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PRODUCTION OF FUEL ASSEMBLIES FOR THE MATERIALS TESTING REACTOR MOCK-UP CRITICAL EXPERIMENTS

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PRODUCTION OF FUEL ASSEMBLIES FOR THE MATERIALS TESTING REACTOR MOCK-UP CRITICAL EXPERIMENTS

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Work done by: C. D. Smith
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ABSTRACT

Twenty-five fuel assemblies and three shim-safety rod fuel sections were fabricated for use in the Materials Testing Reactor Mock-Up Critical Experiments. Two of the assemblies exceeded tolerance in a few of the key dimensions; but were considered acceptable and as a consequence, production was carried out with no rejects.

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FOREWORD

This report on the fabrication of Materials Testing Reactor (MTR) fuel assemblies and fuel sections of shim-safety rods is issued to cover the techniques involved as of early 1950. It covers a phase of development which was started about four years ago and which will probably continue with minor changes in the future up to and after the time that the MTR is built.

Development has been covered in the Technical Division Monthly Progress Reports of the Engineering Materials Section (IV), in the Technical Division Quarterly Reports, and in the Metallurgy Division Quarterly Reports. Recent work has been covered also in the new MTR Quarterly Report.

Early trials and also opinions of experts in aluminum fabrication indicated that production of the fuel assemblies would be a difficult task. Successful fabrication became a reality largely through the gain in experience in trying to fabricate acceptable assemblies; more than 200 mock units were prepared during development. Another factor in improving yields was the relaxation of tolerance in fuel plate spacing.

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INTRODUCTION

To provide the necessary fuel for critical experiments to be run in the Materials Testing Reactor (MTR) Mock-Up, a request was made for the fabrication of 28 fuel assemblies* and shim-safety rod fuel sections(1).

The MTR fuel assembly body consists of a group of 18 curved fuel plates brazed to two grooved side plates (Fig. 1). The fuel plates consist of cores of uranium-aluminum alloy clad entirely with aluminum. The side plates are also of aluminum. Later this unit is provided with suitable aluminum alloy adapters (Fig. 2) which position the assemblies in the reactor core according to the upper and lower reactor grid spacings. The upper adapter is equipped with a stainless steel helical spring, beveled ring and retaining ring.

The MTR control rods are of two types known as shim rods and safety rods. The shim rod consists of a fuel section joined to a thorium section. The safety rod consists of a fuel section joined to a cadmium section. These long units are provided with suitable stainless steel end pieces (adapters).

The fuel section of both control rods is identical and is therefore designated as a "shim-safety rod fuel section". This fuel section is similar to the fuel assembly body but has only 14 fuel plates; the thick upper and lower plates provide structural strength (Fig. 3).

Because of the similarity of the two types of fuel sections and to avoid confusion, the bulk of this report deals with the fuel assembly; details appertaining to the shim-safety rod are treated separately as indicated in the Table of Contents.

SPECIFICATIONS

With the above brief descriptions of the fuel assemblies as a background to orient the reader, further details can now be given. It should be mentioned that four of the fuel assemblies contained less than the standard 18 fuel plates; in these assemblies the 18 plate total consisted of fuel plates plus dummy aluminum plates. Details of the total request are given in Table I.

*Also called "fuel rods", "fuel units", "fuel elements", "sub-assemblies".

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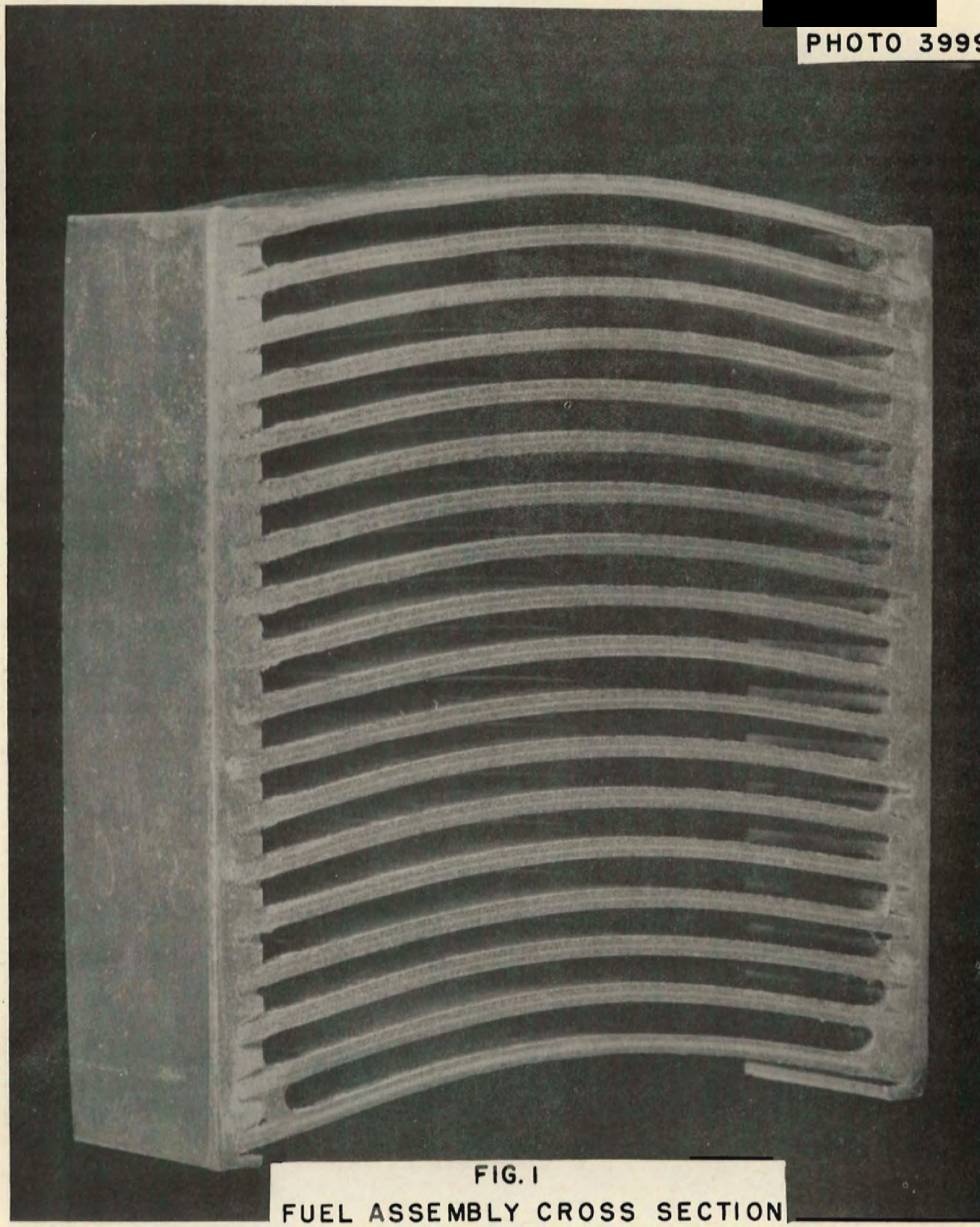

FIG. I

FUEL ASSEMBLY CROSS SECTION

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PHOTO Y-1806

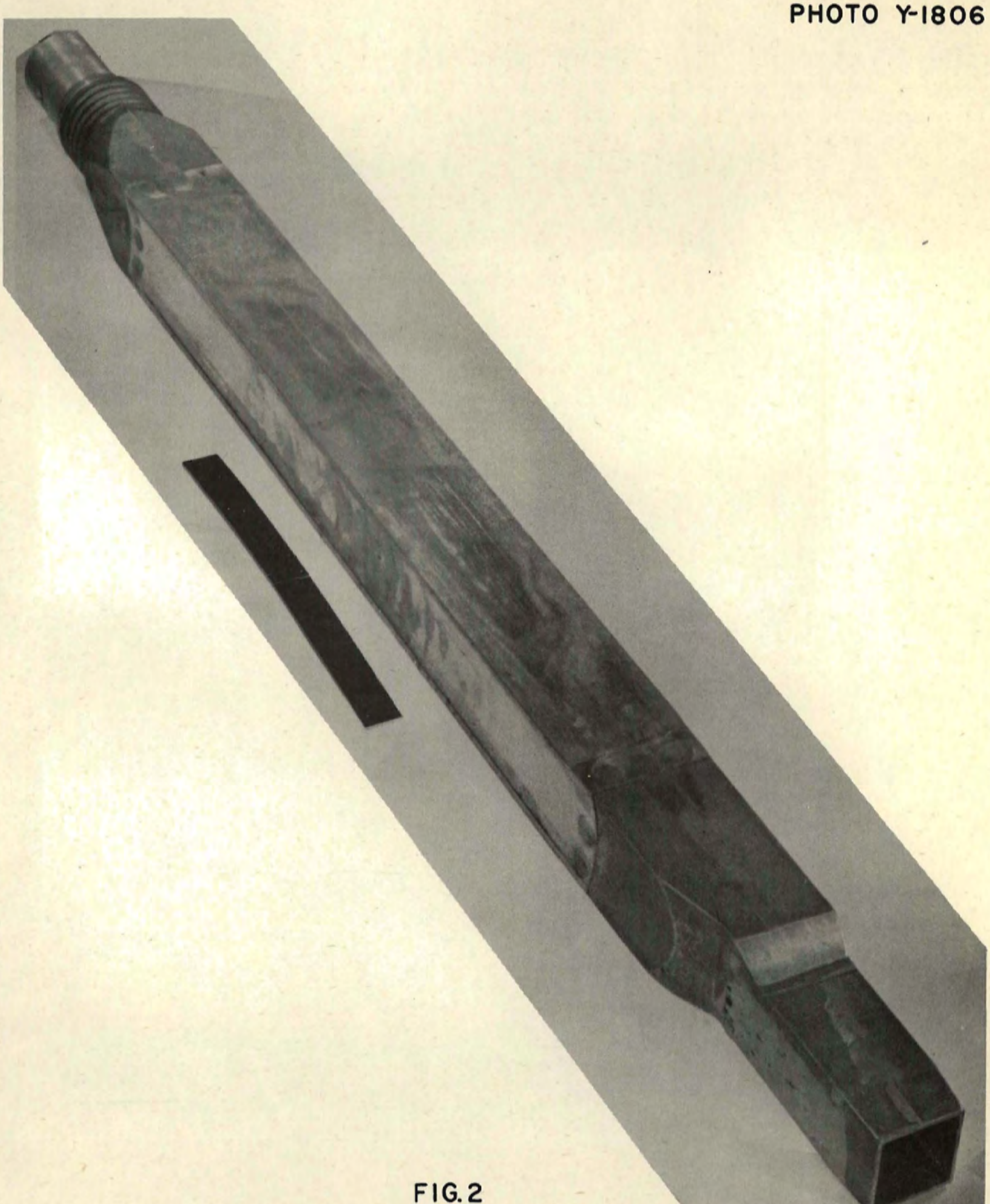

FIG. 2
COMPLETE FUEL ASSEMBLY

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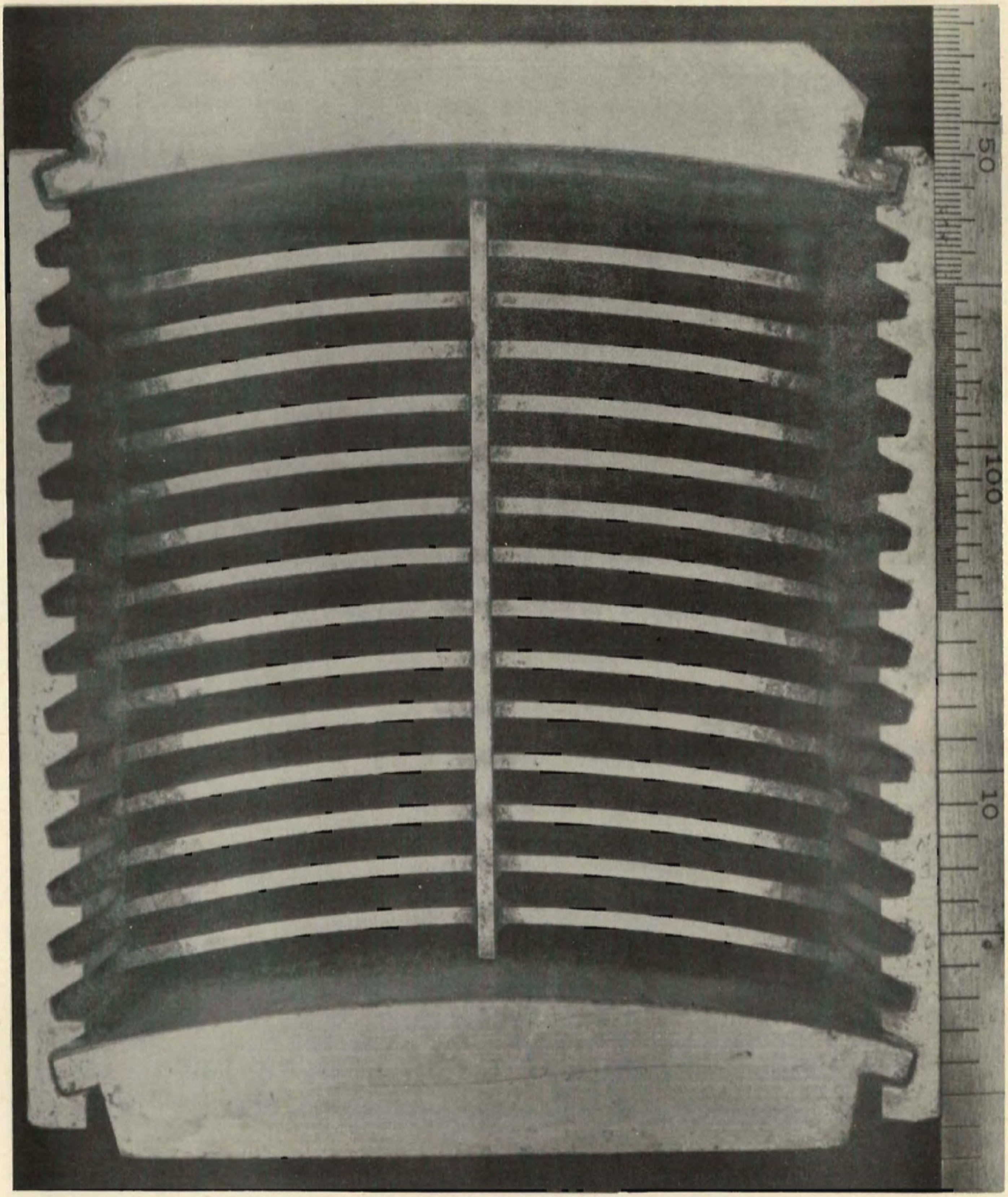

FIG.3

SHIM-SAFETY FUEL SECTION

TABLE I

Assemblies

Quantity	Type	U Content ca. gm/assembly	Number Fuel Plates	Cladding
13	Standard	140	18	Simplex
8	Standard	140	18	Duplex
1	Partial*	92	12	Simplex
1	Partial*	62	8	Simplex
1	Partial*	38	5	Simplex
1	Partial*	23	3	Simplex
3	Shim-Safety Rod Fuel Sections	108	14	Simplex

*Fuel plates spaced for greatest dispersion of fuel.

The most important component of a fuel assembly is, of course, the fuel plate. As might be suspected the development of this component to the point where reasonable production could be obtained was long and tedious. The fuel plate specifications are listed in Table II.

