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YANKEE ATOMIC ELECTRIC COMPANY
RESEARCH AND DEVELOPMENT PROGRAM

INSPECTION AND FABRICATION YAEC CRITICAL EXPERIMENT FUEL RODS

R & D SUBCONTRACT NO. I under
USAEC-YAEC CONTRACT AT (30-3)-222

MARCH 31, 1958

WESTINGHOUSE ELECTRIC CORPORATION
ATOMIC POWER DEPARTMENT
PITTSBURGH, 30 P. O. BOX 355 PENNSYLVANIA

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Yankee Atomic Electric Company

Research And Development Program

INSPECTION AND FABRICATION OF YAEC CRITICAL EXPERIMENT FUEL RODS

Prepared by

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Nuclear Core Engineering

For The Yankee Atomic Electric Company Under Research and Development Subcontract No. 1 of USAEC-YAEC Contract AT(30-3)-222

March 31, 1958

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I. Abstract

The 5509 fuel rods (including 204 special rods) for the Yankee Atomic Electric Company critical experiment were made by sealing sintered UO_2 pellets in stainless steel tubing by welding end plugs to each end of the steel tubes.

The complete history of the fabrication of these fuel rods from the receipt of pellets to the radiographic inspection of the completed rods is discussed in detail. The control of the quality of the UO_2 powder was exercised by comparing certified analyses supplied by the vendor with analyses made by APD on corresponding lots. Chemical analyses, inspection data, procedures and processes are presented in tables and graphs.

INSPECTION AND FABRICATION OF YAEC CRITICAL
EXPERIMENT FUEL RODS

II. Introduction

The fuel rods for the Yankee critical experiment were made from Type 304 weldrawn stainless steel tubes, 49.4" long. Approximately 80 uranium dioxide (enriched in U-235 to 2.7%) pellets 0.6" long and 0.3" in diameter were loaded in each tube. The tube was sealed by welding plugs having various configurations to each end (Figure 1).

A total of 5509 fuel rods, including 204 special fuel rods, were manufactured and shipped to the Westinghouse Reactor Evaluation Center (WREC) at Waltz Mills, Pa.

The history of component inspection and fabrication of the fuel rods is presented in this report.

Approved AEC transfer and accountability procedures were used to account for all the 2.7% enriched uranium dioxide for this project. A balance sheet of the uranium dioxide in the form of acceptable pellets received for the manufacture of CRX fuel rods is presented.

A comparison is made of the results of chemical analyses of uranium dioxide made at the powder vendor's laboratory and as-received. Sintered pellets were also analyzed. Analyses were made of sintered material rejected because of dimensions and physical appearance and of acceptable material.

Inspection equipment was calibrated with the use of secondary standards that were referenced to primary standards. For example, a precisely machined stainless steel pellet was obtained whose dimensions were held to a tolerance of $\pm$ 0.00003". The standard was measured using the accepted U. S. National Bureau of Standards methods.

Inspection was made of random samples of components. A five percent sample plan was used on metal parts. Exceptions were: 1. a 100% measurement made on the diameter of the tube insert section of all end plugs to insure proper fit-up during the welding operation, 2. a 100% length measurement on certain type end plugs.

The pellet sampling plan is presented in Section IV of this report. A sample was extracted from each batch and tested. If all the measurements were within specifications, the batch was accepted. If not, a more thorough analysis was made of the batch in question.

Identification was provided by numbering the fuel rods. The powder and pellet identifications were cross referenced to loaded tube numbers.

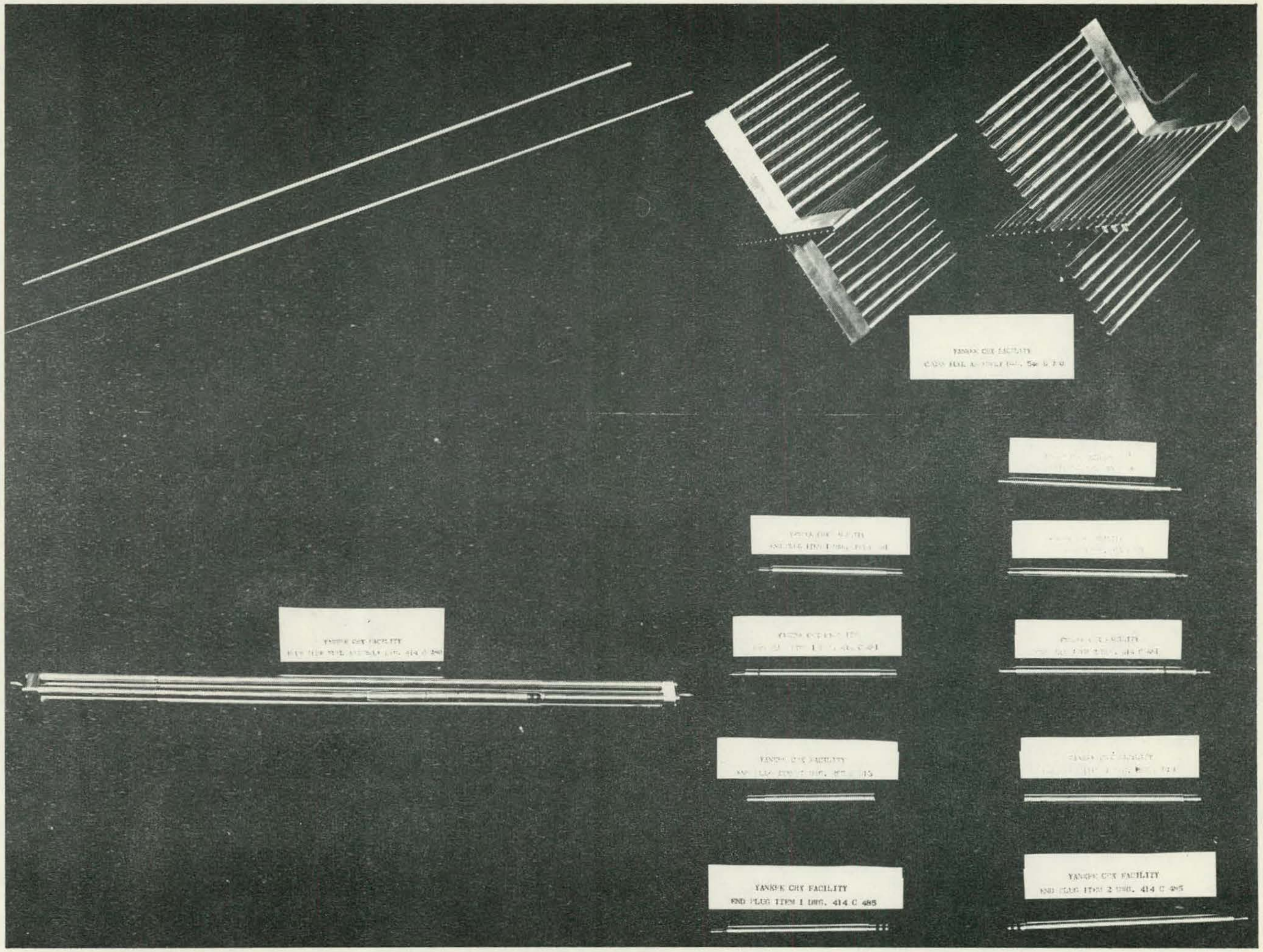


Figure 1

CRITICAL EXPERIMENT FUEL ROD AND COMPONENTS

The completed fuel rod (upper left) contains eighty pellets loaded into the tube (under completed rod) and are sealed (by welding or using O-rings) with end plugs (drawings are included in this report). The cruciform configuration was formed after welding on special end plugs.

III. Uranium Dioxide Powder Inspection

The uranium dioxide powder was produced at the Mallinckrodt Chemical Works by the Ammonium Diuranate Process from 2.7% enriched UF_6.

The uranium dioxide powder was shipped (in polyethylene lined fiber-pack drums with a 57 pound capacity) to Westinghouse Materials Manufacturing Department for fabrication into pellets. Each drum was identified with a code designating the cylinder of UF_6 from which the powder was produced.

A 150 gram sample was extracted with a thief as each drum was processed using the process shown in Table I. The samples were combined from drums composing a "lot" and reduced by quartering to 100 grams. The sample of 100 grams was analyzed at WAPD. Results of the analyses by "lots" are compared to the certified analyses made by the vendor in Table II. Excellent agreement was found between these analyses.

Westinghouse MMD received 3,463,409.1 grams of 2.7% enriched uranium dioxide powder packaged in 136 drums, corresponding to twelve lots. Pellets were placed in polyethylene bags and shipped in one gallon cans. A total of 1015 cans of pellets were received by WAPD. Cans of pellets have been designated and are referred to in this report as "batches". Each batch was identified as shown by the following example:

Lot Number	Drum	Can
LP 15	4	6

The weight of pellets within the 5509 completed fuel rods was 3,114,733.5 grams.

The yield of UO_2 powder to pellets in completed CRX fuel rods was:

$$\frac{3,114,733.5}{3,461,547.5} \times 100 = 90.0\%^*$$

The pellet disposition for Material Balance Area #9, WAPD, Inspection and Manufacturing, is given in tabular form (Table III). The production yield is calculated. The percentage of unaccountable loss incurred during manufacture is also calculated. The disposition is further divided into recoverable and non-returnable material to MBA #9. The recovery of UO_2 used for chemical analysis and experimentation is under investigation. A chart of the accountability procedure is shown in Figure 2.

* Includes loss incurred at W MMD and W APD.

TABLE I

Procedure For Sampling UO_2 Powder for Chemical Analyses

1.	Roll the drum of UO_2 fifty feet.
2.	Turn the drum end over end several times.
3.	Roll the drum back 50 feet.
4.	Turn the drum end over end several times.
5.	Withdraw five samples by using a "thief"or pipe with holes drilled at various distances to insure the extraction of a random sample - one from each cardinal point of the compass and one from the center - about 150 grams total.
6.	Mix the samples from all drums in a lot in a polyethylene bag.
7.	Reduce the composite sample for the lot to 100 gms by quartering.

TABLE II

ANALYSIS UO_2 POWDER FOR YANKEE CRX

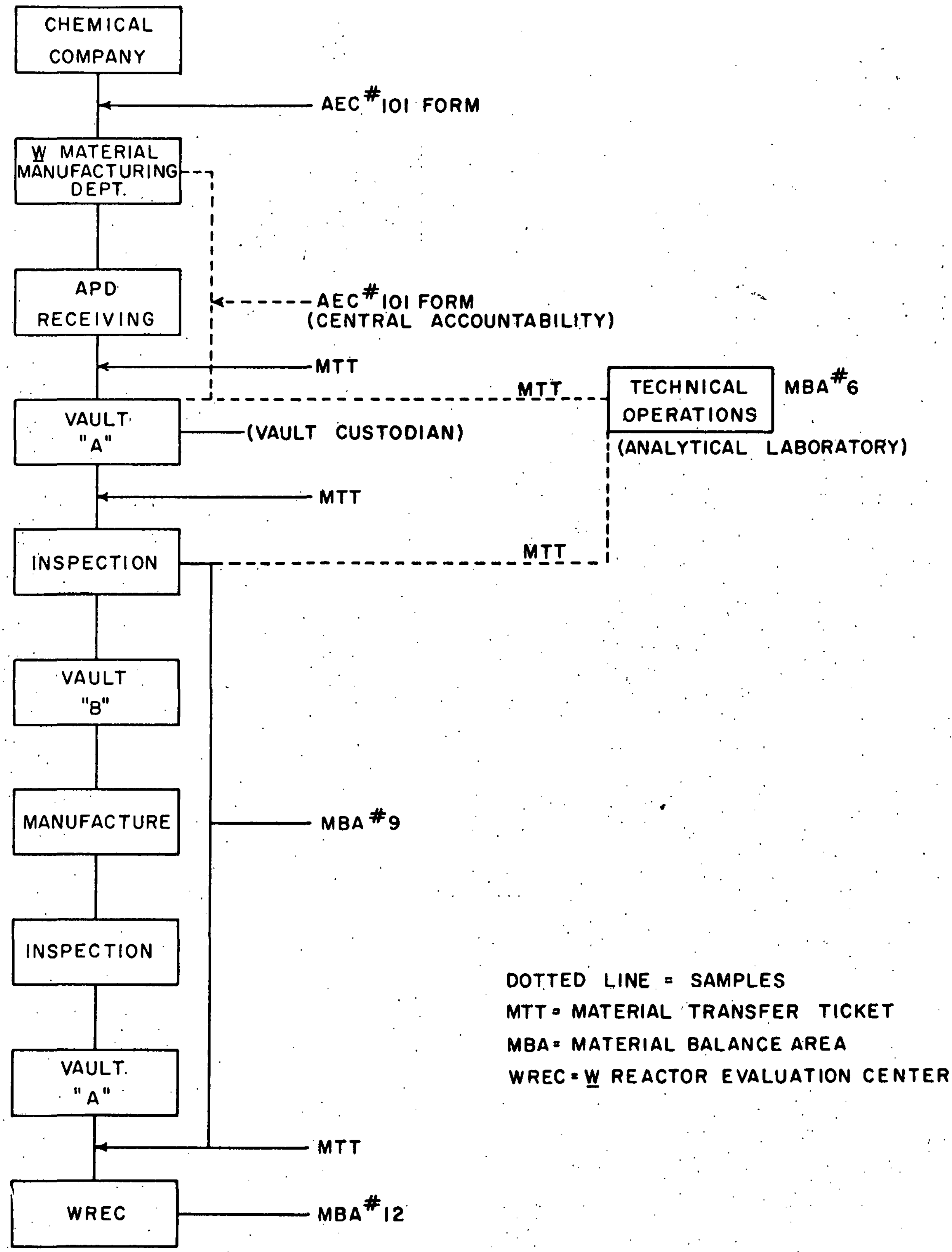
MCW = MALLINKRODT CHEMICAL CO.

LOT	LP	15	LP	16	LP	17	LP	18	MZ	28	MZ	46
ASSAY	MCW	APD	MCW	APD	MCW	APD	MCW	APD	MCW	APD	MCW	APD
U ≧ 85.8%	88.0	88.0	87.9	87.9	87.9	87.9	88.0	87.8	87.9	88.0	87.9	87.1
UO_2 ≧ 95.0	97.5	97.5	97.6	97.2	96.9	97.0	97.9	97.8	95.9	95.0	96.7	96.9
F 500 PPM	50.0	10	50	6	<50	<4	50	6	200	106	50	50
Fe 100 PPM	60.0	77.0	40	60	30	66	60	82	100	86	100	127
Mo 1 PPM	0.4	<2.0	0.4	<2.0	0.6	<2	0.6	<2	1	0.98	0.9	<1.0
B 2 PPM	0.1	0.9	0.2	0.1	0.1	0.2	0.1	0.09	0.2	<0.1	0.1	<0.1
Cu 40 PPM	2.0	1.0	2.0	1.0	3.0	2.0	2.0	3.0	2.0	1.3	2.0	1.0
Pb 40 PPM	1.0	1.1	1.0	1.2	4.0	1.1	1.0	1.8	2.0	2.1	8.0	4.8
Cr 40 PPM	30	31	20.0	19.0	30.0	42	20.0	16.0	40.0	30.0	40.0	38.1
Sm 4 PPM	<1	0.9	1.0	1.1	1.0	1.2	1.0	1.0	1	.74	1	1.6
Ag 1 PPM	0.01	<0.2	0.01	<0.2	<0.01	0.55	<0.01	0.31	<0.01	<.5	<0.01	<0.1
Ni 80 PPM	100	78.3	100	55.3	80	58	100	69	100	65	200	55.0
Si												5.1

The accuracy of determining total uranium is ± 0.1%.

For elements reported in ppm the accuracy is ± 30% of the amount present.

LOT	PS	64	RC	76	RR	77	SM	78	TD	79	AVERAGE	
ASSAY	MCW	APD	MCW	APD	MCW	APD	MCW	APD	MCW	APD	MCW	APD
U > 86.8%	87.9	87.5	87.9	87.7	87.9	87.8	87.8	87.7	87.8	87.7	87.9	87.7
UO_2 ≧ 95.0	96.3	96.5	96.8	96.8	96.4	96.6	95.9	95.7	95.8	96.1	96.7	96.6
F 500 PPM	<50.0	14.0	80	17.4	50	21.5	60	24.5	50	6.8	67.3	24.3
Fe 100 PPM	80.0	93.0	80	105	80	155	50	104	60	151	55.8	100.5
Mo 1 PPM	1.0	0.8	2.0	0.6	8	1.2	0.9	1.0	1	1	1.5	<1.3
B 2 PPM	0.1	<0.2	0.2	<0.2	0.1	<0.2	0.1	<0.2	0.2	<0.2	0.1	<0.2
Cu 40 PPM	3.0	4	2.0	1.6	2.0	1.9	1	2.1	2.0	1.1	2.1	1.7
Pb 40 PPM	8.0	4	2.0	1	1.0	1.8	2	2.0	1.0	1.0	2.8	1.9
Cr 40 PPM	20.0	22.	30.0	34	30	72	30	24	- 20	49	28.2	34.3
Sm 4 PPM	1.0	<1.0	1.0	<1.0	<1.0	<1.0	<1	<1	<1	<1.0	1.0	<2.6
Ag 1 PPM	<0.01	0.1	<0.01	<0.1	<0.01	<0.1	<0.01	<0.1	<0.01	<0.1	0.01	0.21
Ni 80 PPM	40	55	50	59	150	129	150	130	70	129	103.6	80.2
Si		23				1		21		35		



ACCOUNTABILITY PROCEDURE

Figure 2

TABLE III

UO_2 (2.7% Enriched in U-235) Inventory
MBA #9*

		Balance
Total weight of good pellets received at MBA #9	3,151,781.0 gms	
Shipped to WREC	3,114,733.5 gms	
	37,047.5 gms	37,047.5 gms
Difference is made up of the following:		
Shipped from and not returnable to MBA #9		
Used in experiments	3191.5 gms	
Chemical Analysis	7253.9 gms	
Irradiation Samples	4695.0 gms	
	15,140.4 gms	21,907.1 gms
Recoverable, being held in Vault in MBA #9		
Retained Sample	5944.0 gms	
Generated Scrap	11,904.5 gms	
Sub-Total	17,848.5 gms	4,058.6 gms
Unaccountable loss occurring during fabrication at WAPD:		4,058.6 gms

Yield of pellets in completed rods to pellets received is calculated as follows:

$$\frac{3,114,733.5}{3,151,781.0} = 98.82\%$$

The percentage of unaccountable loss is calculated as follows:

$$\frac{4,058.6 \times 100}{3,151,781.0} = 0.12\%$$

The percentage loss for all other reasons:

$$\frac{32,988.9}{3,151,781.0} = 1.06\%$$

* Material Balance Area #9 at WAPD, Inspection and Manufacturing

Table II is a comparison of UO_2 powder (Lot) analysis certified by the vendor to the receiving inspection analysis.

IV. Stainless Steel Component Inspection

A. Tubes

Type 304 weldrawn stainless steel tubing was used for the cladding of the CRX fuel rods (W drawing 295B904-1) Figure 3.

A nominal wall thickness of .0165" and a nominal inside diameter of 0.3060" were specified. The tubing received from the Trent Tube Company had a nominal chemical analysis as follows:

TABLE IV

Nominal Chemical Analysis of Tubes

Element	Percent
C	.06
Mn	1.23
P	.03
S	.015
Si	.50
Ni	9.58
Cr	18.20
Mo	.23
Cu	.35

A random 5% tube sample was inspected for length, inside diameter, outside diameter, wall thickness, length, weight and integrity.

Each tube of the sample was measured at six locations along its length to obtain a minimum and maximum dimension for both inside and outside diameters. A Federal Dimensionair, Model DA-1, graduated in 0.00005" increments was used. The gage was standardized with the use of master setting plugs and rings. Figure 4 shows the measurement of the OD of a CRX fuel tube.

Ovality (deviation from a true circle) was calculated from the maximum and minimum diameter readings for both the inside diameter and the outside diameter. The accumulated data is summarized in Table V. Figures 5 and 6 are the frequency distribution curves for the inside and outside diameter measurements, respectively.

