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開示制限

ラプソディ照射試験集合体
照射前データ

昭和45年11月

動力炉・核燃料開発事業団

概　　要

本報告はラプソディ炉（Fortissimo）において照射中の当事業団製混合酸化物燃料集合体の照射前データを総括したものである。

高速増殖炉開発本部
植松邦彦

目　次

附　録

I. CERTIFICATE AND RECORD OF PNC FUEL PINS FOR IRRADIATION AT RAPSODIE

CONTENTS

1. General Remarks

According to the article of II-1-1 of the agreement for irradiation of fuel pins in Rapsodie Fortissimo reactor, here we send the fuel pins (40), documents and samples specified in Appendix I-A, for furnishing to C.E.A. All the items of the doduments are contained in this report - Certificate and Record of PNC Fuel Pins for Irradiation at Rapsodie.

There are two kinds of pellet, Coprecipitated pellets and mechanically blended pellet. The lot number are three lots for the coprecipitated pellet (RR-01, RR-02, RR-03) and two lots for the mechanically blended pellet (RM-02, RM-03). The pelletizing process of the coprecipitated pellet is shown in Fig. 1-1, and of the mechanically blended pellet is shown in Fig. 1-2.
The pin fabrication process for both pellet is the same shown in Fig. 1-3. The sampling processes for the documents is also shown in these figures.

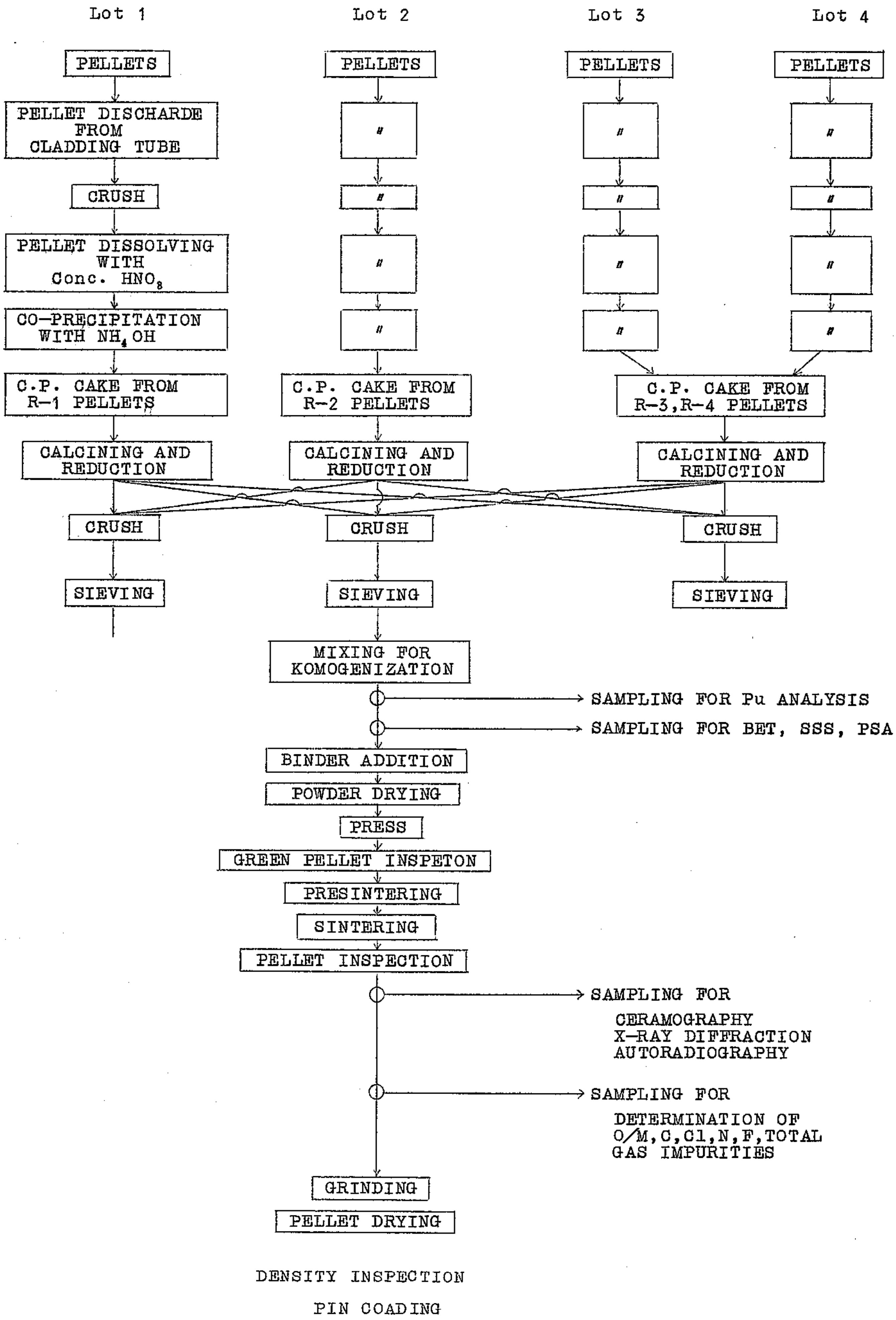


Fig. 1-1 Pelletizing flow sheet(Coprecipitated)

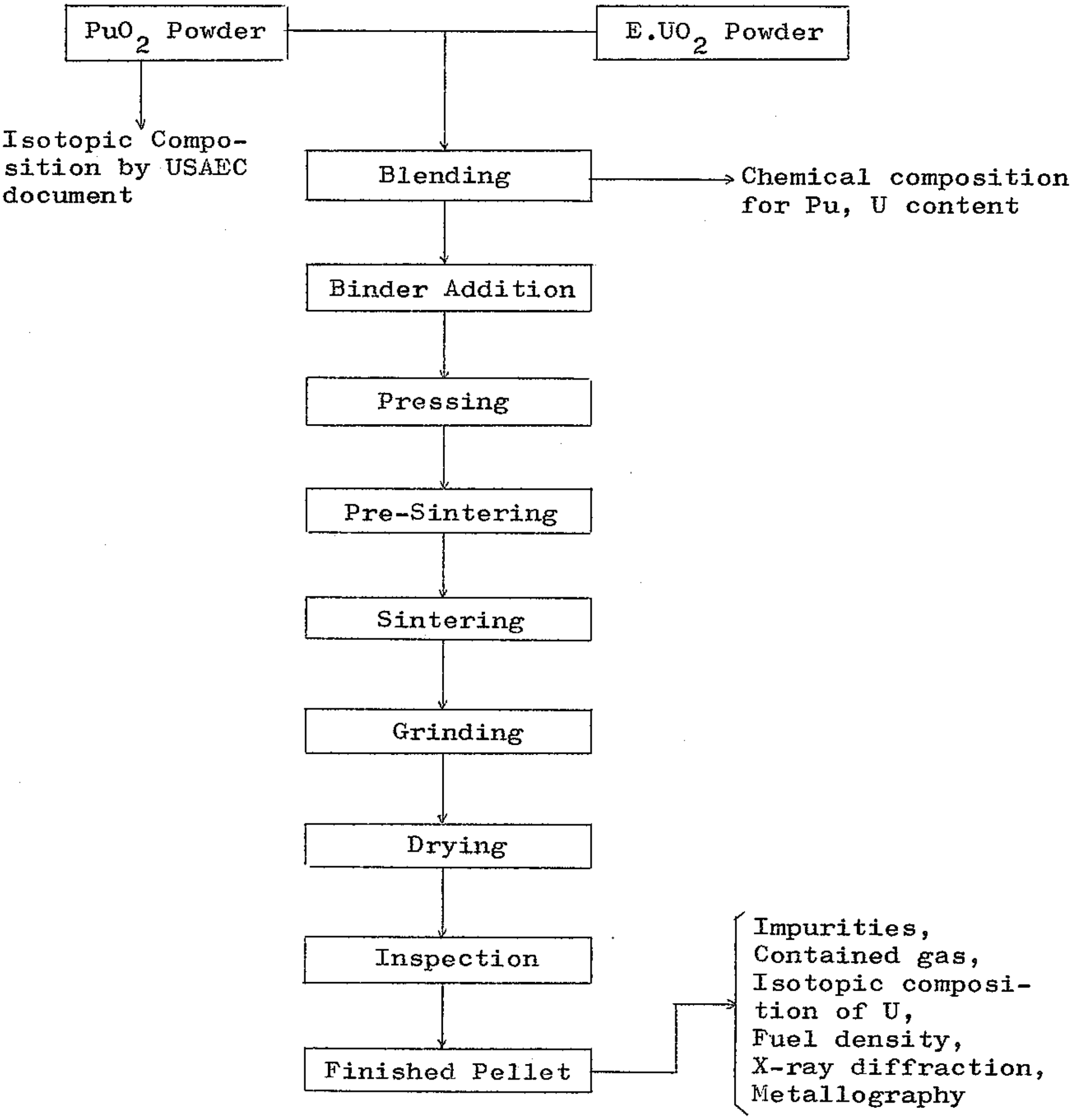


Fig. 1-2 Pelletizing Flow Sheet (Mechanical Blending)

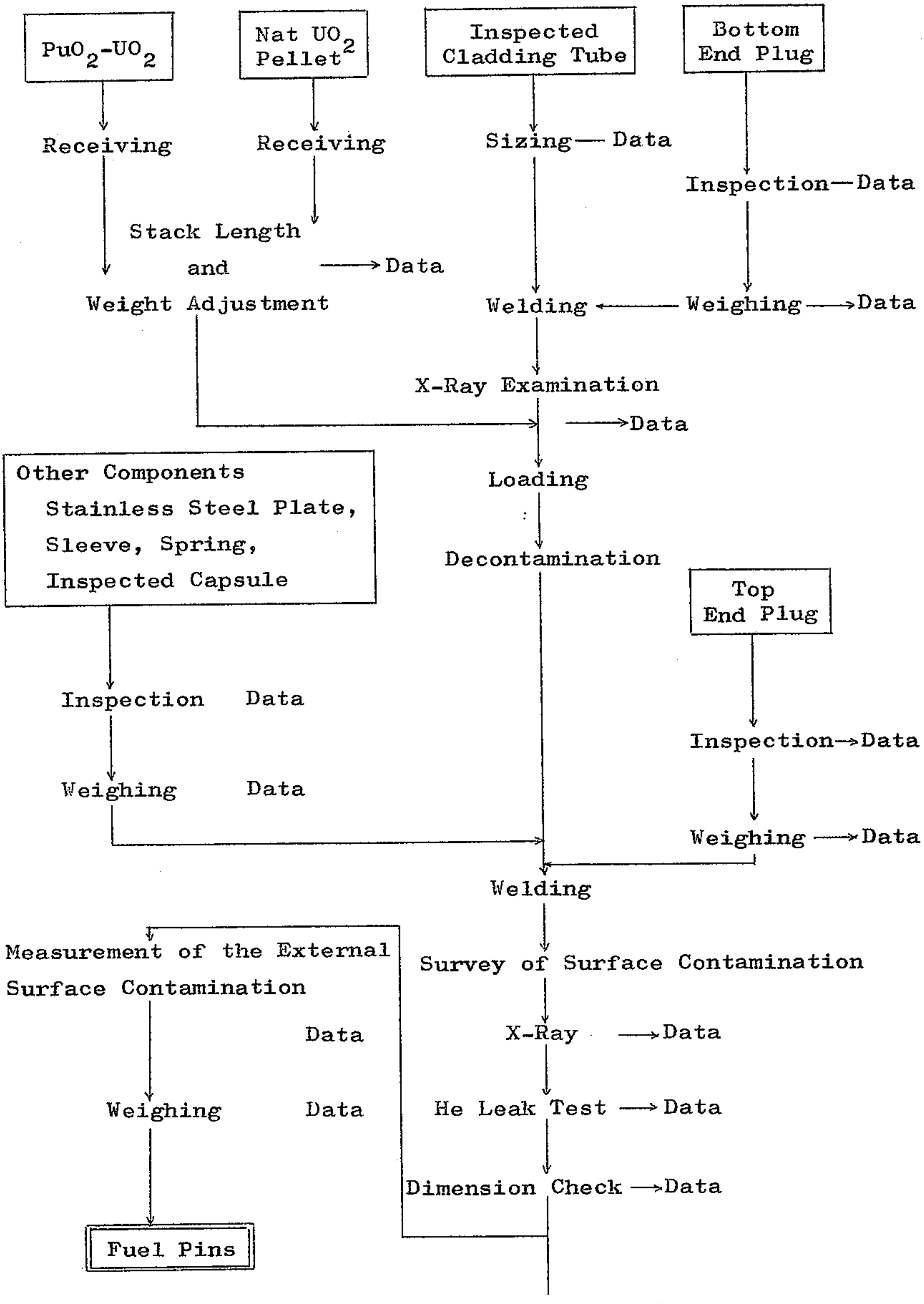


Fig. 1-3 Fuel Pins Fabrication Flow Sheet

2. Specification

2.1 Fuel

2.1.1 Sampling method

A lot size is about 1000 gram and this lot size has been maintained through out the pressing and sintering operations. Seven pellets have been taken out at random from each lot and crushed together in a hand crusher for chemical analysis, spectrographic analysis and the determination of O/M ratio. Furthermore, one pellet has been taken at random from each lot for metallography, autoradiography and X-ray diffraction.

Two gram of each lot has been taken for the determination of Pu and U^{235} containment.

The diameter, length and density of all pellets have been measured. Then the density of all pellets have been calculated and only the qualified pellet has been selected for the pin fabrication process. After centerless grinding, if necessary, pellets are dried and one pellet is taken for determination of total gas release.

2.1.2 Chemical analysis

The methods of the chemical analysis for the fuel have been reported to CEA when two CEA experts visited PNC in November, 1969 as the report entitled as "the Analytical Manual in PNC Plutonium Fuel Laboratory".

The results of the chemical analysis are shown in Table 2.1.2-1.

2.1.3 Contained gases

The amount of gases released from the pellet heated in vacuum (less than 10^{-5} tor) at 1700°C for 30 minutes has been measured and listed in Table 2.1.3-1.

Table 2.1.2-1 Chemical Analysis

ITEM	SPEC.	Lot. 1	Lot. 2	Lot. 3	Lot. 4	Lot. 5
Pu		15.96	15.99	15.92	15.56	15.56
PuO_2	18(%)	18.17	18.13	18.05	17.64	17.64
IMPURITIES						
C	<150	< 50	50	<120	80	110
Cl	< 25	< 5	< 5	< 5	< 5	< 5
F	< 25	7	8	9	5	5
N	<200	< 30	< 30	< 30	< 30	< 30
SPECTR.						
Al	<500	60	70	110	110	80
B	< 20	2.0	2.0	2.0	0.3	0.3
Cd	< 20	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
Cr	<500	20	20	25	20	20
Fe	<500	120	140	350	50	70
Mg	< 25	7	15	20	10	10
Ni	<500	10	15	10	30	30
V	<500	< 10	< 10	< 10	< 10	< 10
Cu	<600	10	10	15	3	3
Zu	<600	< 50	< 50	< 50	< 50	< 50
Si	<600	90	110	110	50	40
Ag	<200	0.3	0.4	0.3	0.7	0.4
Mn	<200	6	10	15	5	5
Mo	<200	10	15	70	30	30
Pb	<200	< 10	15	10	15	10
Sn	<200	< 10	< 10	< 10	< 10	< 10

Table 2.1.3-1 Contained Gases

	Specification	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5
Total gas release	150 μℓ/g	40	< 30	< 30	< 30	50

2.1.4 Isotopic composition

The isotope ratio of Plutonium is the same for all lots because the same Plutonium lot has been used for each lot. The Uranium isotope ratio of lot 1, lot 2 and lot 3 is also the same because these lots has been blended for the homogeneous mixing. The results of the isotope ratio are shown in Table 2.1.4-1.

Table 2.1.4-1 Isotopic Composition

	Specification (%)	Lot 1 (%)	Lot 2 (%)	Lot 3 (%)	Lot 4 (%)	Lot 5 (%)
U -235	60 ± 0.4	60.11	60.11	60.11	59.69	59.76
238		39.89	39.89	39.89	40.31	40.24
Pu-238		0.038	0.038	0.038	0.038	0.038
239		90.142	90.142	90.142	90.142	90.142
240		8.533	8.533	8.533	8.533	8.533
241		1.189	1.189	1.189	1.189	1.189
242		0.098	0.098	0.098	0.098	0.098

2.1.5 Density

A. Density measured by immersion method

Once the immersion method has been done for a pellet which can not used for the fuel pin any more. Therefore density measured by immersion method is only for the reference. The results of the lot 6 sample pellets are shown in Table 2.1.5-1.

Table 2.1.5-1 Density measured by immersion method

Specimen	A (g)	B (g)	C (g)	D (g)	t(℃)	ρ_t	ρ	ρ(%)	ε_T	ε_O	ε_C	ρ'(%)
Lot 4 (1)	2.5241	2.9271	2.5248	0.6388	28.0	0.99626	10.633	96.66	3.34	0.29	3.05	94.50
〃 (2)	2.4979	2.9063	2.4984	0.6388	28.0	0.99626	10.778	97.98	2.02	0.22	1.80	94.95
〃 (3)	2.4375	2.8518	2.4385	0.6372	27.6	0.99609	10.844	98.58	1.42	0.45	0.97	94.83
〃 (4)	2.5206	2.9227	2.5213	0.6386	27.4	0.99615	10.585	96.23	3.77	0.30	3.47	94.39
〃 (5)	2.5410	2.9408	2.5417	0.6368	27.3	0.99618	10.649	96.81	3.19	0.29	2.90	95.07
〃 (6)	2.5084	2.9122	2.5091	0.6380	27.3	0.99618	10.638	96.71	3.29	0.30	2.99	94.69
〃 (7)	2.5170	2.9200	2.5176	0.6368	27.2	0.99620	10.698	97.25	2.75	0.26	2.49	94.93
〃 (8)	2.5469	2.9442	2.5464	0.6355	27.1	0.99623	10.674	97.04	2.96	0.21	3.17	94.09
〃 (9)	2.5975	2.9981	2.5980	0.6378	27.1	0.99623	10.662	96.93	3.07	0.21	2.86	94.67
〃 (10)	2.5525	2.9499	2.5541	0.6368	27.1	0.99623	10.551	95.92	4.08	0.66	3.42	94.85

The equation for the immersion method is expressed as follow;

$$\rho = \frac{A}{C - B + D} \frac{\rho_t}{\rho_0} \times 100$$

$$\varepsilon_T = \left(1 - \frac{\rho}{\rho_0} \right) \times 100$$

$$\varepsilon_O = \frac{C - A}{C - B - D} \times 100$$

$$\varepsilon_O = \varepsilon_T - \varepsilon_O$$

where

A = Specifimen weight in air after drying

B = Basket weight with the specimen in the distilled water

C = Wet specimen weight in air

D = Basket weight in distilled water

t = Distilled water temperature

ρ_t = Distilled water density at C^o

ρ = Pellet density (g/cm^3, %)

ε_T = Total pore fraction (%)

ε_O = Open pore fraction (%)

ε_c = Closed pore fraction (%)
ρ' = Geometrical density
ρ_0 = Theoretical density (11.00 g/cm^3)

B. Density measured by geometrical method

As already described in sampling method, all of the pellets have been measured by the method shown in the report "Preliminary Design of PNC Subassebly for Irradiation at Rapsodie (P. 4-3)". The results of pellet density measured by geometrical method are shown in Table 2.1.5-2.

Table 2.1.5-2 Fuel density obtained from geometrical method

Diameter (mm)

	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5
Average	5.51	5.51	5.51	5.51	5.51
Maximum	5.52	5.53	5.52	5.52	5.52
Minimum	5.49	5.48	5.48	5.50	5.49

Height (mm)

	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5
Average	9.86	9.81	9.96	10.14	10.06
Maximum	10.35	10.48	10.52	10.54	10.54
Minimum	9.50	9.45	9.50	8.71	7.25

Density by geometrical method (% T.D.)

	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5
Average	95.99	95.52	95.27	94.41	96.05
Maximum	96.47	96.49	96.49	96.49	96.49
Minimum	94.57	92.04	93.43	92.56	91.61

2.1.6 X-ray diffraction

X-ray diffraction works in our Plutonium Fuel Division in well described in the report of "X-ray Diffraction Works for PuO_2-UO_2" (AFCPu-Report-012) which is already given to CEA through two CEA experts (Mr. J.L. Ratier, Mr. R. Mas).

The X-ray chart for each lot are shown with lattice parameter in Fig. 2.1.6-1 ~ 2.1.6-5.

2.1.7 O/M

O/M measuring method of our division is already reported to CEA in the same report of "the Analytical Manual in P.N.C. Plutonium Fuel Laboratory".

The results of O/M for each lot are shown in Table 2.1.7-1.

Table 2.1.7-1 Stoichiometry

	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5
O/M	1.980	1.985	1.993	1.987	1.983

2.1.8 Micrography

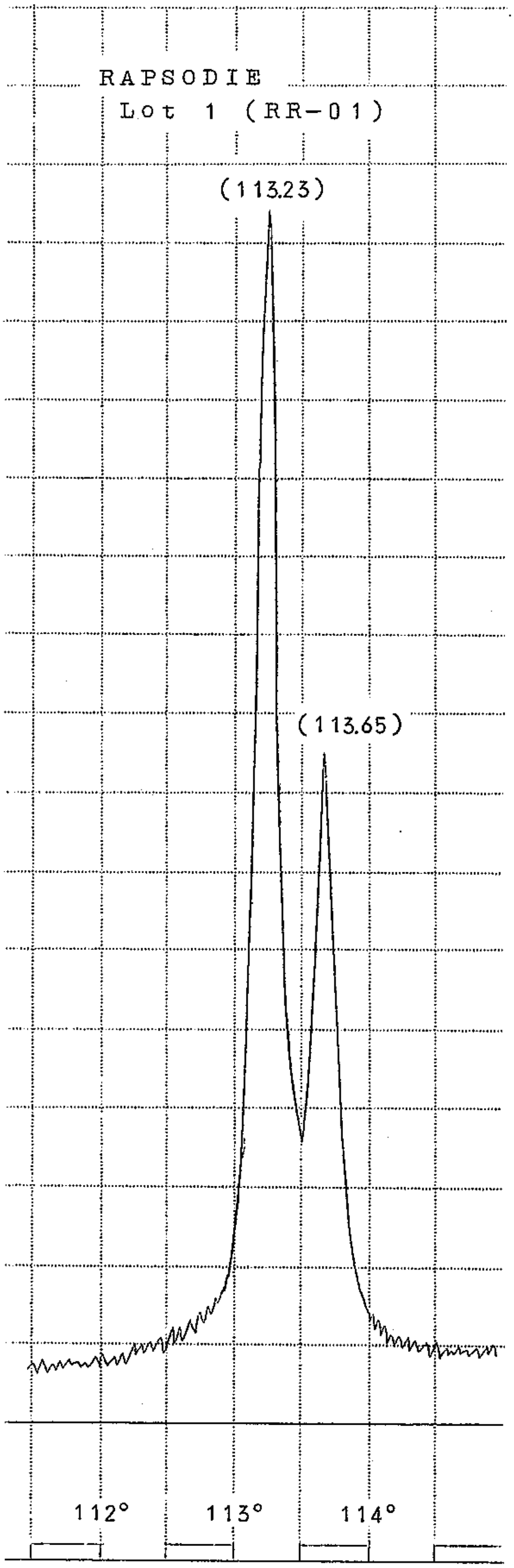
Microphotography for each lot has been taken with the process shown in Fig. 2.1.8-1. The photographies are shown as the following pages.

2.1.9 Total weight of the pin

Total weights of the core and blanket fuel in a pin has been measured and each Plutonium and Uranium weight has been calculated with the value of the chemical analysis.

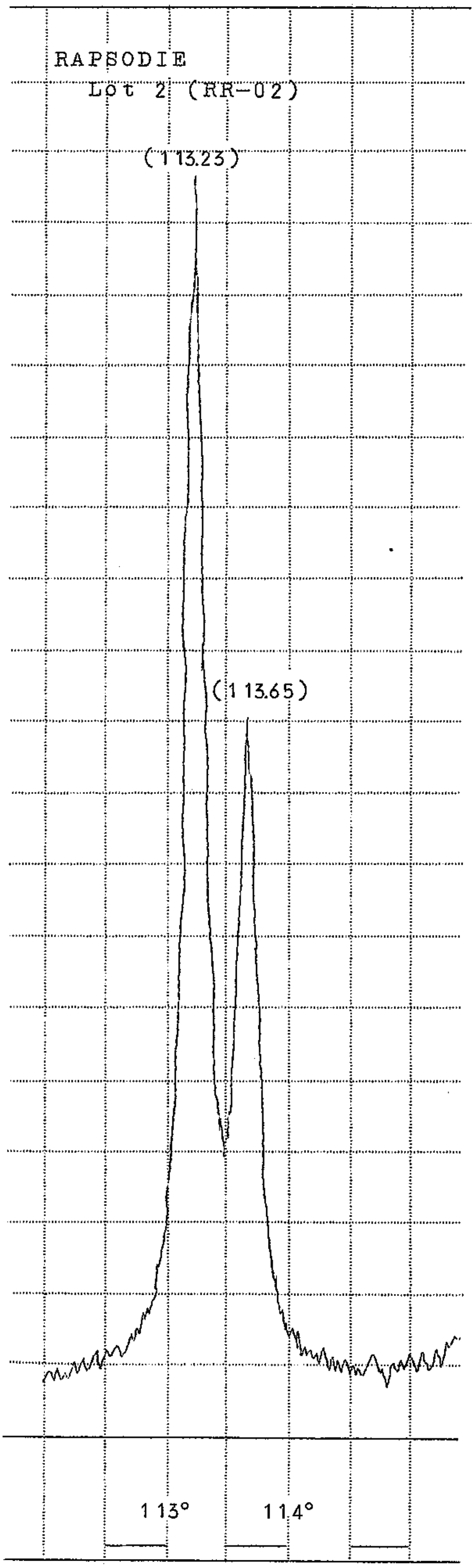
The results are shown in Table 2.1.9-1.

Fig. 2.1.6-1 X-ray chart for Lot 1



Lattice Parameter
(A)
5.4586±0.0003

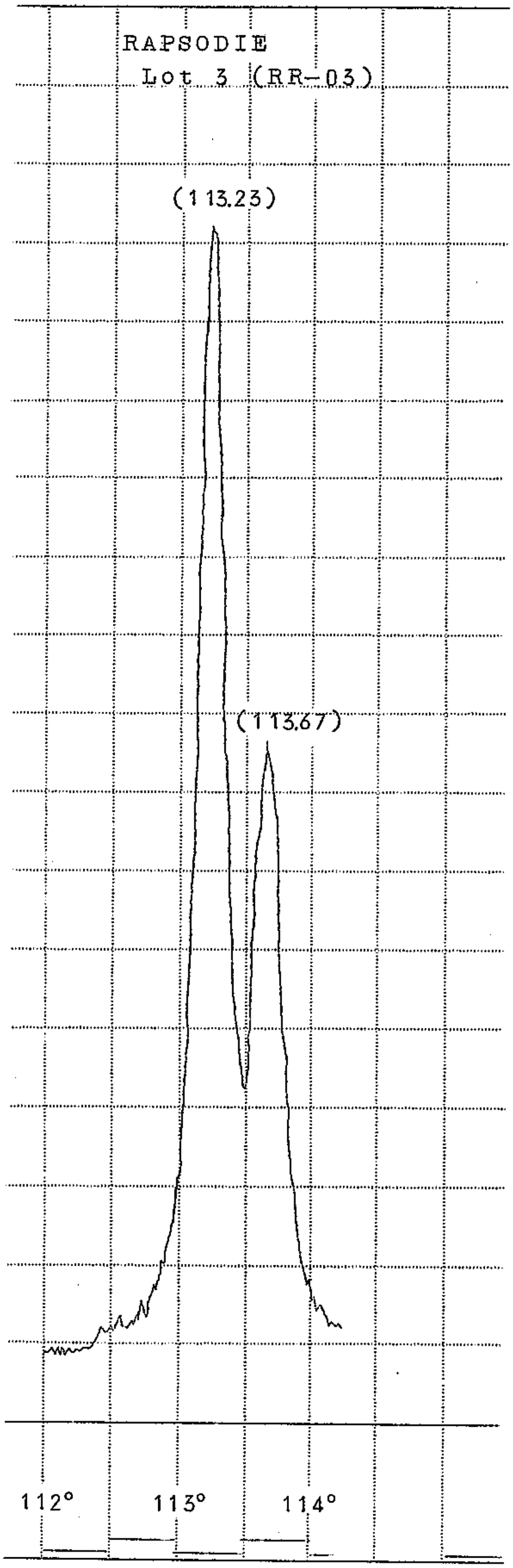
Fig. 2.1.6－2 X－ray chart for Lot 2



Lattice Parameter
(A)

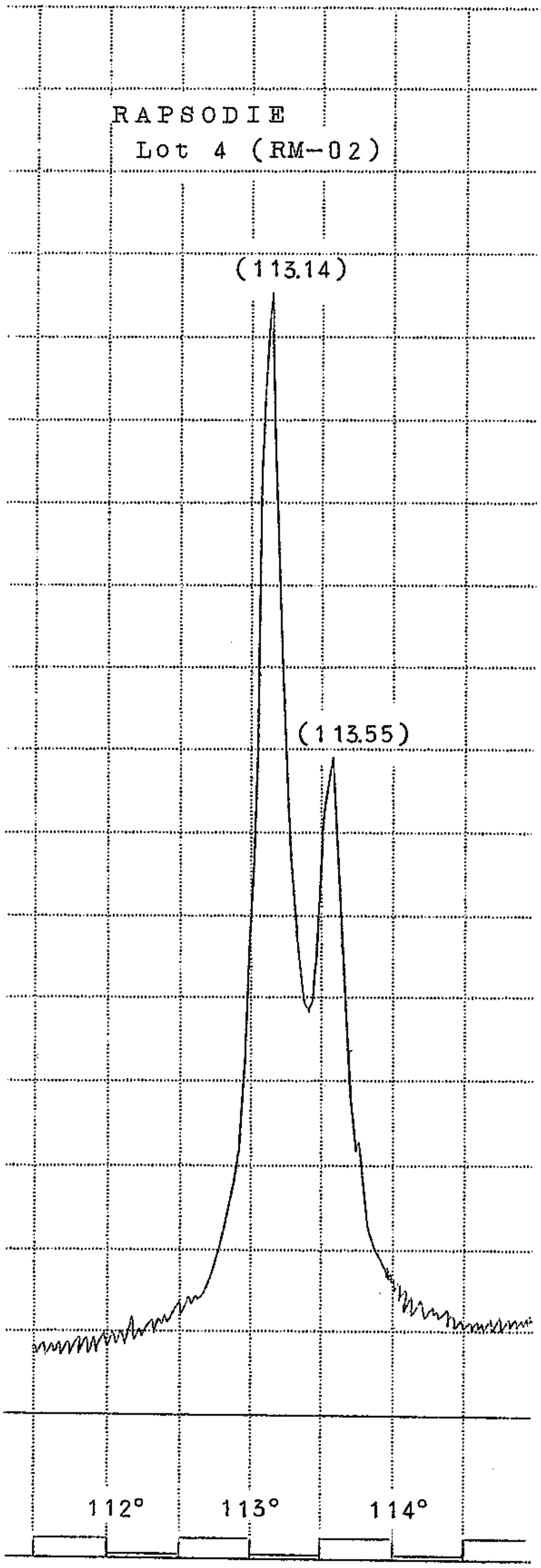
5.4586±0.0002

Fig. 2.1.6－3　X-ray chart for Lot 3



Lattice Parameter
(A)
5.4597 ± 0.0006

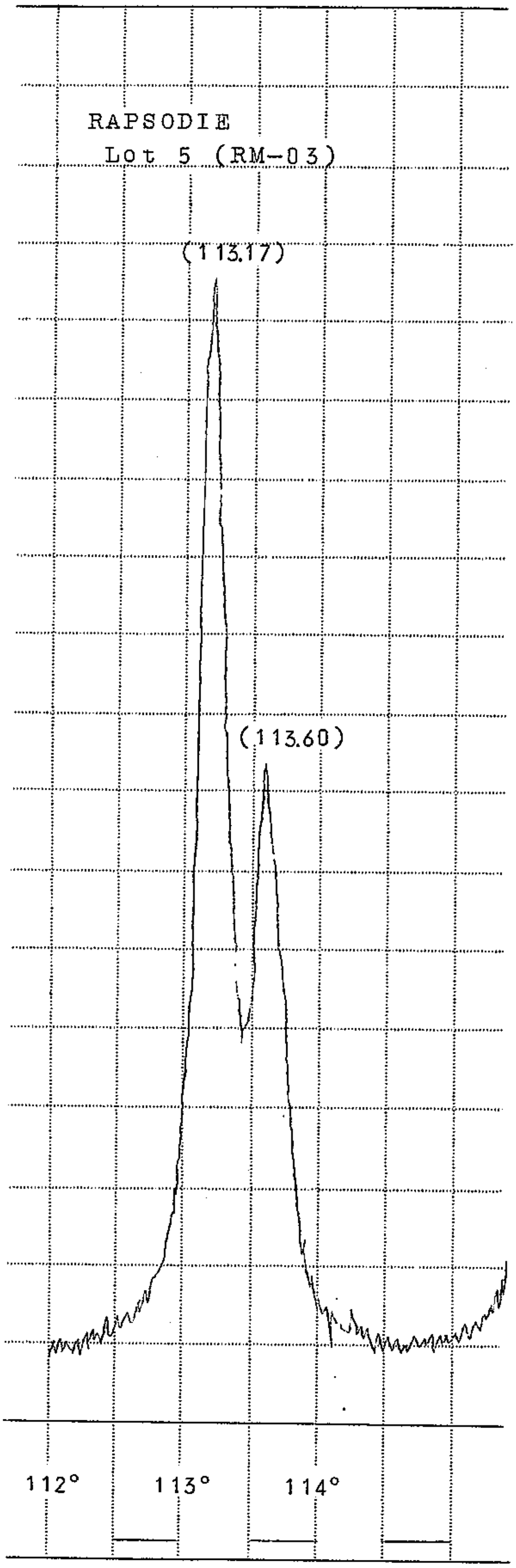
Fig.2.1.6-4　X-ray chart for Lot 4



Lattice Parameter
(A)

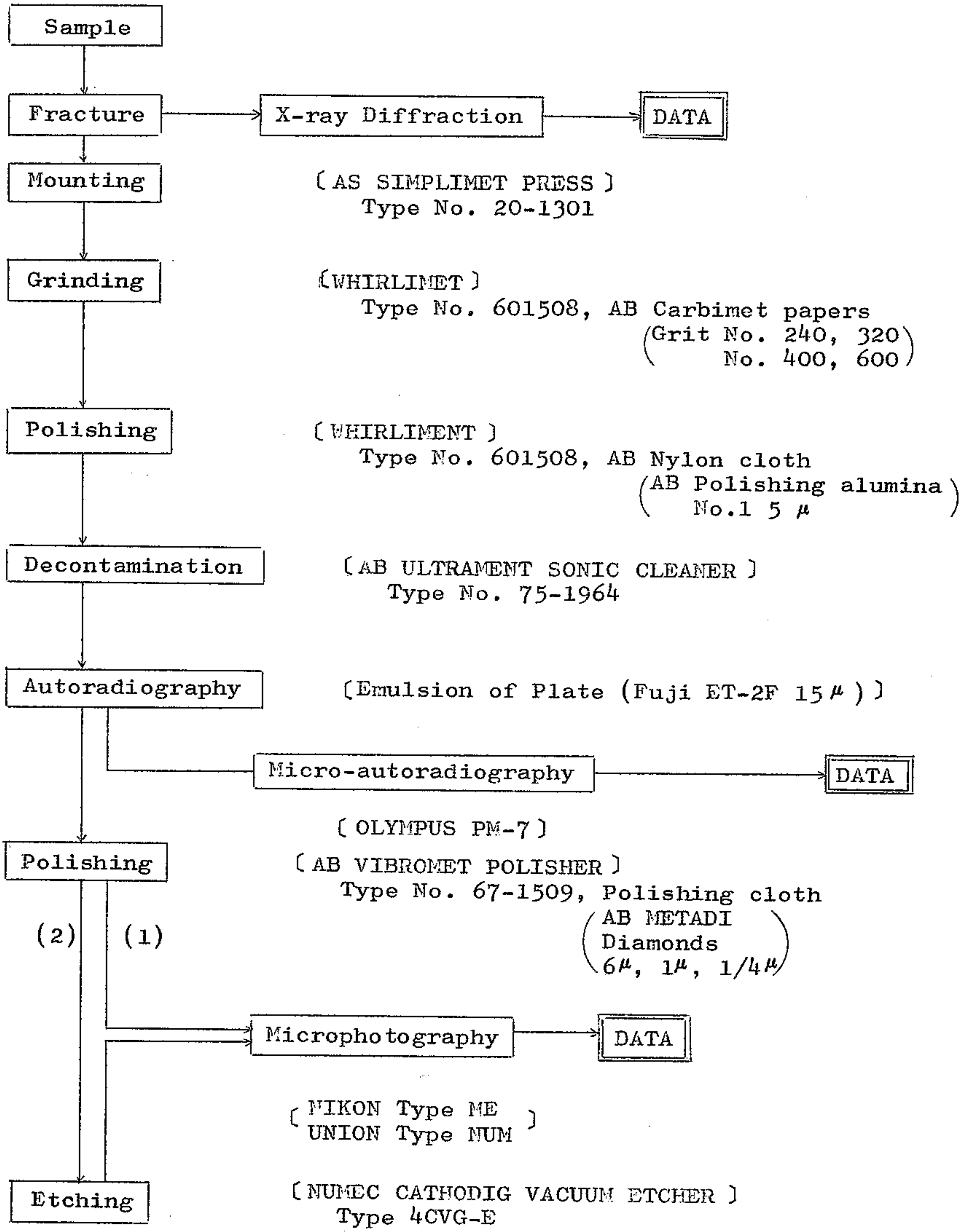
5.4611±0.0005

Fig. 2.1.6-5 X-ray chart for Lot 5



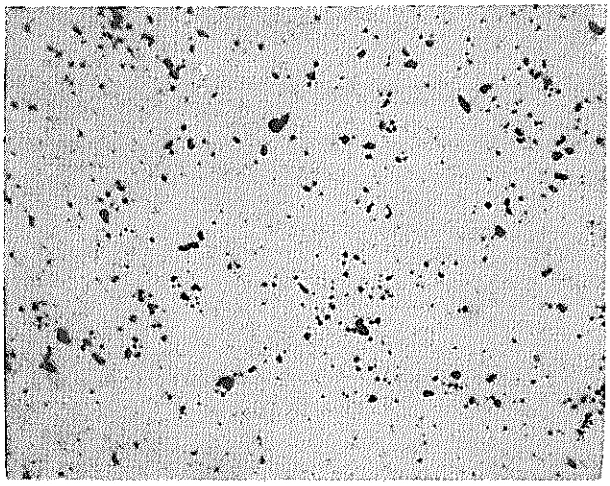
Lattice Parameter
(A)

