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Fabrication Procedures for HFIR Control Plates

G. A. Bowden
G. R. Hicks
R. W. Knight

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A09 Microfiche A01

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ORNL/TM-9365

Operations Division

FABRICATION PROCEDURES FOR HFIR CONTROL PLATES

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Manuscript Completed - August 1984

Date Published - October 1984

Sponsor: J. H. Swanks
Operations Division

NOTICE: This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
operated by
Martin Marietta Energy Systems, Inc.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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ACKNOWLEDGEMENTS

The authors wish to acknowledge the contribution of C. D. Cagle for his work in editing this report. We are also grateful to Brenda Taylor for the fine stenographic work and other help furnished on this report.

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ABSTRACT

The HFIR control system uses Alclad cylindrically shaped components, which have regions containing 31 vol% Eu_2O_3 and 38 vol% Ta, respectively. Exacting control of the water passage between these components and adjacent reactor parts is mandatory, and precise dimensional control of the finished products is required. This report describes the procedures developed for manufacturing outer control plates and inner control cylinders. Results are cited which demonstrate that circular-shaped outer control plates can be produced with less than 0.025-in. variation from the specified 9.300-in. radius in any region of the plate. Other results show that, by the exercise of careful control, inner control plates can be welded into cylindrical geometry with diametrical variations held to less than $\pm$0.010 in. of the intended 17.846-in. average diam. The cylinders can then be explosively sized, while under compression, with diametric variations of less than 0.005 in. while controlling roundness variations to less than 0.030 in. from the specified 17.842-in. finished diam.

INTRODUCTION

The control system used in the HFIR was selected primarily for its ability to adequately control reactivity without introducing undesirable perturbations and asymmetries in the fuel-element power distribution and neutron fluxes in the target region. Basically, the system constitutes a reflector control system that regulates the flow of thermal and epithermal neutrons from the beryllium reflector to the fuel region.[1]

As shown in Fig. 1, ORNL Dwg. 65776, the control elements are located in a 0.866-in.-thick annular region between the outer fuel element and the removable beryllium. The control elements consist of two 1/4-in.-thick concentric cylinders which are separated from each other by a 0.129-in.-thick coolant channel and from the fuel element and beryllium reflector by 0.101-in.-thick and 0.136-in.-thick coolant channels, respectively. Water flows through these channels at about 16 fps. The inner control cylinder,* which is a single piece, is used both as a shim and a regulating element. The outer control cylinder is divided into four quadrants (plates), each used as a shim-safety element and each having its own drive rod and scram mechanism.

The chain reaction is controlled by altering the efficiency of the beryllium reflector as the control cylinders are moved vertically between the core and the reflector. The inner control cylinder is driven downward, thus driving the absorber out of the reactor to increase reactivity, while the outer control cylinder quadrants are driven upward out of the reactor to increase reactivity.

In order to reduce axial variations in the power distribution, the control cylinders are divided into three longitudinal sections, each of which has different neutron absorbing characteristics. The lower section of the inner control cylinder and the upper section of the outer control cylinder contain 31 vol% Eu_2O_3 dispersed in aluminum. These sections are highly neutron-absorbing and are called the "black" regions. The central section of each control element contains 38 vol% tantalum dispersed in aluminum. They are less absorbing than the Eu_2O_3 sections and are called the gray regions. The upper section of the inner control cylinder and the lower section of the outer control cylinder are made of aluminum and are called the white regions. In normal operation, criticality is achieved by driving, in unison, the inner control cylinder down and the outer control quadrants up. The two control cylinders are then gradually withdrawn to compensate for fuel burnup throughout the core life and to maintain symmetry of the power density in the axial direction. A servo control system maintains constant power by moving the inner control cylinder.

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*Certain drawings refer to the inner control cylinder as the inner control rod.

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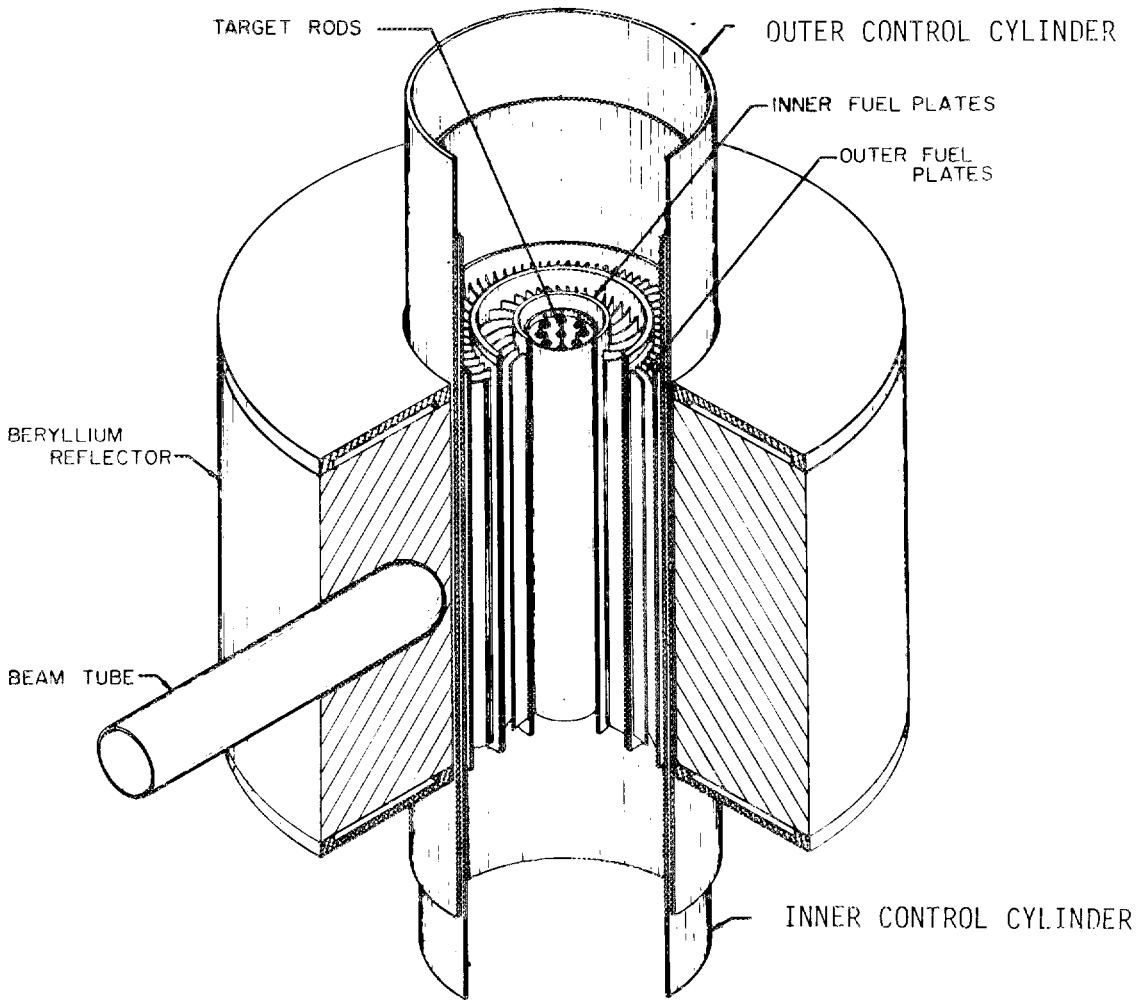


Fig. 1. Schematic of High Flux Isotope Reactor core.

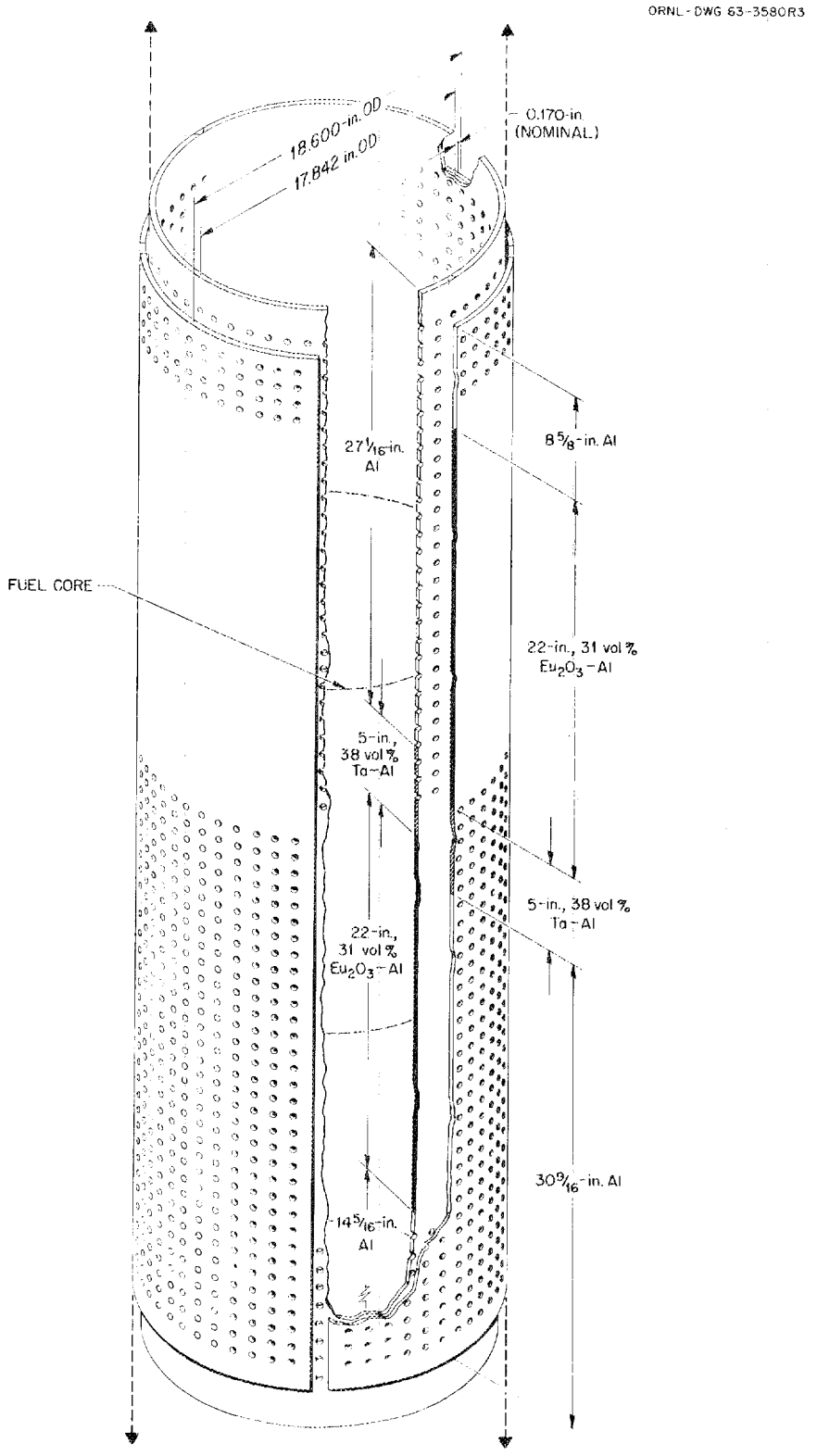


Fig. 2. View of inner and outer control cylinder showing pertinent dimensions.

Pertinent geometric details of the inner cylinder and outer plates are shown in Fig. 2, ORNL Dwg. 63-3580R3. In each case the black, or absorbing, region is 22 in. long. The absorbing region has a nominal thickness of 3/16 in. and is clad with 1/32-in.-thick aluminum. The gray regions are 5 in. long and have the same thickness of absorber and cladding as the black regions. The white regions are of solid aluminum. In order to balance the hydraulic forces, a large number of 1/4-in. holes are drilled through the white and gray regions of each plate. Corrosion studies indicate that edge cladding around these holes is not necessary in the gray region.

The inner cylinder has an outer radius of 8.921 in. and an inner radius of 8.671 in. The overall length is 68 3/8 in. The lower end of the black region is 14 5/16 in. above the lower edge of the cylinder, and the white region extends to the upper edge of the cylinder. The outer plates have an outer radius of 9.300 in. and an inner radius of 9.050 in. The overall width (arc length) of each is 13 9/16 in., and the overall length is 66 3/16 in. The upper end of the black region is 8 5/8 in. below the upper end of the plate, and the lower end of the white region extends to the lower end of the plate.

The inner control cylinder and outer control plates are driven from beneath the reactor by drive rods which extend into the subpile room, where the drive mechanisms are located. Guidance for each outer control plate is furnished by four journal bearings attached to each outer control plate, two at each end, and are run in stationary tracks which extend above and below the core. Four ball bearings are attached to the track assemblies, two at each end of the removable reflector assembly, and bear against the outer control plates. The single inner control cylinder is guided by eight ball bearings, four of which are attached to the track assemblies at each end of the reflector and extend through the slots between the four outer control plates.

The aluminum-based dispersions of Eu_2O_3 and tantalum are prepared by relatively conventional powder metallurgical practices, and the plates are fabricated in the rolling mill facilities at ORNL. After inspection by ORNL's QA&I Department, the plates are shipped to the Y-12 plant for subsequent forming, machining, and explosive sizing operations to produce control components meeting rigid dimensional specifications. The procedures and results described in this report are based on our experience in successfully producing control components for the reactor.

OBJECTIVES

The design concept that two 1/4-in.-thick, approximately 65-in.-long components fit into a 0.866-in.-thick annular region and retain the capability of moving in unison without significantly disturbing the system hydraulics requires extraordinary geometric control in forming these control components to their specified shapes. The specification stipulates that the 0.250-in.-thick inner cylinders, nominally 17.842 in. in outside diameter must be capable of passing through an annulus 0.310 in. wide whose inner diameter is 17.282 in. and whose outer diameter is 17.902 in. without violating these boundaries. Our final inspection is, therefore, based on an inspection of deviations in the radius of the completed cylinder at a minimum of 12 equally spaced locations along the length of the component (2,160 local radial recordings) to make certain that a statistically significant number of measurements are within ±0.030 in. of the nominal outside radius of 8.921 in. This specification is especially demanding when one considers that the cylinder is prepared by welding four curved composite plates together and no machining of the cylindrical surfaces is permitted because of probable violations of the plate cladding.

Although the outer plates are not welded together, control of local deviations in the radius of the formed plate is as demanding as the specifications cited for the inner cylinder. In fact, our target is to control the radial deviations throughout the plate to within ±0.025 in. of the nominal 9.300-in. specified radius.

To meet the specifications, we chose to explosively size these components to final shape after preforming to approximately the specified radius. The inner cylinder is sized while under compression to avoid potential tensile failures. This requirement necessitates careful fixturing while welding the four inner plates together to form the cylinders to avoid presenting a cylinder for explosively sizing which would be unacceptable because the diameter is either undersized or oversized. We feel that it is necessary to produce a welded cylinder with a nominal diameter within +0.010 in. of 17.846 in.

DESCRIPTION OF PROCESS

The general process is summarized in the flow chart identified in Fig. 3. Each phase of the process is subsequently described in detail.

For each fabrication, five inner and five outer plates (one spare for each type) are manufactured using the conventional picture frame technique but with multiple cores of Eu_2O_3 in aluminum and tantalum in aluminum, pressed into powder cores. The assembled billets are evacuated and hot-bonded with a total reduction of approximately 8/1. The control plates are inspected dimensionally, radiographically, ultrasonically, and visually for core location, nonbonds and surface defects. The control plates are shipped to Y-12 from the ORNL rolling facility, where they are bonded to backup plates prior to preforming. These control plates are prepared for preforming to radii approximating the specified radii by first identifying the longitudinal centerline of the core sections in the rolled plate and then scribing guidelines to be used while forming the plate to avoid a serious mismatch between the longitudinal centerline of the cores and the longitudinal centerline of the formed plate, while preforming on a brake press. After preforming and removal of the "backup" plates, the control plates are cleaned and stress-relieved. A hole and slot are machined near the ends of each plate to locate the position of the control plate in the explosive sizing die and again avoid a mismatch between the centerline of the explosively sized control plate and the centerline of the core sections. The main objective in sizing the inner plate is to have a straight, well-shaped plate to exercise excellent control while assembling and welding these inner plates into a cylinder. The welded cylinder is subsequently explosively sized. In the case of the outer plates, this sizing operation is of paramount importance because it is the final phase in shaping the plates. In either case, however, it is possible to resize if deemed necessary. The die is designed with the radius of 9.300 in. to accept an outer plate. However, by shimming the die to a radius of 8.921 in., it can be used to size inner plates and obtain exceptional dimensional control. The outer plates are carefully inspected, a machining layout prepared, and each outer plate machined to its final arc length and overall length. Extreme care is exercised during these layout and machining operations to make certain that the specification stipulating a minimum 0.125-in. aluminum edging along the core section is not violated. Prior to attachment of the end adapters, the 1/4-in. diam holes are drilled through the outer plate using tape control; the dimensions are inspected to ascertain that they have not been disturbed significantly by the hole drilling operations, and the holes are finally radiused.

After the explosive sizing operation and inspection, a layout of the inner plate is made, and three plates of each set of four, are machined to a final arc length of 14.041 in. and the edges beveled preparatory to welding. The fourth plate of each set is machined to an arc length of 14.111 in. During layout and machining, care is taken to assure that the width of aluminum edging between the core section and the machined edge of the plate is at least 3/8 in. On the other hand, it is desirable to keep

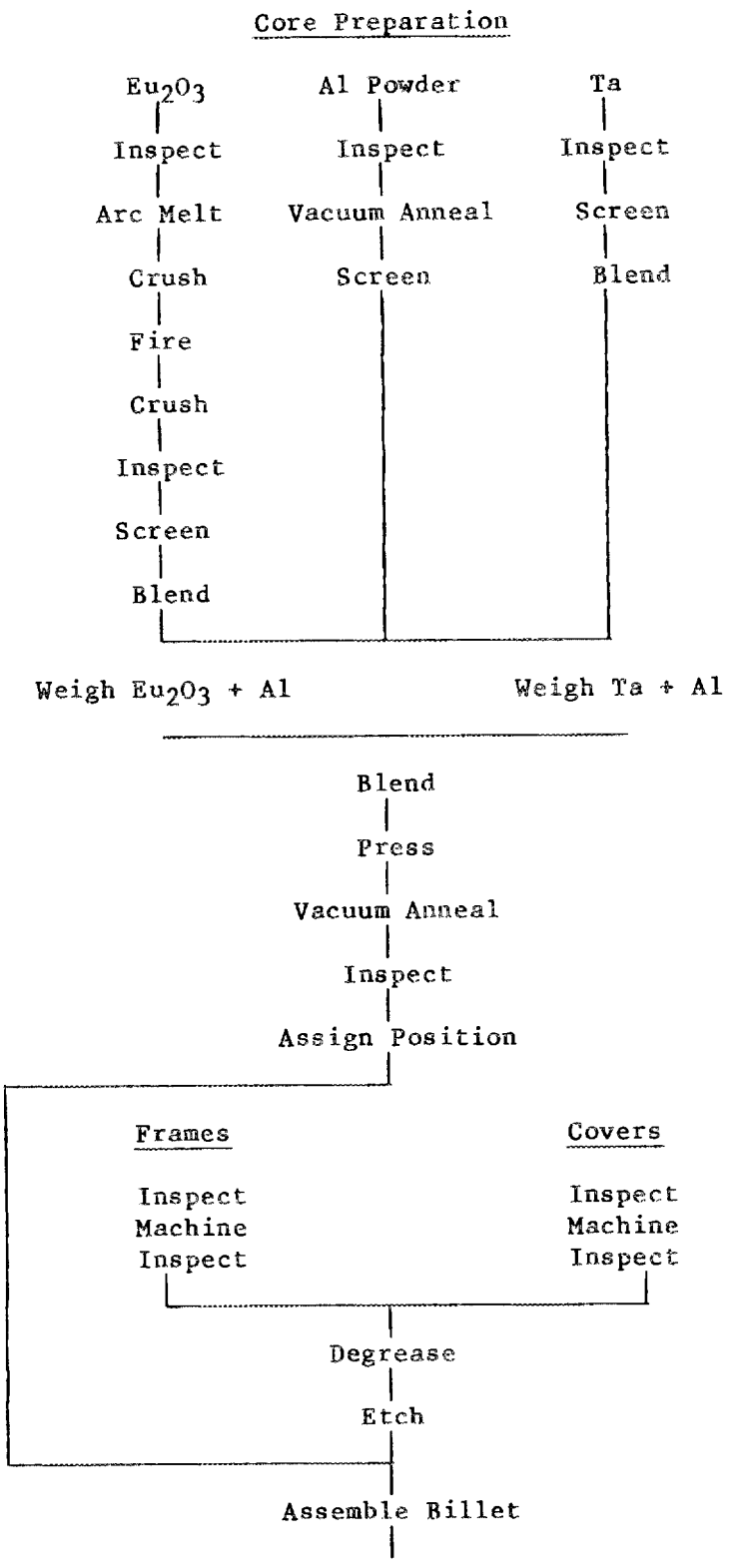


Fig. 3. Flow chart for core preparation.