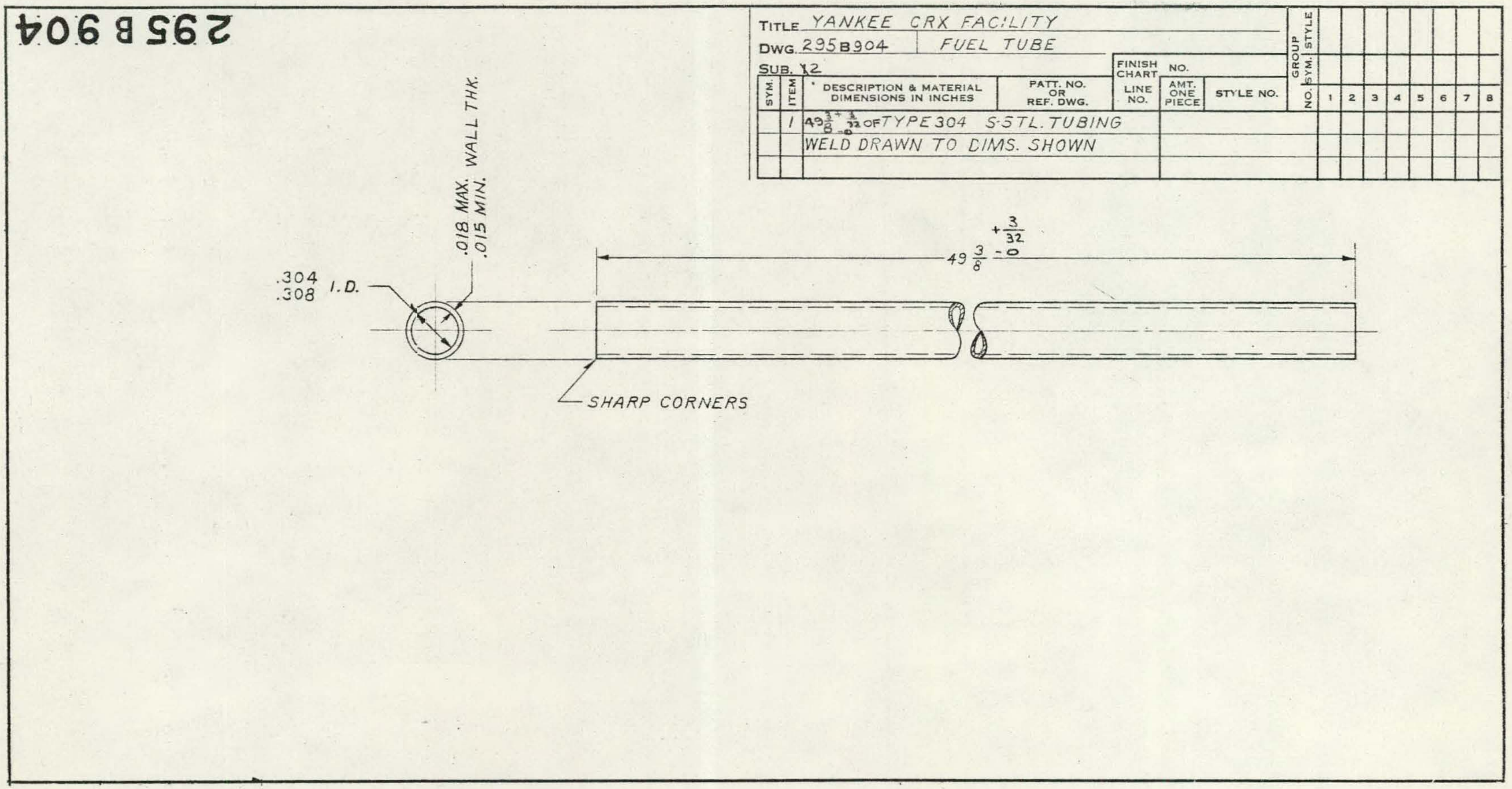


Figure 3

FUEL TUBE DRAWING

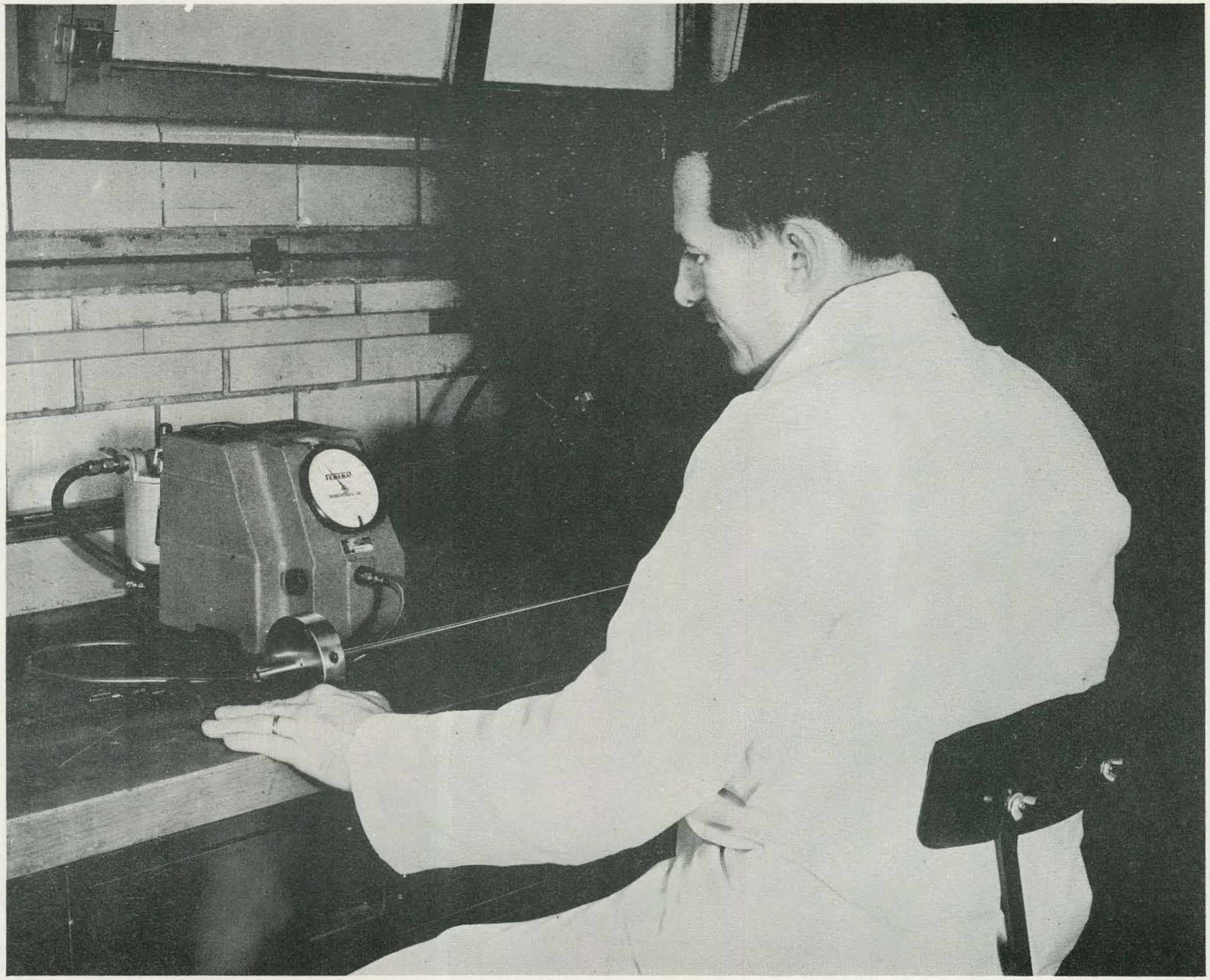


Figure 4

MEASUREMENT OF TUBE OUTSIDE DIAMETER

The measurement of the outside diameter of a CRX tube using an air gage. Inside measurements are made using a two-jet air plug in place of the ring pictured above.

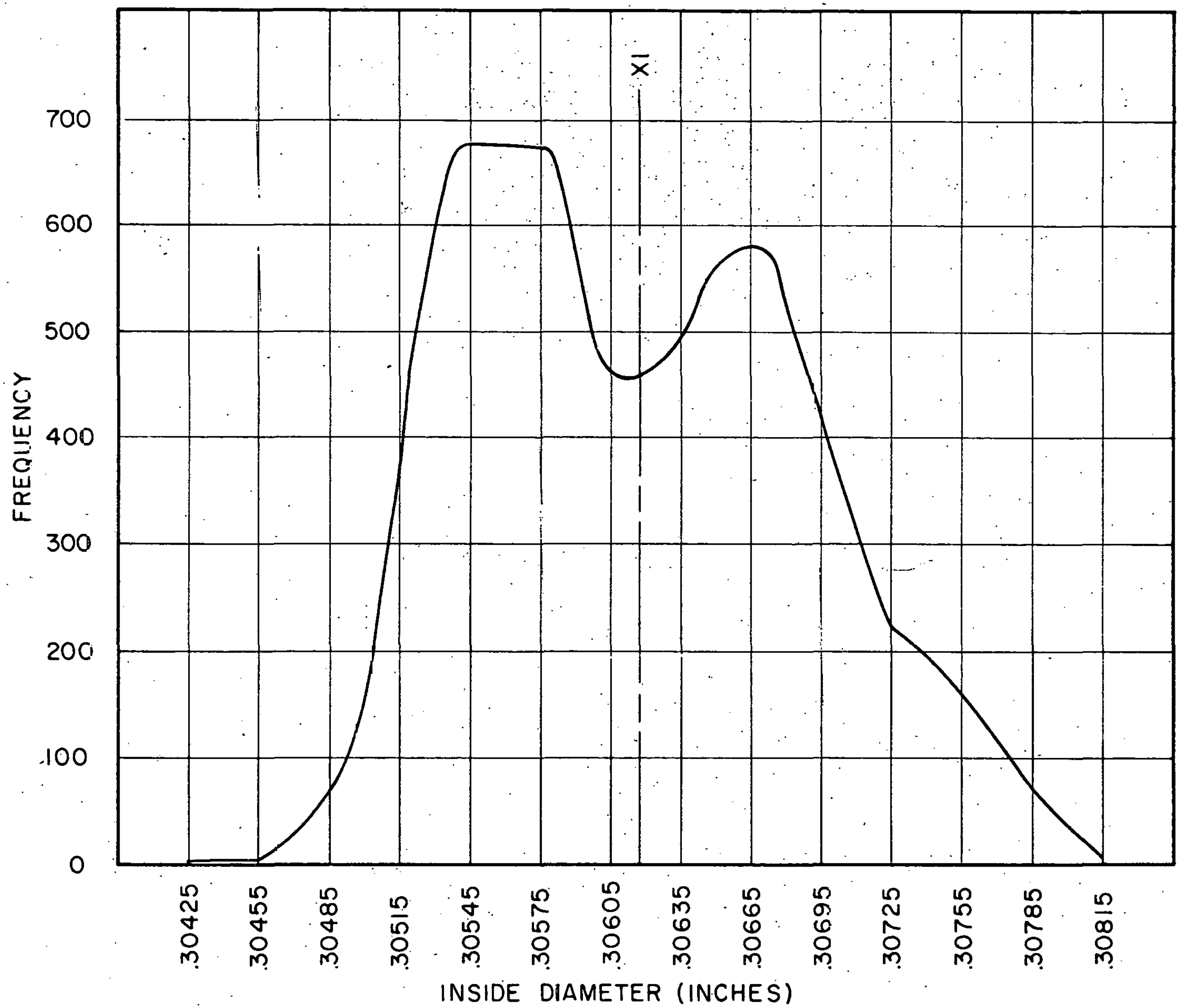


Figure 5

DISTRIBUTION CURVE OF TUBE INSIDE DIAMETERS

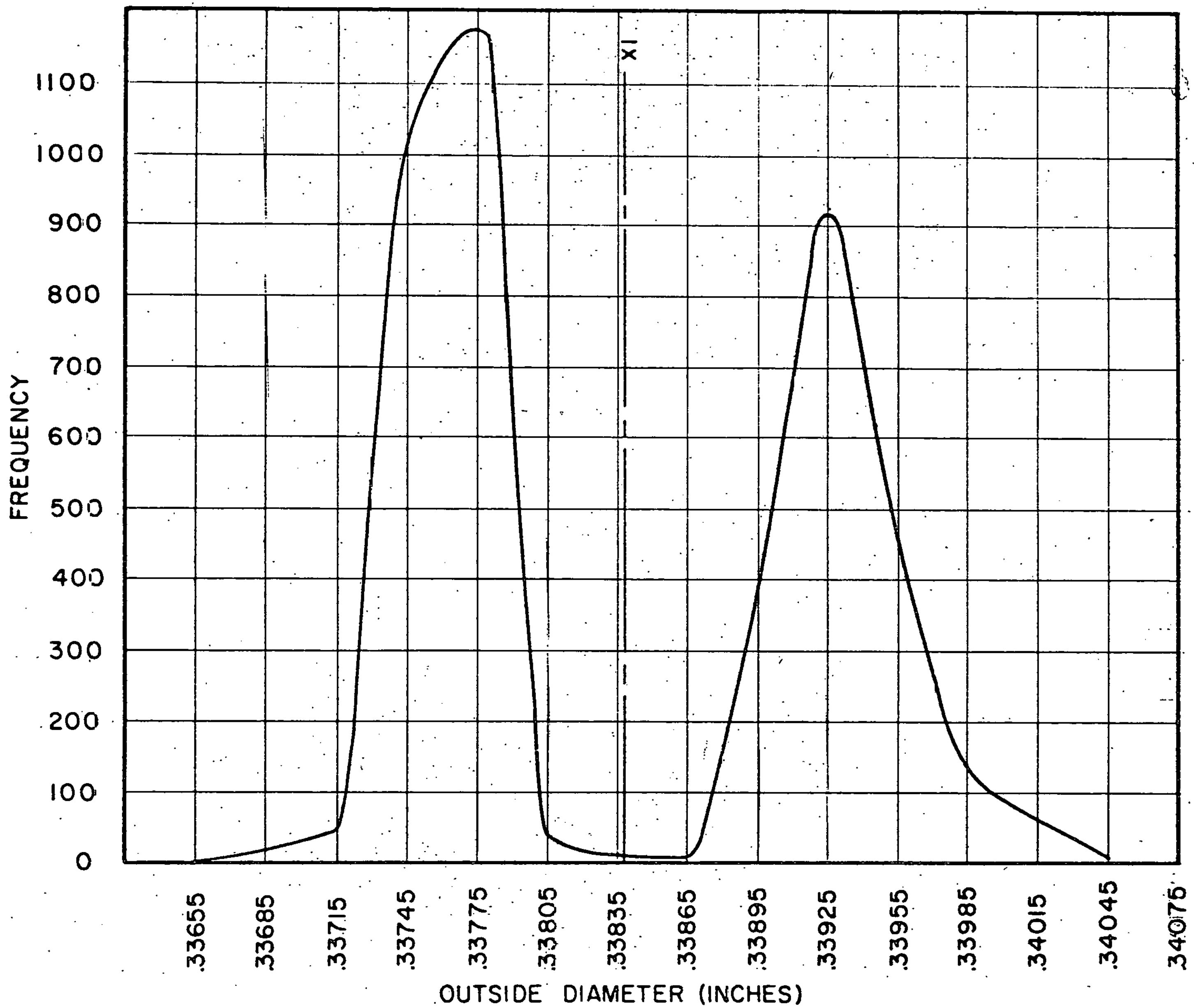


Figure 6

DISTRIBUTION CURVE OF TUBE OUTSIDE DIAMETERS

TABLE V

Tube Inspection Data Summary

Variable	OD	ID	OD Ovality	ID Ovality
Maximum	0.34045"	0.30815"	0.00095"	0.00095"
Minimum	0.33655"	0.30424"	0.00005"	0.00005"
Range	0.00390"	0.00391"	0.00090"	0.00090"
Average	0.33840"	0.30616"	0.00018"	0.00031"
σ *	0.0012	0.0009	0.00010	0.00013
Sample Size (Tubes)	352	352	352	352
No. of Meas.	4224	4224	1408	1408

The wall thickness of the tubes was measured with a Branson Instrument Company Vidigage (ultrasonic resonance method), Figure 7, Model 21. The Vidigage was calibrated by using a 304 type stainless steel standard (.0165" thick) flat and fine adjustments were made using a measured section of one of the CRX tubes. A 50 - 50 solution of glycerine and water containing two drops of a wetting agent (Eastman Kodak, Photo-Flo) was used as a couplant. Discrete measurements were made (instead of the usual practice of sliding the unit along the tube surface) to prevent wear of the search unit (transducer). Tube wall thickness measurements made by using the Vidigage were compared to the thickness as calculated from outside diameter measurements, (Table VI.)

TABLE VI

Calculated VS Vidigage Wall Thickness Measurements

	Sample 1		Sample 2		Sample 3	
	Calc.	Vidi.	Calc.	Vidi.	Calc.	Vidi.
Average	0.01624	0.01616	0.01592	0.01576	0.01610	0.01603
σ*	0.00018	0.00015	0.00023	0.00024	0.00014	0.00018
Range	0.00080	0.00110	0.00100	0.00120	0.00050	0.00090

	Combined	
	Calc.	Vidi.
Average	0.01608	0.01596
σ*	0.00027	0.00028
Range	0.00110	0.00140

* = Root Mean Square Deviation
Note: All measurements in inches.

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Figure 7

MEASUREMENT OF TUBE WALL THICKNESS

Measurement of the wall thickness of the CRX tube using an ultrasonic resonance method.

The observed difference is within the sensitivity of the Vidigage 2%.

Figure 8 is the frequency distribution curve of the Vidigage wall thickness measurements.

The length of the tubes was measured with a gage assembly consisting of a "V" block tube holding device and a Federal dial indicator graduated in 0.001" increments. A stainless steel rod for use as a length standard was calibrated using Bureau of Standards methods.

Figure 9 is the frequency distribution curve for the length measurements. A summary of the tube measurements follows:

TABLE VII

Tube Length and Weight Data

	Length	Weight
Maximum	49.445"	107.250 gs
Minimum	49.400"	100.250 gs
Range	0.045"	7.000 gs
Average	49.420"	104.453 gs
	0.0069	1.350
Sample Size	305	308

A 5% sample of as-received tubing was weighed to the nearest 0.001 grams on a Gramatic Balance. A summary of the tube weights obtained is shown above.

The weight in pounds per foot of the stainless steel tubes was calculated as follows:

$$\frac{49.420'' \text{ (aver. length/rod)}}{12''/\text{ft}} = 4.110 \text{ ft/rod}$$

$$\frac{104.453 \text{ grams}}{453.6 \text{ gm/lb}} \doteq 0.2303 \text{ \#/rod}$$

$$\frac{.2303 \text{ \#/rod}}{4.110 \text{ ft/rod}} = 0.056 \text{ \#/ft of S/S rod}$$

Approximately 5% of the CRX tubes were tested for integrity using a Shell Development Company's Model E Probalog (Eddy Current Tester) Figure 10. Indications of discontinuities were found on 10% of those tubes tested. Five of the tubes were sectioned at the indicated area and microphotographed. No attempt was made at this time to make

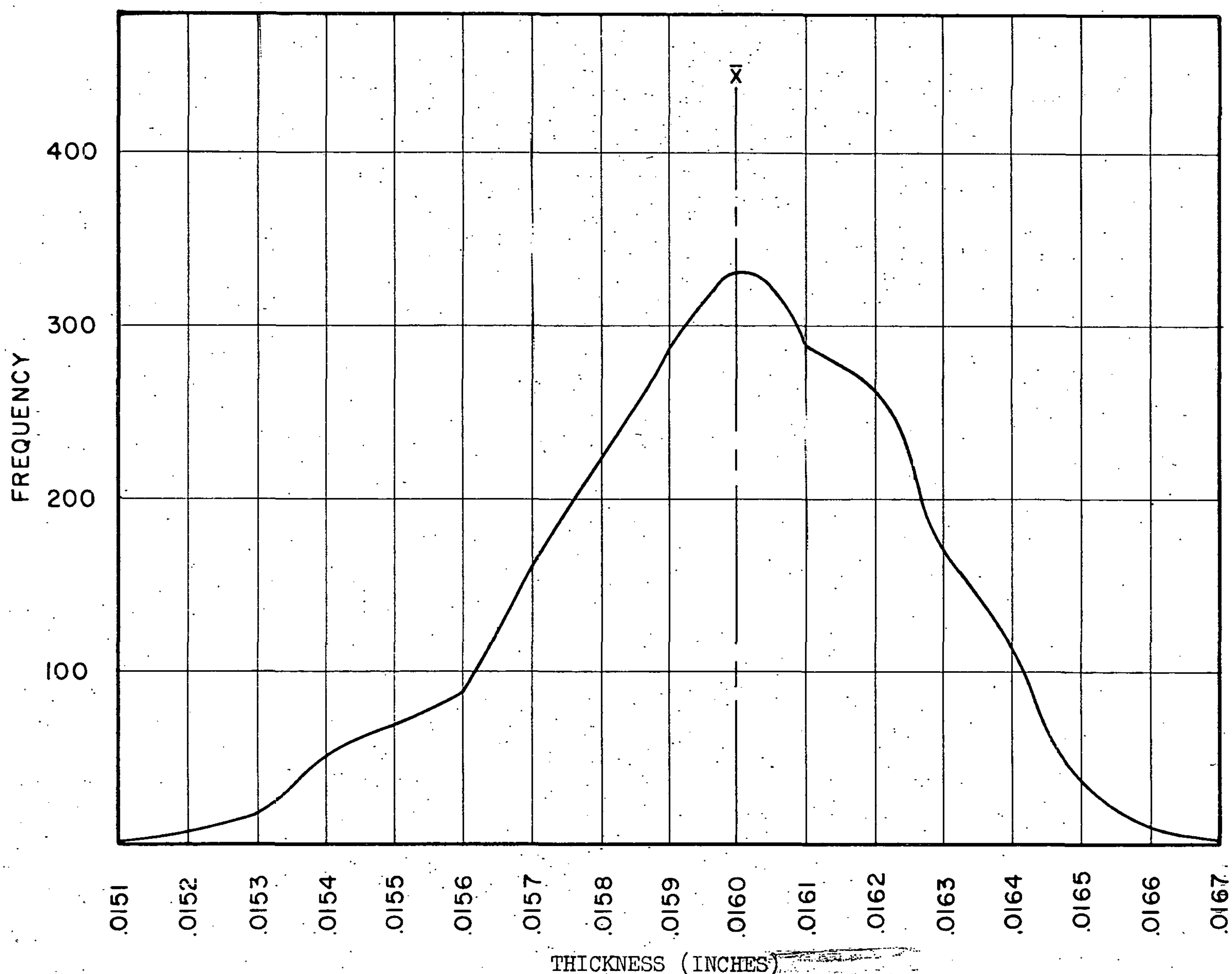


Figure 8

DISTRIBUTION CURVE OF TUBE WALL THICKNESS (VIDIGAGE MEASUREMENTS)

