(Limited)

Certificate and Records of PNC Fuel Pins for RAPSODIE-4 Irradiation Program

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Certificate and Records of PNC Fuel Pins for RAPSODIE-4 Irradiation Program

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1. General remarks

* This document is completed according to the article II in Appendix II of the agreement for irradiation of fuel pins in Rapsodie-Fortissimo reactor.

* Two lots of pellets are provided for fabrication of seven fuel pins.

* Fabrication process of fuel pellet is shown in Fig. 1-1, and fabrication process of fuel pin is also shown in Fig. 1-2.

Pellet fabrication process and Sampling position
(Mechanical blending)

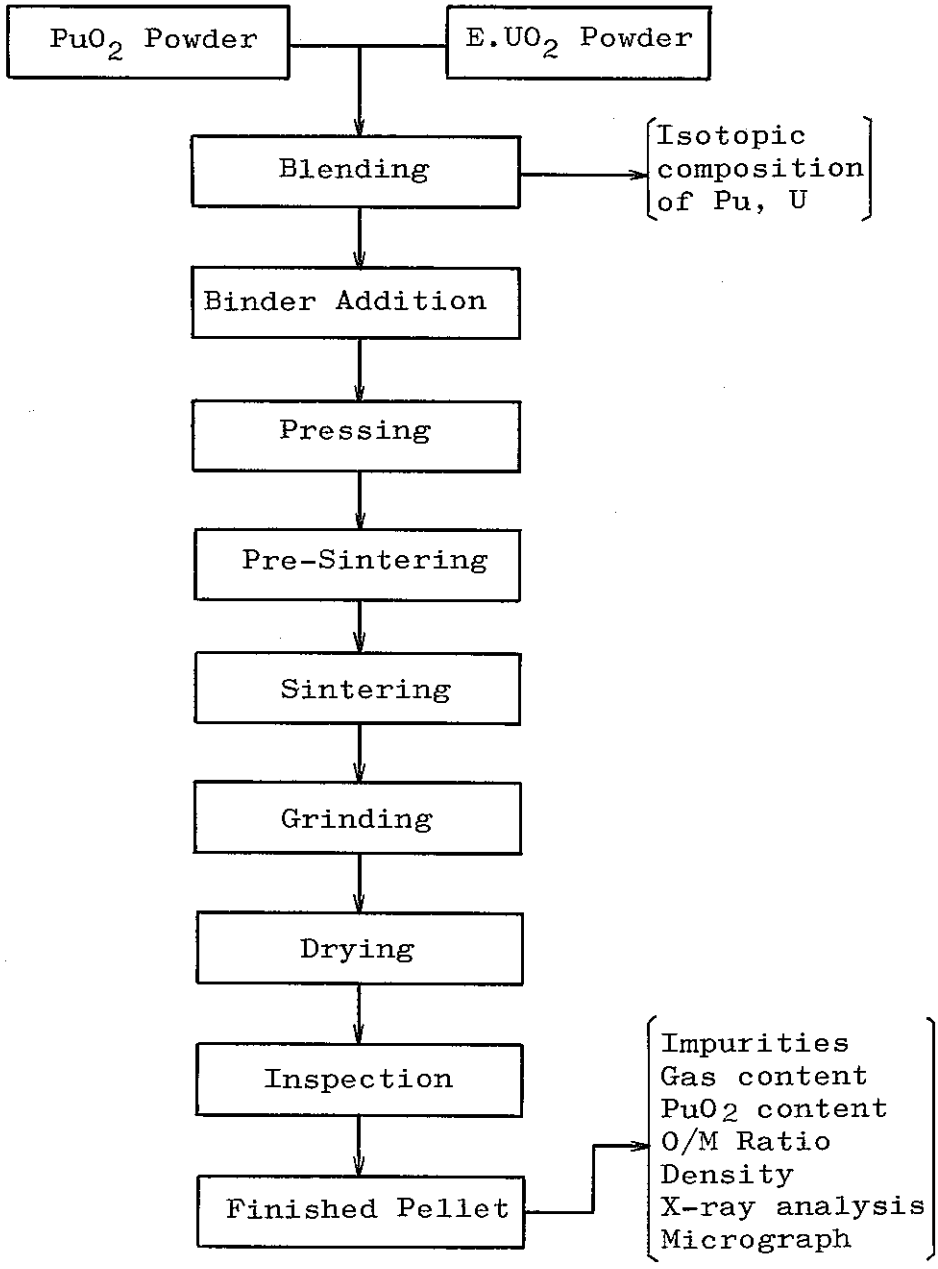


Fig. 1-1 Pellet fabrication process and sampling position

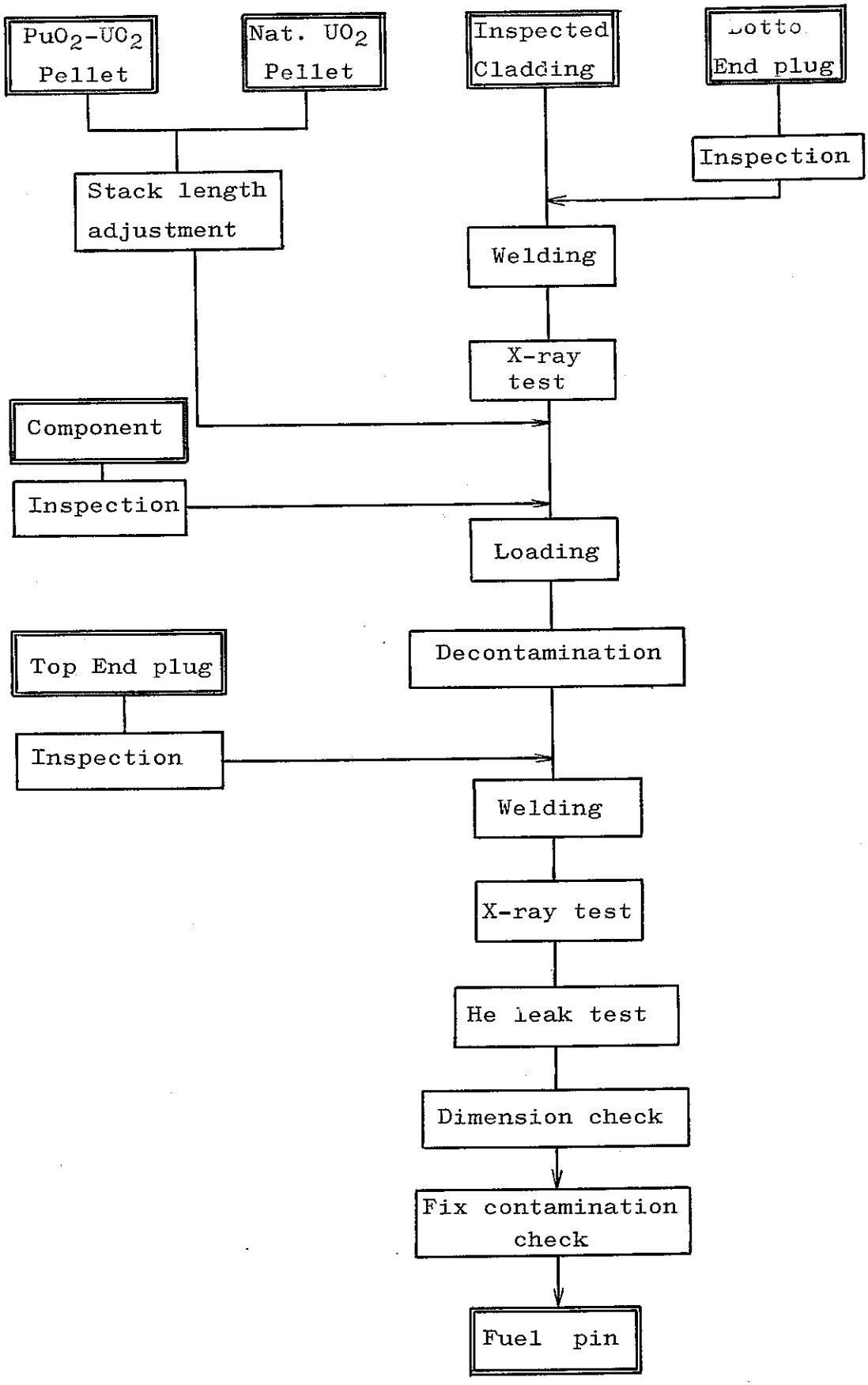


Fig. 1-2 Fabrication process of fuel pin

2. Shipping list

Seven fuel pins and samples of internal structure material were shipped.
Their shipping list are shown in Table 2-1 and Table 2-2 respectively.

Table 2-1

Shipping list of seven fuel pins

1.	Fuel pin	
	Number	Seven.
	Identification	01, 03, 04, 05, 07, 09, 10
	Weight of each fuel pin	
	01	200.67 gr
	03	200.35
	04	199.96
	05	200.46
	07	200.46
	09	200.07
	10	200.45
	Total	1402.42 gr

Table 2-2

Shipping list of samples

1. End plug	Number
Bottom end plug	4
Top end plug	4
2. Other internal structural materials	