TABLE II

Fuel Assembly Plates

a) Overall Dimensions:	
Length (internal plates)	24-5/8 ± 1/64"
Length (external plates)	28-5/8 ± 1/64"
Width (before curving)	2.845 ± 0.001"
Thickness	0.060 ± 0.001"
b) Core Dimensions:	
Length	23-3/4 ± 1/4"
Width	2.50 ± 0.01"
Thickness	0.021 ± 0.001"
c) Composition:	
Total uranium in U-Al alloy	13.3% (approx.)
U^{235} enrichment	95% (approx.)
U^{235} content per plate	7.70 gm. ± 1%

d) Cladding:

Type	Composition
Standard	2S
Duplex	2S
	72 S (outside -0.005" thick)

e) Quality: Blister-free

It is not intended that this report contain all detailed specifications but to furnish enough data to give the reader a general idea of the problem. Details can be obtained from a list of drawings as follows(2):

Complete List of Drawings Concerned with the Fuel Assembly as of January 20, 1950

I. **Mock-Up Fuel Assembly**

Casting Drawings

Upper Adapter	TD-1543
Lower Adapter	TD-1542

Pre-Assem. Mach. Dwgs.

Upper Adapter	TD-1166
Lower Adapter	TD-1165

Brazing Alignment Dwg. TD-1167

Final Machining Dwg. TD-1472

Fuel Assem. Dwgs.

Side Plate	TD-966A
Comb	TD-1533
Std. Fuel Plate	TD-1534
Outside Fuel	TD-1535

Other Fuel Assem. Dwgs.

Beveled Ring	TD-256--New Deisgn - TD-1548
Retaining Ring	TD-257
Upper End Spring	TD-251

II. Future (study dwgs. only) Fuel Assembly

Fuel Assem. Round Lower Adapter	TD-1520
Fuel Assem. Round Lower Adapter	TD-1544

MATERIALS

A summary of the principle parts and processes and the corresponding basic materials required is tabulated below as follows:

Parts	Basic Materials
1. Fuel Plate a. Core alloy	Aluminum pig, 99.75% pure Cryolite, commercial grade U_3O_8
b. Cladding	1/8" 2S aluminum sheet
2. Side Plate	3/16" 2S aluminum sheet
3. Top and bottom plates (for shim-safety rod)	1/2" 2S aluminum sheet
4. Adapters (for fuel assembly	43S aluminum casting alloy
Processes	
A. Brazing (of items 1, 2, 3 above)	11-1/2% Si-Al sheet Eutectic No. 190 flux Methyl alcohol, absolute
B. Welding	11-1/2% Si-Al rod Tungsten electrodes Argon

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PHOTO 6164

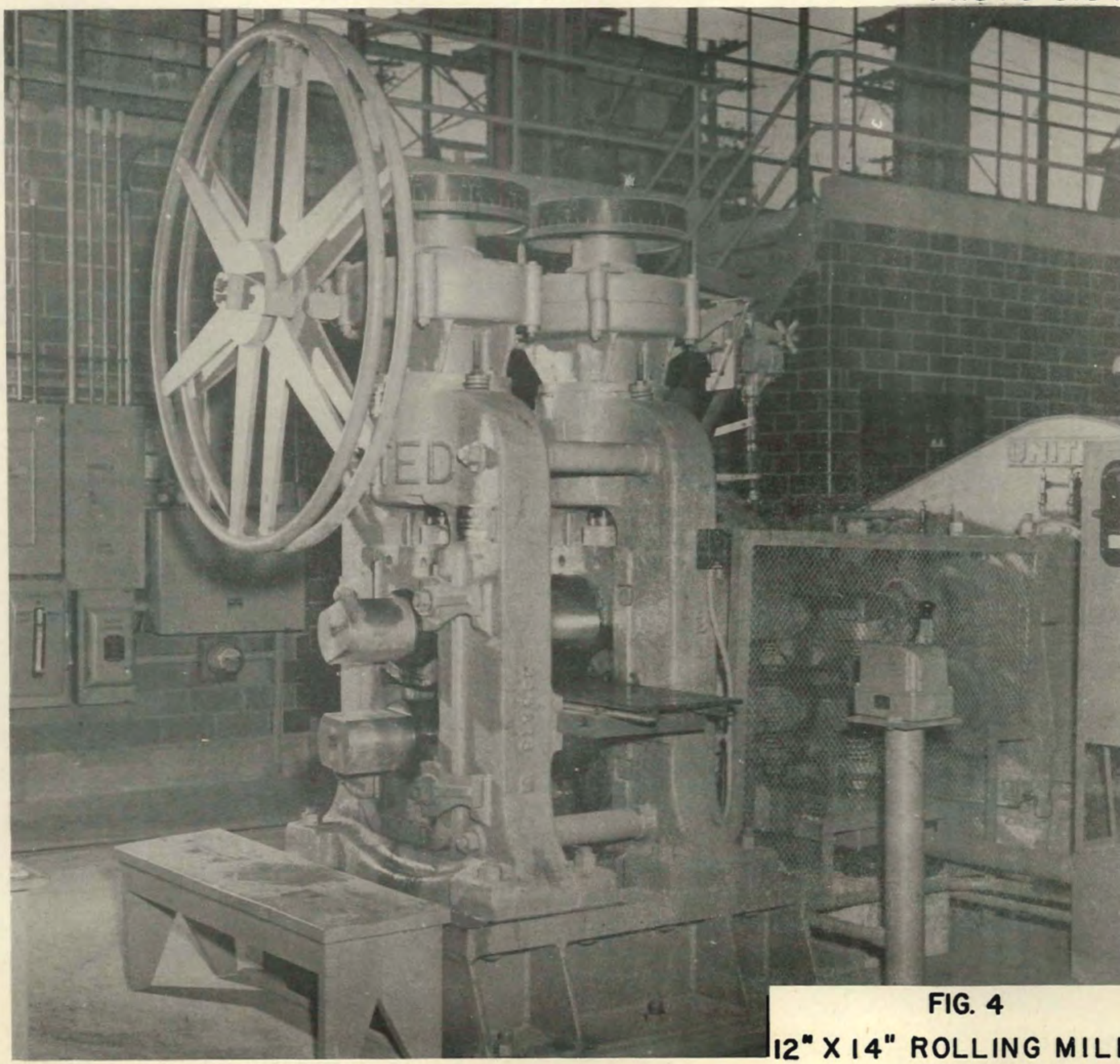

FIG. 4

12" X 14" ROLLING MILL

C. Cleaning — Nitric acid, Hydrofluoric acid, Trichlorethylene

EQUIPMENT

The major items of equipment grouped according to various operations are listed below. Additional information can be obtained from blue prints of the flow sheet and equipment layout included in this report.

Melting, Casting

(1) Spark Gap - High Frequency Converter - 25 KW
(2) 5" OD x 13" length graphite crucibles
(3) 3/4" OD graphite thermocouple protection tubes
(4) 3/8" OD stainless steel thermocouple protection tubes
(5) Chromel-Alumel thermocouples
(6) Portable Potentiometer, 0-1200°C
(7) Graphite molds - Inner chamber 1" x 5" x 8"
(8) Graphite sampling spoons

All graphite items are made of reactor grade graphite.

Rolling

(1) United Engineering & Foundry Company two-high rolling mill, maximum roll open 1-inch, 12" x 14", air driven screws, driven by a 75 HP, 600 rpm DC motor, gear reducer 15 to 1, universal couplings, both rolls driven, balanced top roll (Fig. 4).

(2) Mesta Machine Company two-high rolling mill, maximum roll opening of 1-inch, hand driven screws, 20" x 30" cast chilled iron rolls with no crown, driven by a 375 HP, 600 rpm DC motor, gear reducer 15 to 1, wobbler couplings, both rolls driven, balanced top roll.

(3) 2" x 6", hand-powered jeweler's rolls

Punching, Forming, Bending

(1) 75-ton hydraulic press manufactured by Hydraulic Press Manufacturing Company, equipped with punch and die.

(2) 100-ton Keckley hydraulic press with forming dies (Fig. 10).

(3) Brake for bending 1/8" aluminum sheet - 6" wide.

Shearing

(1) Crop shear - 1" x 6"
(2) Pexto shear, No. 0236, 1/16" x 4'
(3) Long Allstatter, 1/4" x 8', powered squaring shear

Cleaning, Fluxing

(1) Fuel Plate rack (Fig. 12)
(2) Blakeslee vapor degreaser, Type D25
(3) Cleaning tanks
(4) Flux trough (Fig. 13)

Drying, Heating Brazing

(1) Assembly drying jig
(2) Brazing jig
(3) Precision oven, catalog No. 1060, temperature range 35-260°C with on-off indicating controller, Wheelco type.

(4) Hevi-Duty Furnace, Type HD 153012, maximum working temperature 2000°F with Brown indicating and recording electronic controller with proportioning device.

(5) Lindbergh Cyclone Tempering Furnace, Type 244818EH, maximum working temperature 1250°F with indicating and recording Micromax control with proportioning device.

(6) Huppert Electric Box Furnace, Type ST with brown electronic temperature controller and recorder, maximum temperature 2000°F, chamber 24" x 27" x 72".

Inspection

(1) Norelco Searchray 150 KVP cabinet-type X-ray machine with fluoroscope (North American Philips Company, Inc.)

(2) Fuel plate gages used with fluoroscope for:
a. shearing guide (Fig. 8)
b. sheared plate core location check (Fig. 9)

(3) Micrometers
Standard (ranges 0-1", 1-2", 2-3", 3-4")
Chisel edge (range 3-4")
Depth (4" span)

(4) Special height gage for curved fuel plates (Fig. 11)
(5) Cam-type plate-spacing gage (Fig. 18)
(6) Surface plate, height gage, dial indicator
(7) Johanssen blocks

Miscellaneous

(1) Six pairs of tongs of various sizes for handling metal 1/16" to 1" in thickness

(2) Hand operated shop lifter
(3) Welding fixture (Fig. 21)
(4) Final machining fixture (Fig. 22)
(5) Assorted hand tools

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PHOTO 3990

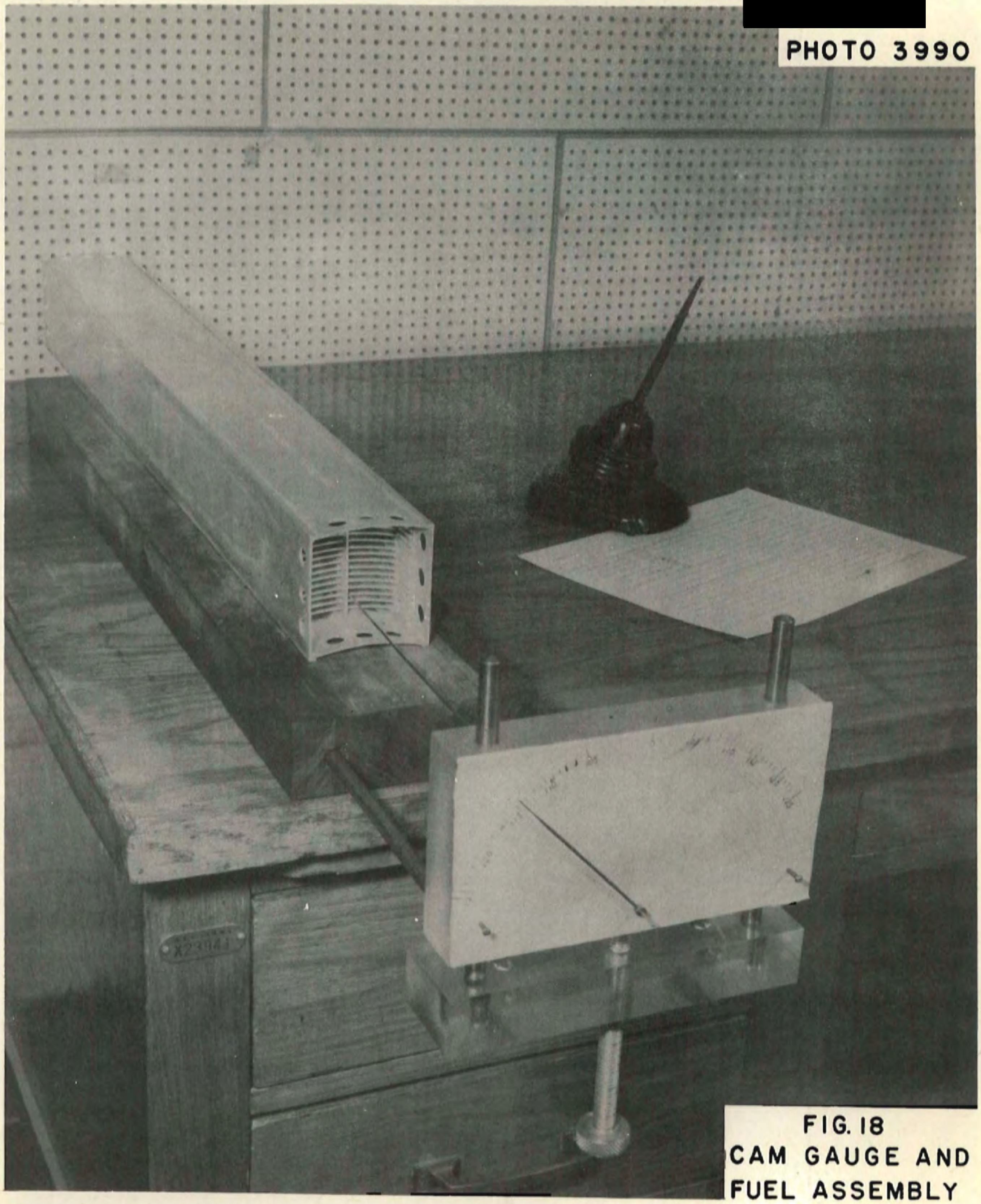

FIG. 18
CAM GAUGE AND
FUEL ASSEMBLY

LAYOUT AND ORGANIZATION

All operations, except machining and welding of end boxes, were carried out in the 101-B Building. Layout of this building is shown in Drawing TD-1205. During fabrication the building was designated a special restricted area with limited access.

Enforcement of access and material removal regulations was maintained by having a guard stationed at the front entrance while all other entrances were closed and locked. All uranium-bearing material was stored in locked combination safes at night. Four safes were provided for this purpose. Fabrication was handled on an 8-hour day, 5-day week basis as indicated below:

REACTOR COMPONENT DEVELOPMENT SECTION

F. Kerze - Section Chief

Casting, Rolling, Cladding

C. D. Smith - Group Leader
H. J. Wallace - Technician
C. F. Cutcher - Technician
F. M. Blacksher - Technician

Brazing Inspection

F. W. Drosten - Group Leader
J. N. Hix - Technician
G. E. Cooley - Technician

RESEARCH SHOPS (Machining)

P. Kofmehl - Superintendent

Further details on costs and manpower for production can be obtained from a memorandum by C. D. Smith to F. Kerze.[4]

FUEL PLATE PRODUCTION

Earlier work on the development of techniques for the production of fuel plates led to a procedure[6,7] which is outlined briefly below. With the start of actual production of fuel plates the yields of acceptable plates dropped off due to blistering induced by high ambient humidity. This led to a modified procedure in which blisters are prevented by treating the plates with brazing flux. The balance of the plates was completed without excessive rejection.