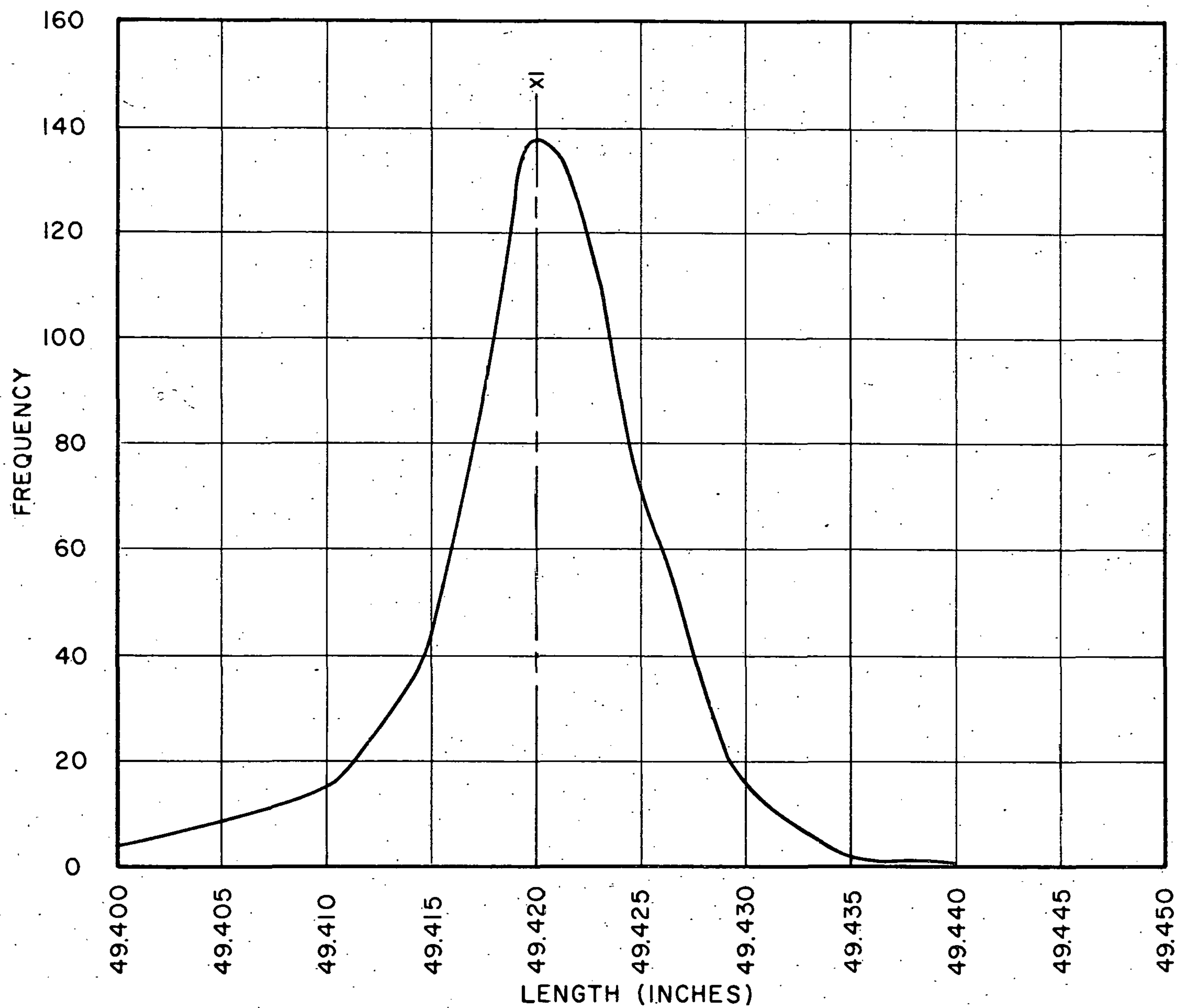


Figure 9

DISTRIBUTION CURVE OF TUBE LENGTH MEASUREMENTS.

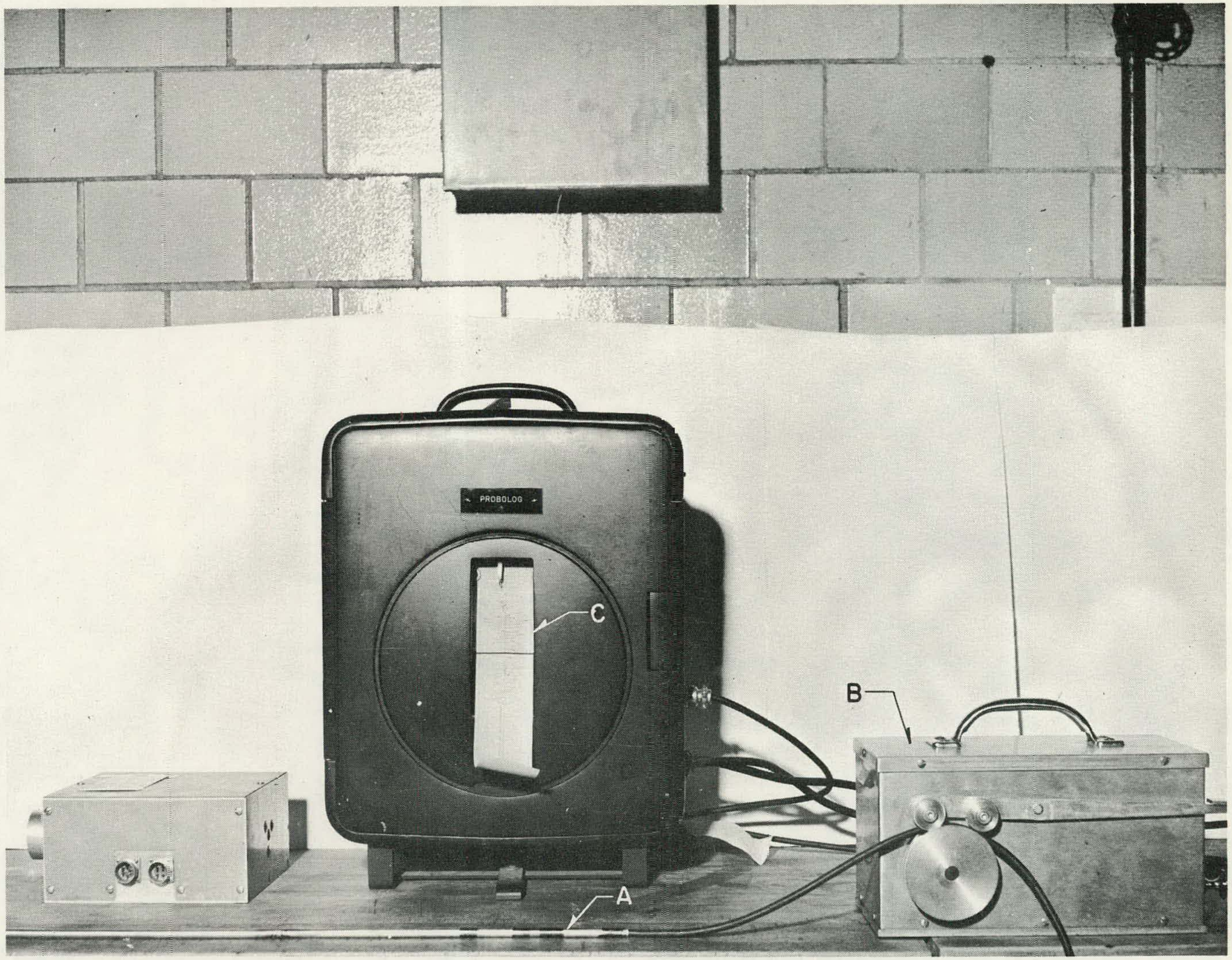


Figure 10

TESTING TUBE INTEGRITY

CRX tube being tested for integrity using the Eddy Current Method. The probe is inserted into tube (A). The puller (B) moves the probe through the inside of the tube at a constant speed. Any discontinuity present will be recorded on the strip chart (C).

this test quantitative. Figure 11(a) represents the trace recording showing a typical indication and Figure 11(b) is an enlargement of a partial area of the sectioned tube.

An investigation was conducted to determine if the as-received tubes were clean enough to be used in the manufacture of the CRX rods. The macroscopic neutron cross-section absorption of foreign matter discovered should total less than the equivalent of 0.001 grams of natural boron (approximately one percent of that due to the steel itself) to be acceptable.

A comparison was made of foreign material on tubes cleaned using the procedure given in Table IX and material on the interior of the as-received tubes by spectrographic analysis. Table VIII is the calculation of the total macroscopic absorption cross-section of the major foreign cations on the interior wall of the as-received tubes based on the spectrochemical analysis.

TABLE VIII

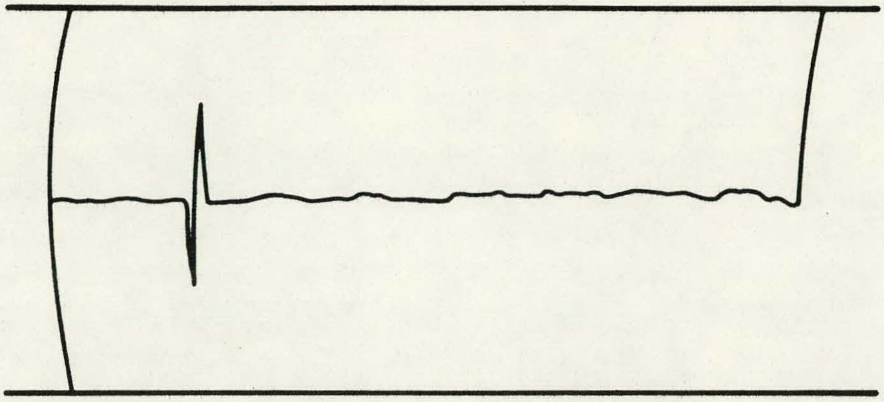
Macroscopic Cross Section Calculations of Foreign Matter on As-Received CRX Tubes

Cation	Macroscopic Absorption Cross Section cm^2/cm^3
Fe	3.50×10^{-5}
B	4.30×10^{-5}
Cu	$.03 \times 10^{-5}$
Cr	1.40×10^{-5}
Ag	$.05 \times 10^{-5}$
Ni	2.40×10^{-5}
Si	$.01 \times 10^{-5}$
Cd	$.05 \times 10^{-5}$
Total	11.74×10^{-5}

The total macroscopic cross section of 0.00012 cm^2/cm^3 is less than 0.1% of the boron cross section in the stainless steel (0.0003 cm^2/cm^3). The as-received tubes could be used for the fabrication of CRX fuel rods without a cleaning step.

Table X is the spectrochemical report sheet for the analysis of foreign matter extracted from the tubes.

Table XI is the spectrochemical report sheet on the analysis of the detergent used to clean the specimens.



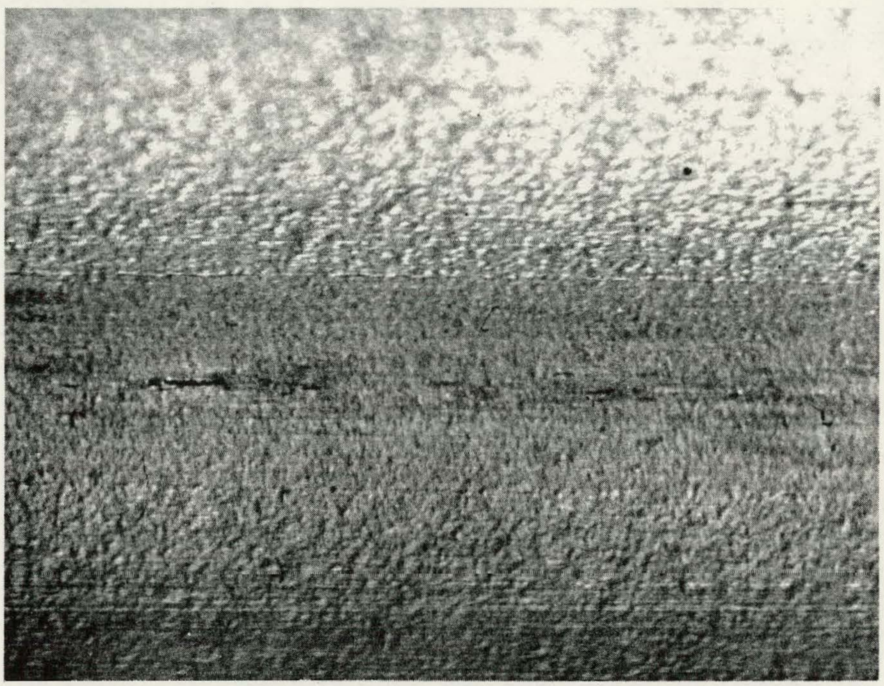


Figure 11

TYPICAL DEFECT FOUND BY EDDY CURRENT TEST

A typical eddy current trace recording (top) of a discontinuity (the "pip" or deviation from trace level) found in a CRX tube. An enlargement of a partial area of the discontinuity is shown in the bottom picture.

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TABLE IX

Cleaning Procedure for CRX Tubes

1.	Wash the tube in a hot detergent solution (Lever DW 300). 1/7 oz./1 gal.
2.	Rinse in cold tap water.
3.	Wash in a 50 - 50 (by volume) methanol and demineralized water solution.
4.	Dry in a forced warm air atmosphere.

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TABLE X

Analysis of Foreign Material on Tubes

METHOD S.Q. — SPECTROCHEMICAL REPORT SHEET — PLATE SHEET NO. 94

= µg/g OF MATERIAL AS EXPOSED (UNCLEANED, CLEANED) — = µg OF METAL REMOVED FROM EACH TUBE ± 30% OF THE AMOUNT PRESENT (UNCLEANED, CLEANED) — DATE:

	= µg/g OF MATERIAL AS EXPOSED				= µg OF METAL REMOVED FROM EACH TUBE ± 30% OF THE AMOUNT PRESENT		
		UNCLEANED	CLEANED		UNCLEANED	CLEANED	
SAMPLE	KLEENEX BLANK	12-57-13	12-57-14		12-57-13	12-57-14	
Ag	< 3	25	30		1.0	1.2	
Al	400	940	920		18	17	
As							
Au	< 100	< 100	< 100		< 4	< 4	
B	< 10	< 10	< 10		< .4	< .4	
Ba	30	110	100		3.2	2.8	
Be							
Bi	< 30	< 30	< 30		< 1	< 1	
Ca	3300	6400	6600		120	130	
Cd	< 100	< 100	< 100		< 4	< 4	
Ce							
Co	< 30	< 30	< 30		< 1	< 1	
Cr	< 10	890	1100		36	44	
Cs							
Cu	70	140	180		2.8	4.4	
Fe	170	670	510		28	20	
Ga							
Ge							
Hf							
Hg							
In							
K							
La							
Li							
Mg	660	1120	1080		18	18	
Mn	140	690	810		22	27	
Mo	< 30	< 30	< 30		< 1	< 1	
Na	1000	1200	1200		8	8	

SAMPLE							
Nb	< 100	< 100	< 100		< 4	< 4	
Ni	< 30	130	60		4	1.2	
P							
Pb	< 10	70	80		2.8	3.2	
Pd							
Pt							
Rb							
Sb	< 100	< 100	< 100		< 4	< 4	
Sc							
Se							
Si	400	900	1000		20	40	
Sn	< 100	< 100	< 100		< 4	< 4	
Sr							
Ta							
Te							
Th	< 100	< 100	650		< 4	26	
Ti	15	120	80		4.1	3.2	
Tl							
U							
V	< 30	< 30	30		< 1	1.2	
W							
Y							
Zn	< 100	< 100	50		< 4	6	
Zr	< 10	< 10	< 10		< .4	< .4	

< EQUALS LESS THAN

TABLE XI

Analysis of Detergent

SPECTROCHEMICAL REPORT SHEET

METHOD S.Q. PLATE SHEET NO. 86

RESULTS ARE IN PPM ± 50% ON THE BASIS OF THE ORIGINAL SAMPLE BY WEIGHT DATE: 11-19-57

SAMPLE	11-57-41		SAMPLE	
Ag	< 1		Nb	< 4
Al	2.5		Ni	3.6
As			P	
Au	<10		Pb	<40
B	<1		Pd	
Ba	<1		Pt	
Be	<.4		Rb	
Bi	<10		Sb	<40
Ca	2.9		Sc	
Cd	<40		Se	
Ce			Si	.8
Co	<10		Sn	<10
Cr	9		Sr	.07
Cs			Ta	
Cu	<4		Te	
Fe	53		Th	
Ga			Ti	<1
Ge	<40		Tl	
Hf			U	
Hg			V	<10
In	<40		W	
K			Y	
La			Zn	<40
Li		LESS THAN 2.0 PPM	Zr	<4
Mg	9			
Mn	<.7			
Mo	<.4			
Na	<.25			

LEVER DW 300 DETERGENT

630

B. End Plugs

The majority (5305 total) of fuel rods were Type A (W Dwg. No. 414C212, Figure 12). Special rods (204 in number) were made for Type E (W Dwg. No. 414C485, Figure 13); Type F (W Dwg. No. 414C480, Figure 14); four-tube fuel assembly (W Dwg. No. 414C280, Figure 15) and cross fuel bundle (W Dwg. No. 548D750, Figure 16).

Three species of end plugs were used to make Type A fuel rods, i.e., lead ends, and two (differing in length) for the handling end. The end plugs were fabricated from 6,400 feet of colddrawn annealed 304 stainless steel rod that had been centerless ground to .3440 - .3450. The average diameter of the ground rod was 0.3447".

Samples of rod were turned down on a lathe. No laps, cracks or seams were found. A summary of inspection data for Type A end plugs follows:

TABLE XII

Inspection Data Summary
Type A Fuel Rod End Plugs (long)

Variable	Length (in.)	Weight (gm)	Tube Insert Diameter (in.)
Maximum	5.756	64.58	0.3090
Minimum	5.740	64.22	0.3080
Range	.007	0.36	0.0010
Average	5.751	64.41	0.3085
σ	.0003	0.09	.0002
Sample Size	2896	143	2889 "Wild" 7

TABLE XIII

Inspection Data Summary
Type A Fuel Rod End Plug (short)

Variable	Length (in.)	Weight (gm)	Tube Insert Diameter (in.)
Maximum	6.2505	70.645	0.3097
Minimum	6.2475	70.255	0.3067
Range	.0030	0.390	0.0030
Average	6.2487	70.4288	0.3086
σ	.0006	0.088	.00015
Sample Size	150	160	2952

DWG. 414C212

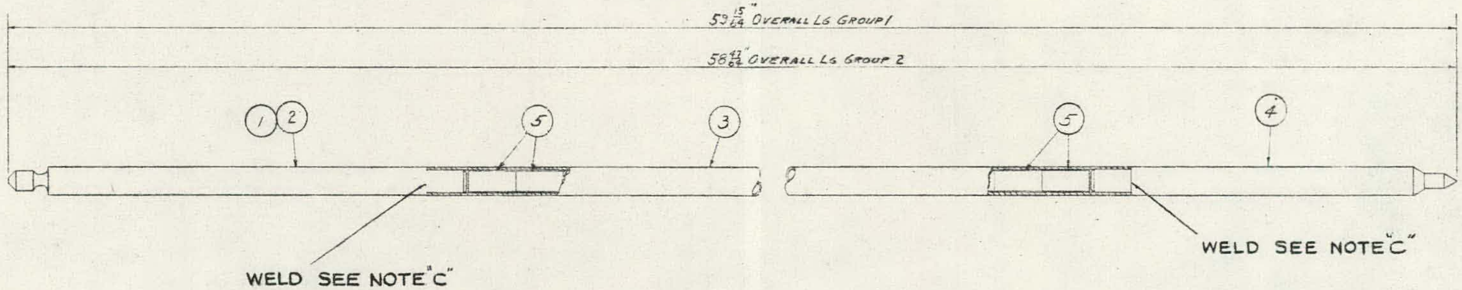
TITLE YANKEE CPX FACILITY
FUEL ASSEMBLY-TYPE A

DWG. 414C212

SUB. ~~1~~ ~~2~~ 3

NOTE	ITEM	DESCRIPTION & MATERIAL DIMENSIONS IN INCHES	PATT. NO. OR REF. DWG.	FIN. CH. LINE NO.	STYLE NO.	1	2	3	4	5	6
	1	END PLUG IT 2 DWG 295B920				1					
	2	END PLUG IT 1 DWG 295B920					1				
	3	FUEL TUBE IT 1 DWG 295B904				1	1				
	4	END PLUG IT 1 DWG 295B921				1	1				
B	5	FUEL PELLET IT 1 DWG 195A087				AS REQ'D	AS REQ'D				

GROUP NO. & GROUP STYLE NO.; FINISH CHART



NOTES:

(A). FUEL TUBE SHOULD BE CLEANED AS PER P.S. 292703-1 BEFORE ASS'Y.

(B). USE AS MANY PELLETS AS REQ'D FOR AN ACTIVE FUEL LENGTH OF 48.000 IN ± 0.250.