(1) Container pipe and sleeve	1 set
(2) End plug of container	1 set
(3) Spring	1
3. Welding specimen	20
(1) Welding specimen of bottom end plug	
K - cladding	5
S - cladding	5
(2) Welding specimen of top end plug	
K - cladding	5
S - cladding	5

3. General records of fuel pin

3-1 Fuel (core fuel)

3-1-1 Sampling method

(1) The lot size of mechanical blending is 3,000 grams and the lot size of sintering is 500 grams.

(2) Three powder samples were taken out at random from each blended lot for mass-spectrometric analysis of isotopic ratio of plutonium and uranium.

(3) Pellets were taken at random from each sintered lot for following examination.

(i)	Plutonium content	2 pellets
(ii)	Impurity (spectroscopy)	1 pellet
(iii)	Impurity (chemical analysis)	6 pellets
(iv)	Amount of gas released	4 pellets
(v)	O/M ratio	3 pellets
(vi)	Ceramography, autoradiography and X-ray diffraction	2 pellets

Two blending lots, R2M-2 and R2M-11 were prepared for fabrication of the seven fuel pins.

3-1-2 Isotopic composition of uranium and plutonium

The isotopic composition of plutonium and uranium are the same for two lots because the same plutonium powder and uranium powder were used for each lot.

The results of analysis are shown in Table 3-1.

The difference of isotopic composition of plutonium between the specification and the analysed value is caused by the natural decay of plutonium.