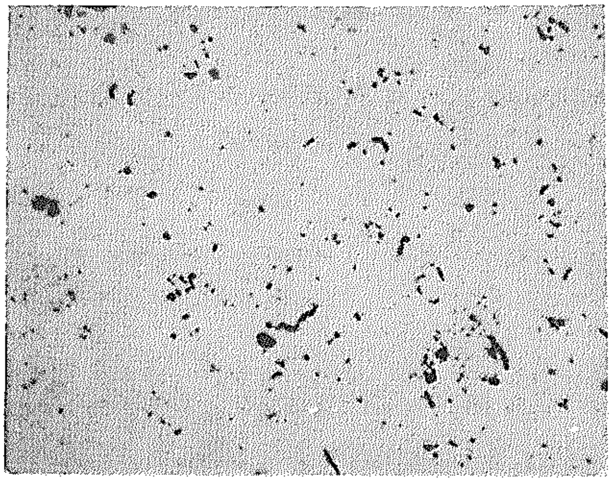
5.4613 ± 0.0006

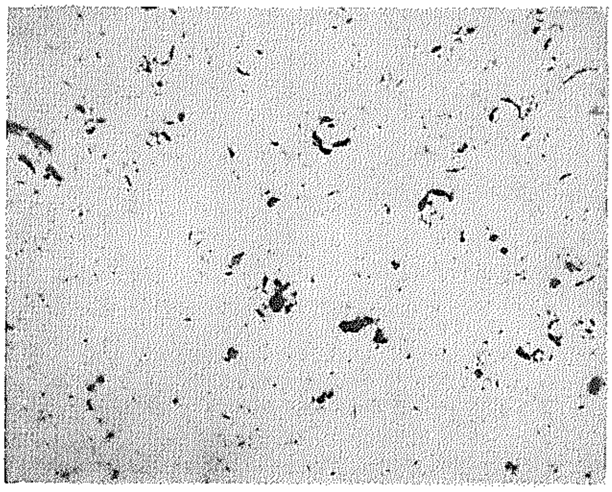


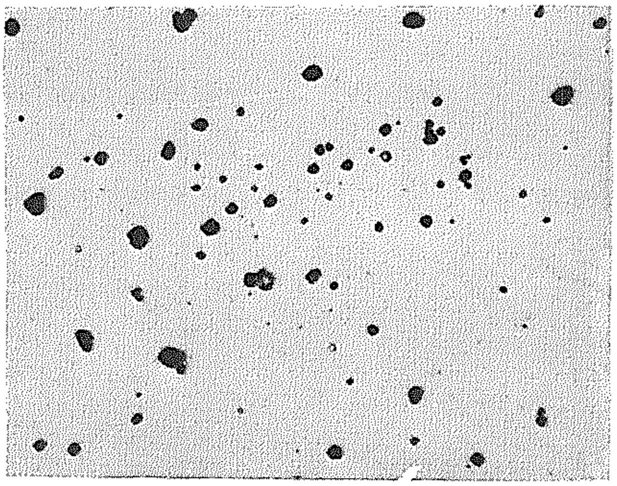
Notel ; 〔 〕 Instrument

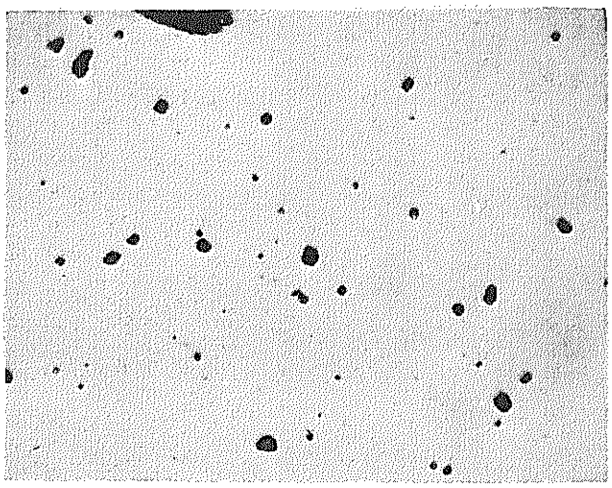
Fig. 2.1.8-1 Ceramography Flow Sheet


Lot 1 (RR-01)


Lot 2 (RR-02)


Lot 3 (RR-03)


Lot 4 (RM-02)


Lot 5 (RM-03)

※※ CERTIFICATE OF SHIPPING ※※

Table 2.1.9 — 1

※※※※※※※※※※※※※※※※※※※※
※ RAPSODIE PIN WEIGHT ※
※※※※※※※※※※※※※※※※※※※※

UNIT — GRAM

		WEIGHT OF CORE FUEL								WEIGHT OF BLANKET FUEL		
PIN №.	CLAD №.	PUO2—UO2 ※	PUO2	PU—METAL	PU239	PU241 ※※	UO2 ※	U—METAL	U235	UO2 ※	U—METAL	U235
000	S2769	37.44	6.70	5.91	5.33	0.07	30.73	27.07	16.23	0.00	0.00	0.00
001	S2808	81.00	14.66	12.93	11.65	0.15	66.35	58.45	35.13	93.00	81.93	0.58
002	S2810	80.43	14.56	12.84	11.57	0.15	65.87	58.03	34.88	102.50	90.30	0.64
003	S2790	80.81	14.65	12.92	11.65	0.15	66.16	58.29	35.03	92.90	81.84	0.58
004	S2817	80.13	14.46	12.76	11.50	0.15	65.67	57.85	34.78	92.90	81.84	0.58
005	S2803	80.53	14.58	12.86	11.59	0.15	65.96	58.11	34.93	102.90	90.65	0.64
006	TIE ROD											
007	S2719	80.17	14.53	12.82	11.55	0.15	65.63	57.82	34.76	102.80	90.57	0.64
008	S2738	79.91	14.10	12.43	11.21	0.15	65.82	57.98	34.61	102.85	90.61	0.64
009	K0040	79.42	14.34	12.65	11.40	0.15	65.09	57.34	34.47	93.00	81.93	0.58
010	S2826	80.73	14.64	12.91	11.64	0.15	66.09	58.23	35.00	92.80	81.76	0.58
011	K0013	81.37	14.35	12.66	11.41	0.15	67.02	59.04	35.28	102.70	90.48	0.64
012	K0014	80.46	14.19	12.52	11.28	0.15	66.27	58.38	34.89	102.80	90.57	0.64
013	K0009	81.52	14.38	12.68	11.43	0.15	67.14	59.15	35.35	102.90	90.65	0.64
014	S2784	79.42	14.38	12.68	11.43	0.15	65.04	57.30	34.44	102.70	90.48	0.64
015	K0050	79.29	14.31	12.62	11.38	0.15	64.98	57.24	34.41	93.00	81.93	0.58
016	K0080	80.61	14.22	12.54	11.30	0.15	66.39	58.49	34.91	103.00	90.74	0.64
017	K0047	80.36	14.17	12.50	11.27	0.15	66.18	58.31	34.80	102.90	90.65	0.64
018	S2749	80.25	14.16	12.49	11.26	0.15	66.10	58.23	34.76	102.50	90.30	0.64
019	S2754	80.50	14.20	12.52	11.29	0.15	66.30	58.41	34.86	102.90	90.65	0.64
020	S2733	79.19	13.97	12.32	11.11	0.15	65.22	57.46	34.30	102.85	90.61	0.64
021	TIE ROD											
022	S2832	79.67	14.05	12.40	11.17	0.15	65.62	57.81	34.51	102.75	90.52	0.64
023	S2792	80.12	14.52	12.81	11.55	0.15	65.59	57.79	34.74	102.80	90.57	0.64
024	K0056	81.06	14.30	12.61	11.37	0.15	66.76	58.82	35.15	103.00	90.74	0.64
025	K0034	81.29	14.34	12.65	11.40	0.15	66.95	58.98	35.25	103.10	90.83	0.64
026	S2828	81.22	14.73	12.99	11.71	0.15	66.49	58.58	35.21	102.90	90.65	0.64
027	S2805	80.89	14.66	12.93	11.66	0.15	66.22	58.34	35.07	93.10	82.02	0.58
028	S2713	79.15	14.29	12.60	11.36	0.15	64.87	57.15	34.35	93.00	81.93	0.58
029	S2823	80.07	14.52	12.80	11.54	0.15	65.56	57.15	34.72	102.70	90.48	0.64
030	TIE ROD											
031	S2708	80.30	14.53	12.82	11.55	0.15	65.76	57.94	34.83	102.60	90.39	0.64
032	K0044	80.95	14.28	12.59	11.35	0.15	66.67	58.74	35.10	102.90	90.65	0.64
033	S2843	81.01	14.66	12.93	11.66	0.15	66.35	58.46	35.14	102.70	90.48	0.64
034	S2772	80.03	14.51	12.80	11.54	0.15	65.52	57.73	34.70	102.80	90.57	0.64
035	S2799	80.14	14.46	12.76	11.50	0.15	65.67	57.86	34.78	92.90	81.84	0.58
036	S2797	80.00	14.44	12.74	11.48	0.15	65.56	57.76	34.72	93.00	81.93	0.54
037	S2802	80.51	14.57	12.85	11.59	0.15	65.94	58.09	34.92	102.90	90.65	0.64
038	S2706	80.13	14.50	12.78	11.52	0.15	65.64	57.83	34.76	103.00	90.74	0.64
039	K0067	80.40	14.55	12.83	11.57	0.15	65.85	58.01	34.87	102.75	90.52	0.64
040	K0054	80.10	14.49	12.78	11.52	0.15	65.61	57.80	34.75	102.80	90.57	0.64
041	S2752	80.71	14.63	12.90	11.63	0.15	66.08	58.22	35.00	102.50	90.30	0.64
042	S2829	79.91	14.49	12.78	11.52	0.15	65.42	57.63	34.64	102.45	90.26	0.64
043	K0077	79.20	14.29	12.61	11.36	0.15	64.90	57.18	34.37	101.50	89.42	0.63
	TOTAL	3250.80	583.36	514.52	463.80	6.07	2667.04	2349.65	1409.40	4012.05	3534.55	24.99

2.1.10 Length of the fuel column

The total lengths of lower blanket, core, upper blanket for each pin has been measured and their results are listed in Table 2.1.10-1.

Table 2.1.10-1 Length of the Fuel Column

Pin No.	Clad No.	Lower Blanket (mm)	Core (mm)	Upper Blanket (mm)	Total Length (mm)
001	S-2808	295.00	320.0	85.10	740.5
002	S-2810	314.35	318.5	104.75	738.5
003	S-2790	294.00	321.0	84.85	740.5
004	S-2817	294.35	320.5	84.55	739.0
005	S-2803	314.25	319.5	104.70	739.5
007	S-2719	313.25	318.5	104.70	738.0
008	S-2738	313.80	321.5	104.70	740.0
009	K-0040	293.65	318.5	84.60	737.0
010	S-2826	293.95	322.0	84.70	741.0
011	K-0013	313.00	321.5	104.4	740.0
012	K-0014	313.00	318.5	104.8	738.0
013	K-0009	315.00	322.5	104.55	742.5
014	S-2784	314.10	318.0	104.8	737.0
015	K-0050	294.20	317.5	84.65	737.0
016	K-0080	313.50	323.0	105.00	743.0
017	K-0047	314.00	323.0	104.95	742.0
018	S-2749	313.00	322.5	104.70	741.0
019	S-2754	313.50	322.5	104.70	741.5
020	S-2733	313.50	320.0	104.65	738.0
022	S-2832	313.70	321.0	104.55	740.5
023	S-2792	313.70	318.5	104.70	737.5
024	K-0056	314.50	321.0	104.75	741.5
025	K-0034	314.00	322.0	104.60	741.5
026	S-2828	313.30	322.0	104.65	740.0
027	S-2805	293.65	322.0	84.70	740.5
028	S-2713	294.30	317.5	84.55	736.0
029	S-2823	313.90	319.5	104.65	738.5
031	S-2708	313.45	318.0	104.70	737.0
032	K-0044	314.50	320.5	104.55	740.0
033	S-2843	314.20	320.0	104.40	738.5
034	S-2772	314.60	319.0	104.50	739.0
035	S-2799	294.3	319.0	84.65	738.0
036	S-2797	294.35	318.0	84.50	736.5
037	S-2802	313.51	318.5	104.85	737.0
038	S-2706	314.10	319.5	104.55	738.0
039	K-0067	314.15	318.5	104.60	737.0
040	K-0054	313.50	317.5	104.45	736.0
041	S-2752	313.35	321.0	104.85	740.0
042	S-2829	313.10	319.0	104.70	737.5
043	K-0077	310.35	317.0	104.85	732.0

2.2 Cladding

All claddings used for the fuel pins has been sent to CEA in January, 1970 for the inspections. Therefore data explained here are only of dimension and mechanical properties of cladding tubes to be used for irradiation.

2.2.1 Dimension (Diameter-thickness)

A. Dimension measurements

(1) Outside and inside diameter measurement

Outside and inside diameter were measured by an airmicrometer through full length of rotating tubes. Standard were used gauges with three dimension such as upper limit, center and lower limit gauge.
Dimension of gauges are as follow;

	Outside gauge	Inside gauge
Upper limit gauge	6.353 mm	5.625 mm
Center gauge	6.299 mm	5.604 mm
Lower limit gauge	6.245 mm	5.577 mm

Accuracy of this measurement is 0.005 mm.

(2) Wall thickness measurement

Wall thickness was measured by micrometer at both of tubing 90 degree interval. Accuracy of this measurement is 0.010 mm.

B. Results

The results of dimensions measurement are shown in Table 2.2.1-1.

Table 2.2.1-1 Dimensions

Pin	Tube	DIMENSIONAL TEST					
		Outside		Inside		Thickness	
No.	No.	Max(mm)	Min(mm)	Max(mm)	Min(mm)	Max(mm)	Min(mm)
	Spec.	6.300 ± 0.030		5.600 ± 0.025		0.30 ± 0.03	
013	K-0009	6.303	6.296	5.593	5.570	0.370	0.360
011	K-0013	6.308	6.276	5.585	5.581	0.370	0.350
012	K-0014	6.310	6.302	5.589	5.585	0.370	0.350
025	K-0034	6.310	6.297	5.588	5.586	0.370	0.350
009	K-0040	6.305	6.297	5.589	5.585	0.370	0.350
032	K-0044	6.302	6.291	5.581	5.578	0.360	0.350
017	K-0047	6.303	6.270	5.585	5.583	0.360	0.350
015	K-0050	6.311	6.304	5.593	5.570	0.370	0.350
040	K-0054	6.304	6.297	5.594	5.588	0.360	0.350
024	K-0056	6.297	6.287	5.587	5.584	0.360	0.350
039	K-0067	6.309	6.301	5.583	5.581	0.370	0.350
043	K-0077	6.307	6.278	5.584	5.581	0.370	0.350
016	K-0080	6.311	6.303	5.584	5.581	0.370	0.350
038	S-2706	6.308	6.298	5.575	5.592	0.360	0.340
031	S-2708	6.302	6.289	5.598	5.573	0.360	0.340
028	S-2713	6.306	6.294	5.595	5.594	0.360	0.340
007	S-2719	6.310	6.295	5.596	5.593	0.360	0.340
020	S-2733	6.310	6.293	5.601	5.593	0.360	0.350
008	S-2738	6.306	6.290	5.601	5.594	0.360	0.340
018	S-2749	6.302	6.287	5.598	5.595	0.370	0.340
041	S-2752	6.307	6.287	5.602	5.594	0.370	0.340
019	S-2754	6.308	6.292	5.601	5.593	0.360	0.340
034	S-2772	6.305	6.289	5.605	5.595	0.360	0.340
014	S-2784	6.308	6.294	5.598	5.595	0.360	0.340
003	S-2790	6.308	6.294	5.599	5.592	0.360	0.340
023	S-2792	6.310	6.291	5.600	5.595	0.360	0.340
036	S-2797	6.305	6.296	5.601	5.594	0.360	0.350
035	S-2799	6.301	6.295	5.599	5.593	0.360	0.340
037	S-2802	6.298	6.295	5.597	5.595	0.350	0.340
005	S-2803	6.308	6.295	5.600	5.594	0.350	0.350
027	S-2805	6.304	6.291	5.599	5.590	0.370	0.340
001	S-2808	6.309	6.294	5.601	5.594	0.360	0.340
002	S-2810	6.302	6.290	5.597	5.594	0.360	0.340
004	S-2817	6.303	6.287	5.596	5.593	0.360	0.340
029	S-2823	6.306	6.296	5.602	5.594	0.360	0.340
010	S-2826	6.306	6.299	5.596	5.593	0.360	0.350
042	S-2829	6.304	6.296	5.596	5.594	0.370	0.240
022	S-2832	6.304	6.297	5.599	5.594	0.360	0.350
033	S-2843	6.304	6.294	5.596	5.594	0.360	0.340

2.2.2 Mechanical properties

Table 2.2.2-1 shows the certificate of test results by manufactures.

Table 2.2.2-1 Mechanical Properties

	Specification	Method	K	S
Tensile Temp. R.T. UTS Kg/mm^2	60	ASTM A370-67	73.0	72.0
YS 0.2% off set Kg/mm^2	45	ASTM A370-67	60.6	57.9
Elongation % mm	25	ASTM A370-67	31.4	32.0
Flare % OD Expansion	21	ASTM A450-66	48	
Flatten % of OD $\leq$ H	2.6	ASTM A450-66	1.2	
Burst Kg/mm^2	800		980	924
Grain size ASTM No	6	ASTM E112-66	9.5	7.3
Surface Roughness	Inside 6s		1.6	0.8
	Outside 6s		1.3	0.8

PNC's Destructive Tests

The tensile strength and rupture strength at elevated temperature are shown in Fig. 2.2.2-1 and 2.2.2-2. The tension test were conducted in accordance with ASTM designation; E21-66T.

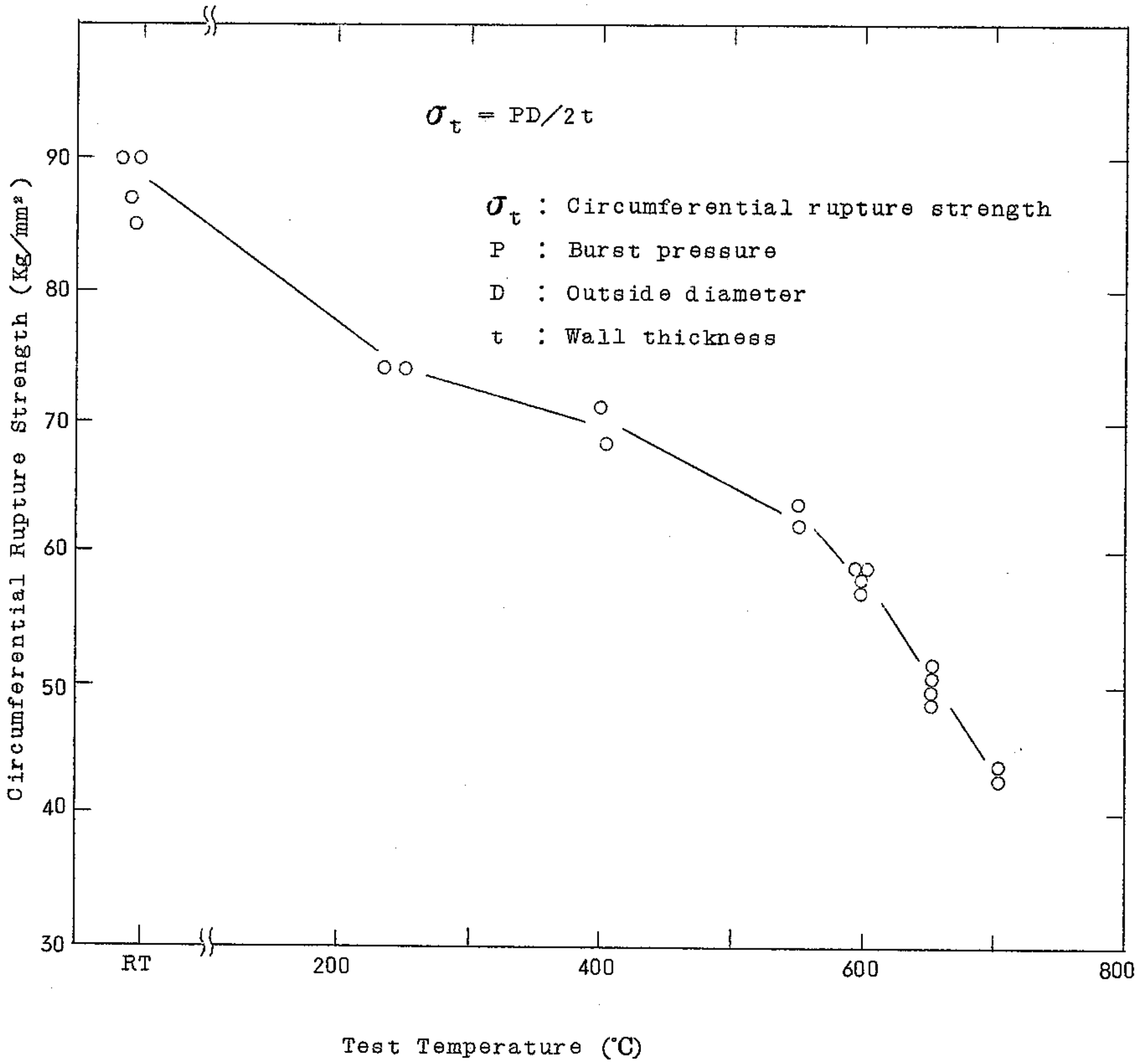


FIGURE 2.2.2.-1 Rupture strength vs test temperature

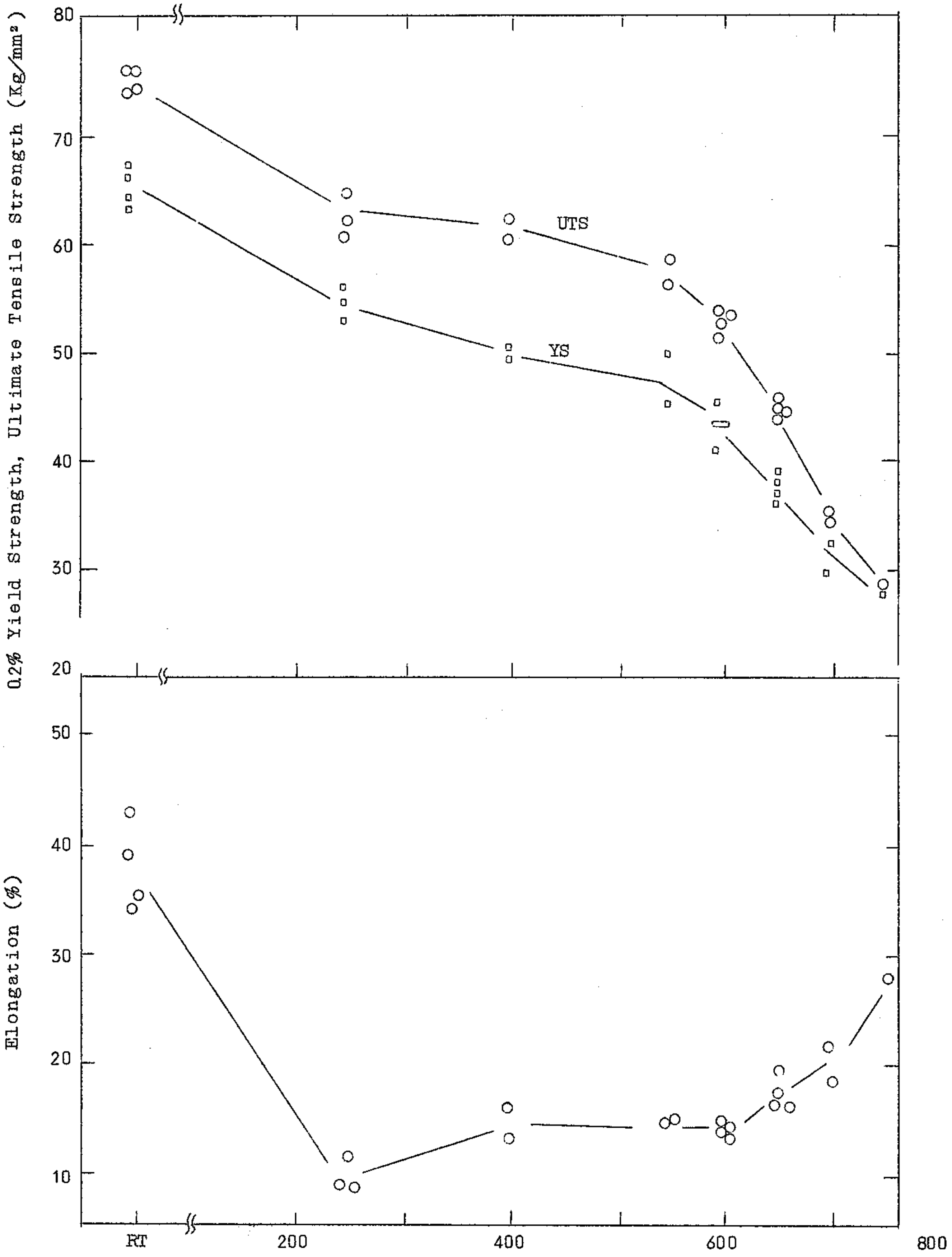


FIGURE 2.2.2-2 Tensile properties vs test temperature

2.3 Other Internal Structure Materials of the Pin

2.3.1 Chemical analysis

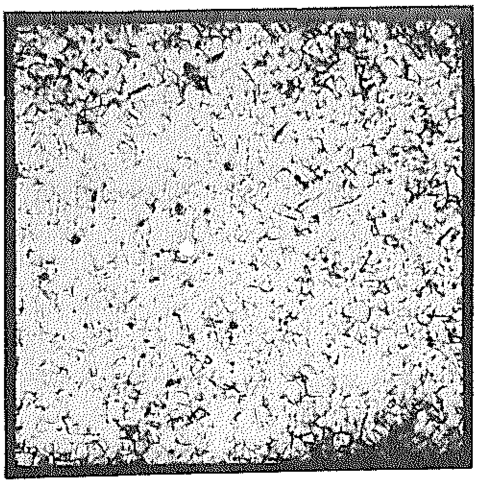
The data of thechemical analyses for the end plugs, stainless steel plate, sleeve and spring are taken from the manufacturer's mill sheet. The data are listed in Table 2.3.1-1.

Table 2.3.1-1 Chemical Components for Other Components of Fuel Pin

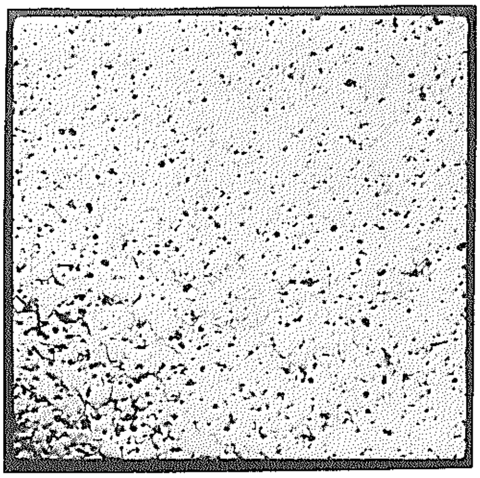
	AIS 316 Standard	Bottom End Plug	Top End Plug	Spring	Stainless Steel Plate	Sleeve
C	<0.08	0.059	0.059	0.05	0.059	0.07
Si	<1.00	0.71	0.71	0.55	0.71	0.66
Mn	<2.00	1.79	1.79	1.38	1.79	1.49
P	<0.040	0.025	0.025	0.033	0.025	0.033
S	<0.030	0.0021	0.0021	0.026	0.0021	0.015
Cr	16.00-18.00	17.06	17.06	16.28	17.06	17.26
Ni	10.00-14.00	13.19	13.19	12.30	13.19	10.71
Mo	2.00- 3.00	2.39	2.39	2.18	2.39	2.54

2.3.2 Micrography

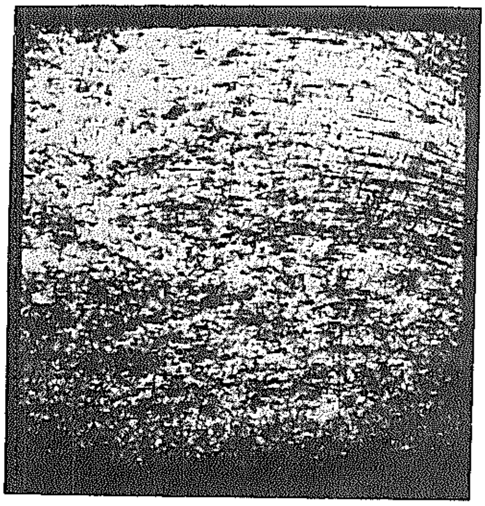
Micrographies for those structure materials are shown in the following page with 100 times enlargement.



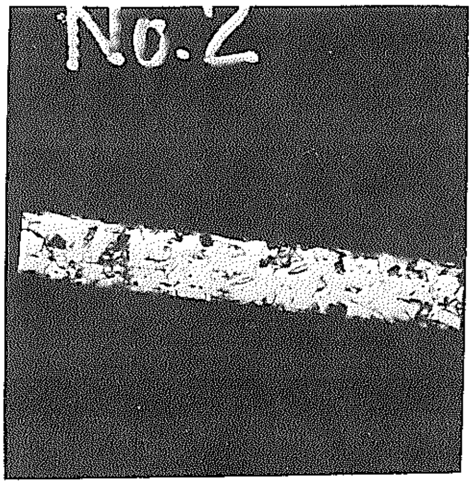
BOTTOM END PLUG



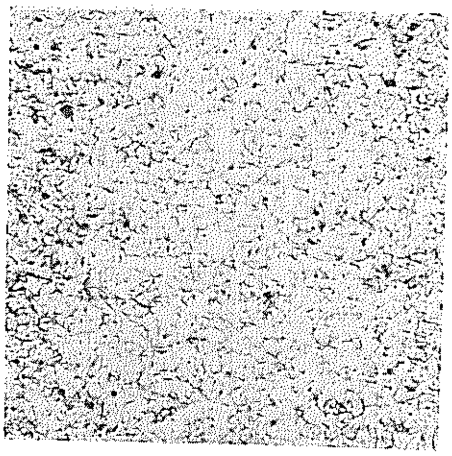
TOP END PLUG



SPRING



SLEEVE



SUS PLATE

2.4 Capsule

2.4.1 Chemical Analysis

The data of the chemical analysis for the capsule clad and end plug are taken from the manufacturer's mill sheet. Those data are listed in Table 2.4.1-1.

Table 2.4.1-1 Chemical Analysis

	Specification	Capsule clad	Capsule end plug
C	< 0.08	0.06	0.05
Si	< 1.00	0.53	0.48
Mn	< 2.00	1.60	1.54
P	< 0.045	0.024	0.025
S	< 0.030	0.011	0.010
Ni	10.00 - 14.00	13.10	13.38
Cr	16.00 - 18.00	16.91	17.06
Mo	2.00 - 3.00	2.45	2.74

2.4.2 Micrography

Micrographies for the capsule clad and its end plug are shown in the following page with 100 times enlargement.

2.4.3 He leak test

He leak test has been done under the following conditions;

- standard samples

  1.8×10^{-8} atm cc/s
  1.84×10^{-6} atm cc/s

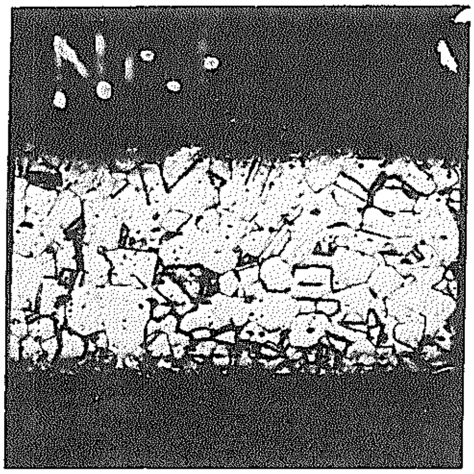
- vacuum degree in the specimens

  10^{-3} mmHg

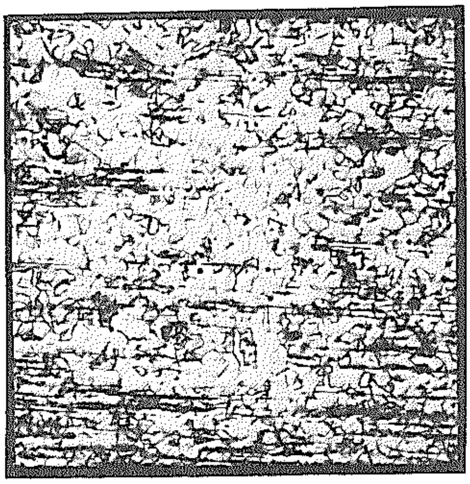
- vacuum degree in the mass spectrometer

  10^{-5} mmHg

There are no indication of helium leak for all capsules.



CAPSULE CLAD



CAPSULE END PLUG

The results are listed in Table 2.4.3-1.

Table 2.4.3-1 Results of He leak test

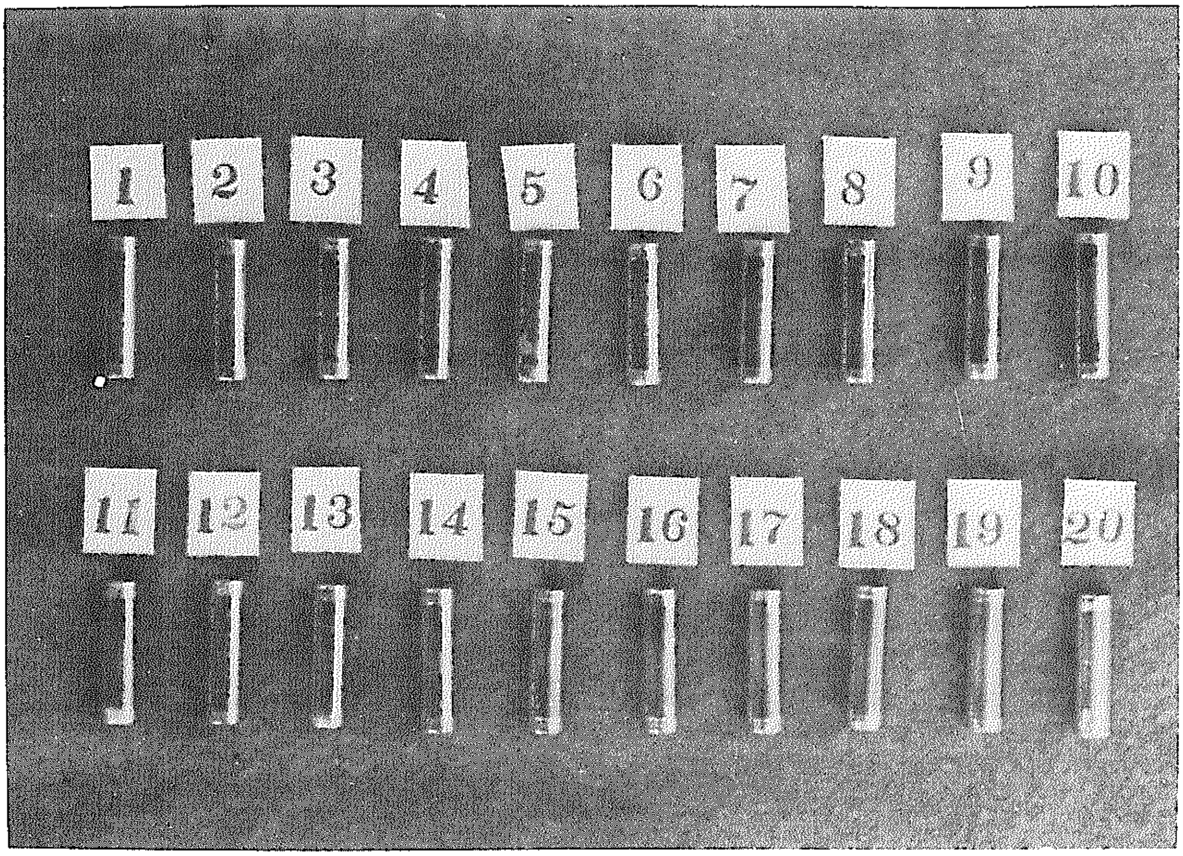
Capsule No.	Leak rate ($\times 10^{-8}$ atom cc/s)	Capsule No.	Leak rate ($\times 10^{-8}$ atom cc/s)
1	< 1.8	11	< 1.8
2	< 1.8	12	< 1.8
3	< 1.8	13	< 1.8
4	< 1.8	14	< 1.8
5	< 1.8	15	< 1.8
6	< 1.8	16	< 1.8
7	< 1.8	17	< 1.8
8	< 1.8	18	< 1.8
9	< 1.8	19	< 1.8
10	< 1.8	20	< 1.8

2.4.4 X-ray film

X-ray film of those capsules has been taken and it will be sent with this report as the attachment No. 1.