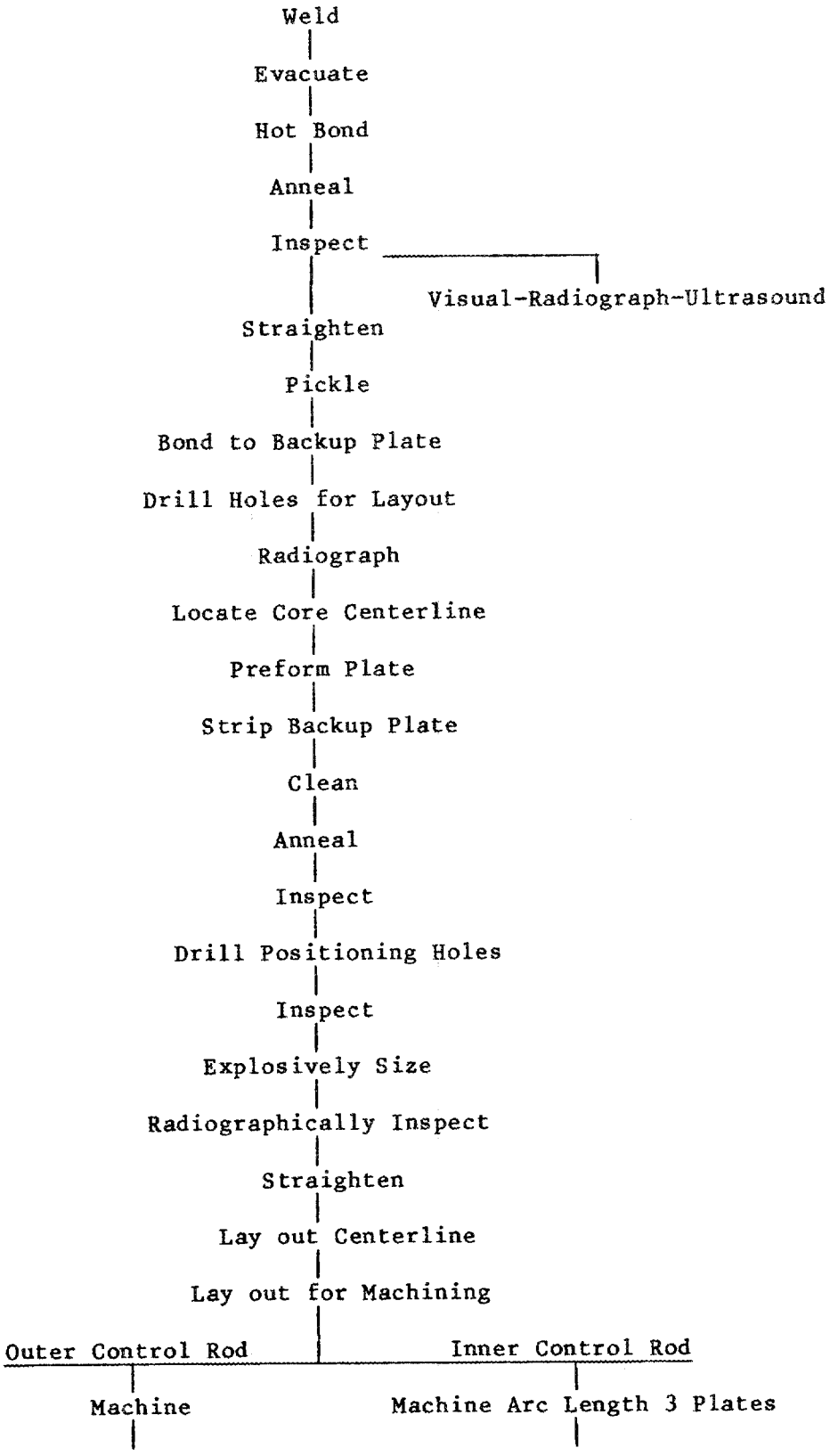


Fig. 3. Continued.

Inspect

Drill 1/4 Diam Holes

Radiograph

Radius Holes

Inspect

Machine End Fitting

Inspect

Set up on Mandrel

Drill 5/8 and 3/4 Diam Holes

Install End Fitting

Inspect

Install Bearings

Inspect

Clean

Ship

Inspect

Weld 2 Plates

Inspect

Planish Welds

Inspect

Machine Arc Length 1 Plate

Weld 2 Plates

Inspect

Planish

Weld 2 Half Cylinders

Inspect

Planish

Inspect

Explosive Size

Inspect

Lay Out

Drill 1/4 Diam Holes

Machine for End Fittings

Inspect

Shrink Fit End Fitting

Attach End Fitting

Inspect

Clean

Ship

Fig. 3. Continued.

the width of aluminum between core sections in adjacent welded plates to a minimum to avoid an excessive neutron "window." A "window" approximately 1 in. wide is deemed acceptable. After the machined plates are critically inspected to make certain of the arc length measurement, the plates are butt-welded together to form a cylinder. Extreme care is exercised in fixturing to ensure a welded product that is 17.850 in. +0.010 in. in diameter. It is important that these diametric tolerances be met to make certain that, when the inner cylinder is explosively sized, it is under compressive loading (inside die diameter is 17.832 in.). Each sequence is started by first welding two inner plates together to determine weld shrinkage so that the arc length of the inner plate withheld from the previous machining can be determined. This value has been established as 14.111 in. and it is welded to an inner plate machined to a 14.041 in. arc length. These welds of two half inner cylinders are scraped and the arc lengths increased, by planishing, from 0.005 to 0.009 in. to achieve a corrected arc length for welding. The two halves are welded together to form an inner cylinder and the welds scraped. By careful programming each planishing operation, no difficulty is experienced in achieving a diameter within a range 17.836 in. to 17.856 in. After each welding operation, the welds are inspected radiographically to assure that a full penetration weld, essentially free of porosity and impurities, was made. Prior to sizing the inner cylinder, the ends are faced and the inner cylinder is compressed in the die and readied for explosive sizing. Two moderate charges rather than one large charge are detonated in sizing the cylinder to its final specified diameter. After radiographic inspection has verified that no failure such as cracks or tears occurred during explosive sizing, the inner cylinder is critically inspected and local variations from the intended diameter are measured. A total of 2,180 holes are then drilled into the part and carefully radiused. The end fitting is attached, a final inspection made of the diametric variations and concentricity, and the component cleaned.

Preparation of Component Powders

These preparation techniques, developed for fabrication at ORNL, are still in use essentially as described.

1. Eu_2O_3. The europium oxide obtained from various vendors is normally of low density and extremely fine particulate size. The individual particles tend to agglomerate and stringer when dispersed in aluminum powder and subsequently fabricated into a composite plate. To reduce this heterogeneous tendency of the dispersion, the material is densified by arc-melting. The necessary operations are (a) inspection of as-received Eu_2O_3, (b) pressing, (c) arc-melting, (d) crushing and firing, (e) blending, and (f) characterization.

    a. Inspection of as-received Eu_2O_3. The oxide is purchased in a "dead burned" form which has been converted from the oxalate to the cubic crystal structure of Eu_2O_3. Total weight loss upon ignition must be less than 0.1 wt %. Each batch of received material is analyzed for total europium oxide and

thoria content. The material must contain a minimum of 98 wt % Eu_2O_3. The thoria content is determined by alpha-activity measurements. Material with alpha counts in excess of 5 counts per minute per milligram above background on a detector with a 50% alpha counting efficiency is considered contaminated and is rejected.

b. Pressing. The pour density of the received powder is only 0.5 to 0.7 g/cm^3. Prior to arc-melting, the oxide is pressed into cylindrical pellets to a density of about 1.5 g/cm^3 to facilitate subsequent handling. Approximately 100 g of the material is poured into a double-acting 2 1/4-in.-diam die that has been lubricated sparingly with 5 wt % stearic acid-carbon tetrachloride solution. A pressure of 500 psi consolidates the powder. The resulting 2 1/4-in.-diam by 1.0-in.-long pellet possesses sufficient green strength to handle without fracture.

c. Arc-melting. An inert-gas, arc-fusion technique is used to produce highly dense europium oxide. Figure 4, ORNL Dwg. 64-4538, illustrates the arc-melting furnace which is pressurized to 10 psig with argon during melting. It uses a hollow thoriated-tungsten electrode tip and a water-cooled copper melting hearth. Passing an equal volume mixture of helium and argon through the hollow tungsten electrode reduces arc instability caused by gas evolution from the dissociation of hydroxides and carbonates. The deep hemispherical cavity minimizes arc scatter associated with spreading of small droplets of molten material.

One pellet of about 100 g is melted at a time. Normally, a duration of only 5 min is required to charge, melt, and remove the pellet from the furnace. After striking the arc, the power is increased (from 300 A at 30 V to 600-800 A at 40 V) and the entire pellet is fused. The resulting button of about 3 in. in diameter is essentially 100% dense. If incomplete fusion is noted, the button is turned over and remelted completely. The latter operation requires only 500-600 A since most of the oxide is fully densified.

The surface of the buttons will exhibit a reddish-brown hue with excessive copper pickup from the melting hearth. These buttons are submerged in 35 vol % aqueous HNO_3 (70%) solution until the reddish color disappears. The pickling may require up to 1 hr duration on heavily contaminated material. Immediately upon removal from the acid bath, the buttons are rinsed in hot tap water and allowed to dry in air.

d. Crushing and firing. The inert-atmosphere arc fusion of Eu_2O_3 always yields a dense, vitreous-appearing product. In contrast to the gray hue of air-fused material, the darkened color of the arc-fused oxide indicates an oxygen deficiency.

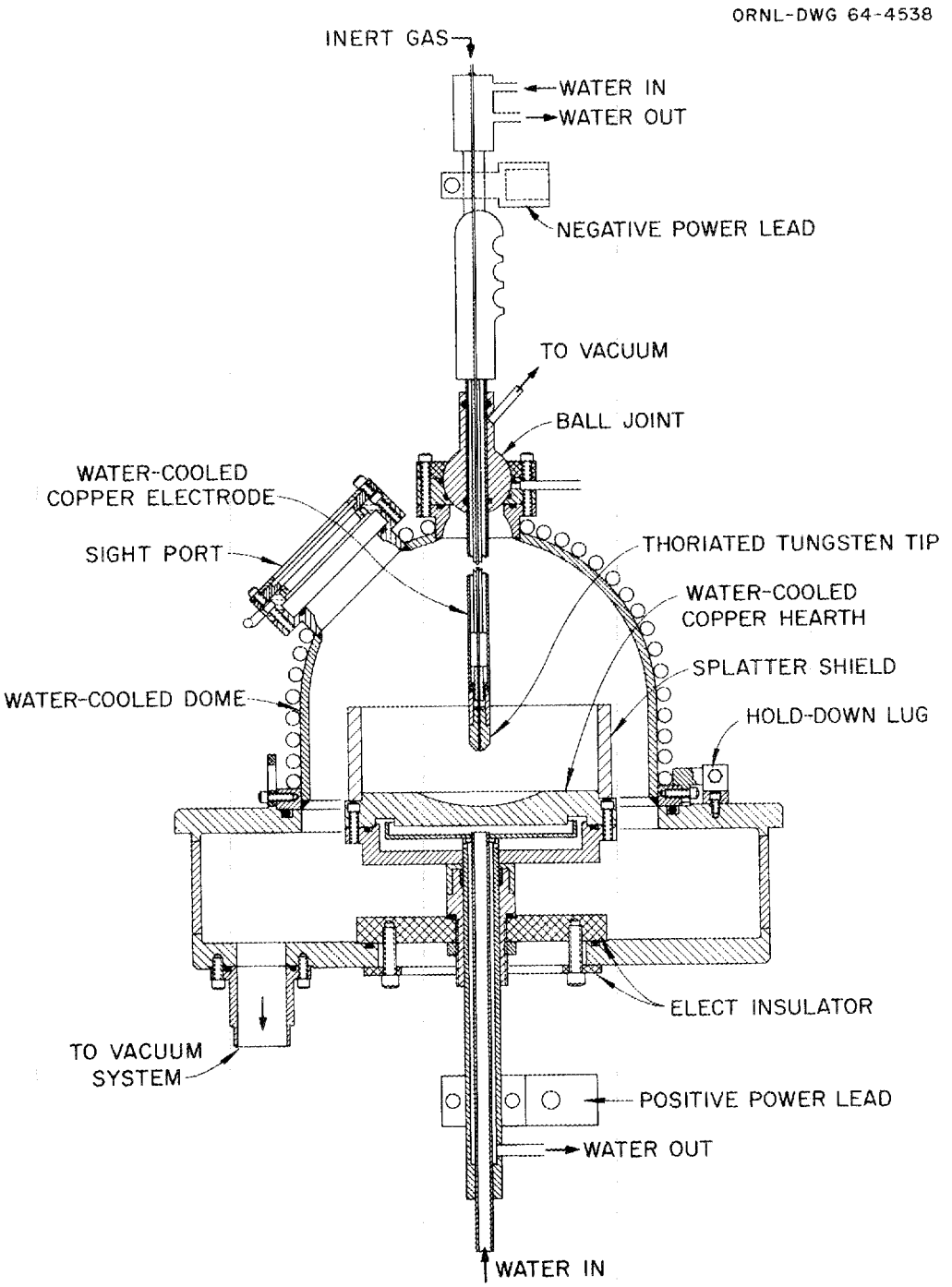


Fig. 4. Hearth assembly for melting europium oxide.

Heating in air at approximately 1000°C, however, restores the stoichiometric oxygen content.

To ensure complete oxidation, it is recommended that the arc-melted oxide be crushed to pass a 2 1/2-mesh U.S. standard sieve before heat treating in air. The material is inherently brittle and can be most inexpensively comminuted to pass the 2 1/2-mesh sieve with a laboratory jaw crusher.

The oxidizing treatment is performed in a conventional resistance-wound furnace with normal atmospheric air. For convenience, hemisperical alumina crucibles of 8 in. diam by 4 1/2 in. high are charged into the furnace at room temperature. Each bowl will hold about 10 kg of crushed oxide. After firing overnight (12 to 18 hr) at 1000°C, the material is usually allowed to cool to near room temperature before being removed from the furnace.

The fired Eu_2O_3 is crushed and screened to give a particle size distribution of less than 3 wt % of +100 mesh, greater than 70% of -100- to +325-mesh and less than 27 wt % of -325-mesh. A Bico, type UA, direct-motor-driven pulverizer equipped with a 2-hp motor and 8-in.-diam grinding plates rotating at 900 rpm readily reduces the material to pass through a 100-mesh sieve.

Initially, the two grinding plates are set 0.125 in. apart. All of the fired material is passed once through the pulverizer at this setting and then screened on a Cenco-Meizer sieve shaker to remove the -100- to +325- and -325-mesh fractions. To minimize the generation of excessive fines, only oversized particles are fed into the pulverizers at progressively smaller settings of 0.032, 0.015, and 0.004 in. On the final setting, the oversize is repeatedly passed through the grinding plates until the particles are less than +100 mesh.

e. Blending. After crushing, the fines content of the -100- to +325-mesh fraction is determined according to ASTM B214-64. Based on the results of this sieve analysis, a blend of the -100- to +325- and -325-mesh materials is prepared to meet the particle size requirements. The quantity of fines in excess of that permitted in the blend is returned to the pressing operation for recovery.

To obtain a homogeneous mixture of Eu_2O_3 particles, the desired quantities of the -100- to +325- and -325-mesh fractions were blended in a twin-shell blender for 1 hr. This "V" type blender rotates at 24 rpm and can easily mix up to 25 kg of fired and crushed Eu_2O_3. The blending action effectively halves and then recombines the powders during every revolution. After blending, the prepared Eu_2O_3 is stored in 1-qt plastic bottles equipped with plastic lids.

f. Characterization. Representative samples of the prepared blend of Eu_2O_3 are analyzed for total europium, general impurities, and for particle size distribution according to ASTM B214-64.

2. Tantalum. Tantalum powders are purchased to the following specifications:

   a. Tantalum content shall be 99.5 wt % or better. Impurities of carbon, oxygen, and nitrogen shall be less than 100, 200, and 300 ppm, respectively.

   b. Material shall be uniform in composition and purity.

   c. Particle size distribution shall be less than 3 wt % +200-mesh, greater than 70 wt % -200- to +325-mesh, and less than 27 wt % -325-mesh. The distribution shall be determined in accordance with ASTM B214-64.

   Representative samples from each batch of received tantalum are analyzed for particle size distribution according to ASTM B214-64 and impurities of C, O, N, Mo, Fe, Ni, Cr, Co, Al, Si, Mg, Mn, Cu, Sn, Pb, and Cb. The minimal tantalum content is defined to be the difference between the summation of all detected impurities and 100 wt %. If the results from the analyses conform to the specification, the batch is stored in plastic bottles equipped with plastic lids. Material with out-of-tolerance levels for particle size and/or impurities is rejected.

3. Aluminum. Aluminum powders are purchased to the following specifications:

   a. Material shall be Alcoa type 101 aluminum powder per product data book 6-20-60 or the equivalent such as Reynolds Metals No. 120.

   b. Particle size distribution shall be less than 0.5 wt % +100-mesh, less than 20 wt % -100- to +325-mesh, and greater than 80 wt % -325-mesh. The distribution shall be determined in accordance with ASTM B214-64.

   c. Impurities of Fe, Si, and Al_2O_3 shall be less than 4000, 2000, and 6000 ppm, respectively.

   Although the specified powder is fine quality aluminum, it is recommended, for uniformity of properties, that the material be annealed before used. The annealing procedure entails simply heating the received powder at 500°C for 1 hr at a pressure less than 7×10^{-4} torr. The material is then cooled to below 50°C before opening the system to atmosphere and bagging in polyethylene. Immediately before use, the powder is passed through a 100-mesh screen. All +100-mesh material is discarded.

To provide a chemical record and to check for gross contamination, a representative sample from each annealing batch of aluminum is analyzed spectrographically for general impurities. For the same reason, the particle size distribution of -100-mesh prepared powder is determined in accordance with ASTM B214-64. Materials with out-of-tolerance levels for particle size and/or impurities are rejected.

Preparation of Compacts

The compact stacking arrangement is shown in Fig. 5, ORNL Dwg. 68-10681. The billet contains (in tandom) 18 compacts of 59.1 wt % Eu_2O_3 and 9 compacts of 80.6 wt % Ta in aluminum. The compacts are prepared by powder metallurgy. The essential operations required in processing are (a) weighing and blending of the component powders for each individual compact, (b) cold pressing the blended powders into a compact of the desired dimensions, (c) degassing the compact to remove pressing lubricants and absorbed gases, and (d) inspection of the degassed compacts.

The principle neutron absorbers in the gray and black sections of the inner and outer control plates are specified in terms of grams of Ta and Eu, respectively. Since the tantalum powder contains impurities and europium is incorporated as Eu_2O_3, it is necessary to determine by calculation the quantities of these materials for each loading.

Typical designs for the HFIR control plate poison compacts are shown in Table 1. The important parameters are the specified quantities of Ta and Eu, their assays, the design total volumes of the rolled core sections, and the experimentally established densifications of the Ta-Al and Eu_2O_3-Al dispersions. The densification is defined by the ratio of measured density to theoretical density of the dispersion; the latter is based on the toluene density of the individual powder components.

As might be expected, the densifications of the dispersions significantly affect the charge of aluminum powder required to meet the dimensional specification of the core in the rolled plate. The values shown in Table 1 apply to the powders, specific equipment, and processing methods used at the Oak Ridge National Laboratory. Any major change in materials or procedures will probably alter these values; and, consequently, it will be necessary to modify the charge of aluminum powders required in the poison compacts.

1. Weighing and blending. Typical charge weights for the gray and black sections of the inner and outer control plates are included in Table 1. The component powders for each individual compact are separately weighed and combined in a single blending container. The weights are made to ± 0.01-g accuracy on a Sauter Top Pan balance of 400-g capacity.