(C). WELD AS PER PROC. SPEC. 292704-1

Figure 12

TYPE A FUEL ASSEMBLY DRAWING

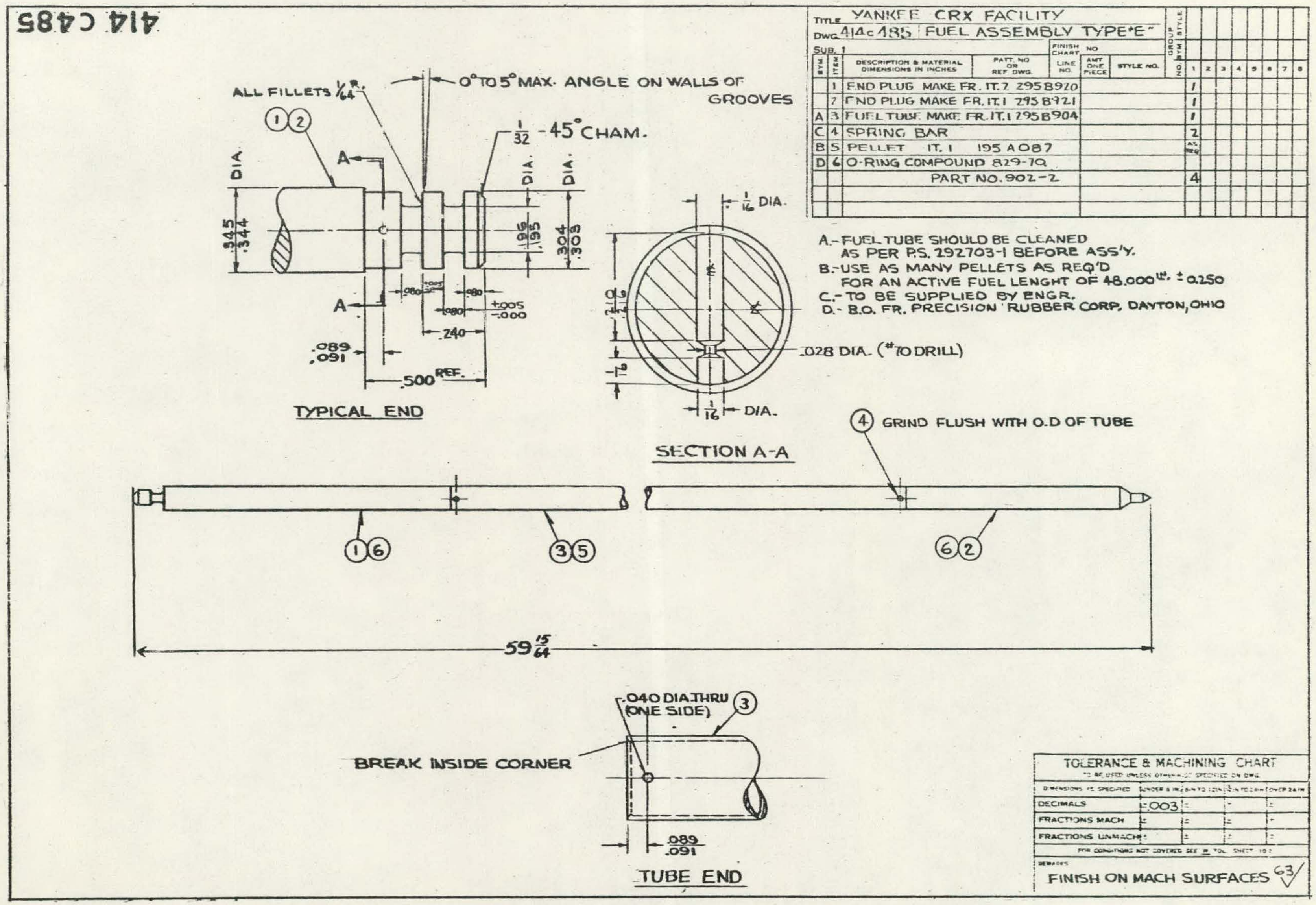


Figure 13
TYPE E FUEL ASSEMBLY DRAWING

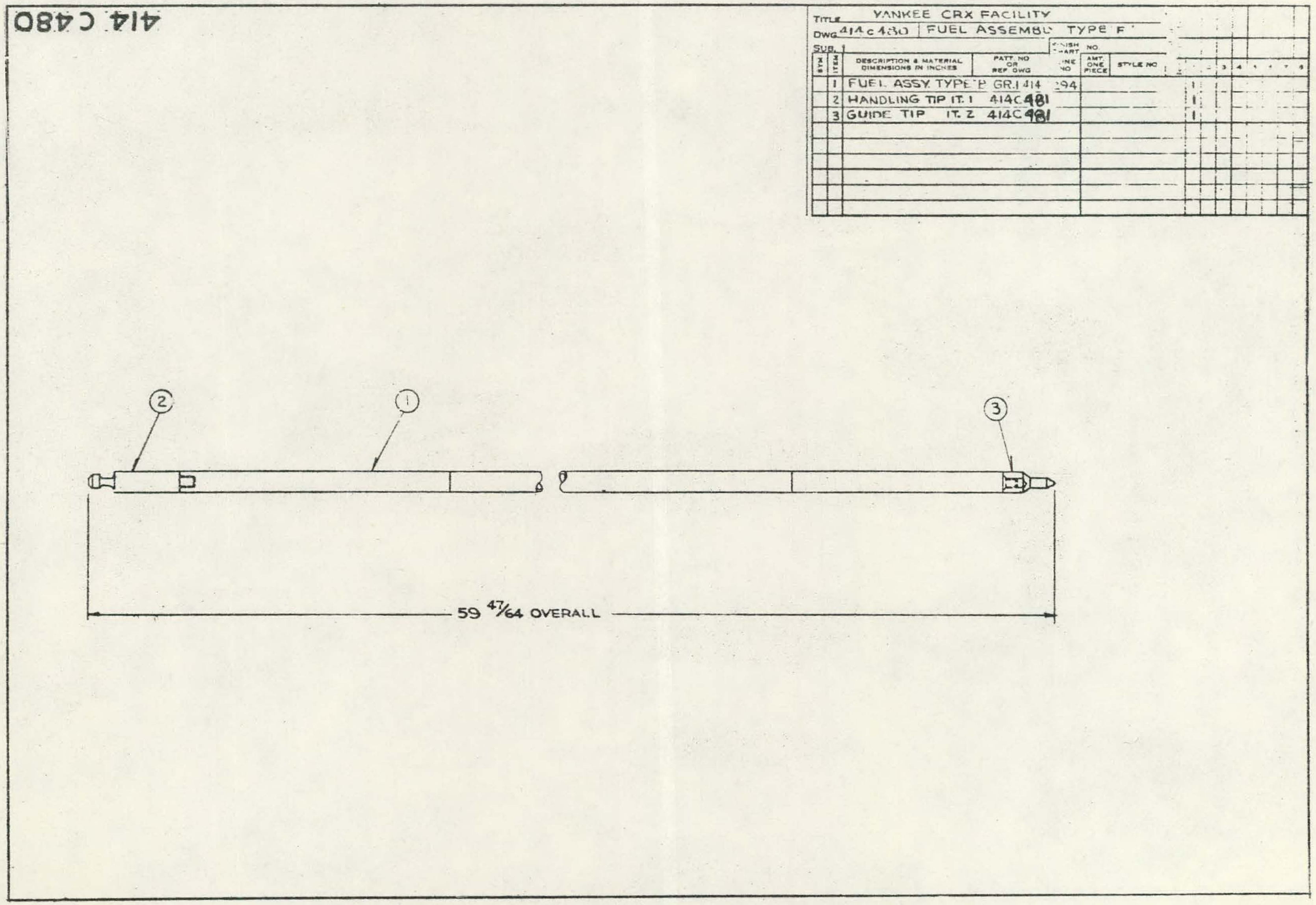


Figure 14

TYPE F FUEL ASSEMBLY DRAWING

DWG. 414C280

TITLE YANKEE CRX FACILITY

FOUR TUBE FUEL ASSEMBLY

DWG. 414C280

SUB. #23

NOTE	ITEM	DESCRIPTION & MATERIAL DIMENSIONS IN INCHES	PATT. NO. OR REF. DWG.	FIN. CH. LINE NO.	CONVERSION NO. AISI	1	2	3	4	5	6
	1	FUEL TUBE ASSY TYPE C GR 1	414C281			2	2	2			
	2	FUEL TUBE ASSY TYPE D GR 1	414C282			2	2	2			
	3	END PLATE IT. 1	195A275			1					
	4	END PLATE IT. 2	195A275				1				
	5	END PLATE IT. 3	195A275					1			
	6	BOTTOM PLATE PIN IT. 1	195A174			1	1	1			
	7	.164-32 S. STL. EYEBOLT			304	1	1	1			
	8	.164-32 X 5/8 FIL. S. STL. MACH SCR.			304	8	8	8			
	9	END PLATE IT. 1	195A274			1					
	10	END PLATE IT. 2	195A274				1				
	11	END PLATE IT. 3	195A274					1			

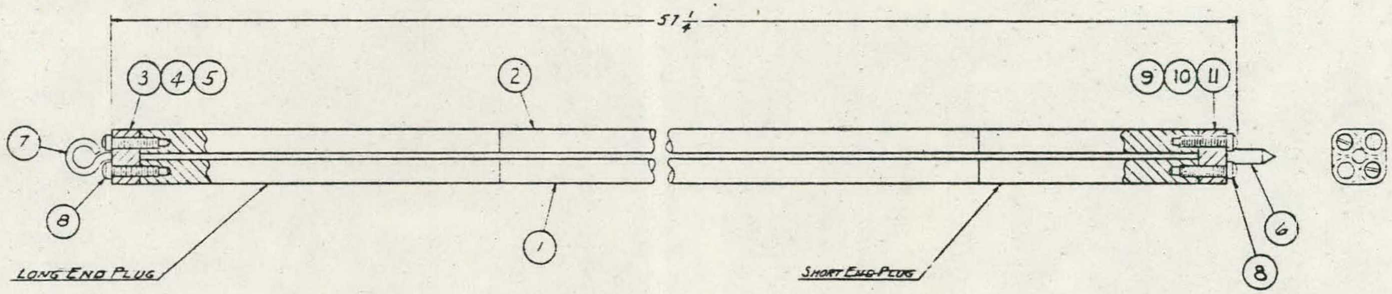


Figure 15

FOUR-TUBE FUEL ASSEMBLY DRAWING

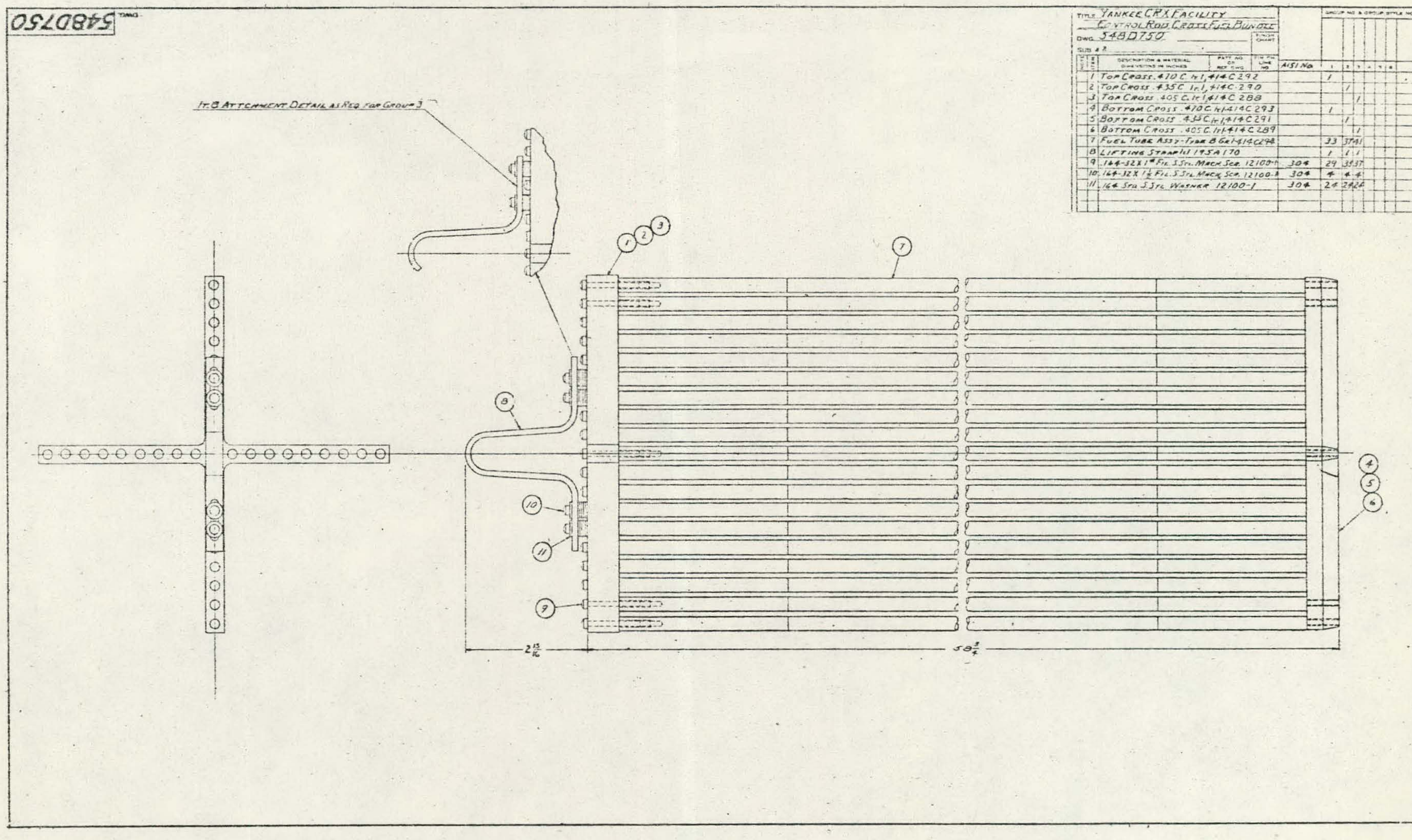


Figure 16

CONTROL ROD CROSS FUEL BUNDLE DRAWING

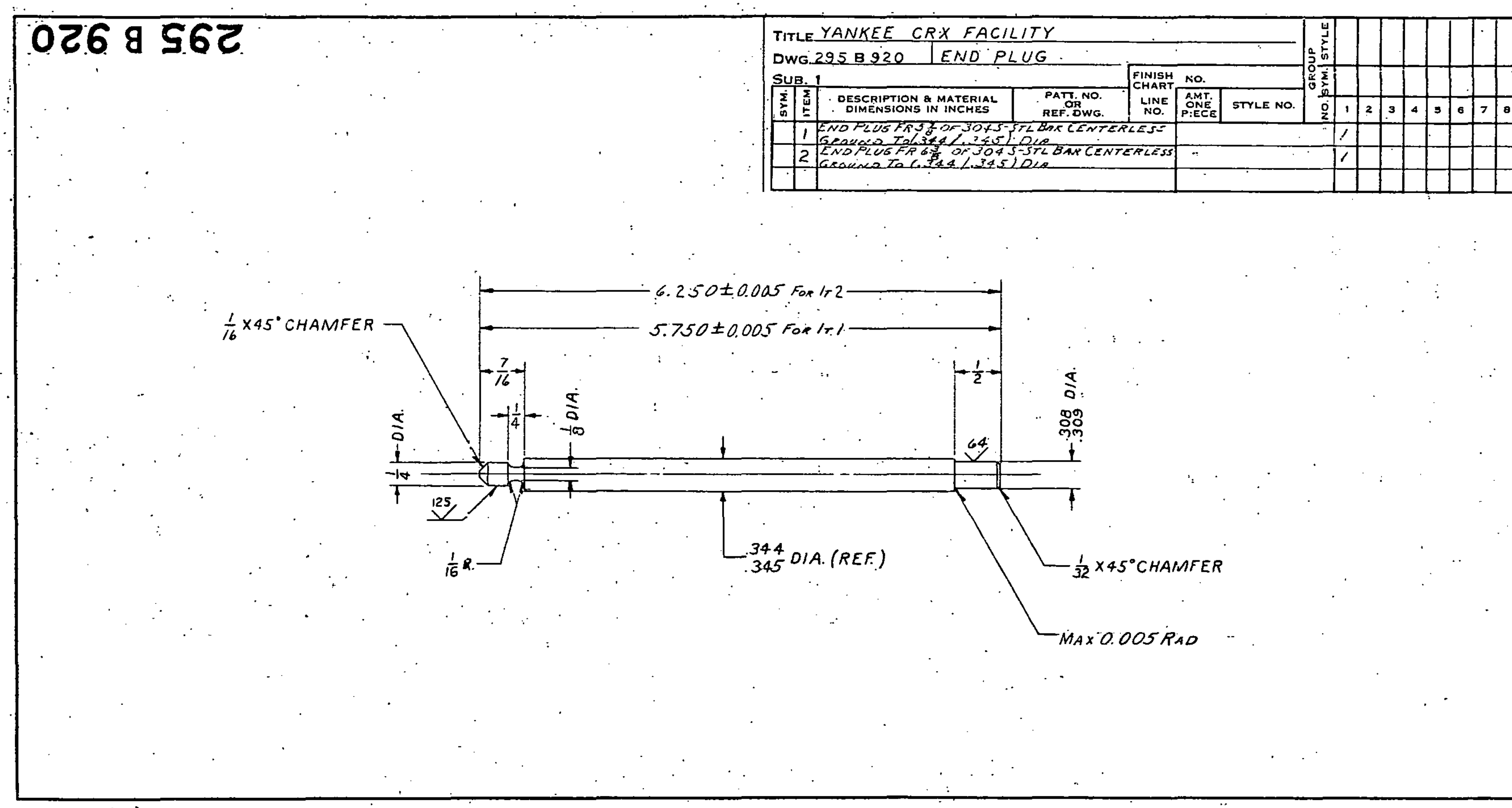


Figure 17

END PLUG DRAWING

636 037

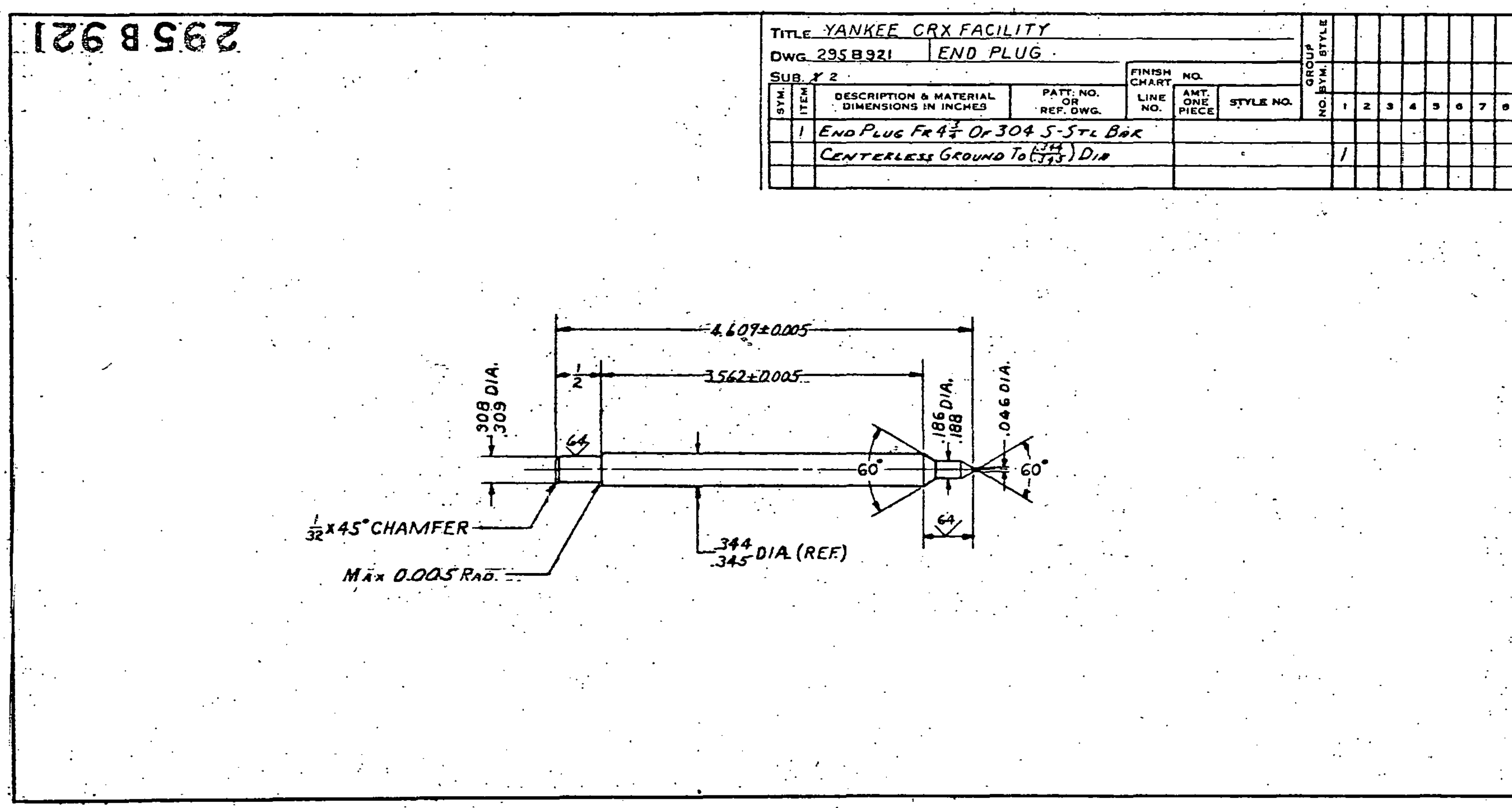


Figure 18

END PLUG DRAWING

636 038

TABLE XIV

Inspection Data Summary
Type B Fuel Rod End Plug

Variable	Length (in.)	Weight (gm)	Tube Insert Diameter (in.)	Tip End Diameter (in.)
Maximum	4.6085	50.225	0.30945	0.1881
Minimum	4.6025	49.865	0.30785	0.0161
Range	.0060	0.360	0.00160	0.002
Average	4.6067	30.0356	0.30869	0.1868
	0.0004	.0677	.0007	0.0009
Sample Size	3192	300	2895	3153

In Figure 19 the frequency distribution curves for the tube insert diameters for the three end plugs are compared.

