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METALLURGY DIVISION

QUARTERLY PROGRESS REPORT FOR PERIOD ENDING JANUARY 31, 1950

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METALLURGY DIVISION

J. H. Frye, Jr., Director

QUARTERLY PROGRESS REPORT

for Period Ending January 31, 1950

Edited by

E. C. Miller

DATE ISSUED: MAR 10 1950

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SUMMARY

Hanford Slug Problem. The study of distortion of uranium by thermal cycling of Hanford canned slugs has been attended by experimental difficulties which place serious limitations on the accuracy of the work. To remedy these, long bare uranium test bars have been substituted in some of the tests for the more complicated canned slug assemblies. Corrosion of the bare uranium bars has led to additional experimental work to develop protective coatings, some of which now appear promising.

ORNL Slug Problem Aluminum-silicon bonded ORNL-size slugs have shown no indication of failure under thermal conditions which would have caused early rupture of unbonded slugs.

Fuel Elements for the Materials Testing Reactor. Production of fuel plates and assemblies for the MTR has proceeded according to schedule, in spite of some difficulties due to blistering. An effective remedy for blistering of the fuel plates appears to have been found. This consists of dipping the plates in brazing flux and then heating to 1100°F.

Fuel assemblies containing enriched uranium are being completed for the MTR critical experiment, within tolerance and without rejections.

The possibility of producing long MTR-type fuel assemblies is being studied and plans are being made for procurement of the necessary additional equipment.

Beryllium. Experimental beryllium work for the MTR has been limited to low temperature extrusions on the ORNL press, preparation of samples for studying the combined effects of irradiation and aqueous corrosion in the Hanford pile, and further development in deep-hole drilling techniques.

Aircraft Reactor (ANP Program). The Division is initiating an extensive program of investigation of potential materials for incorporation into a nuclear reactor to be used for the Aircraft Propulsion Program.

An extensive experimental static corrosion survey of the broad field of high temperature materials and potential coolants is in progress. From the results of this survey, the more promising combinations will be selected for dynamic corrosion, mechanical, heat transfer, and irradiation testing.

Thorium. An induction furnace for melting and casting thorium under vacuum is being made. The vacuum system for the arc melting furnace has been completed and tested. With the arrival of high purity thorium and the availability of this additional furnace equipment, the study of the properties of

thorium and its alloys is being accelerated.

Preferred Orientation and Anisotropy in the Properties of Metals. A new method has been devised for accurate determination of the type and degree of preferred orientation in metals, employing a Geiger counter X-ray diffraction goniometer. It has been employed to determine the preferred orientation in some alpha-rolled uranium bar. In addition to the two fiber textures that have been reported previously, a third type of fiber texture has been found.

URANIUM SLUG PROBLEMS

HANFORD SLUG PROBLEM

Thermal cycling of uranium in connection with the study of distortion of uranium in the Hanford Pile has been continued during the past quarter to include:

(1) Cycling of standard Hanford slugs at relatively low end loads and at approximately 300°C center temperature, as previously described in ORNL 511;[1]

(2) Preliminary cycling of bare uranium rods, as outlined in ORNL 511.[1]

Thermal Cycling of Hanford Canned Slugs. Continued cycling of the standard Hanford slugs with end loads of the order of 1200 to 1500 pounds and center temperatures of roughly 300°C, has not produced distortion after approximately 300 cycles, as indicated by Table I. A test rod (No. 26) made from gamma extruded slugs has been cycled 329 times without showing sufficient distortion to indicate that the changes in dimensions found between 284 and 329 cycles were not due to inaccuracies in measuring the can around the uranium slug. Cycling of this rod is being continued to see if the 0.003 inch increase in average diameter experienced in the last 45 cycles is an indication of actual distortion of the slug.

Measurements taken on alpha rolled lead dipped slugs (Rod 28) after 98 cycles indicated that the lead dipped material was going to elongate. However, continued cycling of this and No. 31 rod did not show any further indications of growth in length. Breakage of the bond between the uranium core and the aluminum can, previously thought to be a contributing factor in distortion, did not have any appreciable effect in the case of slugs Nos. 112 and 114 and in the No. 31 rod.

Thermal Cycling of Bare Uranium Bars. Preliminary work has been started toward cycling bare uranium bars, as indicated in ORNL 511.[1] The test bars, 34-1/8 inches long, were made from uranium bar stock obtained from Hanford. Diameters and lengths of the test section have been varied as dictated by difficulties in operation.

It is the intent of these experiments to test bare uranium in an effort to overcome the difficulties associated with accurate measurement of the dimensions of canned slugs and rupture of the cans during cycling.

(1) Frye, J. H., Jr., *Metallurgy Division Quarterly Progress Report for Period Ending October 31, 1949*, ORNL 511 (January 12, 1950).

TABLE I

Thermal Cycling of Hanford Slugs

ROD NO.	SLUG NO.	SLUG NO.	SLUG NO.	NUMBER OF CYCLES	LENGTH OF CYCLES (hours)	END LOAD (lbs)	CENTER TEMP. (°C)	TEMP. GRADIENT (°C)	CHANGE IN LENGTH (Percent) (Slug numbers indicated in parentheses.)		CHANGE IN DIAMETER (inches)		POWER INPUT (Kw/ft of U)	COOLING WATER VELOCITY (ft/sec)	REMARKS
GAMMA EXTRUDED SLUGS (8 inch)															
26	88	87		108	2	1480	304	210	None		(88)-000	(87)+.001	71.2	41.3	Cycle-Even increase 1 hr at peak 30 min, cool 30 min
	88	87		108-186	2	1240	276	190	None		(88)-000	(87)+.001	66.6	39.4	
	88	87		186-284	2	1200	302	206	None		(88)-000	(87)-000	75.7	39.0	
	88	87		284-329	2	1500	302	206	(88)-0.4	(87)-00	(88)+.003	(87)+.001	73.5	39.6	No change apparent except slight increase in diameter
ALPHA ROLLED TRIPLE DIPPED SLUGS (4 inch)															
27	68, 77	75, 67		18	2	1480	362		None		None			44.0	Pump switch was accidently tripped while rod was on peak load. Cans melted on slugs before automatic stop kicked out
ALPHA ROLLED LEAD DIPPED SLUGS (4 inch)															
28	98, 96	97, 101	92, 91	98	2	1410	290	190	(98)+0.4	(101)-0.0	(98)-0.001	(101)-000	54.7	40.0	Cycle-Even increase 1 hr, at peak 30 min, cool 30 min
									(96)+0.4 (97)-0.0	(92)-0.0 (91)+0.2	(96)-0.001 (97)+0.001	(92)-000 (91)+0.003			
	98, 96	97, 101	97, 101	98-180	2	1350	272	175	None		(98)-000 (96)-000 (97)-000	(101)-000 (92)-0.001 (91)-0.002	51.8	39.4	
	98, 96	97, 101	97, 101	180-290	2	1420	279	180	None		(98)-000 (96)-000 (97)-000	(101)-000 (92)-000 (91)+0.001	53.0	39.5	No. 91 slug has grown out of round and swelled slightly in center
31	114, 113	112, 111	110, 115	153	2	1530	284	105	None		(114)+0.001 (113)-000 (112)+0.001	(111)-000 (110)-000 (115)-000	58.5	40.7	Frost test indicates the can is loose on slugs No. 112 and 114
	114, 113	112, 111	110, 115	153-175	2	1900	282	115	None		(114)+0.001 (113)-000 (112)+0.001	(111)-000 (110)-000 (115)-000	60.5	40.2	Rod does not show any further change

The initial rod (No. 30) was made from alpha rolled uranium, with a test section 1.039 inches in diameter and 16-5/8 inches long. A thermocouple was inserted in the surface of the test section by peening the separate wires approximately one half inch apart on the circumference. Copper sleeves, 5 inches long, were shrunk on at the electrical connections to reduce the current density through the joint. The surface temperature was kept below 70°C since the literature indicated that corrosion of bare uranium in distilled water increases considerably between 70 and 80°C. Calculated and measured surface temperature are presented in Table II. It will be noted that the calculated temperatures are approximately 9°C lower than the measured temperatures. This discrepancy may be due to the several assumptions that had to be made in making such a calculation. The temperature was calculated from the power input and the water velocity. The thermocouple came loose after approximately 140 cycles.

The rod failed after 379 cycles from a crack that developed approximately 6 inches from the inlet end, at the thermocouple, during the first 300 cycles as shown in Fig. 1. Later development of these cracks is shown in the photograph of the entire rod, in the enlarged photograph of the crack near the inlet end, and in the enlarged photograph of the section at the thermocouples. These cracks do not appear to be accompanied by a large amount of oxidation, since the edges of the opening have not been corroded appreciably. Volume measurements of these sections indicate a loss of material (a portion of the material lost was recovered from the spray coolers in the form of metallic uranium).

Results similar to those obtained in cycling No. 30 rod were obtained with No. 34 rod, shown also in Fig. 1.

An attempt to drill the No. 32 rod for a center thermocouple was not very successful. However, a 1/8 in. hole was drilled to a point about 3/4 in. beyond the contact copper sleeve before it was abandoned. The center temperatures of about 300°C given in Table II were taken in this hole.

It is planned to continue the cycling of Hanford canned slugs to failure of the present test rods. Attempts are being made to increase the center temperature of the bare rods to approximately 500°C without detrimental oxidation on the surface. Temperatures of this order should give some definite relationship between the present work and that carried out at Argonne National Laboratory, as well as show some relation to the Hanford slug problem.

TABLE II

THERMAL CYCLING OF URANIUM BARS

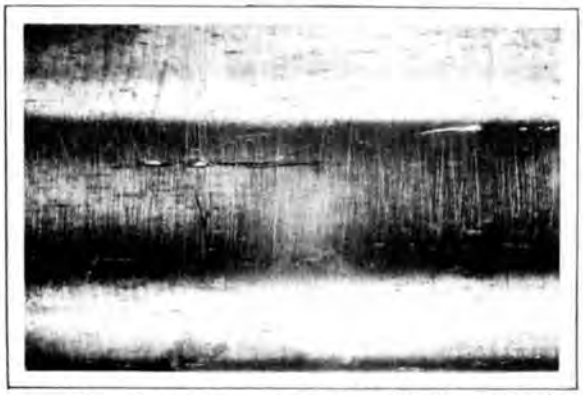
ROD NO.	TYPE OF MATERIAL	NUMBER OF CYCLES	END LOAD (lbs)	CENTER TEMP. (°C)	*SURFACE TEMP. (°C)	ORIGINAL DIAMETER (inches)	DIAMETER AFTER CYCLING (inches)	CHANGE IN LENGTH (percent)	CURRENT DENSITY (Amps/sq in.)	POWER INPUT (Kw/ft)	WATER VELOCITY (ft/sec)	REMARKS
30	α-rolled	107	780		(57.4) 66	1.039	1.039		12450	21.9	26.1	Bare uranium rod. Cycle-Even increase in electrical load for 6 min, held on peak 10 min, cool 10 min
		107-181	850		(61) 66		1.039		13300	24.3	26.1	
		181-240	755		(66)		1.039		13750	26.9	26.1	Small raised places resembling carbide corrosion appearing on surface
		240-302	770		(68)		1.039		14000	28.3	26.1	Rod showed crack about 6 inches from inlet end and at the thermocouple
		302-379	3590		(67)		1.039	None	13650	27.6	26.0	Failed at above mentioned cracks
32	α-rolled	139	4625	304	(59) 67	1.303	1.303		10450	29.6	32.9	No changes apparent although gages indicated shortenings. Apparently contact trouble
		139-169	4590	293	(59)			None	10650	30.7	33.5	Rod failed at contact from overheating (melted end off)
33	γ-extruded	45 45-115	5200 5000		(47) (56)	1.203	1.203 1.204	None	11300 12000	21.5 29.2	32.2 32.4	Rod was sprayed with "Spar Varnish" (about 0.001 in. thick) to prevent corrosion. The varnish peeled off. Rod failed by overheating under contacts.
34	α-rolled	60	4725		(65)	1.201	1.203	0.3	12900	27.0	26.9	Rod split parallel to axis near center. Split about 1¼ in. long

*Temperatures in parentheses are calculated; other temperatures are measured.