2.4.5 Material list

The outer appearance of the total capsules is attached in the next page. And the material list for those capsule is shown in Table 2.4.5-1.



Outer appearance of capsules

Table 2.4.5-1 Material list

Capsule No.	Material	Pin No.	
		lower	upper
1	Nickel	001	
2	Nickel		001
3	Inconel	035	
4	Inconel		035
5	Tantalum	036	
6	Tantalum		036
7	B C No.1	004	
8'	B C No.3		004
9'	B C-C A-2	028	
10	B C-C C-1	015	
11	B C-C C-2		015
12'	B C-C G-2		028
13	B C-C H-1	009	
14	Vanadium No.1	027	
15	Vanadium No.1		027
16	Vandadium No.3	010	
17	Vandadium No.3		010
18'	B C-C B-3	003	
19	B C-C B-2		003
20	B C-C F-1		009

No. 8, No. 9, No. 12 and No. 18 have been encapsulated again into No. 8', No. 9', No. 12' and No. 18' because X-ray inspections for No. 8, 9, 12 and 18 were not so good.

2.5 Pin

2.5.1 He leak test

Helium leak test for all fuel pins have been done under the same condition which has shown to the CEA experts on their visit of PNC.

The results are listed in Table 2.5.1-1.

2.5.2 Dimension and Weight

There is no change of the diameter for each pin compared with that for each cladding except the welding section. The local diametral increase of the bead for each pin is less than 15/100 mm.

The deflection of the fuel pin is also the same of the cladding.

The total length and total weight of fuel pins are listed in Table 2.5.2-1.

2.5.3 Measurement of the external surface contamination

As already shown to the CEA experts, there are two method for measuring the external surface contamination. Those results are tabulated in Table 2.5.3-1.

2.5.4 Micrography on one sample out of twenty weldings

The following pages file the welding condition and micrography on one sample out of twenty weldings. The welding samples which have been welded under the same condition, already handed the CEA experts.

2.5.5 Radiography

X-ray film on the plenum section and the welding section for each pin will be sent with this report as the attachment No. 2 and No. 3.

Table 2.5.1-1 Results of He Leak Test

Pin No.	Clad No.	Leak Rate (x 10^{-9} atom cc/s)	Pin No.	Clad No.	Leak Rate (x 10^{-9} atom cc/s)
001	S-2808	5.0	021	TIE ROD	-
002	S-2810	2.9	022	S-2832	2.9
003	S-2790	2.2	023	S-2792	2.9
004	S-2817	2.2	034	K-0056	2.6
005	S-2803	2.9	025	K-0034	2.6
006	TIE ROD	-	026	S-2828	2.9
007	S-2719	2.9	027	S-2805	2.2
008	S-2738	2.9	028	S-2713	2.2
009	K-0040	2.9	029	S-2823	2.2
010	S-2826	2.2	030	TIE ROD	-
011	K-0013	2.6	031	S-2708	2.9
012	K-0014	2.6	032	K-0044	2.6
013	K-0009	2.6	033	S-2843	2.9
014	S-2784	2.9	034	S-2772	2.2
015	K-0050	2.9	035	S-2799	2.2
016	K-0080	5.0	036	S-2797	2.2
017	K-0047	5.0	037	S-2802	2.9
018	S-2749	5.0	038	S-2706	2.9
019	S-2754	5.0	039	K-0067	2.9
020	S-2733	2.9	040	K-0054	2.6
			041	S-2752	2.9
			042	S-2829	2.9
			043	K-0077	5.0

Table 2.5.2-1 Total length and weight fuel pin

Pin No.	Clad No.	Total length (mm)	Total weight (g)	Pin No.	Clad No.	Total length (mm)	Total weight (g)
001	S-2808	999.54	242.26		TIE ROD		
002	S-2810	999.88	245.48	022	S-2832	999.80	245.09
003	S-2790	999.96	239.82	023	S-2792	999.86	245.34
004	S-2817	999.10	239.00	024	K-0056	999.98	247.74
005	S-2803	999.90	246.11	025	K-0034	999.94	247.77
006	TIE ROD			026	S-2828	999.80	246.85
007	S-2719	999.86	245.71	027	S-2805	999.80	241.06
008	S-2738	999.72	244.72	028	S-2713	999.90	238.09
009	K-0040	999.98	239.49	029	S-2823	999.94	245.54
010	S-2826	999.90	240.90	030	TIE ROD		
011	K-0013	1000.00	247.68	031	S-2708	999.78	245.11
012	K-0014	1000.00	247.00	032	K-0044	999.80	247.36
013	K-0009	999.86	247.82	033	S-2843	999.96	246.18
014	S-2784	999.94	245.00	034	S-2772	999.88	245.25
015	K-0050	999.90	239.75	035	S-2799	999.96	240.95
016	K-0080	999.74	247.76	036	S-2797	1000.00	243.25
017	K-0047	999.74	246.38	037	S-2802	999.94	245.63
018	S-2749	999.50	245.30	038	S-2706	999.88	245.76
019	S-2754	999.44	246.01	039	K-0067	999.90	247.39
020	S-2733	999.82	244.56	040	K-0054	999.94	246.31
				041	S-2752	999.90	245.62
				042	S-2829	999.94	245.44
				043	K-0077	999.82	245.10

Table 2.5.3-1 Results of Surface Contamination Inspection

Pin No.	Clad No.	Smeared Survey (dpm)	Directed Survey (cpm)	Pin No.	Clad No.	Smeared Survey (dpm)	Directed Survey (cpm)
001	S-2808	0	0	021	TIE ROD	-	-
002	S-2810	0	0	022	S-2832	0	0
003	S-2790	0	0	023	S-2792	0	0
004	S-2817	0	100	024	K-0056	0	500
005	S-2803	0	0	025	K-0034	0	0
006	TIE ROD	-	-	026	S-2828	0	100
007	S-2719	0	0	027	S-2805	0	0
008	S-2738	0	0	028	S-2713	0	0
009	K-0040	0	500	029	S-2823	0	0
010	S-2826	0	0	030	TIE ROD	-	-
011	K-0013	0	50	031	S-2708	0	50
012	K-0014	0	0	032	K-0044	0	500
013	K-0009	0	0	033	S-2843	0	0
014	S-2784	0	0	034	S-2772	0	0
015	K-0050	0	0	035	S-2799	0	0
016	K-0080	0	50	036	S-2797	0	0
017	K-0047	0	0	037	S-2802	0	0
018	S-2749	0	150	038	S-2706	0	0
019	S-2754	0	100	039	K-0067	0	0
020	S-2733	0	0	040	K-0054	0	0
				041	S-2752	0	0
				042	S-2829	0	0
				043	K-0077	0	50

Micrography of welds between cladding tube and endplug

Welding : TIG Weld

Welding condition

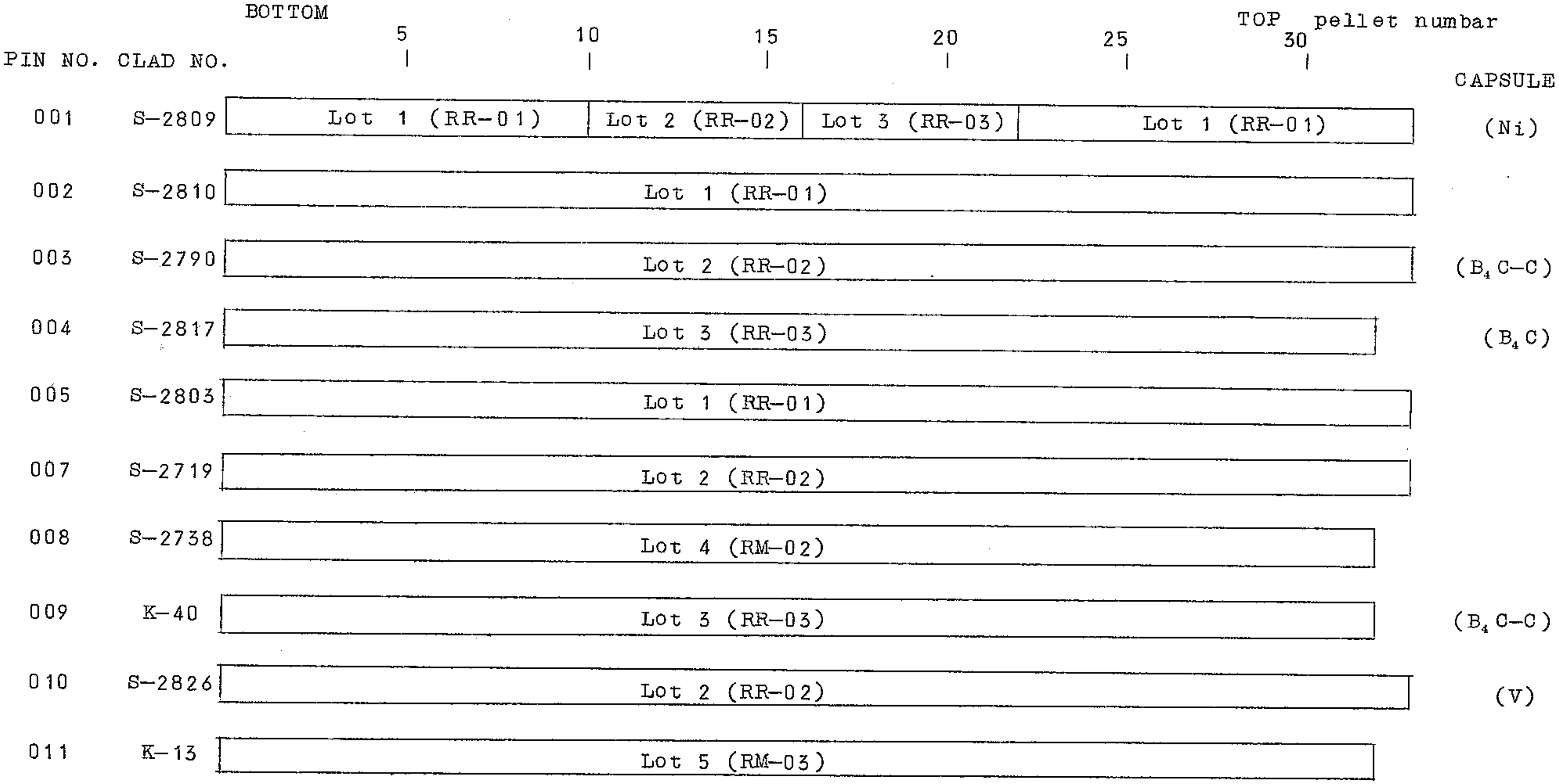
Electrode	1mm ϕ th(1%) − W
Arc gap	0.5 − 0.7mm
Welding speed	12 RPM
Current	7 Amp ± 1 Amp
Atmosphere	1 atm He (He 99.99%)
Vacuum	$<10^{-4}$ mm Hg

3. Individual Record

3.1 Individual file

The individual file contains the pin number, clad number, lot number of fuel pellet and capsule material. Those files for each pin are listed from Fig. 3.1-1 to Fig. 3.1-4.

Fig 3.1-1 Individual File



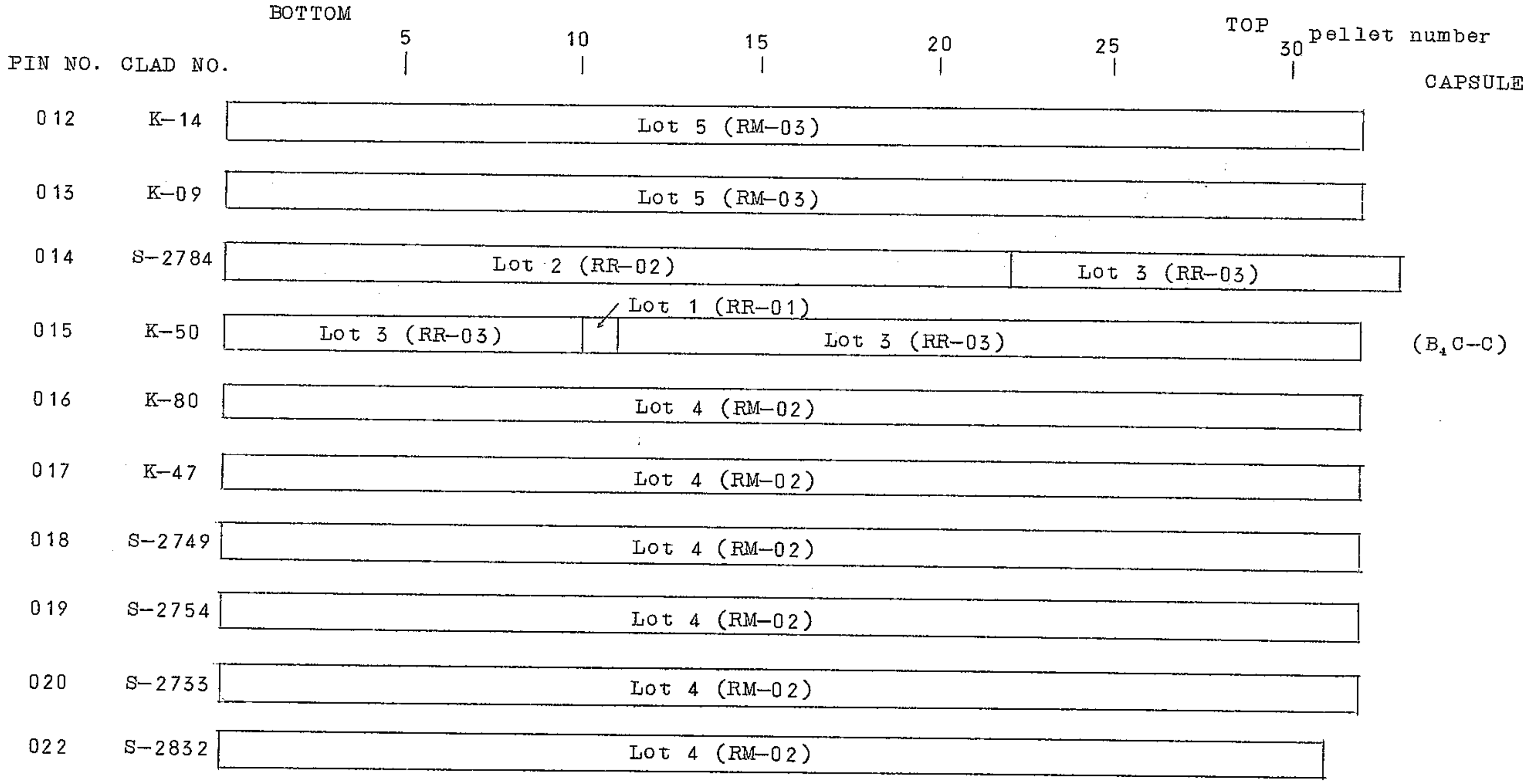


Fig 3.1-2 Individual Filo

Fig 3.1-3 Individual File

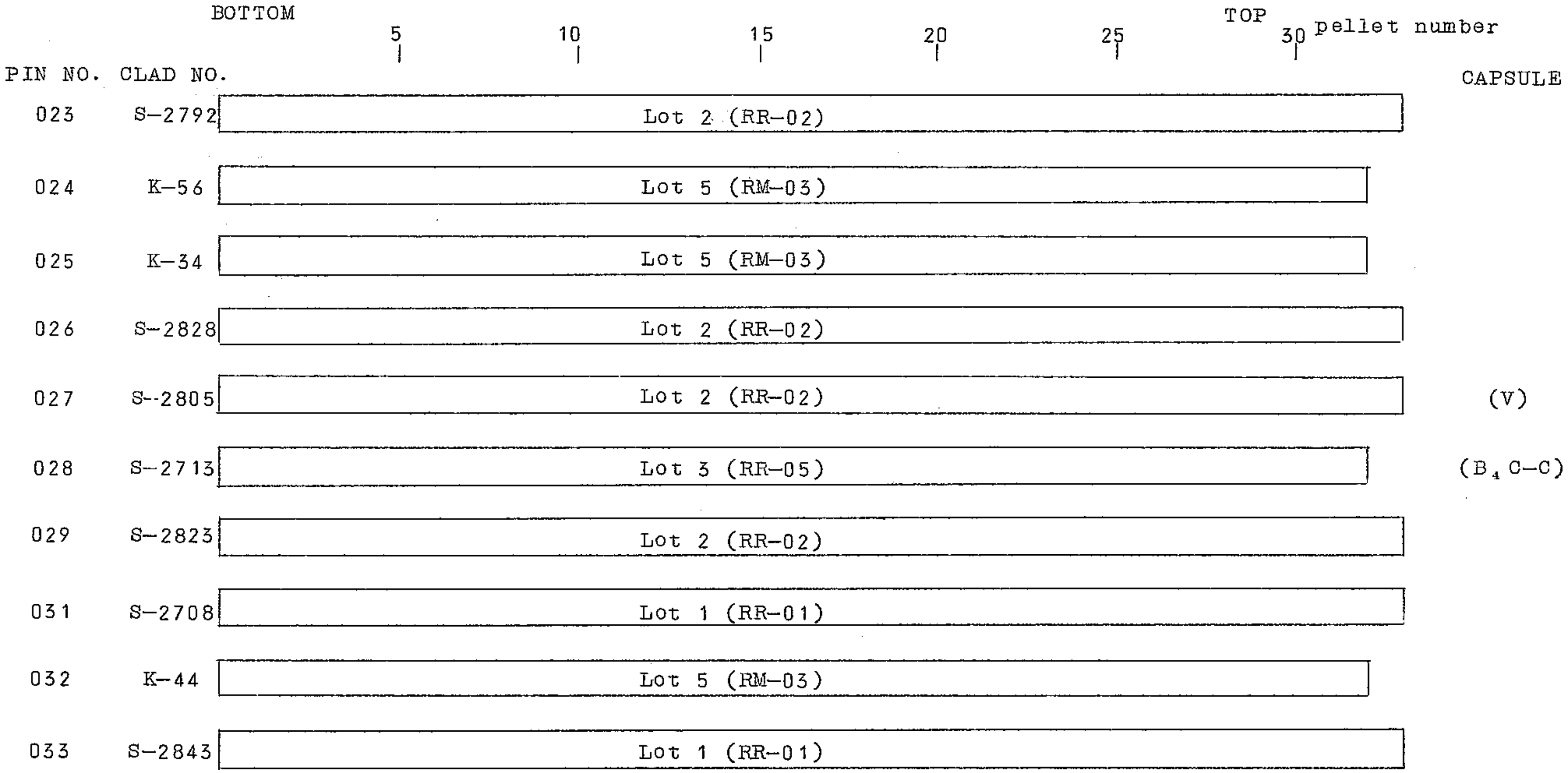
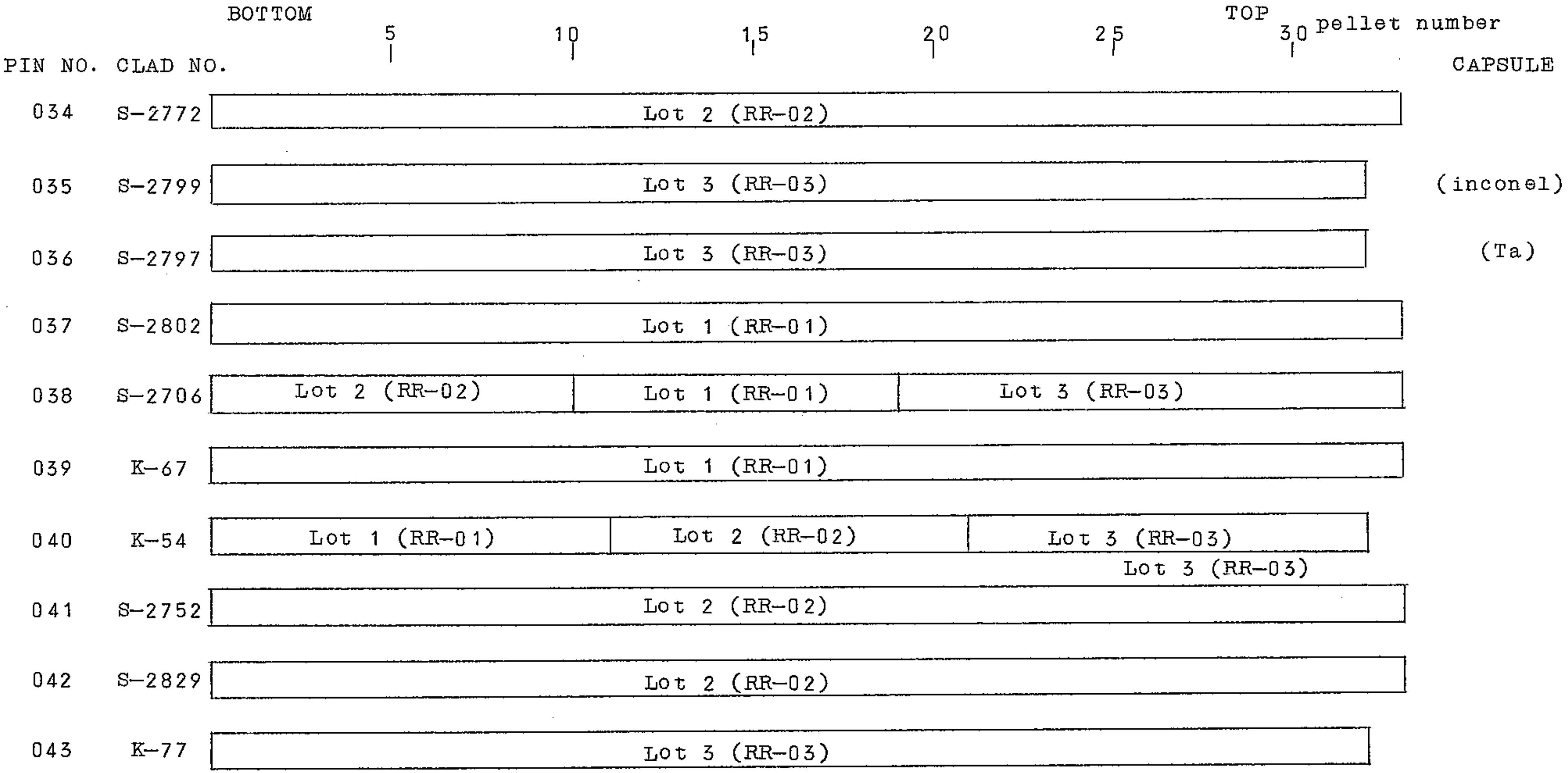


Fig 3.1-4 Individual File



3.2 Density histogram

The histogram of the as-sintered lot 3 pellet density is shown as an example in Fig. 3.2.1. Certainly the specification-over pellets have been taken out and only the specification-in pellets have been used for the fuel pin.

```
   47
   46
   45
   44
   43                                  HH
   42                                  HH
   41                                  HH
   40                              HH  HH  HH
   39                              HH  HH  HH
   38                              HH  HH  HH
   37                              HH  HH  HH
   36                              HH  HH  HH
   35                              HH  HH  HH
   34                              HH  HH  HH
   33                              HH  HH  HH
   32                              HH  HH  HH
   31                              HH  HH  HH
   30                              HH  HH  HH
   29                              HH  HH  HH
   28                              HH  HH  HH
   27                              HH  HH  HH
   26                              HH  HH  HH
   25                              HH  HH  HH
   24                              HH  HH  HH  HH
   23                              HH  HH  HH  HH
   22                              HH  HH  HH  HH
   21                              HH  HH  HH  HH
   20                              HH  HH  HH  HH
   19                              HH  HH  HH  HH
   18                              HH  HH  HH  HH
   17                              HH  HH  HH  HH
   16                              HH  HH  HH  HH
   15                              HH  HH  HH  HH
   14                          HH  HH  HH  HH  HH
   13                          HH  HH  HH  HH  HH
   12                          HH  HH  HH  HH  HH
   11                          HH  HH  HH  HH  HH  HH
   10                          HH  HH  HH  HH  HH  HH
    9                          HH  HH  HH  HH  HH  HH
    8                          HH  HH  HH  HH  HH  HH
    7                          HH  HH  HH  HH  HH  HH
    6                          HH  HH  HH  HH  HH  HH
    5                          HH  HH  HH  HH  HH  HH
    4                      HH  HH  HH  HH  HH  HH  HH
    3                      HH  HH  HH  HH  HH  HH  HH
    2                      HH  HH  HH  HH  HH  HH  HH
    1                  HH  HH  HH  HH  HH  HH  HH  HH
-----------------------------------------------------
CLASS   1   2   3   4   5   6   7   8   9  10  11  12
```

※SAMPLL №. ※ 171

※MAXIMUM ※ 97.30

※MINIMUM ※ 93.43

※RANGE ※ 3.87

※MEAN VALUE ※ 95.082

※VARIANCE ※ 0.361

※SI. DEVIATION ※ 0.600

※MEAN − 3S ※ 93.279

※MEAN + 3S ※ 96.885

※CLASS WIDTH ※ 0.400

※CLASS WIDTH/2 ※ 0.200

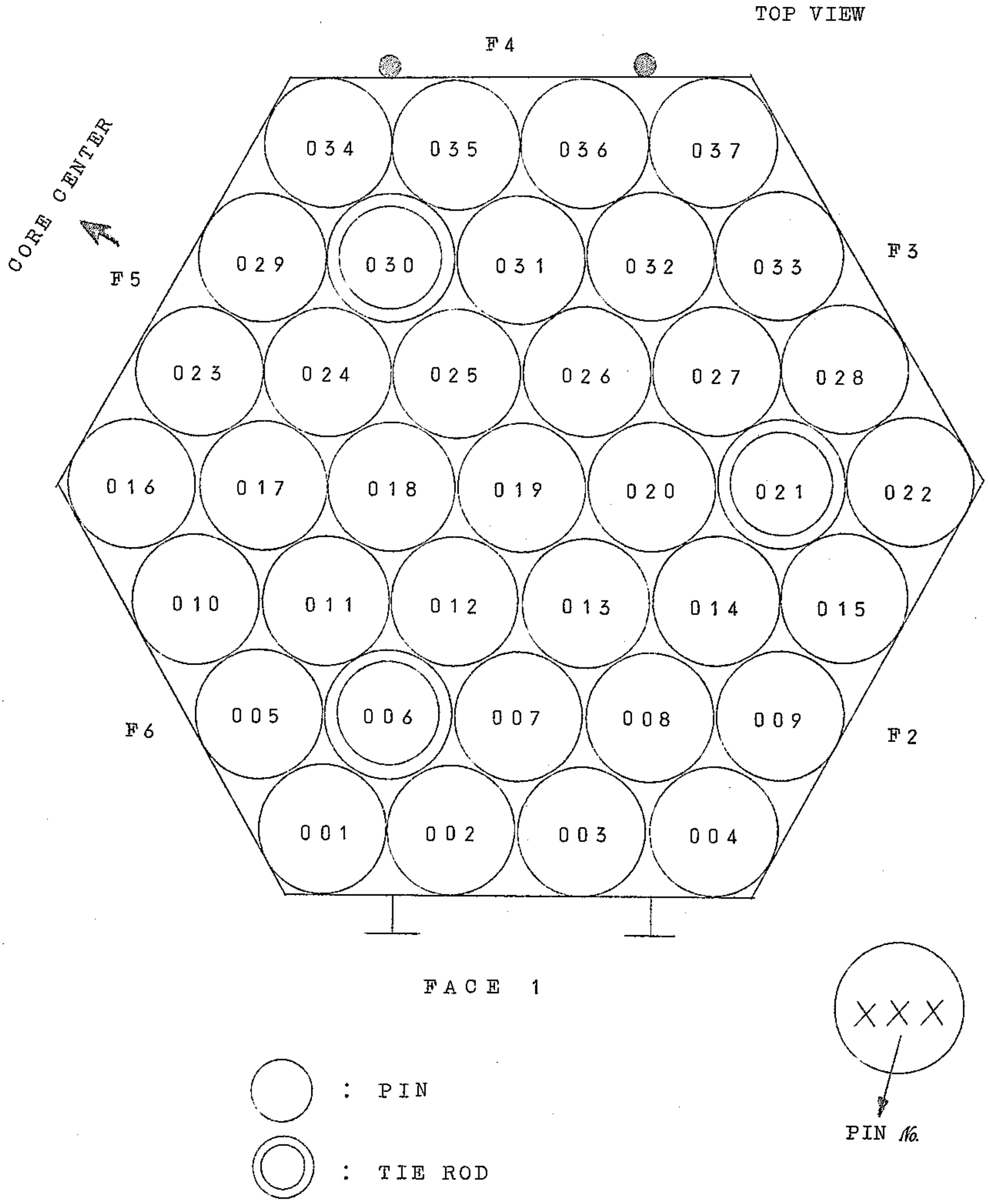
※CLASS	VALUABLE	CENTRAL	FREQUENCY	PER CENT
1	SPEC UNDER	----	0	0.00
2	92.00 -- 92.39	92.20	0	0.00
3	92.40 -- 92.79	92.60	0	0.00
4	92.80 -- 93.19	93.00	0	0.00
5	93.20 -- 93.59	93.40	1	0.56
6	93.60 -- 93.99	93.80	4	2.25
7	94.00 -- 94.39	94.20	14	7.90
8	94.40 -- 94.79	94.60	40	22.59
9	94.80 -- 95.19	95.00	43	24.29
10	95.20 -- 95.59	95.40	40	22.59
11	95.60 -- 96.00	95.50	24	13.55
12	SPEC OVER	----	11	6.21

4. General Records

4.1 Fuel pin arrangement

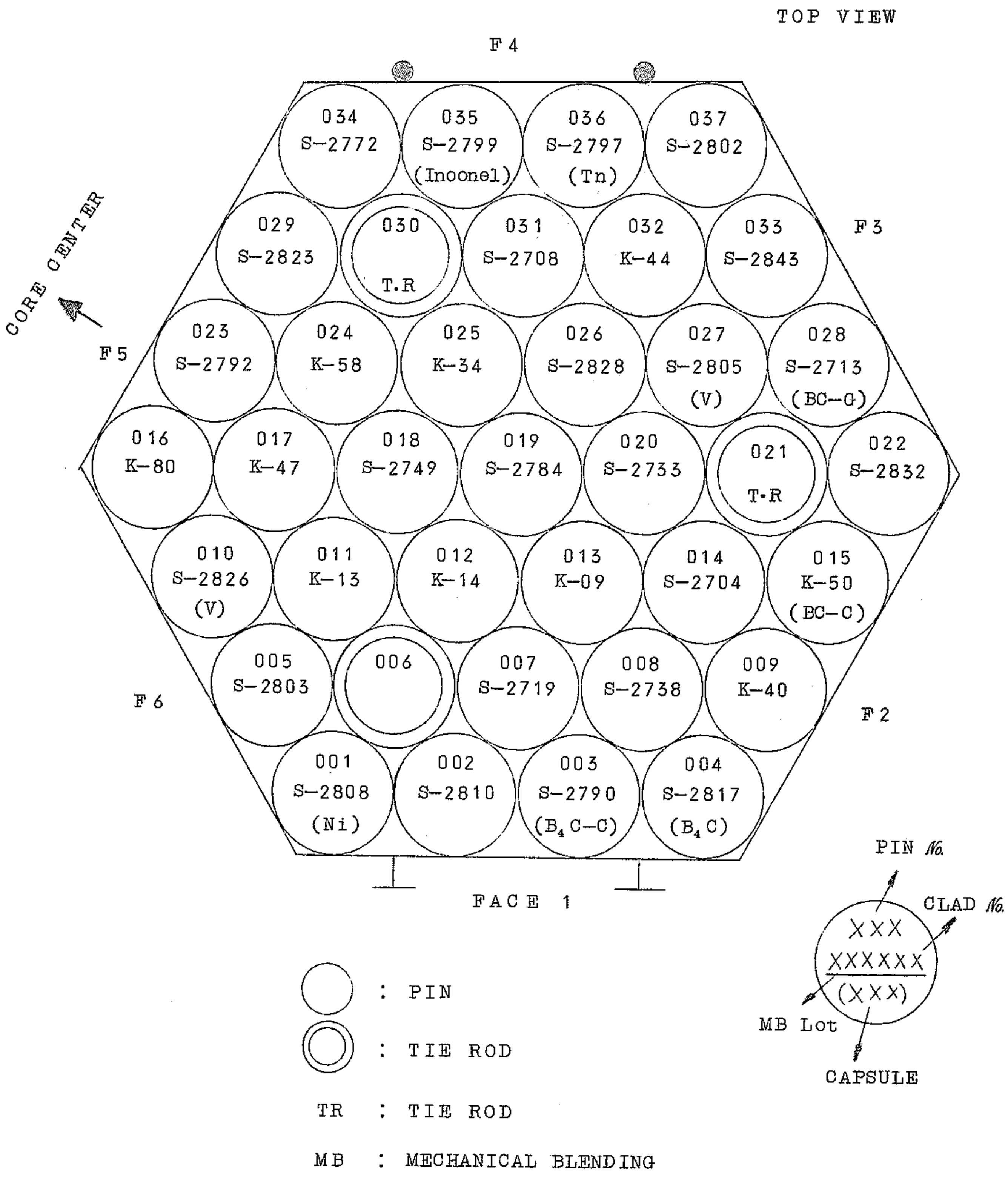
We request that the positions of the fuel pins of PNC assembly should be arranged as shown in Fig. 4.1-1 and Fig. 4.1-2. Especially the fuel pins of No. 016, 017, 018, 019 and 022 should be set in those positions to the core center indicated in the figures. Because those pins have contained the same lot (Lot 4) of the fuel pellet (mechanically blended) and have the different cooling conditions. So if any defect would be found in those pins and wanted to be changed by another pins, we demand CEA to contact the Rapsodie project leader of PNC.

Fuel pins except those discussed above, can be changed with the rest of fuel pins starting the younger number such as 038, 039, 040, 041, 042, 043.



Fuel Pin Arrangement of PNC Assembly

Fig. 4.1－1



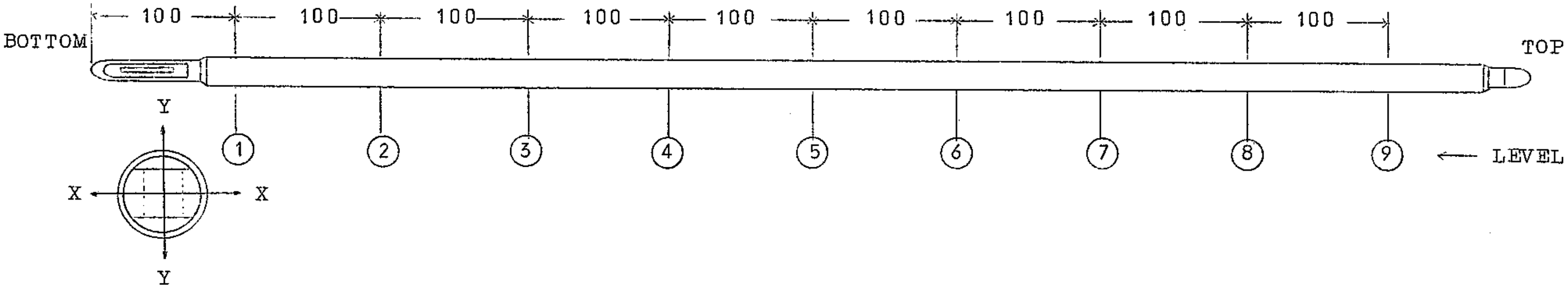
Fuel Pin Arrangement of PNC Assembly in Detail

Fig. 4.1-2

4.2 Detail diametral profile of the fuel pins for the Ceramographic Examinations

The diametral profile of the fuel pins to be for the Ceramographic Examinations at CEA, have been measured with a point micrometer at the reading accuracy less than 1/100 mm and shown in Fig. 4.2-1.