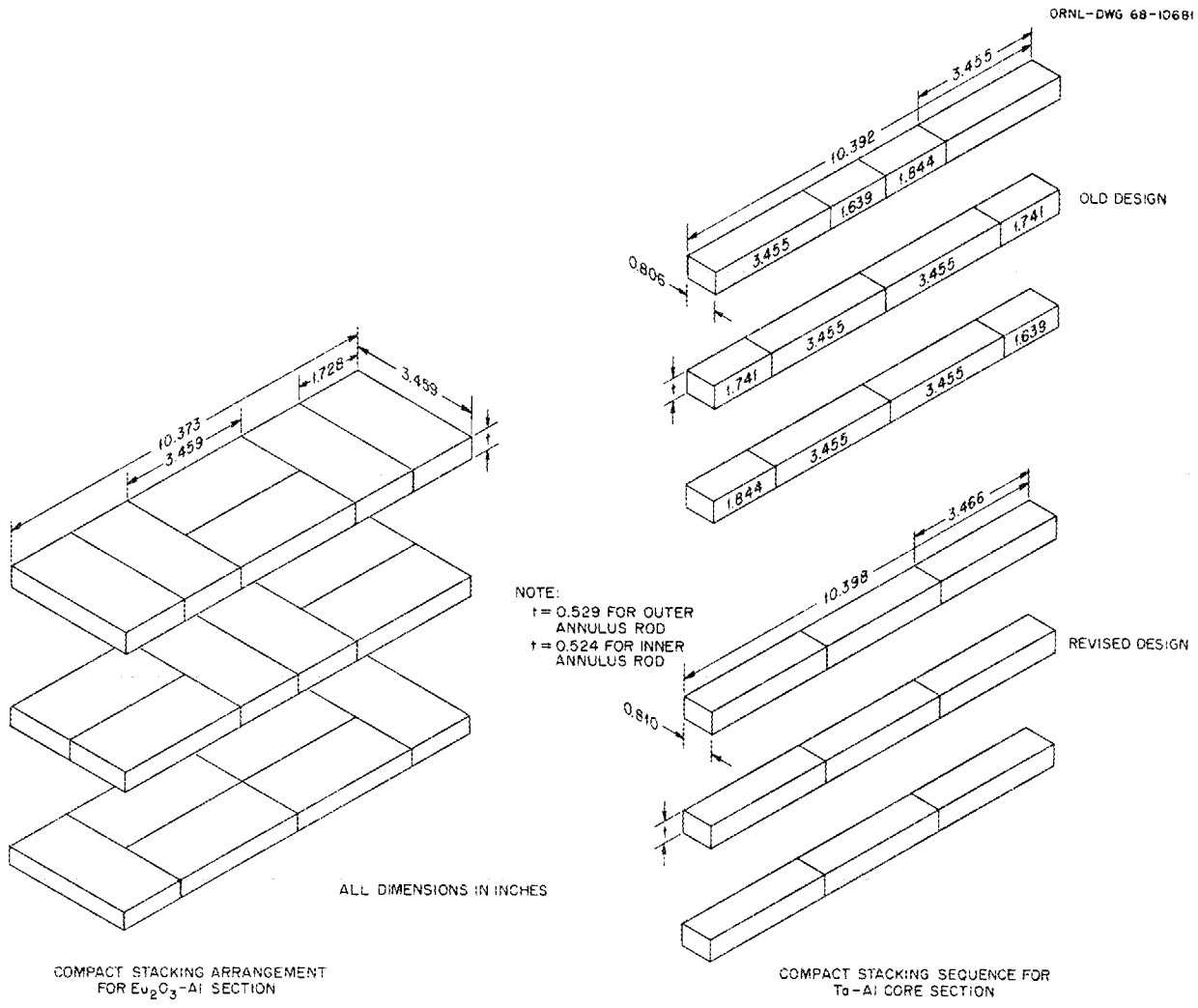


Fig. 5. Orientation of compacts for loaing into billet frames.

Table 1. Summary of pertinent design data for HFIR control plate compacts

	Outer plate		Inner Plate	
	Gray section	Black section	Gray section	Black section
Principle neutron absorber				
Element	Ta	Eu	Ta	Eu
Specified quantity, g	1297	1922	1292	1912
Chemical form	Ta	Eu_2O_3	Ta	Eu_2O_3
Typical assay, wt %	99.8	86.3	99.8	86.3
Toluene density, g/cm^3	16.46	7.933	16.46	7.933
Rolled core				
Typical dispersion composition, wt %	Al plus 80.64% Ta	Al plus 59.14% Eu_2O_3	Al plus 80.64% Ta	Al plus 59.14% Eu_2O_3
Design total volume, cm^3	206.7	914.3	206.1	909.4
Number of individual compacts	9	18	9	18
Densification of dispersions, % T.D.				
Pressed condition	89	92	89	92
Degassed condition	89	91.5	89	91.5
Rolled condition	94	93	94	93
Typical charged weight of dispersion, g				
Dispersion of Ta or Eu_2O_3	144.44	123.73	143.89	123.06
Matrix aluminum	34.67	85.50	34.55	85.00
TOTAL	179.11	209.23	178.44	208.06
Design compact thickness, in.				
Pressed condition	0.5285	0.5260	0.5240	0.5220
Degassed condition	0.5285	0.5280	0.5240	0.5240

To achieve a mixing space of 60 vol % during blending, jars of 4-oz and 8-oz capacities are used for the Ta-Al and Eu_2O_3-Al dispersions, respectively. For convenient handling, clear glass bottles of screw neck and wide mouth design with mating caps of molded black bakelite are recommended.

Material control is maintained on a daily basis for each powder component. Before weighing the first compact charge, sufficient Al, Ta, and/or Eu_2O_3 plus 10 g excess for the day's production are transferred to the balance table. After charging the desired number of blending jars, the starting weight of each component powder less the summation of its charged and residue quantities should agree within ± 10 g.

To obtain a homogeneous mixture, the weighed and contained powders are blended for 2 hr in a modified U.S. Stoneware Company double blender, model 733. The blender cones are replaced by a pair of 2-qt steel cans mounted on the motor shaft at an angle of 30° to the vertical plane. The cans rotate at 20 to 25 rpm during the blending operation. Eight jars, each containing the required quantities of Al and either Ta or Eu_2O_3, are loaded into each can with sufficient padding to prevent breakage. After blending, the jars are placed in a steel tray and carried to the compacting press. The powders must be compacted within 4 hr of blending.

2. Pressing. Immediately after blending, the powders are compacted by cold pressing. As illustrated in Fig. 5, ORNL Dwg. 68-10681, the green compacts are in the shape of rectangular parallelepipeds. To achieve the desired stacking arrangement, with only one powder metallurgy die, the length and width of the Eu_2O_3-Al compacts differ by about a factor of 2.

   The pressing operation utilized conventional powder metallurgy dies and a 500-ton Farquar top-acting hydraulic press. The die set consists of a female die, which is spring mounted to the working surface of the press, die punches, top and bottom, a filler block, and a jack for raising and lowering the position of the bottom die punch. The bottom die punch contacts the jack, while the filler block, positioned on top of the inserted top punch after filling the cavity with powder, contacts the movable ram. To simulate a double-acting press, the female die is allowed to float during the pressing operation.

   The sequence used for the pressing operation is as follows.

   a. With the lower punch in the pressing position, the inside of the die cavity is lubricated sparingly with a 5 wt % solution of stearic acid in CCl_4.

b. The upper 1/2-in. portion of the die cavity is tapered slightly (0.031 in./ft) to facilitate ejection of the compact. To permit leveling of the powder, the bottom die punch is raised by the jack so that the powder can fill the tapered region.

c. The blended powders are then poured into the die cavity, and the jar and cap are lightly tapped against the top of the die to ensure removal of loose particles.

d. The powder is leveled in the die with a metal straight edge. While leveling, the position of the lower punch is adjusted so that the entire volume of powder completely fills the cavity with no edge depressions of densification of the material. With a trained operator, this operation can be performed in 5 to 7 strokes of the straight edge.

e. The leveled powder is then lowered into the pressing position of the die, the top punch is inserted into the die, the filler block is placed on top of the top punch, and the compact is pressed for 6 s. With a relatively constant pressing pressure of 19 to 20 tsi, the powder is compressed to the design thicknesses shown in Table 1.

f. The compact is ejected from the die, the die cavity is wiped clean with a tissue saturated with isopropyl alcohol, and the cycle is repeated. Before proceeding, however, the thickness of the ejected compact is measured and compared to the value shown in Table 1 for the pressed condition. If the average thickness along the diagonal of two consecutive compacts deviates greater than ±0.002 in., the pressing pressure is modified appropriately. Individual measurements should agree within ±0.003 in. The die is shimmed if measurements from the compacts indicate a consistent taper.

g. Each individual compact is assigned a number which distinguishes poison disperisons of identical materials, pressing procedure, and fabrication period. The number is scratched on one major surface of the compacts.

h. To provide a permanent record, six compacts randomly selected from the day's production are individually weighed (±0.01 g) and measured (±0.0005 in.) and the values are recorded.

3. Vacuum annealing. To remove the lubricant entrapped during pressing and any moisture adsorbed during handling, all poison compacts are heat treated. The green compacts are stacked in layers, separated by stainless steel wire screen, inside an aluminum annealing tray. The tray is then inserted into a 6-in.-diam stainless steel horizontal muffle furnace at room temperature. After evacuation to a pressure of less than 0.05 torr, the compacts are heated to 590°C and held at that temperature for

3 hr. While the pressure may rise during the initial heating, it must remain below 0.05 torr for most of the treatment. The compacts are cooled under vacuum to below 50°C and then removed from the furnace. Compacts are handled in all subsequent operations with cotton gloves and/or stainless steel tongs.

4. Inspection. After vacuum annealing, every compact is inspected for weight and thickness and the values are recorded. A compact that deviates by more than 0.1% from a previously established weight is rejected. The thickness is measured at five locations with a micrometer; any variation greater than 0.006 in. is also cause for rejection. Usually, a small increase of 0.001 to 0.003 in. in thickness from the heat treatment will be noted for the Eu_2O_3-Al compacts. A record is made of the length and width of 12 similar compacts pressed during a single fabrication period. During the inspection, a visual check is made for chipped edges, blisters, and inclusions, each of which is cause for rejection.

   All acceptable compacts are placed in plastic bags and stored in a desiccator.

Preparation of Cover Plates and Frames

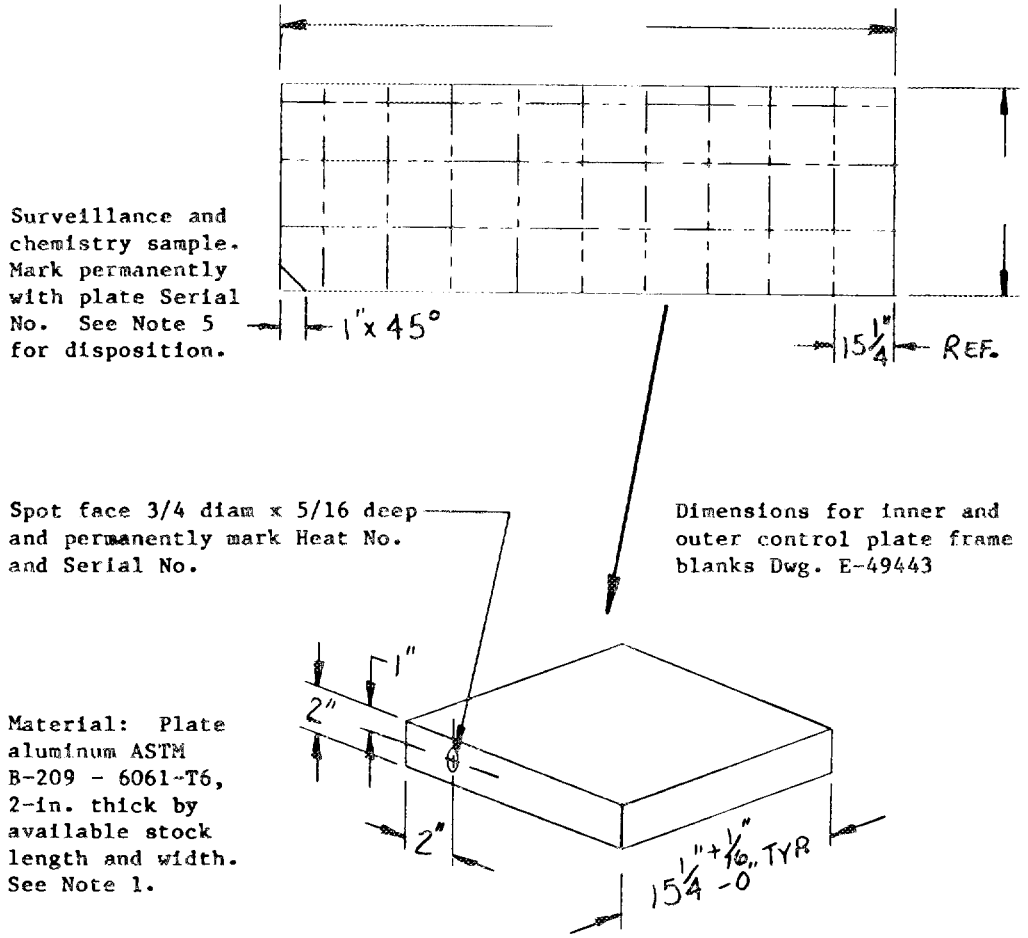
In the HFIR, considerable emphasis is placed upon safeguarding against the use of metals and alloys within the core area that do not have catalogued properties. The cladding material for the control plates is purchased as "mill marked" 1/4- and 2-in.-thick 6061 Al plate. To assure the composition of the original plate and to monitor the use of this plate in the control plate fabrication, a spectrographic analysis is obtained from each plate and an identifying code letter is assigned as a consistent portion of the number given each piece cut from the plate. Additionally, an as-received sample of the plate is placed in the HFIR archives for future reference.

Each control plate requires one piece of 2-in.-thick material for the frame and two pieces of 1/4-in.-thick material for the cover plates. All pieces are about 15 in.^{2}; therefore, 12 pieces may be cut from a single mill size plate. The thick plate is laid out, cut, and labeled to identify each piece as shown in Fig. 6, A-SK-GRH-760510. The thinner cover plate material is sheared to the desired size and labeled with the plate identification. The pieces are numbered consecutively from an individual plate. Identification of the frame material is preserved through the extensive machining by placing the number on a spot-faced area recessed below the final machined edge.

Surface condition of the as-received 2-in.-thick plate is not considered, since this is removed in the machining operation. However, the cover-plate material is inspected for disturbances of the bright mill finish. Pieces exhibiting heavy oxide buildup, deep gouges, or embedded foreign material are considered defective. These plates are chemically milled to the desired thickness and this treatment will not remove defects.

A-SK-GRH-760510

HFIR INNER AND OUTER CONTROL PLATE FRAME
LAYOUT FOR CUTTING AND PERMANENT MARKING



NOTES:

1. Prior to cutting plate, record the following information from the mill marking on plate:
   a. Manufacturer's name _____
   b. Specification No. _____
   c. Alloy designation _____
   d. Heat No. _____
2. Layout and mark Heat No. and blank Serial No. on top surface of each blank before cutting.
3. Saw cut blanks, chemistry sample, and surveillance sample. "Do Not Burn or Grind."
4. Spot face on each blank on sawed edge. Stencil each with Heat No. and Serial No. (see work request for Serial No.).
5. Forward surveillance sample properly marked to the HFIR Operations Supervisor, Building 7910, ORNL.

Fig. 6. HFIR inner and outer control plate frame layout for cutting and permanent marking.

Frames for the inner and outer plates differ in thickness only (the inner 1.560 in. and the outer 1.569 in.), and are shown on Dwg. E-49443. Normal machine shop practices are used to fabricate the frames by milling away the excess metal. Particular concern is given to thickness variations as exhibited by the individual part and to the relationship of the cavity with the frame periphery, since these affect the control plate rolling. Since transverse thickness variations produce plate camber during billet reducting, these are minimized, and although some variation is present, it should not exceed 0.001 in. Misalignment of the cavity with the frame edges is also magnified to cause a problem in obtaining parallogram-shaped ends of the rolled core. The drawing indicates an allowable variation of 0.002 in.; this is considered necessary.

Billet Preparation and Assembly

The rolling billets are an evacuated assembly of the desired reactor poison materials compacted as previously described and loaded into an ultraclean aluminum container as shown in Fig. 7, ORNL Dwg. 64-812R2.

1. Cleaning cover plate and frame. To guard against loss of control plates as a result of blisters in the aluminum, the cover plate material is degreased and cleaned to remove pencil marks, tape, etc., and then heated 2 hr at 500°C to reveal any blister defects. Plates exhibiting any blisters, massive oxidation, and/or embedded foreign particles are rejected.

   During the same day as billet assembly, both the cover plates and frame are cleaned by a standardized procedure for etching with Oakite 160 followed by an alcohol rinse. Details follow.

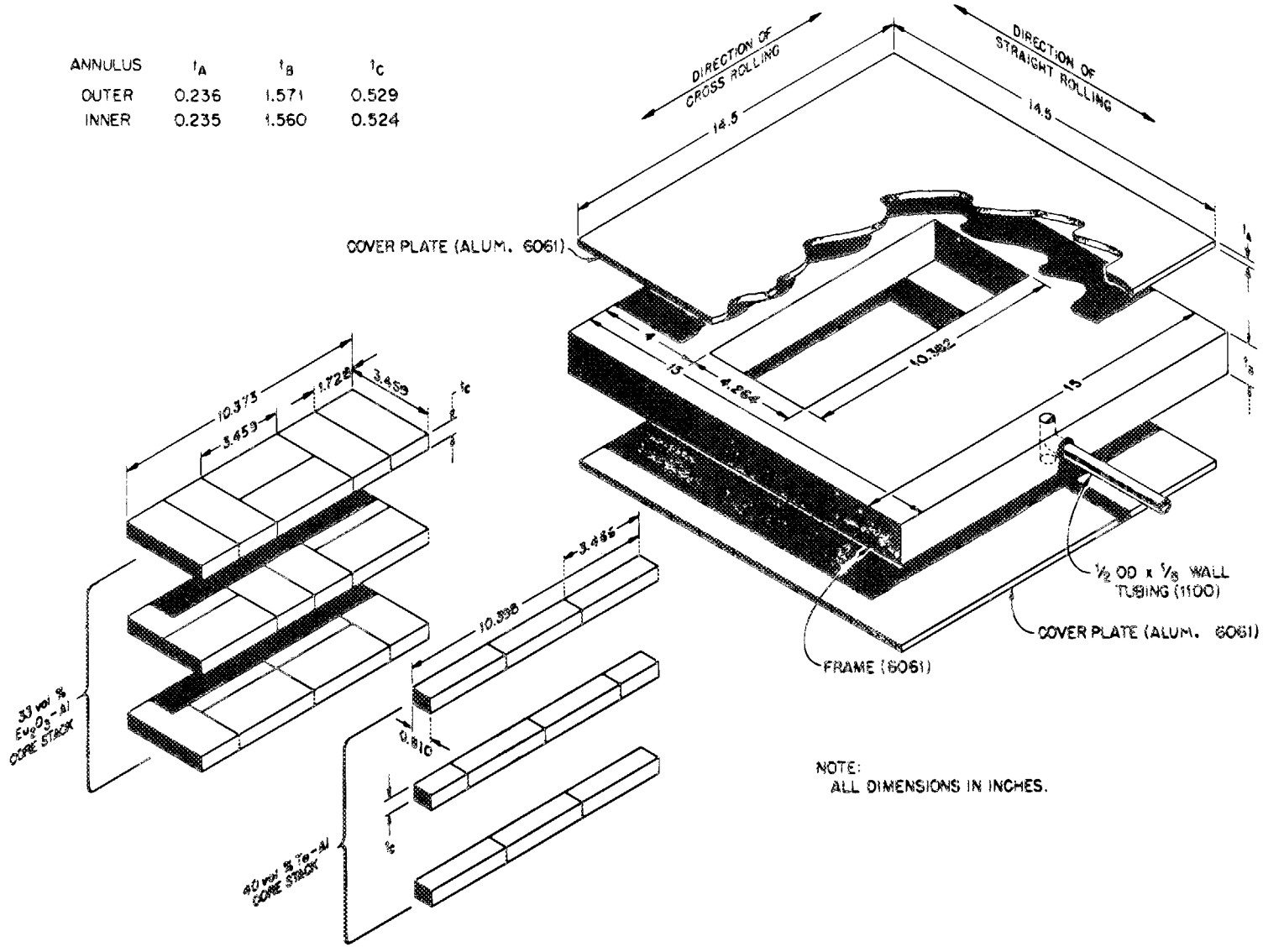
   Immerse in hot (165-175°F) Oakite 160 solution (10 oz/gal water) followed immediately by a thorough rinse in 165-175°F water and neutralization in cold 60% nitric acid (42% assay). If smut is evident after hot water rinsing to remove the acid, the parts are recycled through the Oakite 160 as a rinse only, followed by the other treatments; this treatment is repeated until all evidence of smut disappears. At the end of treatment, parts are allowed to remain in the acid a minimum of 10 min. The acid is then rinsed off with hot water followed by alcohol. The parts are allowed to dry by natural convection.

2. Billet loading. Each billet is loaded with 27 powder metal compacts (see Fig. 7, ORNL Dwg. 64-812R2). The compacts are placed in the frame cavity in three layers. Each of these layers consists of three tantalum- and six europium-bearing compacts. The following step procedure is used to successfully load the poison material into the billet.

   a. Place a clean frame on a clean cover plate in a furnace operating at 500°C.