V. Uranium Dioxide Pellet Inspection

The lack of production information on a batch basis of pellet parameters prompted the selection of a 4% sample, the recording of data in notebooks, and the determination of densities by the "wet" density method (Table XVIII).

Within a short period of time (See Table XV) it became evident that the amount of work entailed to procede on the above basis was a hindrance to an efficient production of fuel rods. It was decided, after studying the accumulated data, to reduce the sampling plan to 2% and use calculated densities as the acceptance standard. Wet densities were run in doubtful cases.

At a later date and after studying the inspection results it was decided to further increase the quantity of pellets released to production by: 1. decreasing the sample size to 1%, 2. constructing a nomograph for determining densities, 3. introducing a single entry card system for recording data. Upon introduction of these measures, no delays occurred which were caused by waiting for release of pellets. Figure 20 shows a typical inspection card.

Table XV shows the evolution of the sampling plan finally developed to inspect incoming pellets.

TABLE XV

Evolution of Pellet Sampling Plan

	Aug	Sept	Oct	Nov	Dec	Jan
Sample Size	← 4%	→| 2% →	←	1%		→
Density	← Wet	→ ✳ ← Calculated		→|← Nomograph		→
Record	←	Notebook	→|←	Cards		→

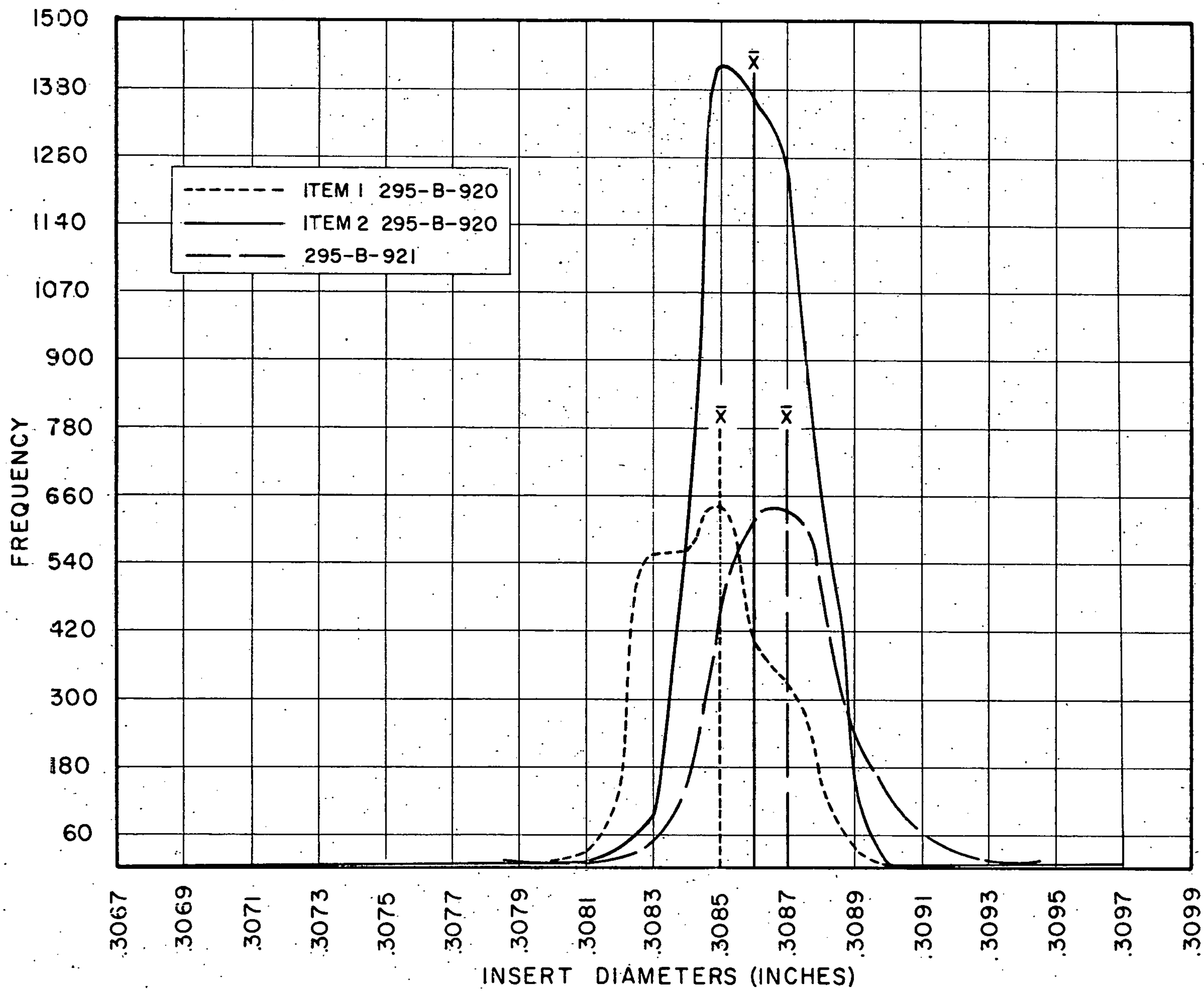


Figure 19

DISTRIBUTION CURVES FOR END PLUG INSERT DIAMETERS

PELLET INSPECTION				
INSPECTOR ______			LOT NO. RC-76-6-3	
SAMPLE SIZE 6 FROM 500			DATE 11/8/57	
	HEIGHT	WEIGHT	DIAMETER	DENSITY
1	.6005	7.0378	.3001	92.22 *
2	.5982	7.0231	.3001	92.40
3	.5981	7.0084	.2995	92.40
4	.5989	7.0283	.2999	92.23
5	.5958	6.9411	.2996	91.78
6	.5949	6.9816	.2997	92.50
AVE.	.5977	7.0034	.2998	92.255 [1] 92.4187 [2]

* NOMOGRAPH READINGS
1. AVERAGE NOMOGRAPH READING
2. CALCULATED FROM AVERAGE HEIGHT, WEIGHT, AND DIAMETER

Figure 20

PELLET INSPECTION DATA CARD

Pellets were sampled and accepted on a batch (one can - approximately 500 pellets) basis. About 1015 batches were received and inspected. The accumulated sample size was 6800 pellets or about 1.5% of the total quantity of pellets received. Figure 21 is the pellet drawing. Figure 22 shows the measurement of length and diameter of pellets.

The pellet inspection data is summarized below:

TABLE XVI

Pellet Inspection Data Summary

Variable	Diameter (in.)	Length (in.)	Weight (gm)
Maximum	.3005	.6850	7.8500
Minimum	.2993	.5250	6.3500
Range	.0012	.0267	1.500
Average	.3000	.5989	7.0699
σ	.0002	.0034	0.1281
Sample Size	6894	6783	6786
	"Wild" 10		"Wild" 15

Figures 23, 24, and 25 are distribution curves for the diameters, lengths, and weights, respectively.

Three methods of determining densities for production control were studied in conjunction with the program to make the pellet inspection program more efficient. Nomograph readings were compared to densities as calculated from data taken from the same samples.

TABLE XVII

Nomograph VS Calculated Density Data

Method	Nomograph	Calculated
Maximum	95.25	95.25
Minimum	90.75	90.25
Range	4.50	5.00
Average	92.97	93.08
σ	1.03	0.83
Sample Size	408	408

WESTINGHOUSE ELECTRIC CORPORATION – DIVISION C.A.P.A. PLANT LOCATION PGH., PA.

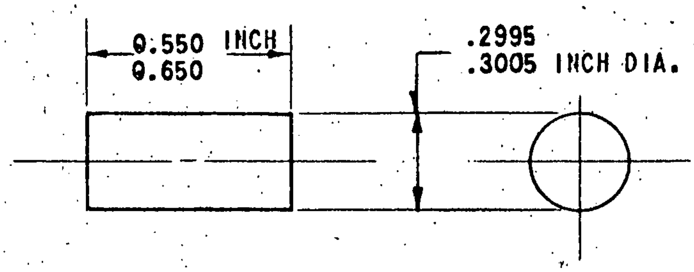
TITLE YANKEE CRX FACILITY

DWG 195 A 087 FUEL PELLET

SUB 1

FINISH CHART NO.

SYM.	ITEM	DESCRIPTION & MATERIAL DIMENSIONS IN INCHES	PATT. NO. OR REF. DWG.	LINE NO.	AMT. ONE PIECE	STYLE NO.	GROUP NO.	1	2	3	4	5	6	7	8
	1	PELLET-FROM SINTERED URANIUM													
	1	DIOXIDE(SPECIFICATION TO BE FURNISHED)													



MATERIAL: SINTERED URANIUM DIOXIDE
(SPECIFICATION TO BE FURNISHED)

DENSITY AT 25°C 93% ± 1.5% T.D. (10.96 GRAMS/CU.CM.)

	MIN.	MAX.
WEIGHT FOR .2995 O.D. X .550 LG. PELLET	6.36 grams	--
WEIGHT FOR .3005 O.D. X .650 LG. PELLET	--	7.83 grams

195A087

Figure 21

PELLET DRAWING

636 048

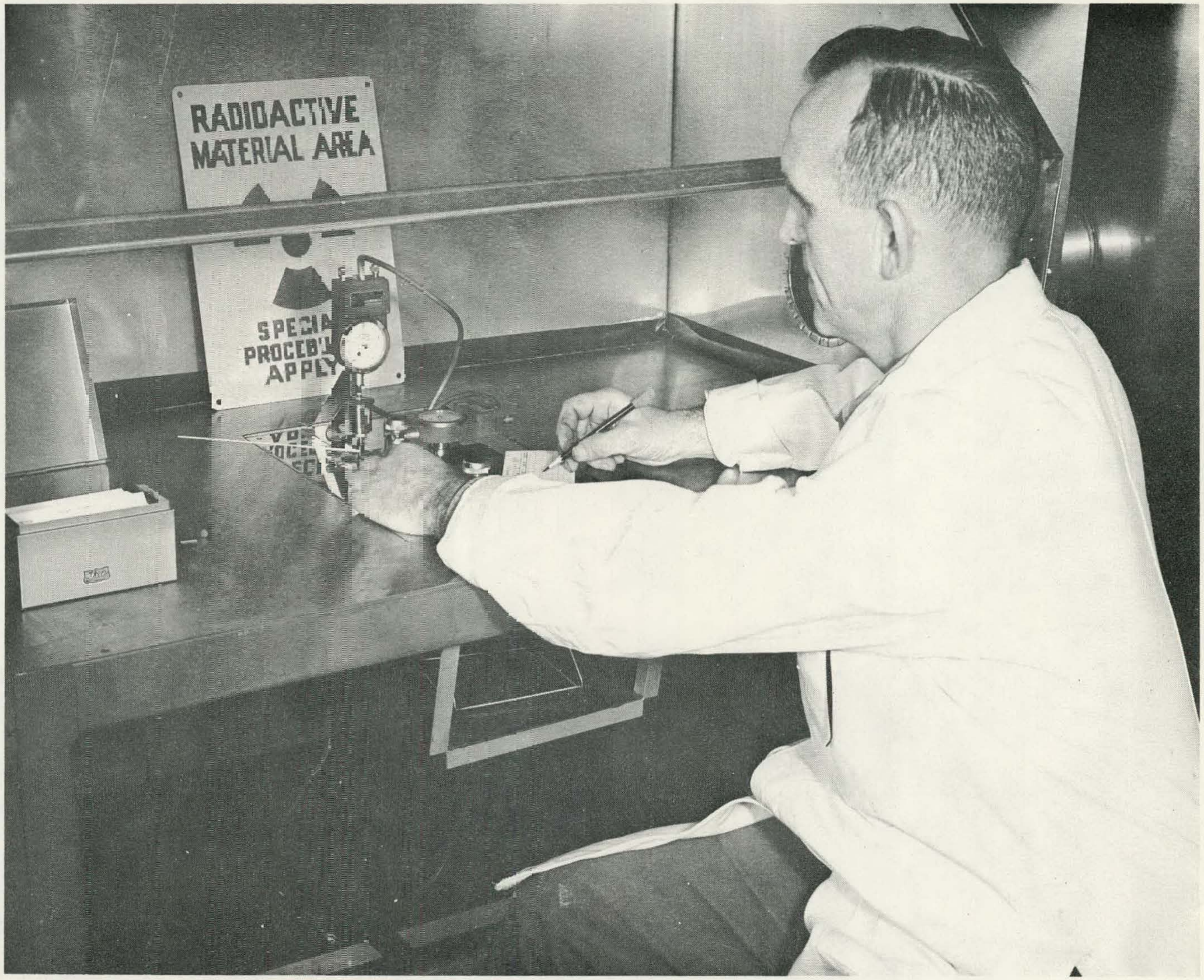


Figure 22

MEASUREMENT OF PELLET LENGTH AND DIAMETER

The arrow points to a pellet being measured.

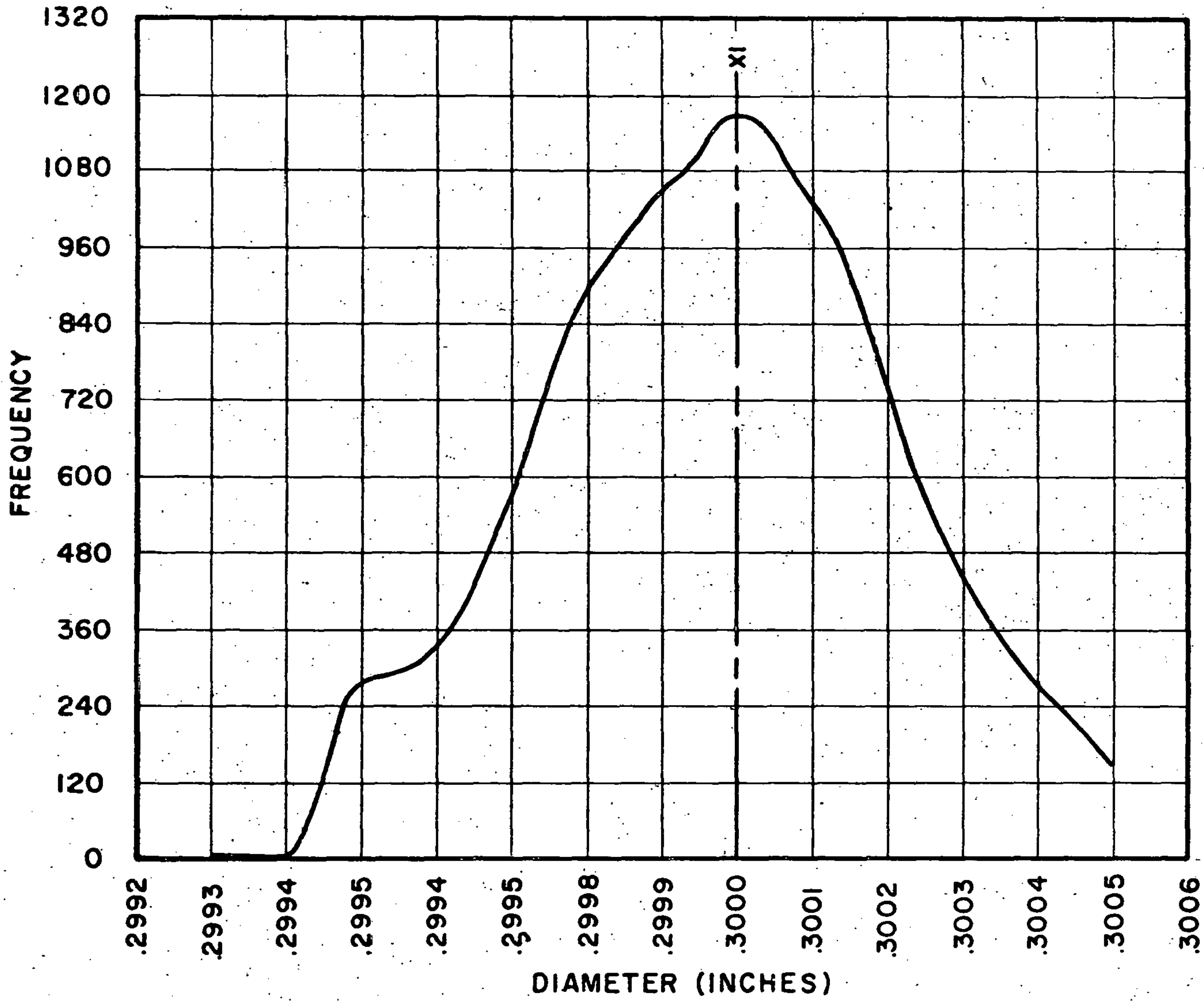


Figure 23

DISTRIBUTION CURVE OF PELLET DIAMETERS

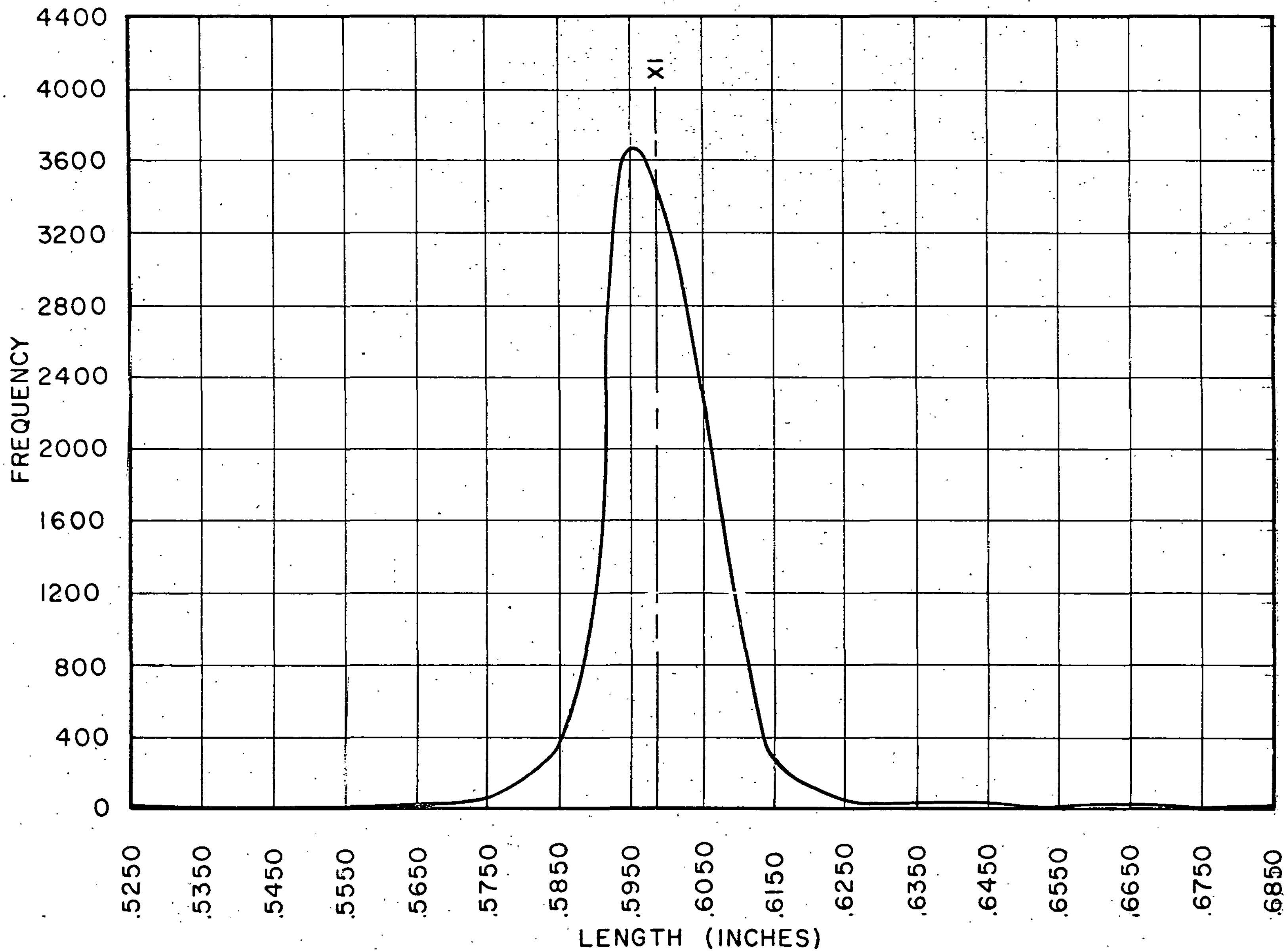


Figure 24

DISTRIBUTION CURVE OF PELLET LENGTHS

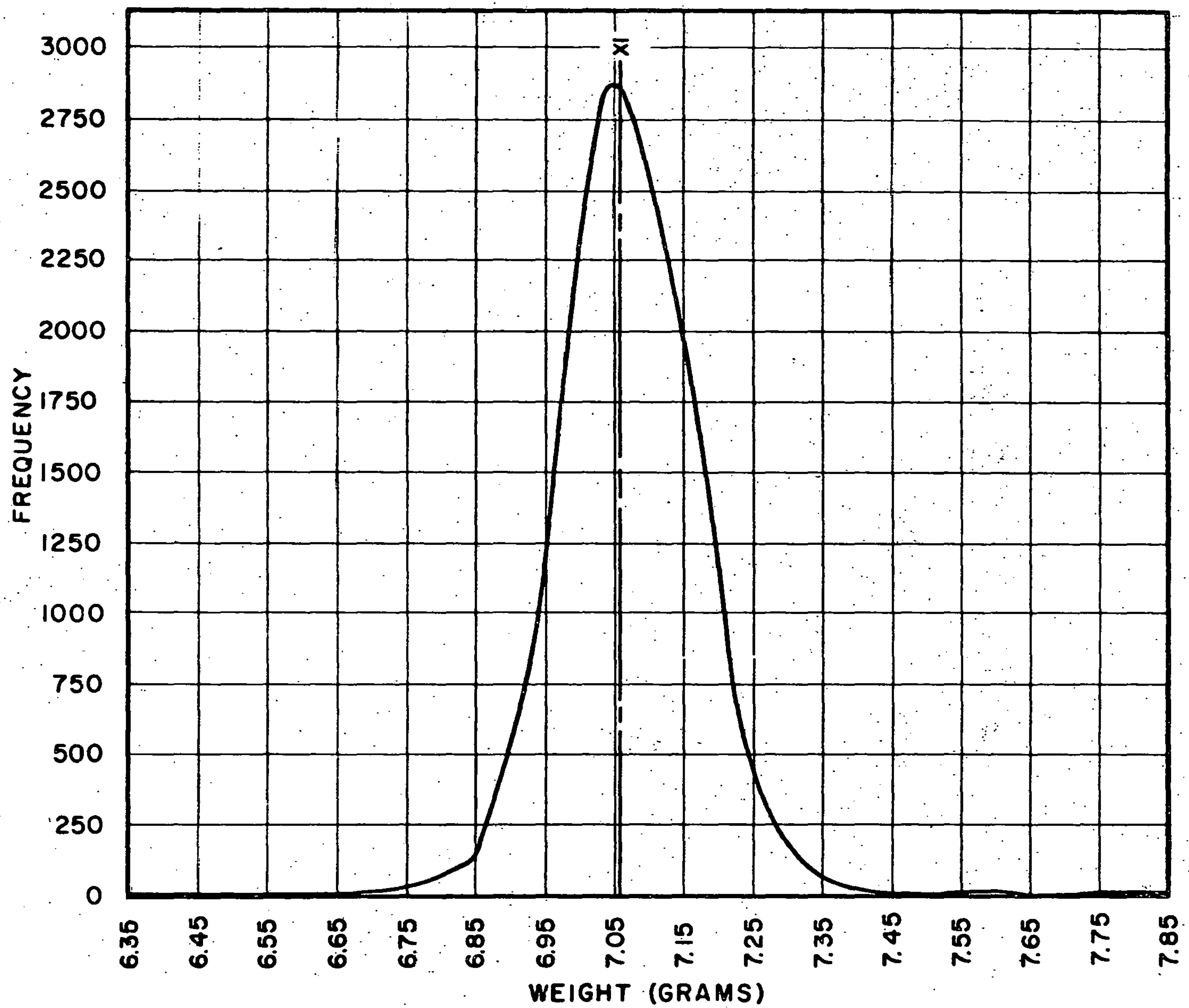


Figure 25

DISTRIBUTION CURVE OF PELLET WEIGHTS

Calculated densities were compared to densities as determined by the "wet" density method (see Table XVIII). Table XIX summarizes these data.