Standard Procedure

(1) Reduction, Alloying, Casting

Melt cryolite and U_3O_8 in graphite crucible
Add aluminum
Hold at 1150°C for 30 minutes
Cool to 825°C to freeze the slag
Reheat to permit slag cake removal

Puddle out remaining slag with graphite rod
Take two 5 gm. alloy samples with graphite spoon
Cast in graphite pig mold
Cool pig in desiccator

(2) Remelt

Melt pig in vacuum (ca. 100 micron)
Break vacuum, take two 5 gm. alloy samples
Cast ingot in graphite mold
Cool ingot in desiccator

(3) Ingot Rolling

Preheat ingot at 1100°F in dried air
Hot roll from 1-1/4" to 0.90" in 4 passes
Apply 0.050" 2S Al cover to both faces
Hot roll to 0.279"

(4) Punching

Punch 2" x 2.3" x 0.297" cores (Fig. 5)
Punch 2S Al frames with same die

(5) Core-Frame Rolling

Insert cores in frames
Preheat at 1100°F in dried air
Hot roll to 0.153" in 4 passes (Fig. 6)

(6) Cladding

Bend U-shape cover of 0.125" 2S Al
Insert Core-frame and press flat
Preheat at 1100°F in dried air
Hot roll to 0.070" in 4 passes
Anneal at 1100°F for 1 hour
Cold roll to 0.060"

(7) Testing and Inspection

First Group (Runs 1 through 24)

A total of 5.749.11 gm. uranium containing 5,433.51 gm. U^{235} was delivered as the chemical U_3O_8 in 23 batches.[10,11] Each batch was sampled, weighed and analyzed prior to use.

Production of plates was started November 1, 1949. Four virgin heats were made according to the procedure outlined previously. Scrap consisting of shrinkage void, trimmings from core punching operation and reject plates was recycled to four new heats with additional U_3O_8. Average charge to any one heat

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PHOTO 3972

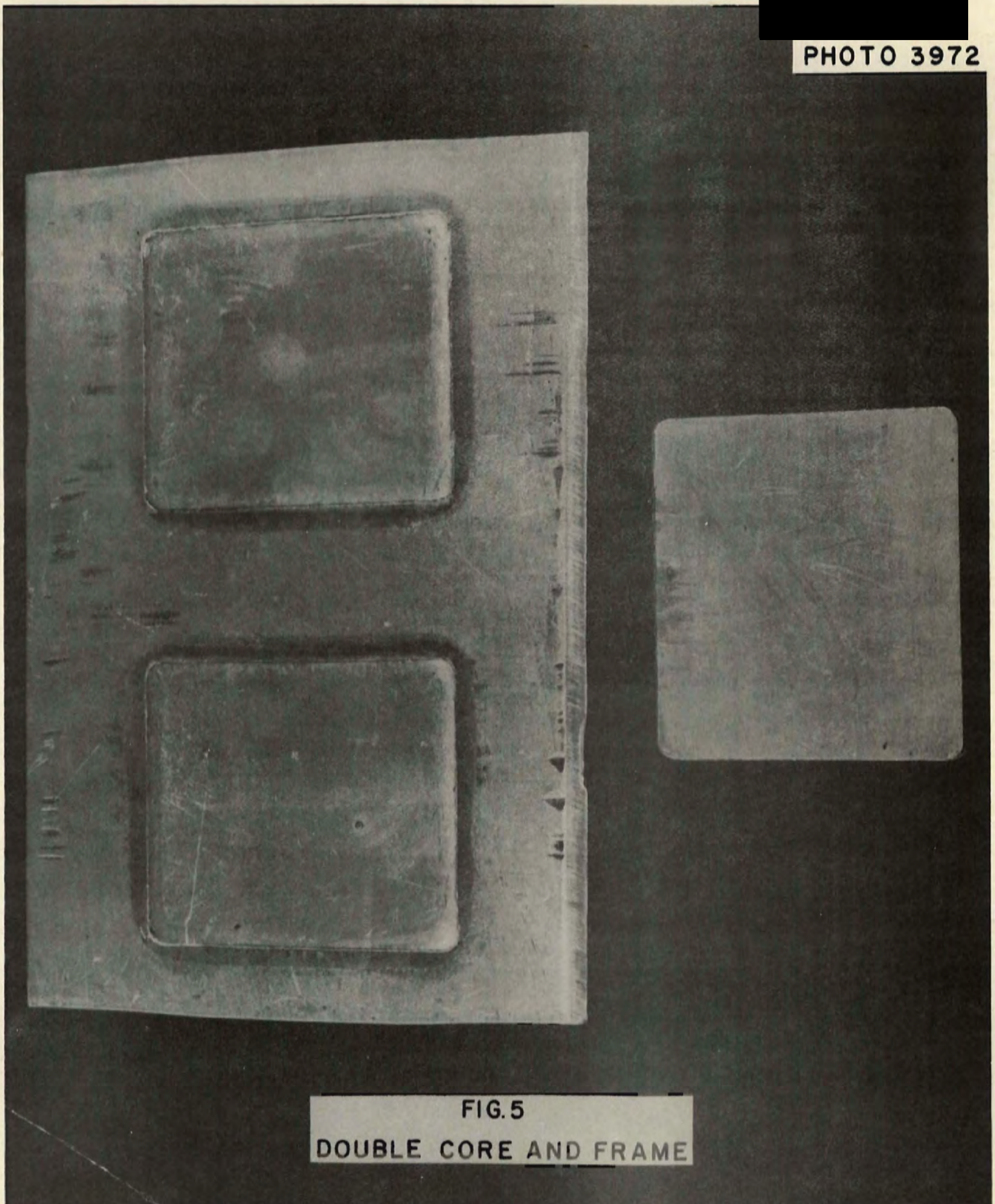

FIG. 5
DOUBLE CORE AND FRAME

[redacted]

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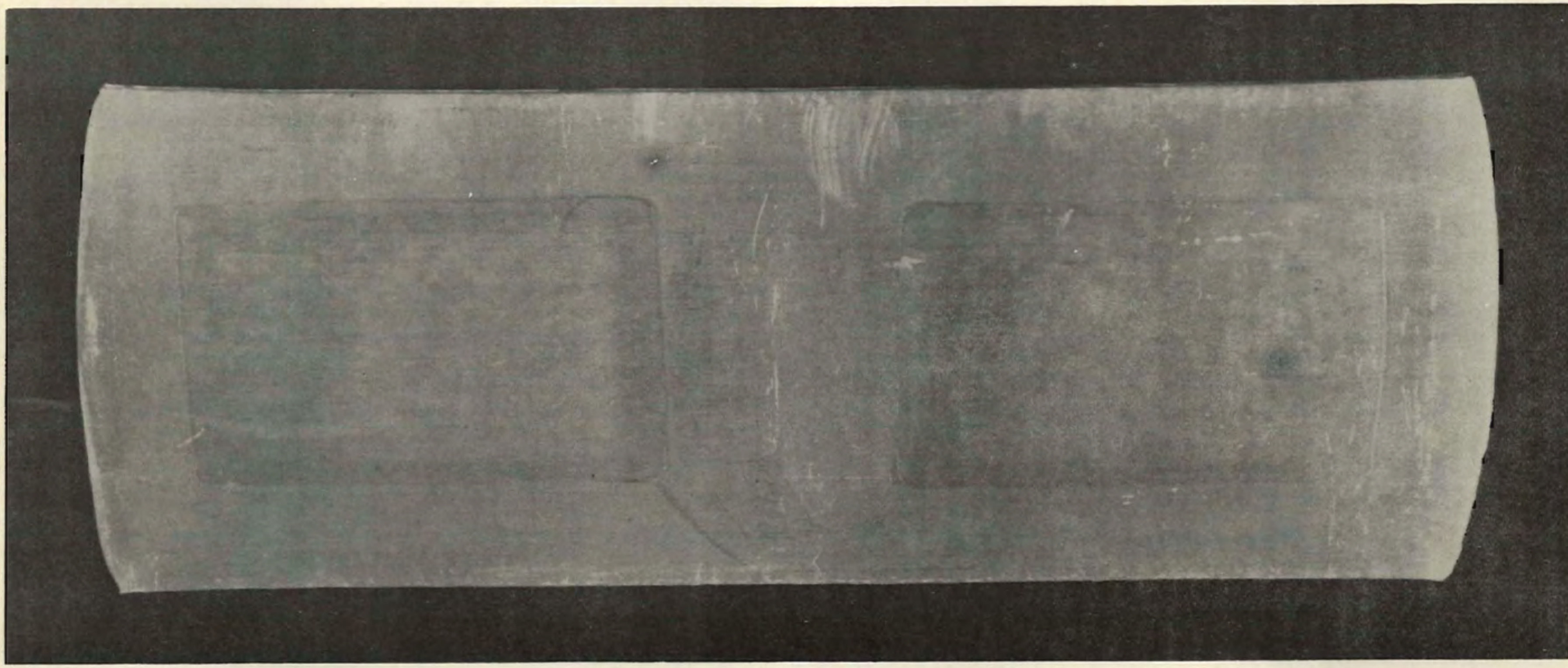

FIG. 6

DOUBLE CORE AND FRAME

(after pre-rolling)

was 300 gm. uranium. On January 10, 1950, 514 plates had been produced in 24 runs; of these, 247 were rejected because of blistering. Of the blistered plates, 66 were recycled to later heats along with the alloy, scrap and dross from all except the last 6 runs.

Blistered plates were far in excess of the number to be expected on the basis of work reported earlier.(7) A study of humidity data showed a correlation between blistering and the absolute humidity of the atmosphere at time of casting, pre-rolling and cladding, verifying earlier work. The humidity prevailing during the ingot breakdown seemed to have no bearing on rejections due to blistering. Table 3 lists yields and humidity data for each run. The trend toward poorer yield with increased absolute humidity is further illustrated in the distribution graphs in Fig. 7. Because of the poor yields obtained, further attempts at fabrication of fuel plates containing enriched uranium were stopped until workable remedies could be applied.

Blistering of Fuel Plates

Previous work indicated that the majority of blisters originated in the core material.(7) It is assumed that these blisters result from the release of hydrogen, which is relatively insoluble in both the aluminum and the U-Al alloy, and which is apparently formed by reaction with water during melting or any operation where the metal is hot. The gas should diffuse out if the metal is heated for a period of time at temperatures below that at which blisters are formed. It is necessary to heat to about 700°F to effect appreciable blistering in clad U-Al alloy.(6) It has also been shown(6) that there is a gas pickup in aluminum when it is exposed to the atmosphere at room temperatures for long periods of time, and that the gas is driven off by heating to 360°C (680°F) in a dry atmosphere.

Since the preventive measure of vacuum melting and dried air atmospheres in preheating furnaces had proved inadequate, a remedial approach to the problem was tried. It is known that clad U-Al plates which had not blistered when annealed in air at 1100°F for 3 hours could be made to blister by cleaning in NaOH and HNO_3 solutions, then coating with brazing flux and heating to 1100°F.(6) However, these blisters occurred in the adjacent unfluxed areas, not in the area which had been covered by flux. Accordingly, two ingots (N23 and N24) were cast in air and rolled according to standard procedures, substituting natural for enriched uranium and with the modifications in heat treatment shown below. To insure blistered cores, both ingots were quenched in water immediately after casting.

All of these plates were subsequently annealed at 1100°F for one hour. None of the plates which had been fluxed and heated or which had been vacuum annealed were blistered, whereas all of the others were. Blisters were more numerous on the plates which had been preheated at 360°C than on those processed by the standard procedure. Four of the blistered plates from run N24 were cold rolled to flatten the blisters, then fluxed, dried and heated 1/2 hour at 1100°F. The blisters then reappeared but were considerably smaller.

[redacted] DWG. 8401

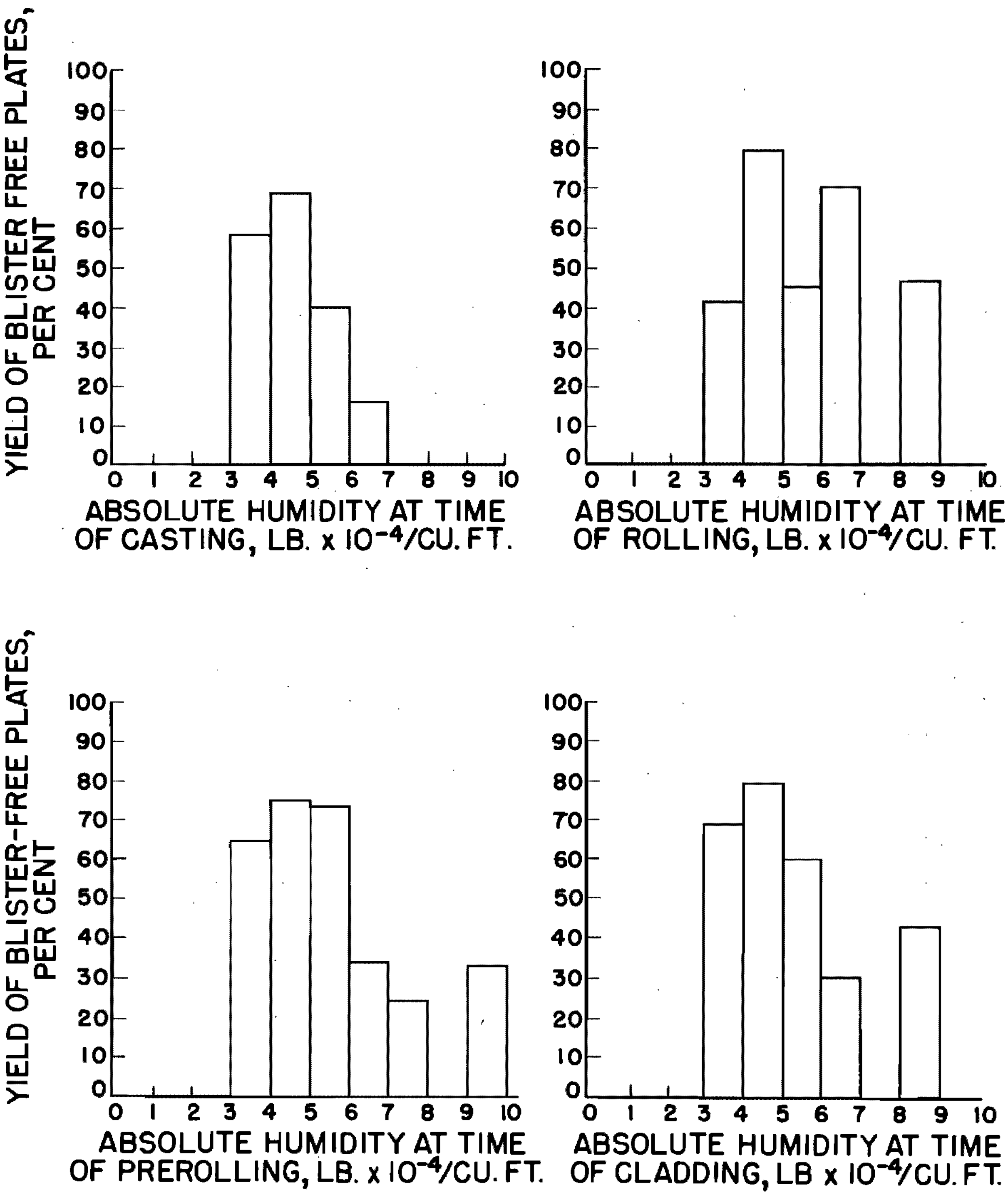

FIG. 7
RELATION OF HUMIDITY TO YIELDS OF BLISTER-FREE PLATES

TABLE III

Effect of Humidity on Yield of Blister-Free Plates

Run	Total Cores	Good Cores	% Yield	Humidity x 10^{-4} #/ft^3 Cast	Roll	Preroll	Clad	
1	20	14	70	3.6	4.8	4.5	4.5	Virgin
2	20	17	85	3.6	4.8	4.5	4.5	"
3	22	17	77	4.5	3.9	5.1	3.9	"
4	22	20	91	4.5	3.9	4.4	4.5	"
5	18	8	44	--	5.5	5.4	5.6	Scrap
6	22	1	5	--	5.5	6.0	6.5	"
7	22	19	86	5.5	7.2	5.9	5.2	"
8	22	12	55	5.5	7.2	5.3	6.2	"
9	22	16	73	3.6	4.2	4.6	4.6	"
10	22	12	55	3.6	4.2	3.6	3.3	"
11	22	17	77	4.6	5.5	6.7	8.2	"
12	22	12	55	3.8	5.5	6.7	5.3	"
13	22	21	95	4.2	4.2	5.5	4.1	"
14	22	22	100	3.3	4.2	3.9	3.2	"
15	20	2	10	3.2	3.8	9.4	5.9	"
16	22	12	55	4.6	9.1	4.0	4.0	"
17	22	12	55	4.0	3.8	9.9	7.5	"
18	22	9	41	4.1	9.1	3.5	3.5	"
19	22	4	18	6.4	3.5	7.3	7.3	"
20	22	0	0	5.9	6.3	6.7	7.8	"
21	20	3	15	5.9	3.5	7.4	7.5	"
22	22	0	0	6.6	6.3	7.0	7.4	"
23	22	15	68	3.6	4.5	7.7	7.7	Virgin
24	20	2	10	3.7	4.5	7.8	8.7	"
Total	514	267	Av. 52					