UNCLASSIFIED
ORNL-DWG 64-812R2

ANNULUS	t_A	t_B	t_C
OUTER	0.236	1.571	0.529
INNER	0.235	1.560	0.524



NOTE:
ALL DIMENSIONS IN INCHES.

Fig. 7. Billet components and compact layout.

b. After 30 to 45 min preheating, the cover plate and frame are removed to a transite-covered support for loading.

c. Place three tantalum-bearing compacts in the cavity at the evacuation tube end and follow these with six europium-bearing compacts to complete a layer. Repeat this process to load all 27 compacts. The orientation of the europium compacts differ with each of the three layers to make discontinuity in the interfacial joints between compacts as they make up the core thickness.

d. The top cover plate is added to the frame.

e. The assembly is held together with four "C" clamps placed over and about 2 in. from the corners of the two cover plates after they are positioned to allow equal distances around the frame edges to be used as welding grooves.

3. Billet welding. The groove made between the frame and the smaller cover plate is filled with a 1/8-in.-diam 4043 Al welding rod in a single pass with an argon-shielded heliarc welder operating at 60V, 200 A.

   Following completion of the cover plate welding, the evacuation tube is inserted into the drilled hole and welded in a manner commensurate with the cover plate welding.

   Should leaks be in evidence when the billet is attached to the vacuum pump, these leaks are located by first placing a large "C" clamp over the cover plates near the center and then applying approximately 10 psi argon pressure. The leak area is then rewelded.

4. Billet evacuation. The billets are placed in a furnace with a door arrangement for extending the evacuation stem to connect with the vacuum equipment. A vacuum of less than 0.025 torr and a temperature of 400°C is maintained for a period of not less than 16 hr. With the vacuum system still attached, the hot billet is removed from the furnace and the evacuation stem closed by forge welding at a point approximately 2 in. from the billet.

Rolling of Plates

To produce the desired control plate dimensions and to create a metallurgical bond between the components, the billets are hot rolled to an 87.7% reduction in thickness, or to 0.250 ± 0.001 in. The reduction is accomplished with a two-high Mesta mill equipped with 19.5-in.-diam by 30-in.-wide rolls. The rolls are operated at a surface speed of approximately 100 fpm and lubricated continuously with a 10% mixture of SAE 90 Pinnacle* cylinder oil in kerosene. Equal reduction of the two billet

*Pinnacle cylinder oil is a product of the Texaco Oil Company.

surfaces which is necessary to the satisfactory rolling of hermetically sealed reactor materials is obtained from rolls preconditioned by hot rolling 6061 aluminum plate to build up an aluminum oxide coating and setting the feed table to deliver the billet to the median roll opening.

The reduction schedule is given in Tables 2 and 3. The normal rolling spread is increased to obtain the desired core width by rolling the fourth through the ninth passes, at 90° to the length axis. Otherwise, during rolling, the billets are rotated 180° about their transverse and longitudinal axes. The lighter reductions at the beginning of the schedule appear to densify the compacts and improve the end effect whereas those at the end reduce roll camber, thereby producing more uniform gauge.

Following the last rolling mill pass, the plate is returned to the furnace for 1 hr at 500°C to soften the plate so that it may be easily straightened and to make visible any blisters that may be incorporated.

Special care is exercised in handling the billet and plate during and after rolling to prevent deep lacerations and foreign material pickup. The plates are set on edge in a furnace fixture that offers support only on a portion that will be removed later, and since shedding of asbestos gloves is a serious problem, only aluminized gloves in good condition are used.

To remove longitudinal curvature that is normally developed during rolling, the annealed plate is bent after cooling by prying over a roller fulcrum. The fulcrum used consists of two 4-in.-diam rollers, one stationary and one free rotating, maintained at 6-in. center distance. To flatten, the plate is simply rolled along to the points of curvature and bending applied as required to straighten. After straightening, the plates are identified by consecutive numbers at the cored end but not over the core. The plates are then stacked four deep between 2-in. aluminum plates and heated to 825°F for 1 hr at temperature to further flatten them.

Inspection of Flat Plate

Each control plate is given a visual inspection to check for blisters, inclusions, laps, scratches, and dents. If any blisters or inclusions, laps, scratches, or dents greater than 0.003 in. deep are found, the plate is rejected. The rejection record is submitted to the Operations Division for disposition.

All control plates are subject to a 100% ultrasonic inspection. Procedures for the inspection are shown in item 19, Appendix A. Nonbond indications 1/8-in. diam or greater are recorded. With the 1/8-in.-diam standard, the core clad outline and occasionally the tantalum-europium interface will indicate nonbond conditions which are considered acceptable. Nonbond indications in areas other than the core clad outline and the tantalum-europium interface are cause for rejection. Rejected control plates are submitted to the Operations Division for disposition.

Table 2. Hot rolling schedule - Mesta mill
Plate No. HC-XXX-I

Plate No. HC-XXX-I Core Order No. _____ Date _____

	Pass No.	2.037 mill settings: Opening (in.)	Dial	Corrected	Heating time (min)	Reduction (based on mill settings): height (mills)	(%)	Billet thickness (in.)
	1	1.833	7+.083		120	204	10.01	107.
	2	1.650	6+.150		12	183	9.98	81.
	3	1.485	5+.235		12	165	10.00	83
Double pass	4*	1.336	5+.086		12	149	10.03	75
	5*	1.336	5+.086		0	0	0.00	
	6*	1.201	4+.201		20	135	10.10	
	7*	1.080	4+.080		12	121	10.07	
Triple pass	8*	1.080	4+.080		0	0	0.00	
	9*	1.080	4+.080		0	0	0.00	
	10	0.934	3+.184		25	146	13.52	
	11	0.080	3+.058		15	176	13.49	
	12	0.699	2+.199		15	109	13.49	
	13	0.604	2+.014		15	95	13.59	
	14	0.522	2+.022		15	82	13.58	
	15	0.452	1+.202		10	70	13.42	
	16	0.391	1+.141		10	61	13.50	
	17	0.388	1+.088	shear	10	53	13.55	
	18	0.292	1+.042		20	46	13.61	
	19	0.272	1+.022		10	20	6.85	
	20	0.259	1+.009		10	13	4.78	
	21	0.25	1+.00		10	7	2.70	
	22	0.25	1+.00		0	0	0.00	

Comments:

A. Furnace temperature: 500°C
B. Hot-rolled thickness: 0.252"
   Tolerance: ±0.002"
C. Reverse rolling direction: yes
D. Flip plate over: yes
E. Test for blisters: yes
   Furnace temperature: 500°C
   Duration in furnace: 60 min
F. Ta end leads last pass
G. Frame size 15" x 15" x 1.562"
H. Cover size 14.5" x 14.5" x 0.235"
I. Outgas billet over night at 850°F
J. Shear plate after pass no. 17:
   Ta end 7"
   Eu_2O_3 end 4"

*Denotes cross rolling passes.

Comments:

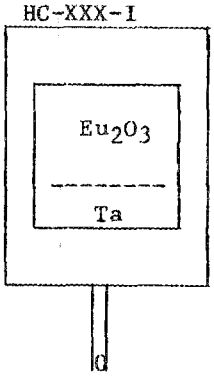


Table 3. Hot rolling schedule - Mesta mill
Plate No. HC-XXX-O

Plate No. HC-XXX-O Core Order No. _____ Date _____

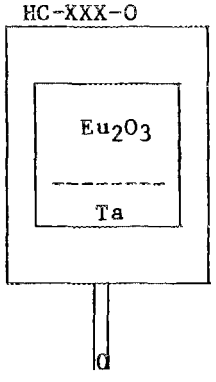
	Pass No.	2.049 mill settings: Opening (in.)	Dial	Corrected	Heating time (min)	Reduction (based on mill settings): height (mills)	(%)	Billet thickness (in.)
	1	1.944	7+.099		120	205	10.00	
	2	1.666	6+.160		12	184	9.99	
	3	1.494	5+.244		12	166	10.00	
Double pass	4*	1.345	5+.095		12	149	9.97	
	5*	1.345	5+.095		0	0	0.00	
	6*	1.206	4+.206		20	139	10.33	
	7*	1.081	4+.081		12	125	10.36	
Triple pass	8*	1.081	4+.081		0	0	0.00	
	9*	1.081	4+.081		0	0	0.00	
	10	0.935	3+.185		25	146	13.51	
	11	0.808	3+.058		15	127	13.58	
	12	0.199	2+.199		15	109	13.49	
	13	0.604	2+.104		15	95	13.59	
	14	0.522	2+.022		15	82	13.58	
	15	0.451	1+.201		10	71	13.60	
	16	0.390	1+.140		10	61	13.52	
	17	0.337	1+0.87	shear	10	53	13.59	
	18	0.292	1+.042		20	46	13.35	
	19	0.272	1+.022		10	20	6.85	
	20	0.259	1+.009		10	13	4.78	
	21	0.25	1+.00		10	7	2.70	
	22	0.25	1+.00		0	0	0.00	

Comments:

A. Furnace temperature: 500°C
B. Hot-rolled thickness: 0.252"
   Tolerance: ±0.002"
C. Reverse rolling direction: yes
D. Flip plate over: yes
E. Test for blisters: yes
   Furnace temperature: 500°C
   Duration in furnace: 60 min
F. Ta end leads last pass
G. Frame size 15" x 15" x 1.570"
H. Cover size 14.5" x 14.5" x 0.236"
I. Outgas billet over night at 850°F
J. Shear plate after pass no. 17:
   Ta end 5 1/4"
   Eu_2O_3 end 3 1/4"

*Denotes cross rolling passes.

Comments:



Finally, the control plates are radiographed using Kodak "type M" or equivalent film. The film density is such that the fullest extent of the core outline is visible. A tungsten wire is attached to the control plate near the tantalum-europium interface before radiographing and is used as a reference during the subsequent core measuring. The control plate core is then measured in accordance with the instructions shown in Appendix D.

PREPARATION OF PLATES FOR PREFORMING

Bonding of Flat Plate to the Backup Plate

In preparation for forming, the control plates are pickled in 1% HF-15% HNO_3, rinsed in water, and dried with isopropyl alcohol. A 3/8-in.-thick plate of type 6061-TO aluminum is sheared to clear the control plate by 2 in. on all sides and also is pickled and dried as stated above. After the pickling operation, the control plates are handled with clean white gloves. The type 6061-TO aluminum plate, which will become the backup plate during preforming, is laid on a table best side up and an outline of the control plate is centered on the surface. A mixture of Armstrong type A-12 bonding cement is blended using 2% of part A and 3% of part B. An elastic bond with minimum fracture during forming is desired. The bonding cement is applied to one side of the control plate and on the type 6061-TO aluminum inside the layout lines. After a thin coat is applied to both surfaces, they are laid together as shown in Fig. 8 (ORNL Photo 64952) and clamped as shown in Fig. 9 (ORNL Photo 64958). Sufficient clamps should be used to pull the control and backup plates tightly together. The composite is then cured in an oven at 71°C (160°F) for 2 hr and is removed from the furnace and allowed to cool (generally overnight) before the clamps are removed. After removal of the clamps, excess bonding cement is removed from the edges and ends of the composite using Armstrong adhesive stripper No. 44. The composite is shipped in a special box to prevent damage in transit.

Location and Measurement of Core Section

The importance of accurate measurement of the length and width of the europium oxide and tantalum core sections and the relative location of their tandem cores within each control plate cannot be over-emphasized. The foremost reason is that significant deviations in the shape and geometrical location of the core causes uncertainties on the efficiency of the control during reactor operations. Also for the outer plates especially, the edging along the plate is rather narrow (0.125 in. min). Since these edges serve to protect the europium oxide from exposure to the water coolant, it is important to identify and maintain these dimensions. Additionally, identification of the symmetry of the core section about its longitudinal axis in the flat plate is necessary in order to compare the centerline with the centerline of the formed control plate. Gross differences could influence the width of the "neutron window" between the control plates when positioned in the reactor.

ORNL-PHOTO 64952

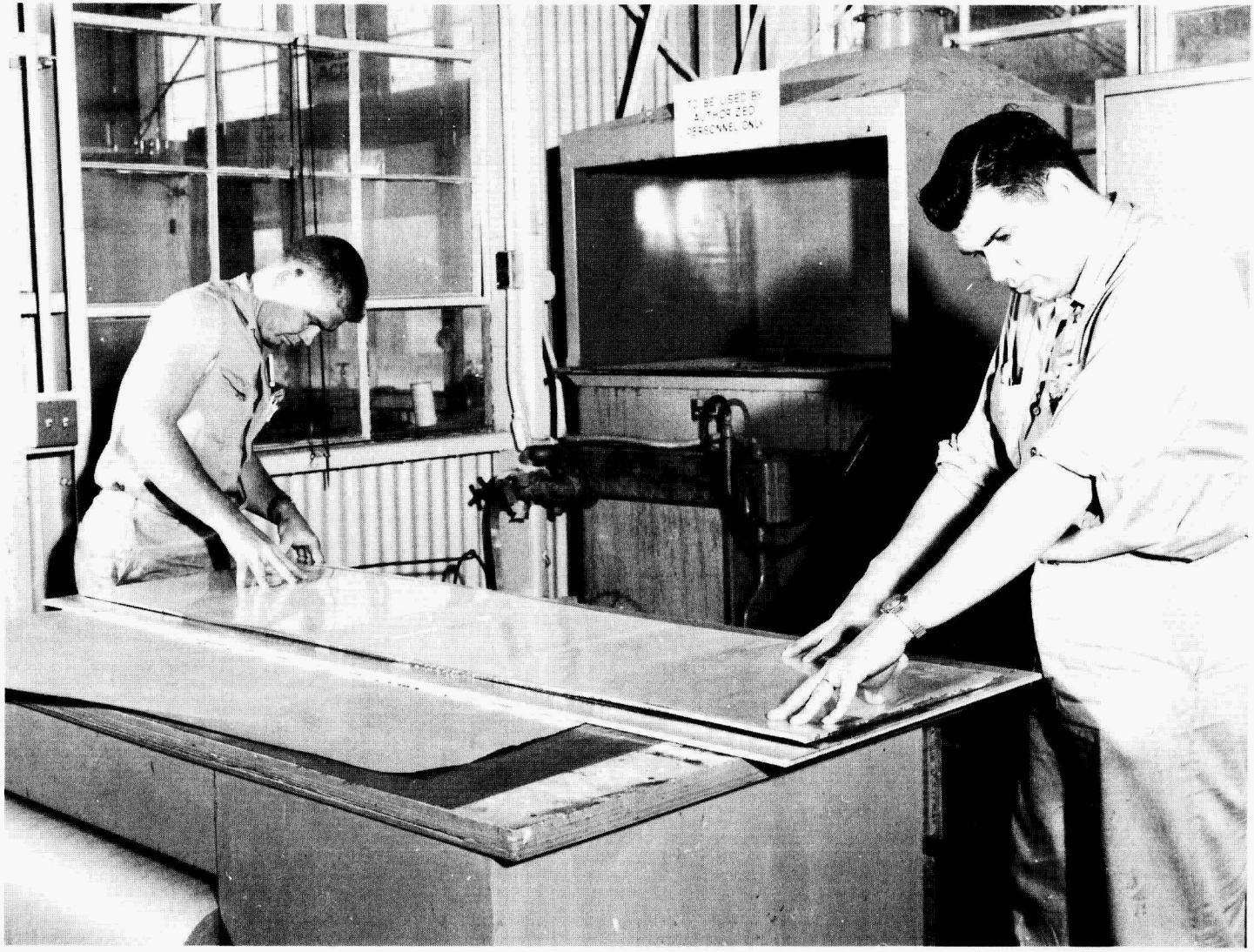


Fig. 8. Bonding control plate to backup plate.

ORNL-PHOTO 64958

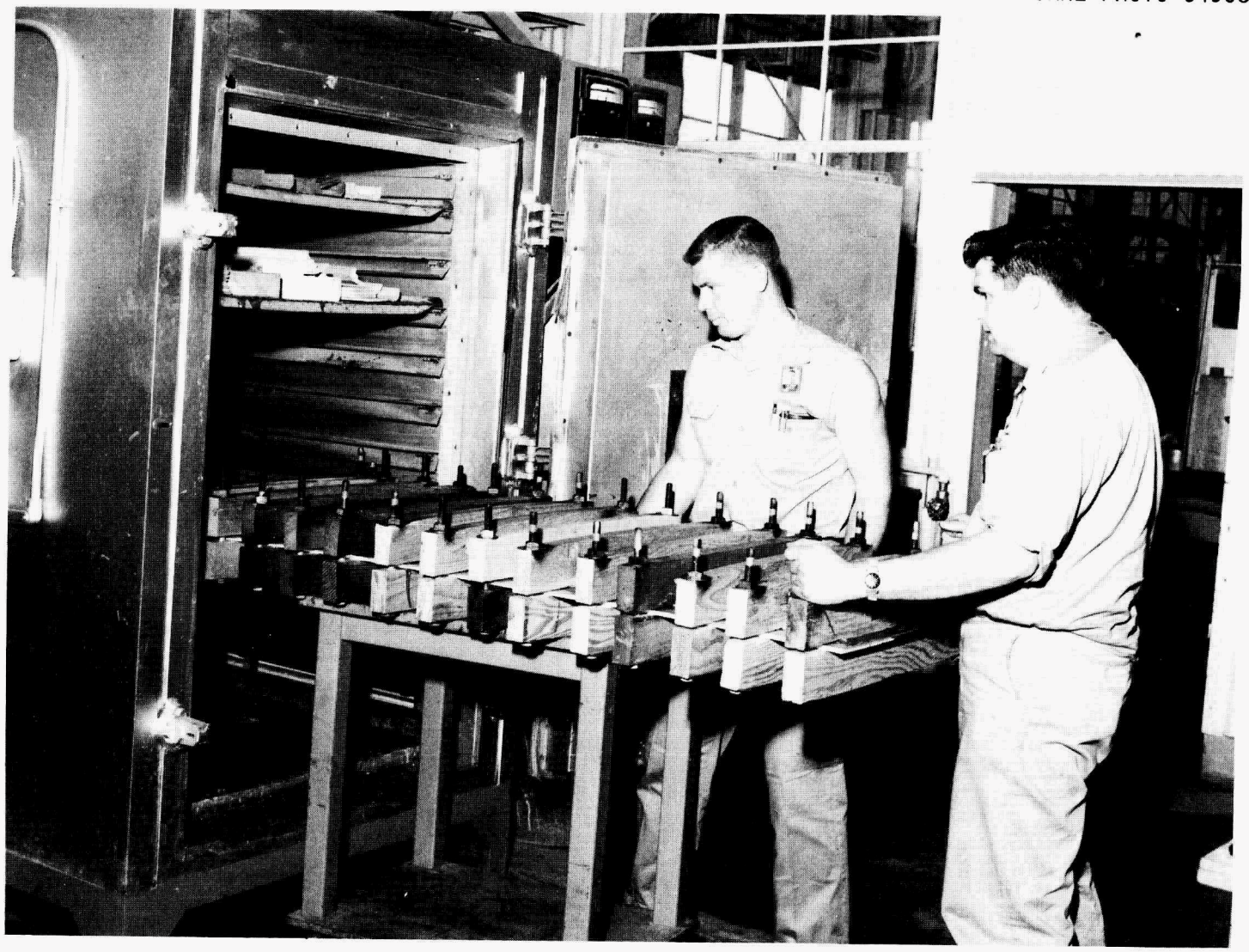


Fig. 9. Control plate assembly ready for epoxy curing.

The technique for measurement and location of the core section involves (1) drilling a series of locating holes into the edges and ends of the plates, (2) positioning a grid onto the control plate, (3) radiographing, (4) measuring the dimensions of the core and establishing its relative location in the control plate using dividers and a scale graduated in 1/64 in., and (5) recording the data.

Each control plate is prepared for the drilling operation by cleaning with an isopropyl alcohol solvent and covering the exposed surface with plastic adhesive tape. (The exposed surface of the backup plate is not covered.) The tape serves to protect the surface during subsequent layout and radiographic operations. Prior to the taping, each control plate is examined for scratches, nicks, and gouges. Control plates with defects more than 0.003 in. deep are subject to review for possible waiver or rejection. A typical plate thus prepared and mounted on the table of a Giddings and Lewis boring mill, ready for the drilling operation, is illustrated in Fig. 10, Y-12 Photo 112416. It can be seen that the backup plate, which is 3/8 in. thick, is wider and somewhat longer than the control plate. Also, observe that the "top" portion of the control plate is identified. This denotes the end of the control plate which bears the control plate number and has the minimum length of aluminum between the core section and the end of the control plate. This end is frequently referred to as the "cored" end of the control plate.