[redacted]

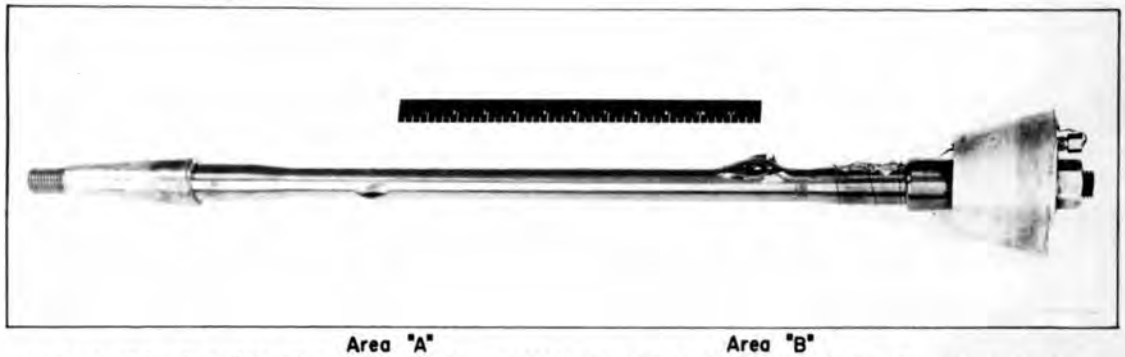
Y-1221

BARE URANIUM RODS AFTER THERMAL CYCLING



Area "A" after 302 cycles. Approximate power input - 28.3 K.W./ft. Surface temp. - 70° C.

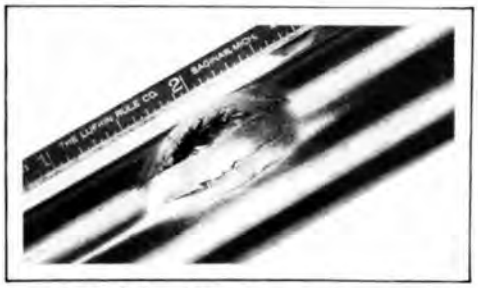
Y-842



Area "A" Area "B"

Number 30 slug line after 379 cycles. Approximate power input - 27.5 K.W./ft. Approximate surface temperature - 70° C.

Y-844

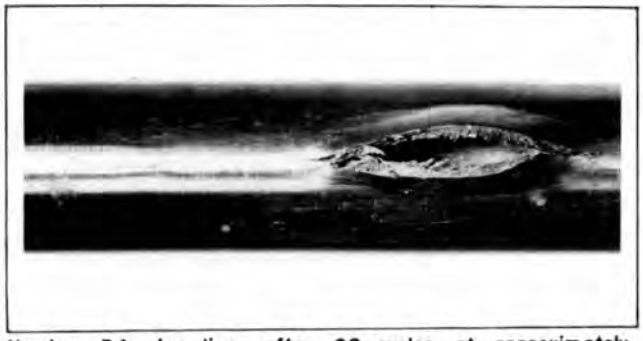


Area "A" after 379 cycles

Y-923

Area "B" after 379 cycles

Y-922



Number 34 slug line after 60 cycles at approximately 27.0 K.W./ft. Shows splitting of uranium rod. Approximate surface temperature - 65° C.

Y-1004

Fig. 1

By Metallography Section

Protective Coatings. Work has been continued on the use of electroplated coatings to prevent water corrosion of the uranium test bars, as discussed above. Thin coatings of Ni, Cu, Ag and Cd failed after short exposures to flowing water at about 80°C. Coatings of Ni, 0.002 in. thick, on uranium, were given various heat treatments, in attempts to bond the coating to the uranium by diffusion as follows: (See Table III)

1. Slug heated in vacuum to approximately 700°C with high frequency induction furnace.

2. Slug heated in air to approximately 700°C with high frequency induction furnace.

3. Slug heated in salt bath to 750-800°C.

4. Slug heat in vacuum resistance furnace to temperatures of 700, 750, 800, 830°C. In this treatment, slugs were brought to temperature slowly while in vacuum, and were then held at temperature for one-half to one hour followed by slow cooling.

The best coating was obtained by slow heating in vacuum to 750°C, holding for one hour, followed by slow cooling. Examination of the microstructure of this slug showed extensive diffusion between the uranium and nickel around the periphery, as seen in Fig. 2. When the slugs were heated rapidly, as in the high frequency furnace or salt bath, the coatings showed numerous blisters presumably caused by evolved gas.

Plated slugs which have received a diffusion heat treatment have not been tested for corrosion behavior. It was hoped that it might be possible to produce a bonded Ni-U alloy layer on the surface of the slugs without heating the interior of the metal into the beta region. Since this does not appear possible on the basis of the above trials, this has been abandoned.

A more promising solution to the problem appears to be the use of a composite electroplate of Ni, Sn, Cu and Cd. Such coatings, according to the literature, can be diffused at a temperature of 300°C. Specimens of uranium are now being so plated.

ORNL (CLINTON) SLUG PROBLEM AND THE U-AL ALLOY SYSTEM

ORNL-size slugs with Al-Si bonding prepared by Hanford have been tested. Three slugs have been held at 550°C in the absence of radiation for fourteen (14) weeks, and have shown no indications of failure. A standard, unbonded slug would rupture in a matter of days under these conditions. It has been

TABLE III

DIFFUSION HEAT TREATMENTS FOR NICKEL PLATES ON ORNL (CLINTON) SLUGS

(See Fig. 2)

Sample Number	Treatment	Results
633 634 635	Slug heated to 700°C in vacuum by induction furnace.	Plate blistered, No diffusion.
636 637 638	Slug heated to 700°C in air by induction furnace.	"Egg Shell" plate, No diffusion.
641 642	Slug heated in vacuum furnace to 830°C for ½ hour.	Ni plate ran, Some overall diffusion.
647 648	Slug heated in vacuum furnace to 700°C for ½ hour.	No diffusion
649 650	Slug heated in vacuum furnace to 800°C for ½ hour.	Ni plate ran, Some overall diffusion.
673	Slug heated in vacuum furnace to 750°C for 1 hour.	Good overall diffusion.
674	Slug heated in salt bath approximately 750°C for ½ hour.	Spotty diffusion areas, Very poor surface.

DIFFUSION OF NICKEL PLATED URANIUM

[redacted] Y-1220

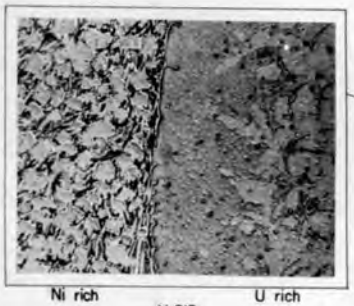
Nickel plated Clinton type slug after being heated in air in a high frequency induction furnace to approx. 700°C.
Specimen Nos. 633, 634, 635
Y-763

Specimen Nos.
647 648 650 649

750°C 800°C

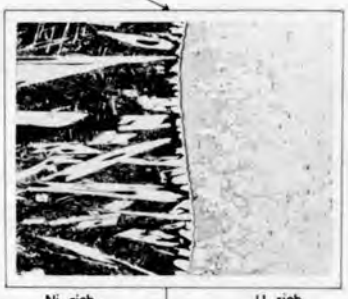
Nickel Plated Clinton Slug Section, Heated in Vacuum
Y-804

Nickel plated Clinton type slug after being heated in vacuum in a high frequency induction furnace to approx. 700° C.
Specimen Nos. 636, 637, 638
Y-762

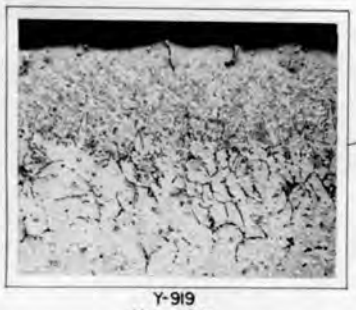


Ni rich U rich
Y-918
Mag. 150x

830° C (1/2 hr.) in vacuum
Spec. 642 Y-924
Mag. 2x



Ni rich U rich
Spec. 649 Y-877
Mag. 100x

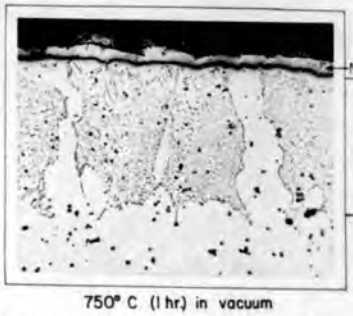


Y-919
Mag. 150x

Y-876
Mag. 200x

Salt bath at 800° C, cooled to 775° C for 48 min. then air cooled.
Spec. 674 Y-932
Mag. 2x

Y-1068
Mag. 100x



750° C (1 hr.) in vacuum
Spec. 673 Y-951
Mag. 250x

Fig. 2

by Metallography Section

observed however, that the bonded slugs have shown some changes in dimensions and some surface roughening. This might be a result of a slight amount of diffusion between the Al can and the uranium core.

Fifteen bonded slugs have been exposed in the ORNL reactor for over six (6) weeks. The channel in which they are being exposed has been partially blocked so that the maximum surface temperature of the slugs is 330°C. No failures or irregularities have been observed.

The work on the effect of Mg and Si additions to aluminum on the rate of diffusion and phase structure in the U-Al system continues, but no new conclusions can be reported from the available data.

REACTOR METALLURGICAL DEVELOPMENT

MATERIALS TESTING REACTOR (MTR) COMPONENTS

Fuel Plates

Fuel Plates for the MTR Critical Experiment. Production of plates for use in the MTR Critical Experiment was started on November 1, 1949. Specifications for the 344 plates ordered are given in Table IV.

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. A breakdown of uranium distribution in the 24 runs is as follows:

Charge, as U_3O_8		4,439.56 gm
Acceptable Plates	2,170.11 gm	
Blistered Plates	1,464.21 gm	
Scrap Alloy	665.37 gm	
Samples	40.87 gm	
Slag, Dross	99.00 gm	
Total		4,439.56 gm

Blistered plates were in excess of the number to be expected on the basis of work reported in ORNL 511.[1] A study of humidity data shows 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 seems to have no bearing on rejections due to blistering. Table V 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. 3. 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—Brazing Flux Treatment. Previous work, ORNL 511, indicated that the majority of blisters originated in the core

(1) Frye, J. H., Jr., *Metallurgy Division Quarterly Progress Report for Period Ending October 31, 1949*, ORNL 511 (January 12, 1950).

TABLE IV

Fuel Plate Specifications for MTR Critical Experiment

Plate

Dimensions

Length	24-5/8 in.
Width	2.845 in.
Thickness	0.060 in.

Core

Dimensions

Length	23-3/4 in.
Width	2.50 in.
Thickness	0.021 in.

Composition

Total U in U-Al alloy	~13.3%
U^{235} enrichment	~95%
U^{235} content per plate	7.70 gm ± 1%

Clad

Type	Composition	Number of Plates
Standard	2S	200
Duplex	2S 72S (outside 0.005 in. thick)	144
	Total	344

