hot well can be indicated on an electric conductivity recorder in the operation control room and also checked by chemical analysis. The activities detected in the hot well

mainly consist of fluorine-18, cobalt-58 and -60, silver-110m and radioiodine. The fluorine-18 is mainly taken by carry over from the reactor water into the hot well through the primary steam line. The radioiodine is transferred both by the carry over and by passing through the clean up demineralizer from the reactor to the hot well. The cobalt-58 and cobalt-60 are transferred and deposited in the hot well either by the carry over, by passing through the clean up demineralizer and by the recovered waste water. The silver-110 m is transferred to the hot well from the waste system through the condensate storage tank, and deposits there. The main source of the silver-110 m seems to be from the hold up ring in the pipe of the neutron flux in-core monitors. This silver-110 m is transferred to the reactor enclosure drain tank, in the in-core monitor coolant, and then to the waste disposal system. The measured distributions of cobalt-58 and cobalt-60 and silver-110 m in the waste system are shown in TABLE 16.

TABLE 16 Distribution of cobalt -58, -60 and silver-110 m in radioactive waste disposal system of JPDR (in 1965)

Sampled date	Sample	⁵⁸ Co		⁶⁰ Co		^{110m} Ag	
		Filtrate	Crud	Filtrate	Crud	Filtrate	Crud
Jun. 18	CST	4×10^{-7}	$< 3 \times 10^{-7}$	2×10^{-8}	$< 2 \times 10^{-8}$	$< 5 \times 10^{-8}$	$< 2 \times 10^{-7}$
" 25	WNT	9.2×10^{-6}	2.9×10^{-6}	4×10^{-7}	2×10^{-7}	ND	$< 1.1 \times 10^{-6}$
" 18	WCT	4.3×10^{-6}	1.2×10^{-6}	2×10^{-7}	6×10^{-8}	1.14×10^{-5}	2.57×10^{-5}
" 18	DWST	1.8×10^{-6}	$< 1.0 \times 10^{-6}$	8.6×10^{-6}	$< 5 \times 10^{-8}$	6.8×10^{-6}	$\leq 6 \times 10^{-6}$
" 24	DWST	1.61×10^{-5}		8×10^{-7}		ND	ND
" 25	DWST	9.7×10^{-6}	$< 1.0 \times 10^{-6}$	5×10^{-7}	$< 5 \times 10^{-8}$	4×10^{-7}	$\leq 6.3 \times 10^{-6}$
Jul. 03	DWST	3.6×10^{-6}	$< 9 \times 10^{-7}$	2×10^{-7}	$< 5 \times 10^{-8}$	1.5×10^{-6}	$\leq 6.3 \times 10^{-6}$
" 05	DWCT	5.9×10^{-6}	$< 9 \times 10^{-7}$	3×10^{-7}	$< 5 \times 10^{-8}$	ND	$\leq 6.3 \times 10^{-6}$

unit in $\mu\text{C}/\text{ml}$, ND=not detectable

CST; Condensate storage tank

WNT; Waste neutralizer tank

WCT; Waste collector tank

DWST; Dirty waste sample tank

DWCT; Dirty waste collector tank

9. Steam

The induced activities released into the steam from the reactor water are mainly nitrogen-13 and fluorine-18. The nitrogen-13 is produced from oxygen-16 in the air leaking into the condenser.⁽³⁾ The nitrogen-13 is by the nuclear reaction $^{16}\text{O}(p, \alpha)^{13}\text{N}$. About 12 curies per hour and ~ 1 curie per hour at the largest are measured as the release rates of nitrogen-13 and fluorine-18 into the primary steam line, respectively, in the full power operation of the JPDR. The specific release rate of nitrogen-13 at the sampling point after the off-gas condenser shows $\sim 2 \mu\text{C}$ per second per MWt, and this value is the same with that of SENN.⁽⁹⁾ For the Dresden, $0.75 \mu\text{C}$ per second per MWt at air ejector is reported.⁽³⁾ The release rates of the fission gases to the steam from the JPDR core are not constant. The release rates are high at the time of reactor start and of the rapid power up. The free gas released into the steam from the reactor core consists of the hydrogen and the oxygen in the volume ratio of about 2:1. For the leak into the feedwater including the turbine-condenser, trace amounts of nitrogen, mixed with the free gas released into the steam, can be detected by gas chromatography.

The fractions of sodium-24 and fluorine-18 released into the steam from the reactor water are measured to be $\leq 5 \times 10^{-4}$ and ≤ 0.6 , respectively, and that of the radioiodine to be less than 10^{-2} . The values measured at the JPDR are similar to those measured at the Dresden.⁽³⁾ The separation factor which is the released fraction, is defined as

$$S_F = \frac{\text{gamma activity of the nuclide in the condensate}^{*\dagger}}{\text{gamma activity of the nuclide in the reactor water}^*}$$

(* counts per minute per ml, † of the steam)

10. Others

10.1 Closed cooling water and Shield cooling water

Cooling water in the closed circuit is used for cooling the non-regenerative heat exchanger, off-gas condenser and pumps, etc. Potassium chromate is dissolved in the cooling water as the inhibitor of the closed cooling system. The concentration of the inhibitor is maintained at about 420~600 ppm., and the pH of the solution is about 8.5~9.5. The shield cooling water circuit is used for the concrete shield surrounding the pressure vessel. Inhibitor is also added; the concentration and the pH range are the same as in the closed cooling water. During the long-period continuous power operation (for instance, the 1,000 hr continuous run), radioactive nuclides, e. g., ^{51}Cr , ^{42}K and ^{24}Na are produced in the shield cooling water by neutron irradiation.