OUTER DIAMETER AT EACH LEVEL



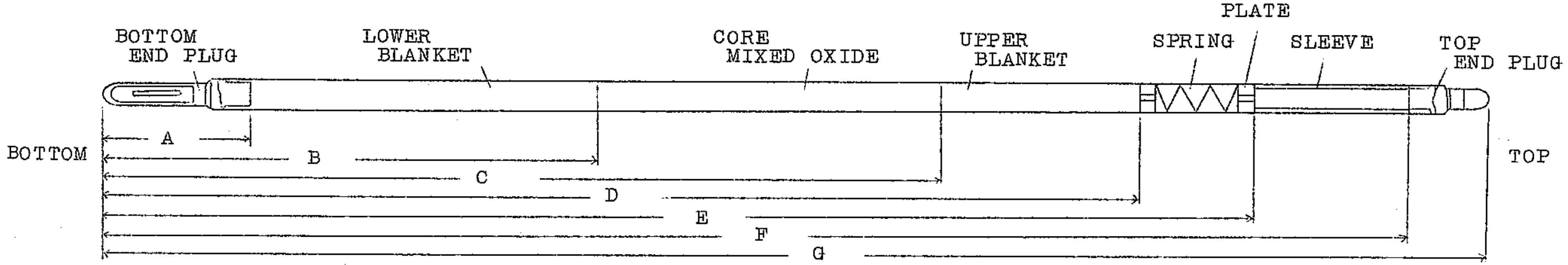
Pin №.	Clad №.		1 (mm)	2 (mm)	3 (mm)	4 (mm)	5 (mm)	6 (mm)	7 (mm)	8 (mm)	9 (mm)
008	S−2738	X	6.300	6.300	6.300	6.303	6.302	6.300	6.302	6.300	6.299
		Y	6.300	6.300	6.300	6.303	6.302	6.302	6.300	6.302	6.299
016	K−0080	X	6.302	6.303	6.304	6.305	6.305	6.306	6.305	6.306	6.305
		Y	6.305	6.302	6.303	6.304	6.306	6.307	6.305	6.305	6.305
017	K−0047	X	6.292	6.292	6.290	6.292	6.291	6.290	6.289	6.291	6.291
		Y	6.292	6.293	6.292	6.292	6.292	6.292	6.290	6.291	6.291
018	S−2749	X	6.299	6.300	6.298	6.300	6.300	6.300	6.300	6.300	6.300
		Y	6.300	6.300	6.301	6.300	6.302	6.301	6.301	6.301	6.299
019	S−2754	X	6.299	6.298	6.300	6.298	6.299	6.298	6.300	6.298	6.299
		Y	6.299	6.300	6.300	6.298	6.300	6.298	6.305	6.299	6.300
020	S−2733	X	6.300	6.301	6.300	6.302	6.300	6.300	6.300	6.298	6.305
		Y	6.304	6.300	6.303	6.305	6.297	6.302	6.302	6.302	6.300
022	S−2832	X	6.301	6.298	6.301	6.302	6.300	6.302	6.302	6.301	6.300
		Y	6.298	6.300	6.303	6.303	6.303	6.300	6.300	6.300	6.302

Fig. 4.2−1 Outer Diameter at Eech Level

4.3 Total lengths of the internal components in the fuel pins for the Ceramographic Examinations

Total lengths of the internal components in the fuel pins to be for the ceramographic Examinations at CEA, have been measured with various slide calipers at the reading accuracy less than 1/20 mm, and shown in Fig. 4.3-1.

LENGTH FROM BOTTOM FOR EACH REGION



Pin №.	Clad №.	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	G (mm)
008	S−2738	54.80	368.60	690.10	794.85	819.62	975.03	999.72
016	K−0080	54.95	368.45	691.45	796.45	819.79	975.15	999.74
017	K−0047	54.95	368.95	691.95	796.90	819.74	975.05	999.74
018	S−2749	55.10	368.10	690.60	795.30	819.60	975.03	999.50
019	S−2754	54.95	368.45	690.95	795.65	819.49	975.09	999.44
020	S−2733	54.75	368.25	688.25	792.90	819.72	975.03	999.82
022	S−2832	54.90	368.60	689.60	794.15	819.70	975.05	999.80

Fig. 4.3−1 Length from Bottom for Each Rengion

4.4 Starting powder specifications

Starting powder specifications have been requested by two CEA experts at their visit of PNC Tokai Works. Those specifications are listed in Table 4.5-1, 4.5-2 and 4.5-3.

4.5 Pellet drying process conditions

Pellet drying conditions after centerless grinding process are also questioned by the CEA experts. Those conditions are as follows;

1.	Temperature	> 80°C
2.	Drying time	4 hours
3.	Atmosphere	in vacuum
4.	Average process amount	200 pellets

Table 4.4-1 Mixed Oxide (Lot 1, 2, 3)

	Lot 1	Lot 2	Lot 3
Pu content	15.96 %	15.99 %	15.92 %
U^{235} content	60.11	60.11	60.11
O/M	1.980	1.985	1.993
Average Particle Size	4.0 μ	4.0 μ	4.0 μ
Impurities (ppm)			
Ag	0.3	0.4	0.3
Al	60	70	110
B	2.0	2.0	2.0
C	50	50	120
Cd	< 1.0	< 1.0	< 1.0
Cl	< 5	< 5	< 5
Cr	20	20	25
Cu	10	10	15
F	7	8	9
Fe	120	140	350
Mg	7	15	20
Mo	10	15	70
N	< 30	< 30	<30
Ni	10	15	10
Pb	< 10	15	10
Si	90	110	110
Sn	< 10	< 10	<10

Pu Isotopic Composition	Pu 238	0.038	Pu 239	90.142
	Pu 240	8.533	Pu 241	1.189
	Pu 242	0.098		

Table 4.4-2 PuO_2 (Lot 4, 5)

1. Isotopic Composition

Pu-238	0.038	Pu-239	90.142
Pu-240	8.533	Pu-241	1.189
Pu-242	0.098		

2.	Pu Content	87.00 w/o
3.	Specific Surface Area	4.5 m^2/g.
4.	Average Particle Size	0.51 μ
5.	Bulk Density	1.49 g/cc
6.	Tap Density	2.86 g/cc

7. Impurities (p.p.m)

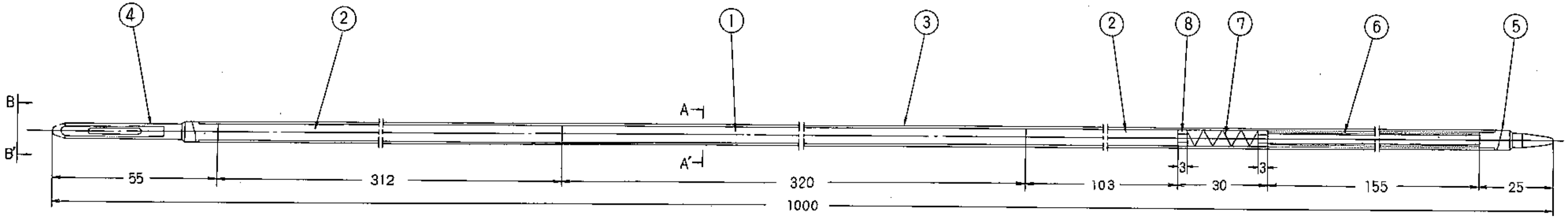
Ag	2	Na	1
Al	< 2	Ni	< 10
B	< 1	Pb	5
Be	< 1	Si	19
Ca	100	Sn	2
Cd	< 1	Ti	5
Cr	<10	V	<100
Cu	< 2	Zn	< 5
Fe	<25		
Mg	< 1	Total Metallic Impurities	
Mn	1		< 303
Mo	<10		

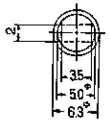
Table 4.4-3 Enriched UO_2 (Lot 4, 5)

	20 % E. UO_2	90 % E. UO_2
Enrichment	19.95 %	90.02 %
U Content	87.50 %	87.43 %
O/U	2.04	2.05
Specific Surface Area	1.2 m^2/g	2.2 m^2/g
Average Particle Size	0.88 μ	0.59 μ
Bulk Density	1.49 g/cc	1.04 g/cc
Tap Density	2.86 g/cc	2.27 g/cc
H_2O		0.12 w/o
Impurities (ppm)		
Ag	< 0.2	0.1
Al	530	<14
B	0.8	< 0.3
Cd	< 0.5	< 0.3
Co	<10	< 5
Cr	15	5
Cu	< 3	8
Fe	70	14
Mg	35	2
Mn	< 6	
Ni	<10	2
Si	340	34
Zn	<50	
Mo	<10	< 3
Pb	10	1
Sn	< 5	2

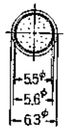
5. Drawings for the Fuel Pins

The definite drawings of the fuel pins for irradiation at Rapsodie, are listed here.





SECTION B - B'



SECTION A - A'

ITEM	NAME	MATERIAL	SUPL. NO	REMARKS
8	HOLLOW PELLET			
7	SPRING			
6	SLEEVE			
5	TOP END PLUG			
4	BOTTOM END PLUG			
3	CLAD			
2	BLANKET FUEL	Nat.UO_2		
1	CORE FUEL			

TITLE
RAPSODIE
FUEL PIN(STANDARD)
PNC-1

SCALE
1/1, 2/1

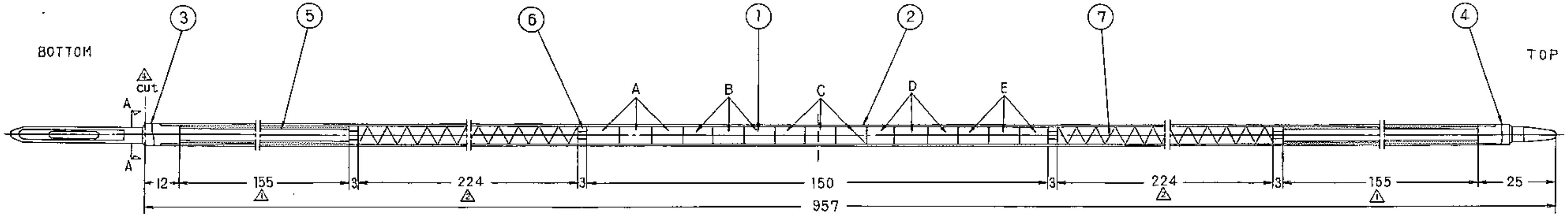
ANGLE.

	NAME	DATE.
DESIGN		
DWG.	Y. Fukushima	69-3-13
CHECK	S. Takahashi	70-6-2
APPR.	H. Mizuta	70-6-2

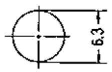
POWER REACTOR AND NUCLEAR FUEL
DEVELOPMENT CORPORATION
TOKAI-JAPAN

DWG. NO
FV41-05-10200
(A8)

記 号 MARK	来 歴 REVISIONS	日 付 DATE	氏 名 NAME
△1	165 ⟶ 155	′70−6−1	Sabu
△2	214 ⟶ 224	′70−6−1	Sabu
△3	Added the pellet explanation table	′70−6−1	Sabu
△4	Cut off the lower Part of the 1−Ep.	′70−6−1	Sabu



Section A−A′



2/1

△3

Region	Lot No.
A	RR−01
B	RR−02
C	RR−03
D	RM−02
E	RM−03

ITEM	NAME	MATERIAL	SUPL.NO	REMARKS
7	SPRING	SUP		Material teken from FCRE
6	PLATE	AISI 316		
5	SLEEVE	AISI 316		Material teken from APDA Thickness 0.3
4	TOP END PLUG	AISI 316		
3	BOTTOM END PLUG	AISI 316		
2	CLAD	AISI 316		
1	FUEL			

TITLE

RAPSODIE
SAMPLE CONTAINER

SCALE 1/1

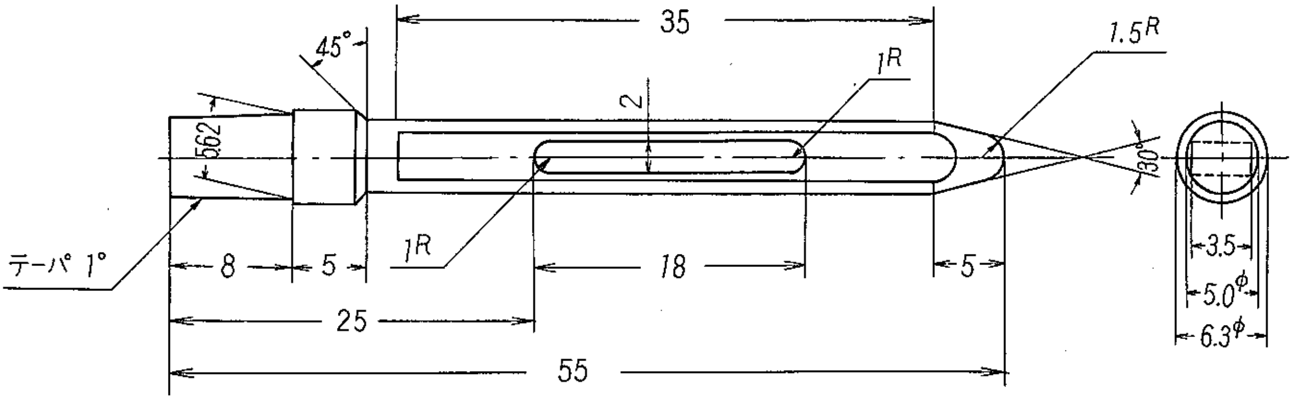
ANGLE.

	NAME	DATE.
DESIGN		
DWG.	Y.Fukushima	70−5−17
CHECK	S.Takahashi	70−6−2
APPR	H.Mizuta	70−6−2

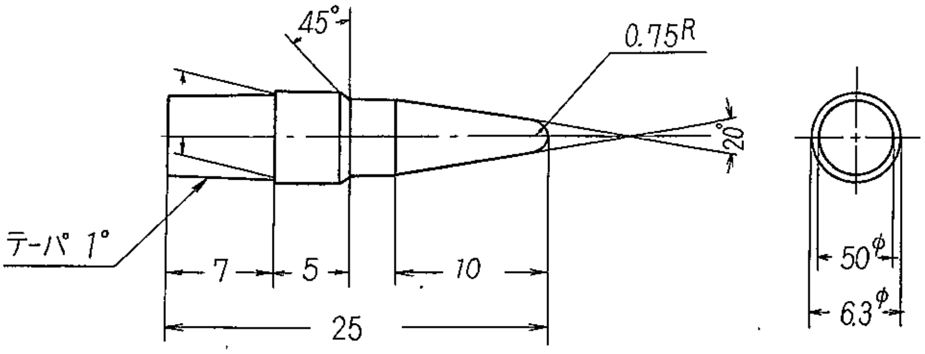
POWER REACTOR AND NUCLEAR FUEL
DEVELOPMENT CORPORATION
TOKAI−JAPAN

DWG.NO
FV41−05−10200−4

①



②

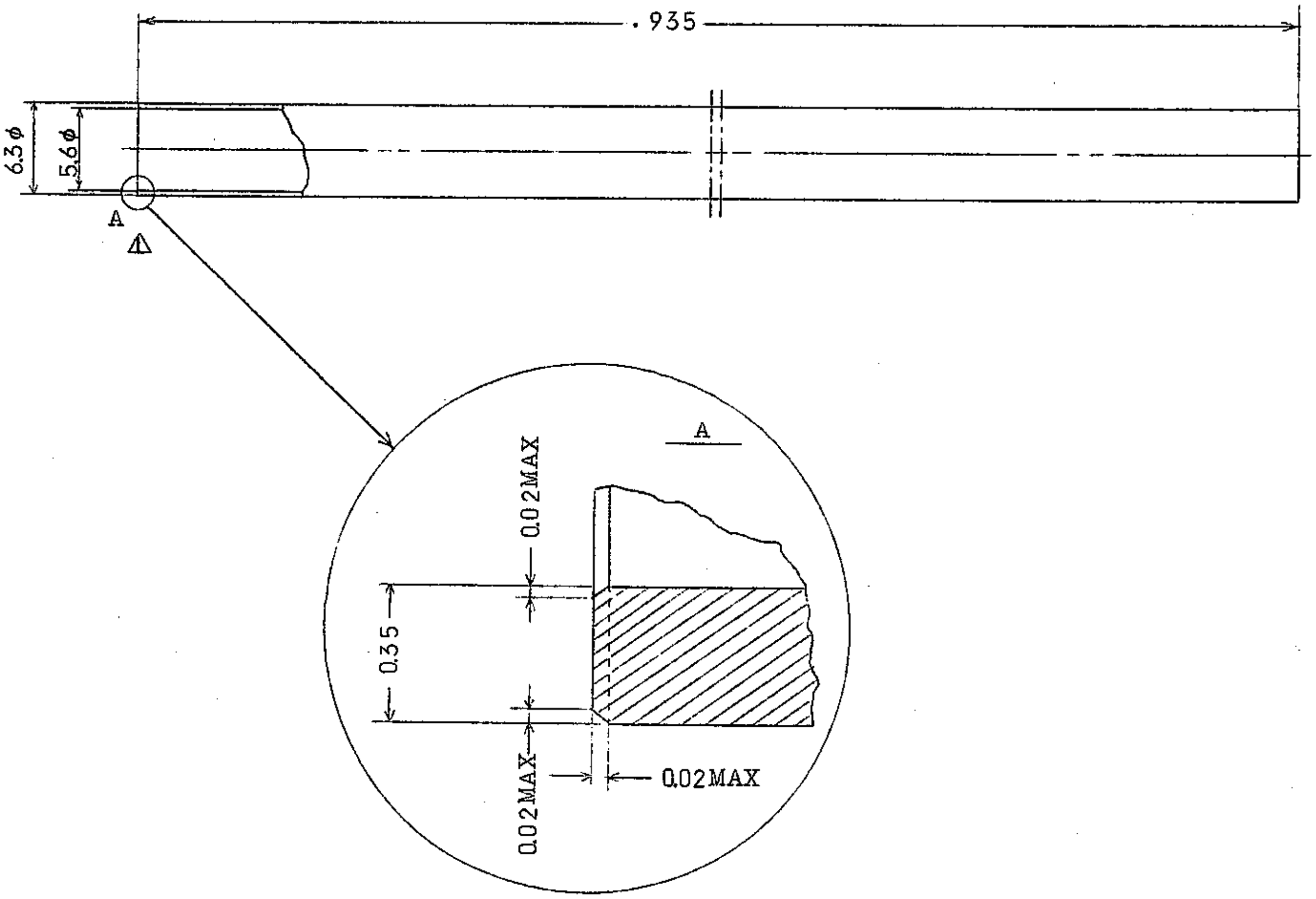


2	TOP END PLUG	AISI 316		
1	BOTTOM END PLUG	AISI 316		
ITEM	NAME	MATERIAL	SUPL.NO	REMARKS

TITLE		NAME	DATE
RAPSODIE END PLUG	DESIGN		
	DWG.	S.Takahashi	70-5-25
	CHECK	Sabu	70-6- 2
	APPR.	H.Mizuta	70-6- 2

POWER REACTOR AND NUCLEAR FUEL DEVELOPMENT CORPORATION TOKAI-JAPAN	SCALE 2/1	DRAWING NO.
	ANGLE	FV41-05-10201-2

記 号 MARK	来 歴 REVISIONS	日 付 '70-1-24
△1	Added the Detail drawing	
△2		
△3		



1	CLAD	AISI 316		
ITEM	NAME	MATERIAL	SUPL.NO	REMARKS

TITLE

RAPSODIE CLAD

	NAME	DATA
DESIGN		– –
DWG.	Y.Fukushima	69–3–
CHECK	S.Takahashi	7– –
APPR.	H.Mizuta	7– –

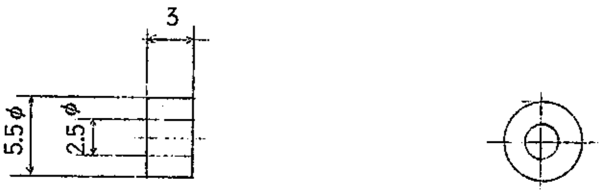
POWER REACTOR AND NUCLEAR FUEL
DEVELOPMENT CORPORATION
TOKAI–JAPAN

SCALE
2/1

ANGLE

DRAWING NO.

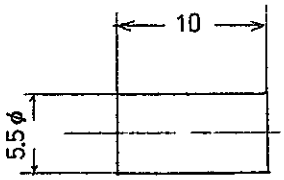
FV41–65–10202
(A 10)

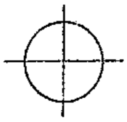


1	PLATE	AISI 316		
ITEM	NAME	MATERIAL	SUPL.NO	REMARKS

TITLE		NAME	DATE
RAPSODI STAINLESS PLATE	DESIGN		— —
	DWG.	Y.Fukushima	69–3–18
	CHECK	S.Takahashi	70–6– 3
	APPR.	H.Mizuta	70–6– 3

POWER REACTOR AND NUCLEAR FUEL DEVELOPMENT CORPORATION TOKAI–JAPAN	SCALE 2/1	DRAWING NO. FV41–05–10203 (A 11)
	ANGLE	





NOTE : SURFACE ROUGHNESS ASA FINISHING MORK
63 CIRCUMFERENTIAL
125 TOP AND BOTTOM

MAXMUM RADIUS AT CORNER 0.03cm

CRACK SURFACE CRACK SHOULD BE LESS THAN 0.0075cm

PIT SURFACE PIT SHOULD BE LESS THAN 0.075cm IN DIAMETER AND 0.025cm IN DEPTH

1	FUEL (CORE)	18w/oPuO_2−60%UO_2		
ITEM	NAME	MATERIAL	SUPL.NO	REMARKS

TITLE RAPSODIE FUEL (CORE)		NAME	DATE
	DESIGN		− −
	DWG.	Y.Fukushima	89−3−18
	CHECK	S.Takahashi	70−6− 3
	APPR.	H.Mizuta	70−6− 3

POWER REACTOR AND NUCLEAR FUEL DEVELOPMENT CORPORATION TOKAI−JAPAN	SCALE 2/1 ANGLE	DRAWING NO. FV41−05−10204 (A 12)

ITEM	NAME	MATERIAL	SUPL. NO	REMARKS
1	BLANKET FUEL	NAT. UO_2		

TITLE

RAPSODIE

FUEL.(BLANKET)

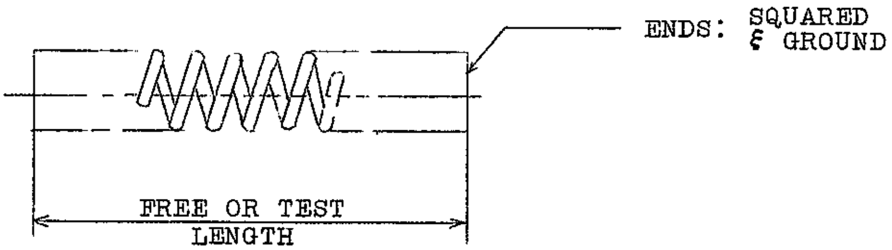
	NAME	DATE
DESIGN		– –
DWG.	Y. Fukushima	89–3–25
CHECK	S. Takahashi	70–6– 3
APPR.	H. Mizuta	70–6– 3

POWER REACTOR AND NUCLEAR FUEL
DEVELOPMENT CORPORATION
TOKAI–JAPAN

SCALE
2/1

ANGLE

DRAWING NO.
FV41–05–10206
(A 14)



DIA. OF WIRE	0.8 (mm)
OUT SIDE DIA	5.3 (mm)
ACTIVE TURNS	9
FREE LENGTH	29 (mm)

ITEM	NAME	MATERIAL	SUPL. NO	REMARKS
1	SPRING	A181 316		

TITLE

RAPSODIE

SPRING

	NAME	DATE
DESIGN		— —
DWG.	Y. Fukushima	69-3-25
CHECK	S. Takahashi	70-6- 2
APPR.	H. Mizuta	70-6- 2

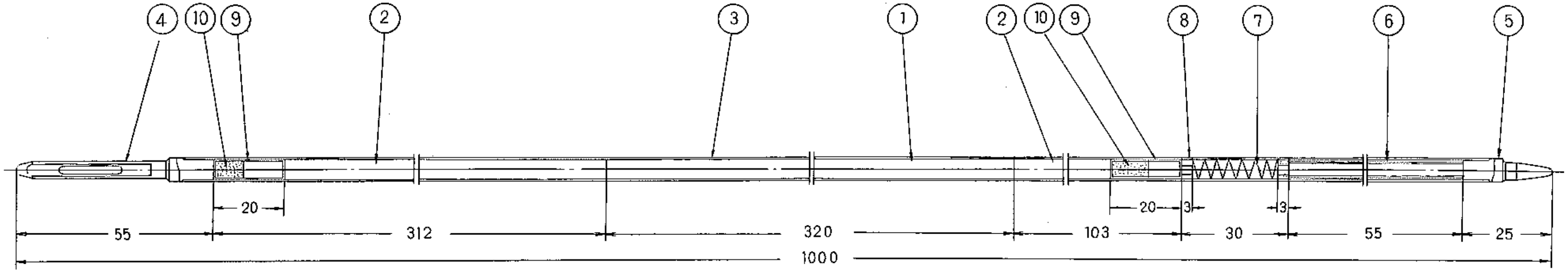
POWER REACTOR AND NUCLEAR FUEL
DEVELOPMENT CORPORATION
TOKAI-JAPAN

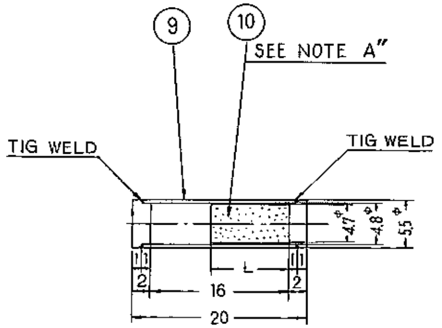
SCALE 2/1

ANGLE

DRAWING NO.

FU41-05-10207
(A 15)





NOTE"A"

Type	MATERIALS	L
I	2.5w/o B_4C	9.0 mm
II	5.0w/o B_4C	9.0 mm
III	B_4C B^{10} 90w/o Enrich	2.0 mm
IV	Ni	9.0 mm
V	Ta	9.0 mm
VI	Inconel-X	9.0 mm

ITEM	NAME	MATERIAL	SUPL.NO	REMARKS
10	STRUCTURE SPECIMEN			
9	STRUCTURE SPECIMEN'S CAN	AISI 316		
8	STAINLESS PLATE	AISI 316		
7	SPRING	AISI 316		
6	SLEEVE	AISI 316		
5	TOP END PLUG	AISI 316		
4	BOTTOM END PLUG	AISI 316		
3	CLADDING	AISI 316		
2	BLANKET FUEL	Nat.UO_2		
1	CORE FUEL	PuO_2-UO_2		

TITLE

RAPSODIE
FUEL PIN(SPECIAL)

SCALE 1/1, 2/1
ANGLE.

		DATE.
DESIGN		
DWG.	Y.Fukushima	
CHECK	S.Takahashi	70-6-2
APPR	H.Mizuta	70-6-2

POWER REACTOR AND NUCLEAR FUEL
DEVELOPMENT COPPORATION
TOKAI-JAPAN

DWG.NO
FV41-05-10300

6. ShippingList

Finally the shipping list is tabulated in Table 6-1. This list covers all the shipping amounts and identifications to CEA in June 22nd, 1970 from Plutonium Fuel Division in Tokai Works of PNC.

Table 6-1 Shipping List

	Weight
1. Fuel pin (40)	
No.001, 002, 003, 004, 005, 007, 008, 009, 010, 011	9787.58
No.012, 013, 014, 015, 016, 017, 018, 019, 020, 022	
No.023, 024, 025, 026, 027, 028, 029, 031, 032, 033	
No.034, 035, 036, 037, 038, 039, 040, 041, 042, 043	
2. Sample	
2.1 Sample pin (1) No.000	108.67
2.2 End plug (10) (5 sets)	52.65
Bottom end plug No.36, 86, 120, 121	
Top end plug No.11, 13, 17, 45, 68	
2.3 Other internal structure materials of the pin	
2.3.1 SUS plate (1)	0.45
2.3.2 Spring (1)	0.60
2.3.3 Sleeve (1)	1.70
2.4 Capsule	
2.4.1 Clad (253 mm long) (1)	10.32
2.4.2 End plug (1)	1.09
2.4.3 B_4C contained in capsule (1)	1.54
2.4.4 B_4C-C contained in capsule (1) No.B-1	0.25
2.5 Welding test sample (5)	131.21

Sample No.	Clad No.	Bottom EP No.	Top EP No.
1	S-2835	36	37
2	S-2835	49	16
3	S-2835	22	87
5	K-0043	44	11
6	K-0043	89	50

3. Subassembly Parts	
3.1 Grid (11)	488.03
No.2, 3, 5, 7, 12, 13, 15, 19, 24, 26, 46	
3.2 Tie rod (6) with nut (2 sets)	1111.83
No.1, 4, 5, 6, 8, 9	
Nut No.1, 4, 5, 6, 8, 9	

Table 6-1 (continued)

3.3	Tie rod sleeve (60) (2 sets) No.1-1, 1-2, 1-3, 1-4, 1-5, 1-6 No.2-1, 2-2, 2-3, 2-4, 2-5, 2-6 No.3-1, 3-2, 3-3, 3-4, 3-5, 3-6 No.4-1, 4-2, 4-3, 4-4, 4-5, 4-6 No.5-1, 5-2, 5-3, 5-4, 5-5, 5-6 No.6-1, 6-2, 6-3, 6-4, 6-5, 6-6 No.7-1, 7-2, 7-3, 7-4, 7-5, 7-6 No.8-1, 8-2, 8-3, 8-4, 8-5, 8-6 No.9-1, 9-2, 9-3, 9-4, 9-5, 9-6 No.10-1, 10-2, 10-3, 10-4, 10-5, 10-6 * Number starts from the bottom end plug.	219.05
3.4	Knock bar (14) (2 sets) No.A-1, A-2, A-3, A-4, A-5, A-6, A-7 No.D-1, D-2, D-3, D-4, D-5, D-6, D-7	179.41
3.5	Framework (2) No.A, D	189.92
	Total weight	12284.30 (g)

II. SUMMARY OF STRUCTURE AND ABSORBER MATERIAL SPECIMEN

1) Position of Capsule in fuel pin

No. of fuel pin	Material specimen	Position of Capsule in fuel pin		Status
		top of pin	bottom of pin	
001	Nickel	(Capsule No) 2	(Capsule No) 1	under irradiation
035	Inconel	4	3	under irradiation
036	Tantalum	6	5	under irradiation
004	Enriched B_4C	8'	10	
015	B_4C-G	11	10	
028	B_4C-G	12'	9'	
009	B_4C-G	20	13	
003	B_4C-G	19	18'	
027	Vanadium	15	14	under irradiation
010	Vanadium	17	16	under irradiation

2) Capsule Number and Specimen

Capsule No.	Specimen	Diameter (mm)	Height (mm)	Weight (g)	Capsule No.	Specimen	Diameter (mm)	Height (mm)	Weight (g)
1	Nickel	4.613	9.085	1.33	11	B_4C-Graphite C-2	4.680	8.981	0.25
2	Nickel	4.620	8.913	1.30	12'	B_4C-Graphite G-2	4.699	9.047	0.25
3	Inconel	4.610	9.002	1.22	13	B_4C-Graphite H-1	4.685	9.005	0.25
4	Inconel	4.620	9.035	1.23	14	Vanadium Alloy No-1	4.676	9.083	0.88
5	Tantalum	4.585	9.078	2.47	15	Vanadium Alloy No-1	4.567	9.082	0.85
6	Tantalum	4.610	9.035	2.49	16	Vanadium Alloy No-3	4.635	9.015	0.92
7	Enriched B_4C No-1	4.710	3,985	0.15	17	Vanadium Alloy No-3	4.535	9.109	0.88
8'	Enriched B_4C No-3	4.742	4.001	0.16	18'	B_4C-Graphite B-3	4.685	9.015	0.26
9'	B_4C-Graphite A-2	4.688	8.998	0.25	19	B_4C-Graphite B-2	4.690	9.032	0.27
10	B_4C-Graphite C-1	4.684	9.010	0.25	20	B_4C-Graphite F-1	4.707	8.983	0.26

III. DESCRIPTION OF STRUCTURE AND ABSORBER MATERIAL SPECIMENS

1. Enriched B_4C pellet

(1) Dimension and Weight

	diameter	height	weight
No. 1	4.710	3.985	0.15
No. 3	4.742	4.001	0.16

(2) Enrichment of Boron - 10

90.38 atom %

(3) Chemical Analysis

Total B	79.31 ± 0.21 wt %
Total C	20.90 ± 0.34 wt %

Impurities	ppm
Si	740
Fe	356
Al	< 50
Ca	59
Mg	16
Cu	< 5
Co	< 10
Ni	< 25
Mn	< 5

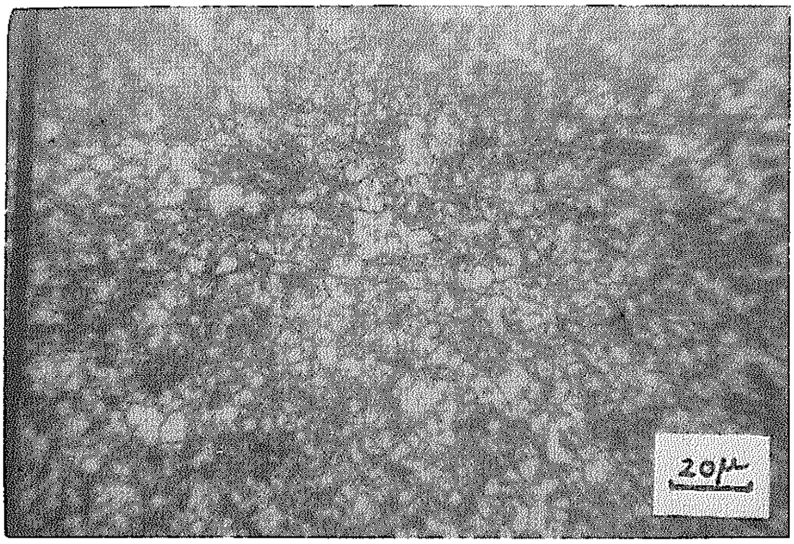
(4) Fabrication Method of B_4C pellet

Hot pressing using graphite mould.