Quality: Blister-free

[redacted]
DWG. 8401

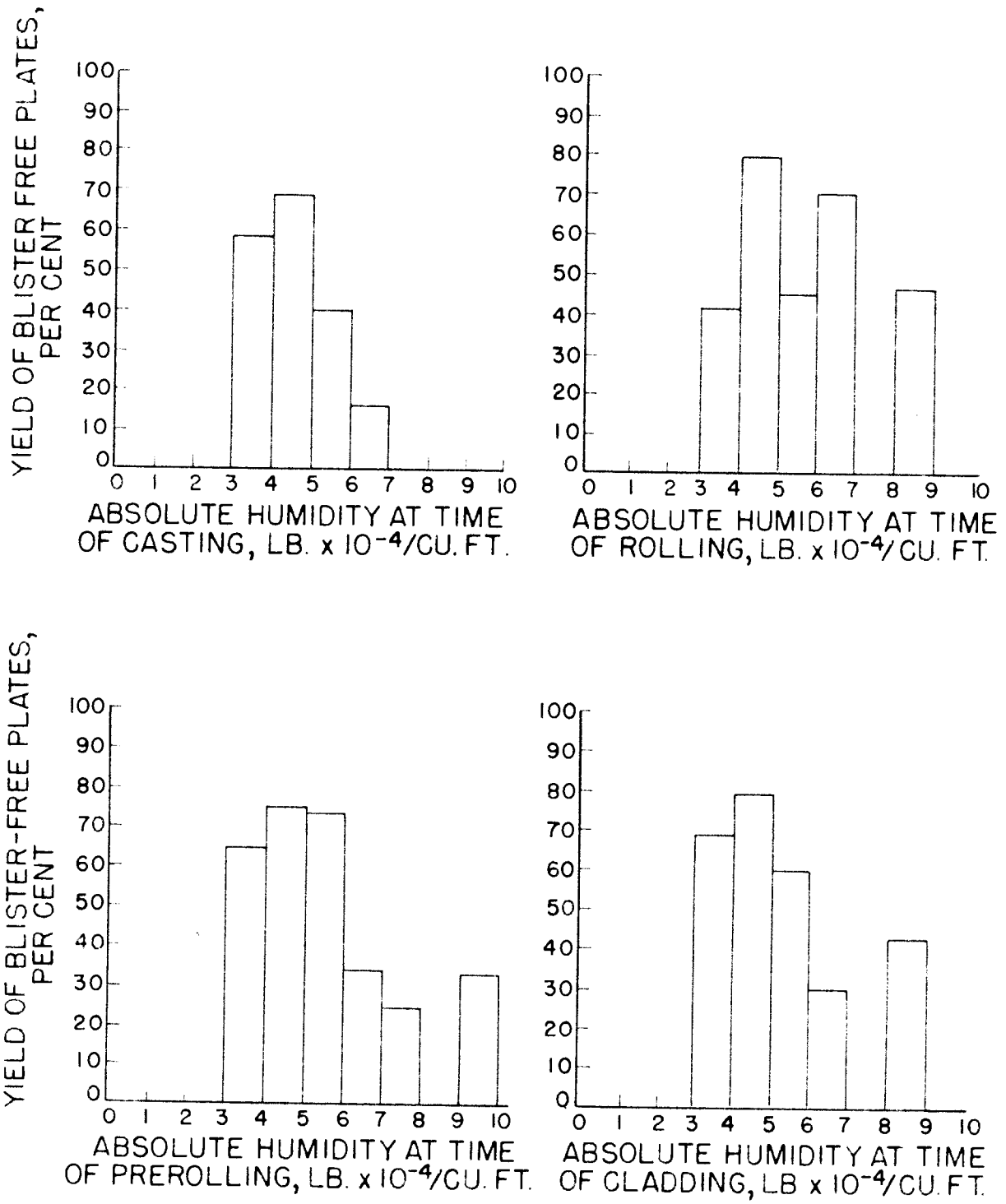


FIG. 3
RELATION OF HUMIDITY TO YIELDS OF BLISTER-FREE PLATES

TABLE V

Relation of Humidity to Yield of Blister-Free Plates

RUN	TOTAL CORES	GOOD CORES	YIELD (Percent)	ABSOLUTE HUMIDITY, 16 x 10^{-4}/cu ft				
				CAST	ROLL	PREROLL	CLAD	SOURCE
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	Virgin
3	22	17	77	4.5	3.9	5.1	3.9	Virgin
4	22	20	91	4.5	3.9	4.4	4.5	Virgin
5	18	8	44	—	5.5	5.4	5.6	Scrap
6	22	1	5	--	5.5	6.0	6.5	Scrap
7	22	19	86	5.5	7.2	5.9	5.2	Scrap
8	22	12	55	5.5	7.2	5.3	6.2	Scrap
9	22	16	73	3.6	4.2	4.6	4.6	Scrap
10	22	12	55	3.6	4.2	3.6	3.3	Scrap
11	22	17	77	4.6	5.5	6.7	8.2	Scrap
12	22	12	55	3.8	5.5	6.7	5.3	Scrap
13	22	21	95	4.2	4.2	5.5	4.1	Scrap
14	22	22	100	3.3	4.2	3.9	3.2	Scrap
15	20	2	10	3.2	3.8	9.4	5.9	Scrap
16	22	12	55	4.6	9.1	4.0	4.0	Scrap
17	22	12	55	4.0	3.8	9.9	7.5	Scrap
18	22	9	41	4.1	9.1	3.5	3.5	Scrap
19	22	4	18	6.4	3.5	7.3	7.3	Scrap
20	22	0	0	5.9	6.3	6.7	7.8	Scrap
21	20	3	15	5.9	3.5	7.4	7.5	Scrap
22	22	0	0	6.6	6.3	7.0	7.4	Scrap
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	Virgin
Total	514	267	Avg. 52					

material. 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 produce appreciable blistering in clad U-Al alloy.[2] It has also been shown[3] 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 program was tried. In ORNL 407, it was reported 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. 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.

N23 - 20 cores total

- 4 - Standard procedure
- 4 - Cores and frames preheated 2 hours in dry air at 360°C prior to cladding
- 4 - Vacuum annealed at 1100°F after cladding
- 6 - Dipped in alcohol slurry of Eutectic No. 190 flux and heated through the following cycle:

  ½ hr at 300°F

  1 hr at 850°F

  38 min at 1100°F
- 2 - As above without flux

Heat N24 - 20 cores

- 4 - Standard procedure

(2) Frye, J. H., Jr., *Metallurgy Division Quarterly Progress Report for Period Ending July 31, 1949*, ORNL 407 (October 14, 1949).

(3) Keller, Fred and Edwards, J. D., ''Composition and Properties of the Natural Oxide Film on Aluminum,'' *Metal Progress*, 54 (August, 1948) 195-200.

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:

½ hr at 300°F

½ hr at 1100°F

All of these plates were subsequently annealed at 1100°F for one hour. None of the plates which had been fluxed and heated 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 given the standard procedure. Four of the blistered plates from run N24 were cold rolled to flatten the blisters, then fluxed, dried and heated ½ hr at 1100°F. The blisters then reappeared but were considerably smaller. Results are not yet available on the vacuum annealed samples.

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 lower temperatures in dried air, prior to cladding, had no effect on blistering.

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

Two additional natural uranium alloy heats have been cast and rolled. These will be clad and treated with flux to remove the blister-forming gas. If reasonable yields from these runs are obtained, production of fuel plates containing enriched uranium will be resumed, with the modifications in procedure indicated by the above experiments.

Purity of Aluminum. Spectrographic analysis of samples from heats 1, 2, 3, 4, 5, 12, 13, 14, 22 showed that elements with very high cross sections, such as Cd, Li, and B, were not present. Ca, Cu, Fe, Mg and Si were the principal constituents, all being present in trace amounts. There seemed to be a slight build-up in Fe and Cu with continued alloy recycling, up to a saturation value corresponding to that of 2S aluminum. This is to be expected, since 2S aluminum is used as a cover and frame material.

The 1/8 in. 2S aluminum cover plates used in heats 1 through 12 had been annealed 8 hours at 800°F. As a further check, additional plates from this same batch were annealed for 8 hours at 1100°F. Examination of these plates showed areas which either had been attacked by some corrodant or had fused

locally, possibly due to some low melting impurity. No differences in analysis could be found between a fused area and a clean area on the same sheet. This implies that whatever caused the attack was no longer present. All plates showing this condition were rejected.

Health Physics Considerations. Air samples were taken during the various production operations to determine if any hazard due to radioactive contamination existed. This work was under the supervision of the Health Physics Division. Results showed that with careful handling there was no hazard. The principal source of trouble was in transferring the U_3O_8 from its original container to a mixing bottle. It was suggested that a hood or enclosure for this operation would constitute an improvement. No activity was found on smears taken from rolls or clad plates. This work will be presented in more detail at a later date.

Fuel Assemblies

MTR Critical Experiment. Several assemblies containing plates with natural uranium cores were fabricated. Because of minor changes made in furnace baffle adjustments, it was found necessary to reestablish the brazing cycle:

(1) Assembly drying, two hours at 295° - 305°F;
(2) Assembly preheat, fifty minutes at 845° - 855°F;
(3) Assembly brazing, thirty-eight minutes at 1100° - 1110°F.

ORNL 511 describes modifications made to the plate forming die and hydraulic press. These have resulted in more uniform active plate curvature, but assemblies fabricated from these plates show somewhat smaller final assembly width. Comparison of dimensions indicates that an increase in plate curvature has resulted from the changed forming conditions, necessitating a 0.006 inch increase in plate width to produce assemblies of desired overall size. Future assemblies will be made from plates machined to a width of 2.845 inches ±0.001 inches.

Fourteen fuel assemblies using enriched uranium for the MTR Mock-Up Critical Experiment have been completed with no rejects. Ranges for the key dimensions are as follows:

Width	2.988 in. to 2.996 in.
Vertical Center Height	3.061 in. to 3.084 in.

Sagitta	0.120 in. to 0.135 in.
Upitta	3.295 in. to 3.309 in.
Plate Spacing	0.104 in. to 0.125 in.

These values are also typical of values obtained on natural uranium fuel assemblies fabricated for the Mock-Up.

Four of the active assemblies contained, in place of some of the enriched alloy plates, plates of 2S aluminum of similar size and shape. No difficulties were experienced in preparing these assemblies.

Brazed Joint Examination. Satisfactory joining has been accomplished, but some irregularities of brazing have been noted on six of the assemblies:

(1) Poor fillets were found at the ends of active plates.

(2) Portions of braze metal strips were noted adjacent to joints within the assembly.

(3) Excessive metal build up, or "run-through," was observed in the bottom annulus, extending out some 3/8 in. to 1/2 in. from the side plates.

Investigations are planned to determine the causes of the variations in metal flow. From previous experience it should be noted that:

(1) Insufficient cleaning results in poor brazing.

(2) Incomplete removal of degreasing solvents hampers braze metal flow.

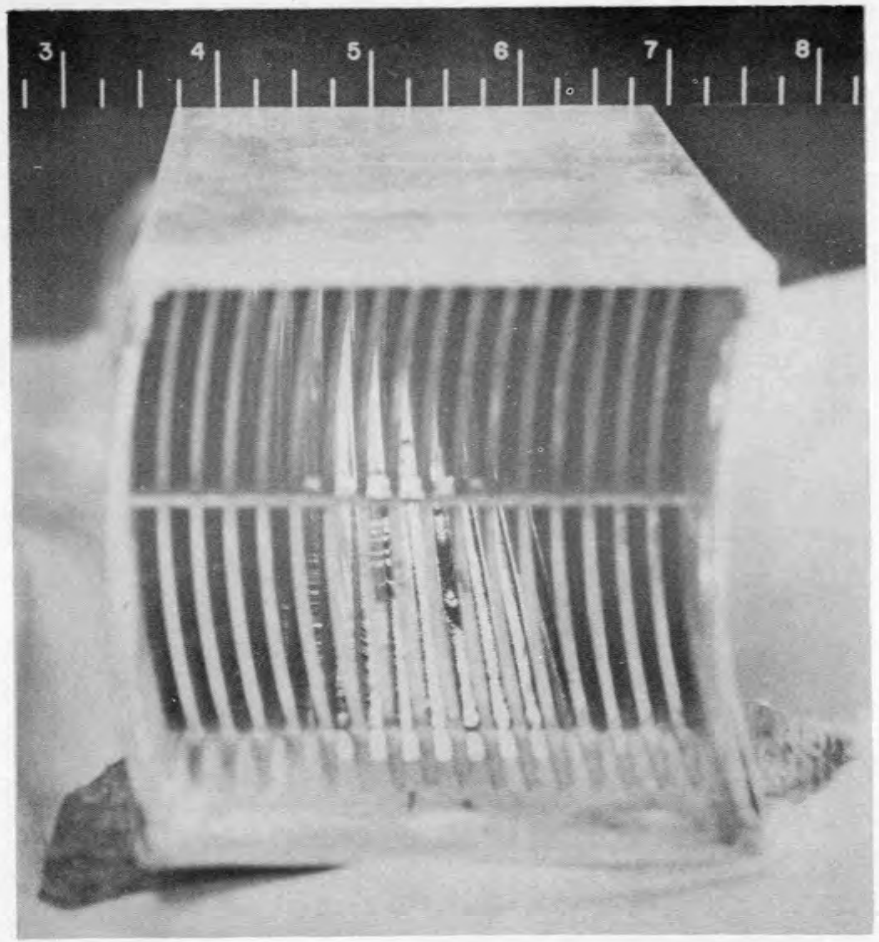
(3) Variations in flux composition may cause irregularities in brazed joints.

(4) Variations in filler metal composition may cause poor metal bonding and flow.

Several assemblies showing joint irregularities were again fluxed and subjected to a second operation. It was found that brazed assemblies after such recycling showed improved metal flow and fillet formation. Typical of these assemblies is No. 197, which has been photographed, Figs. 4 and 5, along the brazed joints from each end both before and after a second brazing cycle. It can be seen that spotty, irregular fillets have been replaced by uniform ones, due to more regular metal distribution.