HEAT N23

No. of Cores	Procedure
4	Standard
4	Cores and frames preheated in dry air at 360°C prior to cladding
4	Vacuum annealed at 1100°F after cladding
6	Dipped in alcohol of Eutectic No. 190 flux and heated through the following cycle: 1/2 hour at 300°F 1 hour at 850°F 38 minutes at 1100°F
2	As above, without flux
20	Total

HEAT N24

No. of Cores	Procedure
4	Standard
4	Cores and frames preheated 2 hours in dry air at 360°C prior to cladding
12	Dipped in alcohol slurry of Eutectic No. 190 flux and heated through the following cycle. 1/2 hour at 300°F 1/2 hour at 1100°F
20	Total

From these experiments it appears that:

(1) Coating clad plates with a flux slurry and heating to 1100°F removes the blister-forming gas.

(2) Heating at temperatures lower than 360°C in dried air, prior to cladding, had no effect on blistering.

(3) Heating previously blistered and rolled plates with flux at 1100°F does not eliminate the blisters.

(4) Vacuum annealing removes the blister-forming gas.

Two additional natural uranium alloy heats were cast, rolled and treated with flux. After annealing these clad plates at 1100°F it was found that 2 of them had blistered. Since there was not a vacuum furnace available of sufficient size to handle annealing of plates on a production basis, this method of preventing blister formation was not tried further.

Second Group (Runs 25 to 35)

Production of enriched uranium plates was resumed with a modified procedure incorporating an extra step, that of heating the clad plates to 1100°F while coated with a slurry of brazing flux. Yields were much improved over those obtained previously, despite the fact there was not appreciable change in absolute humidity. Of 235 plates rolled, 201 did not blister. A listing of individual yields for each run is shown in Table 4. During the runs 31, 33, and 35, a very heavy coating was applied. A thin coating was brushed on the plates from runs 32 and 34. As can be seen from Table 4 the former treatment seems to be best. An average yield of 96% was obtained from runs 31, 33, and 35 while only a 69% yield was realized with runs 32 and 34.

Shearing

Plates that were blister-free were sheared to 3" width and 24-7/8" or 28-7/8" length. To insure proper core centering, guide lines were scribed with the aid of a special gage and fluoroscope (Fig. 8).

After shearing, the plates were again fluoroscoped and with the aid of a second special gage (Fig. 9), plates having cores within 0.160" of the edge are rapidly detected and discarded. Rejects are rare if moderate care is exercised.

Punching

Three 3/8" holes are punched at each end of the long top and bottom plates. These will accommodate the plug welds which join the fuel assembly body and the adapters.

Milling

After shearing, the plates were milled in groups of twenty or more, employing a side cutting milling machine operation. To maintain core centering

TABLE IV

Yield of Blister Free- Plates

Heat	Total Plates	Blistered Plates		% Yield
25	20	4		80
26	21	4		81
27	22	2		91
28	22	2		91
29	22	3		86
30	20	3		85
31*	22	0		100
32	20	6		70
33*	22	2		91
34	22	7		68
35*	22	1		97
	235	34	Av.	85.5

*Heavy flux coating applied; balance coated lightly.

similar amounts of metal were milled from all edges. After milling, burrs were removed by means of fine emery cloth. The milled plates were then examined fluoroscopically; only four plates were rejected because of exposed uranium aluminum alloy core.

Forming

The milled plates were then formed to a 5.5" radius by special dies and 25-ton pressure (Fig. 10).

Inspection of the curved plates was carried out by means of a surface plate and a special dial indicator gage (Fig. 11). Plates exceeding tolerance for longitudinal straightness or lateral curvature were re-formed; in some cases, flattening and reannealing was required.

AUXILIARY COMPONENTS

Side Plates

The grooved side plates were prepared by milling. Successive passes of a single milling cutter were made on sheets of 2S aluminum of proper thickness, held to the milling table by means of vacuum chucking. Inside ends of these side plates were milled to provide areas mating with corresponding areas on adapter castings. A punching operation provided holes for suitably plug brazing adapters into position.

Combs

Groups of combs were milled from braze-clad aluminum sheet. One of these used at each end of fuel body plate center line aids in alignment and reinforcement.

Braze Metal Strips

The braze metal strips were prepared by shearing rolled 11½% silicon-aluminum alloy sheet as follows:

	Braze Alloy	
Fuel Plates	Thickness, Inches	Width, Inches
Upper and lower	0.030	0.125
Internal	0.040	0.100

All strips were annealed after shearing and then straightened by stretching. They were then cut to lengths slightly longer than the corresponding fuel plates and the ends were rolled to 0.020" to facilitate subsequent attachment to the fuel plates by bending over the ends (Fig. 12).

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PHOTO Y-1440

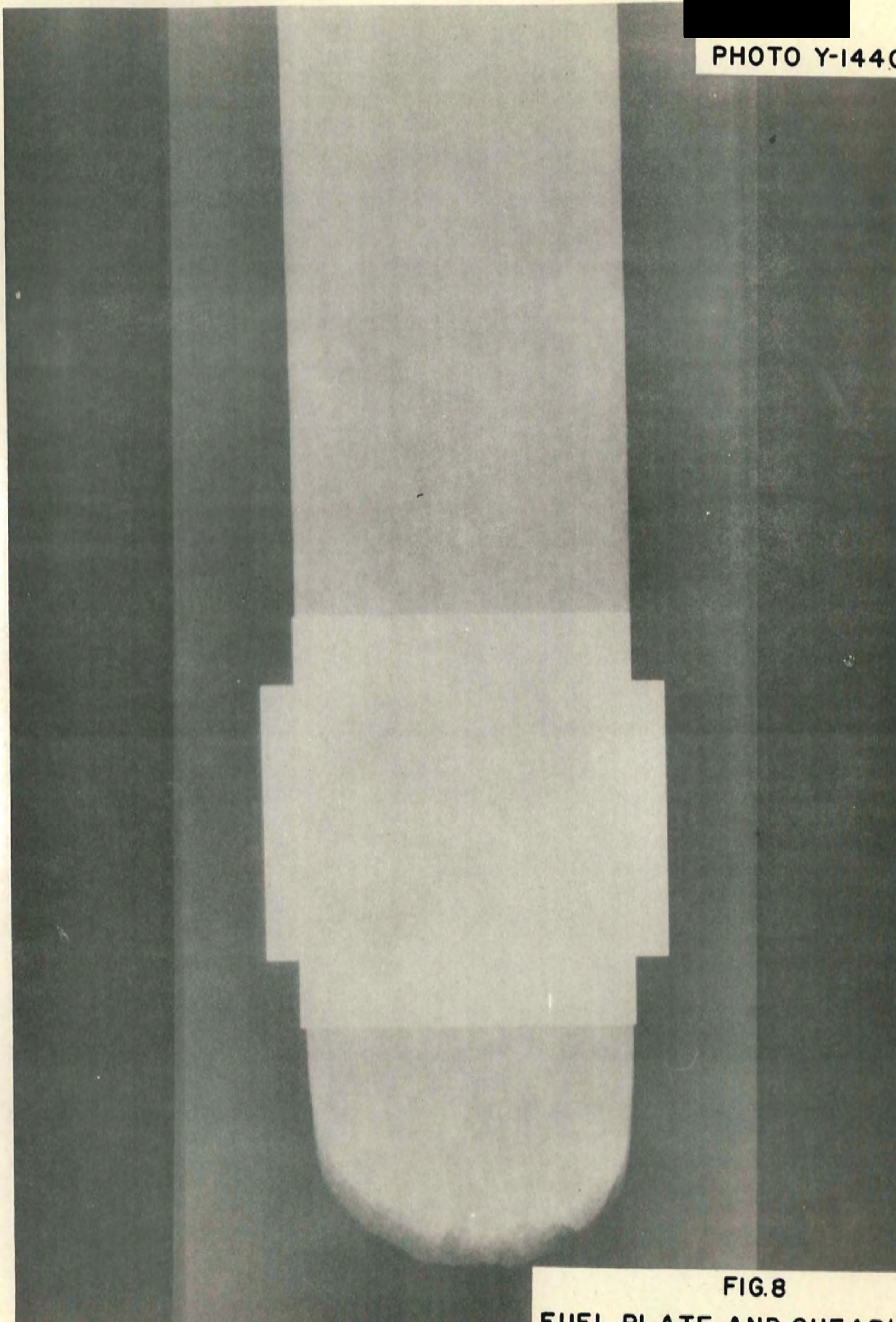

FIG.8
FUEL PLATE AND SHEARING GUIDE

[redacted]

PHOTO Y-1439

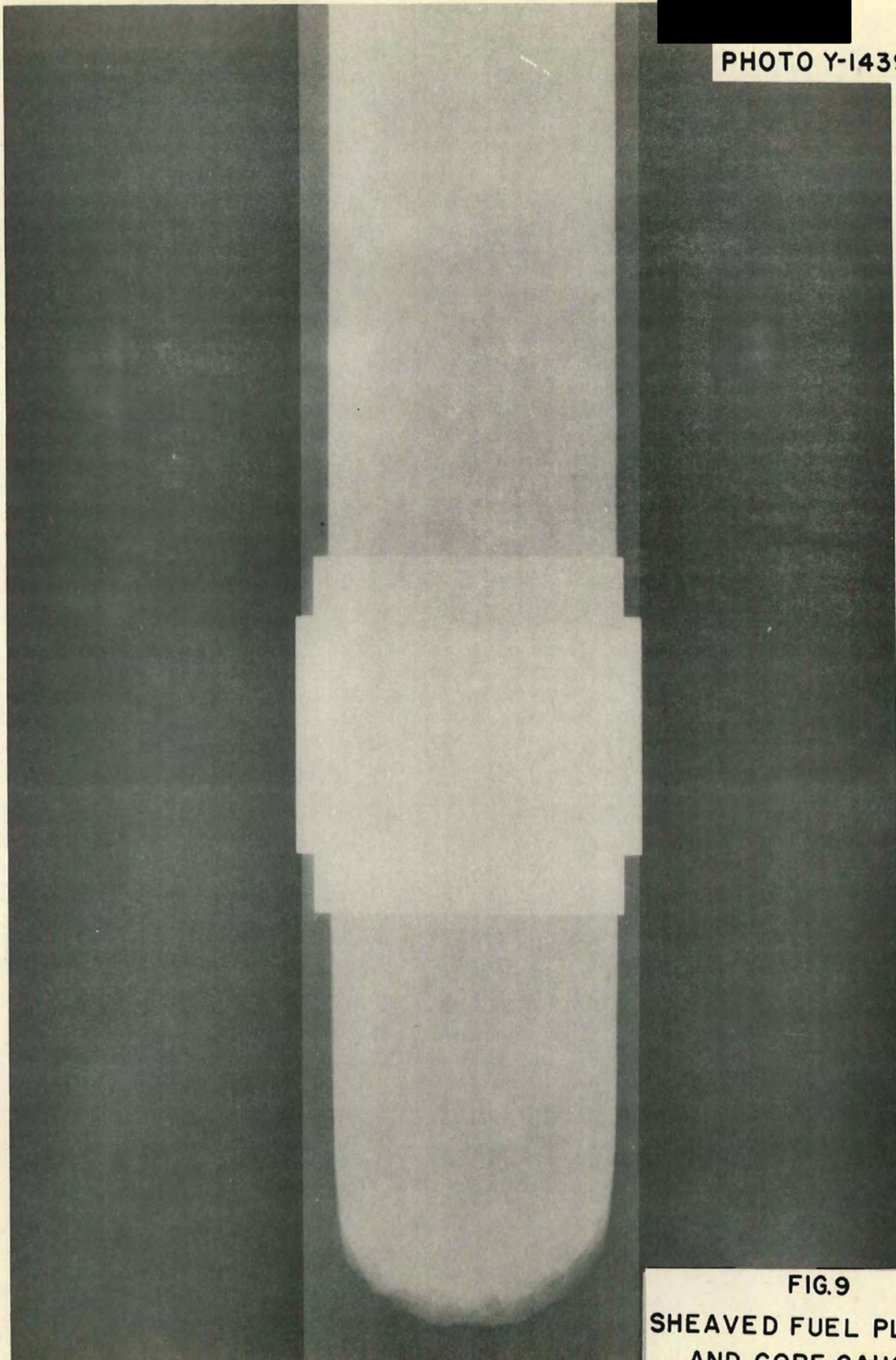

FIG. 9
SHEAVED FUEL PLATE
AND CORE GAUGE

Adapters

The fuel assembly adapters were received in the form of rough sand castings. An initial machining operation prepared one end for insertion into the fuel assembly body (after brazing and inspection). For machining, the adapter was jigged in such a way that the alignment permitted proper final machining of the cast surfaces after welding.

ASSEMBLY OF COMPONENTS

Cleaning

All parts to be brazed except fuel plates were cleaned by processing as follows:

(1) Vapor degrease
(2) Air dry at 300°F for 1 hour
(3) Acid dip (10% HNO_3, 1/4% HF)
(4) Water rinse
(5) Air dry at 300°F for 1 hour

The fuel plates were handled in a special stainless rack provided with spacers (Fig. 12). Fuel plates were degreased only.

Braze Strip Attachment

After the above cleaning cycle, clean cotton gloves were used in all handling of the parts. The braze strips were fastened to the upper fuel plate edges by bending over the ends (Fig. 12). Excess braze strip was trimmed with side-cutting pliers.

Brazing Flux Application

The brazing flux was used in the form of a slurry containing 300 gm. of Eutectic No. 190 aluminum brazing flux and 200 ml. of absolute methyl alcohol. The slurry was applied by dipping the fuel plate edge in a shallow aluminum trough (Fig. 13).