As shown in Fig. 11, a pattern of 1/4- and 1/6-in.-diam holes is drilled in each control plate in regions which are later machined from the control plates. The hole pattern must be accurately drilled because a grid must be precisely aligned with the 1/4-in.-diam holes when the control plate is radiographed. This grid pattern appears on the x-ray film and is used to locate and measure the core region in the control plate.

This hole pattern provides six 1/16-in.-diam holes beyond and along each edge of the Eu_2O_3 and Ta regions as well as a pair of 1/4-in.-diam end holes in the vicinity of the longitudinal centerline of the Eu_2O_3 region and two 1/16-in.-diam holes 1 in. offset from and parallel to the 1/4-in.-diam holes. Identifying hole numbers are scribed adjacent to the respective holes. Subsequent layout is referenced to these holes. While the control plate is set up for hole drilling, accurate measurements are made of the layout distances between holes 1 and 3, 2 and 4, 1 and 2, and 3 and 4. These dimensions are later used to accurately locate the core of the control plate with respect to the layout holes and also to determine the accuracy of the layout pattern in the subsequent radiograph.

Figure 12, Y-12 Photo 114910, shows the control plate being prepared for radiography. A grid fixture, Y-12 Dwg. N D-M-34945, consisting of a sheet of 1/4-in.-thick Plexiglas with a series of five tungsten wires spaced in the axial and lateral directions is keyed to the control plate by 1/4-in. dowel pins placed in holes Nos. 19 and 21. A dowel placed in hole No. 20 also permits a wire to be stretched between holes Nos. 19 and 20. Radiograph film is placed under the control plate, and a plumb bob is used to align the x-ray source over the area to be radiographed. The

Y-112416

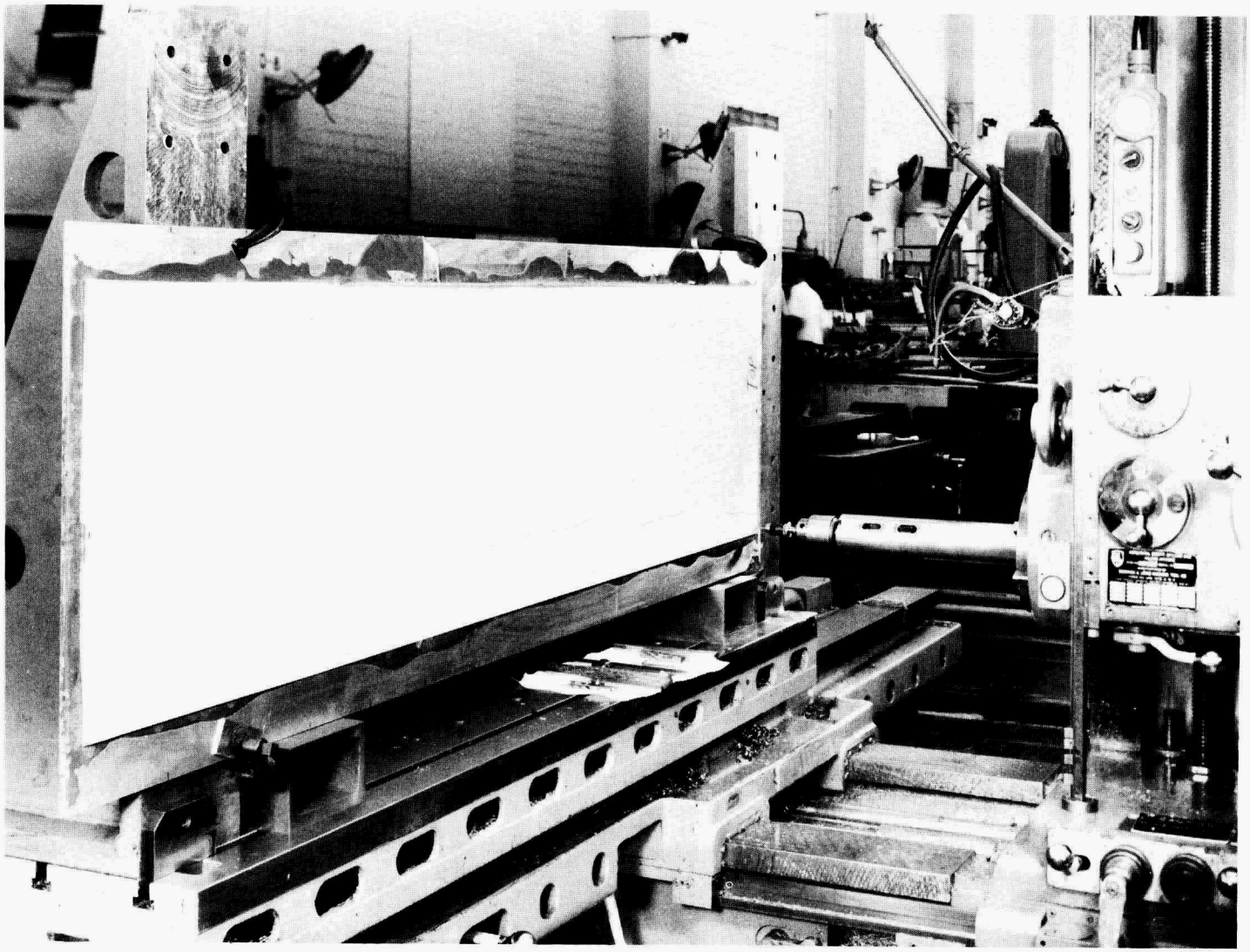
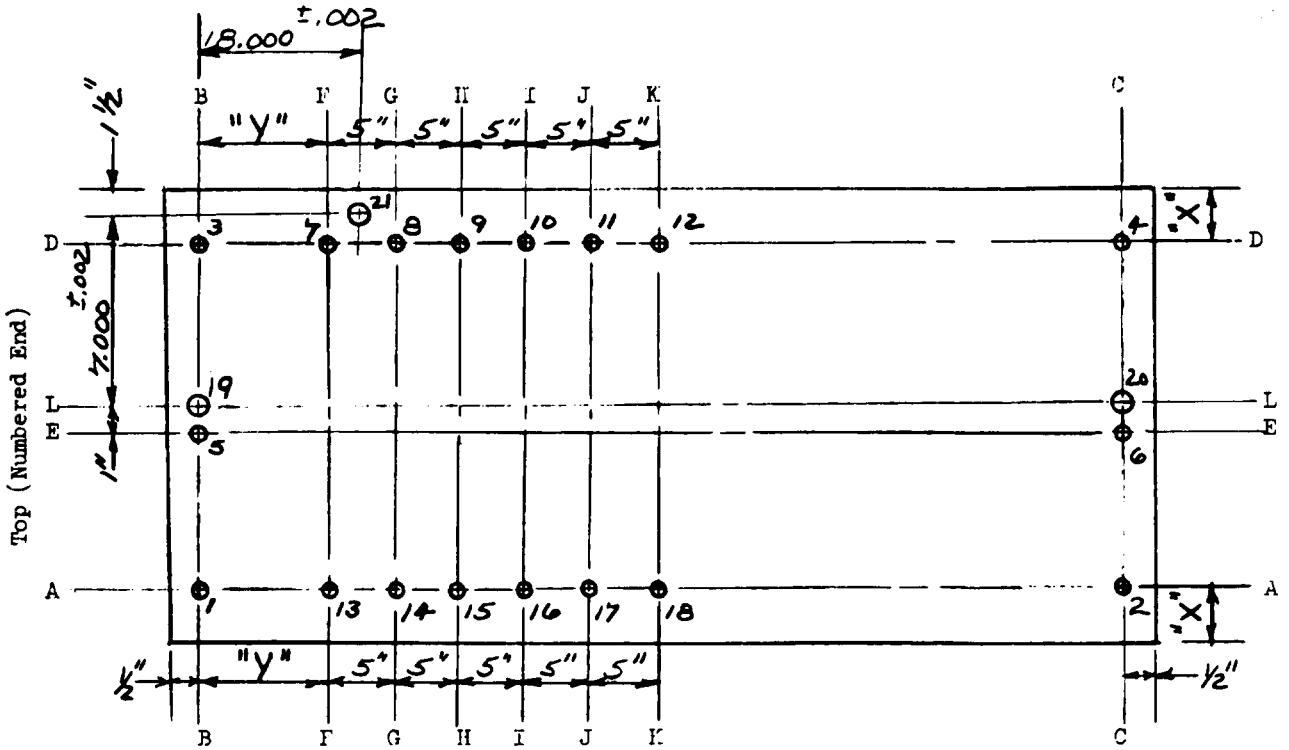


Fig. 10. Control plate set up for drilling.



NOTES:

1. Calculate Dimension "X": Outer, "X" - $\frac{W - 17.5"}{2}$; Inner, "X" = $\frac{W - 15"}{2}$

   where "W" is the average width of the control plate.
2. Dimension "Y" = 12" for the Outer control plates.
3. Dimension "Y" = 17.5" for the Inner control plates.
4. Holes 1-18 are 1/16" in diameter and must go through the 1/4" plate. Holes 19-21 are drilled and reamed for a 0.250" dowel and must go through both the 1/4" plate and the backup plate.
5. Lines AA, DD, and LL are parallel to each other. Lines BB and CC are parallel to each other and perpendicular to lines AA, DD, and LL.
6. Locate and drill holes 1 and 2.
7. Locate and drill holes 13 through 18.
8. Locate and drill holes 3 and 4.
9. Locate and drill holes 7 through 12.
10. Locate and drill holes 5 and 6.
11. Locate and drill holes 19 and 20.
12. Locate and drill hole 21.
13. Scribe the hole number next to each hole
14. Measurements between holes 1 and 2, 3 and 4, 2 and 4, and 1 and 3 should be taken to the nearest 0.001" and recorded for each part on the inspection form before the plate is removed from the setup.

Fig. 11. Layout hole pattern for HFIR inner or outer control plates.

Y-114910

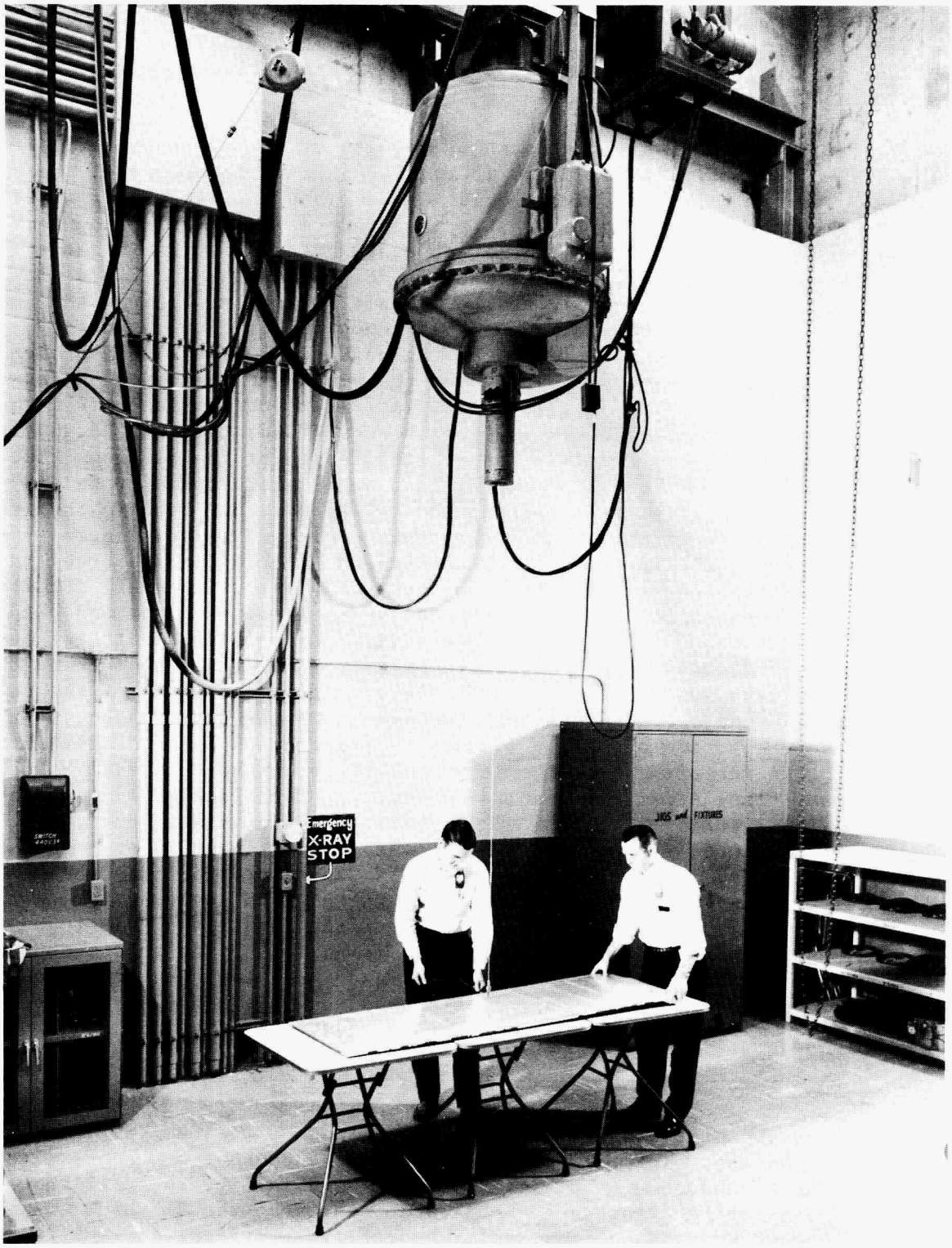


Fig. 12. Control plate set up for radiographing.

x-ray source is 100 in. above the control plate, and by using overlapping films and radiographing small areas in 6-in. intervals, divergence and projection effects are minimized. In this manner, the locations and diversions of the Eu_2O_3 and Ta sections can be identified. The centerline of the core region can be described and the average black-gray interface determined.

Typical dimensions illustrated by results of measurements of outer plate HC-65 are detailed in Figs. 13 and 14, showing locations of the grid wires. The distance, a, between grid wire, G, and the gray-black interface for each core section is measured and recorded. At this interface, an intermingling of the Ta and Eu_2O_3 occurs, and a variation in shades of gray exists. The gray-black interface is defined as the interface where the black starts changing to gray. Similarly, measurements from the grid wire, c, to the interface between the aluminum and the Eu_2O_3 section describes the location of this end of the core, with accurate knowledge of the grid wire intervals. The length of the black section can be determined in this outer plate; it is 22.063 in. Also, the distance from the gray-black interface to hole No. 19 can be described; that is, 33.266 in. for outer plate HC-65. In this manner, the length of the aluminum that must be removed from the "top" end of this outer plate to maintain a dimension of 30 5/8 in. from the top end of the control plate to the gray-black interface is established. Using this arrangement, the length of the aluminum between the Ta-Eu_2O_3 interface and the "bottom" end of the control plate varies slightly from one control plate to another. Figure 15 mainly describes the distance between the edges of the core and the 1/16-in.-diam locating holes along the edge. These measurements establish the amount of aluminum that must be removed from each edge to machine the control plate to its final width. They also define the width of the core and establish the core centerline. The length of the gray region is based on a measurement made along the line on the radiograph between holes Nos. 19 and 20. A measurement of the length of the black section is also made at the same time. From the results of Fig. 15, the black section at this location is 33 20/64 - 11 17/64 = 22 3/64 in. The gray section is 38 10/64 - 33 20/64 = 4 54/64 in. A summary of pertinent measurements for outer plate HC-65 is tabulated in Fig. 13. The record includes the maximum variation in the overlap of the black region into the gray region from the average gray-black interface. The specification allows this to be a maximum of 0.250 in. Care must be exercised not to err in this measurement because a row of 1/4-in.-diam holes is drilled through the control plate into the gray section only 1 in. beyond the average black-gray interface.

Layout for Preforming

Preforming of the control plate while glued to the backup plate must be done with care. Initial attempts to form the control plates resulted in cracking of the control plates as illustrated in Fig. 16, Y-12 Photo 111114. This was attributed to the low ductility of the 31 vol % Eu_2O_3-Al dispersion. Gluing the 3/8-in.-thick backup plate effectively shifted the

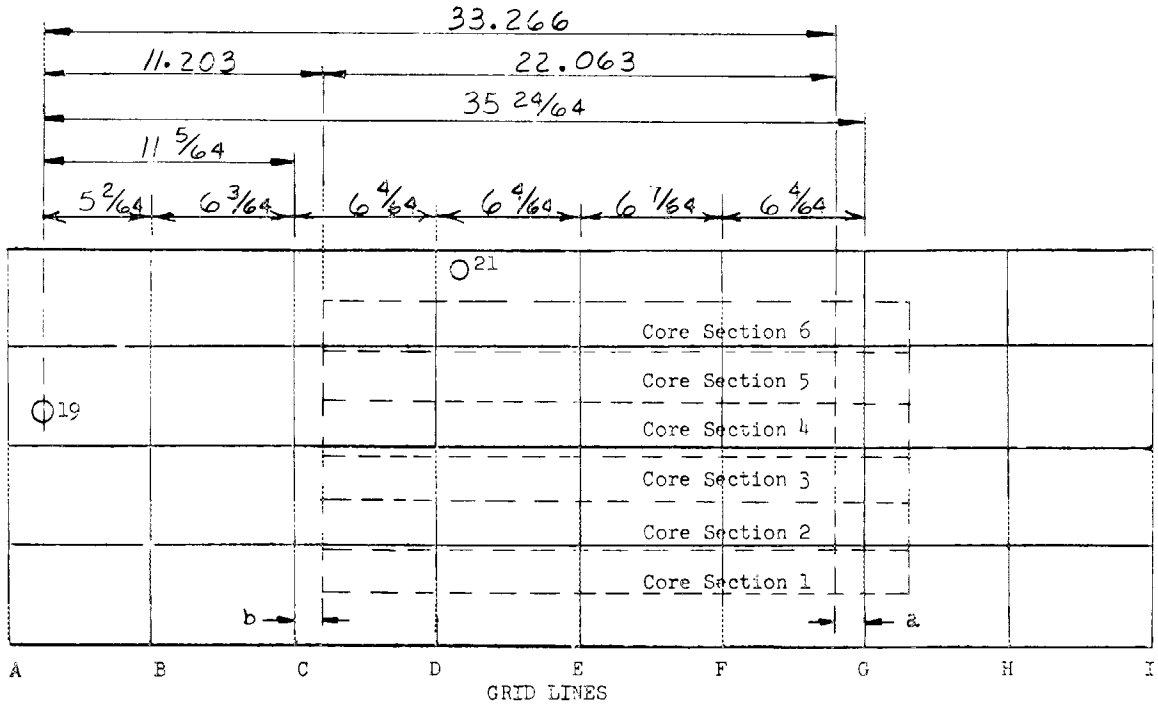
neutral axis into the backup plate, keeping the control plate in compression. The designers and fabricators felt that even under these circumstances they should gently form the control plates in increments as opposed to forming the control plate in one operation. In addition, a uniform radius with minimum twist in order to achieve good results in the subsequent explosive sizing operations is desired. Lines scribed at intervals along the edge of the control plate are very useful in guiding the preforming work. Figure 17, Y-12 Photo 112516, illustrates the setup used for scribing these lines. The plate is mounted so that the longitudinal centerline of the core (℄l) as measured by radiography is parallel to the surface plate. The centerline is located by using the Cadillac height gauge, and both the backup and control plates are marked with a precision scribe. Figure 18 provides layout information for the scribing operation. The lines depicted are scribed on each end of the control and backup plate at 0.50-in. increments. The form showing the measurement from holes No. 1, 2, 13, and 17 to the centerline is retained to verify the important part of this procedure.

Data tabulation of HFIR core location
in outer segment part HC-65

Average distance of black-gray interface from grid line G	1.734
Distance of grid line G from centerline of layout hole No. 19	35.000
Distance of average black-gray interface from centerline of hole No. 19	33.266
Average distance of black-white interface from grid line C	0.203
Distance of grid line C from centerline of hole No. 19	11.078
Distance of average black-white interface from centerline of hole No. 19	11.203
Average length of black section	22.063
Maximum overall length of black section	22.406
Distance from centerline of hole No. 19 to top edge of plate	2.641
Maximum variation of black section from average black-gray interface	0.140

Fig. 13. Data tabulation of HFIR core location in outer segment part HC-65.