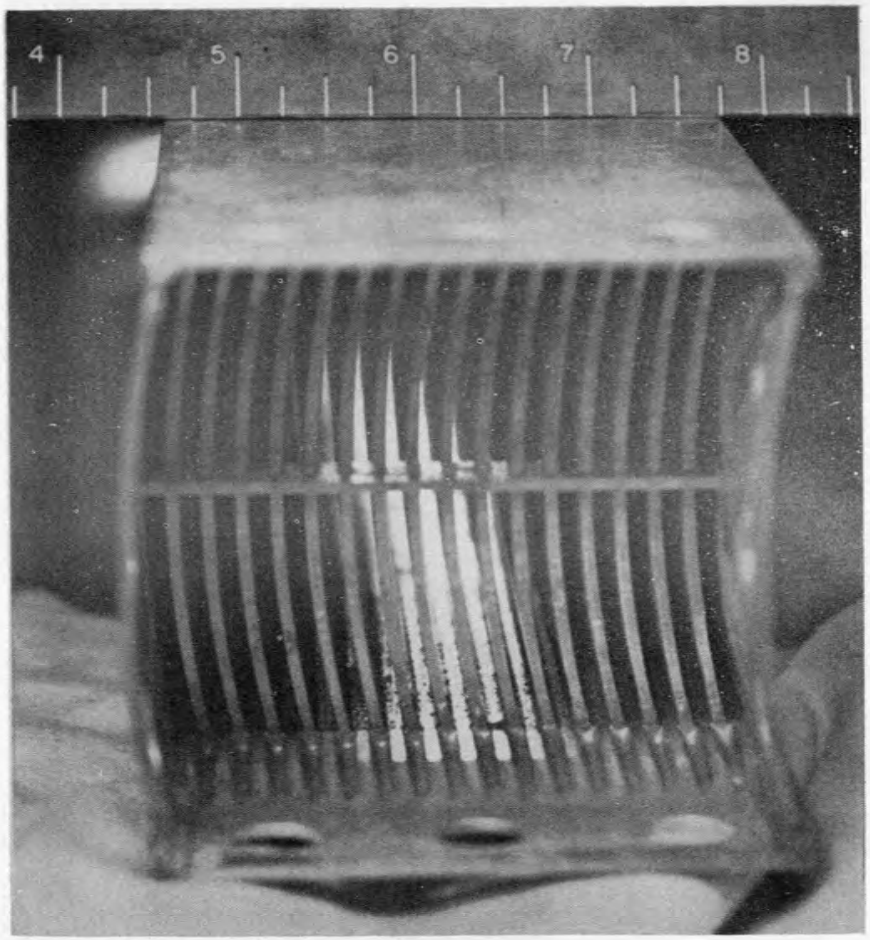
It was also found that additional braze metal could be supplied at points of insufficient filler material. On the other hand, excessive amounts of braze metal in some locations could be distributed by slight mechanical agitation of the molten metal surface. This was accomplished by inserting and quickly removing narrow strips of aluminum.

Cleaning after Brazing. Post-cleaning has been a production problem, as reported in ORNL 511. Water quenching of hot assemblies results in distortion.



Before re-brazing

Y-930



After re-brazing

Y-913

Fig. 4. M.T.R. Fuel Assembly No. 197, A-End

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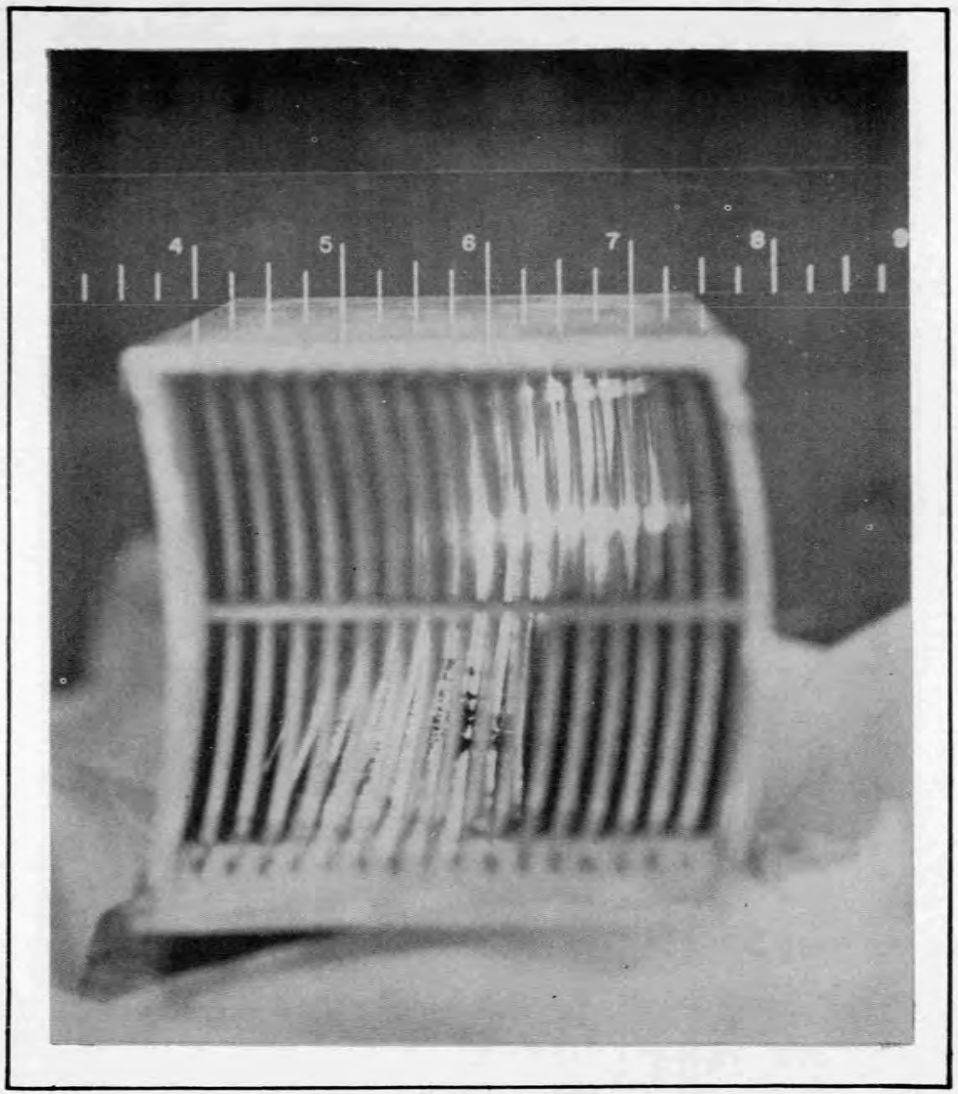
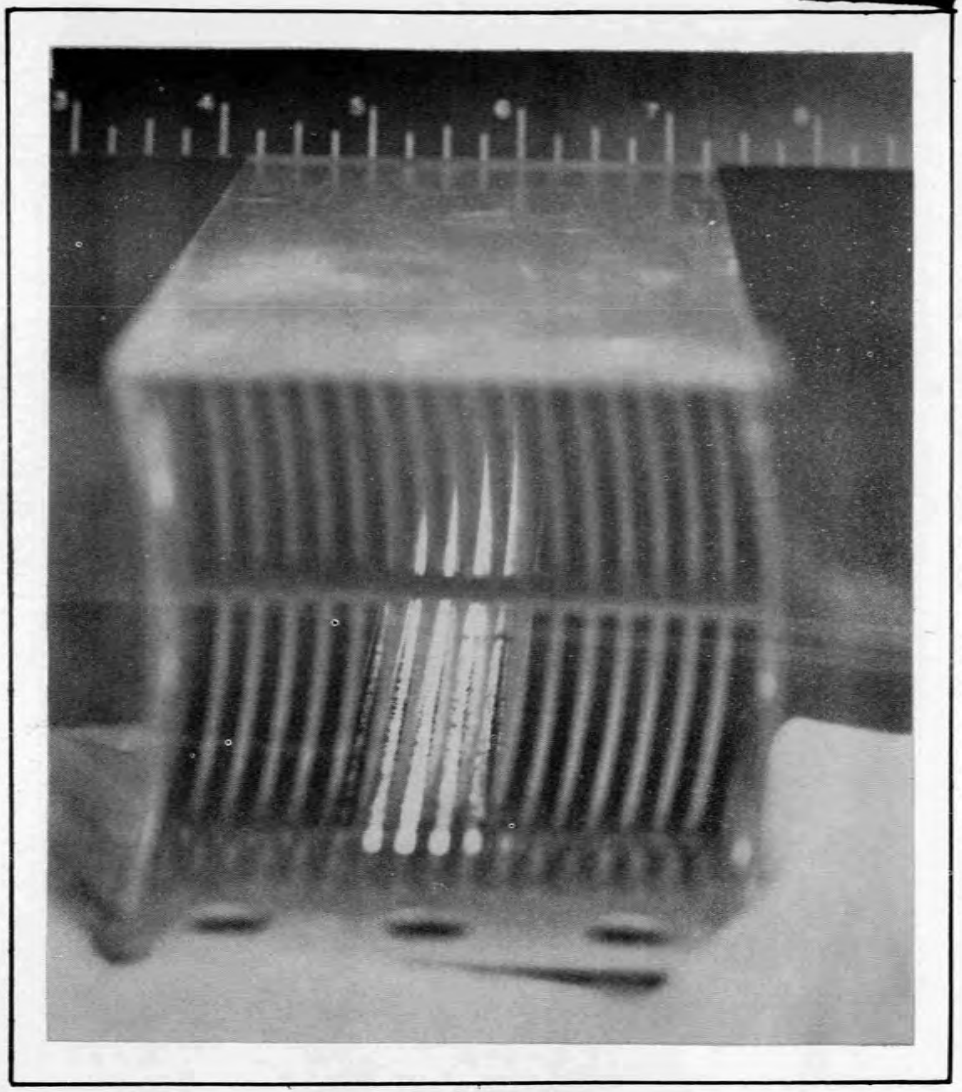


Before re-brazing

Y-931



After re-brazing

Y-914

Fig. 5. M.T.R. Fuel Assembly No. 197, B-End

Assemblies made for the MTR Mock-Up were cleaned in hot water, followed by cold water, but this did not provide a chemically clean surface. Considerable oxidation of aluminum takes place during the removal of the residual flux, giving the surface a dusty white film. Several methods of cleaning were investigated. Use of hot aviation type soapy aluminum cleaners, hot sodium silicate solutions, and hot phosphoric acid-chromic acid mixtures were equally unsatisfactory. Alcoa's "Welding and Brazing Alcoa Aluminum" suggests the use of 10% nitric acid containing 1/4% hydrofluoric acid. Use of this bath following water washing, cleaned assemblies free of the white powdery film in less than a minute.

MTR-Type Long Fuel Assemblies. The problem of producing MTR-type fuel assemblies having cores up to 140 cm in length is being studied. Preliminary tests were made on the forming of long plates by successive pressings in the present die.

This method produced irregular plates, considerably twisted along their length. It will be necessary to obtain suitable dies, press equipment, and furnaces.

Jigging equipment must also be prepared to handle the longer units. The ORNL shops will fabricate the drying fixture. The brazing jigs can be supplied in rough shape by American Lava Company subject to final machining to tolerance.

Degreasing equipment bids were received recently covering the size unit required.

Consideration will be given to a double acting press in order that the operation of blanking out the plates can be achieved either just prior to or after the forming operation.

A larger surface plate will be required to inspect the active plates and assemblies.

Beryllium for the MTR

Most of the experimental work in the development of beryllium for the MTR has been completed. It is presently planned that hot-pressed beryllium will be used for about 90% of the pieces. After production at the Brush Beryllium Company plant, the blocks will be cut to approximate size and autoclaved before shipment to Oak Ridge. The autoclave test specifications are being developed in the Technical Division of ORNL. Acceptable beryllium

will be machined at Y-12 and flow-corrosion tested by the ORNL Technical Division. The beryllium reflector sections are being redesigned to take advantage of the ability of the hot-pressing method to produce larger pieces than can be made by extrusion. Each reflector section will be made from a single piece, thereby eliminating bolting or brazing of the beryllium. Deep drilling of off-center holes in beryllium is a major fabrication problem in the new design. Further work on this is planned.

Irradiation-Corrosion. Samples for studying effects of irradiation on beryllium corrosion have been sent to Hanford. After an autoclave test, samples of several types of extruded and of hot-pressed beryllium will be exposed to process cooling water in process holes for periods of three months and of ten months. Additional samples will be subjected to flow corrosion laboratory tests concurrent with the pile exposure tests.

Extrusion. One series of extrusions was made at ORNL. Four billets, in steel cans, were pushed through the 1-3/8 in. round cornered square insert die at 1800°F. This die is a two-piece die with the center insert made from a cobalt-chromium alloy cast by the Doss Die Company of Detroit. All these rods were good and the die stood up well. However, with present practice the plain steel dies are proving satisfactory and are much cheaper.

Three copper-jacketed billets were extruded at temperatures of 700, 800 and 900°F, respectively. All rods were rattlesnaked but the quality improved slightly with decreasing extrusion temperature. These billets were all pushed without difficulty; in fact, less than two-thirds of the press capacity was required. One billet was to be extruded at 650°F, but a can with a copper plated steel nose was used in error. This billet stalled the press before the beryllium started through the die.

Machining. During the past quarter, three removable and six new *A* type reflector units were fabricated for the Mock-Up critical experiments. Figure 6 shows four of the six *A* type units in various stages of completion. The 1/2 in. hole shown in billet 283 is actually the short length loading and unloading tap found on the upper end of the unit.