Excess flux was allowed to drip away from the edge first prepared, after which the opposite edge was treated in like manner. The fluxed plates were immediately inserted between side plates set in place in the assembly drying jig. One comb was fluxed and put in position in the comb holder (Fig. 14). The fluxed plates were inserted into position in the side plates and the comb, one at a time. After all but the top and bottom plates had been inserted, the other comb was fluxed and fitted into place. The top and bottom plate were then put into position. Since the drying jig had been extended somewhat laterally to permit easy insertion of fuel plates, it was then tightened into closed position.

BRAZING CYCLE

Drying

The assembly was dried in a circulating atmosphere electric oven at 300°F for a period of two hours.

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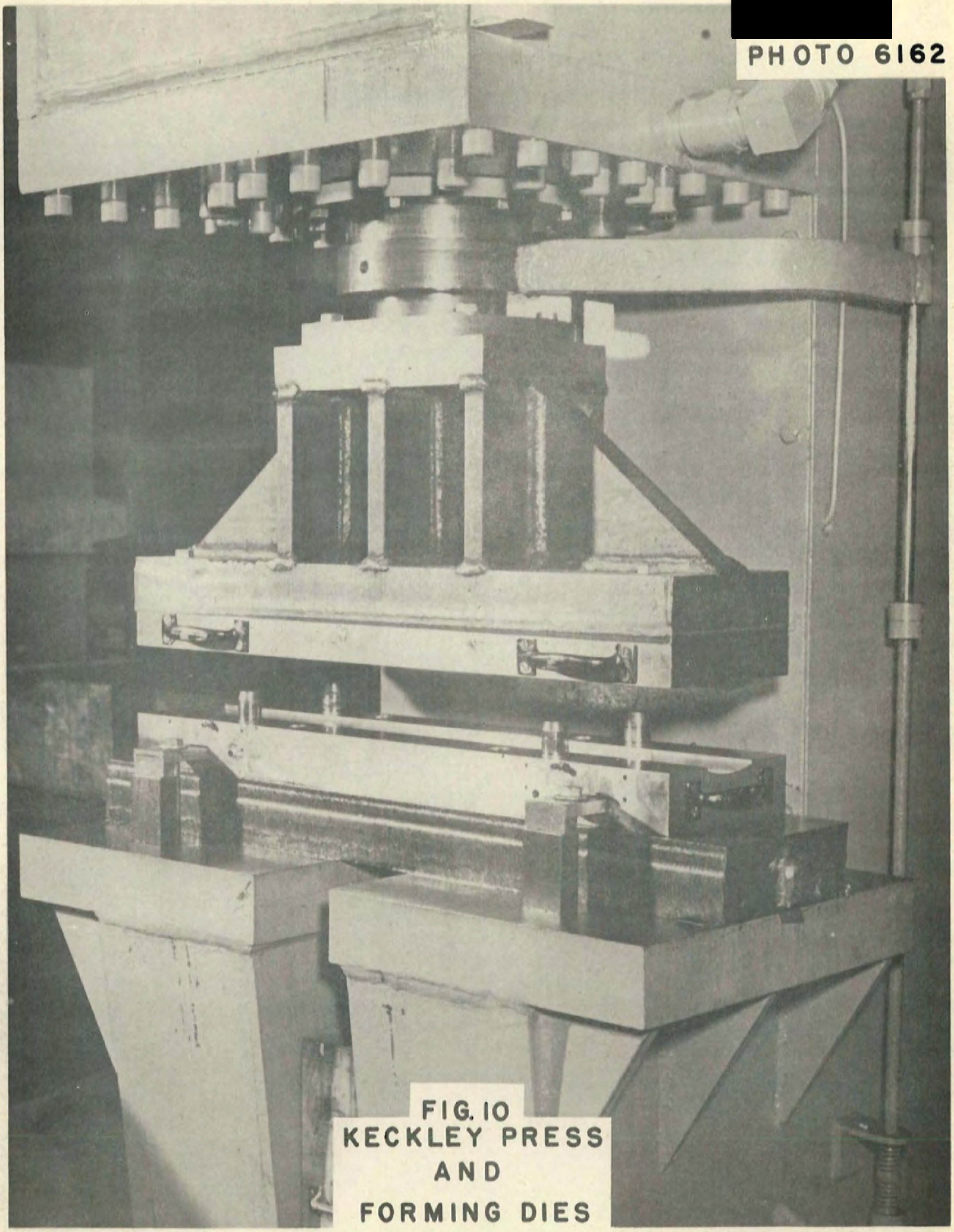

FIG. 10
KECKLEY PRESS
AND
FORMING DIES

[redacted]

PHOTO 3987

FIG. 11

INSPECTION OF FORMED PLATES

Preheating

The dried assembly was then removed from the drying jig and put, while hot, into a preheated ceramic jig. This brazing jig, consisted of four fitting pieces of Alsimag No. 202, fired and ground to such size as to allow for lateral expansion of the brazed aluminum assembly. Both the drying and brazing jigs are shown in Fig. 15. The dried assembly and jig were placed in the sand pan on the stainless steel charging cradle and charged into a box type electric furnace at a temperature of 850°F. The entire unit was allowed to remain in the furnace for a period of fifty minutes after the furnace air had regained control temperature.

Brazing

The entire preheated charge was removed (charging cradle, sand pan, jig and fuel assembly), and charged into the Lindberg convection furnace at a temperature of 1110°F. The furnace was allowed to remain at temperature for thirty-eight minutes, after which the controls were turned down, to allow solidification of filler metal. When the temperature had dropped below 1000°F, the assembly was removed from the furnace and the jig. Excess flux was removed by tilting the hot assembly. The assembly was then cooled with a blast of compressed air. Fig. 16 shows the drying oven and the two furnaces.

After use, brazing jigs were returned to the drying oven. This was necessary since the brazing fluxes are hygroscopic and mositure pickup in the jig may cause fracture of the structure upon reheating.

Cleaning

The cold assembly was washed first in hot, then in cold water, after which it was rinsed in cold 10% nitric acid (containing 1/4% HF). After cold water rinsing, the cleaned assembly was blown dry with a blast of air.

INSPECTION

Once the fuel bodies had passed the crucial brazing cycle, careful evaluation was required to determine advisability of further processing.

Although many measurements can be taken, the basic philosophy was to limit these to a small group of key dimensions which provided an adequate amount of information. The key dimensions are shown in Fig. 17.

The dimensional aspects of a fuel assembly body may be considered on two bases as follows:

Internal

In this case measurements of plate spacing are good indices. Abnormal plate spacing can result from:

a. Deviations in plate thickness. This is not common.

[redacted]

PHOTO 3986

FIG. 12

PLATE CLEANING RACK;
ATTACHING BRAZE STRIPS

[redacted]

PHOTO 3985

FIG. 13

FLUXING OF FUEL PLATES

b. Deviations in plate curvature. This can be prevented by:
I. checking milled plate width.
II. checking formed plate curvature.

Excessive spacing in one channel usually resulted in smaller spacing in an adjacent channel.

External

The fuel assemblies are nested quite closely together in the reactor core. The spacing between assemblies should fall within certain limits particularly between the external fuel plates of adjacent assemblies. The assembly spacing is affected by several characteristics as follows:

a. Lower adapter: The accuracy of this item was usually satisfactory as it was machined according to selected reference points on the fuel body.

b. Width: This was not much of a problem since the heat removal along the side plates was less than in the case of a fuel plate.

c. Center line thickness: This dimension was hard to control since variations in the outer fuel plates affect it.

d. Warping: This was not a problem since the brazing jigs are accurately ground. Warping could be detected by use of the surface plate.

e. External fuel plates: These tended to show some distortion as indicated in the sagitta and upitta measurements. As long as this distortion was not excessive, the condition could be compensated by using the plate centerline external surfaces as reference during final machining of the lower adapter.

A typical record card of measurements taken is shown in Fig. 19. These were obtained according to the inspection procedure outlined below. A plot of key dimensions for the 25 fuel assembly bodies is given in Fig. 20.

(1) Brazed Joints: These were examined visually by sighting along each channel toward a light source. Two types of brazing imperfections may occur and could often be remedied as indicated below:

a. Incomplete joints: These were corrected by local application of flux and a short strip of fluxed braze alloy and then rebrazing the entire assembly.

b. Braze alloy run-through: In this case an excess of braze alloy accumulated at the joints of the lower fuel plate. The excess could be removed by means of thin rods of aluminum or stainless steel at near-brazing temperature.

(2) Fuel Plate Surface: The surfaces were examined for blisters. Due to precautions taken earlier, the occurance of blisters was very infrequent. Those located outside of the core area were not considered serious. Those located inside the core area would interfere with heat removal particularly if they are large and if two blisters occur on opposite sides of a given point.

[redacted]

PHOTO 6166

FIG.14
ASSEMBLY OF COMPONENTS
IN DRYING JIG

[redacted]

PHOTO 3993

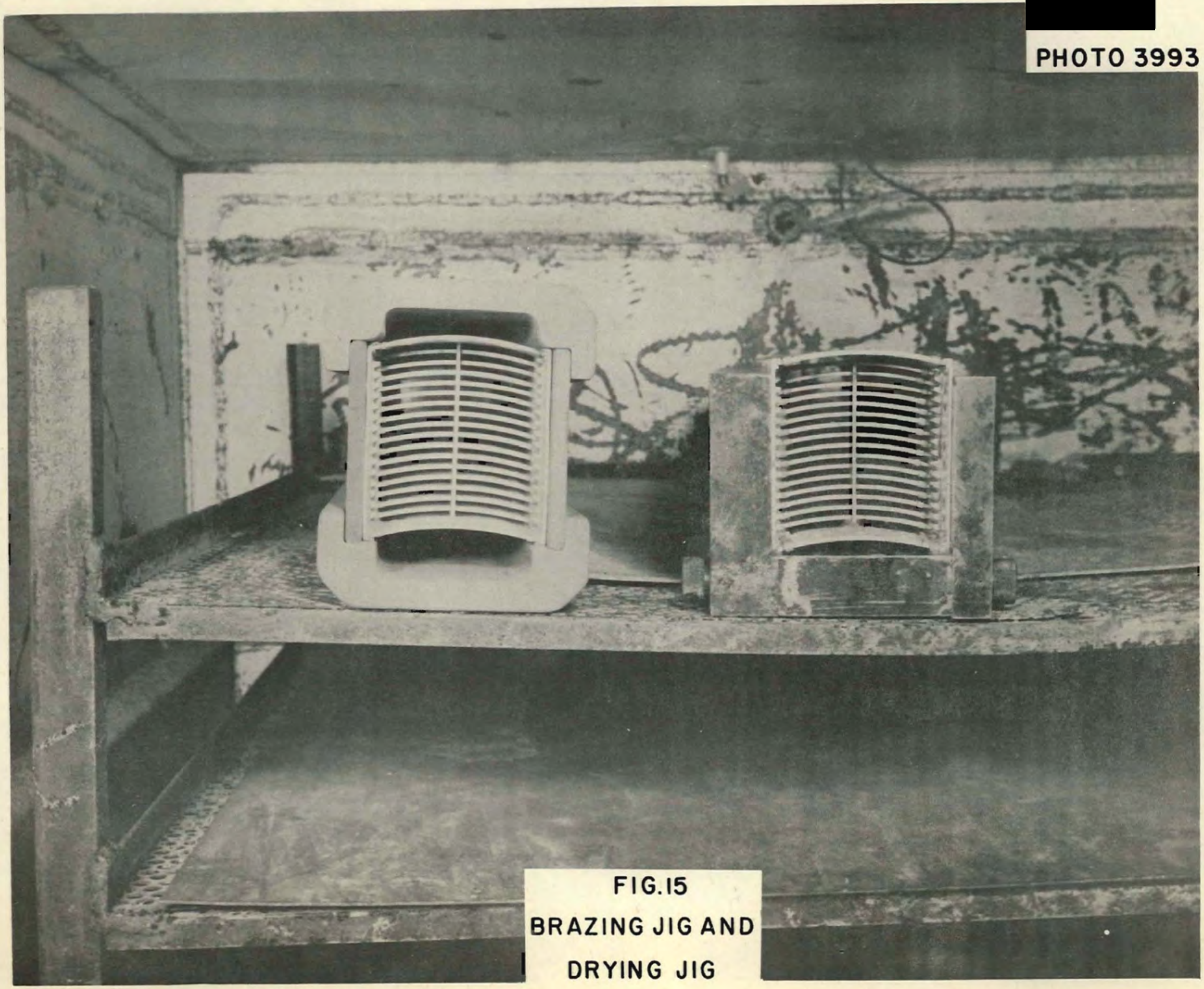

FIG. 15
BRAZING JIG AND
DRYING JIG

(3) Plate Spacing: Four measurements were obtained along the plate centerline by means of the cam gage.[20] Specifications call for a value of 0.117" ∓ 10%; this value was exceeded only in two measurements on one of the fuel bodies.

(4) Bottom Sagitta: Four measurements were obtained along the fuel body bottom by means of the depth micrometer. It should be pointed out that the value obtained is not a true sagitta but is somewhat larger.

(5) Vertical center height: Four measurements were obtained along the fuel body centerline with a 3" micormeter which has one anvil ground to a chisel-edge to accommodate the concave surface of the bottom plate.

(6) Width: Six measurements were taken with a standard 3-4" micrometer along the fuel body length at the top, center and bottom.

(7) Uppita: Six measurements were obtained by means of a surface plate, height gage and dial indicator.

An assembly having met the above requirements was then ready for further processing.

FINAL FABRICATION

Adapter Attachment

The fuel assembly body and adapters were aligned in a special welding fixture (Fig. 21). The joining was accomplished by the plug welding technique employing an argon-shielded wolfram electrode and 11½% Si-Al alloy rod as a filler. Special care must be taken to avoid distortion, particularly during the welding of the top and bottom plates.

Final Machining

The final machining determines the position of the fuel assembly bodies relative to each other in the reactor core according to the bottom and top supporting grids. The sequence of operations is as follows:

(1) Sides: The plug welds are milled flush.

(2) Top: A shaped cutter is used to mill the assembly body ends to 5½" radius flush with the surface of the top plate. This operation trims the side plates and removes excess plug material. About 2" from the end of the assembly body the cutter is raised gradually and continues along the assembly length, providing a curved side plate edge.

(3) Bottom: The bottom is prepared similarly by a second shaped cutter.