HFIR CORE LOCATION AND DEFINITION FORM FOR OUTER SEGMENT PARTS



Core Section	Dimension 'a' Max.	Min.	Ave.
1	1 54/64	1 50/64	1 52/64
2	1 53/64	49/64	51/64
3	1 50/64	46/64	48/64
4	1 46/64	1 42/64	44/64
5	1 44/64	42/64	43/64
6	1 44/64	38/64	41/64
Ave.			1.727

Core Section	Dimension 'b' Max.	Min.	Ave.
1	7/64	0	4/64
2	33/64	3/64	18/64
3	13/64	8/64	11/64
4	18/64	13/64	16/64
5	25/64	21/64	23/64
6	25/64	10/64	17/64
Ave.			0.232

Dimension "a" was measured from grid line G

Dimension "b" was measured from grid line C

Plate No.: HC-65 Radio Inspector: [illegible] Date: 5-4-65

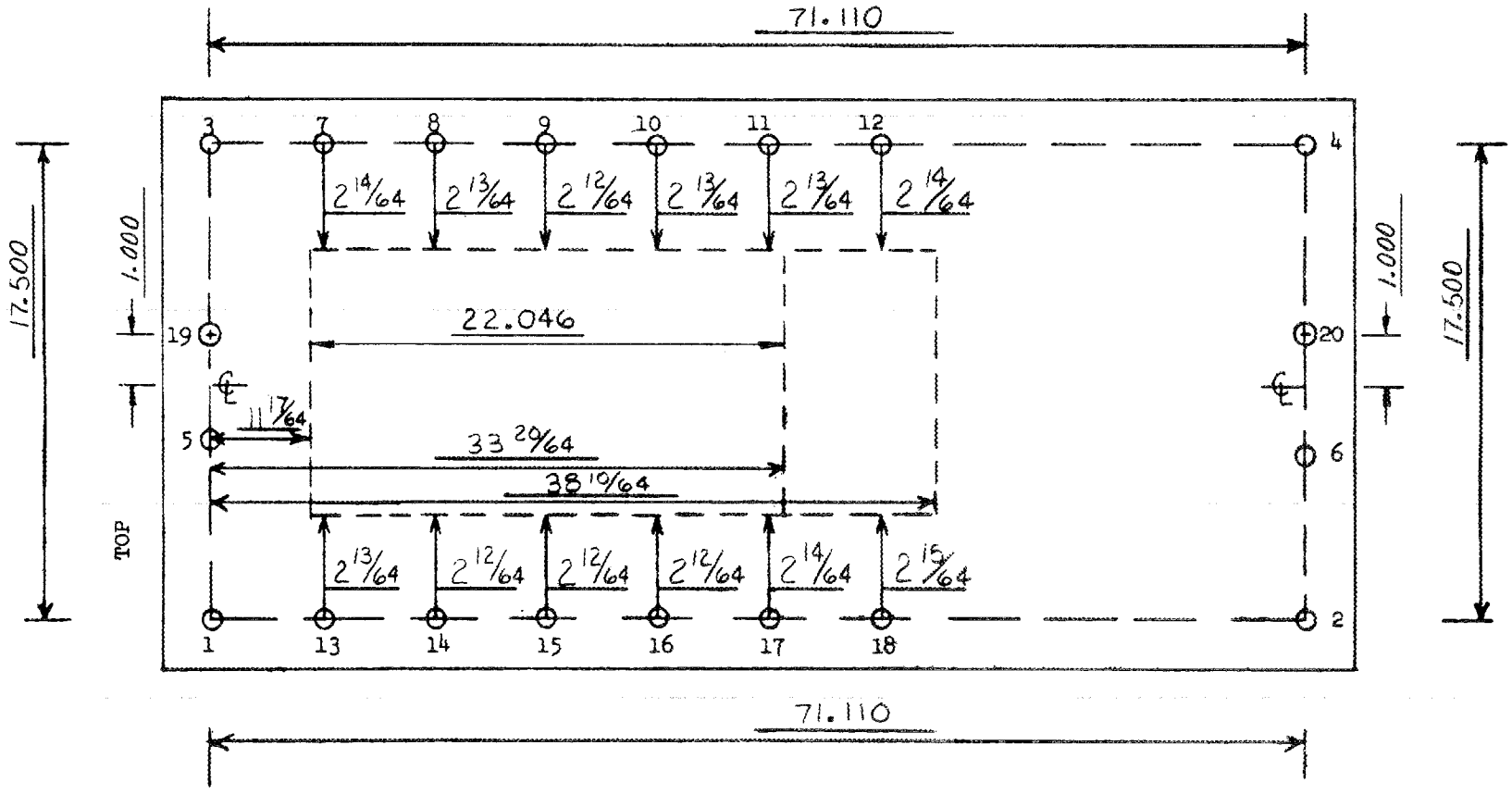
Fig. 14. HFIR core location and definition form for outer segment parts.

HFIR PLATE PROCESS INSPECTION FORM

Plate Number HC-65 Layout Inspector _____ Date _____

For Inner Cylinder or Outer Segment. Radio Inspector [illegible] Date 5-4-65

For Flat Plate or Curved Plate.



NOTE: Layout Inspector measures and records distances between layout holes 1 & 3, 2 & 4, 1 & 2, and 3 & 4 to nearest 0.001 in.

Fig. 15. HFIR plate process inspection form.

Y-111114

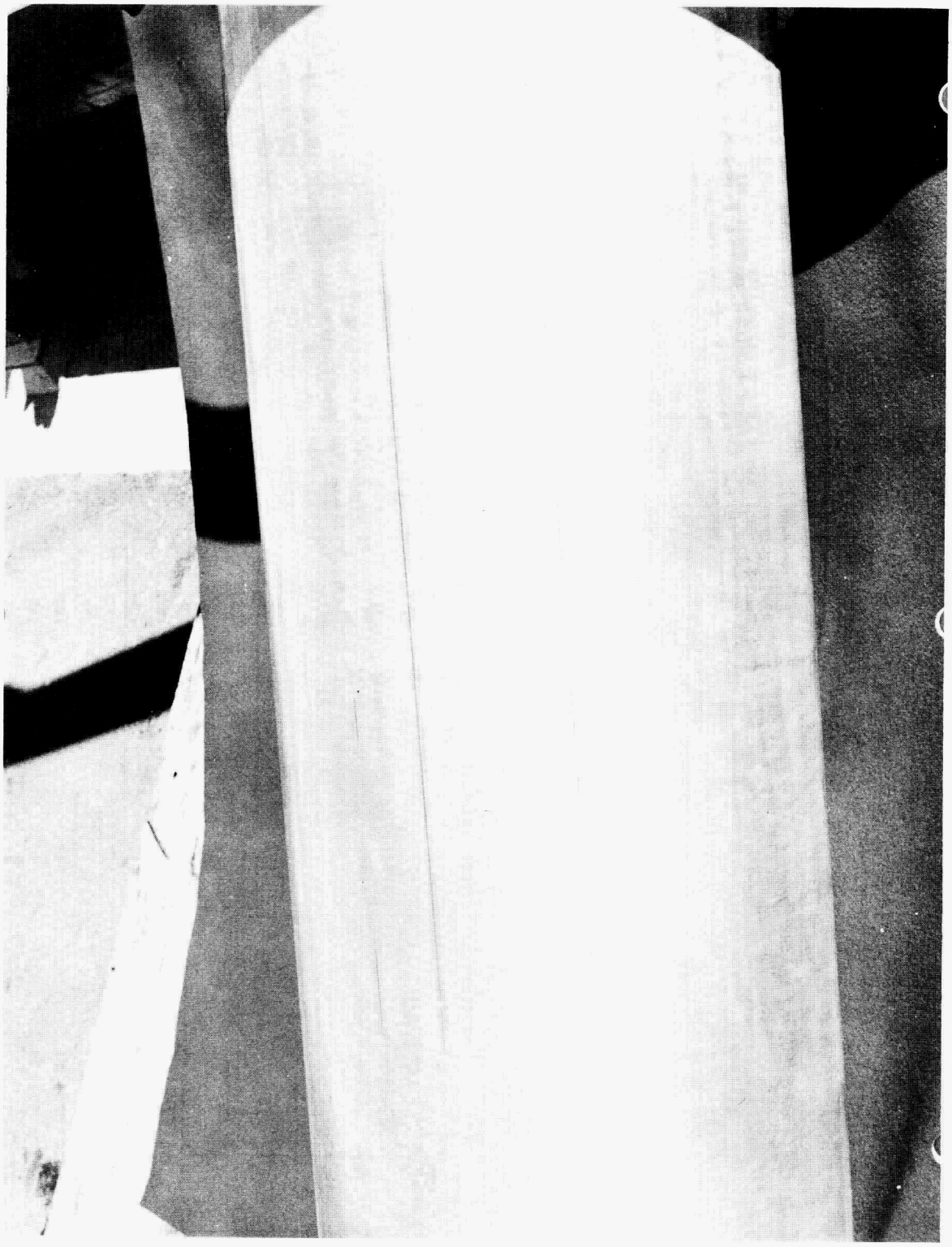


Fig. 16. Control plate formed without backup plate.

Y-112156

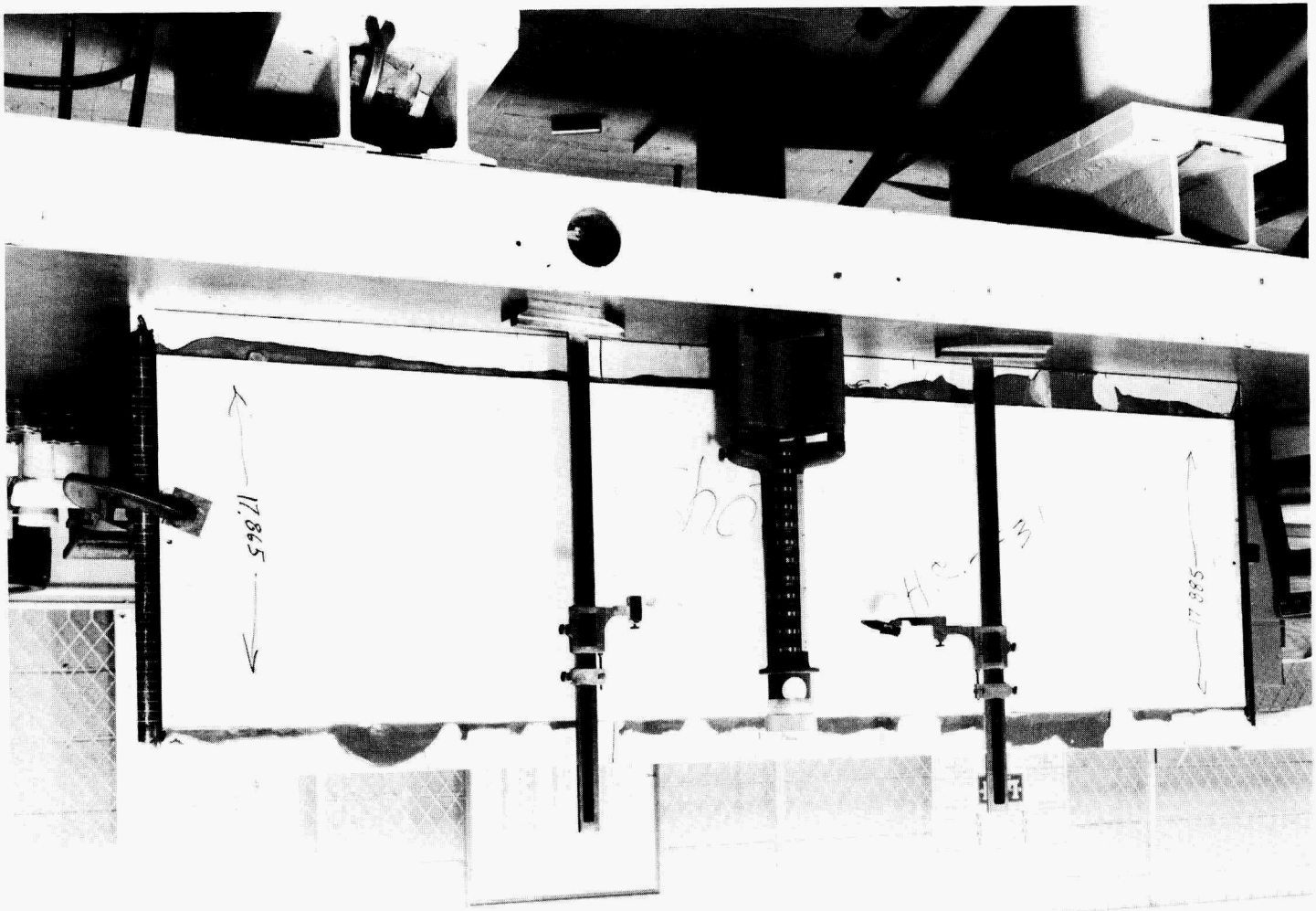


Fig. 17. Backup plate scribed for forming.

HFIR PLATE LAYOUT INSTRUCTIONS

Plate Number HC-65

For Inner Cylinder or Outer Segment

Layout By

Date 5/6/65

J.F.L.

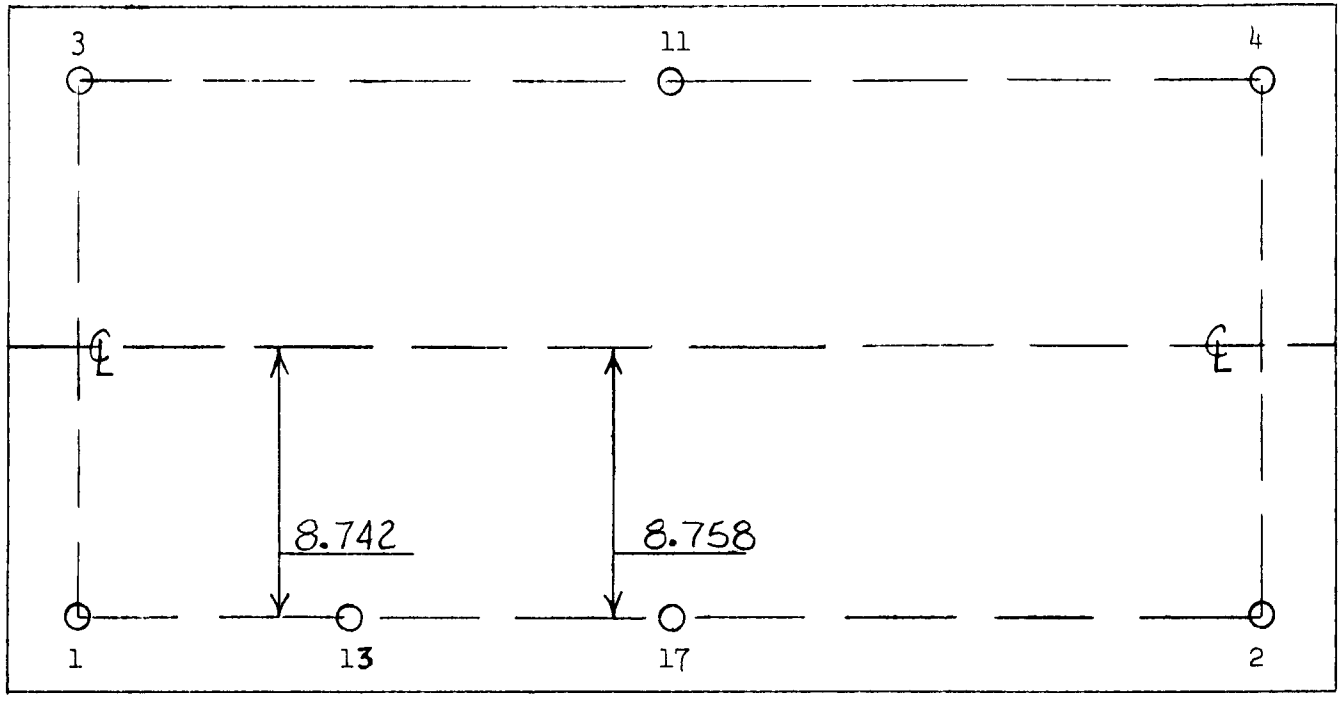


Fig. 18. HFIR plate layout instructions.

Preforming

The inner and outer plates are curved to a radius of 9 1/2 and 9 7/8 in., respectively. This preforming is a roughing operation in preparation to final explosive sizing. Since this is a prologue to final sizing, straightness and symmetry are extremely important.

A 1/2-in. by 10-ft rated Pacific Press Brake is used for the preforming operation. The setup is illustrated in Fig. 19, Y-12 Photo 112153, and a control plate in the latter stages of forming is shown in the press brake in Fig. 20, Y-12 Photo 112154. A punch with a radius of approximately 8 in. is fastened to the ram of the press brake. Retractable pointers at each end of this punch are used to locate the guidelines scribed at the control plate ends. The base of the die is a solid slab of polyvinyl chloride cured to about a 75 durometer. To compensate for end deflection, there is a shim 3/16 in. x 18 in. x 12 in. under each end of the polyvinyl chloride. The rubber-covered table in the foreground and the paper-covered table in the background are used to support the control plate when it is not in the forming die.

The press brake is set with a predetermined stroke. The control plate is lined up under the retractable pointers at each end of the punch. This arrangement maintains the punch parallel to the core centerline. When the punch moves down, it forms an approximately 1-in.-wide strip of the preform over the full length. The white coating on the bottom of the plate is talcum powder which was used to make it easier to slide on the rubber in the die.

The procedure used is given below:

1. Prior to forming, the plastic adhesive tape covering the surface of the control plate is removed; the surface is thoroughly cleaned with isopropyl alcohol and the surface is covered with heavy kraft paper. Masking tape is used to cover the exposed regions of excess epoxy to contain particles in the event of breakaway. The masking tape also serves to hold the kraft paper in place.

2. Align the punch parallel with the die mounted on the press brake.

3. The composite is placed in the die and the centerline of the control plate is aligned with two retractable end pointers on the punch. Talcum powder is used as a lubricant when necessary.

4. The punch is gently lowered until it is in firm contact with the control plate and the stroke limit is set at zero.

Y-112153

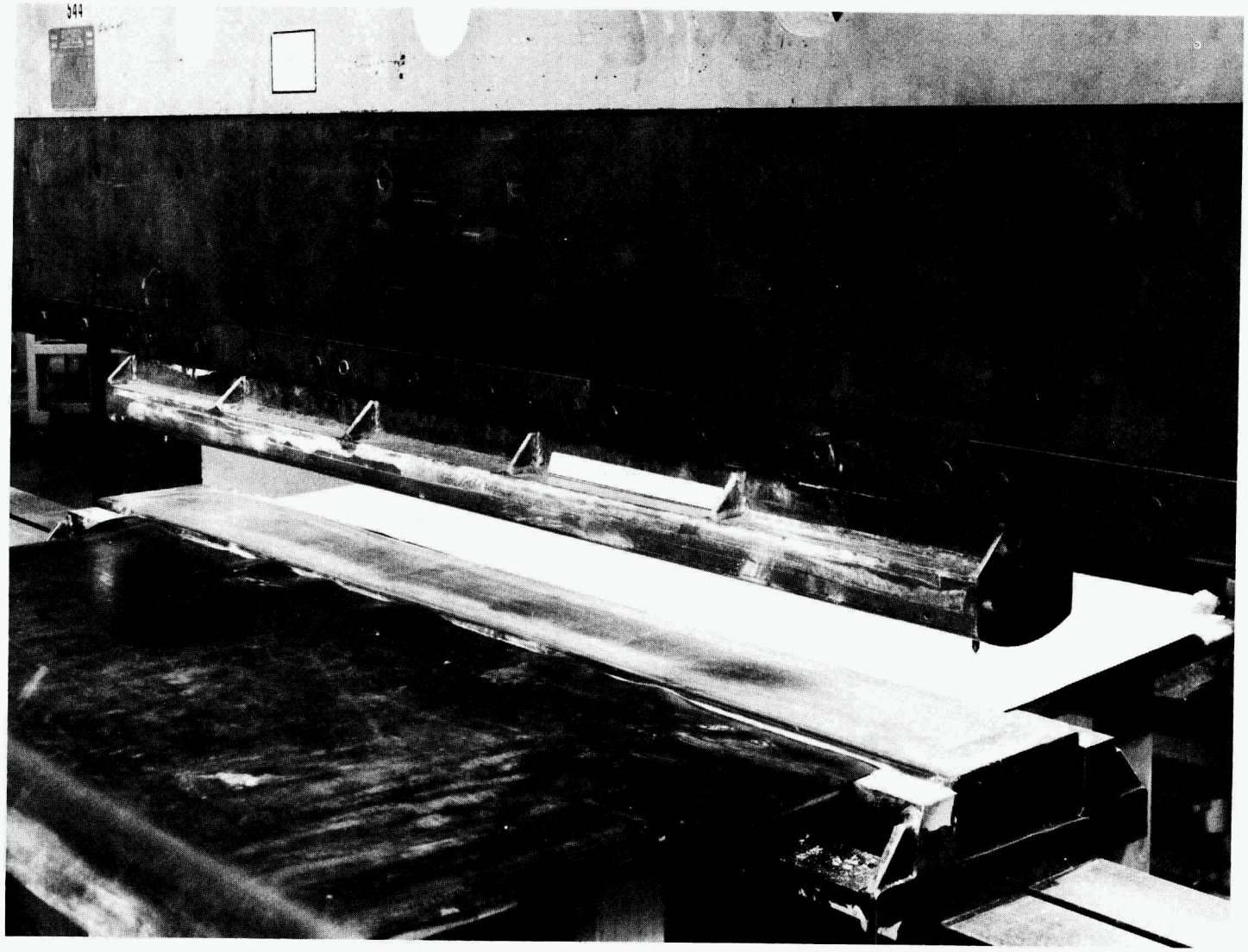


Fig. 19. Punch and die for preforming control plates.