Pertinent deep hole drilling data on fabricating the narrow 3/16 in. water cooling channel in each *A* unit are tabulated on the following page.

The machining time required to fabricate the new *A* type unit design is only 48 hours. This is a reduction of approximately 1/3 the number of hours required for a similar unit of three-piece bolted construction.

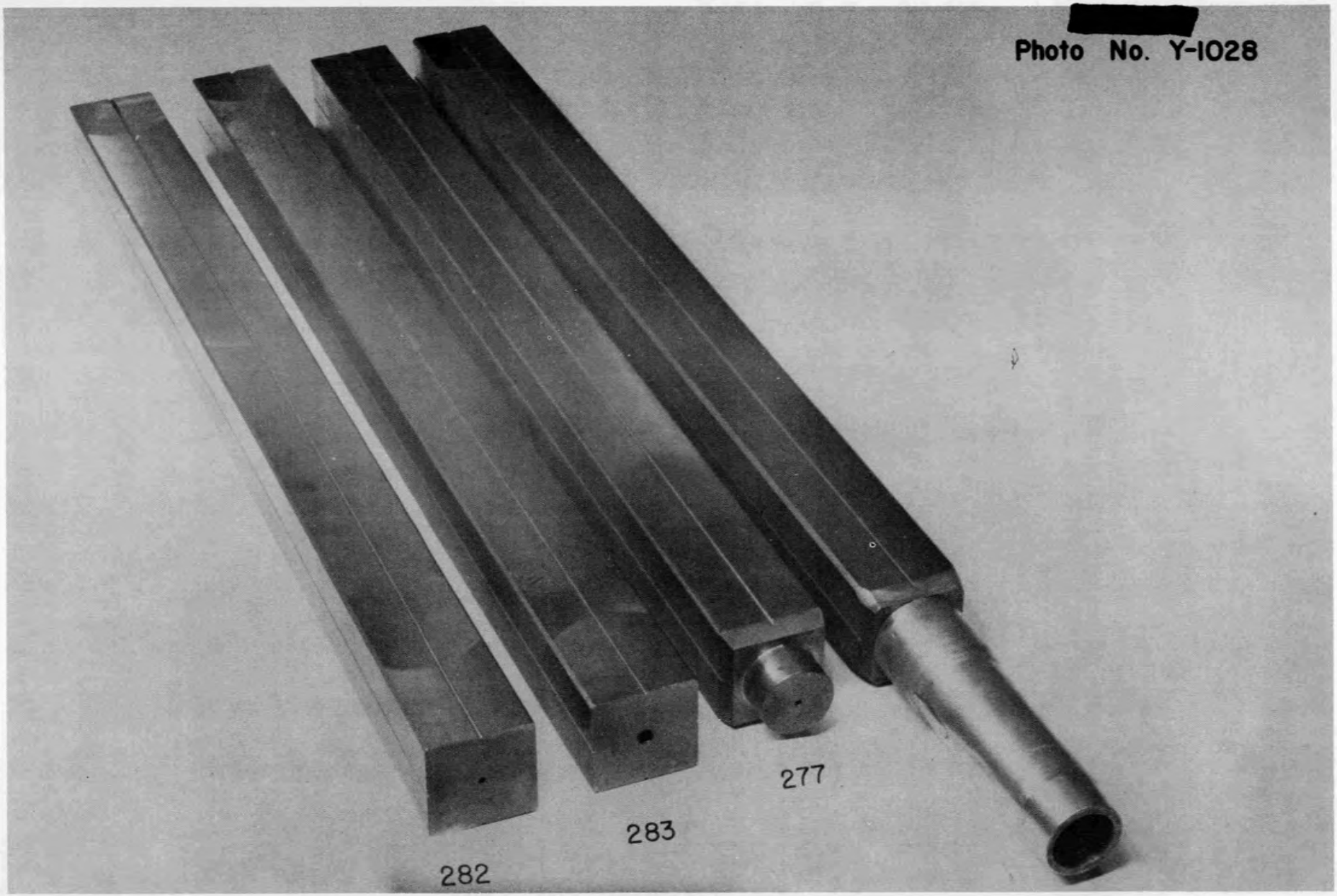


Fig. 6
"A" TYPE BERYLLIUM
REFLECTOR UNITS

MATERIAL	BILLET NUMBER	HOLE DIAMETER		OFF-COURSE BETWEEN DRILL AND WORK AXIS (in.)	RUN OUT AFTER RECENTERING (in.)
		DESIRED (in.)	ACTUAL (in.)		
Vacuum Cast and Extruded	269	0.1875	0.171	1/4	0.005
Vacuum Cast and Extruded	277	0.1875	0.177-0.178	3/16	0.010
Vacuum Cast and Extruded	282	0.1875	0.183-0.187	7/32	0.015
Vacuum Cast and Extruded	283	0.1875	0.181-0.184	3/16	0.015
Vacuum Cast and Extruded	284	0.1875	0.178-0.180	1/16	0.010
Sintered Powder	4405	0.1875	0.178-0.179	1/32	0.010

MTR Top Plug

The Metallurgy Division was requested by the Design Section of the Technical Division to make recommendations on a procedure for filling the top plug of the MTR with lead. The following recommendations were made:

(1) The shell should be constructed from a stabilized stainless steel, such as AISI 347.

(2) A system for venting the air from the blind compartments should be incorporated into the design.

(3) The shell should be heat treated by heating to between 1950-2050°F and water quenching.

(4) A sound lead casting without voids or pipe is feasible.

MTR Neutron Window

Tests to produce a value that will permit estimating the creep to be expected in the large slabs of lead to be used in the neutron window, have been continued during this period. Two series of tests are being run, one with the specimens loaded to the expected load (30 psi), and the other at twice the load. Both sets are maintained at 150°C which is the anticipated operating temperature.

The creep does not appear to be the serious problem that was originally expected. The tests were set up to measure changes of length of the order of tenths of a millimeter and since the actual changes are of the order of only 0.03 millimeter, poor checks are being obtained. It appears, but is not yet certain, that creep of the order of 0.15% of the length per year may be expected.

The tests are being checked using SR-4 strain gages to obtain a more accurate measure of the creep.

AIRCRAFT REACTOR MATERIALS

The Division, as a part of the Laboratory's participation in the Aircraft Nuclear Propulsion Program, is investigating the suitability of various materials for use in a high temperature liquid metal cooled reactor and its associated heat transfer and propulsion equipment. Close contact is being maintained with NEPA to avoid duplication of effort.

Engineering and nuclear specifications for the reactor components have not yet been established; rather, it is probable that these specifications will depend partly on the information developed in the materials investigation. This requires that the investigation consider a wide variety of constructional materials, coolants, and reactor conditions, although in some instances arbitrary selections have been made to expedite the work.

Coolants being considered include: lithium, bismuth, lead, tin, magnesium, sodium, potassium, combinations of these, and possibly some low melting, high boiling point compounds. Potential constructional materials are being studied for high temperature mechanical properties, resistance to corrosion in liquid metals and resistance to oxidation at high temperatures. These materials include: metallic elements (Fe, Ni, Co, Mo, Cr, Ti, Zr, W, Ta, Be, V, Mn, Cb, Si, and possibly some others); selected high temperature alloys; composites of materials having high temperature strength, coated with materials possessing good corrosion resistance; and possibly some ceramets and ceramics.

Specific projects now in progress are discussed below. These are likely to be modified as added information permits more precise definition of engineering and nuclear requirements.

Static Corrosion Sorting Tests. In the initial stages of the work, major emphasis is being placed on a broad program of static corrosion testing, designed to sort out the more promising of the material and coolant combinations for additional consideration. These sorting tests are in active progress.

In tests to date, samples of the more readily available of the materials being considered have been exposed to liquid lithium in evacuated and welded Armco iron capsules in four-hour tests at 1000°C. A similar series has been run using bismuth instead of lithium. Figure 7 shows the design of the capsule and its relation to sample and liquid coolant. The capsule is being redesigned to eliminate the need for threading the sample and capsule. The sample is charged into the capsule and solid bismuth or lithium is added, the lithium suitably protected by a volatile organic solvent. The plug is cold pressed

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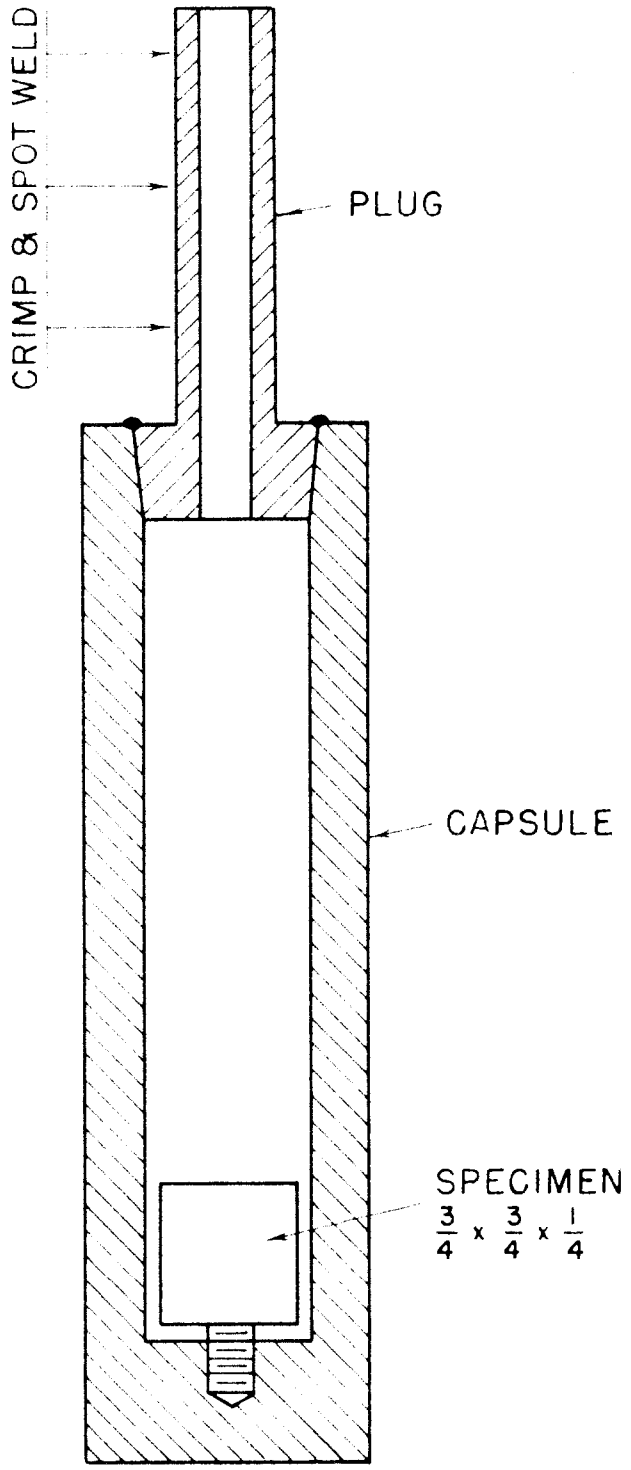


FIG. 7
LIQUID METAL CORROSION TEST
CAPSULE ASSEMBLY

into the capsule, the capsule evacuated to remove the solvent, and the peripheral joint between the plug and capsule welded. The weld is helium leak-tested. Occasional leaks have been observed in the iron capsule material itself. While the leaks are readily welded in this application, it is probable that Armco iron, despite its low solubility, is not well suited to the construction of a lithium or gas-tight coolant system. After leak-testing, the capsule and contents are heated under vacuum to just above the melting point of the lithium or bismuth. The tubular extension of the plug is then triple-crimped and spot-welded, the vacuum line removed, and the end of the tube bead-welded. The capsules, two to a furnace, are placed in one of four Burrell Globar tube furnaces, and the furnace is tilted to a position which covers the sample with liquid metal. An inert gas surrounds the capsules to prevent scaling and to minimize danger from possible leaks. Following the required exposure, the furnace is tilted to drain the liquid metal from the samples. After removal of the capsules from the furnaces and solidification of the contents, the plug end of the capsule is sawed off and the capsule contents removed for examination. The lithium and bismuth are analyzed spectrographically for the component elements of the samples. The lithium or bismuth is removed from the surface of the sample, the sample is weighed and its surface is examined microscopically and by X-ray or electron diffraction.

Results from the lithium tests at 1000°C for four hours, while neither complete nor conclusive, indicate that (1) iron, molybdenum, and zirconium suffered less weight change than the other materials tested, (2) tungsten, tantalum, and columbium were not severely attacked, (3) cobalt and nickel underwent substantial weight loss. The zirconium developed a brassy tarnish which X-ray diffraction showed to be a zirconium nitride film, indicating probable nitrogen contamination of the lithium. Interpretation of these preliminary test results should take into account the facts that equipment and procedures for insuring uniformly low contamination of lithium by oxygen and nitrogen are not yet in operation, and that a third component, the iron of the capsules, was present in each of the systems. Significant results will be subject to confirmation in tests in capsule liners made of the materials undergoing test.