TABLE XIX

Calculated vs Wet Densities

Method	Calculated	Wet
Maximum	95.25	94.25
Minimum	91.25	90.75
Range	4.00	4.50
Average	93.02	93.09
σ	1.14	1.64
Sample Size	58	58

Figure 27 shows the distribution curves for the pellet densities as determined by three different methods on essentially the same pellet samples.

Table XX is a comparison of analyses made on the different "lots" of pellets.

VI. Manufacture of Fuel Rods

The manufacturing procedure is given in Table XXI. The three main steps are: 1. loading pellets into the tubes, 2. welding end plugs, and 3. inspection of welds.

A. Tube Loading

There are five natural variables (in addition to shape deformities, i.e. ovality, out of round of pellets) to be considered in the fitting of sintered ceramic compacts or pellets into tubes to make fuel rods. These are:

1. Variation in diameter within a pellet.
2. Variation in diameter from pellet to pellet.
3. Variation in inside diameter within a tube.
4. Variation in inside diameter from tube to tube.
5. Variation due to allowable clearance tolerances.

The limiting design factors are the maximum allowable gap (diameter differences) as determined from heat transfer calculations and the minimum gap that will permit ease of insertion of the pellets in the tube. In order to have 100% certainty that all pellets would fit in all tubes, a minimum gap of 0.0025" is necessary. The CRX fuel rod was designed to have a nominal gap of 0.0060". The maximum and minimum gaps are 0.0085" and 0.0035", respectively.

TABLE XVIII

Procedure for Determining Density of UO_2 Pellets by the Wet Density Method

1.	Modify a Stanton balance (Model B) as shown in Figure 26 by replacing the left pan with a suspension wire to hold a basket made from fine mesh stainless steel screen. Position a platform directly beneath the suspended basket to raise the beaker of water to a predetermined level.
2.	Zero the balance.
3.	Select ten pellets randomly from the batch under test and weigh together in the basket in air. Record as weight of pellets and basket in air.
4.	Preset the dialed weights to the approximate weight of pellets and basket in water.
5.	Raise the beaker of water (containing two drops of wetting agent, Photo-Flo, Eastman Kodak) to the predetermined level.
6.	Immediately, start a stop watch and weigh to the nearest 0.0001 gram. Take subsequent readings every fifteen seconds for three minutes. (12 weights) Extrapolate the weight to zero time by plotting the twelve points. Record the zero time weight as the weight of pellets and basket in water.
7.	Record the temperature of the water.
8.	Remove the pellets from the basket and weigh the basket suspended in water. Record the weight of the basket suspended in water.
9.	Dry the basket and weigh suspended in air. Record the weight of the basket in air.
10.	Calculate the percent of theoretical density by using the following formula: $$\frac{Wa\ K\ 100}{(Wa-Ww)\ 10.96} = \%\ \text{theoretical density}$$ where, Wa = weight of pellets and basket in air minus the weight of basket in air. Ww = weight of pellets and basket in water minus the weight of basket in water. K = the density of water in g/cc for the temperature of water at time of determination, corrected for the presence of the wetting agent. 10.96 = the theoretical 100% density of sintered UO_2 pellets.

TABLE XX

UO_2 PELLET ANALYSIS

ASSAY	LP	15	LP	16	LP	17	LP18	MZ28	NZ46	PS64	RC-76	RR-77	SM 78	TD 79	VG 80	REPROCESSED BMP
	SCRAP	APD	SCRAP	APD	SCRAP	APD	APD	APD	APD	APD	APD	APD	APD	APD	APD	APD
U %	87.1	88.2	88.3	87.8	88.2	87.7	88.1	87.9	88.2	88.0	88.2	88.0	88.2	88.3	88.0	88.1
U II %	1.5	2.0	0.7	0.4	1.0	0.6	0.2	0.3	0.3	0.3	0.3	0.4	0.3	.7 *	-	3.0
UO_2 %	98.1	97.8	99.4	99.2	98.9	98.8	99.7	99.4	99.7	99.5	99.7	99.4	99.7	99.4	-	96.5
C %	.007	0.010	0.005	0.003	0.006	0.018	0.020	0.005	0.005	0.007	0.003	0.008	0.007	-	-	-
Fe PPM	243	598	385	335	270	960	710	670	660	730	625	720	750	665	830	576
Mo PPM	1.5	1.0	2.0	1.0	4.0	3.0	0.5	0.5	0.3	0.4	0.5	0.5	0.6	1.8	3.1	17
B PPM	<0.1	0.2	<0.2	<0.2	<0.2	< 2.0	0.4	0.7	0.6	<0.2	<0.2	<0.2	<0.2	0.2	1.8	0.5
Cr PPM	56	60	37	30	33	67	62	70	83	102	77	66	74	88	39	96
Cd PPM	<0.5	<1.0	<0.2	<0.2	<0.2	<0.2	<0.5	<0.5	<0.5	<0.5	< 0.5	< 0.5	<0.5	< 0.5	<0.5	<0.2
Co PPM	<1.0	<1.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	1.2	-
Ag PPM	-	-	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.2	-

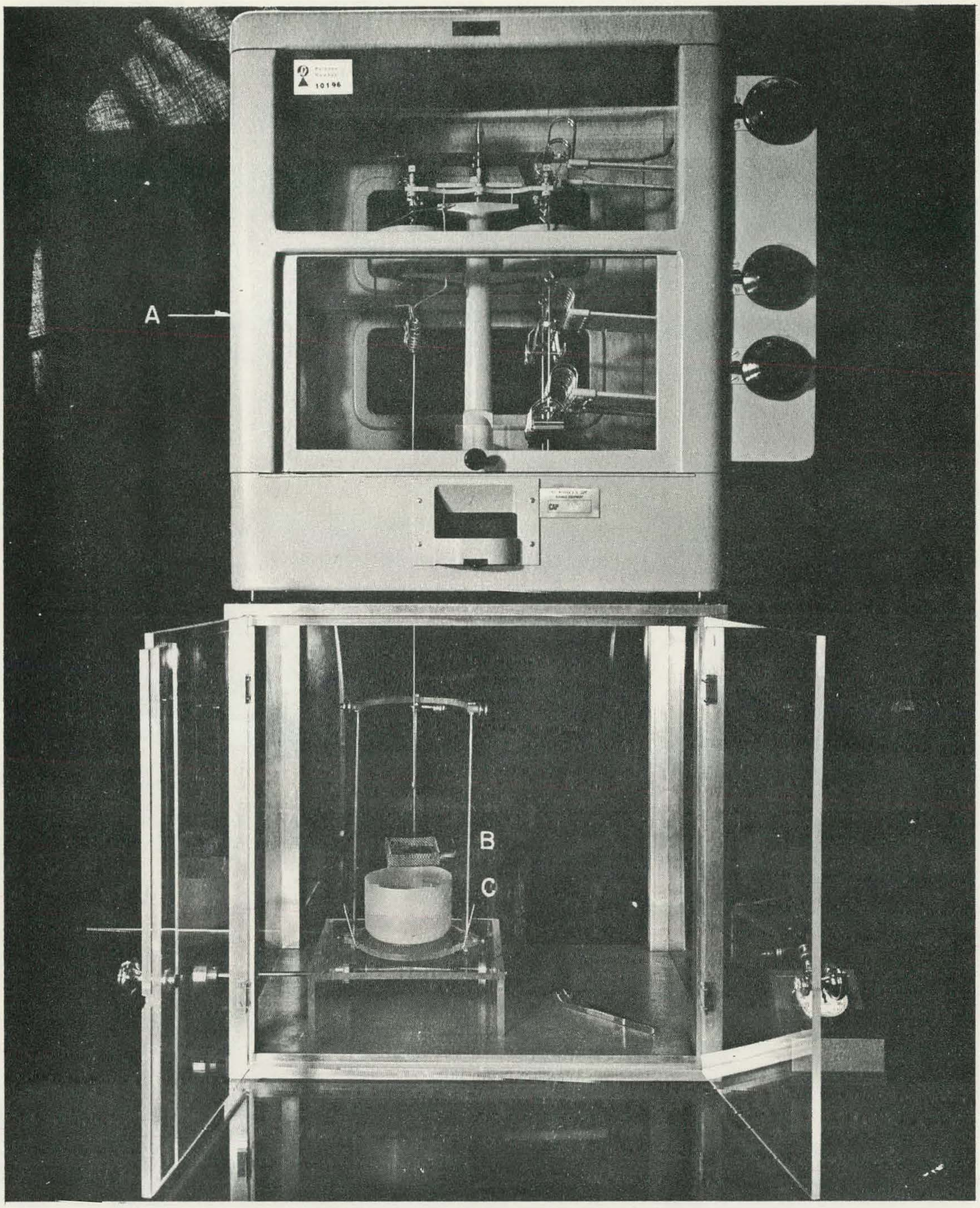


Figure 26

EQUIPMENT FOR DENSITY DETERMINATIONS

A precision balance (A) is mounted above closed case. The pellets are placed in the basket (B) and weighed. The elevator holding a beaker of water (C) is raised to a predetermined level and the pellets are weighed suspended in the water.

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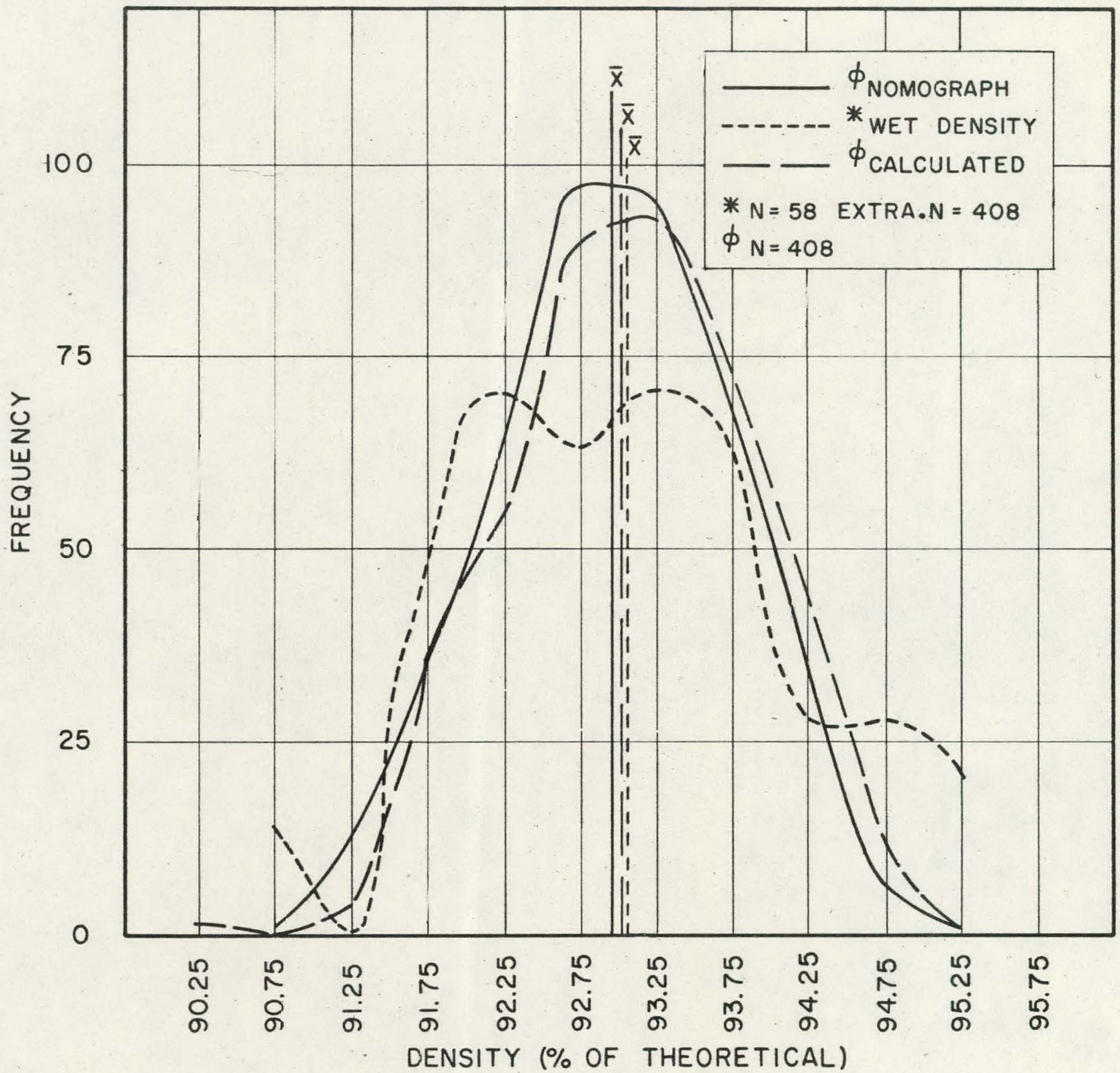

Figure 27

DISTRIBUTION CURVE OF PELLET DENSITIES

TABLE XXI

CRX Manufacturing Procedure

1.	Inspect a 5% tube sample for ID, OD, length, wall thickness and integrity. Record results. Accept or reject.
2.	Inspect 5% sample of various types of end plugs for length and weight. Measure the insert diameters of each end plug. Record results. Accept or reject.
3.	Inspect a 1% sample of each batch[1] of pellets for diameter, length, and weight. Determine density by using a nomograph. If any of the pellets in a batch do not meet specifications, the batch is to be resampled. Record results on single entry. Accept or reject batch.
4.	Align approximately 48" of stacked fuel pellets in a "V" block using a Syntron parts aligner.
5.	Measure and record the length of the fuel column to the nearest 0.001" using the gage assembly. Record results on a single entry card.
6.	Clean the tube before using.
7.	Number individual tube for identity, weigh, empty. Record on same card as in 5 above. Place in tube holder.
8.	Insert the pellet column in the fuel tube by pushing on the pellets.
9.	Weigh the loaded rod. Record weight on the same card as step 5 above. Calculate weight of fuel and record on card. Note: These weights are to be used for physics calculations and for uranium accountability purposes.
10.	Clean end plugs and wipe out each end of loaded tube with Q-tip soaked in Acetone.
11.	Identify the "handling" end plug W 414C920 (items 1 and 2) by stenciling number on the withdraw knob portion. Match corresponding numbered end plug and numbered tube. Press both end plugs into tube.
12.	Weld end plugs into tubes.
13.	Swage pointed end-weld area to reduce area and improve weld.
14.	Centerless grind lead end to .339" to assure entry into 0.350" holes in support and spacer plates of the critical experiment tank.
15.	Visually inspect and X-ray welds.
16.	Place 50 completed rods in shipping container.

[1] A batch is the contents of a pellet shipping container ≅ 500 pellets or less.

TUBE LOADING DATA

TUBE NO. 2145 UO_2 BATCH NO. RC-76-13-7 DATE 11/18/57

WEIGHT LOADED	662.5 GMS.
WEIGHT EMPTY	103.1 GMS.
WEIGHT OF UO_2	559.4 GMS.
EFFECTIVE LENGTH	48.070 IN.

NOTES:

Figure 28

TUBE LOADING DATA CARD

Several different designs of equipment to be used in the loading of pellets into CRX fuel tubes were made and tested. An upright tube loader, Figure 29, was made, whose main feature was that a load could be applied to the piston enabling the loading of a tube with one end plug welded in place. This design was considered for loading 16" long tubes. A new design specification of a 48" length made it necessary to find a more feasible method.

Consideration was given to two types of mechanisms; manual and automatic. The manual pellet loader consisted of a simple "V" block 50" long which is used to count and manually orient the pellets. Attached to one end of the "V" block was a tube holder, offset to make up the tube wall thickness and maintain a straight line for the pellets to travel into the tube.

The automatic device considered consisted of a feeder to orient the pellets and feed them to an escape mechanism. At this point, the pellets are individually pushed down a gravity feed track to a loading mechanism, which in turn loads the pellets into the tubes. The loader incorporated counters, photoelectric lights, and mechanisms. The loading rate was 80 to 100 pellets per minute.

The three reasons for choosing the procedure as given in Table XXI were:

1. The large pellet-to-tube gap (nominal = 0.0060").

2. Measurement of the active length of each fuel rod and its weight for nuclear calculations.

3. Ease of accountability.

A pellet chipping study showed that a loss of less than 0.5% of UO_2 would be generated if a Syntron parts feeder was used. Scrap actually generated plus the unaccountable loss totaled 0.54%.

In the production of the CRX fuel rods, the pellets are aligned in a vibratory device, fed down a chute, and stacked in a "V" block. The "V" block is calibrated to receive a nominal length of 48" of stacked pellets. A gage assembly, calibrated with a standard rod is used to measure the length of the fuel column.

A pre-weighed tube is placed and clamped in the tube holder. The "V" block containing the measured column of pellets is lined up with the clamped tube. The pellets are inserted in the tube by pushing on the column.

The loaded tube is weighed. The length measurement and the tube weights are recorded on an inspection card (Figure 28) and the weight of the fuel in the rod is calculated. Figures 30 and 31 show the equipment used for the loading operation.

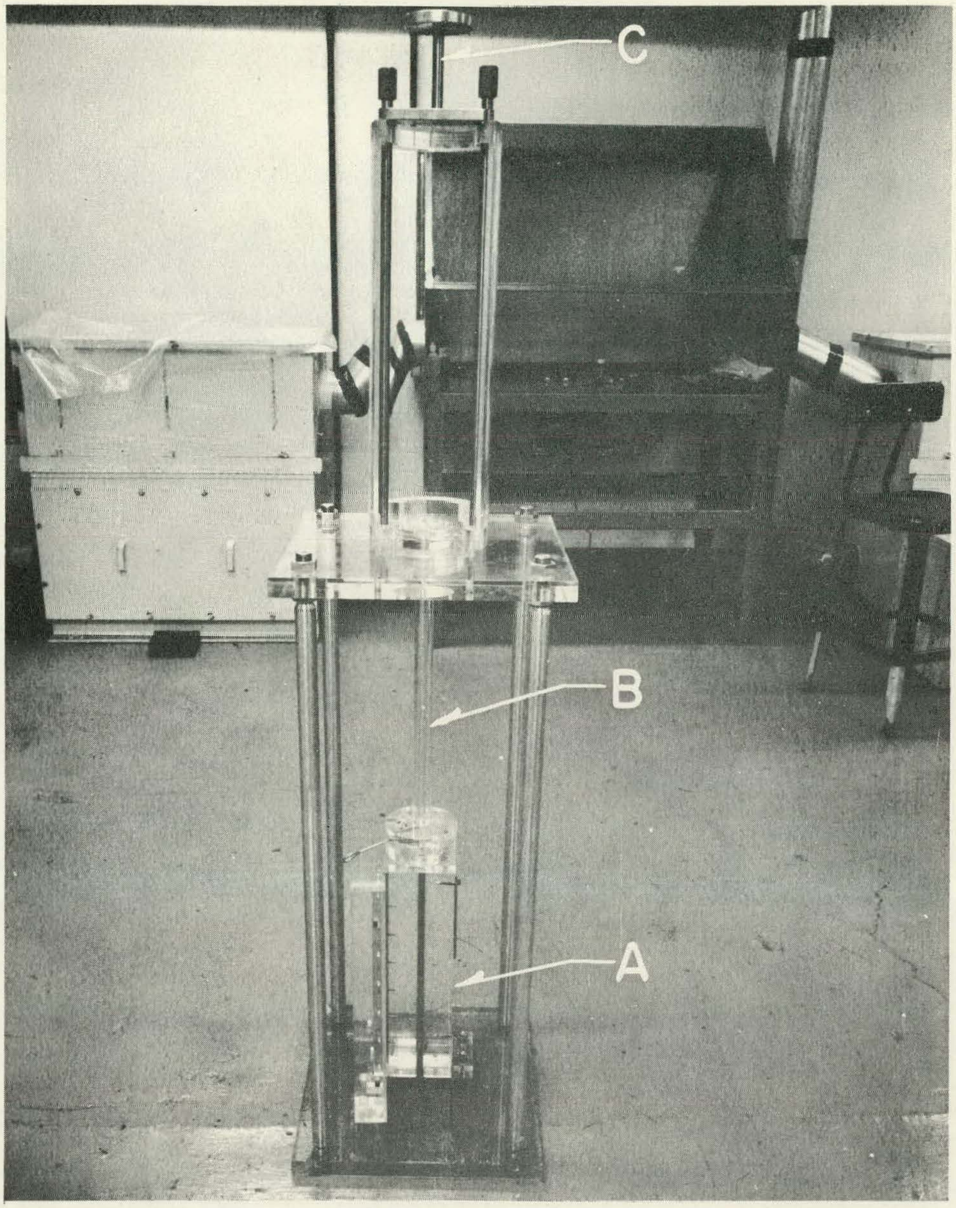

Figure 29

UPRIGHT PELLET LOADER

The upright type pellet loader considered for the manufacture of CRX rods. The tube with one end plug welded in place is secured in holder (A). Pellets are fed from the channeling tube (B). Force needed to insert pellets into the tube is applied by piston (C). This device proved impractical for the CRX fuel rods.