Y-112154

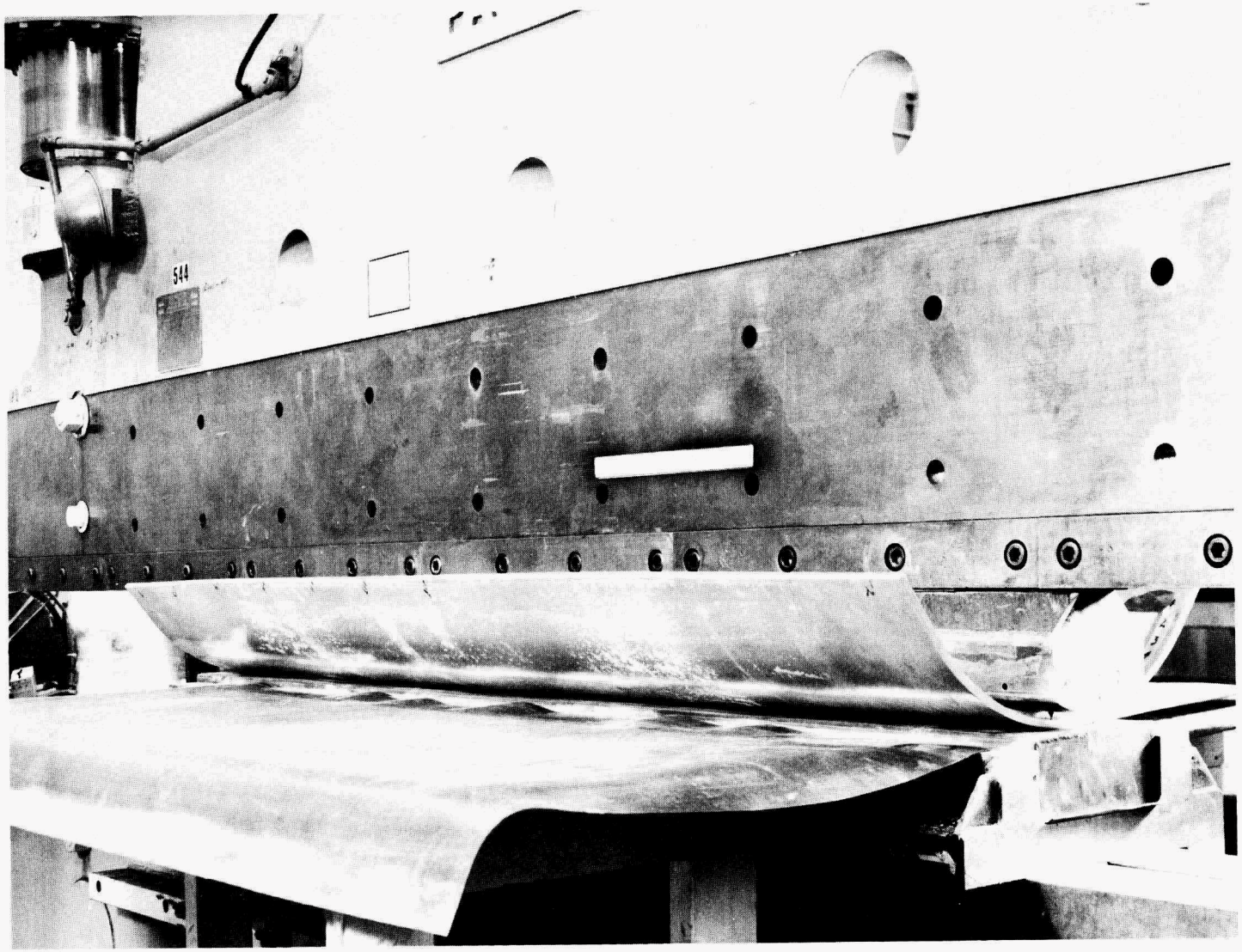


Fig. 20. Preforming a control plate using a punch and die set.

5. The stroke limit is adjusted to advance the punch 0.050 in. below the flat control plate setting in step 4. The press brake is operated to form the part along the centerline. If no forming occurs, the press brake is lowered in 0.050-in. intervals until bending becomes apparent. The punch is wiped with a clean cloth after each stroke to remove foreign particles which may damage the control plate.

6. When bending is apparent, the composite is shifted in the die to the scribe line 1 in. from the centerline and the forming operation is repeated, first forming on one side of the centerline to the edge of the control plate and then shifting to the other side of the centerline.

7. The part is then rotated 180° and aligned 1/2 in. off the centerline, and the stroke is increased 0.025 in. and the forming operation repeated as described in step 6.

8. The starting position is changed for each successive forming operation in the order: (a) on centerline, (b) 1/2 in. off centerline, (c) 1/2 in. off centerline to opposite side, (d) 1 in. off centerline, and (e) 1 in. off centerline to opposite side. This sequence is repeated until the control plate is formed. For each starting position, the die stroke is increased 0.025 in. and for each starting position, the control plate is rotated 180°.

9. Between each change in stroke setting, the radius is monitored using a series of templates graduated in size increments to the finished radius of 9 1/2 in. and 9 7/8 in., respectively, for the inner and outer plates. During these inspections, end spread or bellmouth is also checked. If this occurs, additional shims are inserted under the rubber at the ends of the die. It is very important that, during the preforming, the composite be maintained parallel to the punch centerline by always accurately positioning the respective scribe lines at each level under the retractable alignment pointers.

The preformed part with the protective paper removed is shown in Fig. 21, Y-12 Photo 112152. The surface shows evidence of the forming intervals. These marks are insignificant and are removed during subsequent pickling and explosive forming operations.

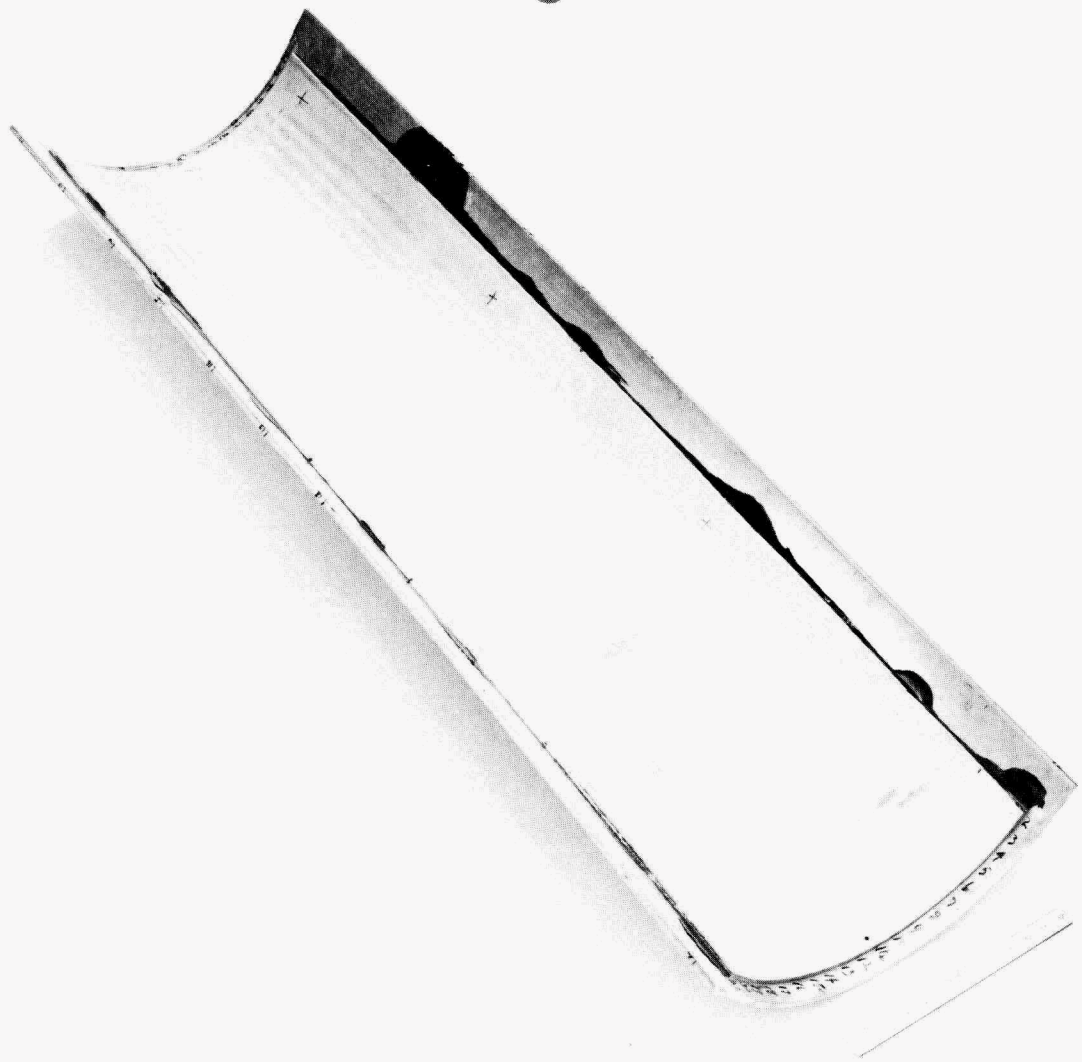


Fig. 21. Formed control plate with backup plate attached.

Removal of Preforming Backup Plate

After preforming the control plates, the backup plate is removed and discarded. The removal is accomplished by heating the Armstrong A-12 epoxy to the softening temperature, approximately 250°F (121°C), to destroy the adhesion and allow the control plate to separate from the backup plate by gravity.

The control plates are heated with the 12-Kw open radiant heating unit shown in Figs. 22 and 23 (ORNL Photos 95388 and 95389). Applying the heat to the concave or control plate side effectively releases the control plate leaving most of the adhesive on the backup plate. The remaining adhesive is removed with Armstrong adhesive stripper no. 44. The last traces of adhesive are removed by rinsing in 1 vol % hydrofluoric acid and 15 vol % nitric acid in water followed by a water rinse.

ORNL-PHOTO 95388

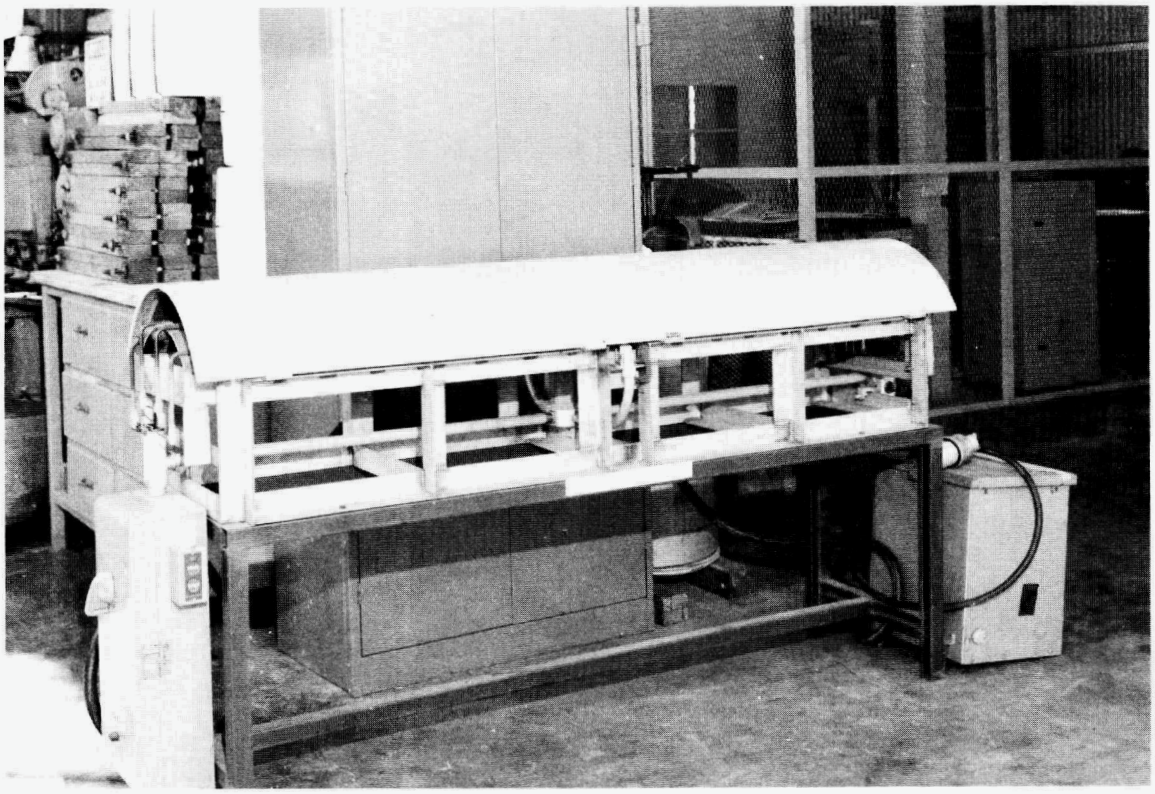


Fig. 22. Heater for removing backup plates.

ORNL-PHOTO 95389

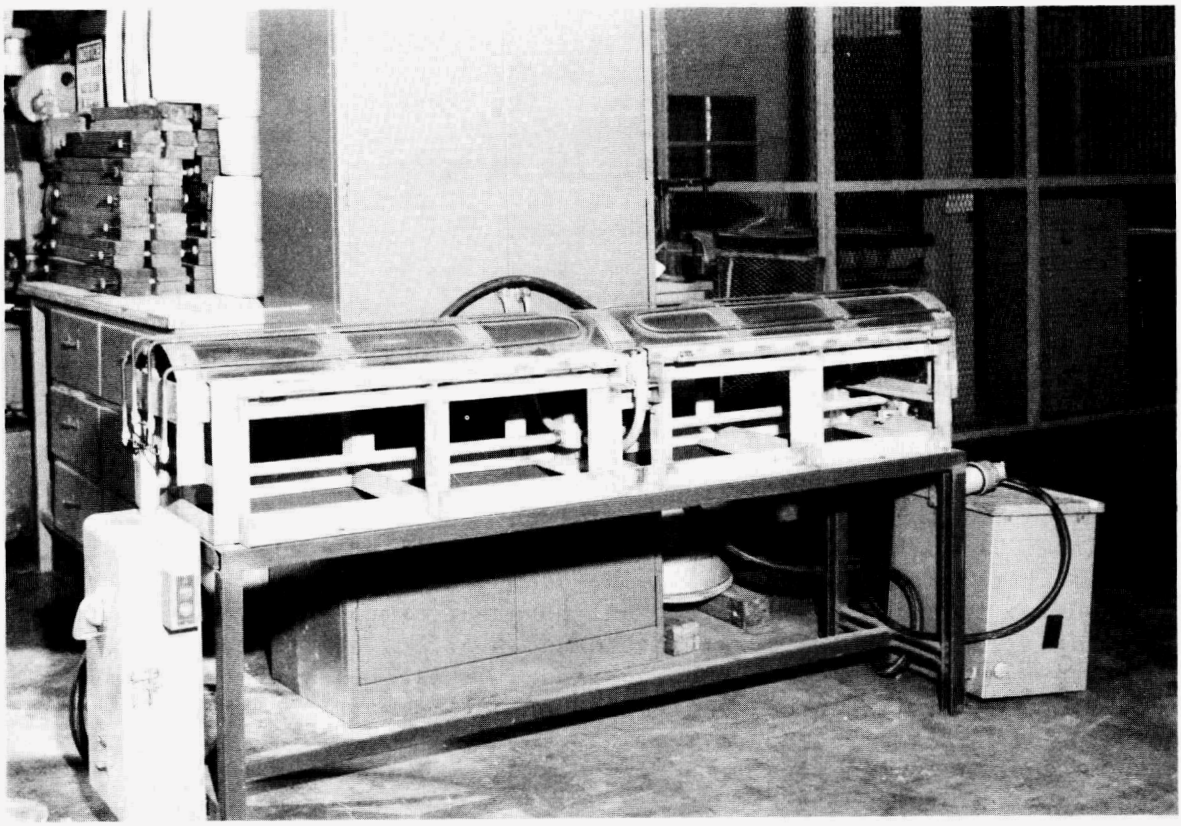


Fig. 23. Backup plate being removed.

The neutral axis of the composite during forming is in the 3/8 in. backup plate so when the control plate is released from the backup plate, it exhibits a reverse springback and assumes the target radius for explosive forming of 9 1/8 and 9 3/8 in. ± 1/8 in. for the inner and outer plates, respectively.

Heat Treatment

Because of the close control of dimensions demanded of the finished part, there was concern that a stress relief treatment of the completely finished control plate component would result in sufficient distortion to cause a rejection. In analyzing the fabrication process, it was felt that major stresses would be produced in the preforming operation - a stress relief was instituted between the cleaning and explosive sizing operations. Each plate is set in a furnace with the edges down and heated to 775°F for 3 hr and furnace cooled. Plates are not stacked. No significant distortion has occurred. The temperature is somewhat high for a stress relief, but it was deliberately increased to 775°F to assure adequate stress relief of the dispersion-type neutron absorber core material. After heat treatment, the control plate is given a final visual inspection for blisters, scratches, and dents before being processed further.

Explosive Sizing of Preformed Plates

Sizing of the preformed plates is done explosively in order to more closely shape them since machining of the formed radius would reduce the clad over the Eu_2O_3 and Ta sections. The inner plates are sized explosively primarily to minimize the bow and twist remaining from the preforming operation in order to more closely fit the precise fixturing required for the future welding operations; since four of the inner plates are welded together to form a cylinder which is again explosively final formed.

Boring Positioning Locators

The radius of the preformed control plate is larger than the radius of the explosive forming die. To prevent misalignment during the explosive forming, a hole is bored at one end of the control plate and a slot at the other end along the core longitudinal centerline as shown in Y-12 Dwgs. E-M-56370 and E-M-55623 for outer and inner control plates, respectively. The hole and slot are positioned to match two pins in the die cavity. The diameter of the hole and width of the slot is 0.469 in. to permit clearance with the 0.437-in.-diam pins. The length of the slot is 0.750 in. to allow for longitudinal movement of the control plate during sizing. The holes are bored in the end portions of the control plate and are removed during subsequent machining. These holes are bored after forming to eliminate the possibility of hole distortion which can occur during the preforming operation.

Description of Forming Die

The explosive forming die and accessories are shown in Fig. 24 (Y-12 Photo 110146). The die body is made of 12-in.-thick hot-rolled steel plate machined to a radius of 9.300 $\pm$ .002 in. Straightness of the die along its length is 0.003 in. Details of the die design are shown on Y-12 Dwg. E-T-46184. The tapped holes on each side of the top are for positioning the explosive and for eye bolts used for lifting the die. The row of tapped holes around the outside of the cylindrical surface are for bolting down flanges on the rubber liner. Four small-diameter holes exist on the sides of the die for evacuating the air from the space between the die, rubber, and control plate. Two of these are shown on the inside surface of the die. Nipples for attaching rubber hoses are welded at the exit ports of these holes. Two of these nipples can be seen on the front face of the die body. The 1/4-in. rubber liner for sealing the control plate during evacuation is shown in the foreground. The aluminum strips lying on the rubber diaphram have beveled edges and are positioned along the edges of the control plate covering the evacuation holes to protect the rubber from being extruded into the evacuation holes and being sheared by the control plate edges.