The four-hour, 1000°C tests in bismuth, subject to the same or similar qualifications as the lithium tests, showed nickel and zirconium to be severely attacked whereas visual observation did not indicate attack of the iron, tungsten, tantalum, molybdenum, or columbium.

The next series of tests will be conducted at 1000°C for forty hours, followed by tests for still longer periods of time and by tests at other temperatures.

Improved methods of handling—using an inert atmosphere in a dry box—and of purifying the liquid metals, will be used.

A greater variety of potential high temperature materials, particularly alloys, is being procured for inclusion in the testing program.

Dynamic Corrosion Testing. Static corrosion tests cannot predict with complete certainty the corrosion behavior of a material in a heat transfer system. Complicating factors include erosion, temperature coefficients of solubility, and uncertainty regarding the disposition of material precipitated out of solution in the cold part of the system. Experience at other installations indicates that thermal convection loops (harps) give a better picture of the effects of these factors.

As a next step in the corrosion testing program, material-and-coolant combinations which show promise in the static tests will be operated in thermal convection systems. This should also give an indication of the feasibility of fabricating some of the high temperature materials into heat transfer equipment. Several such harps are in process of construction or planning.

As the number of potential materials is still further limited by the above tests, positive circulation corrosion test loops will be made. Investigations of pumping problems are in progress.

Mechanical Testing. Orders have been placed for creep and stress-rupture testing units. Electronic control equipment and furnaces for testing in a liquid metal environment are being designed.

Effects of Alloying Elements and Structural Factors. In addition to the testing program outlined above, a number of investigations are in progress to obtain more fundamental information concerning the nature of liquid metal corrosion in the systems under study. These include studies of (1) purification and of lithium and other liquid metals, (2) effects of impurities in the liquid metals, (3) effect of carbon content of iron and of high temperature alloys, (4) relation of lattice structure to corrosion of iron-base alloys, (5) a comparison of the behavior of different type-base high temperature alloys.

Protective Coating of High Temperature Materials. One possibility being considered is that materials may be found which have suitable resistance to corrosion by liquid metals but do not have adequate mechanical properties.

An investigation is being made of the feasibility of using such corrosion resistant materials as a coating for suitable high-temperature metals or alloys, and of fabricating complex reactor or heat exchange units out of such composite materials.

THORIUM PROGRAM

THORIUM ALLOY DEVELOPMENT

The work on thorium alloy development was held up pending receipt of a purer grade of Ames thorium than was previously available. This metal has now been delivered and the alloying program has been renewed.

A new furnace for melting and casting thorium has been designed and is now being made. This furnace consists of a vacuum chamber, 16 in. inside diameter and 18 in. high. The induction coil, crucible and mold are all contained within the vacuum chamber. The entire furnace rotates, with a movable seal being located at the connection with the 500 cu ft/min vacuum system. This design allows the melt to be poured into the mold, in contrast to the present drip casting techniques.

The vacuum system for the arc melting furnace has now been completed and tested, and it is planned to start melting in this equipment immediately. It is hoped that the high-purity crystal bar thorium prepared by Battelle can be melted in this furnace and the resulting ingots cast and rolled for testing for mechanical and physical properties.

PHYSICAL METALLURGY OF THORIUM

Bars of the latest shipment of the purer grade of Ames thorium were rolled from 1¼ in. diameter to 13/16 in. diameter to prepare stock for tensile test specimens. X-ray diffraction patterns of both cold rolled and annealed material were made for determination of preferred orientation. Both showed preferred orientation. Tensile test specimens have been made and will be used for determination of modulus of elasticity, Poisson's ratio, and other properties available from tensile test data.

A bar of the recent shipment of pure Ames thorium, containing between 0.011 and 0.052% carbon, was progressively cold worked from 0.895 in. diameter to 0.105 in. diameter. This represented 98.2% reduction and was accomplished without a large amount of cracking. No cracking appeared until 97.2% reduction was attained. The hardness of the thorium increased from 80.6 to a maximum of 117.2 Vickers hardness number, using a 10 kg load. Samples of this material will be used for recrystallization studies.

STUDIES OF THE PROPERTIES OF URANIUM AND OTHER PURE METALS

MECHANICAL PROPERTIES OF PURE METALS

A report on the theories of tensile testing is in preparation. This is an extension to the general case of an earlier program for the study of stress-strain diagrams.

CREEP TESTING OF URANIUM

A program is being initiated for the study of creep in uranium. Orders have been placed for the creep-testing units. The electronic controls, extensometers, and automatic recording equipment are being designed.

PREFERRED ORIENTATION AND ANISOTROPY IN PROPERTIES OF METALS

A method has been devised for accurate determination of type and degree of preferred orientation employing a Geiger counter X-ray diffraction goniometer (North American Philips Company-Type No. 12021).

An X-ray diffraction specimen is prepared in the form of a sphere with a stem positioned to identify the longitudinal direction and marked to identify the transverse direction of the shape from which the specimen is taken. By means of a special holder, the specimen is mounted on the goniometer so that the longitudinal direction is in a horizontal plane—the same plane as that containing the incident and diffracted X-ray beams. The holder provides for rotation of the specimen about a vertical axis and also about a horizontal axis (the longitudinal direction) both through the center of the sphere. The specimen thereby can be mounted in the various orientations with respect to the pole of the reflecting plane necessary to scan an entire pole-figure quadrant.

To determine the preferred orientation of the material in the specimen, the Geiger counter is moved along the goniometer arc to the proper 2θ angle to receive the diffracted beam from the family of planes being examined. The intensity of the diffracted beam is recorded for the desired angles of rotation of the specimen about the vertical axis ($\phi = 0°$ when the longitudinal direction coincides with the pole of the reflecting plane) and, for given values of ϕ,

for the desired angles of rotation about the horizontal axis—the longitudinal direction ($\alpha = 0°$ when the transverse direction is in the horizontal plane). Since a spherical specimen, when rotated about any axis through its center, presents the same geometry to the incident and diffracted beams, there is no change in focusing or in diffracting volume with change in orientation of the specimen. Accordingly, the measured intensities can be related directly to the percentage of material in the diffracting volume having a specified lattice orientation. No variation in intensity with specimen orientation therefore indicates random orientation, whereas observed variations reflect accurately the type and degree of preferred orientation of the material composing the specimen. Figure 8 shows how the various orientations of the specimen in terms of ϕ and α can be plotted on the stereographic net using as the plane of projection the plane containing the longitudinal and the transverse directions.

In actual practice the Geiger counter is not held in a fixed position but is moved through an arc of several degrees containing the nominal 2θ value for the reflecting plane to be certain of recording the peak intensity of the diffraction line and to check the alignment and sphericity of the specimen. Variations in the 2θ value for peak line intensity with specimen orientation indicates misalignment or eccentricity of the specimen.

Figure 9 shows the special specimen holder and Figures 10 and 11 show the holder mounted on the X-ray diffraction goniometer. The holder consists of a multiple rectangular base the upper section of which is dovetailed into the lower section. The upper section supports a turret by means of a pin-and-collar arrangement. The turret in turn supports on two bearings a horizontal shaft on which the specimen is mounted. The entire assembly is rigidly attached to the flange of the goniometer bushing. The specimen can be subjected to five independent motions for its alignment and orientation:

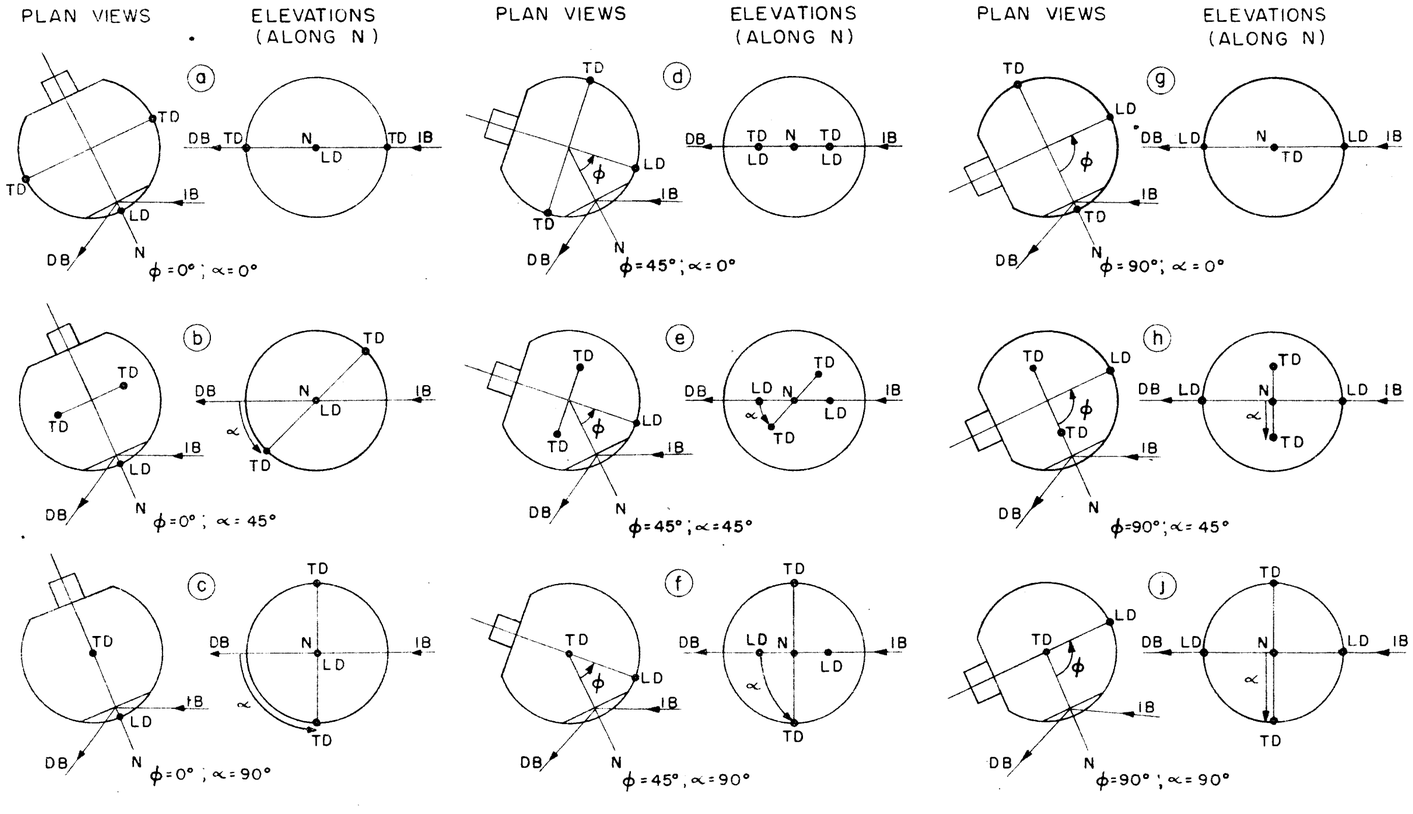
1. Movement of the Geiger counter along the goniometer arc through an angle 2θ rotates the specimen about a vertical axis (not through the center of the sphere) through an angle θ.

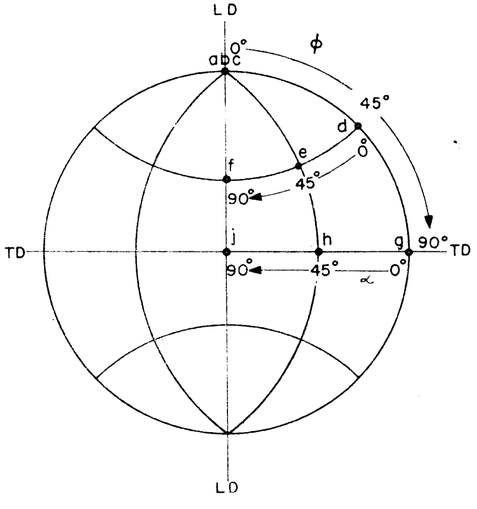
2. Movement of the upper section of the base with respect to the lower section along the long dimension positions the specimen in the X-ray beam.

3. Rotation of the turret rotates the specimen about the vertical axis through the center of the sphere through angle ϕ.

4. Rotation of the shaft rotates the specimen about the horizontal axis through the center of the sphere through angle α.