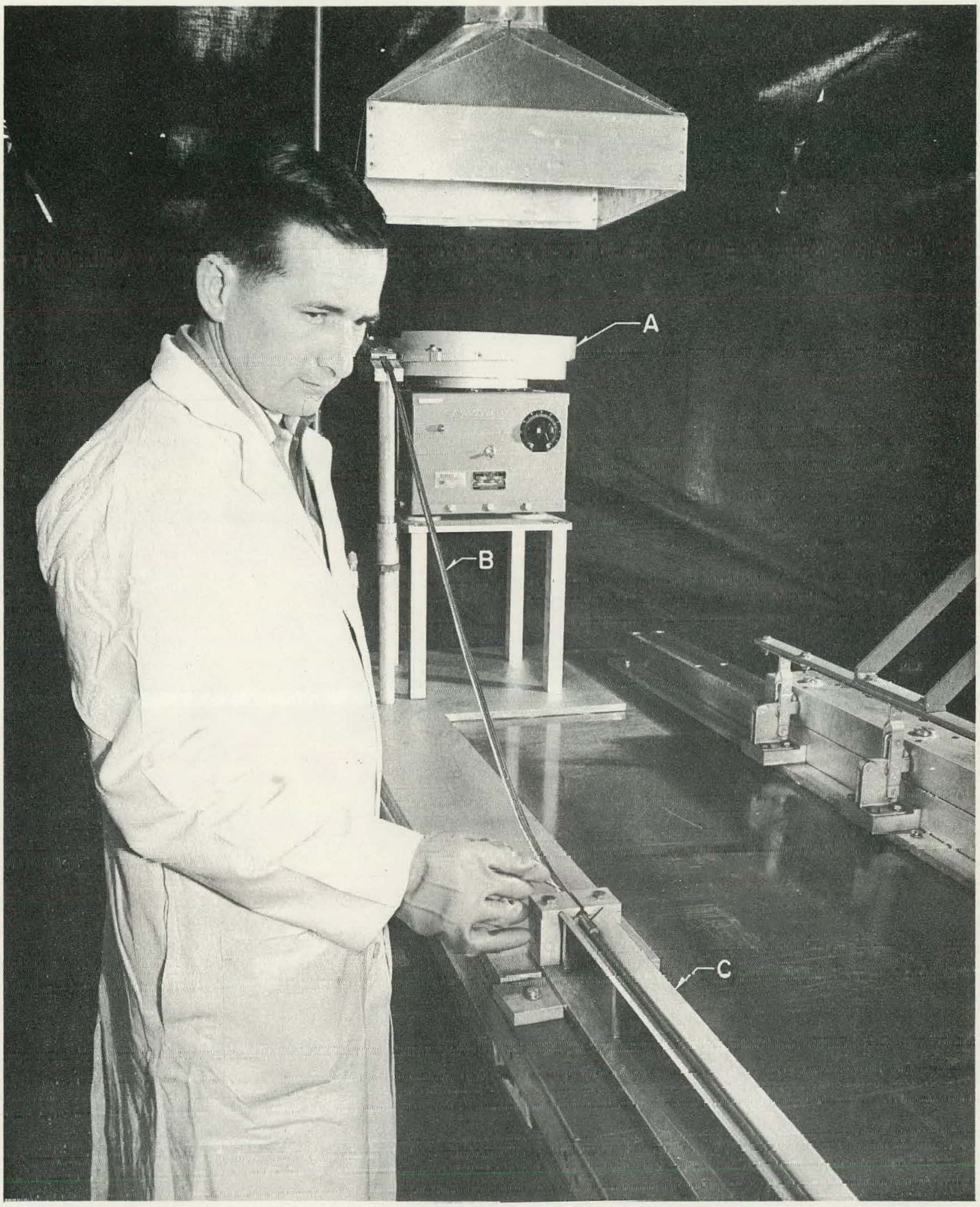

Figure 30

PELLET ALIGNMENT EQUIPMENT

Pellets are aligned for insertion into tubes. Pellets are dumped into a vibratory parts aligner (A) and fed down chute (B) into a "V" block (C). The nominal length of 48" is inscribed on the "V" block to insure the correct number of pellets.

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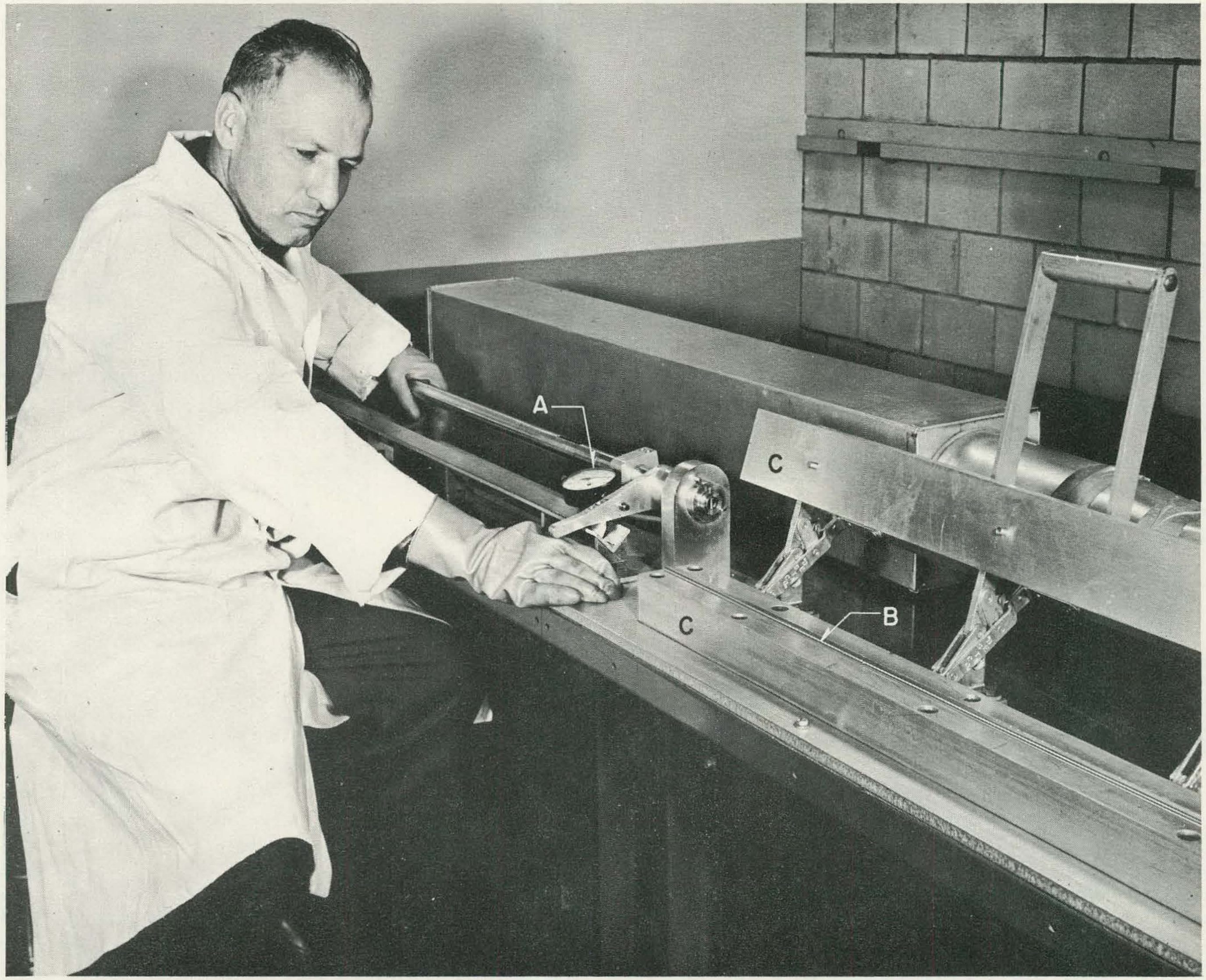

Figure 31

PELLET LOADING EQUIPMENT

The stacked pellets are measured with gage assembly (A) prior to insertion (by pushing on the stack) into tube (B) held in clamping device (C). A straight line for ease of loading is assured in this manner.

TABLE XXII

Fuel Rod Inspection Data Summary

Variable	UO_2 Weight per rod (gms)	UO_2 Length per rod (in.)
Maximum	580.0	48.375
Minimum	548.0	46.675
Range	32.0	0.700
Average	566.04	47.997
σ	4.582	0.150
Sample Size	5483	5483

The average weight per foot of the UO_2 fuel in the CRX rods was calculated to be:

$$\frac{566.042 \times 12}{47.997 \times 453.600} = 0.3120 \text{ \#/ft of } UO_2$$

The distribution curves for the weights per rod of UO_2 and the active lengths of each rod are shown in Figures 32 and 33.

B. End Closure Welds

End closures of CRX fuel tubes were produced by welding a circumferential bead at the tube-to-end plug joint. Rigid control of the welding current, electrode gap, parts fit-up, and cleanliness of weld area were necessary to produce satisfactory welds.

The tube was held in a rotating collet and end-centering stop while the helium shielded electrode was positioned over the joint.

A total of 10,880 welds were made on the CRX tubes. Two hundred thirty eight visible defects (peel back and/or blow hole, see Figure 37) or 2.2% were observed.

The visible defects were repaired by subsequent passes or by patching with filler rod and rewelding.

The welding procedure is given in Table XXIII.

A typical end closure Defect Log is shown in Table XXIV. Figure 34 shows a weld being made and the equipment used in the production of CRX fuel rods.

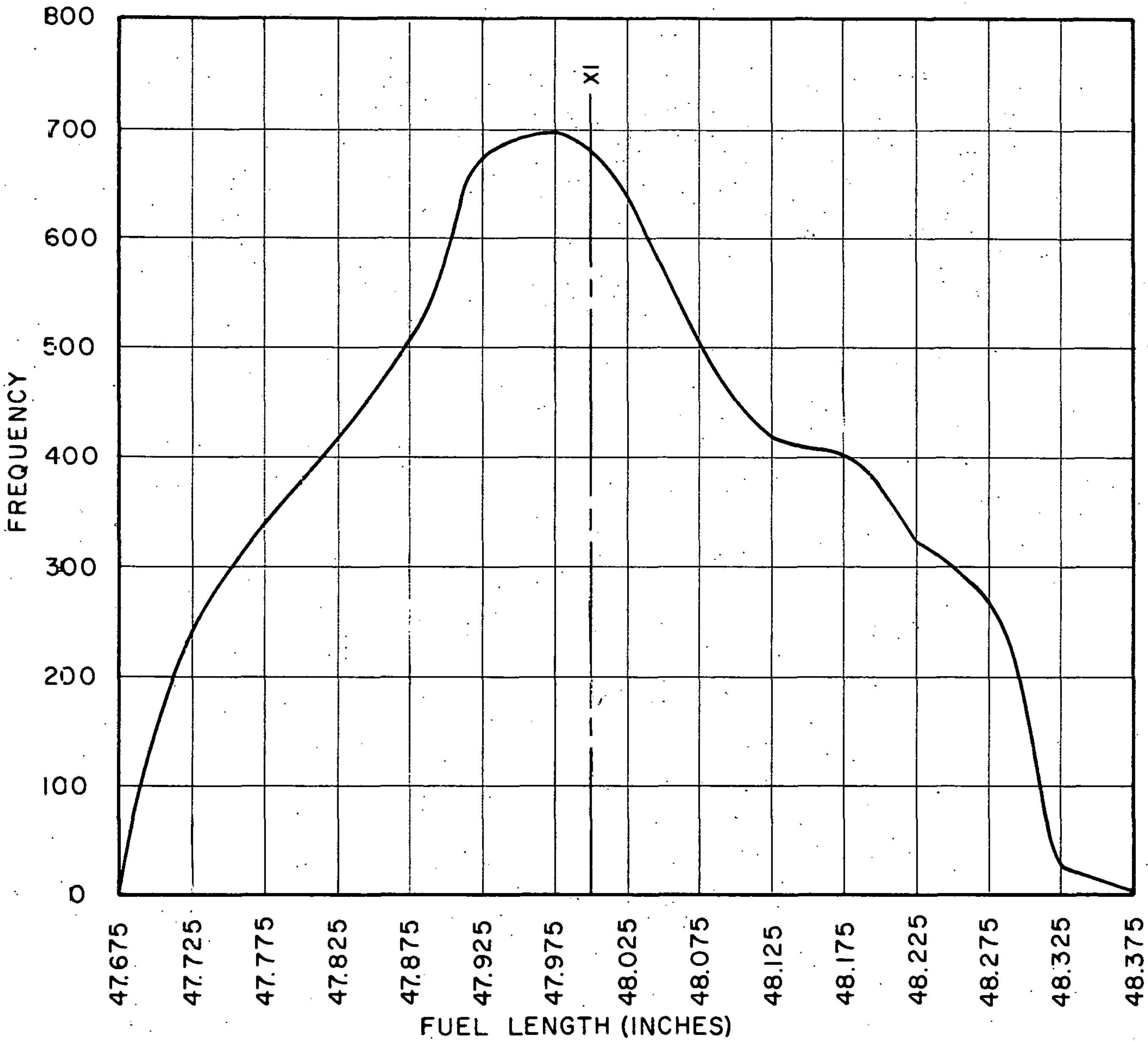

Figure 32

DISTRIBUTION CURVE OF WEIGHTS OF FUEL IN RODS

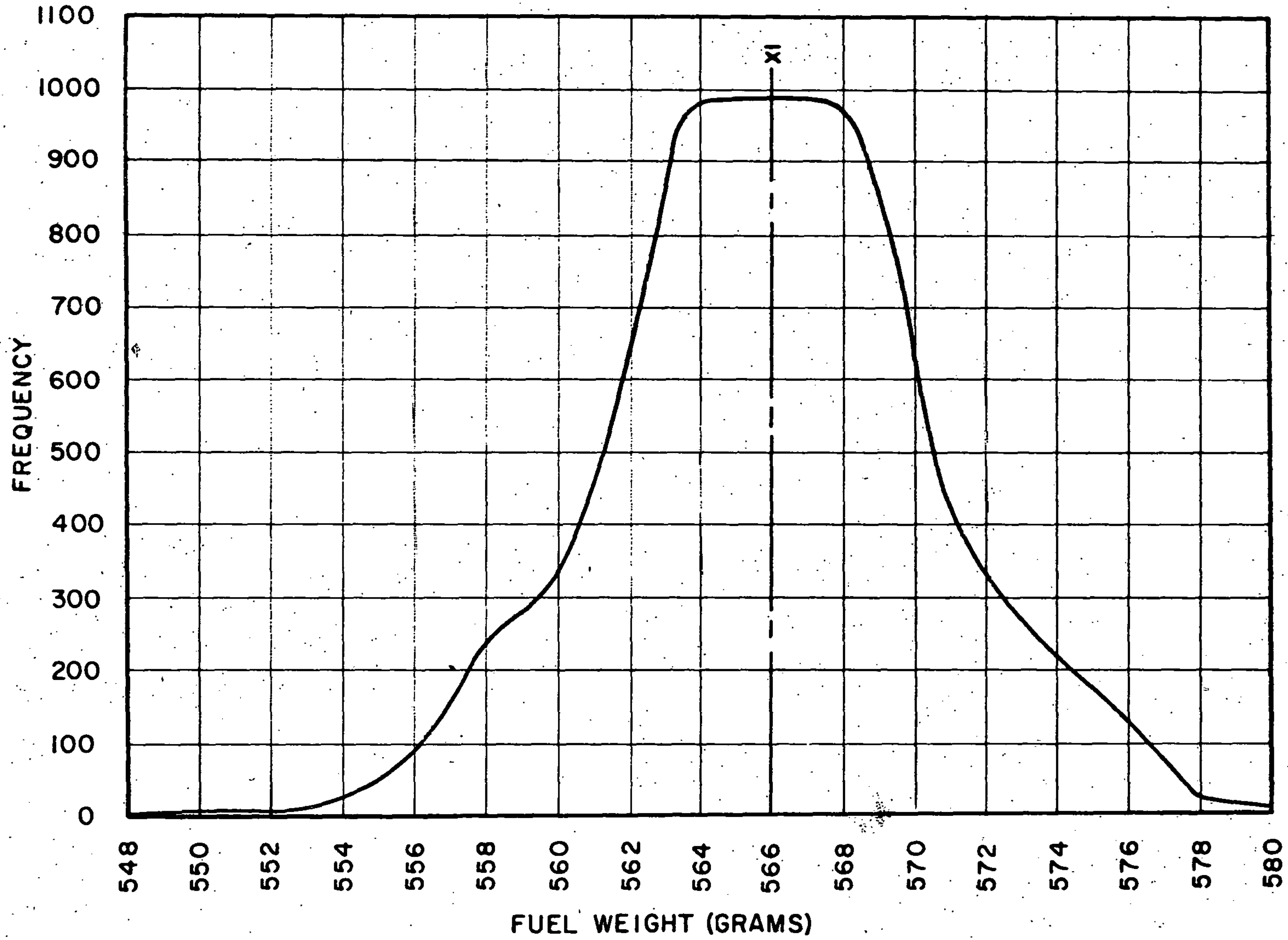

Figure 33

DISTRIBUTION CURVE OF LENGTHS OF FUEL IN RODS

TABLE XXIII

Procedure for End Closures for Type CRX Stainless Steel Fuel Tubes for Radioactive Systems

1.	Clean the joint areas so that they are free of grease, oil, fingerprints, and UO_2 particles before seating the end plugs. Clean end plugs and tubes prior to loading.
2.	After loading the tube with pellets, wipe the open end of the tube with an acetone soaked cotton swab to remove any UO_2 particles.
3.	Wipe the tube ends with dry Q-tips and allow to air-dry.
4.	Inspect the tube and the end plug to assure an interference fit of at least .0005". Measure the tube lip to assure that it is less than .005" from the end plug shoulder, at all points.
	Note: Any noticeable flaring of the tube ends will cause "peelback" of the weld. Flaring which causes tube end ovality greater than .010" is cause for rejection.
5.	Set aside for further inspection and reseating or rejection all tubes with improperly seated plugs or flared ends.
6.	Place the loaded tubes in the end plug welder and run them against an adjustable positioning stop which shall be set for each type of end plug.
7.	Set the electrode gap at .020" $\pm$ .002 with a feeler gage and offset the electrode point on the end plug side of the joint from .005 to .010".
8.	Use a 1/16" diameter, 2% thoriated tungsten electrode first ground to a sharp point, then slightly flattened.
9.	Set the collet rotating motor for a speed of 24 to 25.5 rpm and check the tube for eccentricity.
	Note: Reseating the tube in the collet or tapping the end plug lightly with a soft mallet usually removes any eccentricity present.
10.	With a helium gas flow of 30 to 40 cfh, set the d-c, straight polarity current at 25 amperes for tube thicknesses of .016 to .020".
11.	Start the weld by a high frequency, starting voltage as the tube is rotating and then continue welding until a 180° overlap is made.
	Note: A graph of the current and voltage is automatically drawn as the weld is made.
12.	As soon as the weld is completed, inspect the weld zone for blowholes or "peelback". Immediately reject all "peelbacks".
13.	Small blowholes may be closed by repeat passes over the weld zone. However, if the blowholes are not closed after three passes, remove the tube from the collet and repair with an inert gas shielded metal electrode welding hand torch and a stainless steel filler rod. Grind the filler metal flush with the tube surface and reweld by using the end closure welder.
14.	Keep a log (Table XXVI) of all defective welds; stating the tube number, the end where defect occurred, and the procedure used to repair the weld.