2100°C Argon 0.7 atm 1 hour

(5) Optical Micrograph

(polished and etched)



2. Inconel - X pellet

(1) Dimension and weight

	diameter (mm)	height (mm)	weight (g)
No. 1	4.610	9.002	1.22
No. 2	4.620	9.035	1.23

(2) Chemical Analysis of Impurities

Element	Analysis data ppm	Standard
Si	0.10	< 0.50
C	0.028	< 0.08
Cr	14.77	14 - 17
Fe	6.29	5 - 9
Ni	Bal	Bal
Mn	0.01	< 1.00
Cu	Tr	< 0.50
Al	0.82	0.4 - 1.0

Element	Analysis data ppm	Standard
Ti	2.65	2.25 - 2.75
Nb+Ta	0.92	0.7 - 1.2
B	0.002	-
S	< 0.005	< 0.010
Zr	0.005	-
Mg	0.013	-

(3) Micro Vickers Hardness

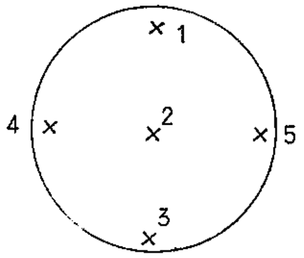


Fig. 1

Measured points are shown in Fig. 1

The load in the measurement:
200 grams

Position	Hardness
1	396
2	386
3	396
4	399
5	404
Mean Value	396

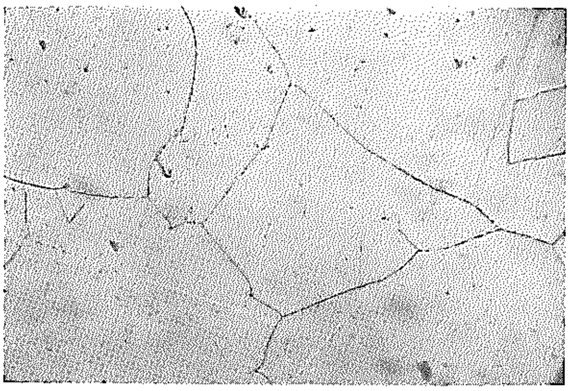
(4) Fabrication

Forging temperature	1150 - 850°C
Heat treatment	1149°C x 2 hours cooling in air 843°C x 24 hours cooling in air

(5) Mechanical properties

Tensile Strength	120	kg/mm^2
Yield Strength	82	kg/mm^2
Elongation	22	%

(6) Optical Micrograph



3. Tantalum pellet

(1) Dimension

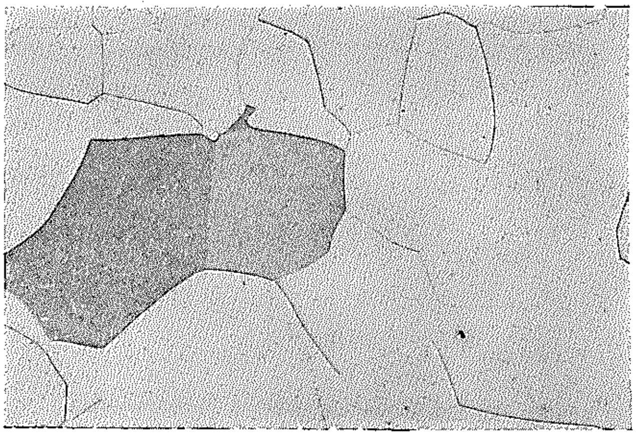
	diameter	height	weight
No. 1	4.585	9.078	2.47
No. 2	4.610	9.035	2.49

(2) Chemical Analysis of Impurities

Element	%
Nb	0.016
Mo	0.005
Fe	0.002
Ti	<0.0005
Mn	<0.0005
W	0.046
Ni	<0.0010
O	0.005
C	0.004

(3) MicroVickers Hardness	90
(4) Mechanical Properties	
Tensile Strength	40 kg/mm^2
Elongation	10 %

(5) Optical Micrograph (x 80)



4. Nickel pellet

(1) Dimension and Weight

	Diameter (mm)	height (mm)	weight
No. 1	4.613	9.085	1.33
No. 2	4.620	8.913	1.30

(2) Chemical Analysis of Impurities

Element	%
S	0.001
Mn	0.18
Si	0.09
Fe	0.01
Cu	0.01
C	0.044
Mg	0.07

(3) Fabrication history

$$\begin{tikzcd}
\text{Melting} \arrow[d] \\
\text{Casting} \arrow[d] \\
\text{Billet Making} \arrow[d] \\
\text{Hot Rolling} \arrow[d] \\
\text{Cold Drawing} \arrow[d] \\
\text{Surface Polishing}
\end{tikzcd}$$

(4) Measurement of Vickers Hardness

Vickers hardness was measured on both T section and L section of large rod.
before machining to pellets (Fig. 1)

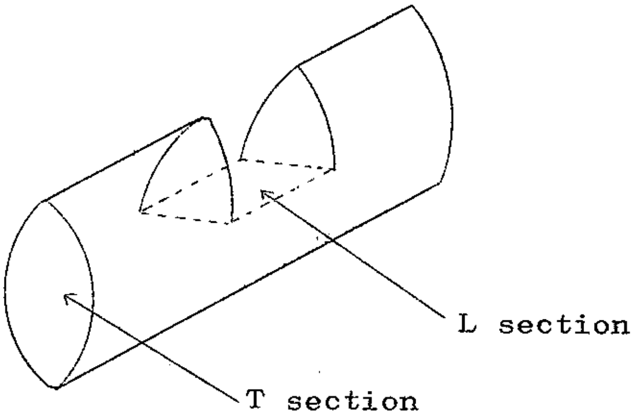
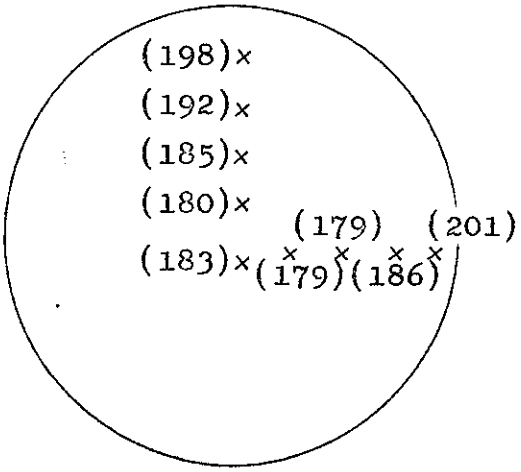
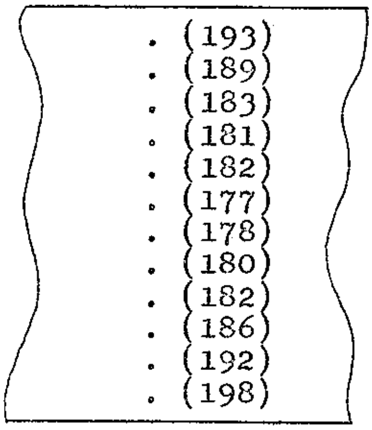


Fig. 1



T section

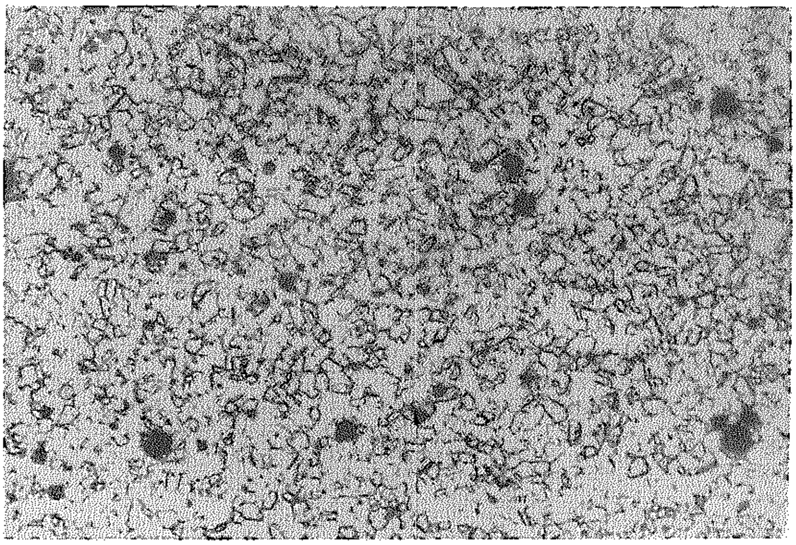


L section

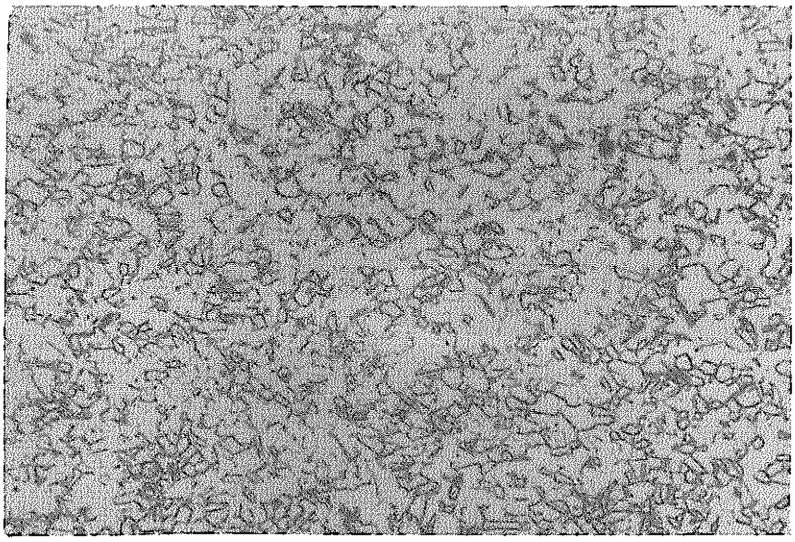
Fig. 2

The result of measurement is shown in Fig. 2 (load 10kg) The averaged values are 187 and 185 for T and L sections respectively

(5) Optical Micrography



1 Central part of T section



2 Central part of L section

5. Vanadium Alloy pellet

(1) Dimension

	diameter (mm)	height (mm)	weight (g)
No.1 - 1	4.676	9.083	0.88
No.1 - 2	4.567	9.082	0.85
No.3 - 1	4.635	9.015	0.92
No.3 - 2	4.535	9.109	0.88

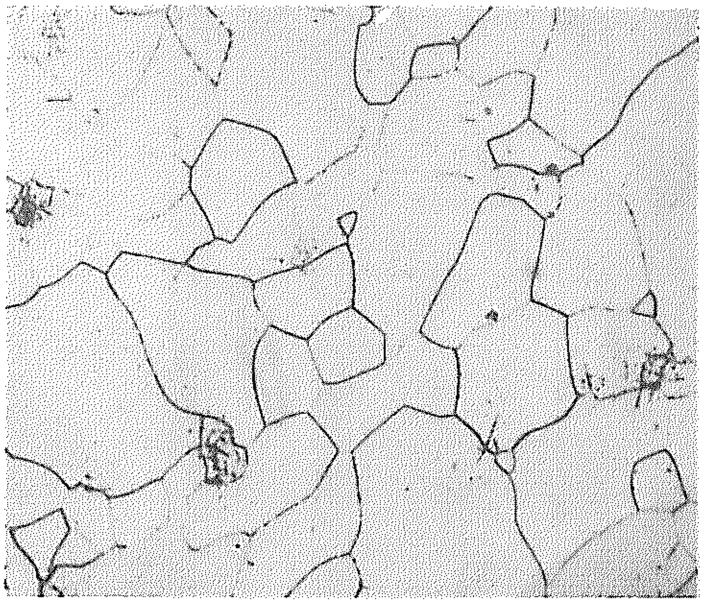
(2) Chemical Composition

Element	No.1	No.2
Ti	20 %	9.8%
Nb	-	9.5
O	0.05	0.032
N	0.01	0.01
Fe	0.04	0.04
Al	0.02	0.02
Si	0.01	0.01
Cu	0.03	0.03
V	bal	bal

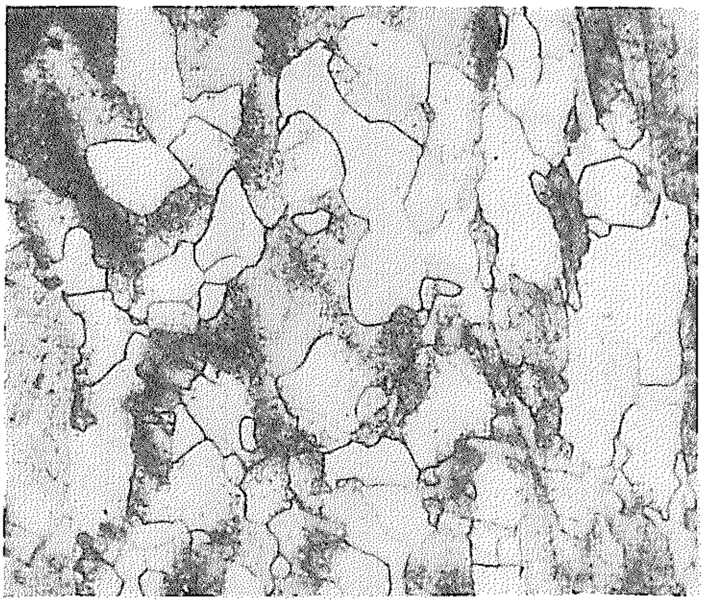
(3) Vickers Hardness (load 5 kg)

Vanadium	No 1	208
Vanadium	No 3	212

(4) Optical Micrograph



1 V - 20 Ti (x 280)



2 V - 10 Ti - 10 Nb (x 280)

6. Graphite pellet containing B_4C dispersion

(1) Dimension and Weight

Specimen	Diameter (mm)	Height (mm)	Weight (g)	B content %
A - 2	4.688	8.998	0.25	0
C - 1	4.684	9.010	0.25	3.7
C - 2	4.680	8.981	0.25	3.7
G - 2	4.690	9.047	0.25	9.3
H - 1	4.676	9.083	0.88	8.9
B - 3	4.685	9.015	0.26	4.3
B - 2	4.690	9.032	0.27	4.3
F - 1	4.707	8.983	0.26	8.7

(2) Chemical Composition (%)

Specimen	B content	S	Ash
A	0.0	0.03	0.17
B	4.3	0.10	0.17
C	3.7	0.20	0.17
F	8.7	0.08	0.17
G	9.3	0.11	0.17
H	8.9	0.20	0.17

Composition of Ash

SiO_2	0.0688 %
Al_2O_3	0.0044
CaO	0.0009
MgO	0.0002
Fe_2O_3	0.0684
V_2O_5	0.0272
NiO	0.0020
CuO	0.0002

(3) Fabrication history

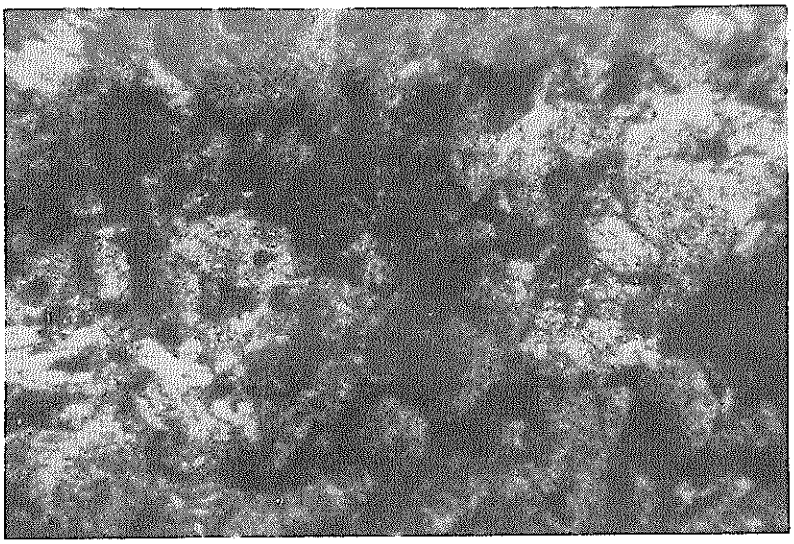
A	Extruding press	at 2000°C
B	"	at 2400°C
C	"	at 2000°C
F	"	at 2400°C
G	"	at 2000°C
H	"	at 1400°C

Starting powder of graphite : Artificial graphite

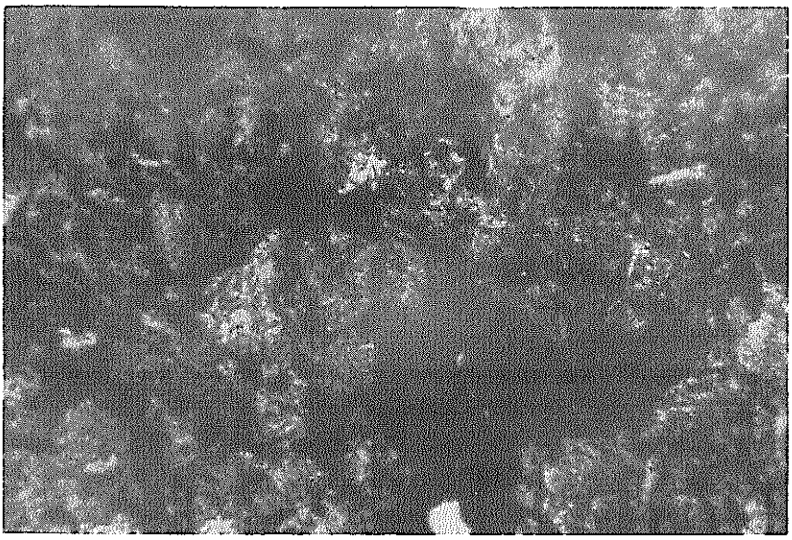
(4) Mechanical properties

	Youngs Modulus kg/mm^2	Shear Strength kg/mm^2	Bending Strength kg/mm^2
A	770	113	127
B	1126	104	144
C	921	111	131
F	1483	93	135
G	789	90	110
H	778	112	126

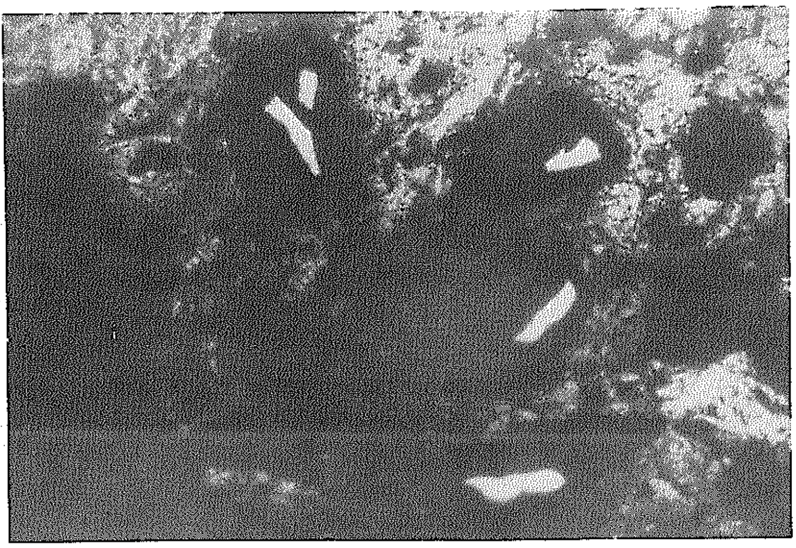
(5) Optical Micrography



1 A (x 65)



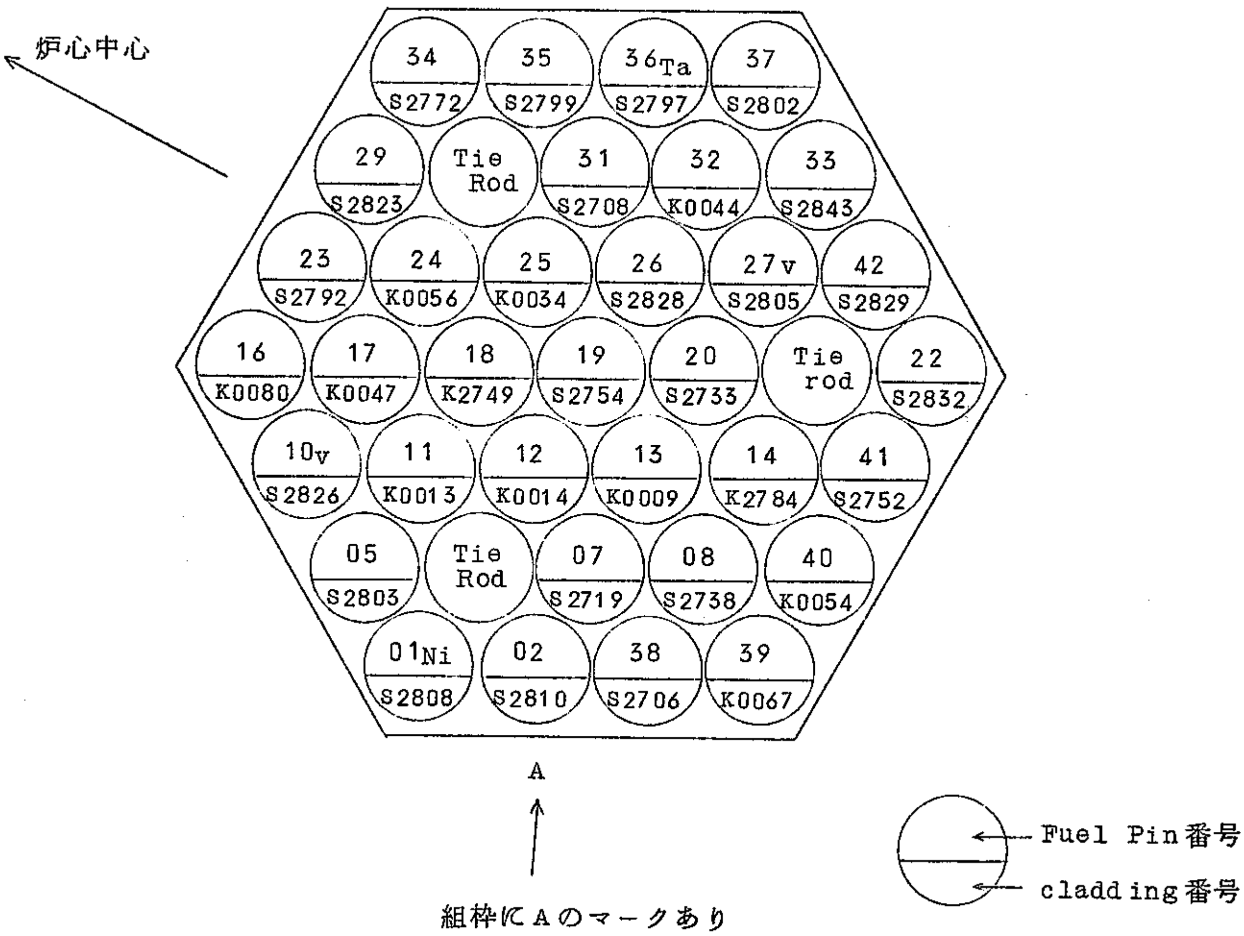
2 C (x 65)



3 C (x 65)

Ⅳ　集合体燃料ピン配置図

（昭和45年8月26日照射開始）



V　…バナジウム・カプセル入り

Ni …ニッケル・カプセル入り

Ta …タンタル・カプセル入り

V　ラプソデイ照射用被覆管検査結果（フランス側最終報告）

１９７０年３月１６日

G. DURET
G. POULLOT
A. SAMOEL
B. SPRIET

われわれは Rapsodie におけるＰＮＣ照射用に用いる日本製被覆管（２つのロット）を検査した。ロットＫ－神戸製鋼の製造による管、ロットＳ－住友金属工業の製造による管。検査は破壊試験、ならびに非破壊検査の双方について行なつた。

２つのロットの性質は優秀であることを示している。ただ１本の管だけは（全部で約１００本の管のうち）、大きな欠陥（厚さの減少による突出）を呈している；検出された他の欠陥はこれと同じタイプであるが、その大きさはより小さなものである。

ロットＫはロットＳより劣る形晶粒形（６－７ＡＳＴＭでなく７－８ＡＳＴＭ）を持つている；２つのロットの冷間加工率は実際上は全く同一（１３％）である。

機械的特性（応力、内圧のもとのクリープ）は最終の冶金学的状態の達しうる機械的特性に合致している。

緒　言

Rapsodie 照射のため、ＰＮＣは燃料ピンの製造に用いる異なるメーカーで製造した被覆管（２つのロット）を検査のためわれわれのもとへ送つて来た。：ロットＫ（神戸製鋼の管）ロットＳ（住友金属工業の管）。

これら２つのロットの加工法はハイパー焼入れ処理を除いては原理上同一であつた（圧延４０％、引抜２０％）。ハイパー焼入れの場合、ロットＫは高温で短時間の焼鈍を行なつたものであるが、他方、ロットＳのハイパー焼入れは全く在来の方法（１０４０℃）である；管は冷間圧延された状態で引渡された。

鋼の組成はやはりロットによつて相異があり、ロットＳはカーボン含有度が多い（Ｋが0.０４７％、Ｓは0.０７％、表１参照）。

第１章：非破壊検査

検査は２つのロットを含めた１００本の被覆管に対して行なわれた。

ロットＫ５４本の管

ロットＳ４６本の管

被覆管のデイメンションは次の通りである：

ϕ_e ： 6.3 0 ㎜

ϕ_i ： 5.6 0 ㎜

厚さ： 0.3 5 ㎜

長さ： 1 m .

検査のサイクルは次のようになされた。

厚さの同時測定がなされる超音波検査

平均・外径の同時測定がなされるうず電流による検査

最終選択

A ー寸法検査

1) 厚さ ：

測定は Branson の厚さ測定器（ヴイデイゲージ）を使つて、超音波により連続的に行なわれる。

figure (1) は2つのロットについて、平均厚さの分布・組織図を示すものである。

a ーロットS

この系列の管はすべて、公称寸法となつている0.3 4 5 ㎜〜0.3 5 0 ㎜間の平均厚さに入つている。

すなわち、これらの被覆管の厚さ特性は、1 8 μの最大偏心率に対して、平均偏心率は1 0 μにすぎないのですぐれたものである。

b ーロットK

平均厚さは、ここではすべての管が0.3 5 0 ㎜ー0.3 5 5 ㎜の間にあるから、やはりすぐれている。

平均偏心率はやはり1 0 μであるが、最大偏心率が1 4 μにすぎないため、偏心率は殆んど全くないことに注目すべきである。

2) 外径 ：

9 0° で4つの計器を使つて管の平均直径が連続的に測定された。検定は、6.2 7〜6.3 3 ㎜の許容範囲の直径をもつ標準測定棒でなされる。

a ーロットK

外径には少しも偏差がない。

管はすべて6.3 0 ± 0.0 1 の同一寸法をもつている。

b ーロットS

この系列に対しても同様である。平均直径はここではやはりすべての管に対して6.3 0 ± 0.0 1 である。

これらの寸法検査から、これらの管は格別に良好であると云える。しかしながら、K系列については、過度の研磨のためにⅢ.1 で見られるとおり超音波・検査の感度にかなりな影響を与えることに注目すべきである。

B－健全性の検査

1）超音波による検査

これは次の条件のもとに行なわれた。：

— 回転速度　　：　1,200 t/㎜

— ピッチ（Pas）：　0.7　㎜

— 周 波 数　　：　4 m H_z

— 感　　度　　：　60dB

以下の表はその結果を集めたものである。：

ロットK：

	良	疑わしい	不良
数	24	21	7
%	47	40	13

ロットS：

	良	疑わしい	不良
数	39	6	1
%	85	13	2

K系列で疑わしい管の割合は大きく、S系列にも若干それが現われていることがわかる。

figure(2) はこれら2つのロット間の相異を双眼顕微鏡で拡大したものを示す。われわれは下記の欠点を示すものを〃疑わしい〃として分類した：

縦方向の条痕（S系列とK系列）

過度な研磨による横断線方向の条痕（K系列）

振幅の小さい局所的な信号

これらの条痕はいわゆる欠陥ではないが、しかし超音波ビームの直接反射をひき起す。それらはこうして大きな欠陥を遮蔽しうる永久的なバックグラウンド・ノイズをつくる。そのため超音波による検査が不可能となり、条痕をもつ管が〃疑わしい〃種類の中に入られたのであつた。

疑わしい種類別に入る管は局所的な信号を出す。

2）うず電流による検査：

検査は banc Fordume に対して実施される。

banc Fordume は10〜100 KH_z の defectograph と700 KH_z の Dudu ををもつて作動される。

実験条件 ：

管はそれぞれ、17cm／Sの速度の control head を横断する2つの回路で行なわれる。

調節は次の通りである。：

－Defectograpp※　（※ 探傷器の一種）

	周波数	位 相	微 分※	感 度	波
1 次回路	100KH$_\mathrm{z}$	90°	8	S. 5. 6	3H$_\mathrm{z}$－40H$_\mathrm{z}$
2 次回路	10KH$_\mathrm{z}$	90°	8	S. 5.10	3H$_\mathrm{z}$－40H$_\mathrm{z}$

－Dudu

調節は2つの回路に対して全く同一である。

＊ コイル JFIS

＊ 発振器（ Oscillators n°3

＊ 微 分 8

＊ 感度記録記録器 S1

＊ ろ波 3H$_\mathrm{z}$－40H$_\mathrm{z}$

次の各表は検査の結果を集めたものである。

ロットK：検査された管の本数：50

	良	疑わしい	不 良
本 数	44	6	0
%	88	12	0

ロットS：検査された管の本数：46

	良	疑わしい	不 良
本 数	41	1	3
%	91	2	7

注意 ： 上記2種類の製造のうち、疑わしい、不良、と分類された在来の管はすべて、デイメンションの変化において、垂直位相で周波数10KH$_\mathrm{z}$以上の欠陥は呈されていない。

3）最終選択

K系列

<table>
<tr><th>良　（22）</th><th>疑わしい（23）</th><th>不　　良（7）</th></tr>
<tr><td>29−75−67−56−47
50−16−13−14−34
54−44−37−101−
77−90−78−80−9−
1−40−41</td><td>43−85−84−89
46−10−8−7−4−
20−74−70−73−
72−65−63−17−
85−2−36−18−11
215−</td><td>23−19−30−31
69−55−32−(33)</td></tr>
<tr><td>41％</td><td>43％</td><td>16％</td></tr>
<tr><td colspan="3">管№24は検査されなかつた（末端が拡がりすぎていたため）、管№33は標準管として利用された。
管№36は超音波検査のみうけ、この場合〝良〟である。</td></tr>
</table>

−良（Bons）に分類された管は｛超音波、うず電流｝検査で良である。

−疑わしい（Douteux）に分類された管は｛超音波またはうず電流｝検査で疑わしいものである。

（管№46だけがうず電流−検査で疑わしく、超音波検査で良である。；うず電流−検査で疑わしい他のすべての管は超音波検査でも疑わしいか、または不良である。）

−不良に分類された管は｛超音波またはうず電流｝検査で不良である。

S系列

良　（35）	疑わしい　（7）	不　　良（3）
2749−2713−2708− 2738−2728−2719 2706−2733−2752 2784−2778−2790 2792−2797−2772 2832−2834−2808 2754−2769−2810 2811−2818−2817 2825−2826−2805 2828−2829−2843 2799−2800−2802 2805−2770−	2794−2748−2774− 2855−2821−2819− 2801−	2831−2711−2717
76％	16％	8％

第2章：破壊検査

A－金属組織

1）欠陥の探索（探傷）

figures 3～7は非破壊検査の途中に証明された欠陥の相を示す。最後のもの（figure 7）を除いて、これらの欠陥のすべては極わめて小さい。；それらは超音波に、それらの特殊な形状のため、その重力と不均衡な応答を与える。あらゆる場合、厚さの減少を伴なつた多少とも伸びて、多少とも深い表面の突出が認められる。

2）顕微鏡組織

figures 8.8（2図）と9.9（2図）——ロットKとロットSに対応するもの——から次の点が注目される。

——構造は冷間圧延されてある。：双晶と変形帯状部の存在

——ロットSでは、炭化物の比較的大きい析出物があり、並んで存在するところもある。したがつてハイパー焼入（hypertrempe）は、炭化物が全体的に溶解しないような温度と時間の条件下で行われた（同じく炭素・含有度の影響も考慮して）。

——結晶粒の大きさは微細である。

ロットK：Index 7－8ASTM

ロットS：Index 6－7ASTM

B－機械的試験

1）引張試験：室温、550°～750℃

試験結果は第11表とfigures 10～13に掲げてある。；比較のため、われわれは同じく、2つのロット——それぞれ8％と20％に冷間圧延の鋼316、他ですでに試験済み（ロットD，C，Orphée）——をもつて対照してみた。

弾性限度と伸びは冷間圧延構造に十分対応するものである。；鋼316に対する検定。曲線から評価される冷間加工率は2つのロットで実際上全く同一である。

ロットK：冷間加工率　13　％

ロットS：冷間加工率　12.5％

2）内圧試験

われわれは、16kg／mm²に近い接線応力のもとの650℃でのクリープから約2時間後得られた値を第Ⅲ表にかかげた（同じ試験時間に関係ある変形と速度）。

結　論：

以上2つのロットの各管はすぐれた性質をもつていることを示している。超音波による検査では、ロットKにおいて機械的研磨が悪く検査が若干乱されたが、これは、このロットKにおける疑わしい管の割合が大きいことを説明するものである。同じタイプの欠陥（厚さの減少を

伴つた突出）はすべて、重力が小さく、唯一の管が例外である（ロットKの管No.33）。

不良と分類された管の数が比較的多いが、検出されたどんな欠陥によつても、管が取除かれると云う極わめて厳密な選択基準によつたことを十分知られたい。準一工業的検査の在来の条件下では、ただ1本の管だけが廃品にされたであろう。

応力の機械的特性から見て、2つのロットの持つ挙動は7～10%（ロットD Orphée）の冷間圧延・鋼の挙動にちかいものである。反対に、クリープの特性はロットC Orphée（20%冷間圧延）はずつと近い。

定数的な冷間加工率では、ロット間で確認された相違は、組成（炭素含有度）と同じく製造段階から多く影響されている。

ロットKのフラッシュ焼なましは、結晶粒の微細な断層（および炭化物の完全な溶解）例外的に低いクリープ速度、と関連するため、特に有効であつた。

以　　上

GD/RE

フランス外秘

Département de Développement
des Eléments Combustibles

Service de Développement
des Eléments Combustibles

Section des Eléments
Combustibles Céramiques

Cadarache, le 16 mars1970

Note technique n° SECC 70-16

de G. DURET
G. POULLOT
A. SAMOEL
B. SPRIET

RESULTATS DES CONTROLES DE GAINES PNC

Nous avons examiné 2 lots de tubes d'origine japonaise, destinés à l'irradiation PNC dans Rapsodie : lot K tubiste Kobé, lot S tubiste Sumitomo. Des controles aussi bien destructifs que non destructifs on été effectués.

La qualité des 2 lots se révèle excellente. Un seul tube (sur un total d'une centaine) présente un défaut important (arrachement avec diminution d'épaisseur) ; les autres défauts détectés sont du même type mais de plus faible amplitude. Le lot K a une taille de grain inférieure à celle du lot S (7-8 ASTM au lieu de 6-7 ASTM) ; le taux d'écrouissage des deux lots est pratiquement identique (13%). Les propriétés mécaniques (traction, fluage sous pression interne) sont conformes á celles que l'on peut attendre de l'état métallurgique final.

INTRODUCTION

Pour ses irradiations dans Rapsodie, PNC nous a expédié pour contrôle deux lots de tubes de provenance différente, destinés à la fabrication des aiguilles combustibles : lot K (tubiste KOBE), lot S (tubiste SUMITOMO). La transformation de ces 2 lots a été en principe la même (laminage 40 %, etirage 20 %) à l'exception du traitement d'hypertrempe où le lot K a subi un recuit flash de courte durée à haute température (1200°C) alors que l'hypertrempe du lot S est tout à fait classique (1040°C); les tubes sont livrés à l'état écroui.

La composition de l'acier est également variable d'un lot à l'autre, le lot S ayant une teneur en carbone nettement supérieure (0,07 % au lieu de 0,047 %, tableau I)

CHAPITRE I : Controles non destructifs

Le contrôle a porté sur 100 gaines réparties en deux lots :

- Lot K 54 tubes
- Lot S 46 tubes

Dans les deux cas, la nuance est la même. Les gaines ont les dimensions suivantes :

- $\emptyset_e$: 6,30 mm
- $\emptyset_i$: 5,60 mm
- epairsseur : 0,35mm

Longueur : 1 m.

Le cycle de controle a été le suivant :

- Contrôle par ultra-sons avec mesure simultanée de l'épaisseur.
- Contrôle par courants de Foucault avec mesure simultanée du diamètre extérieur moyen.
- Sélection finale.

A - CONTROLES METROLOGIQUES

1) Epaisseur :

La mesure s'est faite en continu par ultra-sons avec un appareillage vidigage Branson. La figure (1) donne l'histogramme de la répartition des épaisseurs moyennes pour les deux lots.

a - Lot S

Tous les tubes de cette série on une épaisseur moyenne comprise entre 0,345 mm et 0,350 mm qui était la cote nominale. C' st dire que les caractéristiques d'épaisseur de ces gaines sont excellentes puisque de plus, l'excentricité moyenne est de 10 μ pour une excentricité maximale de 18 μ seulement.

b - Lot K

L'épaisseur moyenne est là aussi excellente puisque tous les tubes se situent dans la fourchette 0,350 mm - 0,355 mm. Il faut noter de plus l'absence presque complète d'excentricité puisque l'excentricité moyenne est encore de 10 μ , mais l'excentricité maximum n'est que de 14 μ .

2) Diamètre extérieur :

On a mesuré en continu le diamètre moyen des tubes à l'aide de quatre capteurs à 90°. L'étalonnage s'est fait à partir de piges étalon ayant comme diamètre celui de la limite de tolérance soit 6,27 mm et 6,33 mm.

a - Lot K

Il n'y a aucune dérive du diamètre extérieur. Les tubes ont tous la meme cote 6,30 ± 0,01.

b - Lot S

Il en est de même pour cette série. Le diamètre moyen est là aussi pour toutes les gaines 6,30 + 0,01.

On peut déduire de ces contrôles métrologiques que les caractéristiques dimensionnelles de ces tubes sont particulièrement bonnes. Il faut toutefois souligner que pour la série K, il en a été ainsi à cause d'un polissage poussé et nous verrons au paragraphe III.1, que la sensibilité du contrôle ultra-sonore s'en est trouvée affectée.

B - CONTROLES DE SANTE

1) Controle par ultra-sons

Il a ete fait dans les conditions suivantes :

- Vitesse de rotation : 1 200 t/mn
- Pas : 0,7 mm
- Frequence : 4 mHz
- Sensibilite : 60 dB.

Le tableau ci-dessous rassemble les resultats :

Lot K :

	Bons	Douteux	Mauvais
Nombre	24	21	7
%	47	40	13

Lot S :

	Bons	Douteux	Mauvais
Nombre	39	6	1
%	85	13	2

On voit apparaitre une forte proportion de tubes douteux dans la serie K et quelques uns dans la serie S. La figure (2) donne l'explication en montrant grossie a la binoculaire la difference d'aspect entre les deux lots.

Nous avons classe douteux les tubes presentant :

- des rayures longitudinales (Serie S et Serie K)
- des rayures transversales dues a un polissage trop pousse (Serie K)
- des signaux localises de faible amplitude.

Ces rayures ne sont pas a proprement parler des defauts, mais elles provoquent une reflexion directe du faisceau ultrasonore. Elles creent ainsi un bruit de fond permanent qui peut masquer des defauts importants. C'est pourquoi etant incontrolables aux ultrasons, les tubes concernes ont ete classes dans la categorie "douteux".

Les tubes classes mauvais presentent des signaux localises.

2) Controle par courants de Foucault :

Le controle s'est effectue sur le banc Fordume. Celui-ci a fonctionne avec le defectograph a 10 et 100 kHz et le Dudu a 700 kHz.

Conditions experimentales :

Chaque tube effectue deux passages a travers la tete de controle a une vitesse de 17 cm/s.

Les reglages sont les suivants :

- Defectograph

	Frequence	Phase	Differentiation	Sensibilite	Filtre
1er passage	100kHz	90°	8	S. 5,6	3Hz-40Hz
2e passage	10kHz	90°	8	S. 5,10	3Hz-40Hz

- Dudu

Les reglages sont identiques pour les 2 passages.

* Bobine JF1S
* Oscillateurs n° 3
* Differentiation 8
* Sensibilite enregistreur S1
* Filtre 3 Hz - 40 Hz

Les tableaux ci-dessous rassemblent les resultats du controle.

Lot K : Nombre de tubes controles : 50

	Bons	Douteux	Mauvais
Nombre	44	6	0
%	88	12	0

Lot S : Nombre de tubes controles : 46

	Bons	Douteux	Mauvais
Nombre	41	1	3
%	91	2	7

Remarque : Dans les deux fabrication tous les tubes classes douteux ou mauvais ne presentaient de defauts qu'a la frequence 10 kHz dans la phase perpendiculaire aux variations dimensionnelles.

Soulignons cependant que tous les defauts enregistres sont de faible amplitude.

3) Result ts globaux et selection finale

- Serie K -

Bons (22)	Douteux (23)	Mauvais (7) .
29 - 75 - 67 - 56 - 47 50 - 16 - 13 - 14 - 34 54 - 44 - 37 - 101 - 77 - 90 - 78 - 80 - 9 - 1 - 40 - 41 -	43 - 85 - 84 - 89 - 46 - 10 - 8 - 7 - 4 - 20 - 74 - 70 - 73 - 72 - 65 - 63 - 17 - 83 - 2 - 36 - 18 - 11 215	23 - 19 - 30 - 31 69 - 55 - 32 - (33)
41 %	43 %	16 %
Le tube n° 24 n'a pas ete controle (extremites trop evasees). Le tube n° 33 a ete utilise comme tube etulon. Le tube n° 36 n'a ete controle qu'aux ultra-sons ou il est bon		

- Les tubes classes Bons, sent bons, aux ultra-sons, aux courants de Foucault.