Table 3-1

Isotopic composition

	Spec. %	Isctopic composition %			
		Sample-1	Sample-2	Sample-3	Average
U-235	65.0 ± 0.5	65.64	65.56	64.87	65.36
U-238	35.0	34.36	34.44	35.13	34.31
Pu-238	0.62 ± 0.01	0.82	0.83	0.83	0.83
Pu-239	75.28 ± 0.06	75.56	75.46	75.56	75.53
Pu-240	14.39 ± 0.04	14.40	14.31	14.32	14.34
Pu-241	8.32 ± 0.02	7.91	7.93	7.91	7.92
Pu-242	1.39 ± 0.01	1.39	1.38	1.39	1.39

3-1-3 Chemical analysis

The methods of the chemical analysis such as plutonium content and impurities are described in the Preliminary Design of PNC fuel pin for Rapsodie-2 irradiation.
The result of the chemical analysis are shown in Table 3-2.

3-1-4 Amount of gas released

The amount of gases released from the pellet was analyzed at 1700°C for 30 minutes.
The detail procedure of measurement is described in the preliminary design report.

The result of analysis is as follows;

	Spec.	R2M-2	R2M-11
Total gas released	μℓ/g 150	76	45

Table 3-2

Results of the chemical analysis

	Specification	Lot R2M-2*	Lot R2M-11
Pu		17.91	17.97
PuO_2 %	20.0 ± 1	20.31	20.37
ppm			
Al	< 500	20	15
B	< 20	0.6	< 0.3
C	< 150	60	63
Cd	< 20	< 1.0	< 1.0
Cl	< 25	< 25	< 25
Cr	< 500	45	18
F	< 25	< 5	9
Fe	< 500	240	65
Mg	< 25	2	5
N	< 200	30	< 50
Ni	< 500	50	40
V	< 200	< 10	< 10
Cu+Zn+Si	< 600	141	< 72
Ag+Mn+Mo+Pb+Sn	< 200	< 99	< 57

* Lot number which was designated in the preparation of the pellet. Refer to the pellet preparation record.

3-1-5 O/M ratio

The O/M ratio of the pellet was determined by thermogravimetric method.

The results is as follows;

	Spec.	Lot R2M-2		Lot R2M-11	
		Sample-1	Sample-2	Sample-1	Sample-2
O/M	1.96～2.00	1.98	1.99	1.99	1.99

3-1-6 Dimension and density

The diameter, height and weight of all finished pellets were measured for geometrical density determination.

Measured value and calculated density are listed in following table.

Lot / Fuel pin	R2M-2			R2M-11			
	03	04	05	01	07	09	10
Diameter (mm)	Spec. 5.4 ± 0.05 (mm)						
Max.	5.44	5.44	5.44	5.43	5.42	5.43	5.44
Min.	5.40	5.40	5.40	5.38	5.37	5.35	5.35
Ave.	5.42	5.42	5.42	5.40	5.41	5.42	5.42
Height (mm)	Spec. 10 (mm)						
Max.	10.09	10.08	10.08	10.34	10.83	10.64	10.61
Min.	9.80	9.24	9.75	8.75	10.10	10.01	10.07
Ave.	9.93	9.92	9.92	10.03	10.31	10.27	10.23
Weight (g)							
Max.	2.19	2.16	2.18	2.22	2.32	2.31	2.26
Min.	2.07	2.00	2.08	1.84	2.12	2.11	2.10
Ave.	2.12	2.12	2.12	2.14	2.20	2.19	2.19
Density (% T.D.)	Spec. 85 ± 2 (% T.D.)						
Max.	86.32	85.82	86.50	85.85	85.66	86.26	85.99
Min.	83.15	83.09	83.00	83.02	83.15	83.03	83.07
Ave.	84.33	84.11	84.35	84.32	84.70	84.62	84.36