DWG. 8398
UNCLASSIFIED





LEGEND

IB _ INCIDENT BEAM
DB _ DIFFRACTED BEAM
N _ NORMAL TO REFLECTING PLANE
LD _ LONGITUDINAL DIRECTION
TD _ TRANSVERSE DIRECTION

FIG. 8

RELATIONSHIP BETWEEN ORIENTATION OF X-RAY DIFFRACTION SPECIMEN WITH RESPECT TO REFLECTING PLANE NORMAL AND POSITION ON STEREOGRAPHIC NET

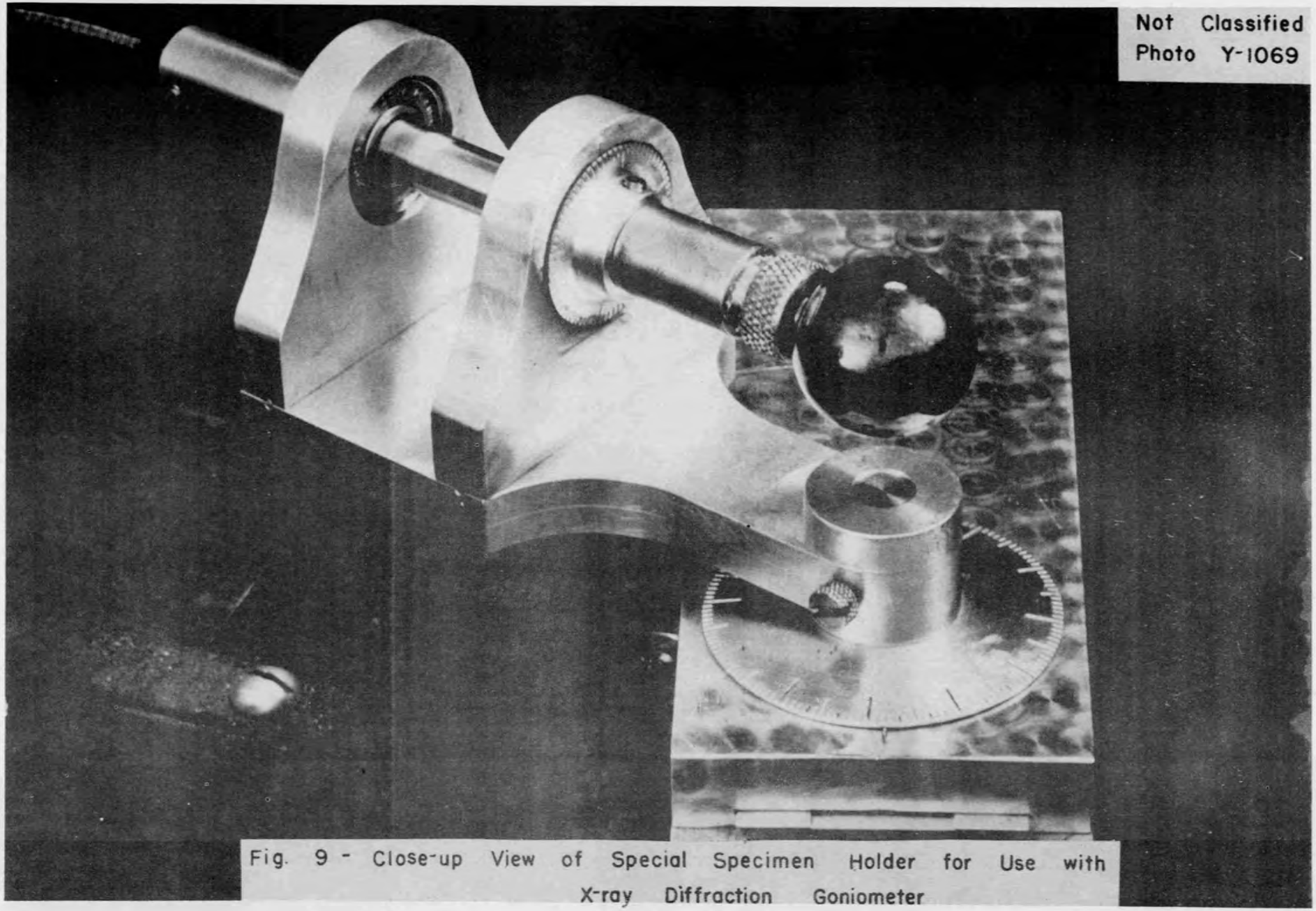


Fig. 9 - Close-up View of Special Specimen Holder for Use with X-ray Diffraction Goniometer

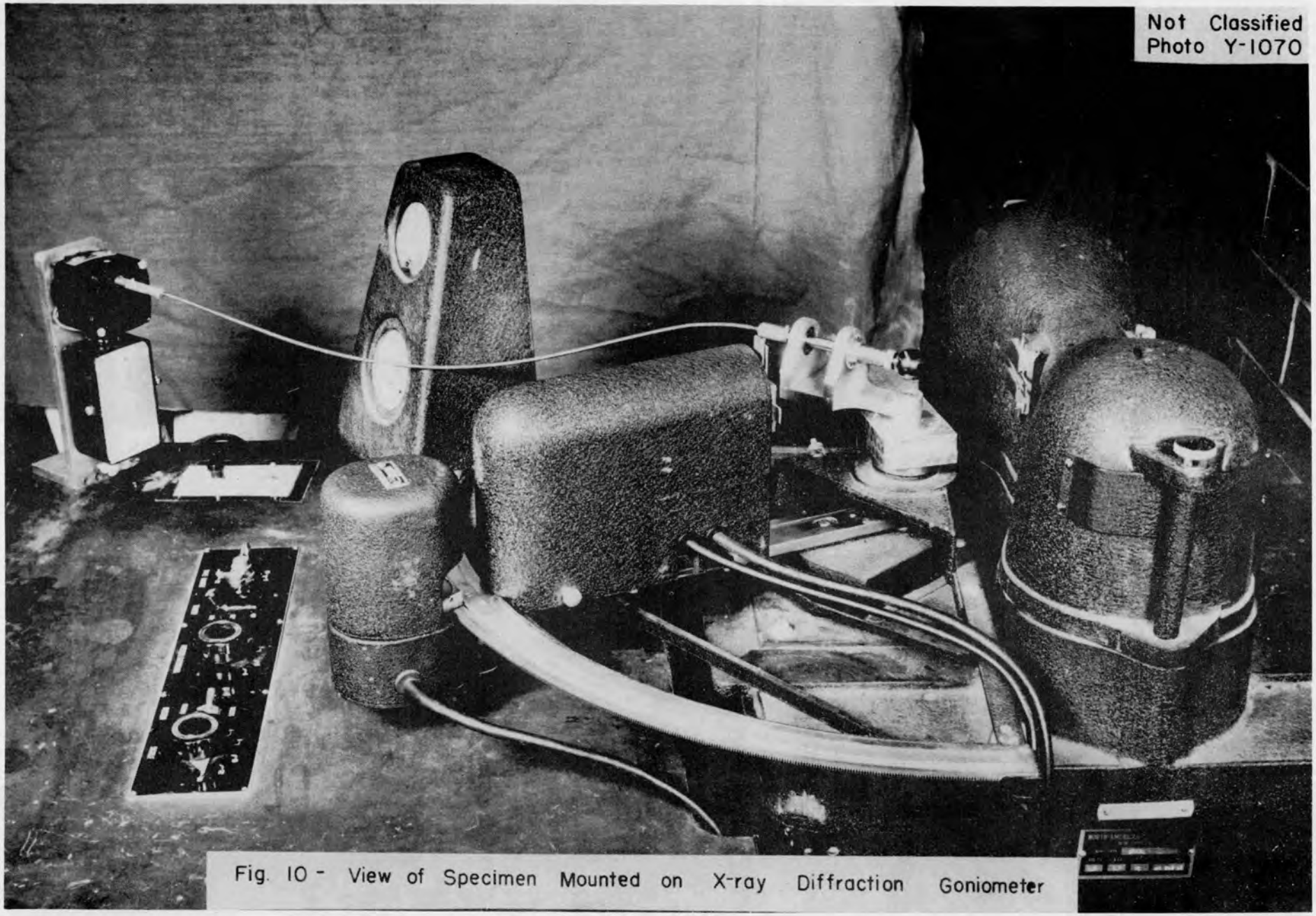


Fig. 10 - View of Specimen Mounted on X-ray Diffraction Goniometer

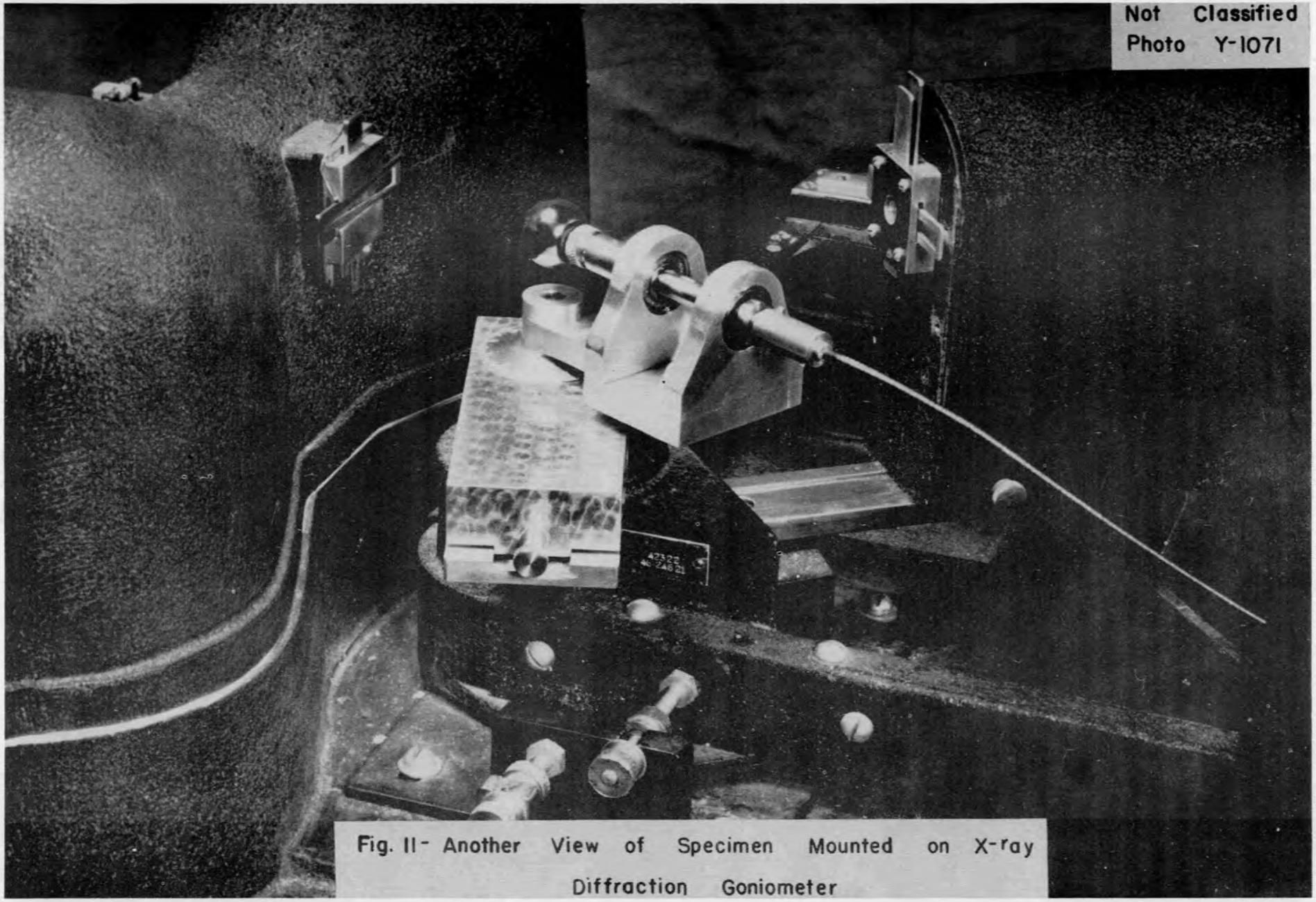


Fig. 11- Another View of Specimen Mounted on X-ray Diffraction Goniometer

5. Movement of specimen along the shaft centers the sphere on the axis of rotation of the turret.

Graduated discs indicate the angle ϕ and α. For materials exhibiting fiber textures the specimen is rotated continuously during exposure through all angles about the horizontal axis by means of a motor (60 rpm) and flexible shaft drive.

The X-ray diffraction specimens are machined on a lathe containing a ball-cutting attachment and then lapped to precision spheres. The surface layers deformed by machining and lapping are removed by electropolishing.

The feasibility of this method has been demonstrated by the reproducibility and consistency of the data obtained on some α-rolled uranium bar (rolling practice not known) annealed 8 hr at 600°C. Plot of intensity *vs* angle for the various families of planes for one of the specimens are given in Figs. 12 and 13.