- Les tubes classes Douteux, sont deuteux aux ultra-sons ou aux courants de Foucault

(Saul le tube n° 46 est douteux aux courants de Foucault et bon aux ultrasons ; tous les autres tubes deuteux aux courants de Foucault sont ou douteux ou mauvais aux ultra-sons).

- Les tubes classes Mauvais, sont mauvais aux ultra-sons ou aux courants de Foucault

- Serie S -

Bons (35)	Douteux (7)	Mauvais (3)
2749 - 2713 - 2708 - 2738 - 2728 - 2719 - 2706 - 2733 - 2752 - 2784 - 2778 - 2790 - 2792 - 2797 - 2772 - 2832 - 2834 - 2808 - 2754 - 2769 - 2810 - 2811 - 2818 - 2817 - 2823 - 2826 - 2805 - 2828 - 2829 - 2843 - 2799 - 2800 - 2802 - 2803 - 2770	2794 - 2748 - 2774 - 2835 - 2821 - 2819 - 2801 -	2831 - 2711 - 2717
76 %	16 %	8 %

CHAPITRE II : Controles destructifs

A - METALLOGRAPHIE

1) Recherche des defauts :

Les figures 3 a 7 montrent l'aspect des fefauts mis en evidence au cours des controles non destructifs. A l'exception du dernier (figure 7), tous ces defauts sont tres petits ; ils donnent aux ultra-sons des reponses disproportionnees avec leur gravite en raison de leur forme particuliere. Dans tous les cas, on observe des arrachements superficiels plus ou moins etendus et plug ou moins profonds, s'accompagnant d'une diminution d'epaisseur.

2) Structure micrographique :

Les figures 8. 8 bis et 9. 9 bis, correspondant aux lots K et S, amenent les remarques suivantes :

- La structure est ecrouie : presence de macles et de bandes de deformation.
- La precipitation de carbures est relativement importante dans le lot S avec, parfois, des alignements de precipites (figure 8 bis). L'hypertrempe a donc ete faite dans des conditions de temperature et de

duree telles que les carbures ne sont pas totalement mis en solution (effet egalement de la teneur en carbone).

- La taille de grain est faible :

  Lot K : indice 7-8 ASTM
  Lot S : indice 6-7 ASTM

B - ESSAIS MECANIQUES

1) Essais de traction : temperature ambiante, 550°- 750°C

Les resultats sont presentes dans le tableau II et les figures 10 a 13 ; a titre de comparaison, nous avons fait egalement un rapprochement avec deux lots d'acier 316 ecroui a 8 % et a 20 % respectivement, deja etudie par ailleurs (lots D et C Orphee).

La limite elastique et les allongements correspondent bien a une structure ecrouie ; le taux d'ecrouissage, evalue a partir de courbes d'etalonnage sur l'acier 316, est pratiquement identique dans les deux lots :

Lot K : taux d'ecrouissage 13 %
Lot S : taux d'ecrouissage 12,5 %

2) Essais sous pression interne :

Nous avons porte sur le tableau III les valeurs obtenues apres 200 heures environ de fluage a 650°C sous une contrainte tangentielle voisine de 16 kg/mm^2 (deformations et vitesses rapportees a une meme duree d'essai.

CONCLUSIONS :

Les deux lots de tubes se revelent d'excellente qualite. Les controles par ultra-sons on ete quelque peu perturbes par un polissage mecanique assez defectueux du lot K, ce qui explique la proportion elevee de tubes douteux dans ce lot. Les defauts, tous du meme type (arrachement avec diminution d'epaisseur), sont de faible gravite, a l'exception d'un seul (tube n° 33 au lot K). Si le nombre de tubes classes mauvais est relativement important, il faut bien voir que, pour une experience d'irradiation, les criteres de chois sont extremement severes puisque tout defaut detecte ontraine l'elimination du tube. Dans les conditions habituelles d'un controle semi-industriel, seul un tube aurait ete rebute.

Au point de vue des proprietes mecaniques en traction, les deux lots ont un comportement voisin de celui d'un acier ecroui a 7 - 10 % (lot D Orphee) Par contre les caracteristiques en fluage les rapproche plutot du lot C Orphee (ecrouissage 20 %).

Il est probable que, a taux d'ecrouissage constant, les differences constatees d'un lot a l'autre proviennent autant de la gamme de fabrication que de la composition (teneue en carbone). On remarque que le recuit flash du lot K a eu un effet particulierement benefique puisqu'il associe a une faible faille de grain (et une mise en solution complete des carbures) une vitesse de fluage exceptionnellement basse.

TABLEAU I 第 I 表

	LOT K		LOT S		
	Tubes 1ère Analyse	Tubes 2ème Analyse	Lingot	Tubes 1ère Analyse	Tubes 2ème Analyse
C	0,047	0,047	0,07	0,07	0,07
Si	0,67	0,64	0,58	0,66	0,65
Mn	1,68	1,59	1,49	1,55	1,53
P	0,019	0,019	0,003	0,003	0,003
S	0,013	0,013	0,017	0,006	0,008
Ni	12,57	12,69	13,16	13,20	13,18
Cr	16,73	16,66	16,80	16,60	16,60
Co	0,035	0,035	0,02	0,02	0,02
Mo	2,34	2,29	2,52	2,60	2,57
B	0,0018	0,0017	0,0004	0,0005	0,0004
N	0,027	0,029	0,0268	0,0250	0,0255
Sn	0,065	0,065			
Ti	0,025	0,025			
As	0,009	0,007			
Cu			0,24	0,24	0,24

Analyses.

TABLEAU II 第II表

tensile test

Essais de Traction

*L 長さ
E 厚さ

Température	Lot	R Kg/mm^2	L_E^* 0,2 Kg/mm^2	A% réparti 分布	A, Total
20 °	K	75,5	60	20,5	28,3
	S	72,8	58,2	25	31,1
550°	K	50,7	41,1	10,5	12,9
	S	52	40,5	10,65	15,7
650°	K	43,6	33,1	8,4	13,25
	S	46,6	40	7,67	13,7
700°	K	38,1	33,8	5,2	17,4
	S	36,6	33	4,17	19,25
750°	K	31,5	29,1	2,67	23,2
	S	28,5	25,4	3,08	23,2

Longueur des éprouvettes 100 mm 試験片の長さ

Vitesse de traction 5 %/mn

Traction à chaud sous vide 真空下の tensile test

TABLEAU III 第Ⅲ表

Lot	Déformation %	Durée h	平均速度 Vitesse moyenne 10^{-6}/h
K	0,175	192,6	5,20
S	0,507	192,5	26,31
冷間圧延 écroui 8%	0,704	192,5	36,1
冷間圧延 écroui 20%	0,40	194,5	20,8

Fluage sous pression interne à 650 % σ = 16 Kg/mm²

650%の内部圧のもとのクリープ

FIGURE N°1

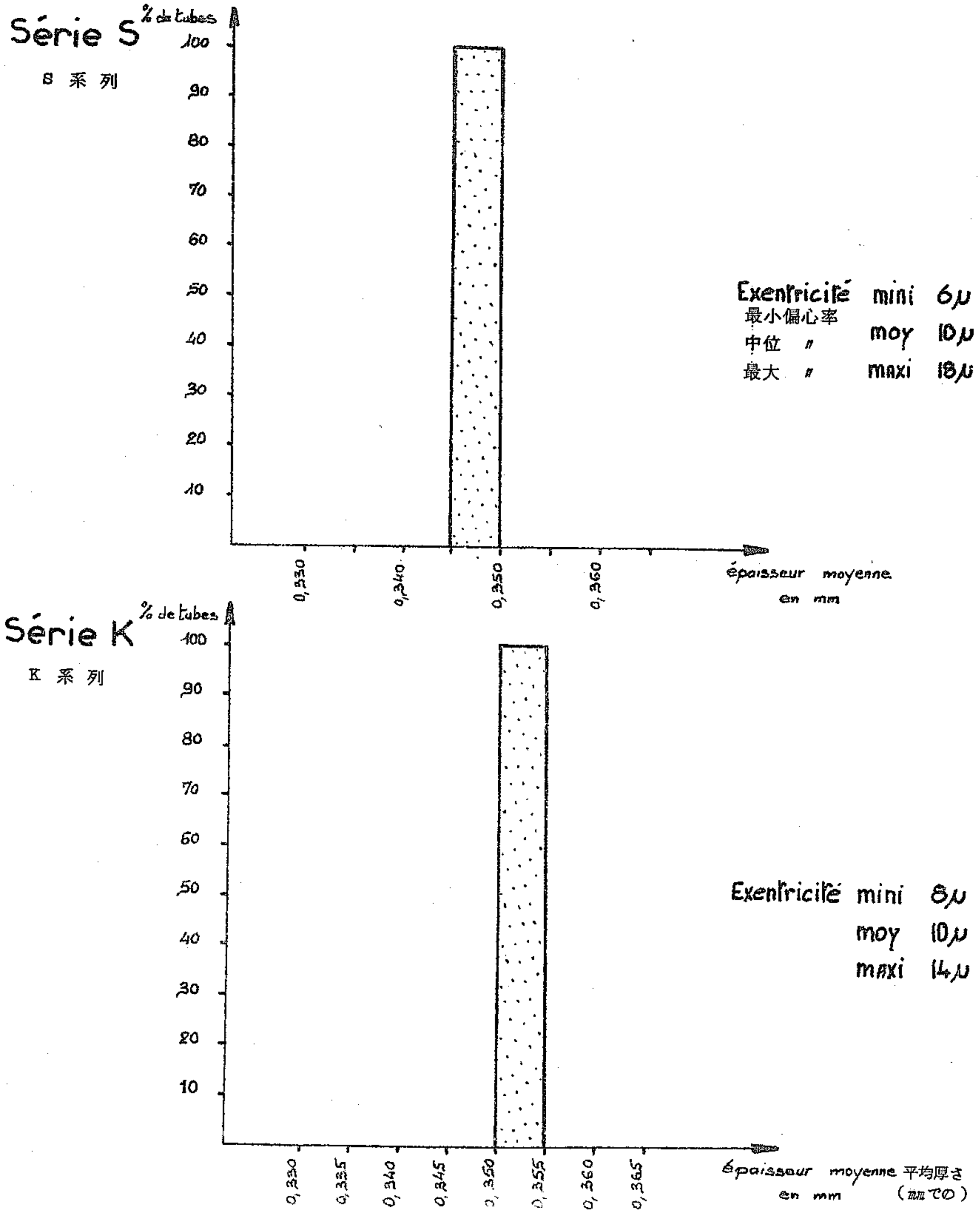

Série S
S 系列
% de tubes
100
90
80
70
60
50
40
30
20
10
0,330
0,340
0,350
0,360
épaisseur moyenne en mm
Exentricité mini 6μ
最小偏心率
中位 〃 moy 10μ
最大 〃 maxi 18μ
Série K
K 系列
% de tubes
100
90
80
70
60
50
40
30
20
10
0,330
0,335
0,340
0,345
0,350
0,355
0,360
0,365
épaisseur moyenne 平均厚さ
en mm （mmでの）
Exentricité mini 8μ
moy 10μ
maxi 14μ

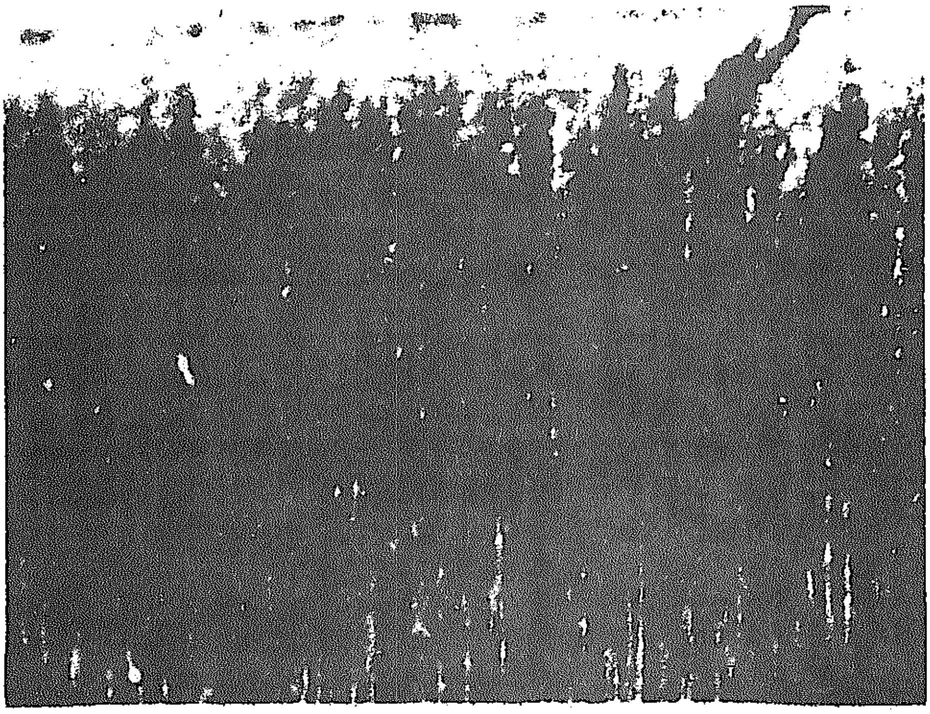
FIGURE N°2

外部表面

SURFACE EXTERIEURE G 200

GAINE S

S 被覆管



GAINE K

K 被覆管

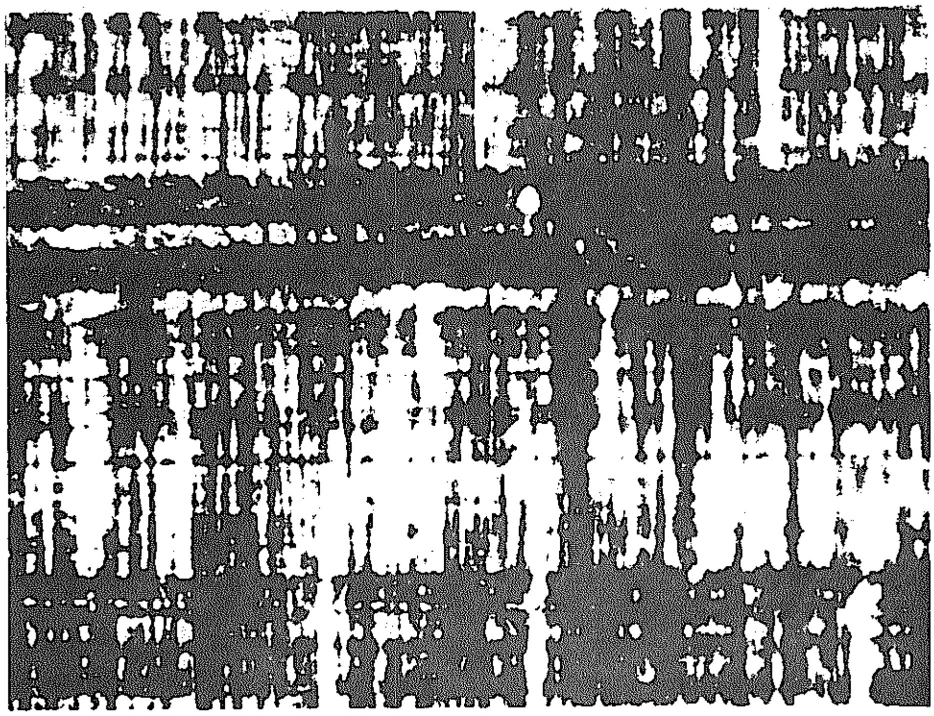
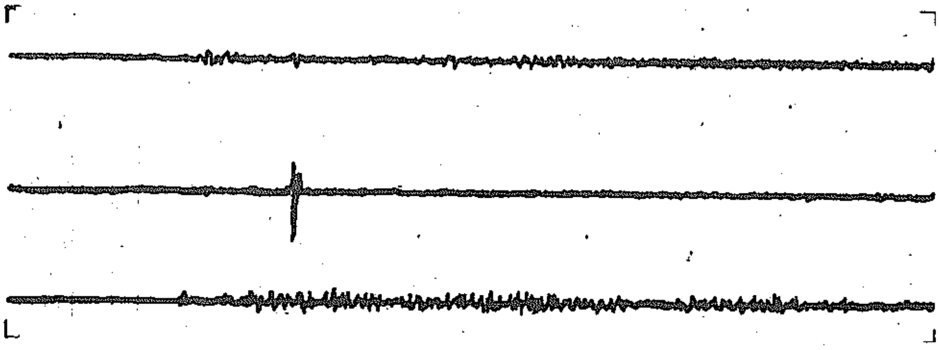


FIGURE N°3

被覆管
GAINE N° 2711 S

ENREGISTREMENT C.D.F.



MICROGRAPHIE G 150

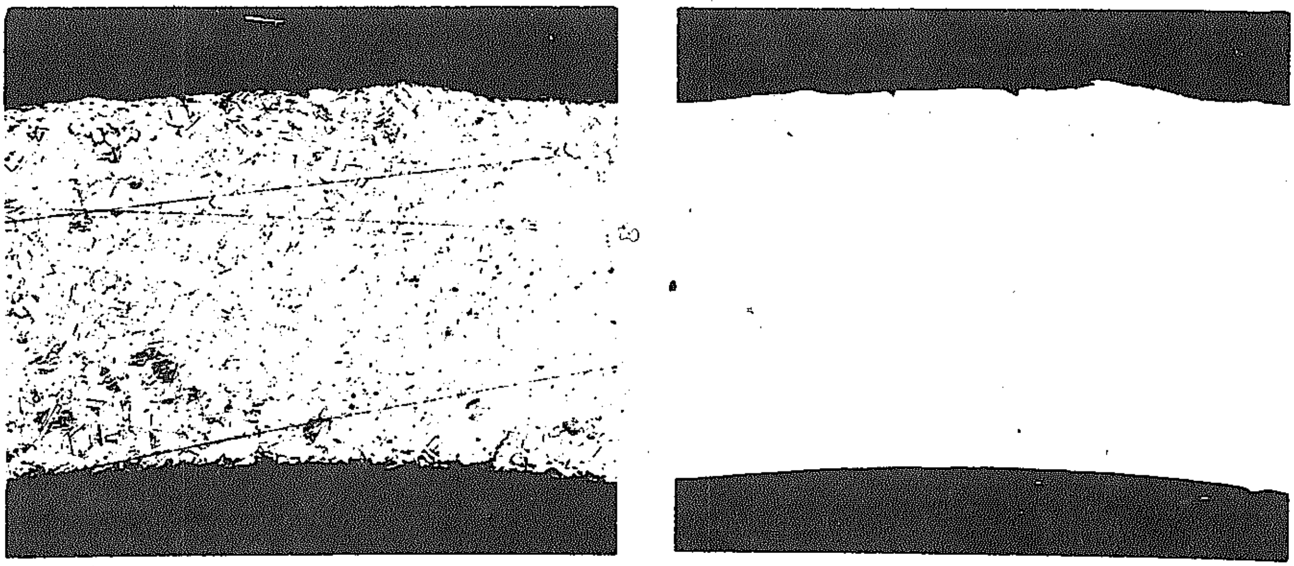
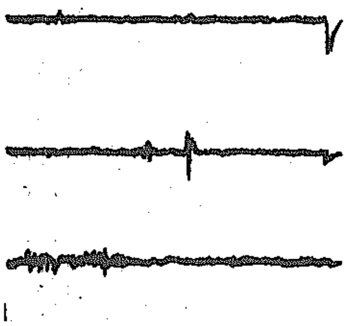


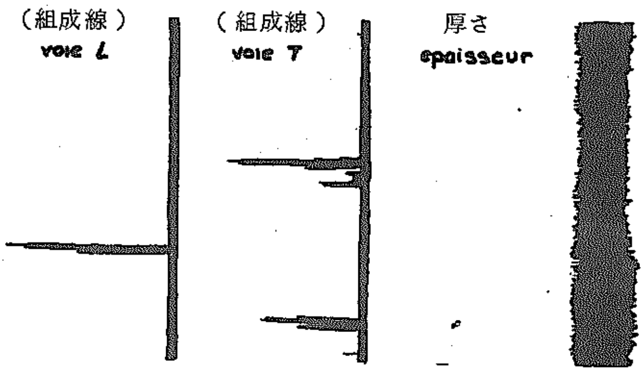
FIGURE N°4

GAINE N° 2831 S

ENREGISTREMENT C.D.F.



U.S.



MICROGRAPHIE G 150

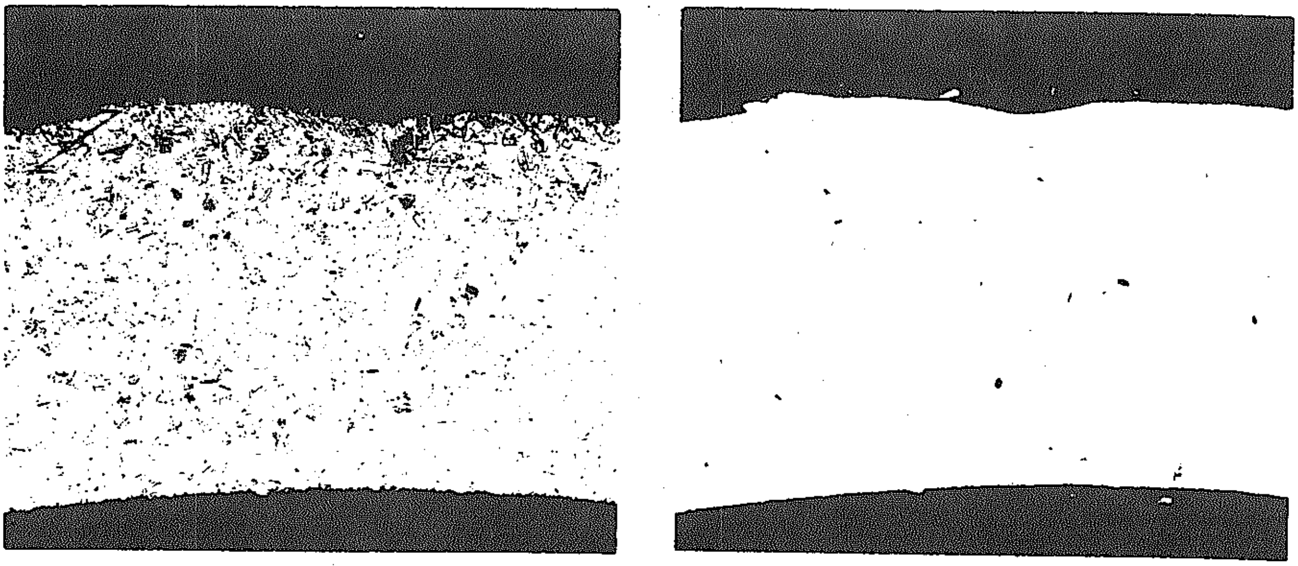
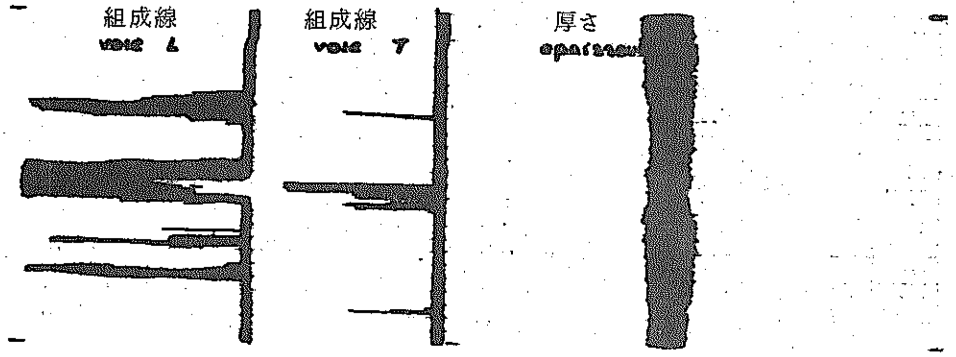


FIGURE N°5

GAINE N°69, K

ENREGISTREMENT U.S.



MICROGRAPHIE G 150

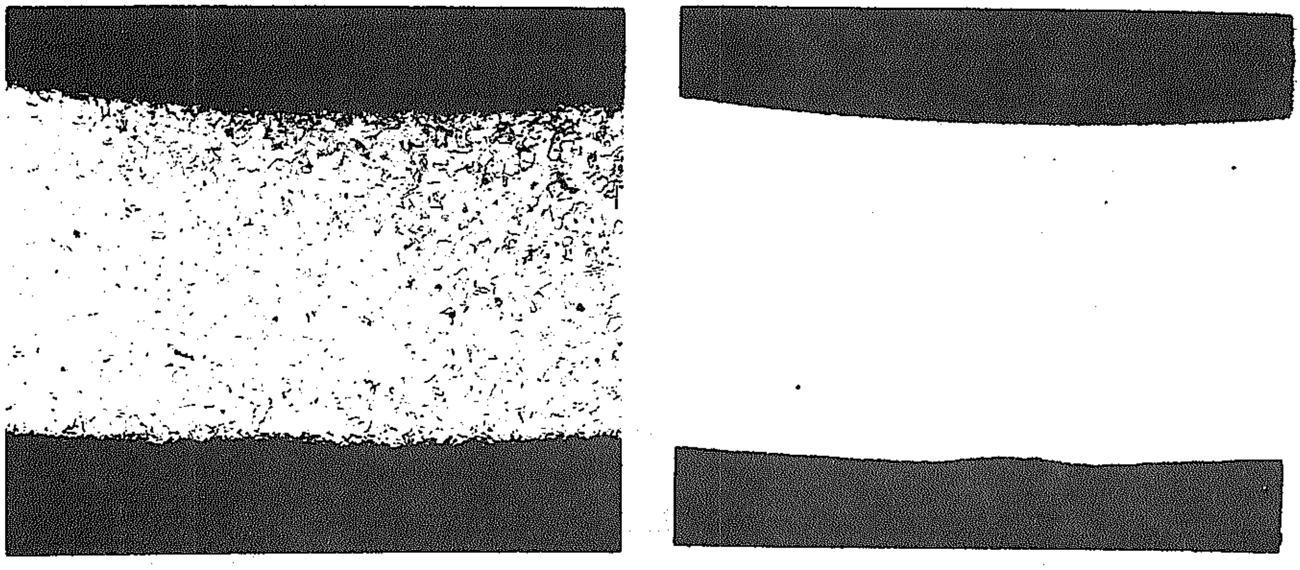
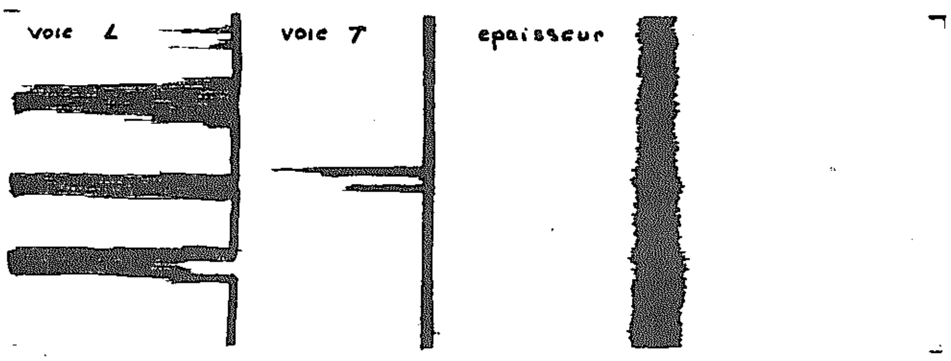


FIGURE N°6

GAINE N° 69_2 K

ENREGISTREMENT U.S.



MICROGRAPHIE G 150

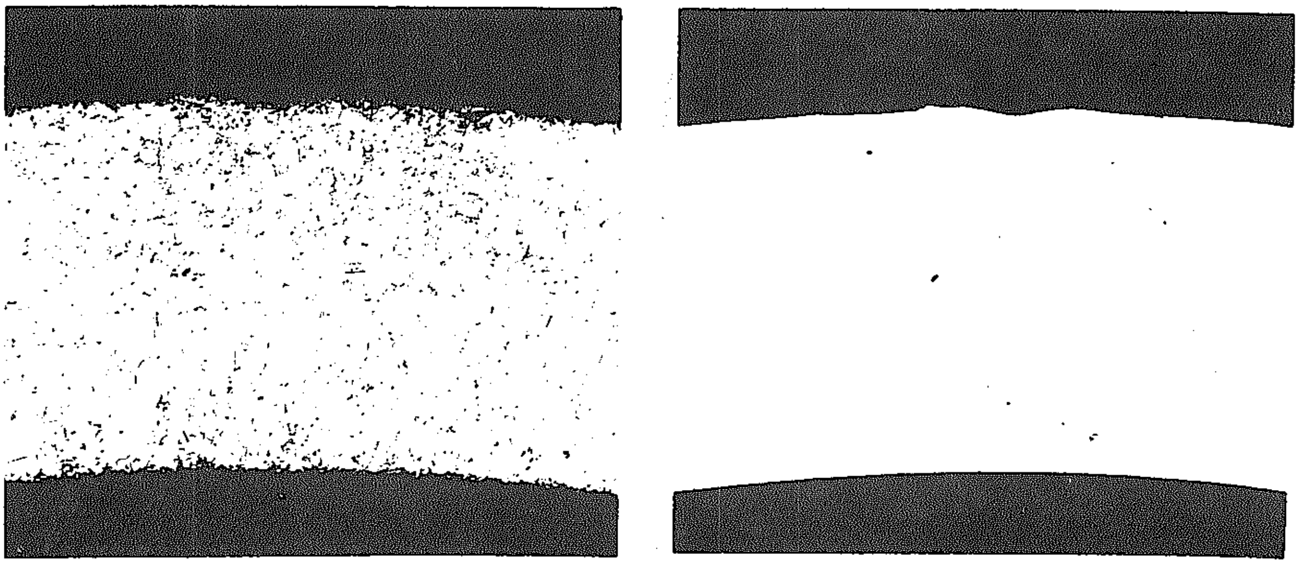
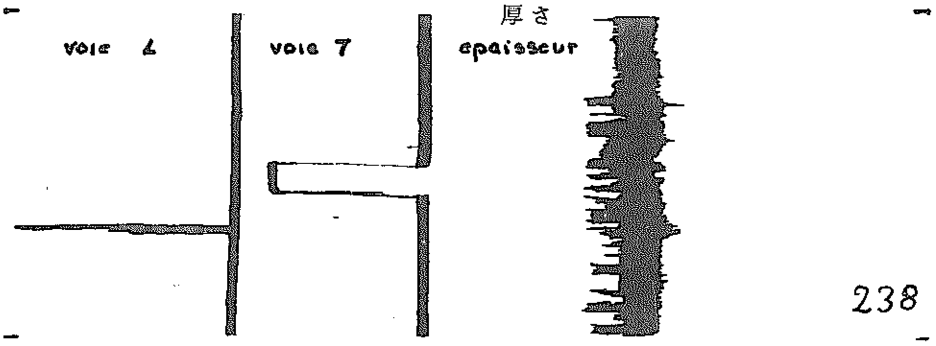


FIGURE N°7

GAINE N° 33 K

ENREGISTREMENT U.S.



MICROGRAPHIE G 150

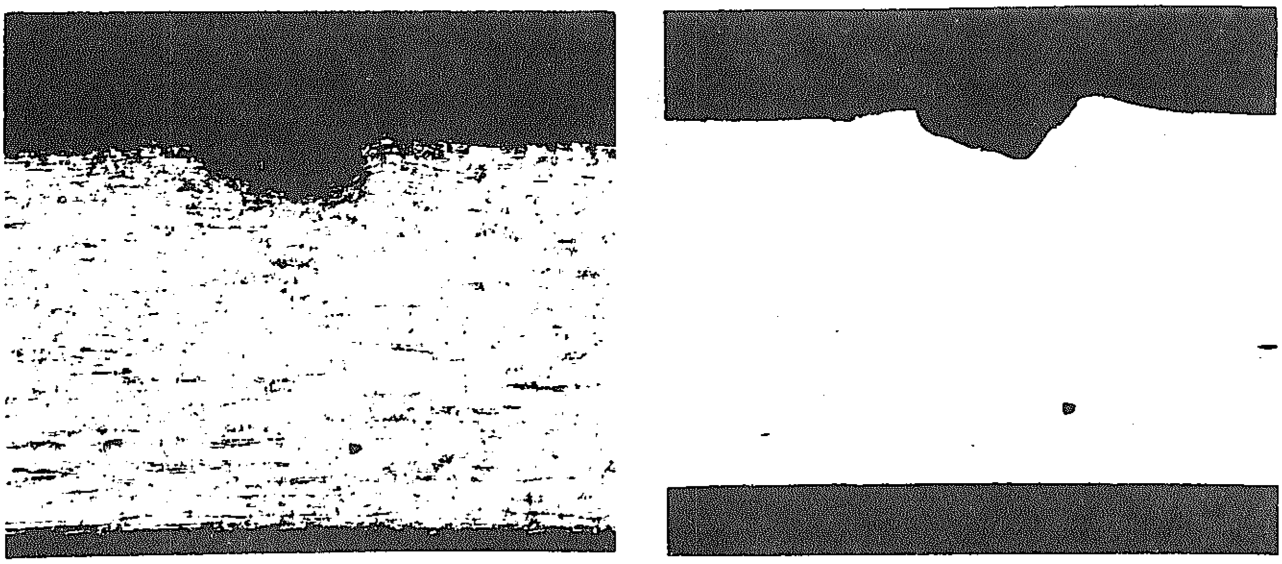
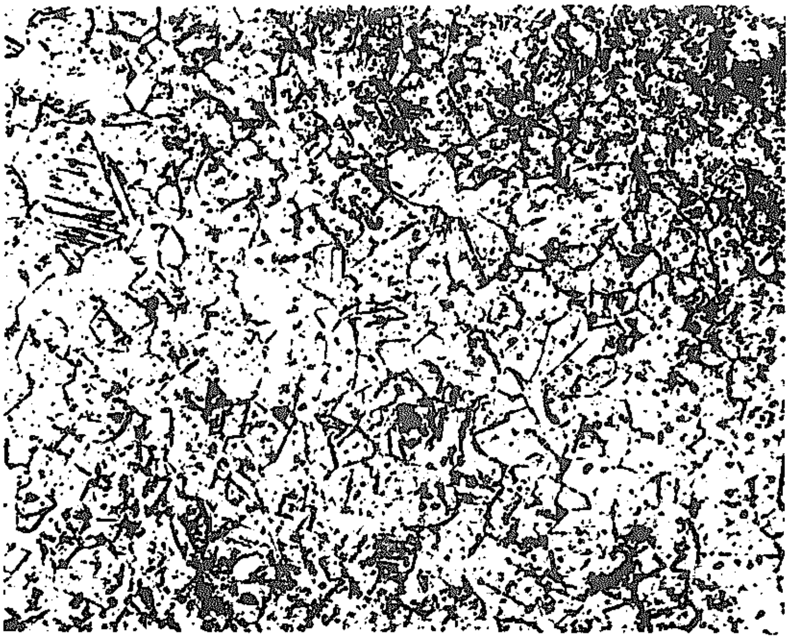


FIGURE N° 8

SUMITOMO

G 150



G 300

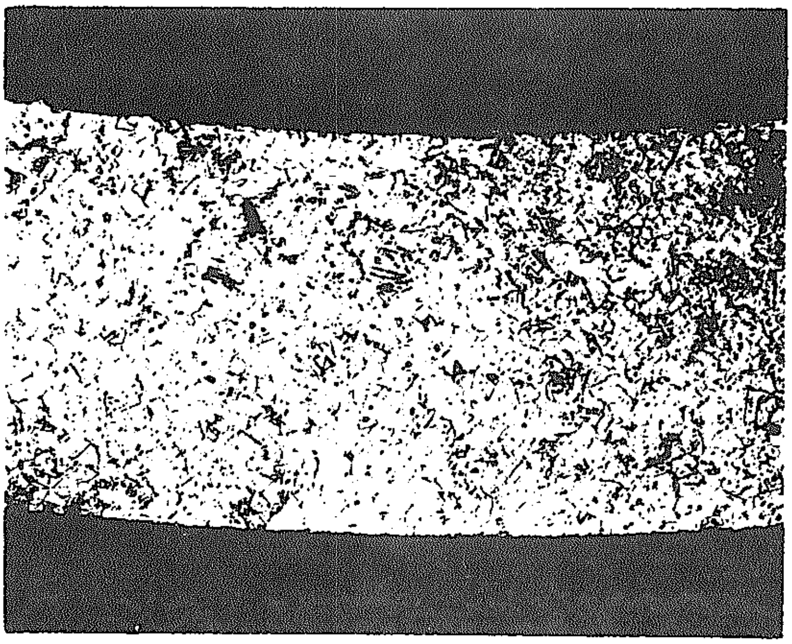
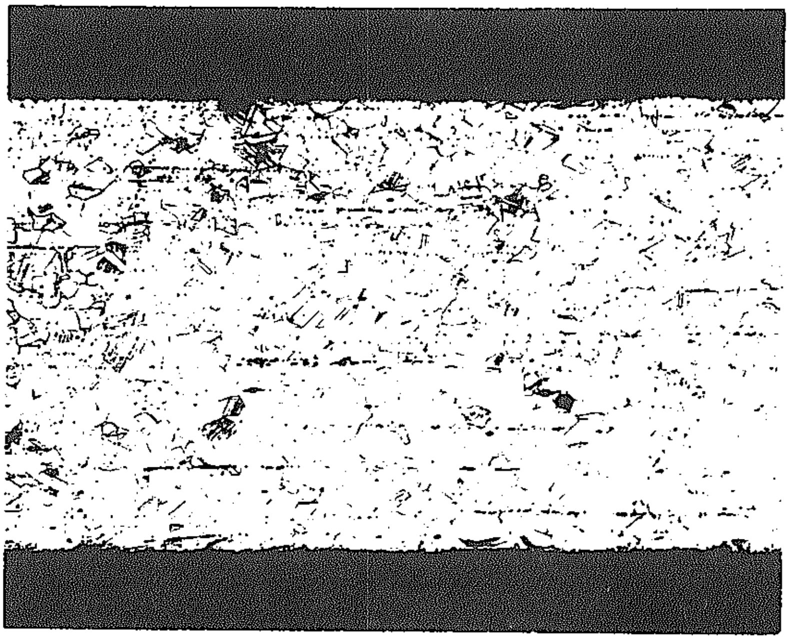