3-1-7 X-ray diffraction

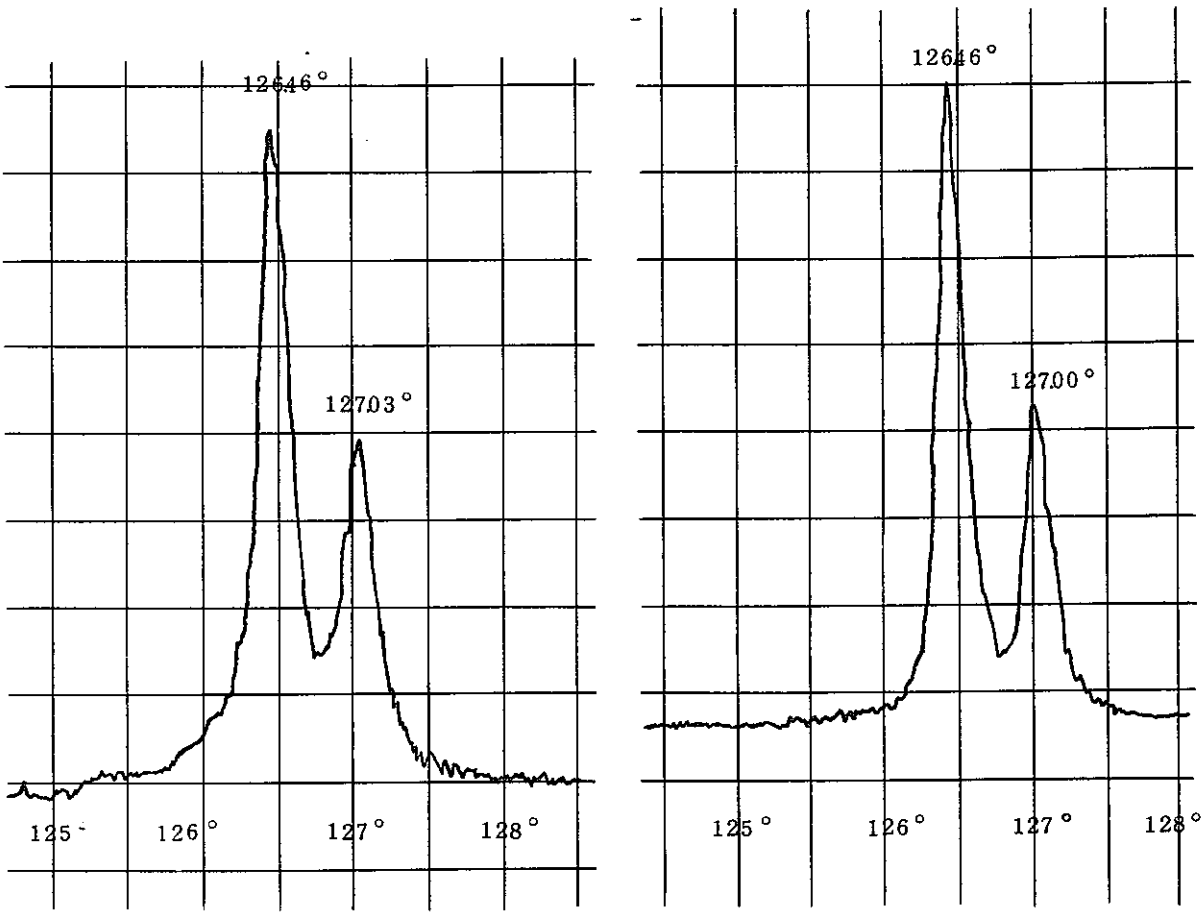
The detail method of X-ray diffraction examination is described in our preliminary design.

The X-ray charts for each lots are shown in Fig. 3-1-1.

3-1-8 Micrography

The ceramography and alpha-autoradiograph of fuel pellet are shown in Fig. 3-1-2 and Fig. 3-1-3.