10.2 High-pressure and low-pressure boron poison tanks solutions

About 700 liters of the solution containing about 77 kg of borax and about 75 kg of boric acid are stored in the high pressure boron poison tank made of carbon steel. The pressure in the tank is maintained at about 117 kg/cm² at room temperature. The solution in the tank contains about 13.5 % of sodium pentaborate.* About 19 m³ of the same solution in the low pressure boron tank contains about 1.25 tons of borax and about 1.21 tons of boric acid, and this solution contains about 8.3 % of sodium penta borate.* These solutions are used to stop the nuclear fission in the core when an accident occurs in the primary coolant. The boron concentration in these solutions is checked by routine chemical analysis, and if necessary, the required amounts of boric acid and borax are added to the solutions after the reactor shut-down.

(* Sodium pentaborate is the borate in the solution containing boric acid and borax in the mole ratio of about 6 : 1, respectively.)

11. Discussion

According to the experience up to now since the initial power up test of the JPDR in 1963, the minor variations of the other conditions in the reactor core except those mentioned in this paper, have almost no effects on the behaviors of radiolytic gases, corrosion products, induced activities and fission products in during the normal power operation. The various measurements in the EBWR, the Dresden, the JPDR and the SENN are compared in TABLE 17. The differences in the concentration of metals and some induced activities from the corrosion and

TABLE 17 Comparison of results of various measurements in several reactors

Measurements	JPDR	EBWR	Dresden	SENN
Radiolytic gas release rate (l/min/MWt)	1.6	0.6 as O ₂	0.53 as O ₂	1.5
Major radioactive nuclides (Identified)	¹³ N, ¹⁸ F ⁶⁴ Cu, ⁵⁶ Mn, ⁵⁸ Co, ²⁴ Na	¹⁶ N ²⁴ Na, ⁵⁶ Mn, ⁵⁸ Co	¹³ N, ¹⁶ N, ¹⁹ O ⁶⁴ Cu, ⁵⁶ Mn, ⁵⁸ Co, ²⁴ Na	¹³ N, ¹⁸ F ⁶⁴ Cu, ⁵⁶ Mn, ⁵⁸ Co, ²⁴ Na
Carry over factor, ¹⁸ F	≤ 0.6		≈ 0.5	
²⁴ Na	≤ 5 × 10 ⁻⁴	3 × 10 ⁻⁴	≤ 1.3 × 10 ⁻⁴	≤ 5 × 10 ⁻⁴
¹³¹⁻¹³⁵ I	< 10 ⁻²			
¹³ N			≈ 2	
¹³ N release rate (μc/sec·MWt)	~ 2		0.75	1.2~2.4
Dissolved oxygen (ppm)	0.3~0.4	0.28~0.37	0.2~0.3	0.1~0.3

the coolant among the respective reactors seem to be caused by the different power capacities and designs of each reactor.^{(4), (5), (6), (9)} But on the whole, the tendencies are almost the same. The results of chemical analyses of the deposits on the fuels surfaces and the control rods surfaces show that the major part of the deposit of corrosion products in the JPDR is iron, copper and nickel. The radioactive nuclides detected are the same in each reactor. No significant release of large amounts of fission products, due to the visible rupture of a fuel element or to visible cladding defects has been experienced in the JPDR.

12. Conclusion

- 1) The water quality required for the power operation as well the scavenging functions of the demineralizers, has been excellent.
- 2) The release rate of metals (Cu and Ni) from the surface of the feed water heater pipe is estimated to be about 1~1.5 μg/cm²/hr at the flow rate of 72.5 tons/hour.
- 3) The induced radionuclides (longer than 10 min in the half lives) in the reactor water are mainly copper-64, manganese-56, fluorine-18, sodium-24 and cobalt-58, and in the primary steam nitrogen-13 and fluorine-18. The radioactive nuclides detected in other BWR's such as the Dresden and SENN are nearly the same.
- 4) The water decomposition in the reactor vessel apparently proceeds by the stoichiometrical reactions. The apparent specific release rate of the radiolytic gas is about 1.6 liters per min per MWt, which was measured in the primary steam line of the JPDR. The oxygen concentration in the JPDR reactor water is approximately the same with those of other BWR's.
- 5) The ratio of the apparent measured formation rate vs. the apparent release rate of iodine 133 is in the magnitude of 10². The carry over coefficient for the radioiodine is less than 10⁻² in the normal power operation. The excellent retention in the JPDR primary coolant system for the released radioiodine from the fuel is shown from these results described above. No significant release of large amounts of fission products has been experienced in the JPDR in the range ~ approximately 10,000 MWD (thermal).
- 6) The experience for three years in the chemical aspect of the JPDR plant has shown the excellent safety and practicability of the JPDR.

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