FIGURE N° 8 bis

SUMITOMO

N° 8-1

G 150



N° 8-2

G 300

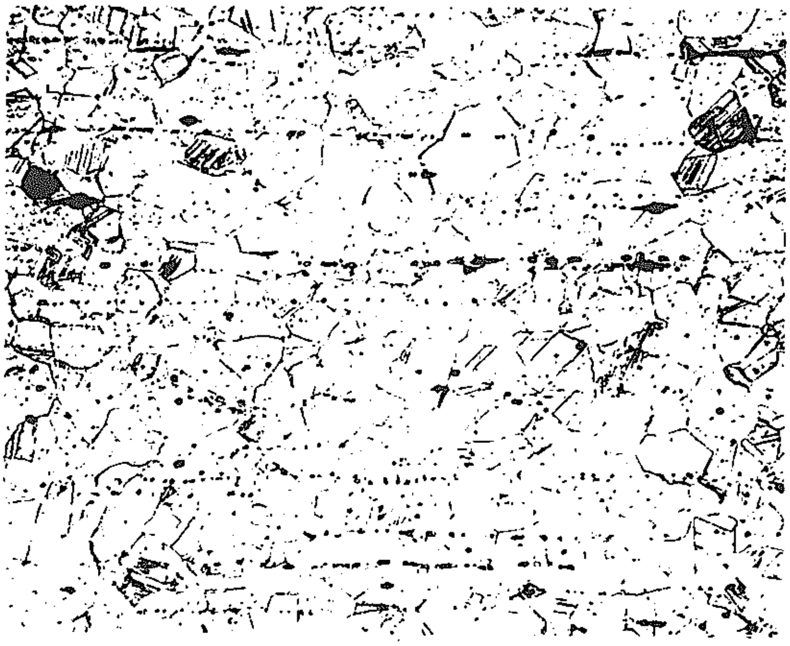
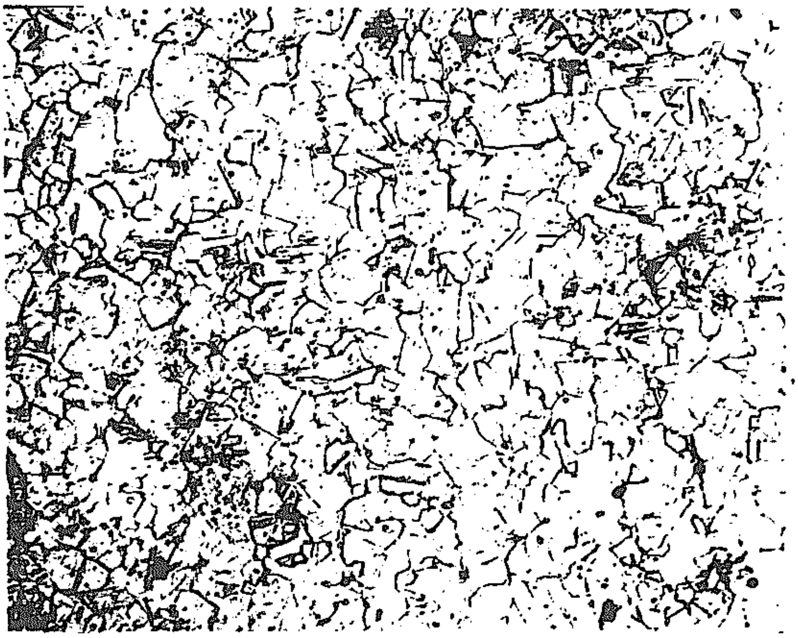


FIGURE N°9

KOBE

G 150



G 300

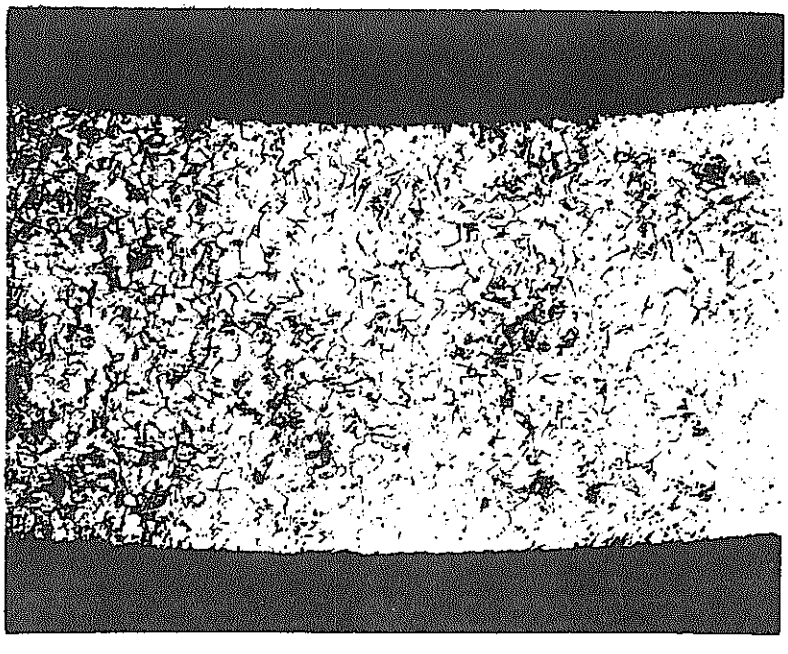
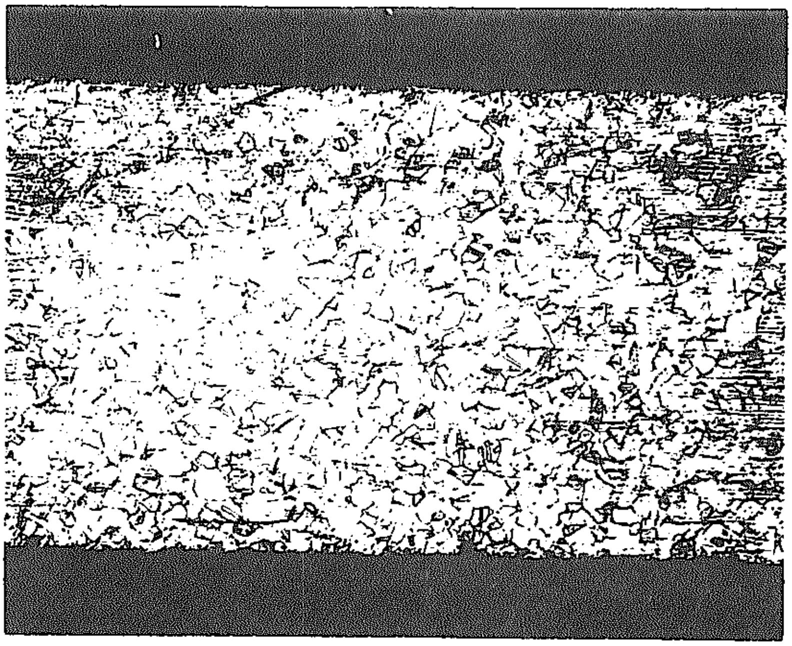


FIGURE N°9 bis

KOBE

G 150



G 300

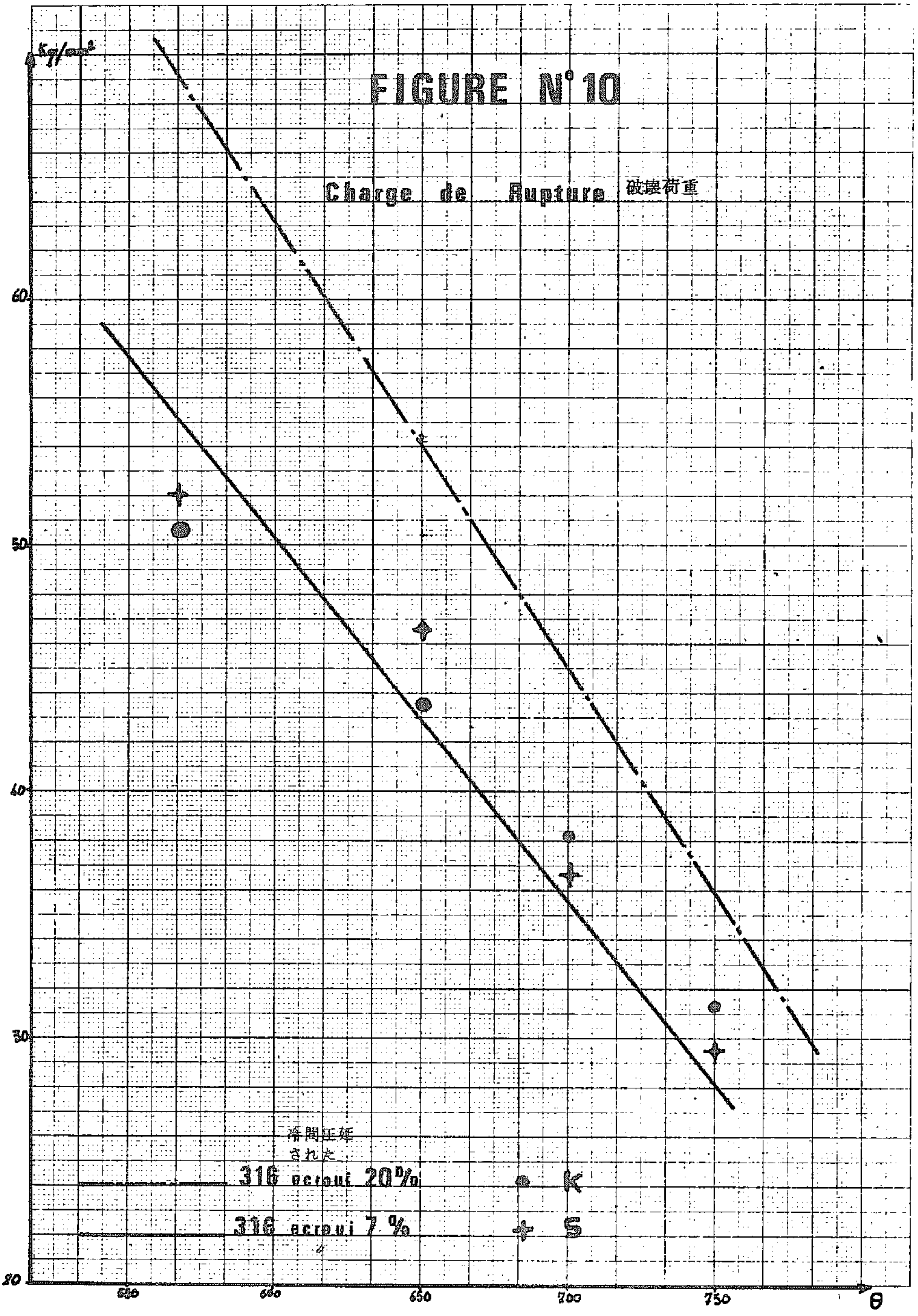


FIGURE N°10

Charge de Rupture 破壊荷重

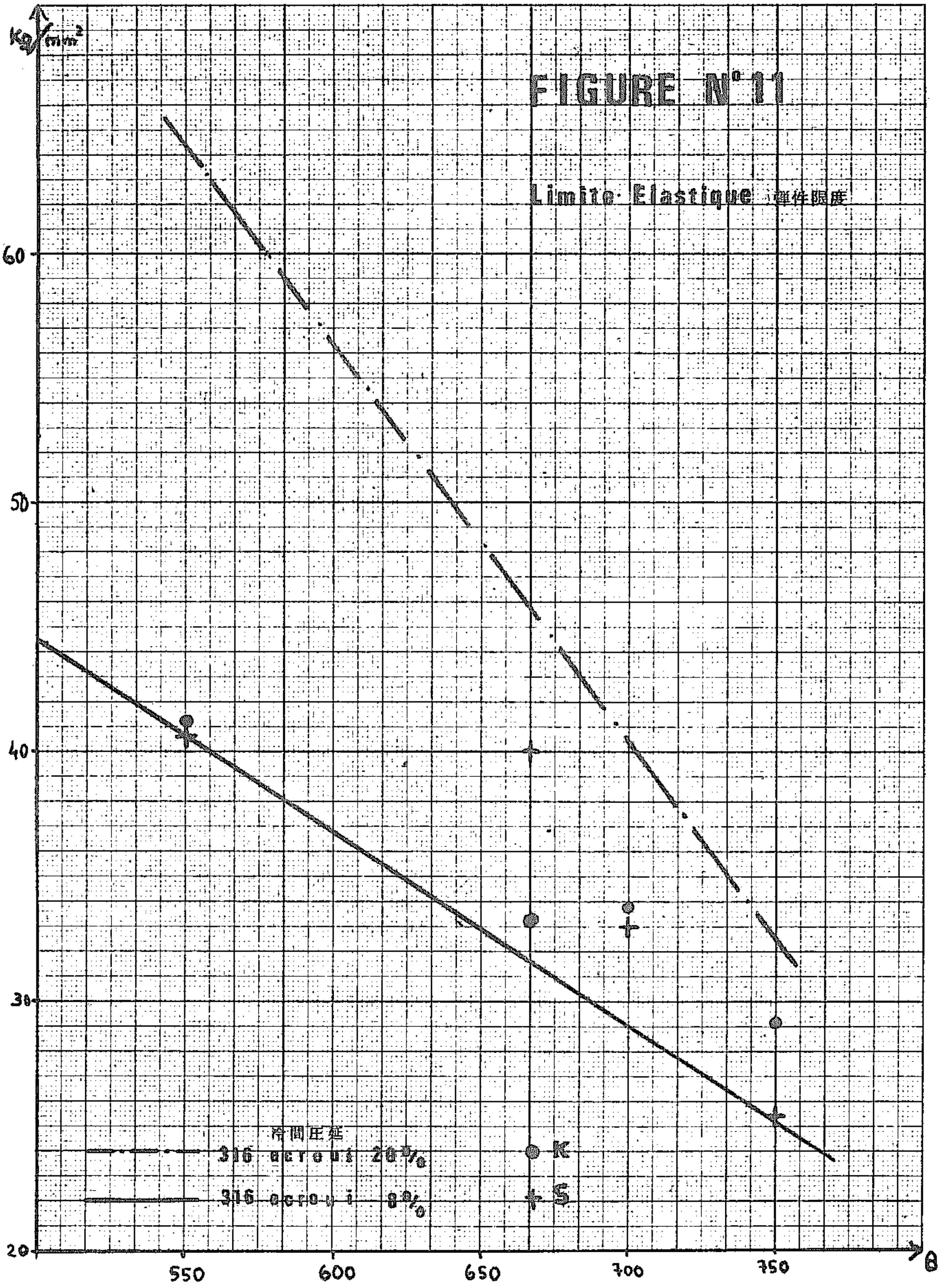


FIGURE N°11

Limite Elastique 弾性限度

FIGURE N° 12

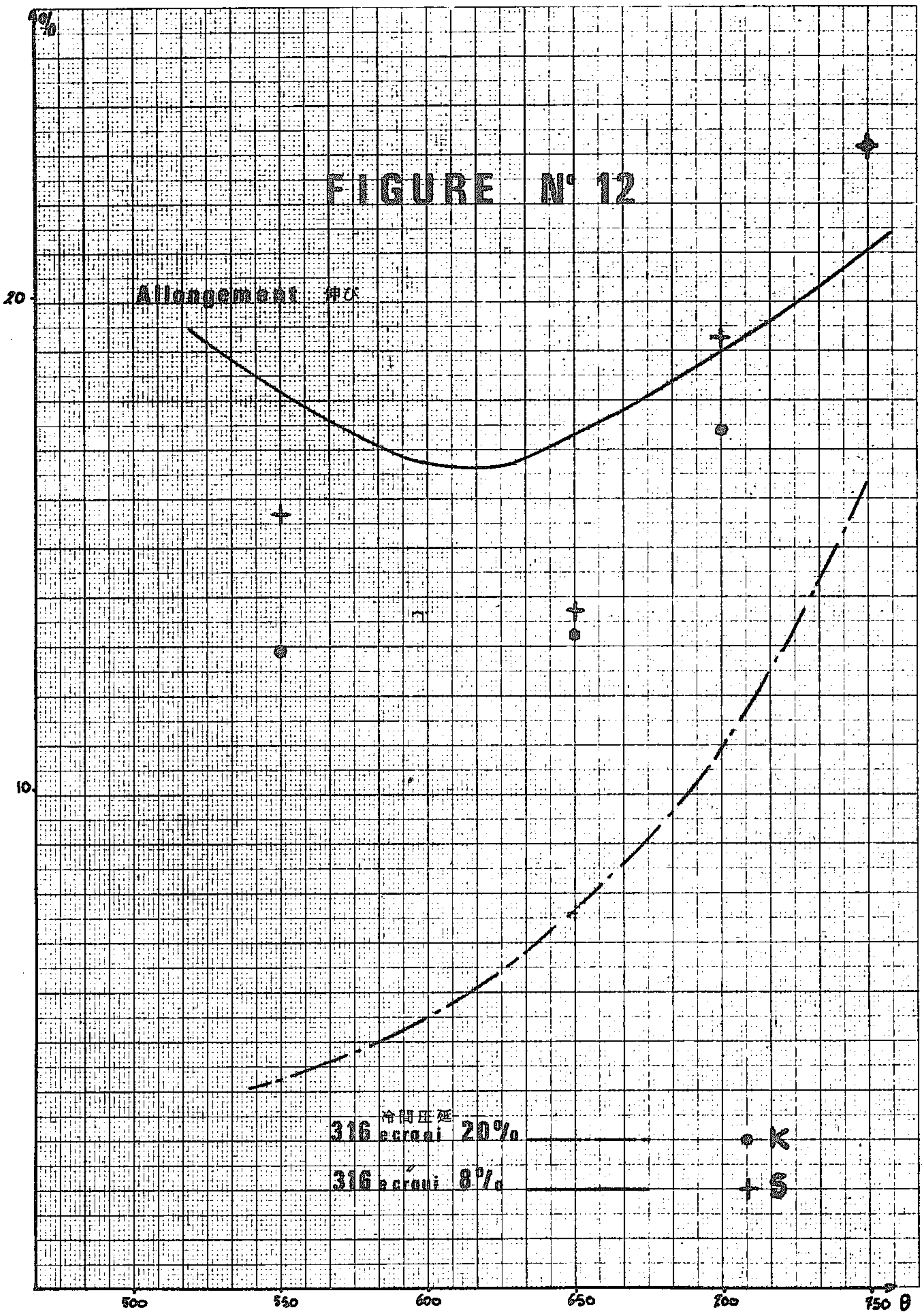
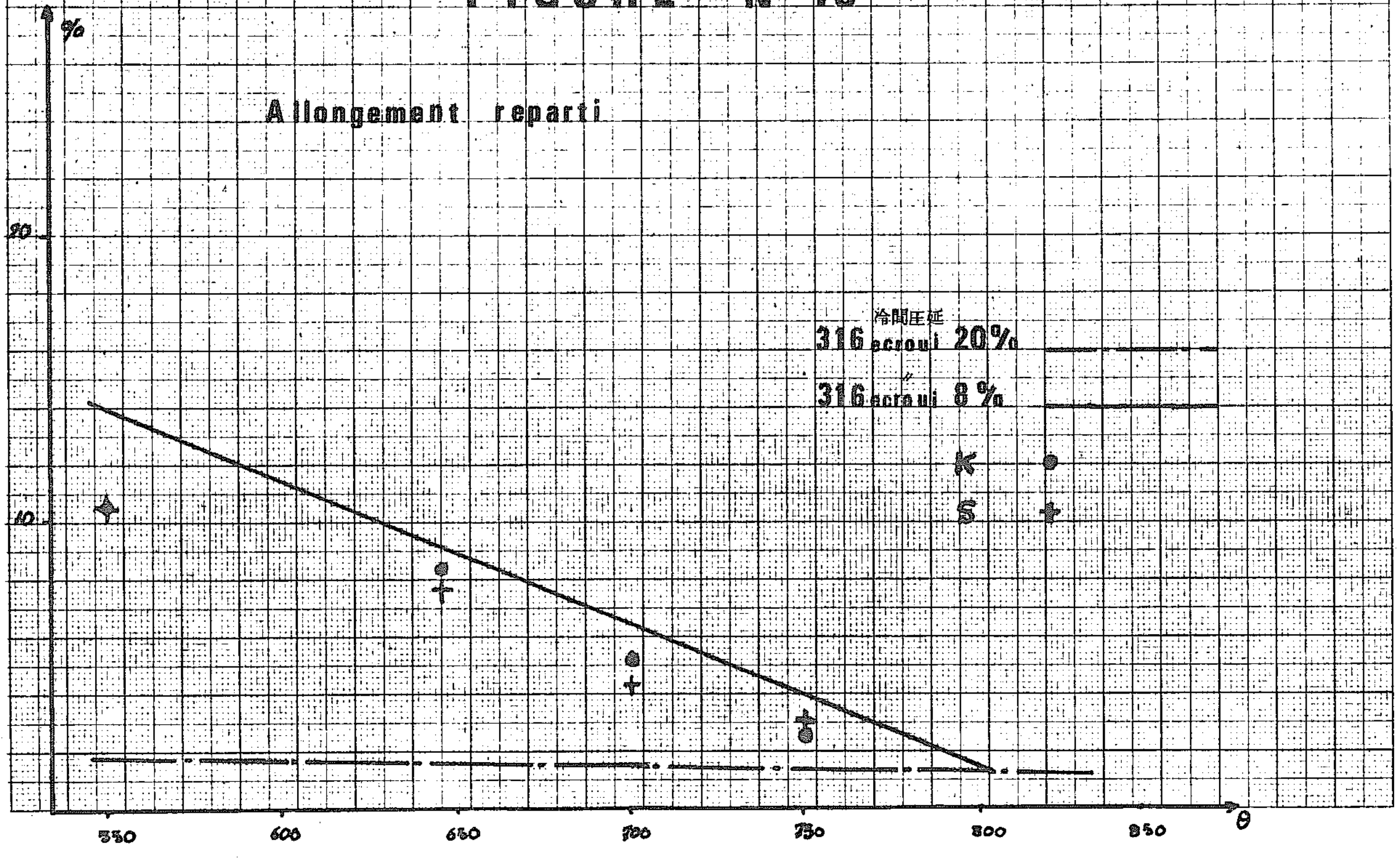

A%
20
10
Allongement 伸び
316 冷間圧延 ecroui 20% ● K
316 ecroui 8% + S
500
550
600
650
700
750 θ

FIGURE N°13


%
Allongement reparti
20
10
冷間圧延
316 ecroui 20%
″
316 ecroui 8%
K ●
S +
550
600
650
700
750
800
850
θ

この頁はPDF化されていません。

内容の閲覧が必要な場合は、技術資料管理

担当箇所で原本冊子を参照して下さい。

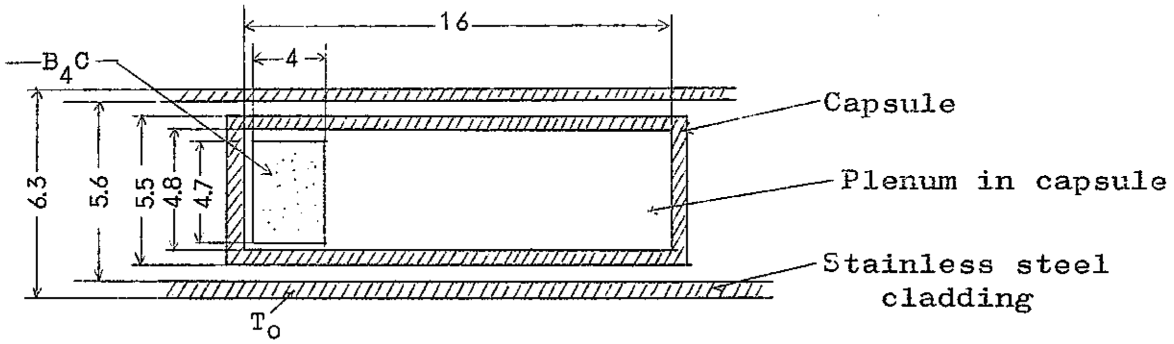
119頁 ～ 120頁

附 録 1

Temperature and Helium gas formed in Enriched B_4C pellet and Graphite pellet containing B_4C dispersions

1. Enriched B_4C specimen

1) The dimensions of specimen and capsule are shown in the following figure



2) Irradiation condition used for calculation

Irradiation time (t) : 140 days (1.2096×10^7 sec)

Fast neutron flux (ϕ) : 3×10^{15} n/cm^2 sec

Capture cross section of boron at 0.3 MeV (σ_c) : 0.7 barns

Temperature of inner surface of Stainless (T_0) Steel cladding : 626°C

3) Description of B_4C pellet

Density (ρ)	2.32 g/cm^3
Enrichment of B^{10}	90%

(In the calculation, all boron atoms is assumed as B^{10})

Release rate of He generated in B_4C pellet during irradiation : 100 %

4) Calculation

Since number density of B is

$$6.023 \times 10^{23} (n/mol) \times \frac{2.32 (g/cm^3)}{55,267 (g/mole)} \times 4 = 1.0113 \times 10^{23} n/cm^3$$

Rod power Q(w/cm) can be calculated as

$$Q=1.0113x10^{23}(n/cm^3)x0.7x10^{-24}(cm^2)x1.5x10^{15}(n/cm^2sec)$$

$$x\pi x0.235^2(cm^3)x3.08(MeV)x1.6x10^{-13}(w.sec/MeV)= 9.07\ w/cm$$

(Power generation by carbon was neglected)

5) Temperature distribution

At the outer surface of capsule (Toc)

$$Toc = 626 + \frac{9.07}{\pi \ x\ 0.55\ x\ 0.8517} = 632^{\circ}C$$

At the inner surface of capsule (Tic)

$$Tic = 632 + \frac{9.07x\ln(\frac{0.55}{0.48})}{2\ x\ 0.215} = 633^{\circ}C$$

At the surface of B_4C pellet (T_{Bs})

$$T_{Bs} = 633 + \frac{9.07}{\pi \ x\ 0.47\ x\ 0.8517} = 640^{\circ}C$$

At the center of B_4C pellet (T_{BC})

$$T_{Bc} = 640 + \frac{9.07}{4\pi \ x\ 0.0023} = 954^{\circ}C$$

6) Amount of He gas released to the plenum of capsule

He gas volume at 0°C, 1atm, (V_{He}) is calculated as

$$VHe = 22.4\ x\ 10^3(cm^3/mole)\ x\ 1.0113\ x\ 10^{23}(n/cm^3)$$
$$x\ 1.2096\ x\ 10^7(sec)\ x\ 0.7\ x\ 10^{-24}(cm^2)\ x\ 3.0$$
$$x\ 10^{15}(n/cm^2sec) \div 6.023\ x\ 10^{23}\ (n/mole)\ x$$
$$\pi\ x\ 0.235^2\ x\ 0.4\ (cm^3) = 6.622(cm^3)$$

Since the volume in the plenum of capsule (V_p) is

$$V_p = \pi\ x\ 0.24^2\ x\ 1.6 - \pi x\ 0.235^2\ x\ 0.4 = 0.2200\ cm^3$$

The pressure built up in plenum (P_p) is calculated as

$$P_p = \frac{6.622}{0.2200}\ x\ \frac{273 + 650}{273}\ x\ 1 = 101.8\ atm.$$

Where plenum temperature is assumed as 650°C

7) Pressure stress in plenum (σ_p)

$$P = (\frac{r_o}{d} - \frac{1}{2})\sigma P$$

$$= (\frac{2.4}{0.35} - \frac{1}{2}) \times (101.8 - 63.6^*)$$

$$= 242.8 \text{ kg/cm}^2$$

* The estimated pressure in fuel pin.

8) Thermal stress (σ_t)

$$\sigma t = \frac{\alpha E \cdot \Delta T}{2(1-\gamma)} = \frac{18.6\text{x}10^{-6}\text{x}1.52\text{x}10^{6}\text{x}1}{2(1-0.31)} = 20.2 \text{ kg/cm}^2$$

Yield strength of stainless steel at 650°C = 1,400 kg/cm^2

9) $\therefore \quad \frac{1}{4}\sigma t + \sigma p = 247.8 \text{ kg/cm}^2 < \sigma y$

$$\frac{\sigma t}{2} = 10.2 \text{ kg/cm}^2 < \sigma y$$

$$\frac{4}{3}\ \sigma p = 323.6 \text{ kg/cm}^2 < \sigma y$$

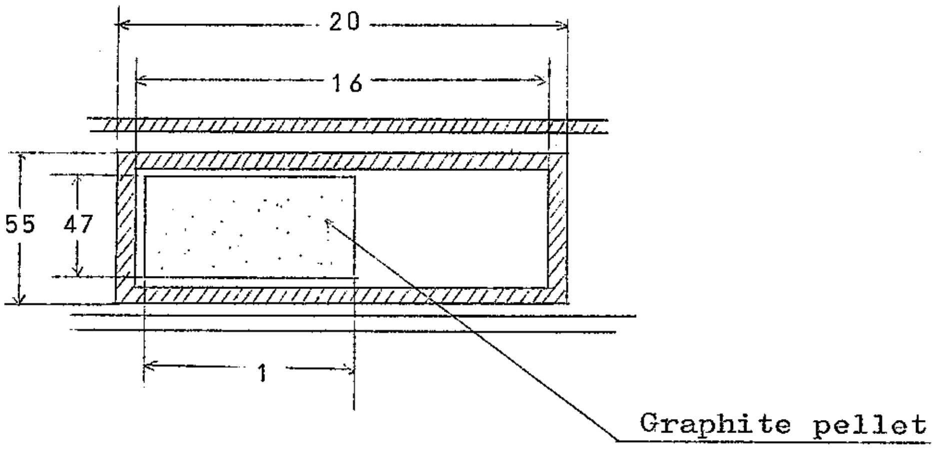
10) The rate of He release from B_4C pellet which was assumed as 100% is very conservative. The actual release rate is lower than 100%.

Accordingto BNWL-679, "The effects of irradiation on boron carbide" (1968) by T.W. Evans, one hot pressed natural B_4C pellet (3/8ø x 1/8 in) was irradiated to 37% burnup of B-10 at a temperature of 480°F. Following a measurement of He release, the sample was subsequently heated in stages to -- 1800°F and the additional He release was measured.

At a temperature of 1418°F, a total accumulated He release of 39% was observed.

2. Graphite pellet containing B_4C dispersions

1) The dimension of specimen and capsule are shown in the following figure



2) Assumption

(1) B_4C content in graphite was assumed as 10%, because the value is the maximum among those content in actual four specimens.

(2) Average neutron energy in the irradiation position of Rapsodie reactor is assumed as 0.3 MeV

(3) The conversion of w/o to v/o

$$\rho = \frac{W}{V} \qquad \therefore V = \frac{W}{\rho}$$

$$\frac{V1}{V1+V2} = \frac{\frac{W1}{\rho 1}}{\frac{W1}{\rho 1} + \frac{W2}{\rho 2}} = \frac{\rho 2}{\rho 2 + \rho 1 \frac{W2}{W1}}$$

Where	$V1$	volume of B_4C
	$\rho 1$	density of B_4C
	$W1$	weight of B_4C
	$V2$	volume of graphite
	$\rho 1$	density
	$W2$	weight

$$\frac{V_1}{V_1+V_2} = \frac{1.65\ g/cc}{1.65(g/cc)+2.37(g/cc)\frac{0.90}{0.10}} = 0.07\ (7\%)$$

(4) Natural B_4C was used as dispersion

		mass number
B - 10	0.196%	10.013
B - 11	0.804%	11.0093

Mass number of C

Density of B_4C powder particles (ρB_4C)

Used for preparing specimen

$$\rho B_4C = 2.37 \ g/cm^3$$

Density of graphite pellet

$$\rho_c = 1.65 \ g/cm^3$$

(5) Number density of B_4C molecule

$$(N_{B4C}) = \frac{\rho}{A} No = \frac{2.37(g/cc)}{55.267} (0.6023 \times 10^{24})$$

$$= 0.02583 \times 10^{24} \ (n/cm^3)$$

Number density of boron is

$$N_B = 4 \{ (N_{B4C})o \times (V/o)_{B4C} \}$$

$$= 4(0.02583 \times 10^{24} \times 0.07)$$

$$= 0.007233 \times 10^{24} \ n/cm^3$$

Number density of carbon is

$$N_c = (N_c)_o x(V/o)_c + (N_{B4C}) \times (V/o)_{B4C}$$

$$= (0.0838x10^{24})(0.93)+(0.02583x10^{24})(0.07)$$

$$= 0.08155x10^{24} \ (n/cm^3)$$

3) Calculation of heat generated in the pellet during irradiation

(1) Heat generation by B is calculated as

$$Q = N_B \triangle c \ \phi \ qB$$

$$= 0.007233x10^{24}(n/cm^3)x0.7x10^{-24}(cm^2)$$

$$x \ 3 \ x10^{15}(n/cm^2 sec)x3.08(MeV/cap)$$

$$= 0.04678x10^{15} \ (MeV/sec \ cm^3)$$

$$= 7.485 \ (w/cm^3)$$

Heat generation per unit length of specimen Qe is

$$Q_e = 7.485(\mathrm{w/cm^3}) \mathrm{x} 0.1734(\frac{\mathrm{cm^3}}{\mathrm{cm}}) = 1.2979(\mathrm{w/cm})$$

$$V = \pi R^2 L$$

$$= 3.14 \mathrm{x} (0.47/2)^2 \mathrm{x} 1 = 0.1734(\mathrm{cm^3/cm})$$

where the length of specimen L is assumed as 1 cm

R is the radii of B_4C-graphite pellet

(2) Heat generation by C (Q_c) is calculated as

$$Q_c = N_c(\Delta_c)_c \ \phi \cdot q_c \cdot c \cdot v$$

$$Q_B = N_B(\Delta_c)_c \ \phi \cdot q_B \cdot c \cdot v$$

$$Q_c = Q_B \cdot \frac{N_c \ (\Delta)_c \ \cdot q_c}{N_B \ (\Delta)_B \ \cdot qB}$$

$$= 1.2979 \ \frac{(0.08155 \mathrm{x} 10^{24})(0.001 \mathrm{x} 10^{-24})(4.95)}{(0.007233 \mathrm{x} 10^{24})(0.7 \mathrm{x} 10^{-24})(3.08)}$$

$$= 0.03244 \ (\mathrm{w/cm})$$

where

$(\sigma_c)_c$ is assumed as 0.001 barn on the basis of LAMS-2543 Hassen & Roach "Six and Sixteen group cross sections for Fast and Intermediate Critical Assemblies".

$$Q(B_4C\text{-graphite}) = 1.2979 + 0.03244 \simeq 1.33(\mathrm{w/cm})$$

(3) Amount of H_e gas released to the plenum of capsule

He gas volume at 0°C, 1 atm, V_{He} is calculated as

$$V_{He} = 22.4 \ \mathrm{x} \ 10^3(\mathrm{cm^3/mole}) \ \mathrm{x} \ 7.233 \ \mathrm{x} \ 10^{21}(\mathrm{n/cm^3}) \ \mathrm{x} \ 1.2096 \ \mathrm{x} \ 10^7(\mathrm{sec}) \ \mathrm{x} \ 0.7 \ \mathrm{x} \ 10^{-24}(\mathrm{cm^2}) \ \mathrm{x} \ 3.0 \ \mathrm{x} \ 10^{15}(\mathrm{n/cm^2 sec}) - 6.023 \ \mathrm{x} \ 10^{23}(\mathrm{n/mole}) \ \mathrm{x} \ \pi \ \mathrm{x} \ (0.235)^2 \ \mathrm{x} \ 1(\mathrm{cm^3}) = 1.185(\mathrm{cm^3})$$

Since the volume in the plenum of capsule (V_p) is

$$V_p = \pi \ \mathrm{x} \ 0.24^2 \ \mathrm{x} \ 1.6 - \pi \ \mathrm{x} \ 0.235^2 \ \mathrm{x} \ 1 = 0.116 \ \mathrm{cm^3}$$

The pressure built up in plenum is calculated as

$$P_p = \frac{1.185}{0.116} \times \frac{273+650}{273} \times 1 = 34.54 \text{ atm}$$

where plenum temperature is assumed as 650°C and the release rate of He from B_4C - graphite is assumed as 100%.

附録 2

The dimensional changes of Graphite, Borated Graphite and Boron carbide

1. Graphite and borated graphite

The dimensional changes of graphite and borated graphite by irradiation are shown in Fig. 1.

Please refer the specimen number and pin number to the documents forwarded to Mr. Nollet or April 28, 1970. (Our reference number 70-2-0073)

All irradiation data are obtained in thermal flux irradiation at 8.15 x 10^{13}, epithermal 5.95 x 10^{12}, fast 3.90 x 10^{13} n/cm^2 sec.

2. Boron carbide

We have no data on boron carbide irradiation induced dimensional change, but according to the report, WAPD-261, the volumetric change is expected as 1.52% per 1% burnup of total boron (0.3% per 1% burn-up of boron 10 for natural boron carbide).