Fig. 3-1-1 X-ray chart



R2M-2

Lattice parameter

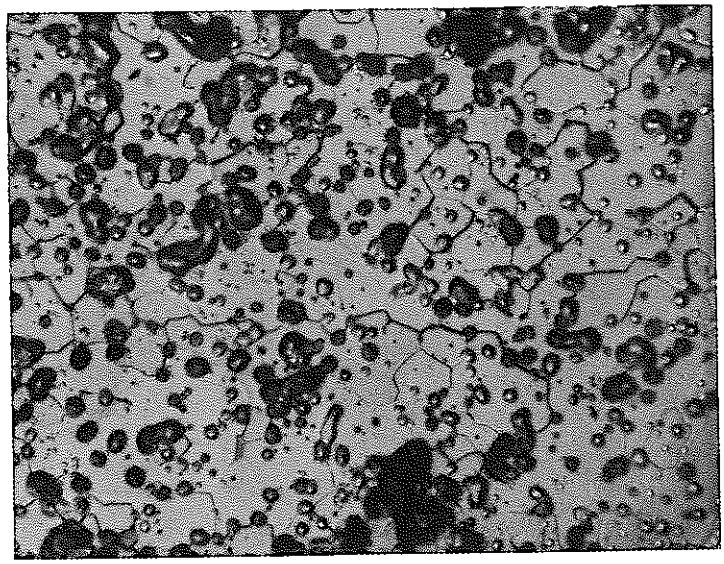
$5.45638 \pm 0.199 \times 10^{-3}$

R2M-11

Lattice parameter

$5.45702 \pm 0.169 \times 10^{-3}$

R2M-2



R2M-11

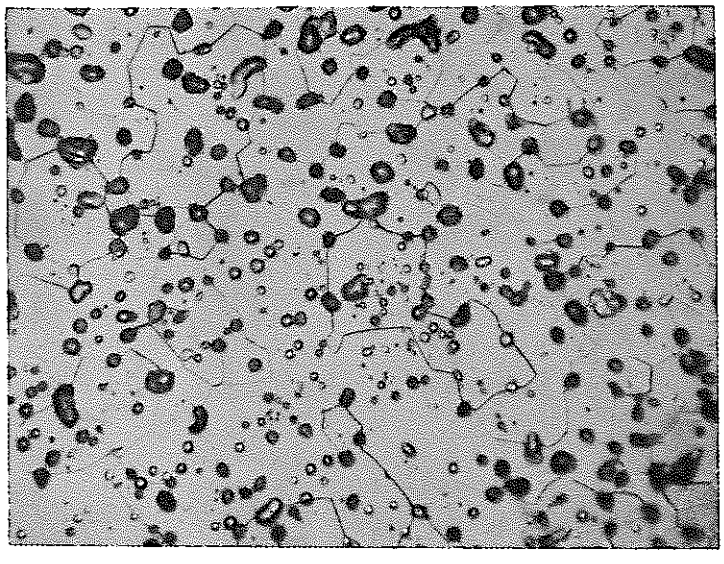
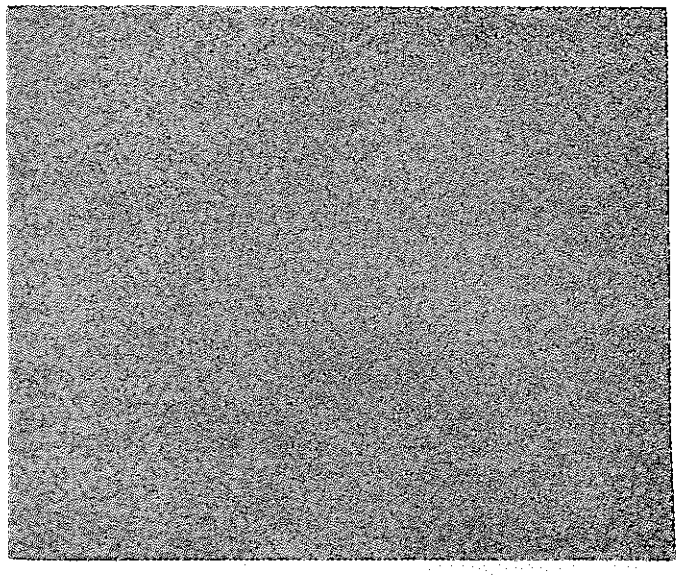


Fig. 3-1-2 Ceramograph

R2M- 2



R2M- 11

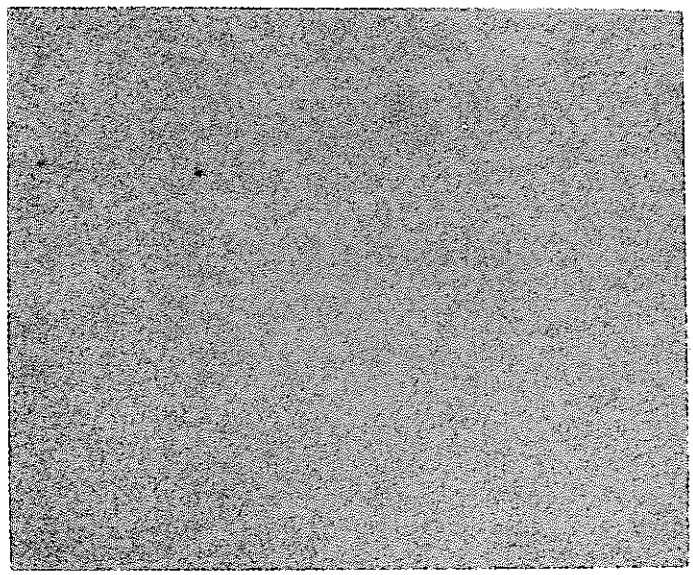


Fig. 3-1-3 Autoradiograph

3-2 Axial blanket pellet

3-2-1 Dimension and density

The diameter, height and weight of all finished pellets were measured for geometrical density determination.

The measured value of 500 pellets is shown in Table 3-2-1.

Table 3-2-1

Dimension and density

	Diameter	Height	Weight	Density
	(mm)	(mm)	(g)	(%T.D.)
Max.	5.33	10.02	2.32	94.97
Min.	5.31	9.95	2.28	92.75
Ave.	5.32	10.0C	2.29	94.18

3-2-2 O/U ratio

The result of O/U ratio measured by ignition method is 2.008.

3-2-3 Amount of gas released

The result of analysis is 30 $\mu\ell/g$.

3-2-4 Impurities

The result of impurities analysis is shown in Table 3-2-2.

Table 3-2-2

The result of chemical analysis

Item	Specification	Result of analysis
(ppm)	(ppm)	(ppm)
Al	<200	<14
B	< 10	0.2
C	<150	17
Ca	< 25	<10
Cd	< 20	< 0.3
Cl	< 25	<10
Cr	<200	< 8
F	< 25	<10
Fe	<200	70
H	< 5	5
Mg	< 25	6
N	<150	23
Na	<200	5
Ni	<200	10
V	<200	< 3
Cu+Zn+Si+Ti	<600	83
Ag+Mn+Mo+Pb+Sn	<200	9

3-3 Cladding

All claddings used are the same with those of PNC-2 irradiation program, and have been inspected by CEA.

3-3-1 Chemical ccmposition

Chemical analysis of cladding made by manufacturers are shown in Table 3-3-1.

Table 3-3-1

Chemical analysis of cladding

Item	Spec.	Cladding-K	Cladding-S
	(%)	(%)	(%)
C	0.04～0.08	0.05	0.07
Mn	< 2.00	1.56	1.61
P	< 0.03	0.02	0.002
S	< 0.03	0.01	0.01
Si	< 0.75	0.50	0.56
Ni	11.00～14.00	13.0	13.23
Cr	16.00～18.00	16.4	16.84
Mo	2.00～3.00	2.3	2.50
Co	<0.10	0.02	0.03
B	<0.001	0.001	0.003
N	<0.035	0.018	0.03
Fe	Balance	Balance	Balance

3-3-2 Mechanical properties

Mechanical properties such as tensile properties were measured by manufacturers, but some measurements were done by PNC.

(1) The mechanical properties measured by manufacturers are shown in Table 3-3-2.