(4) Top Adapter: The assembly is aligned in a special machining fixture (Fig. 22) using the top and bottom plate centerline surfaces as references. The sequence is as follows:

[redacted]

PHOTO 6163

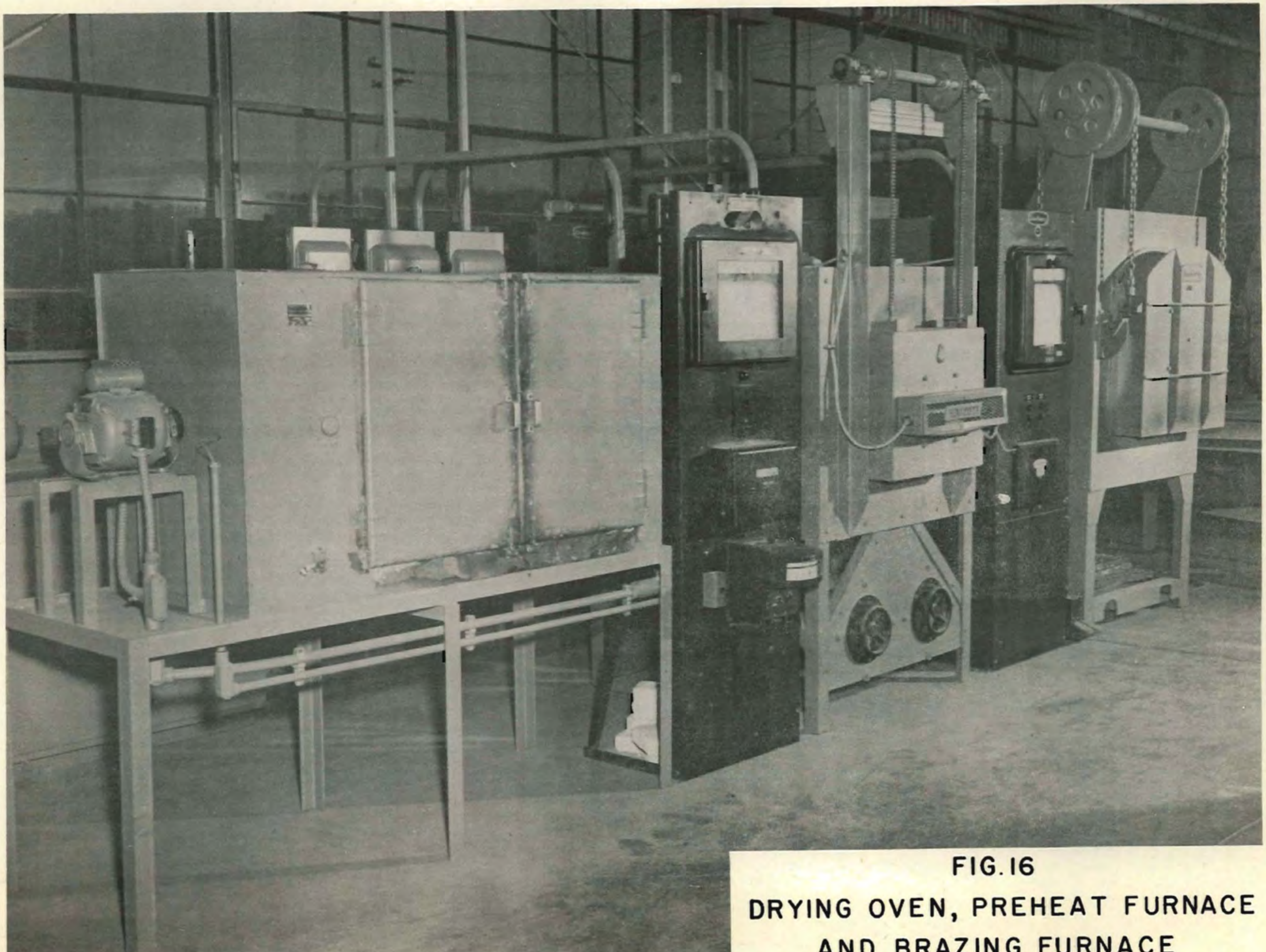

FIG. 16

DRYING OVEN, PREHEAT FURNACE AND BRAZING FURNACE

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DWG. 9081

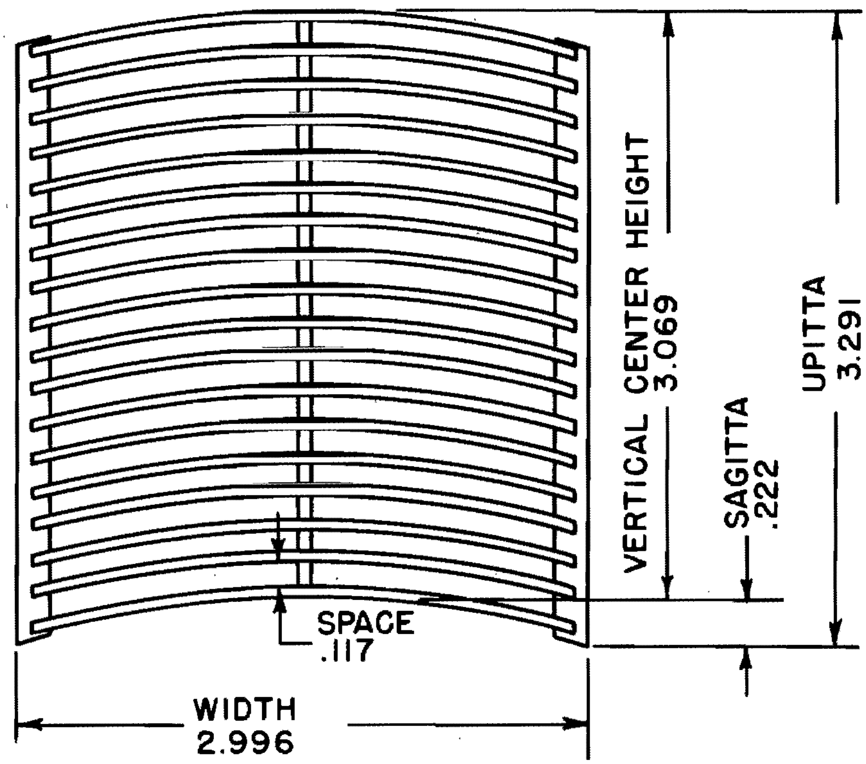

FIG. 17
FUEL ASSEMBLY DIMENSIONS

a. Machine cylindrical surface

b. Machine slot to fit a retaining ring for the helical spring and beveled ring which will be fitted later.

c. Machine the inside to the required diameter.

d. Cut away excess metal at end.

e. Drill a 3/8" hole diametrically to provide a grip for the assembly handling tools.

(5) Bottom Adapter: Using the same fixture as a guide, mill the various bosses to specification.

Final Inspection

Because the grid casting was available, this part was used as checking fixture for final fuel assembly inspection. A proposal has been made to substitute this part with a "go-nogo" inspection fixture. Additional surface plate inspection may be required if handling damage is suspected.

Storage

The completed units were wrapped in paper and cadmium foil. The paper layer prevents pickup by the assembly of small amounts of cadmium (CF 49-12-104 and CF 50-2-48).

SHIM-SAFETY ROD FUEL SECTION

As mentioned in the introduction, the shim safety rod fuel section is similar to the fuel assembly body; differences in parts or processes are indicated below:

(1) Fuel Plate: The fuel plate differs only in being somewhat narrower in width (2.684 ± 0.001"). These were selected from the stock of standard milled fuel plates with the aid of a third special gage and fluoroscope to permit further milling of the sides without exposing the core. About 50% of the fuel plates were suitable. After milling in groups of 14 plates a fluoroscopic check for core exposure was made.

(2) Top and Bottom Plate: The top and bottom plates are slightly shorter (27-7/16") than the corresponding fuel assembly plates. They were fabricated out of 1/2" 2S Al plate as follows:

a. Prepare inner curves surfaces (concave and convex) with special $5\frac{1}{2}$" radius milling cutters.

b. Mill the edges to fit the special wide grooves and to allow for braze strip placement and proper filleting.

(3) Side Plates: The side plates are of the same length as the thick top and bottom plates and are provided with wide outer grooves.

DATE: Brazed {1/3/50, 1/4/50}

FIG. 19

Assembly No. 198

Inspected 1/5/50

	A	WIDTH B	C	V C H	SAGGITTA	UPPITTA
2-1/2"	2.993	2.993	2.994	3.078	.223	3.304
7	2.991	2.993	2.992	3.071	.226	3.306
12	2.990	2.992	2.989	3.064	.231	3.309
16	2.988	2.991	2.990	3.065	.232	3.309
21	2.989	2.991	2.993	3.074	.223	3.306
26-1/8	2.993	2.993	2.994	3.077	.224	3.305
DESIGN						

	PLACE SPACING			
TOP	2-1/2	12	16	26-1/8
1	.119	.122	.120	.125
2	.117	.115	.115	.115
3	.119	.117	.118	.117
4	.115	.119	.117	.114
5	.116	.115	.116	.119
6	.115	.120	.117	.117
7	.119	.116	.118	.116
8	.115	.113	.113	.116
9	.116	.119	.116	.114
10	.116	.111	.116	.115
11	.115	.120	.120	.118
12	.117	.120	.116	.116
13	.114	.114	.117	.113
14	.119	.116	.115	.115
15	.117	.112	.116	.116
16	.117	.115	.117	.119
17	.115	.111	.111	.116

NOTES: Brazing time - 38 minutes.
All joints sound, no run-through.

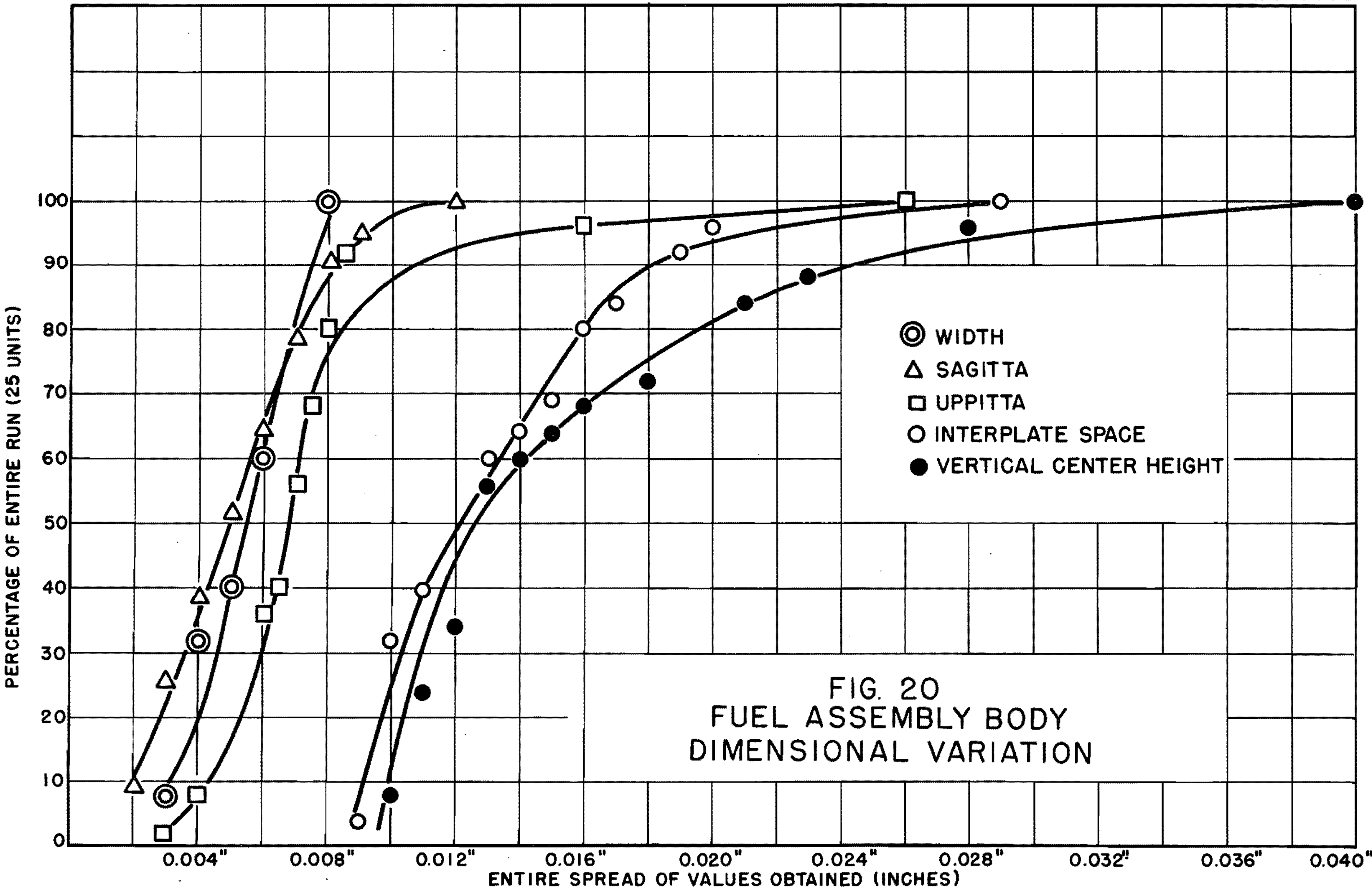

FIG. 20
FUEL ASSEMBLY BODY
DIMENSIONAL VARIATION

(4) Brazing: Thin 2S Al shims placed along the sides adapt the drying jigs to this narrower (2.837 ± 0.001") fuel section. The top plate braze strips (0.040" x 0.155") were laid in the grooves instead of fastened by bending over the ends.

(5) Machining:

a. Sides: If the section exceeded the required close tolerance in width, it was corrected by milling.

b. Top and bottom: Special cutters were used to shape the upper and lower curved surfaces.

c. Ends: The end internal surfaces were milled to fit:

I. stainless steel sleeve which joins the fuel and cadmium sections.
II. stainless steel shock lower assembly.

(6) Drilling: The section end holes were drilled and reamed to provide accurate machine screw fastening to the corresponding adjacent parts.

(7) Final Assembly: The various parts were shrink-fitted and fastened by stainless steel flat-head machine screws.

Further details may be obtained from the list of drawings tabulated below.[19] The drawings are in need of revision.

Safety rod	TD-302, TD-304
Shim rod	TD-303

FUTURE MODIFICATIONS

In the present stage of development of the MTR fuel assemblies, production can be carried out with practically no rejects. At this time it seems that some modifications in parts or procedures should be considered as follows:

(1) Side plates: The present technique of cutting the grooves individually is a carry-over from the development phase in which the groove angles were varied frequently. Cutting the grooves in one pass with a gang mill cutter would save machining time. A quotation of 43 cents per foot for grooved plates has been received; at this figure, 1000 feet would have to be ordered to cover the cost of the cutting tool.

(2) Adapters: These are received in the form of sand castings. With the freezing of the design, the use of permanent mold castings should be considered. This may eliminate the necessity of initial machining of the ends to fit the fuel body.

(3) Brazing cycle: Recent work indicates that it may be possible to braze the fuel body without using the drying and preheating steps. Further tests are planned.