The data are shown in Table 1 and Fig. 2.

Table o)

Swelling Data for Boron Carbide Samples $\frac{\Delta V^{**}}{V}$

Sample No	Enrichment %	Irradiation Facility	B-10 burnup %	total B* burnup	Density decrease %	%
HC25-26	natural	Loop	15	2.97	2.4	2.45
			25	4.95	10.0	11.11
			42	8.32	9.1	10.01
			46	9.11	11.6	13.12
			59	11.68	25.8	34.77
PB17	natural	Loop	30	5.94	9.0	9.89
HC19	natural	Loop	57	11.29	37.0	58.73
HC21	natural	Loop	62	12.28	34.0	51.51
HC101	natural	Process Water	27	5.35	13.5	15.60
HC105	Enriched	Process Water	30	11.48	15.3	18.06
PB37	Enriched	Process Water	28	10.72	41.2	70.06

* total B burnup was calculated by P.N.C.

** $\frac{\Delta V}{V}$ was calculated by P.N.C. according to the following equation

$$\frac{\Delta V}{V} = \frac{1}{1 - \frac{\Delta \rho}{\rho}} - 1$$

where ρ is density

o) Excerpt from WAPD-261

Fig. 1

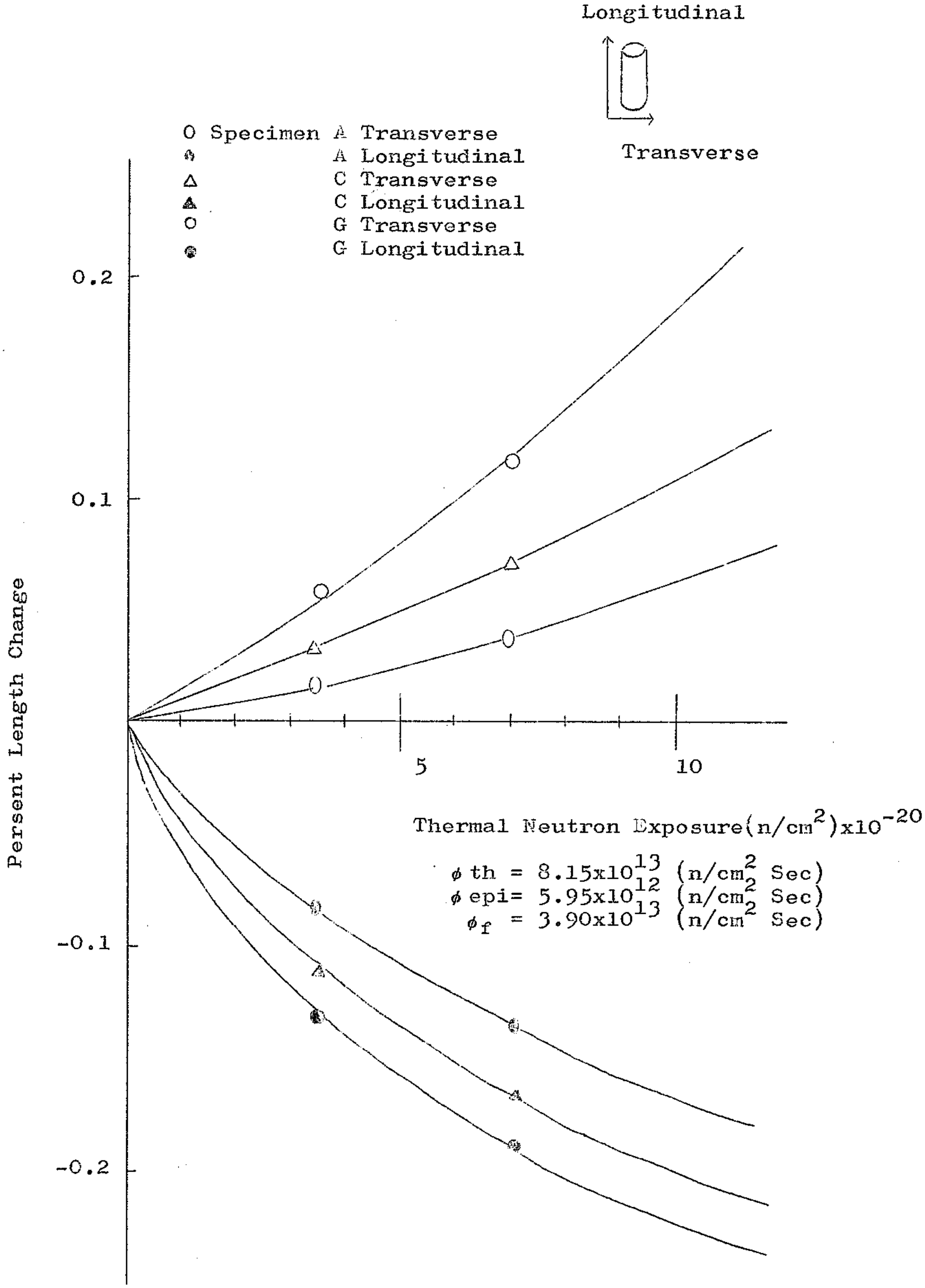
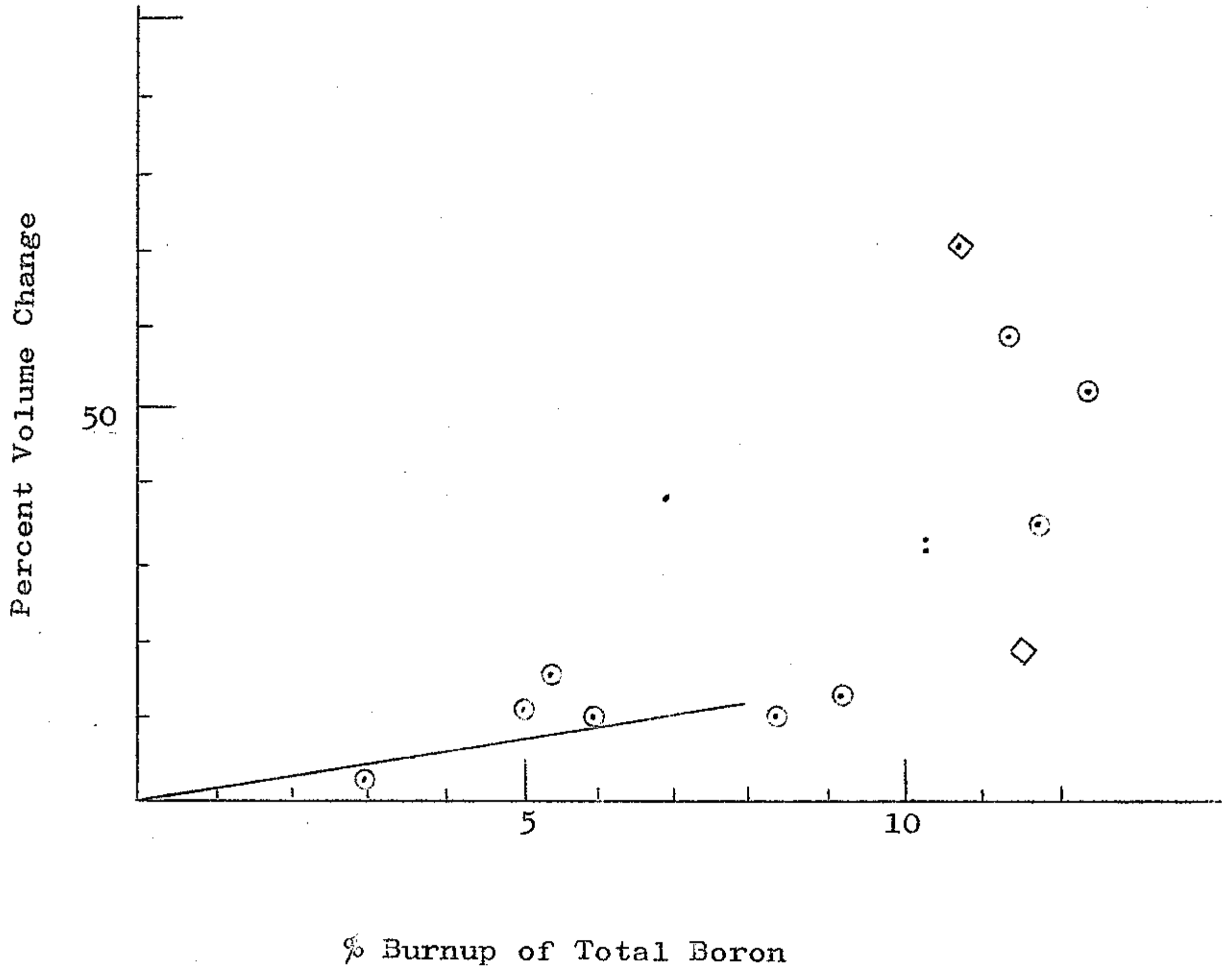

Longitudinal
Transverse
O Specimen A Transverse
A Longitudinal
△ C Transverse
▲ C Longitudinal
O G Transverse
● G Longitudinal
0.2
0.1
-0.1
-0.2
Persent Length Change
5
10
Thermal Neutron Exposure(n/cm^2)x10^{-20}
ϕ th = 8.15x10^{13} (n/cm^2 Sec)
ϕ epi= 5.95x10^{12} (n/cm^2 Sec)
ϕ_f = 3.90x10^{13} (n/cm^2 Sec)

Fig. 2

WAPD-261
Gray, R.G. and Lynam, L.R., "Irradiation Behavior of Bulk B_4C and B_4C-SiC Burnable Poison Plates"



附録 3　照射開始通知に関するＣＥＡ書簡

AMBASSADE DE DRANCE
AU JAPON
L'ATTACHE POUR LES
QUESTIONS NUCLEAIRES

ANJ/70-489

August 31, 1970

TOKYO, Le

Dr. UEMATSU

FBR
POWER REACTOR & NUCLEAR FUEL
DEVELOPMENT CORPORATION

Sankaido Bldg.
Akasaka, Minato-ku,

TOKYO

Dear Dr. Uematsu,

This is to inform you that we just received a cable telling us that your prototype fuel element to be irradiated in RAPSODIE has been put in pile on Aug. 24th and that power operation at 22 MW has started on Aug. 26th. This power corresponds to a linear power of 250 w/cm for the pin at the peak neutron flux.

No difficulty has been reported.

So I understand everything is going on all right.

Very truly yours,

R. Mas

C.DREX

C.C.　計管　：　元田，藤村
核燃　：　中村
東海　：　天沼次長，鈴木Ｐｕ燃部長，安久津技術部長
ＦＢＲ　：　大山理事，市野

附 録 4

ラプソディ炉（Fortissimo）特性

CARACTERISTIQUES RAPSODIE - FORTISSIMO (March 3, 1969)

1 - COMBUSTIBLE

Oxyde mixte UO_2 - PuO_2
teneur en Pu O_2 30 % en poids 30 w/o
Uranium enrichi a 85 % en poids 85 w/o
Poids de combustible dans un assemblage

UO_2 - Pu O_2	2781 g
U	1717 g
Pu	737 g

2 - ASSEMBLAGE FISSILE

Les formes exterieures sont semblables a celles des assemblages actuels de Rapsodie.

La region fissile est formee par un faisceau de 61 aiguilles combustibles. La hautaur de la colonna combustible est de 320 mm, le plan median du coeur sera 20 mm au-dessue du plan median du coeur actuel.

La couverture axiale inferieure est formee par un faisceau de 7 aiguilles fertiles.

La couverture axiale superieure est constituee d'un bloc d'acier hexagonal.

3 - CHARGEMENT DANS LE REACTEUR

Les assemblages combustibles formant le coeur de Rapsodie - Fortissimo seront entoures par un reflecteur Nickel.

4 - REGIME NOMINAL DE FONCTIONNEMENT

Puissance thermique	≃ 40 MW
Volume du coeur	≃ 45 litres
Debit total de sodium	= 1100 m^3/h
Temperature d'entree du sodium	= 410°C
Temperature de sortie de sodium	= 520°C

5 - CARACTERISTIQUES NEUTRONIQUES

5.1 - Taux de fission absolue au centre du coeur

Isotopes	Taux de fission		
U^{235}	1090	10^{10}	Fission/gr/sec
U^{238}	74,8	10^{10}	"
PU^{239}	1268	10^{10}	"
PU^{240}	488	10^{10}	

5.2 - Taxu de fission relatifs

La figure 1 donne les courbes des taux de fission relatifs le long de l'axe du coeur.

Les figures 2 - 3 - 4 donnent les courbes des taux de fission relatifs dans le plan median du coeur.

Remarque :

Les courbes de taux de fission relatifs du Pu^{240} sont assimilees a celles du Pu^{239}.

5-3 - Flux neutronique

Flux neutronique maximum eu
centre du coeur : 3×10^{15} $n/cm^2.s$

Flux neutronique moyen sur
le cosur : $2,2 \times 10^{15}$ $n/cm^2.s$

Les figures 5 et 6 donnent les flux totaux et superisure a 1,4 Mev selon l'axe du coeur et dans son plan median.

5.4 - Autres donees

Le coefficient d'applatissement radial $\overline{Q}/Q$ max varie de 0,87 au centre a 0,91 a l'interface coeur - reflecteur nickel.

Poide en reactivite de l'assemblage
central : 1800 pcm

Poide en reactivite de l'assemblage
peripherique: 420 pcm

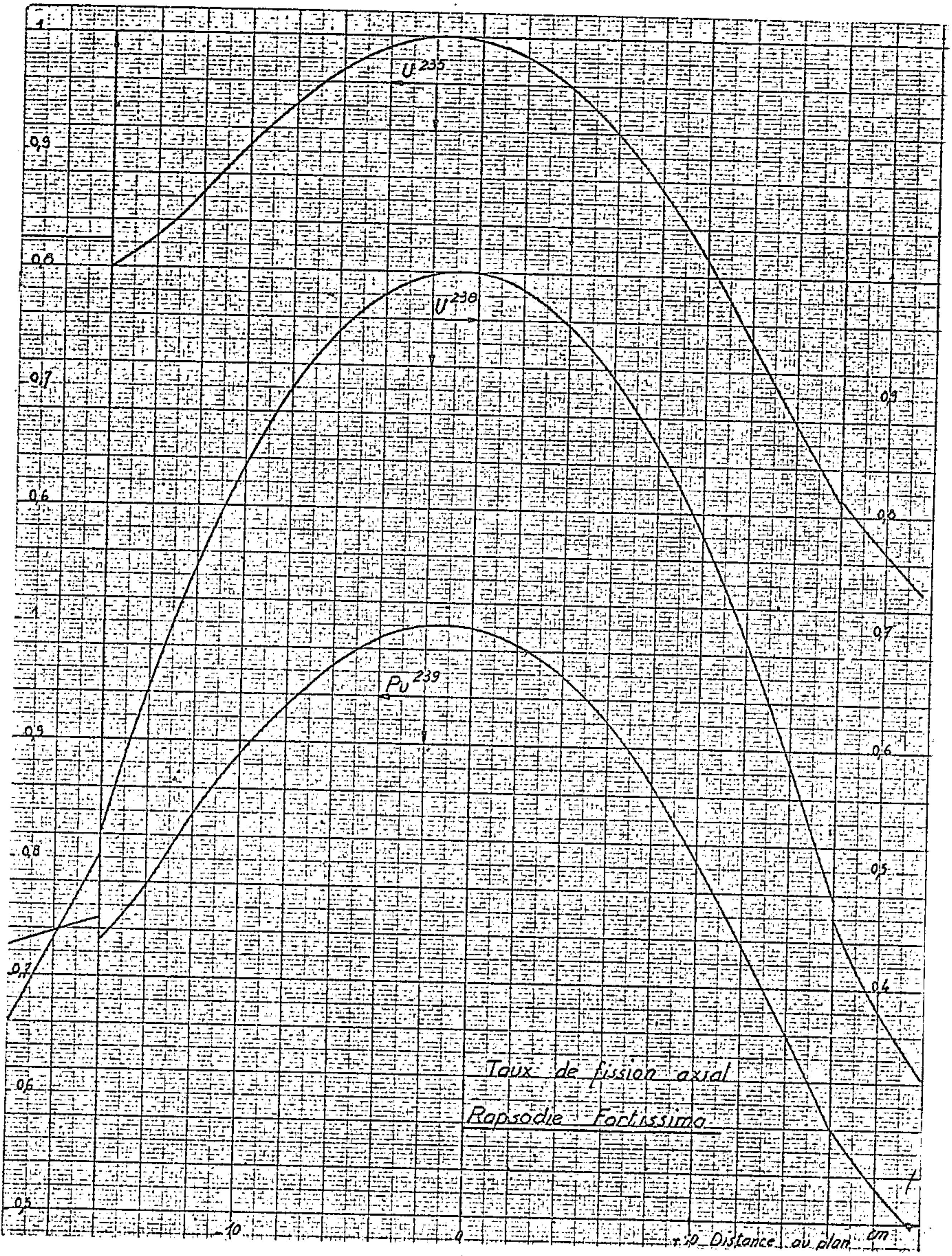
6 - CARACTERISTIQUES HYDRAULIQUES

Debit total dans le reacteur	1100 m^3/h
Debit dans le coeur	$\simeq$ 850 m^3/h
Debit dans l'assemblage central	$\simeq$ 3900 cm^3/s
Vitesse du sodium dans le faisceau fissile de l'assemblage central	$\simeq$ 6 m/s
Parte de chargetotal du reacteur	$\simeq$ 2,5 bars
Perte decharge admissible dans un assemblage avant la miss du diaphragme	= 2 bars

7 - CARACTERISTIQUES THERMIQUES

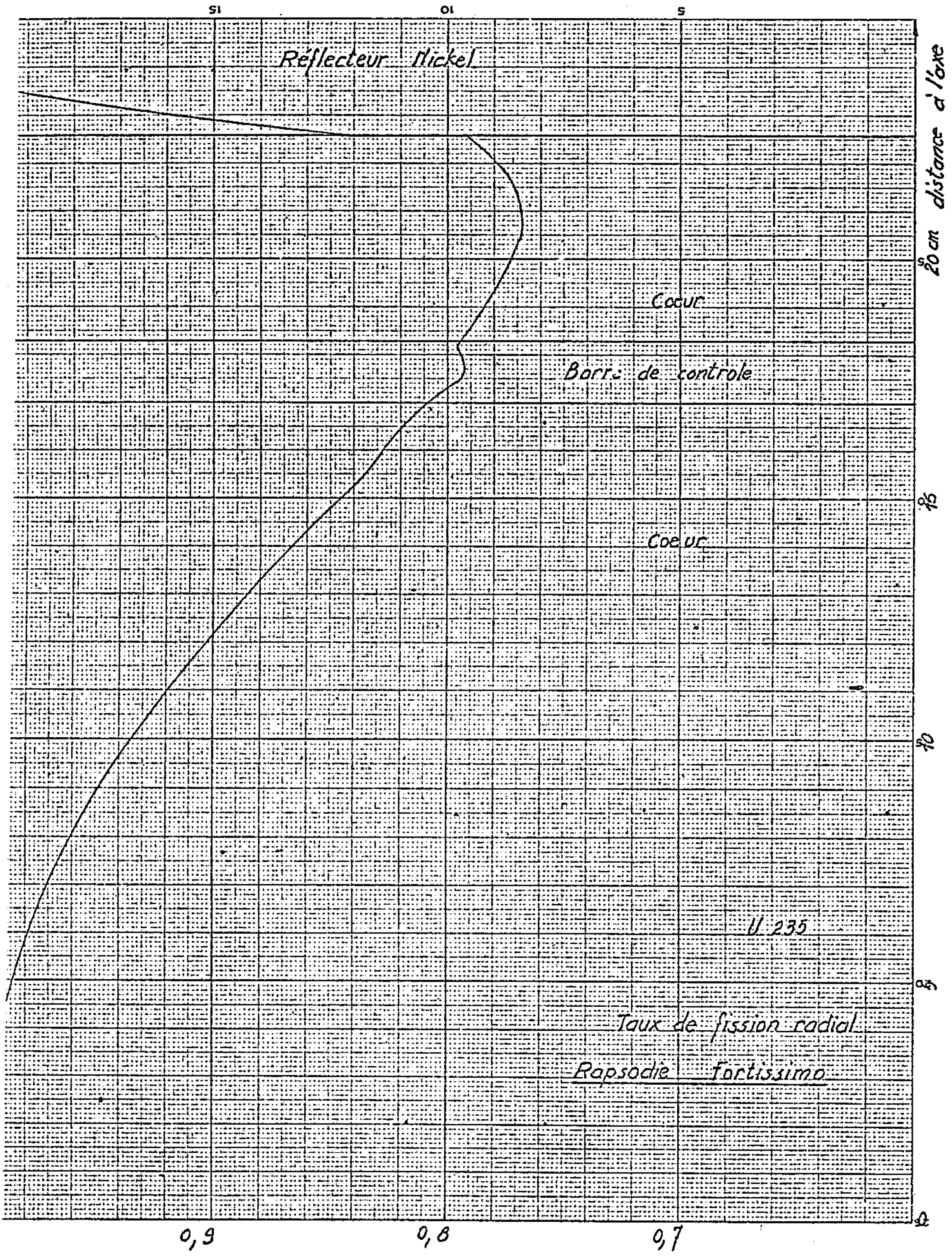
ΔT du reacteur	110°C
ΔT du coeur	150°C
ΔT assemblage central	165°C

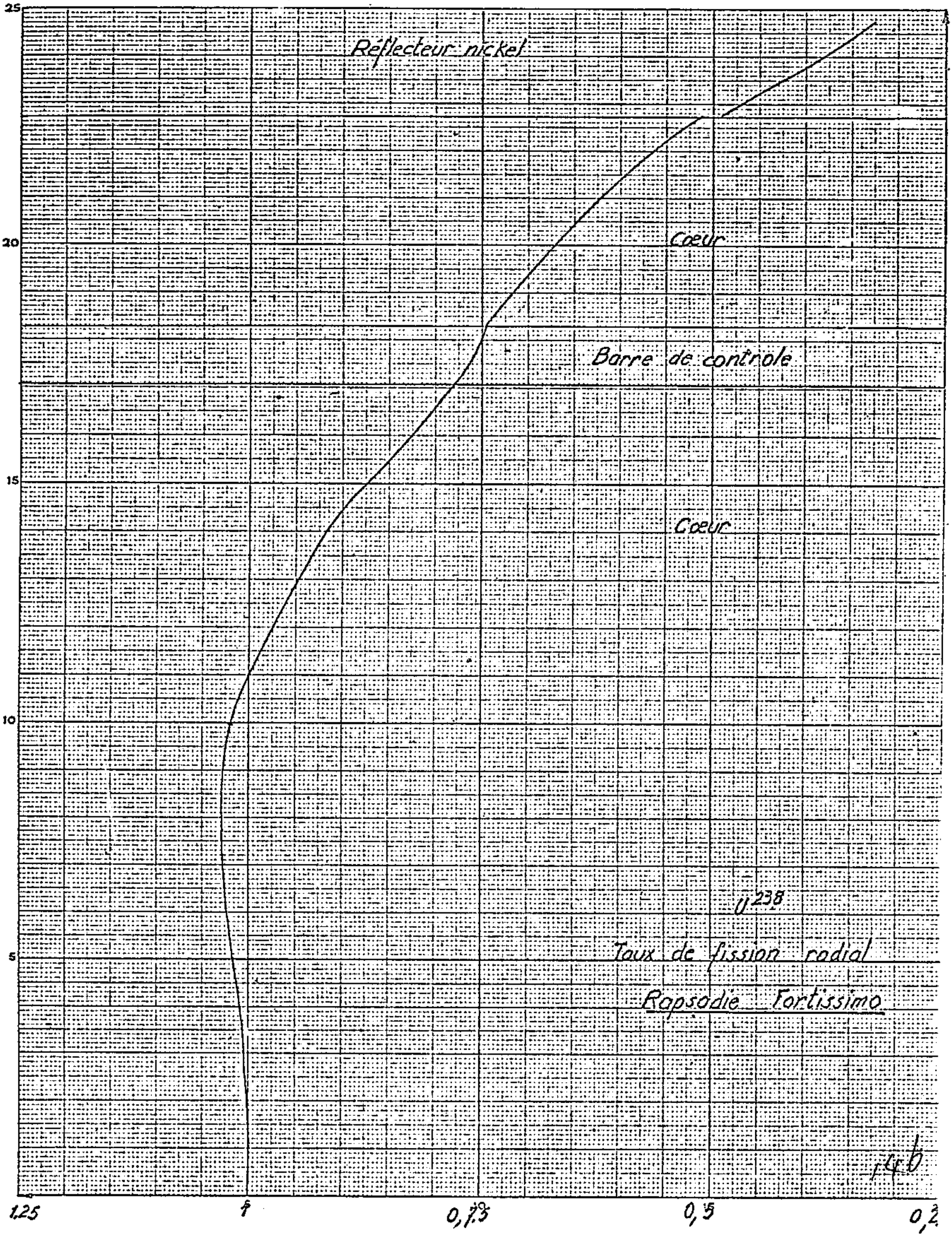
Temperature maximum au point chaud
gaine = 700°C.



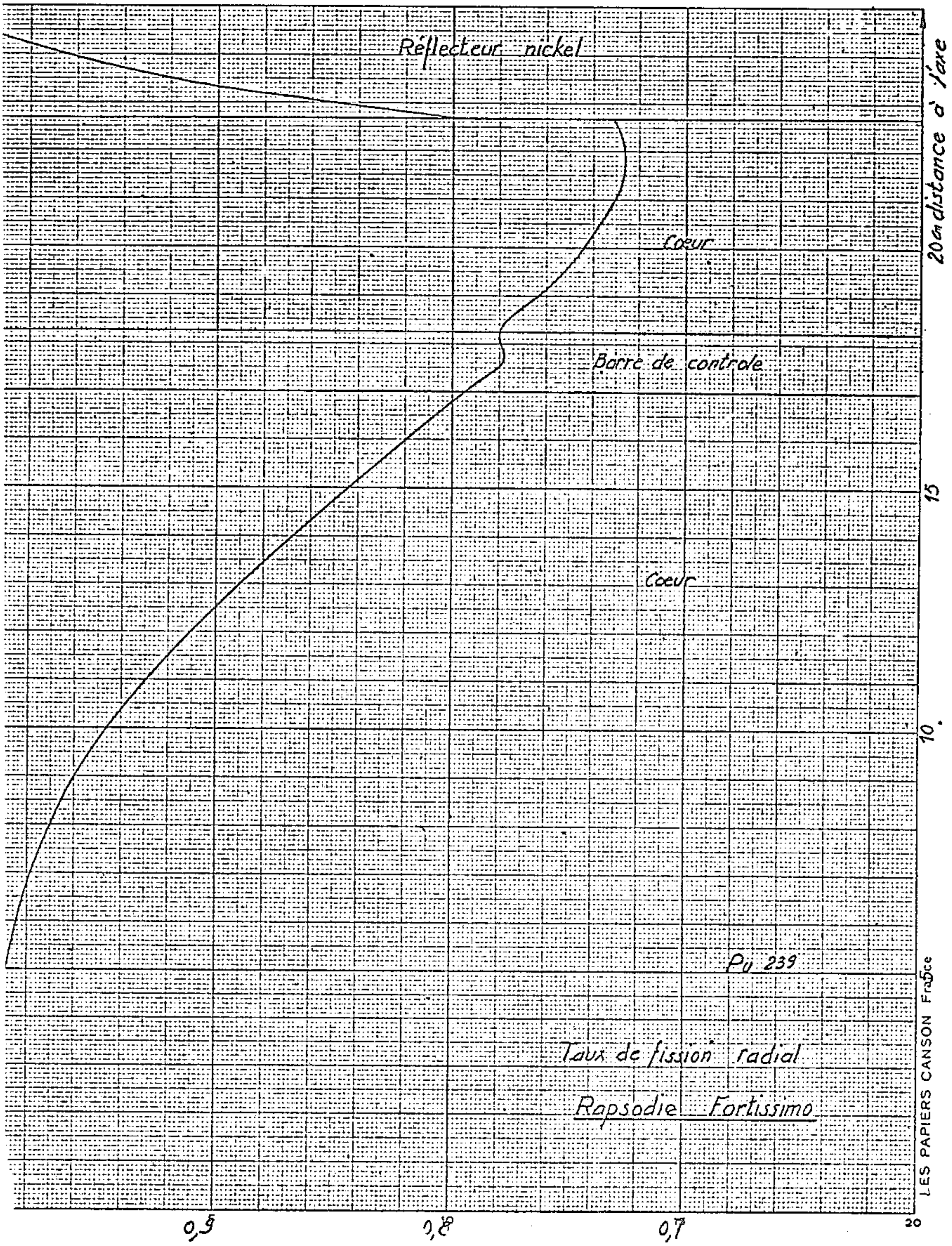
Taux de fission axial

Rapsodie - Fortissimo


Réflecteur Nickel
Coeur
Barre de controle
Coeur
U 235
Taux de fission radial
Rapsodie Fortissimo
20 cm distance d'l'axe
15
10
5
0
0,9
0,8
0,7

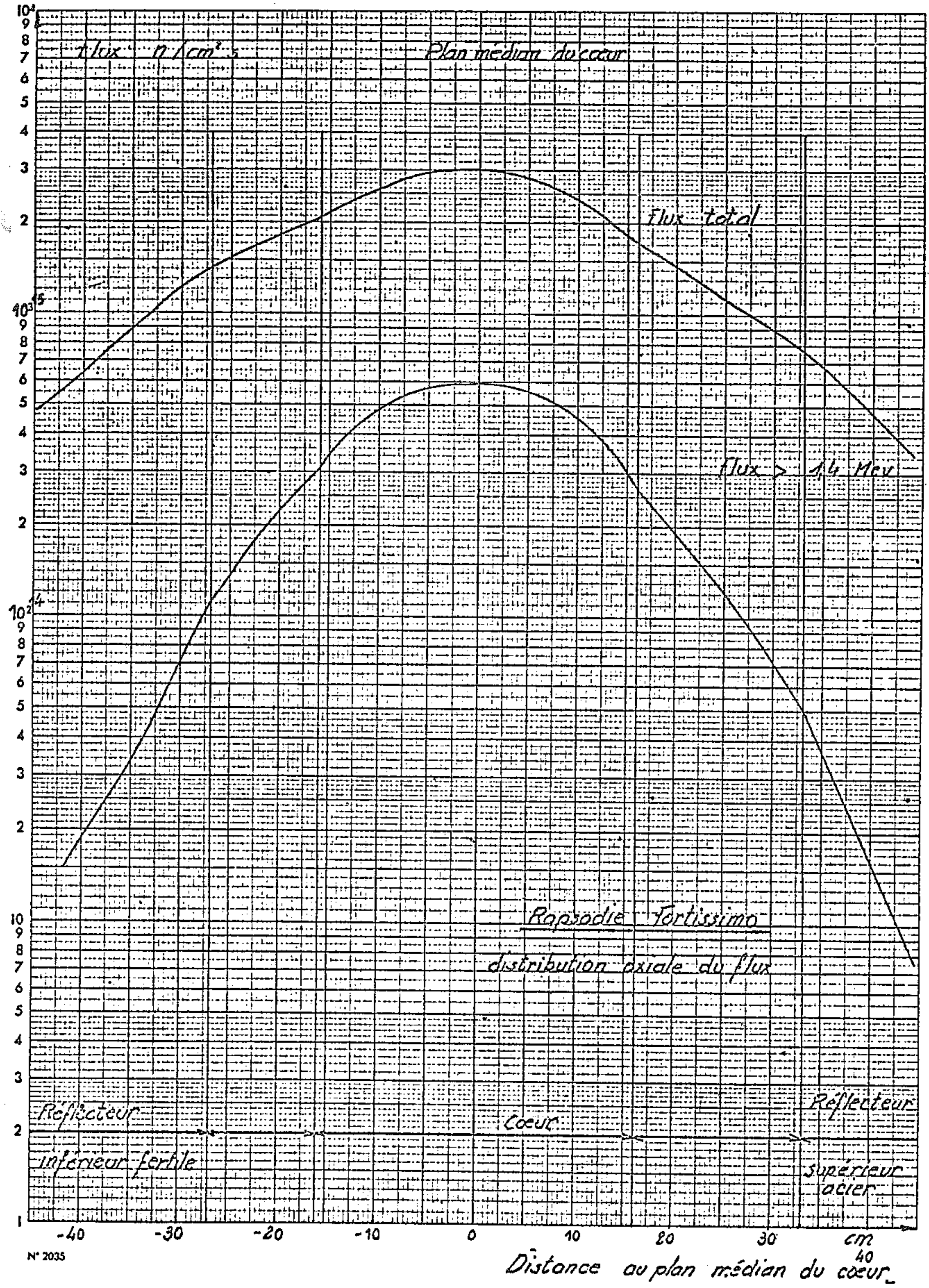

Réflecteur nickel
Cœur
Barre de controle
Cœur
U^{238}
Taux de fission radial
Rapsodie Fortissimo
25
20
15
10
5
1,25
1
0,75
0,5
0,2

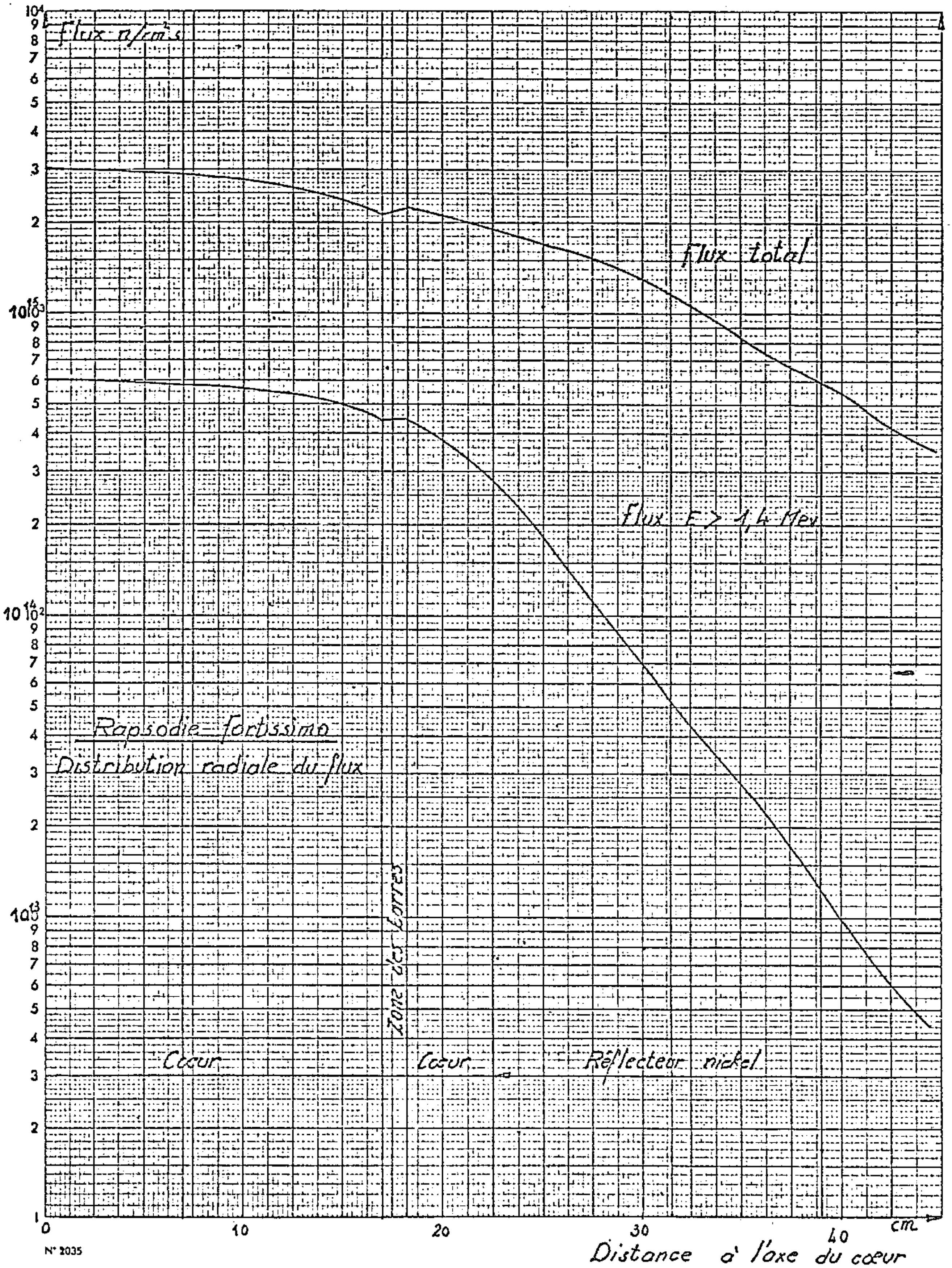
14b



Taux de fission radial

Rapsodie Fortissimo


Flux n/cm² s
Plan médian du cœur
Flux total
Flux > 1,4 Mev
Rapsodie Fortissimo
distribution axiale du flux
Réflecteur
inférieur fertile
Cœur
Réflecteur
supérieur
acier
10^4
10^3 15
10^2 14
10
9
8
7
6
5
4
3
2
1
-40
-30
-20
-10
0
10
20
30
40
cm
N° 2035
Distance au plan médian du cœur

flux n/cm²s
10^4
9
8
7
6
5
4
3
2
10^{15}
10^{14}
10^{13}
1
flux total
flux E > 1,4 Mev
Rapsodie fortissimo
Distribution radiale du flux
Zone des barres
Cœur
Cœur
Réflecteur nickel
0
10
20
30
40
cm
Distance à l'axe du cœur
N° 2035