Table 3-3-2

Mechanical properties

	Spec.	Cladding-K	Cladding-S
Tensile strength (Kg/mm^2)			
At room temp.	>60	70.7	72.6
At 650°C	>30	39.4	42.1
Yield strength (Kg/mm^2)			
At room temp.	>40	63.2	55.8
At 650°C	>20	35.9	32.4
Elongation (%)			
At room temp.	>25	41.0	33.0
At 650°C	>15	35.7	28.0
Grain size	6	8.7	7.4
Hardness		248	226
Hydrostatic strength (Kg/cm^2)			
Rupture pressure	800	925	863
Yield pressure	650	855	812

(2) The mechanical properties measured by PNC.

The result of tensile strength are shown in Table 3-3-4.

Table 3-3-4

Tensile properties

	Cladding-K		Cladding S	
	R.T	650°C	R.T	650°C
U.T.S. (Kg/mm^2)	70.2	38.1	71.9	37.8
Y.S. (Kg/mm^2)	56.4	29.9	56.0	28.4
Elongation (%)	35.1	25.1	36.1	24.1

Note; (1) Samples

Room temp. (K4900 series, S5654-2-1, S5654-2-3

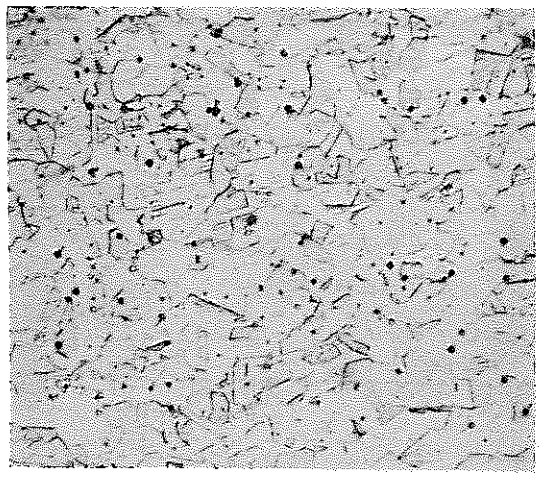
650°C (K-4900 series, S5654-2-4, S5654-2-5

(2) Data listed in Table 3-3-4 are average value of test data.

3-3-3 Metallography

Metallogical test such as grain size and inclusion were made by PNC, and the results are shown in Fig. 3-3-1.

Cladding-K



× 400

Cladding-S

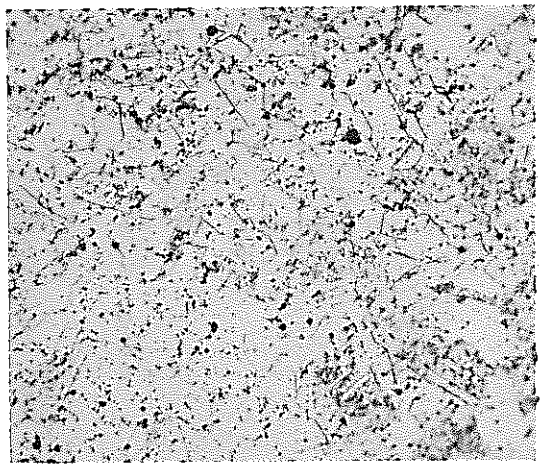


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Fig. 3-3-1 Micrography of cladding

3-3-4 Dimension

Outside and inside diameter were measured by an air-micrometer over the full length of tube.

The results are shown in Table 3-3-3.

Straightness was also measured by the thickness gauge method to the tubes rolled on a surface plane, and all tubes show the acceptable value of 0.01 mm.

Table 3-3-3

Dimensions

Pin No.	Tube No.	Outer diameter		Inner diameter		Thickness	
		Max.	Min.	Max.	Min.	Max.	Min.
	Spec.	6.300 ± 0.030		5.600 ± 0.025		0.350 ± 0.030	
01	K 4985-1	6.303	6.300	5.593	5.590	0.355	0.345
03	K 4998-2	6.310	6.308	5.589	5.586	0.355	0.349
04	S 5621-2	6.299	6.295	5.590	5.588	0.354	0.346
05	S 5905-2	6.300	6.295	5.591	5.589	0.356	0.340
07	K 4969-2	6.303	6.301	5.597	5.593	0.347	0.336
09	K 4976-1	6.305	6.301	5.594	5.590	0.355	0.345
10	K 4976-2	6.305	6.300	5.589	5.586	0.355	0.347

3-4 End plug of fuel pin and end plug of containers.

3-4-1 Chemical composition

Chemical analysis of end plug material were made by manufacture and their results are shown in Table 3-4-1.

Table 3-4-1

Chemical analysis

	Specification	Result
C	0.04 ~0.08%	0.065%
Si	<0.75	0.59
Mn	<2.00	1.32
P	<0.03	0.014
S	<0.03	0.012
Ni	11.0 ~14.0	12.18
Cr	16.0 ~18.0	17.58
Co	<0.10	0.02
Mo	2.00 ~ 3.00	2.50
B	<0.001	0.0003
N	<0.035	0.026

3-4-2 Mechanical properties

Mechanical properties such as tensile strength, yield strength reported by manufacture are as follows;

	Spec.		Result	
	R.T.	650°C	R.T.	650°C
Tensile strength (g/mm^2)	>60	>30	60.6	35.6
Yield strength (g/mm^2)	>30	>20	39.4	25.1
Elongation (%)	>25	>15	65.7	53.0

3-5 Sleeve and container tubes

3-5-1 Chemical composition

The results of chemical analysis made by PNC is as follows;

	Result
C	0.03%
Si	0.57
Mn	1.82
P	0.020
S	0.014
Ni	14.06
Cr	16.42
Mo	2.33

3-6 Spring

3-6-1 Chemical analysis

Chemical analysis done by manufacturer are shown in Table 3-6-1.