[redacted]

PHOTO 6165

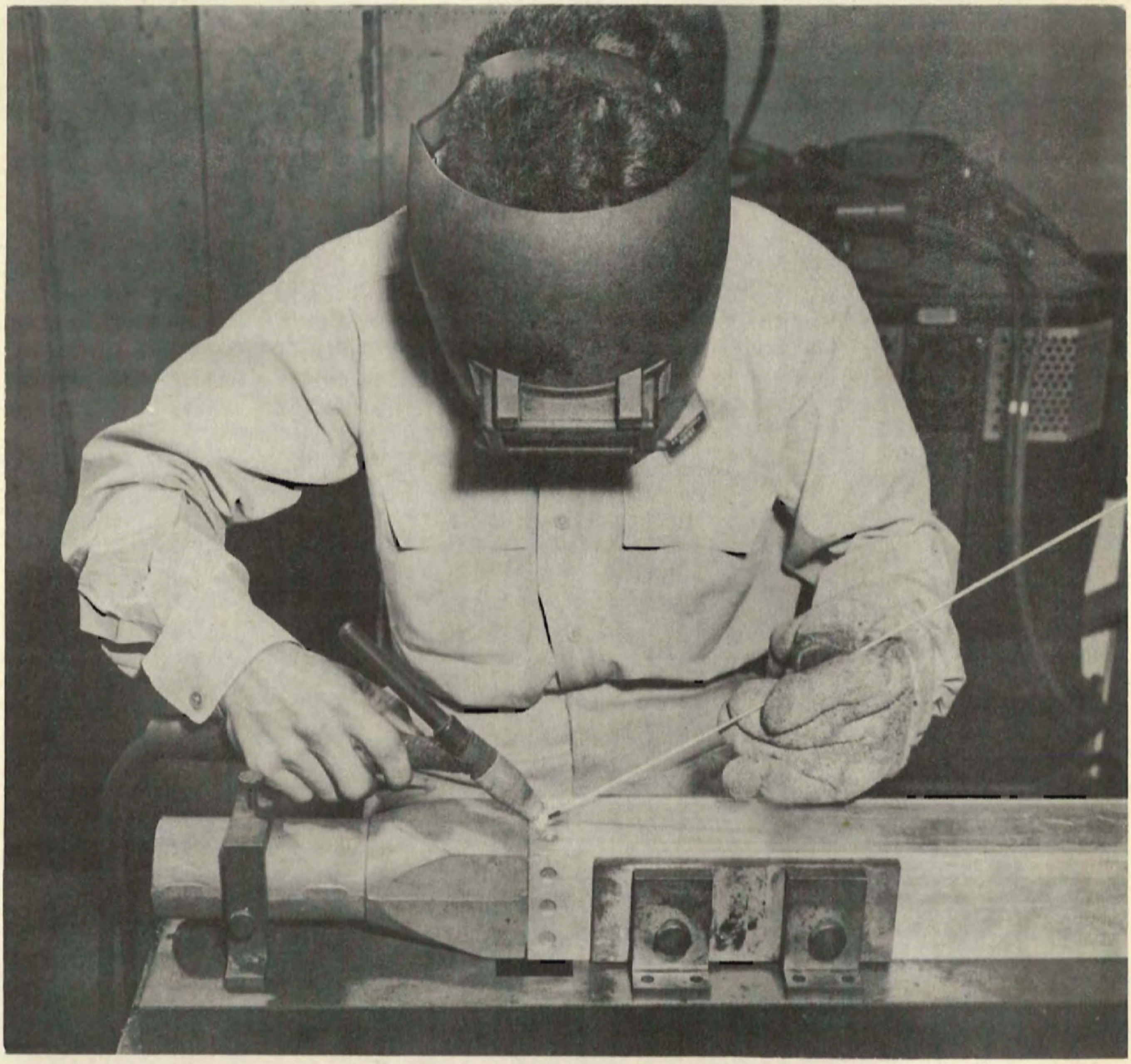

FIG. 21

PLUG WELDING OF UPPER ADAPTER

(4) Brazed joints: With the present techniques it seems that some brazing flux is always entrapped in the brazed joints. This occurs in the upper fillets as revealed by metallographic examination of fuel body cross-sections. Although the amount of flux is not detrimental from the standpoint of its lithium content, it would be desirable to eliminate entrapment altogether.

(5) Fuel plates: Some consideration has been given to the possibility of punching-out and curving the fuel plates in one operation after marking the core location. It is not known if the accuracy attained by this method is adequate.

ACCOUNTABILITY-PRODUCTION DATA

The active material (U_3O_8) was delivered in twenty-three containers. The amount of uranium in any one of these varied from 95 grams to 327 grams. The enrichment varied from 93.29% to 95.48%. The crucibles and molds used in reduction and remelting are designed for melts containing approximately 300 grams. Larger melts cannot be handled because of this limitation and the hazard involved with fissionable materials. Significantly smaller melts give lowered yields and are harder to handle. It was necessary, therefore, to mix material from several batches to obtain the proper charge.

It has been estimated that the charge of uranium in any one heat will subsequently be distributed as follows:

Analytical Samples	1%
Slag	2%
Piped Section of Ingot.	20%
Scrap from Punching Operation	22%
Clad Plates (Reject)	5%
Clad Plates (Acceptable)	50%

For economy of feed material, the 47% represented by reject clad plates, punching scrap, and piped section of ingot was recycled back to the melting operation. This involved additional mixing of uranium from different batches.

A breakdown of uranium distribution in the 35 heats is given in Table V. Duplicate samples were taken of each batch of U_3O_8 and from each melt, one sample being stored as a protection against loss of the one being analyzed. Samples were weighed only once by operating personnel. These weights were, however, checked by the analytical group prior to dissolution. Only 2 errors were found in approximately 100 weighings.

In the beginning, the pig was remelted only after receipt of chemical analysis. This resulted in a considerable amount of holdup of material. When this became apparent, it was decided to make a density determination on the samples from the reduction heat to determine uranium content using this as a basis for adjusting composition. This resulted in a greater scatter in final remelt analyses and ultimately in the uranium content of the cores. The actual range is illustrated in the distribution graph shown in Fig. 24. A similar graph showing the range of scatter of assembly uranium content is given in Fig. 23. The average U^{235} content of the 21 full assemblies was 138.73 gm.

[redacted]

PHOTO 6160

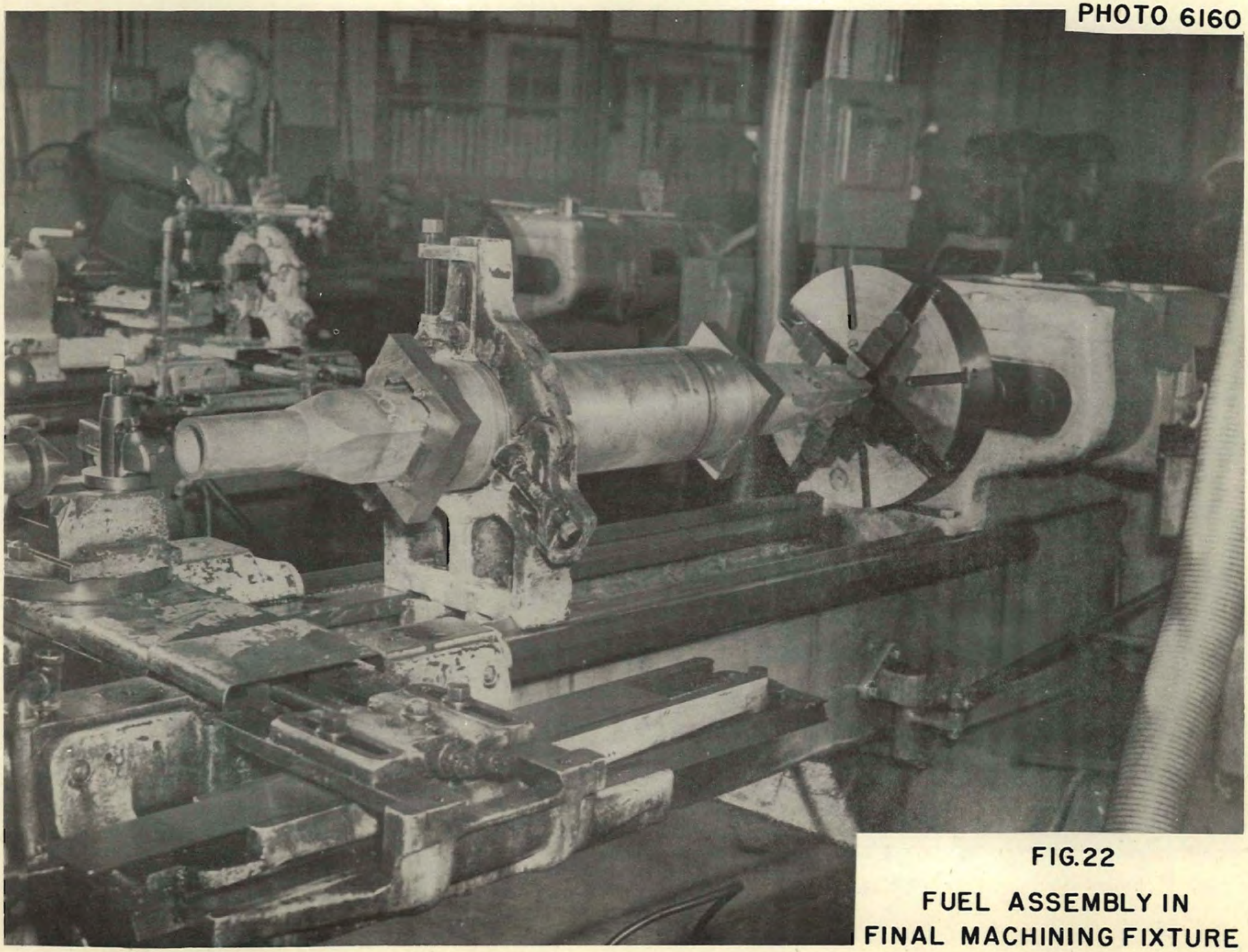

FIG.22

FUEL ASSEMBLY IN FINAL MACHINING FIXTURE

TABLE V

Uranium Accountability Data

		Weight, gm.
Received as U_3O_8		5,749.11
Charged as U_3O_8		5,591.38
Samples Transferred out	47.61	
Samples Stored (duplicates) . . .	40.96	
Good Plates	3,797.36	
Blistered Plates - not recycled	1,555.73	
Alloy Scrap from Last Run . . .	93.98	
Slag (35 runs)	55.72	
		5,591.38

Cores from any one ingot were weighed as a group, to the nearest milligram. It had previously been determined that there was not enough variance in individual weights among cores cut from a single roll slab with a punch and die, to warrant individual weighings. Variation was less than 1%.

Since the cores are clad during the ingot breakdown, it is necessary to apply a correction factor to the weight before multiplying the uranium percent to obtain the uranium weight,

where T_1 = thickness of alloy core

T_2 = thickness of Al cladding

d_1 = density of alloy core

d_2 = density of Al cladding

$$U \text{ Wt. (gm)} = \text{Core wt (gm)} \times \frac{T_1 d_1}{T_1 d_1 + T_2 d_2} \times \% U$$

In the case of a 13.3% U-Al alloy having a cladding which is 10% of the total thickness, the quantity $\frac{T_1d_1}{T_1d_1 + T_2d_2}$ resolves to the constant 0.91.

All weighings plus any other pertinent information regarding production was recorded in a bound notebook (CL1971). Appropriate operational information was recorded on suitable logs provided for the purpose. Complete material balances were made for each stage of manufacture which resulted in changes of amount or form of the uranium.

To check the possibility of contamination with natural U, melt samples from runs CE20 and CE34 were submitted to the Y-12 analytical laboratory for mass analysis. Calculated values and actual values as determined at Y-12 are listed below. Since approximately 40% of the charge to any one heat was scrap from previous heats, these values are a good check on the U^{235} enrichment of all heats.

	U Weight		U^{235} Weight	
Run	Calculated	Actual	Calculated	Actual
CE20	0.400 gm.	0.400 gm.	0.378 gm.	0.379 gm.
CE34	0.483	0.483	0.460	0.460

HEALTH PHYSICS

Air samples were taken during the various production operations to determine extent of hazards due to radioactive contamination. This work was conducted under the supervision of the Health Physics Division. Results are listed in Tables VI and VII. The principal source of high air activity was found to be any operation involving transferral of U_3O_8. In the first four heats, the procedure was as follows:

(1) Weigh U_3O_8 in bottle
(2) Add cryolite to bottle
(3) With stopper in place, mix U_3O_8 and cryolite
(4) Pour mix into aluminum cans
(5) Transfer cans to crucible
(6) Melt.

As can be seen from Table VI, high air counts were obtained. To minimize this contamination, the procedure was modified as follows:

(1) Weigh cryolite in bottle
(2) Add U_3O_8 to bottle
(3) With stopper in place, mix U_3O_8 and cryolite
(4) Transfer U_3O_8 - cryolite to crucible. Hood over crucible.

TABLE VI

Air Contamination during Weighing and Transferring U_3O_8

			Sample Time, Min.	Alpha Count M Curies/cc x 10^{-11}	% Tolerance
1-	Background		60	0	0
2-	Sample Weighing		45	0.25	8
3-	Weigh Charge, Mix, Can		30	14.0	461
4-	Weigh Charge, Mix, Can		15	1.9	61
5-	Transfer to Mix Bottle	1 heat	5	1.8	58
6-	Add cryolite	1 heat	5	9.75	315
7-	Can Mix	1 heat	5	51.5	1661
8-	Transfer, Add cryolite	1 heat	6	10.6	346
9-	Can Mix	1 heat	5	175.0	564
10-	Add oxide to bottle containing cryolite		5	9.0	290
11-	Add oxide to bottle containing cryolite		10	7.78	235
12-	Add oxide to bottle containing cryolite		30	0.83	26
13-	Add oxide to bottle containing cryolite		10	0	0

TABLE VII

Air Contamination During Melting

			Time, Min.	Alpha	% Tolerance
1-	Reduction Heats (3)		60 ea.	0	0
2-	Reduction Heat		60	0.27	9.0
3-	Reduction Heat		90	0.22	7.0
4-	Slag Removal		15	0	0
5-	Melting Mix	1 heat	25	0.54	17.0
6-	Add Aluminum, Melt	1 heat	45	0.22	7.0
7-	Reduction Heat		70	0.05	1.5
8-	Melting Mix	1 heat	25	0	0
9-	Add Aluminum, Melt	1 heat	45	0	0
10-	Vacuum Remelt		60	0	0
11-	Vacuum Remelt		45	0.02	0.6
12-	Vacuum Remelt		45	0.02	0.6
13-	Vacuum Remelt, Pour		70	0	0
14-	Vacuum Remelt, Pour		60	0	0

The air count was still above tolerance for the first 2 heats employing this procedure. However, contamination was kept below tolerance in later heats by pouring the U_3O_8 along the side of the bottle rather than "dumping" into the bottle. Table VII shows relatively little contamination during any of the melting operations.

Quantitative uranium determinations were made on urine specimens from the two individuals conducting the transferring and weighing of U_3O_8. To establish a norm for excretion for personnel not previously exposed to uranium hazards, determinations were made on urine specimens of five individuals. The average alpha activity for these was 0.25 counts/minute above background for 500 ml samples. The highest value was 0.55 counts/minute; the lowest 0.23 counts/minute. Results of uranium analysis of the two exposed persons are listed in Table VIII.

Smears were made on various pieces of equipment, on various surfaces in the working areas, and on alloy ingots and clad plates. Results are shown in Table IX. No counts were found on those taken in the main office, on the rolls, or on the clad plates. Some contamination was found on the floor and tables in the weighing and melting rooms. The highest value was obtained from the cutting edges of the shear used to crop the ingot prior to rolling.