TABLE XXIV

Defect Log

TUBE NO.	TUBE END		BLOWHOLE	PEELBACK	PASSES TO REPAIR	FILLER ROD USED	REPAIRED	REJECTED	REMARKS
	T	B							
5	✓		✓		3	✓	✓		
6	✓			✓	2		✓		
19	✓			✓	–	✓		✓	BEVEL POOR FIT
35		✓		✓	2		✓		
29		✓	✓		3		✓	NOT REJECTED	FOREIGN MTL.
32		✓	✓		2		✓		
31		✓	✓		2		✓		
30	✓		✓		2		✓		
32	✓		✓		2		✓		
19	✓				2		✓	NOT REJECTED	GLASSY INCLUSION NOT REPAIRED
70	✓		✓		3		✓	REWELD	
68	✓		✓		3		✓	REWELD	
67	✓		✓		2		✓		
55		✓	INCOMPLETE FUSION		2		✓		ECCENTRIC TUBE & PLUG
92	✓		✓		2		✓		
103		✓	INCOMPLETE FUSION		2		✓		
162		✓	INCOMPLETE FUSION		2		✓		
134	✓		✓		2		✓		
186	✓		✓				✓		
215	✓		✓				✓		BAD FIT
216	✓		✓				✓		BAD FIT
174	✓		✓				✓		BAD FIT
196	✓		✓				✓		BAD FIT

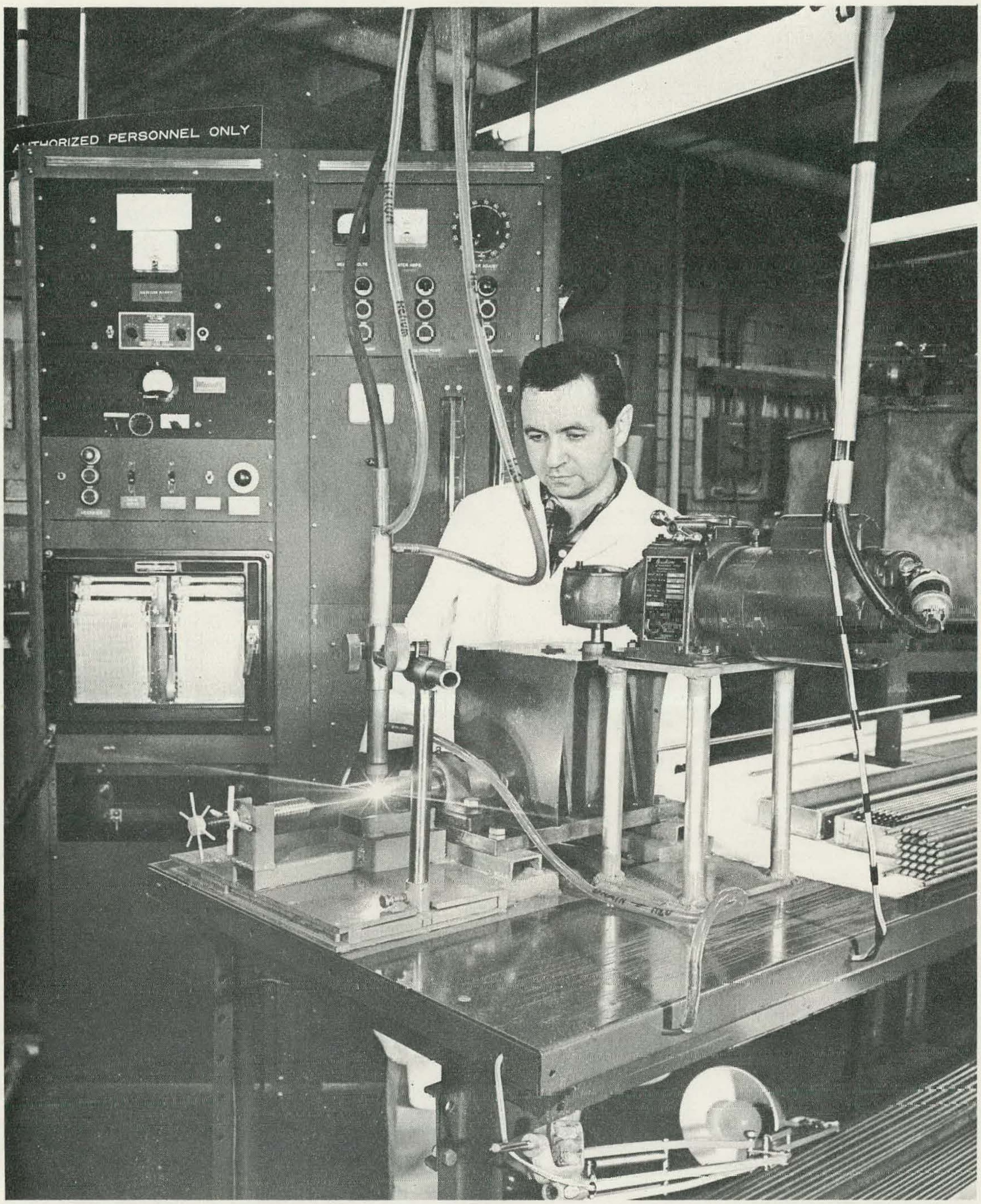

Figure 34

WELDING OF FUEL ROD END PLUG

A fuel rod is sealed by welding end plugs into the tubing.

C. Weld Inspection by Radiographic Means

Defective weldments found by visual inspection were repaired by the welder. Two other types of defects (porosity and lack of penetration or incomplete fusion) were detected by radiographic means.

Twenty percent (or 2176 welds) of all welds made were radiographed. Sixty seven were found with less than 100% penetration and 12 were porous welds. It is to be expected that if all 10,880 welds had been radiographed that a total of 395 would be found that were porous or lacked complete penetration (3.6%). No attempt was made to make this test quantitative because of the application of the fuel rods for the CRX experiment.

A modified Westinghouse Productograph equipped with a 250 constant potential kilovoltage tube with a maximum amperage of 10 milliamperes and a focal spot of 3.5 millimeters was used for inspection. The tube-film distance was constant at 36". A lead lined sleeve was constructed to allow the radiographing of the long fuel rods.

The X-ray procedure is given in Table XXV.

Figure 35 shows fuel rods in place prior to insertion in the productograph. Figure 36 shows welds in position to be radiographed. Note the weld correction form and the position of the penetrameter.

Figure 37 shows typical examples of: 1. an acceptable weld, 2. blowhole defect; 3. "peelback" defect; 4. radiograph showing porosity; and 5. radiograph showing the lack of weld penetration.

TABLE XXV

Procedure for Radiographic Inspection of End Closure Weldments

1.	Insert the weldments of 25 fuel rods into the weld correction form (correction form is used to prevent undercutting and scatter of the X-ray beam).
2.	Position the correction form parallel to the major axis of the film so that the inside edge is no more than one inch from the major axis of the film.
3.	Place penetrameter whose thickness is 2% of wall thickness of the total thickness of metal on the film next to the farthest weld from the center.
4.	Radiograph all welds twice. (90° rotation after first shot)
5.	Use standard 4-1/2" x 17" cardboard cassettes with .005" lead antimony screens in front and in back of the film. Use Kodak Type M film.
6.	Identify each weld by the use of lead numbers.
7.	Use the following parameters: a. 190 KVCP b. 600 miliampere seconds exposure c. 1 mm thick aluminum source filter d. 36" target to film distance e. cardboard cassettes front and back screens 0.005" thick lead-antimony
8.	Develop films for 8 minutes using Kodak Industrial developer and fixer. Wash all exposed negatives with Kodak Photo-flo wetting agent prior to drying.
9.	Read the negatives by using a W fluorospot high-intensity illuminator in a subdued background lighting.

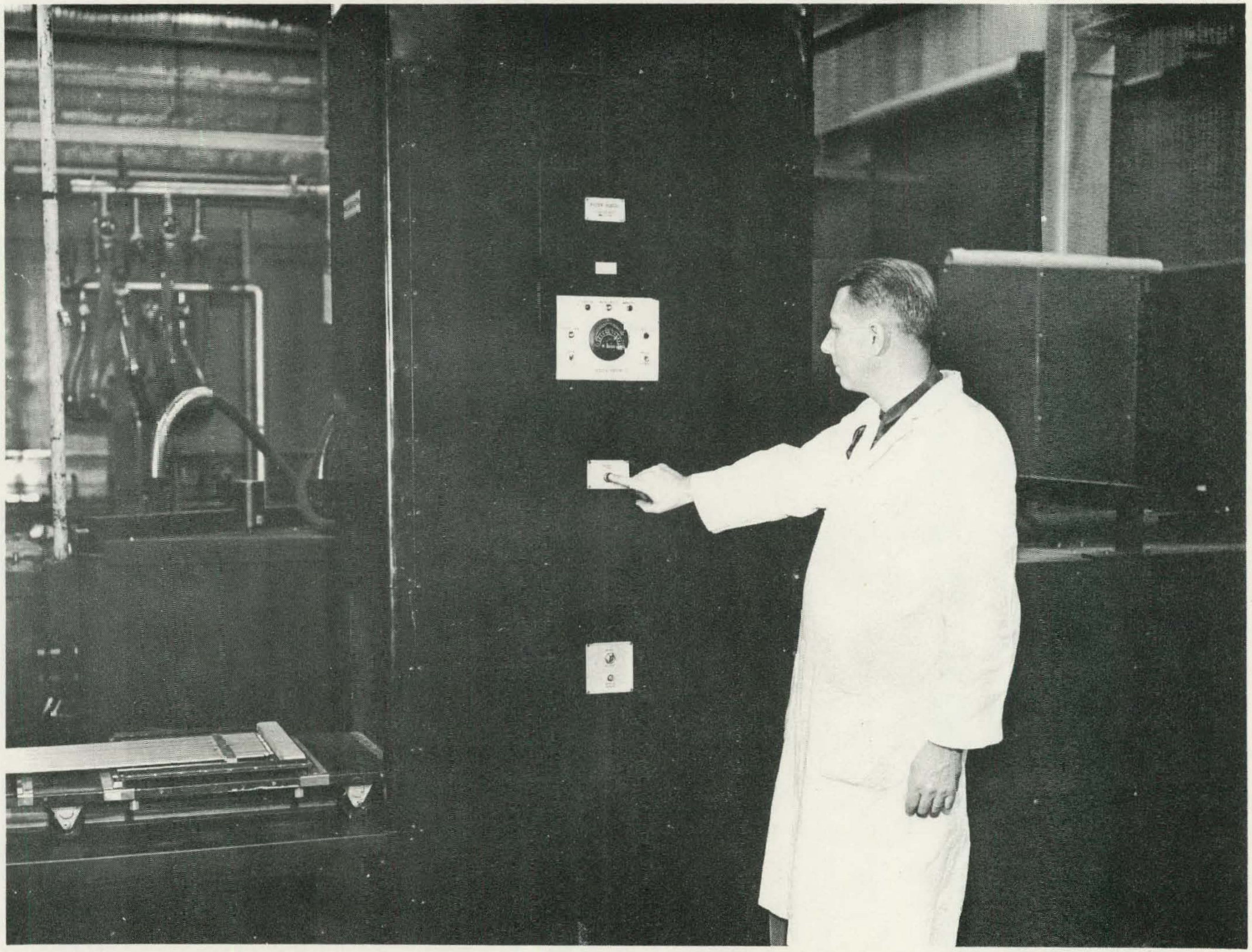

Figure 35

FUEL RODS BEING INSERTED IN X-RAY MACHINE

The rods to be X-rayed are placed on dollies to insure proper placement in the machine.

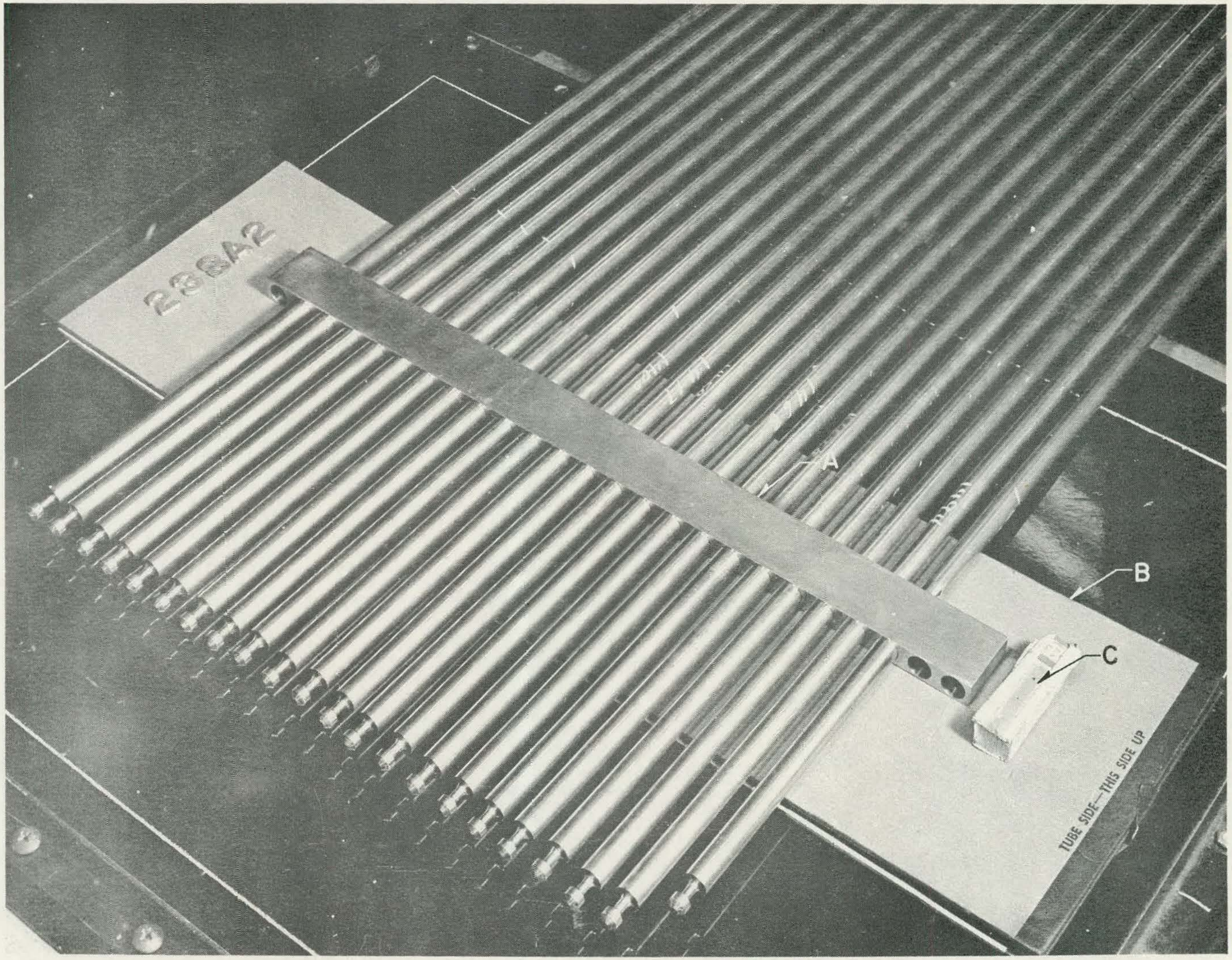

Figure 36

FUEL RODS READY FOR X-RAY

Completed fuel rods are radiographed by placing the welds in the correction form (A) over the film holding cassettes (B). The sensitivity of the exposure is measured by the use of a penetrameter (C) 0.005" thick.

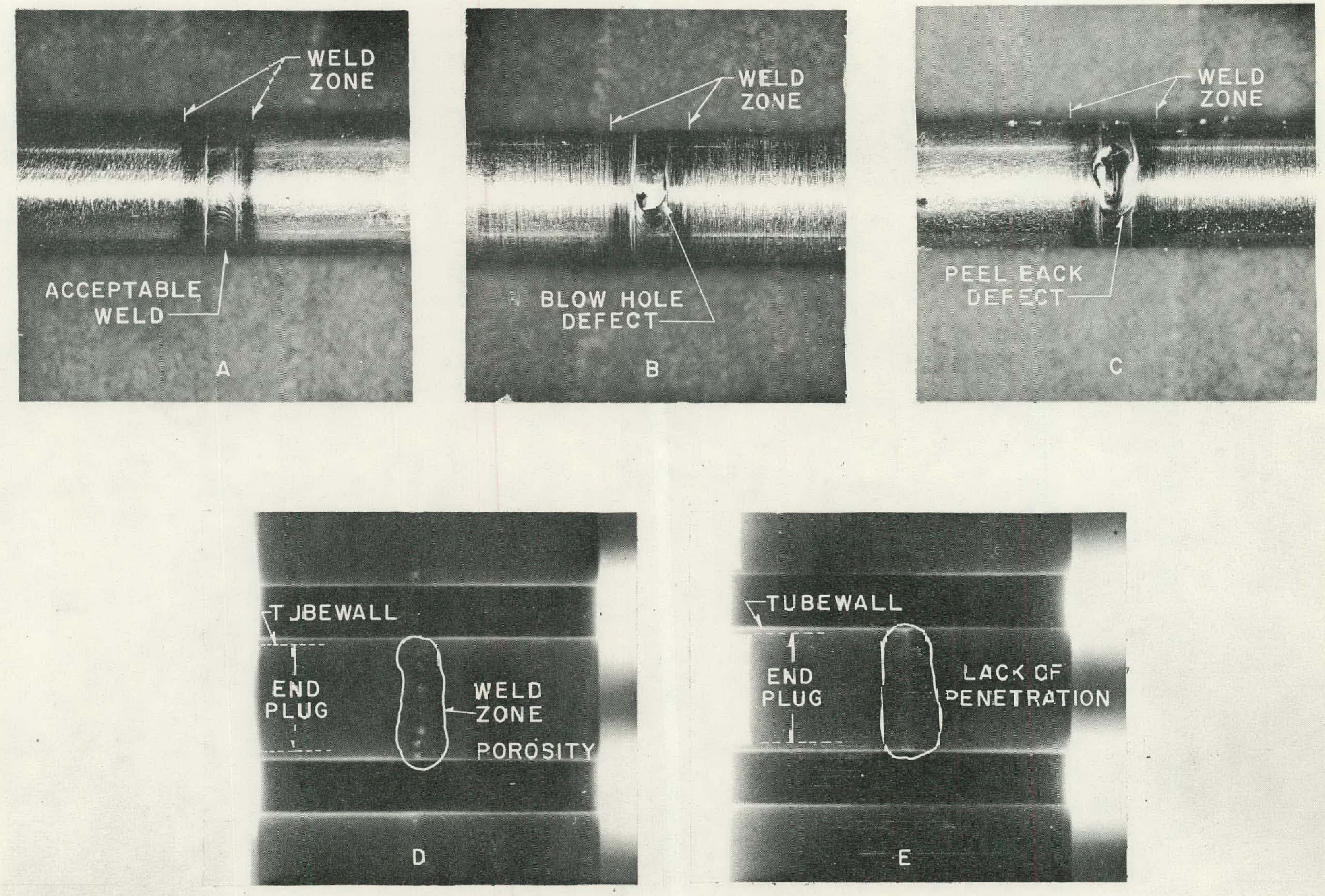

Figure 37

EXAMPLES OF (A) ACCEPTABLE WELD, (B) BLOWHOLE DEFECT, (C) PEELBACK DEFECT, (D) RADIOGRAPH OF POROSITY, (E) LACK OF PENETRATION OF THE WELD.

VII. Summary

The 5509 fuel rods made for the YAEC critical experiment used 3,114,733.5 grams of acceptable UO_2 pellets. To produce these pellets 3,463,409.1 grams of UO_2 was required. The total yield from the pellet fabrication process and the fuel rod fabrication process was 90.0%. Accountability records show that the yield in the fuel manufacturing step alone was 98.8%. The losses sustained are: 1. scrap generated - 0.38%, 2. unaccountable (dust collectors, clean up waste) - 0.12% and 3. all other reasons (chemical analysis, experimentation, retained sample) - 0.7%.

There was good agreement between chemical analysis performed at MCW and at WAPD on UO_2 powder samples.

Inspection of the tubes used resulted in the following average figures:

Outside Diameter	0.3384 inches
Inside Diameter	0.3062 inches
Wall Thickness	0.0160 inches
Length	49.420 inches
Weight	104.453 grams

The weight of one foot of tube was calculated to be 0.056#. Inspection of the three major types of end plugs resulted in the following average figures:

End Plug	Length	Weight	Insert Diameters
Item 1	5.7510"	64.410 gms	0.3085"
2	6.2487"	70.429 gms	0.3086"
3	4.6067"	50.036 gms	0.3087"

Inspection of the pellets resulted in the following average figures:

Diameter	0.3000 inches
Length	0.5989 inches
Weight	7.0699 inches
Density (wet)	93.08% theoretical

The pellet-to-tube gap (diameter differences) averaged 0.0060" with a maximum measurement of 0.0085 inches and a minimum measurement of 0.0035".

The average weight of UO_2 in a completed rod was 566.04 grams. The average length of UO_2 in a completed rod was 47.997 inches. The average weight per foot of UO_2 per rod was calculated to be 0.3120 lbs/ft.

There were 10,880 welds made (some special rods were not welded but rather were sealed using O-rings). During welding a total of 238 visual defects were discovered and repaired. X-ray inspection data revealed that if every weld that had been made were radiographed, there would have been 395 that were defective.

VIII. Acknowledgement

The author wishes to acknowledge the work done by the various personnel of WAPD who made it possible to collect the data for this report. Mr. R. Winchell, Chemistry and Ceramics, followed the fabrication of pellets, Mr. P. P. King, Metallurgy Section, followed the welding. Mr. N. Gordon, Technical Operations, supervised the analytical work. C. Benton, Drafting, constructed the density nomograph. Messrs. B. Hanson and R. Bremmer supervised the production, accountability, inspection and developed the equipment used.