Analysis of these data reveals the existence of a multiple fiber texture which can be described as follows:

1. (001) parallel to longitudinal direction
   [100] 5° from longitudinal direction

2. (001) parallel to longitudinal direction
   [100] 25° from longitudinal direction

3. (001) parallel to longitudinal direction
   [100] 90° from longitudinal direction ([010] parallel to l.d.)

Textures 2 and 3 have been reported, but texture 1, as far as is known, has not been observed previously.

In view of the suspected importance of type and degree of preferred orientation in the fabrication and serviceability of uranium, a program has been inaugurated to determine the stable textures that obtain in uranium fabricated in various ways. The program is set up in such a way that important features of the deformation and recrystallization mechanisms in polycrystalline uranium are likely to be revealed.

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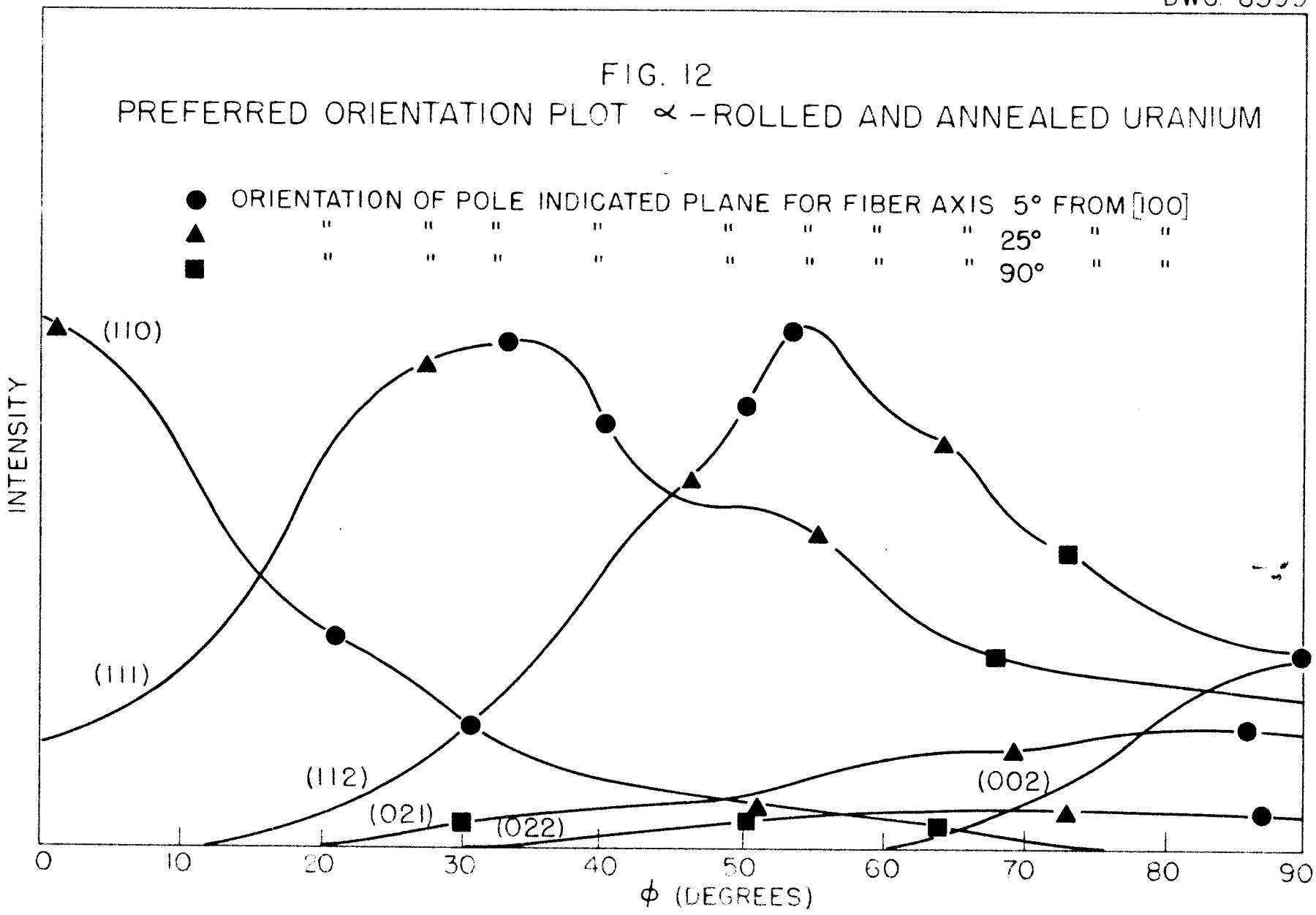
FIG. 12

PREFERRED ORIENTATION PLOT α - ROLLED AND ANNEALED URANIUM



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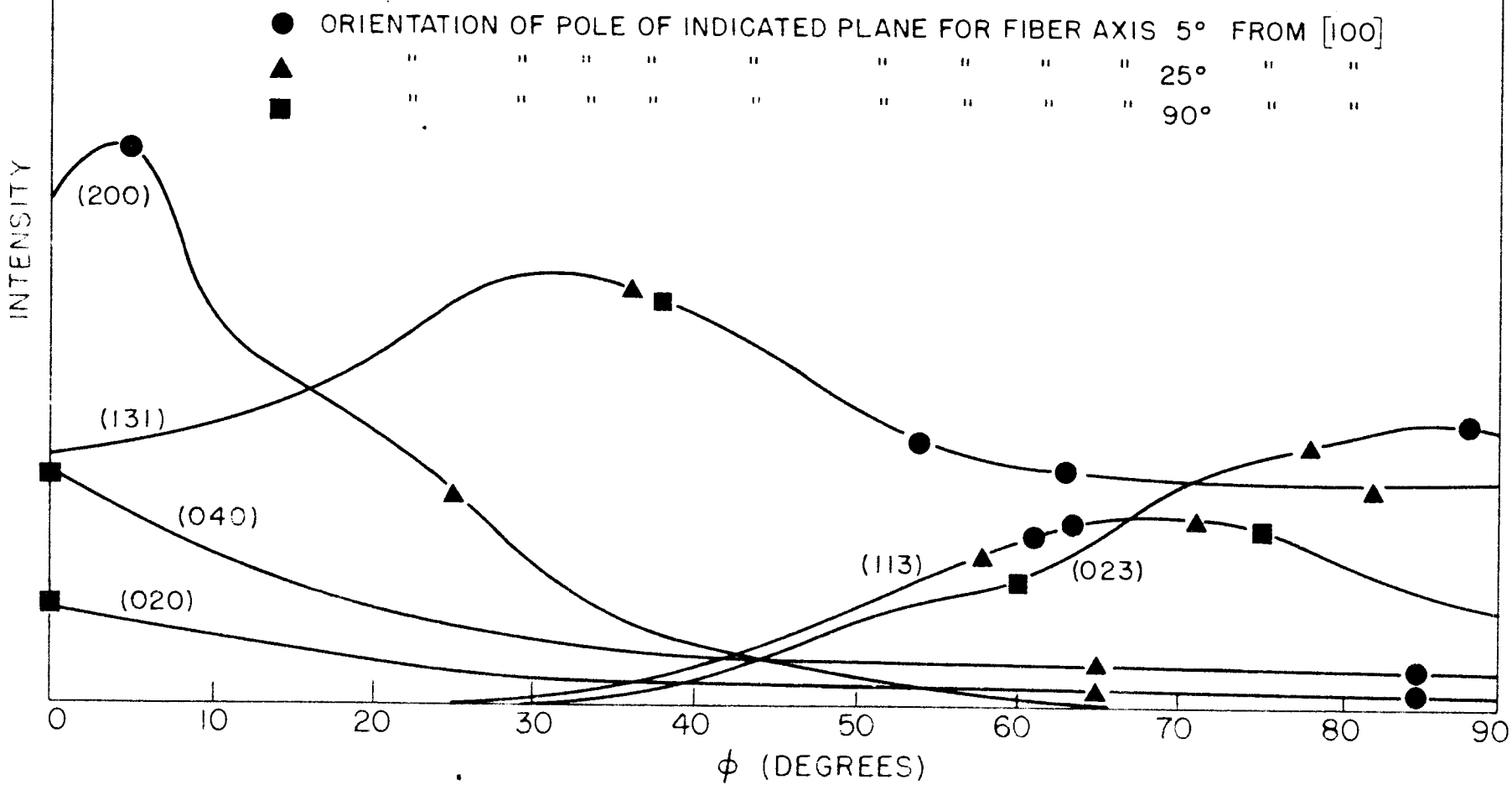
DWG. 8400

FIG. 13

PREFERRED ORIENTATION PLOT α-ROLLED AND ANNEALED URANIUM



SERVICE WORK

Melting and Casting. A considerable part of the effort of the Melting and Casting Department has been concerned with service work for other sections. This work includes the following:

(1) An alloy of 90% Ag-10% Cu was cast into sleeves for electrical contacts on the Hanford slug line in the thermal gradient apparatus.

(2) Five beryllium ingots were cast for extrusion.

(3) Three uranium ingots were cast for extrusion.

(4) High purity copper alloys were prepared for use in radiation damage studies. These consisted of solid solution alloys of copper with zinc, gallium, germanium, arsenic, and antimony.

(5) Two melts to scrap platinum were made to permit recovery of the platinum.

(6) A cupro-nickel alloy was melted and cast for extrusion into tubing.

(7) A phosphor-copper alloy containing 2% Sn and 0.05% Pb was prepared for fabrication into resistance wire for low temperature work of the Physics Division.

(8) A number of metals were prepared for Health Physics Division scattering studies. These metals included thorium, titanium, magnesium, bismuth, cadmium, and various grades of steel.

Rolling. Two tantalum rods, 0.162 inches round cross section, were rolled through a 0.125 inch pass for Y-12. One small button of depleted uranium weighing about 8 grams was rolled to 0.010 inches, also for Y-12.

Radiographic.

1. Billets of all heats of core material were X-ray photographed.
2. Fluoroscopic examination was made of all machined fuel plates.
3. Fluoroscopic selection was used to secure well centered cores for use in the production of active plates for shim safety rod uranium sections.
4. X-ray photographs were made of special uranium and other alloys for the casting group.

PERSONNEL

Table VI lists the members of the Metallurgy Division whose work is presented in this report. It includes the organization as of February 1, 1950.

TABLE VI

Metallurgy Division Organization

J. H. Frye, Jr. - *Director*

Roberta Hudson, *Secretary*

L. E. Banker - *Administrative Assistant*

Helen Carr, *Secretary*
Doris Jacox, *Stenographer*
Delores Poe, *Stenographer*

A. G. H. Andersen	*Fundamental Research and Properties of Pure Metals*	R. T. Clem W. C. Weaver
J. C. Wilson	*Pure Metals Research*	
D. S. Billington	*Radiation Effects*	
G. T. Murray	*Radiation Effects*	
B. S. Borie, Jr.	*X-ray Diffraction*	
E. J. Boyle	*ORNL and Hanford Slug Problems, Thorium Alloy Development*	
J. H. Erwin	*Hanford Slug Problem*	G. D. Goldston D. E. Rosson J. P. Turner
D. E. Hamby	*Thorium Alloy Development* *Melting and Casting*	E. E. Layne J. B. Flynn
W. D. Manly	*Physical Metallurgy of Thorium and its Alloys* *Hanford Slug Problem*	
R. O. Williams	*ORNL Slug Problem and Thorium Alloy Development*	C. L. Smith
R. J. Gray	*Metallography*	E. R. Boyd E. P. Griggs B. C. Leslie
R. S. Crouse	*Metallography*	

L. K. Jetter	*Fundamental Physico-Metallurgical Research*	
G. H. Boss	*Fundamental Physico-Metallurgical Research*	
F. Kerze, Jr.	*Reactor Development (ANPP and MTR)*	
E. C. Miller	*Reactor Development (ANPP)*	
J. E. Cunningham	*Liquid Metals (ANPP)*	T. W. Fulton L. R. Trotter
J. T. Howe	*Liquid Metals (ANPP)*	R. M. Wallace
W. H. Bridges	*Liquid Metals (ANPP)*	
G. M. Adamson	*Beryllium Fabrication; Lead Creep (MTR)*	
C. D. Smith	*Melting, Rolling, Cladding (MTR)*	F. M. Blacksher C. F. Cutcher
H J Wallace	*Melting, Rolling, Cladding (MTR)*	
F. W. Drosten	*Brazing, Fabrication (MTR)*	G. E. Cooley J. N. Hix

ACTIVE CONSULTANTS

J. L. Gregg	*Metallurgical Coordinator of Beryllium for the Materials Testing Reactor*
E. E. Stansbury	*General Consultation*
N. J. Grant	*Aircraft Reactor Program*
E. C. Creutz	*General Consultation*