TABLE VIII

α Activity of Urine Specimens

Name	Date	Volume Analyzed, cc	Cts/Min. Less Background
Operator A	11-2-49	200	0.458 ± 0.18
Operator B	11-2-49	150	0.308 ± 0.13
Operator A	11-3-49	170	0.140 ± 0.11
Operator B	11-3-49	250	0.226 ± 0.11

[redacted]

DWG. 10487

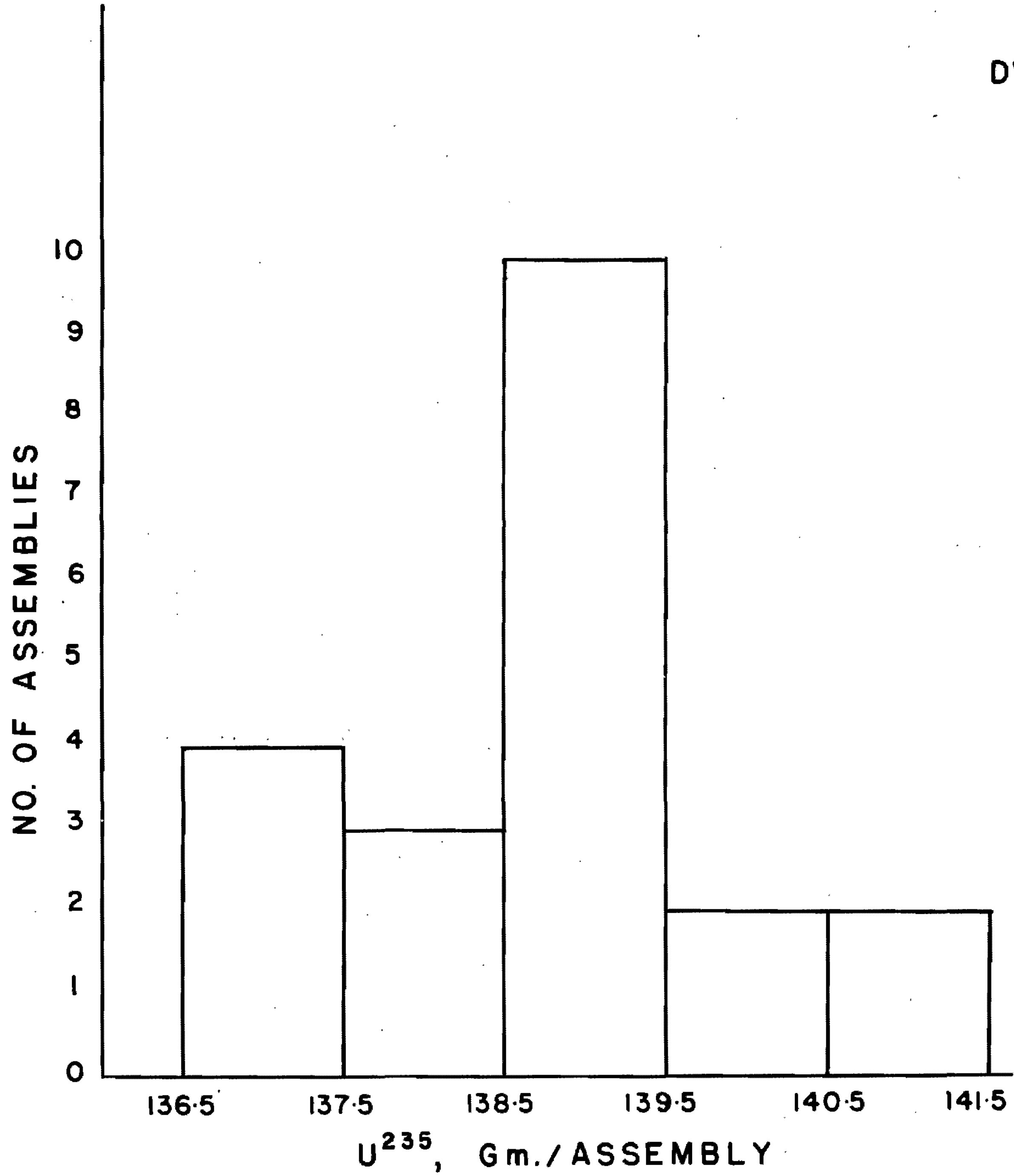

FIG. 23

DISTRIBUTION OF U^{235}

CONTENT OF FUEL ASSEMBLIES

[redacted]

DWG. 10488

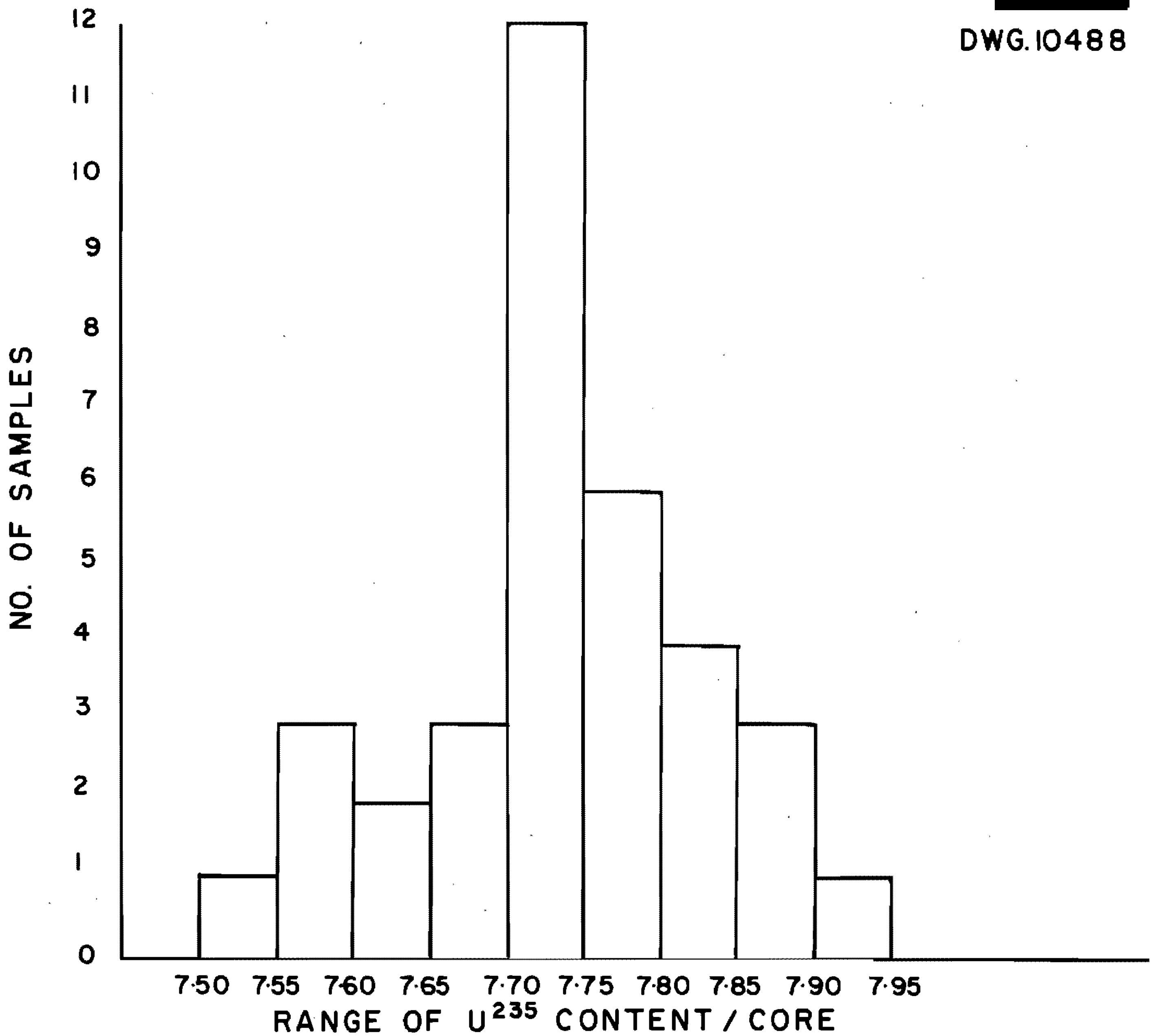

FIG. 24

DISTRIBUTION OF U^{235}

CONTENT OF CORES

TABLE IX

Activity of Smear Samples

Location	Alpha Counts/Minute	Beta Counts/Minute
U-Al Ingot	400	---
Clad Plates	--	--
Rolls	---	---
Crop Shear	45 to 1574	28 to 141
Office	--	--
Weighing Room	20 to 87	0 to 24
Melting Room	40 to 80	0 to 25

NOT CLASSIFIED

TD-1205

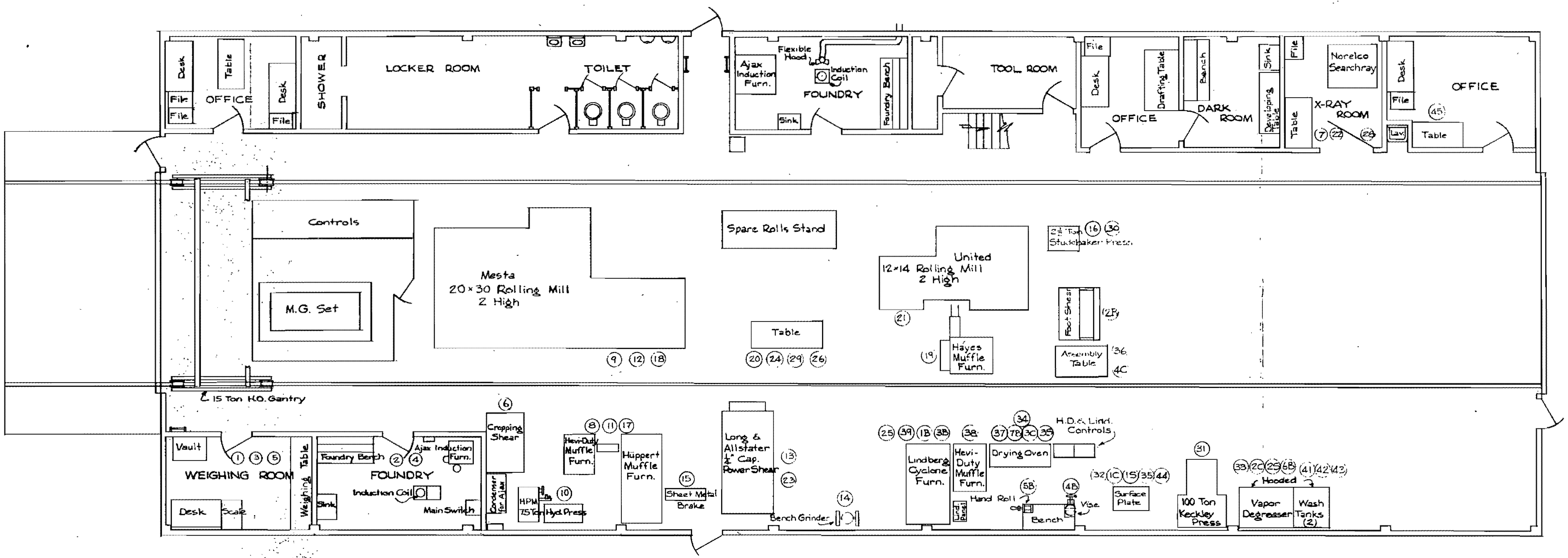

FIG. 25

Reference D1070

TOLERANCE UNLESS OTHERWISE SPECIFIED FRACTIONS ± 1/64 DECIMALS ± .005
BREAK ALL SHARP EDGES UNLESS OTHERWISE SPECIFIED.
FINISH MARKS ASA STANDARD.
DO NOT SCALE THIS DRAWING.

NOT CLASSIFIED

APPD.	DATE	OAK RIDGE NATIONAL LABORATORY
		TECHNICAL DIV. — P.O. BOX P. — OAK RIDGE, TENN.
		BUILDING 101 B EQUIPMENT LAYOUT FOR METALURGICAL ENGINEERING LABORATORY

DRAWN BY	DATE	SCALE
J.T. Howe	4-22-49	3/16" = 1'-0"
CHECKED BY	DATE	DRAWING NO. TD-1205

REV. NO.	REVISION	APPD.	DATE

[redacted]

TD-1109

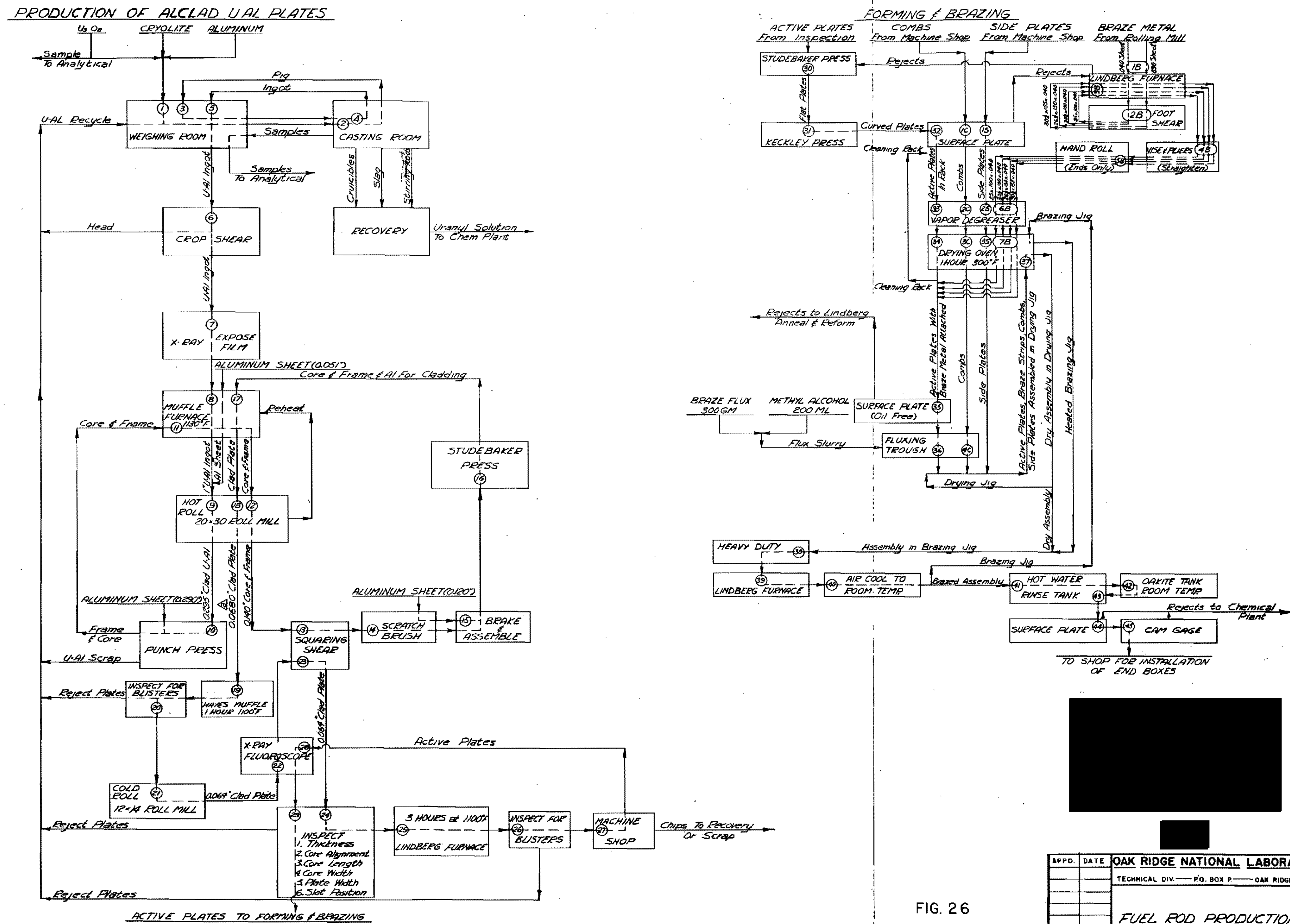

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FIG. 26

APPD.	DATE	OAK RIDGE NATIONAL LABORATORY
		TECHNICAL DIV. — P.O. BOX P — OAK RIDGE, TENN.
		FUEL ROD PRODUCTION

DRAWN BY	DATE	SCALE		
ROBERTS	3-4-49	None		
CHECKED BY	DATE	DRAWING NO.	TD-1109	REV. a

REV. NO.	REVISION	APPD.	DATE
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