Table 3-6-1

	Specification	Result
C	0.60 ~ 0.85%	0.81%
Si	0.12 ~ 0.32	0.18
Mn	0.30 ~ 0.90	0.50
P	<0.025	0.009
S	<0.030	0.011
Cu	<0.20	0.01

3-6-2 Spring constant

Spring constant was measured by PNC for ten samples from a hundred springs.

The result is about 0.15 Kg/mm .

3-7 Container of SiC pellet

SiC pellet is encapsuled into the container.
Dimension and weight of SiC pellet and SiC container are shown in Table 3-7-1.

Table 3-7-1

Capsule No.	SiC pellet			SiC container		
	Dia.(mm)	Length (mm)	Weight (g)	Dia.(mm)	Length (mm)	Weight (g)
1	2.21	15.20	0.17	5.29	40.03	2.48
2	2.28	15.15	0.17	"	40.08	2.51
3	2.20	15.10	0.16	"	40.00	2.48
4	2.26	15.20	0.18	"	40.09	2.49
5	2.19	15.25	0.16	"	40.02	2.46
6	2.26	15.25	0.18	"	40.05	2.49
7	2.21	15.30	0.18	"	40.02	2.47
8	2.20	15.05	0.16	"	39.94	2.47
9	2.19	15.20	0.16	"	40.00	2.50
10	2.26	15.15	0.18	"	39.97	2.49
11	2.20	15.20	0.17	"	40.13	2.50
13	2.21	15.05	0.17	"	40.00	2.49
14	2.26	15.05	0.17	"	40.07	2.48
15	2.22	15.00	0.16	"	40.02	2.50

Results of Helium leak test are good for all capsules.

4. Individual records of fuel pin

4-1 Dimension and weight of fuel pin

(1) Weight of fissile material in the core fuel

Weight of fissle material is shown in Table 4-1-1.

(2) Weight of components in the fuel pin are shown in Table4-1-2.

(3) Length of components, total length of core fuel and blanket fuel were measured. The results are shown in Table 4-1-3.

(4) Diameter of fuel pin was measured, and the result is shown in Table 4-1-4.

Table 4-1-1

Weight of fissile material (g)

Fuel pin	PuO_2-UO_2	PuO_2	Pu metal	Pu fiss.	UO_2	U metal	U-235	Lot No.
03	67.97	13.80	12.17	10.16	54.17	47.72	31.19	
04	67.71	13.75	12.12	10.11	53.96	47.54	31.07	R2M-2
05	68.06	13.82	12.19	10.17	54.24	47.79	31.24	
01	68.52	13.95	12.30	10.26	54.57	48.08	31.43	
07	68.32	13.92	12.28	10.25	54.40	47.93	31.33	R2M-11
09	67.79	13.81	12.18	10.16	53.98	47.56	31.09	
10	67.95	13.84	12.21	10.19	54.11	47.67	31.16	

Table 4-1-2

Weight of components

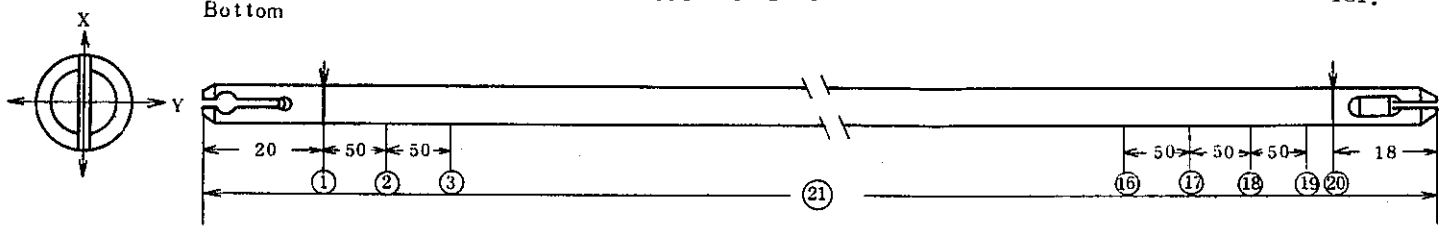
Fuel pin	01	03	04	05	07	09	10
Cladding	K 4985-1	K 4998-2	S 5621-2	S 5905-2	K 4969-2	K 4976-1	K 4976-2
Cladding & 1st.end plug	54.70	54.71	54.73	54.85	55.02	54.74	55.06
SiC container (lower)	2.49	2.47	2.47	2.49	2.51	2.48	2.48
Tagging gas capsule	4.47	4.51	4.55	4.50	4.45	4.46	3.48
UO_2 blanket (lower)	45.5	45.6	45.6	45.5	45.4	45.5	45.4
PuO_2-UO_2	68.52	67.97	67.71	68.06	68.32	67.79	67.95
UO_2 blanket (upper)	9.2	9.2	9.1	9.2	9.0	9.2	9.2
SiC container (upper)	2.49	2.49	2.50	2.46	2.50	2.50	2.48
Spring	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sleeve	8.0	8.1	8.0	8.1	8.0	8.1	8.1
2nd end plug	4.40	4.40	4.40	4.40	4.40	4.40	4.40
Total	200.67	200.35	199.96	200.46	200.46	200.07	200.45

Table 4-1-3

Weight of components (mm)

Pin	01	03	04	05	07	09	10
Cladding	K 4985-1	K 4998-2	S 5621-2	S 5905-2	K 4969-2	K 4976-1	K 4976-2
SiC container	40.1	40.0	39.9	40.1	40.1	40.0	40.0
Tagging gas capsule	70.1	70.1	70.1	70.0	70.0	70.0	70.0
Blanket (lower)	200.1	200.1	200.0	199.9	200.1	199.9	200.0
Core	320.8	317.7	317.4	317.6	319.7	318.3	317.2
Blanket (upper)	40.1	40.1	40.0	40.1	40.1	40.0	40.0
SiC container	40.0	40.0	40.0	40.0	40.1	40.0	40.1
Sleeve	211.1	214.0	214.0	213.0	212.5	213.2	215.3
Fuel pin	999.8	999.9	999.9	999.9	999.8	1000.0	1000.0

Table 4-1-4



(mm)

E.P. No.	Clad No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
01	K4985-1	X	6.367	6.301	6.305	6.298	6.297	6.300	6.300	6.295	6.296	6.305	6.305	6.306	6.302	6.303	6.300	6.305	6.305	6.305	6.301	6.344	(mm) 999.8	(g) 200.67
		Y	6.378	6.302	6.302	6.297	6.298	6.301	6.302	6.295	6.294	6.306	6.304	6.308	6.305	6.304	6.300	6.305	6.304	6.305	6.306	6.361		
03	K4998-2	X	6.376	6.313	6.314	6.314	6.313	6.312	6.313	6.311	6.313	6.313	6.313	6.314	6.302	6.309	6.309	6.310	6.304	6.307	6.308	6.383	999.9	200.35
		Y	6.383	6.312	6.315	6.315	6.313	6.313	6.313	6.314	6.313	6.313	6.312	6.313	6.300	6.309	6.310	6.308	6.309	6.308	6.307	6.371		
04	S5621-2	X	6.356	6.297	6.298	6.297	6.293	6.298	6.297	6.295	6.293	6.295	6.295	6.291	6.293	6.292	6.293	6.291	6.298	6.299	6.298	6.359	999.9	199.96
		Y	6.382	6.297	6.297	6.298	6.292	6.298	6.298	6.295	6.292	6.296	6.295	6.291	6.291	6.292	6.292	6.291	6.299	6.299	6.299	6.380		
05	S5905-2	X	6.387	6.314	6.313	6.309	6.311	6.310	6.310	6.312	6.310	6.307	6.306	6.309	6.314	6.315	6.314	6.314	6.313	6.317	6.314	6.352	999.9	200.46
		Y	6.371	6.314	6.312	6.309	6.310	6.310	6.310	6.311	6.311	6.307	6.306	6.308	6.314	6.314	6.314	6.314	6.314	6.316	6.314	6.368		
07	K4969-2	X	6.369	6.315	6.316	6.317	6.316	6.317	6.318	6.318	6.317	6.316	6.316	6.316	6.317	6.317	6.315	6.315	6.314	6.316	6.316	6.375	999.8	200.46
		Y	6.368	6.316	6.318	6.317	6.317	6.316	6.317	6.316	6.318	6.318	6.318	6.316	6.315	6.317	6.315	6.313	6.316	6.317	6.318	6.377		
09	K4967-1	X	6.381	6.312	6.312	6.309	6.309	6.308	6.307	6.306	6.308	6.307	6.306	6.305	6.306	6.304	6.305	6.305	6.305	6.303	6.303	6.362	1000.0	200.01
		Y	6.371	6.313	6.311	6.312	6.309	6.312	6.307	6.309	6.308	6.308	6.307	6.305	6.305	6.304	6.306	6.305	6.306	6.304	6.301	6.378		
10	K4976-2	X	6.381	6.310	6.311	6.302	6.303	6.303	6.303	6.302	6.303	6.302	6.302	6.301	6.301	6.297	6.297	6.298	6.296	6.298	6.297	6.362	1000.0	200.45
		Y	6.380	6.311	6.312	6.306	6.302	6.302	6.301	6.302	6.303	6.302	6.303	6.303	6.302	6.298	6.298	6.297	6.297	6.297	6.297	6.378		

4-2 Helium leak test

Helium leak test was made and the total leak rate of seven fuel pins are 2.0×10^{-10} atm.cc/sec..
This value is below enough than the allowable leak rate of 1.0×10^{-8} atm.cc/sec.

4-3 X-ray radiography

Welding section and components of fuel pin were inspected by X-ray radiography.
X-ray films of each fuel pin will be sent to CEA together with this document.

4-4 Surface contamination

The result of loose contamination and fix contamination is shown in Table 4-4-1.

Table 4-4-1

Surface contamination

Fuel pin	Loose contami.	Fix contami.
01	0 (dpm)	< 50(dpm)
03	0	< 50
04	0	< 50
05	0	< 50
07	0	< 50
09	0	< 50
10	0	< 50