The straight and curved metal strips which contain holes are flanges which serve to seal the rubber liner against the die. Figure 25 (Y-12 Photo 116188) is another view of the die which shows the two pins that position the plate in the die. The large square head lugs on each side of the upper face of the die support the charge positioning sticks and allow

Y-110146

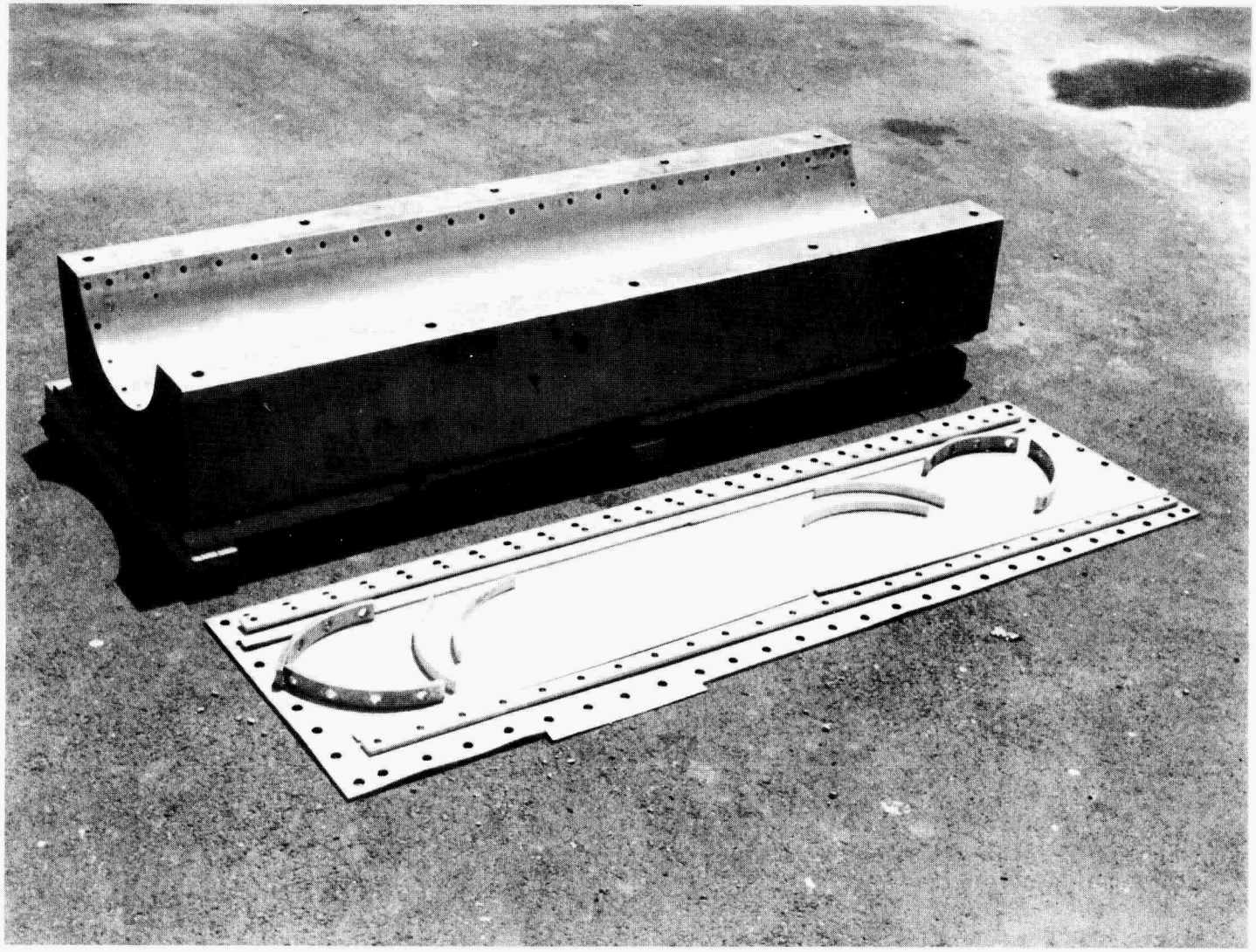


Fig. 24. Explosive forming die and fixtures.

Y-116188

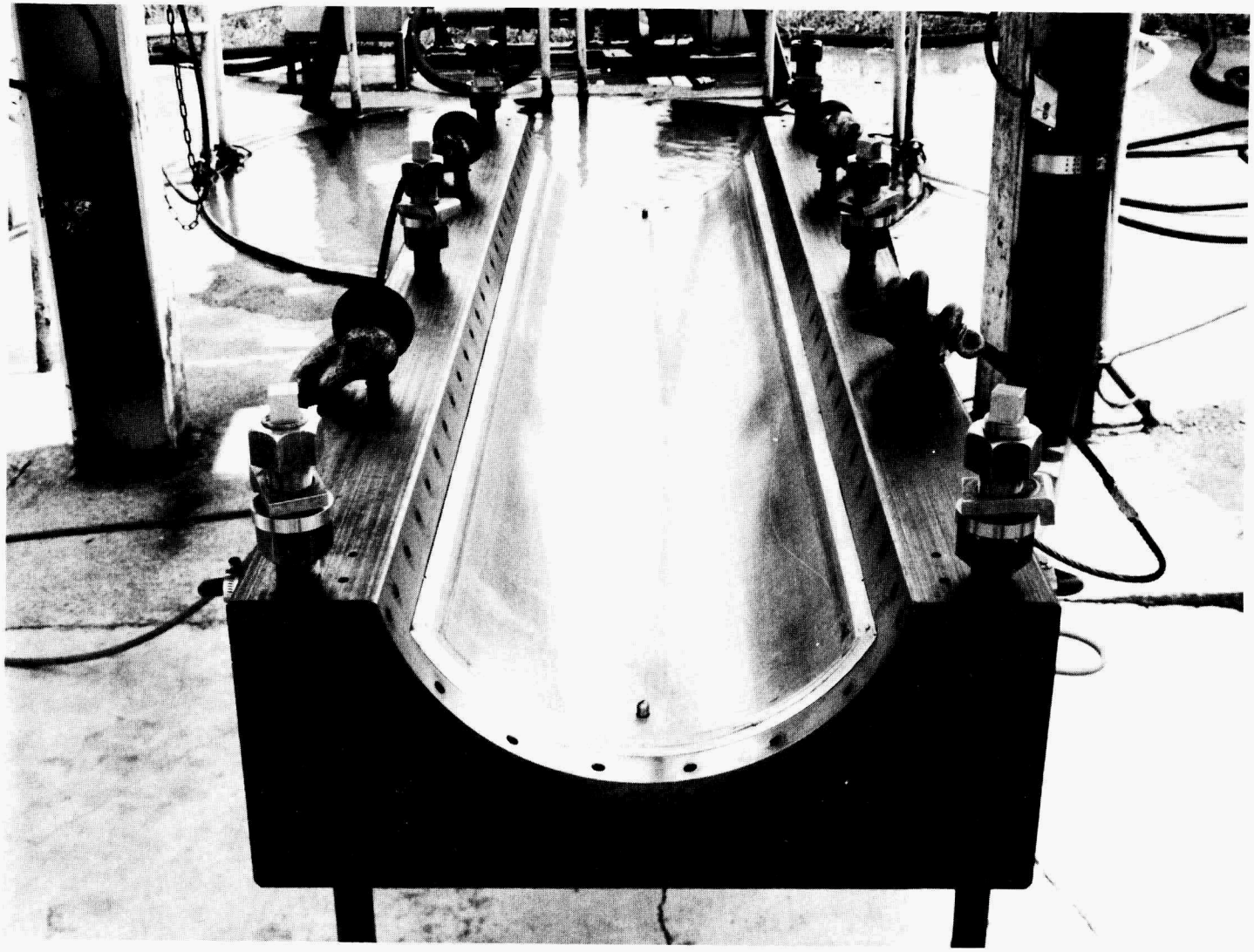


Fig. 25. Control plate in explosive forming die - without fixtures.

the sticks to be raised or lowered to give the desired charge stand-off. The eye bolts and shackles are used for attaching slings which allow the die to be hoisted and lowered into the water-filled tank using an overhead crane.

The same die is used for shaping both inner and outer control plates. The inside radius of the die is machined to form the outer control plate, and a 0.375-in.-thick shim is inserted when forming the inner control plates. The die is designed to accept the unmachined control plates which provides a control plate arc length longer than the final arc length. This extra material is left on the control plate to further assure a more uniform finished product since the control plate edges do not form as well as the interior portion. The extra material is machined away during subsequent manufacturing operations. It was previously stated that the outside radius of the preformed control plates is larger than the forming die. This is necessary since the explosive forming operation causes the edges of the control plate to spring away from the die. The strain created by forcing the larger radius plate into the die minimizes this springback effect. The outside radius of the outer plate is 9 3/8 in. with a die radius of 9.300 in. and the inner plate is formed to an outside radius of 9 in. for a die radius of 8.925 in.

Assembly of Plate in Forming Die

The radius of the preformed control plate is larger than the forming radius of the die, thus, requiring special handling to assemble the control plate to the die. A pusher arrangement, is illustrated in Fig. 26 (Y-12 Photo 116185). The wood, 2 in. x 4 in., forces the control plate into the die and is held firmly against the die with the steel screw-downs. This fixture is not removed until the rubber diaphram shown covering the control plate is securely fastened in place, the interior evacuated, and the assembly checked for leaks.

The complete assembly is shown in Fig. 27 (Y-12 Photo 110118). The assembly is ready to be lowered into the water for firing. The vacuum hoses on the left side of the die go to each end and evacuate the die; those on the right side of the die go to a vacuum gauge. The rubber hoses are weighted to keep them from floating and being blown off by the explosion. The two explosive charges (50-grains/ft prima cord) are positioned above the die on the wooden sticks. Broken sticks from the previous shot can be seen floating in the water. A size 6 or 8 detonation cap is fastened to each end of both explosives. Four additional detonators are fastened to the prima cord 1/4 of the distance from each end.

The lead wires from these caps are shown extending from the left side of the die at each end. There is a directional effect from the explosive and this shooting method is an attempt to create two shock waves which meet at the center of the die.

Y-116185

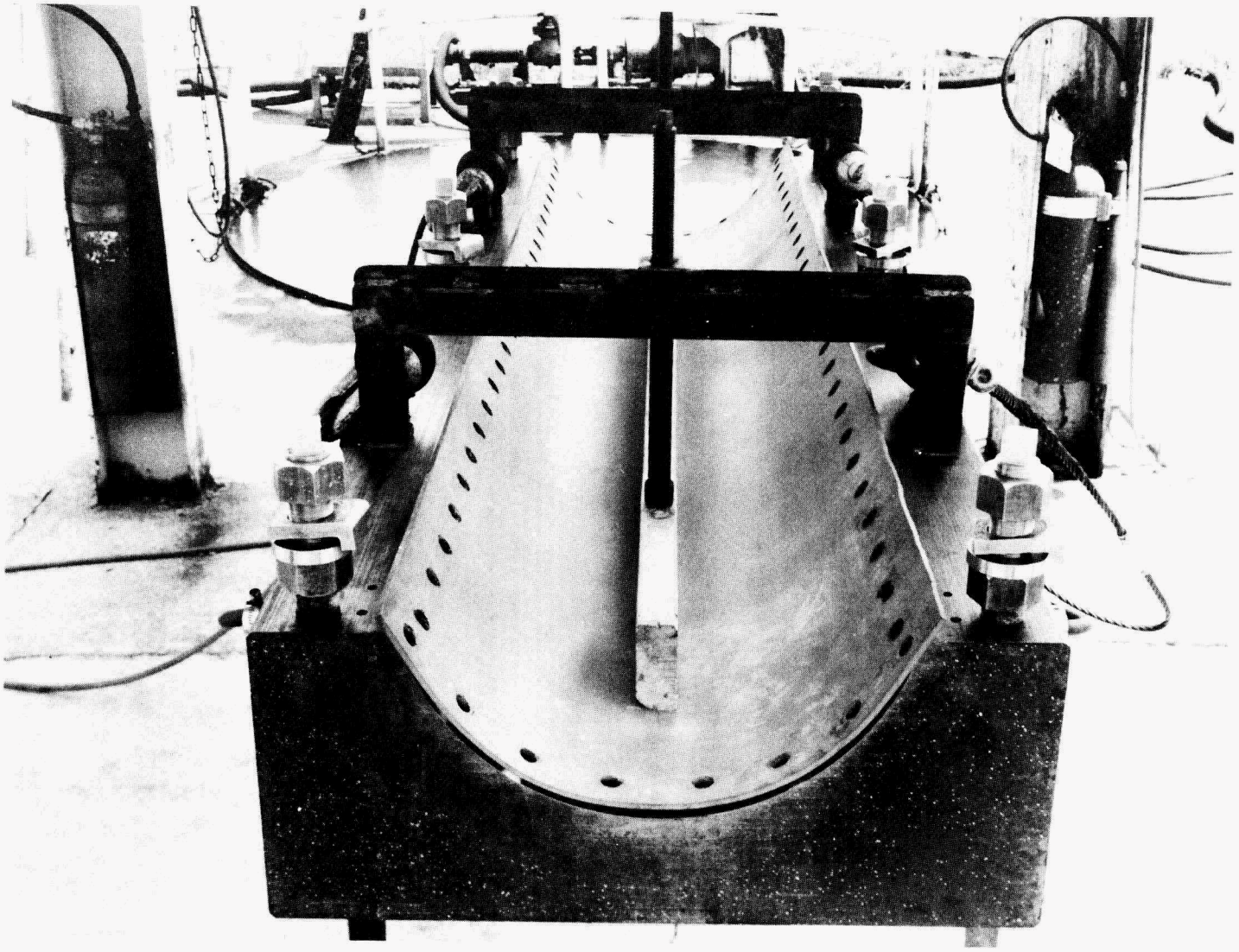


Fig. 26. Forming fixture with hold-down fixture and explosive pad.

Y-110118

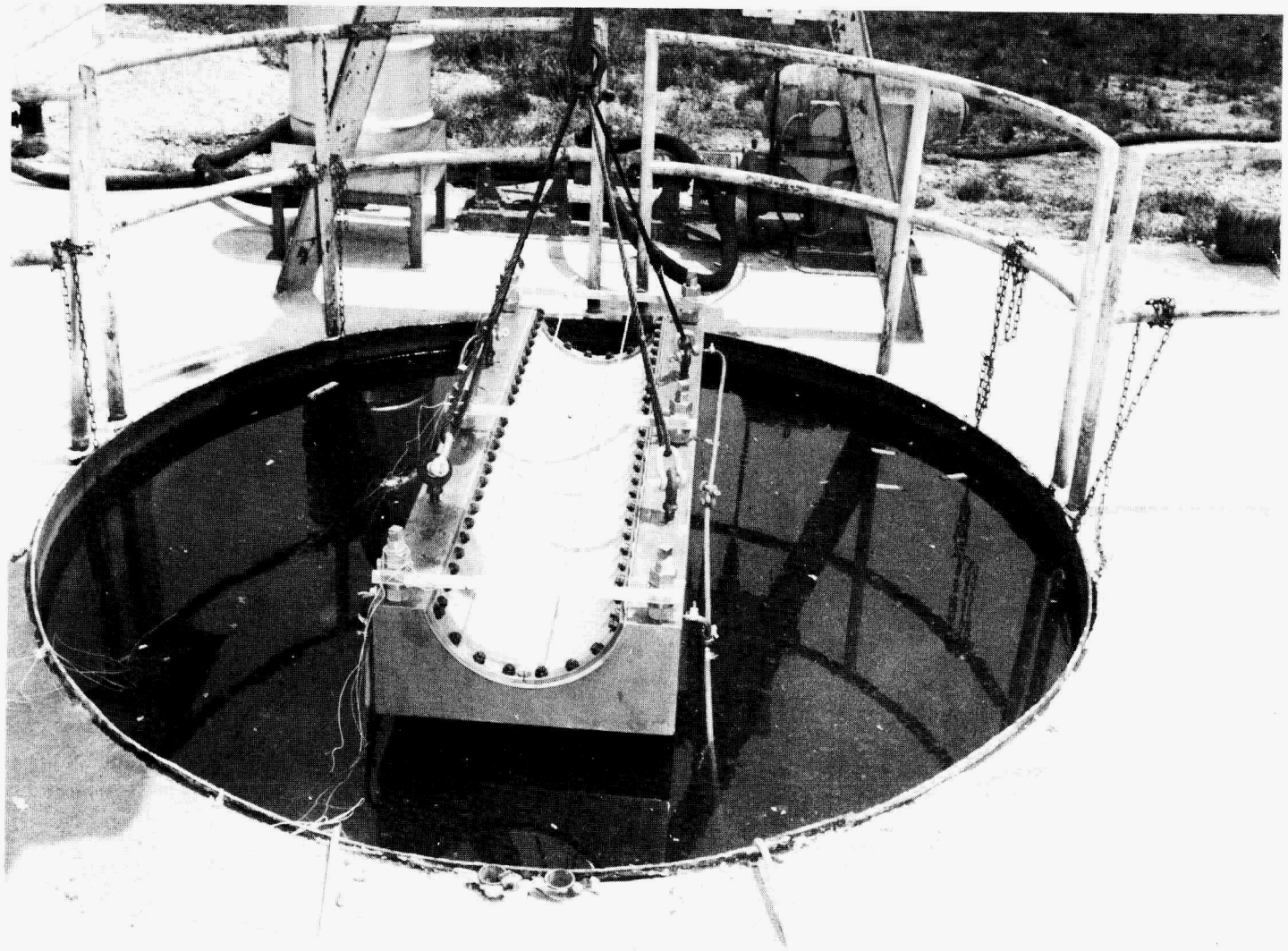


Fig. 27. Explosive forming die assembled ready for shooting.

Summary of Assembly and Shooting Procedures

1. The control plate radius is inspected to see that it is larger than the die radius - 9 3/8-in. minimum and 9 7/8-in. maximum for outer plates, 9-in. minimum and 9 1/2-in. maximum for inner plates.

2. Prior to placing the control plate into the die, both control plate and die are carefully cleaned in isopropyl alcohol and finally wiped with a cloth to remove all dust and dirt.

3. The control plate is carefully positioned in the die so that the alignment hole and slot are positioned over the die pins.

4. The rubber diaphragm is placed over the control plate and the pusher is installed on the die. The control plate is forced against the die with the pins in the hole and the slot.

5. The beveled aluminum edge strips are installed along the edges of the control plate with the beveled edge away from the plate. And rubber strips 1 1/2-in. wide by 1/4-in. thick are placed at each end of the control plate. (The aluminum and rubber strips are used to keep the rubber diaphragm from being sheared by the control plate during the explosion).

6. The rubber diaphragm hold-down clamps are bolted to the edges and ends of the die to make a vacuum-tight joint.

7. The die is evacuated using a mechanical vacuum pump, and the system is inspected for leaks. Any indication of leakage on the gauge is considered unacceptable.

8. The pusher is removed from the die and atmospheric pressure holds the part firmly against the die.

9. The charge positioning sticks and holders are prepared and positioned to give the desired standoff and lateral position above the part. Three sets of positioners are used.

10. Two strands of 50-grains/ft prima cord are strung between the charge positioning sticks, stretched out, and taped in position. The charges are positioned in a horizontal plane 10 in. above the center of the die contour and in a vertical plane 5 in. from the centerline of the die. They are armed, using detonators at 1/4 the distance in from each end.

11. The die and armed charges are positioned under a 4-ft head of water in the shooting tank and the charges are fired simultaneously (all detonators wired in parallel).

12. The die is removed from the tank, dried using compressed air, disassembled, and the control plate removed.

13. The control plate is qualitatively inspected using a template to the mean radius of the control plate (9.050 in. for the outer plate and 8.675 in. for the inner plate).

14. Whenever the control plate is 1/8 in. oversize, the sizing operation is repeated. Before repeating the sizing operation, the control plate is given a thorough inspection to determine whether twist has developed. If the control plate is twisted or undersize, it is sent back to preforming to remove the twist and reestablish the preform radius.

The effects of the underwater explosion can be seen in Fig. 28, Y-12 Photo 110120. The rubber hose in the foreground goes to a vacuum gauge hanging on the column in back of the switch box. The vacuum lead lines are shown on the left side of the column. The lead wires to the electric detonating caps can be seen at the left of the column next to the rubber hoses.

Dimensional Inspection of Sized Plates

Before proceeding with subsequent operations, it is necessary to determine whether or not the explosively sized control plate is acceptable. This consideration is most important for the outer plate since the as-sized contour is the final shape of the control plate. The inner plates are subsequently welded together to form a cylinder and their final contours are establised by explosively sizing the welded cylinder.

Resizing of the outer plate is required when variations greater than 0.020 in. from the nominal 9.300 radius are observed. Resizing is also specified when the mismatch between the centerline of the formed outer plate and the core regions does not yield a minimum of 0.125-in. aluminum edge clad in the final plate.

Each control plate is x-rayed and the radiographs are measured to determine the distance between the reference holes and the core edge. From this measurement, the amount of aluminum to be removed from each control plate edge is established, measurements are also made of the core regions to reconfirm measurements previously taken. The distance between holes and core edge is usually less than the flat plate dimension because of the compressive forming.

As illustrated in Fig. 29, Y-12 Photo 114908, the control plate is positioned in a fixture so that the x-rays can be focused onto the edges of the control plate which are aligned perpendicular to the source to keep divergence and projection at a minimum. A series of radiographs are made (17 for outer and 18 for inner), each with the x-ray head perpendicular to the film. The source is positioned 100 in. from the work and is moved longitudinally with respect to the plate to take the many radiographs. The lead numbers shown in the illustration are hung on a wire stretched along the control plate. These identify the location of the different radiographs. The data listed in Fig. 30 describe the actual dimensions obtained from a series of radiographs. X-ray procedures are given in Appendices A, B, and C.

Y-110120

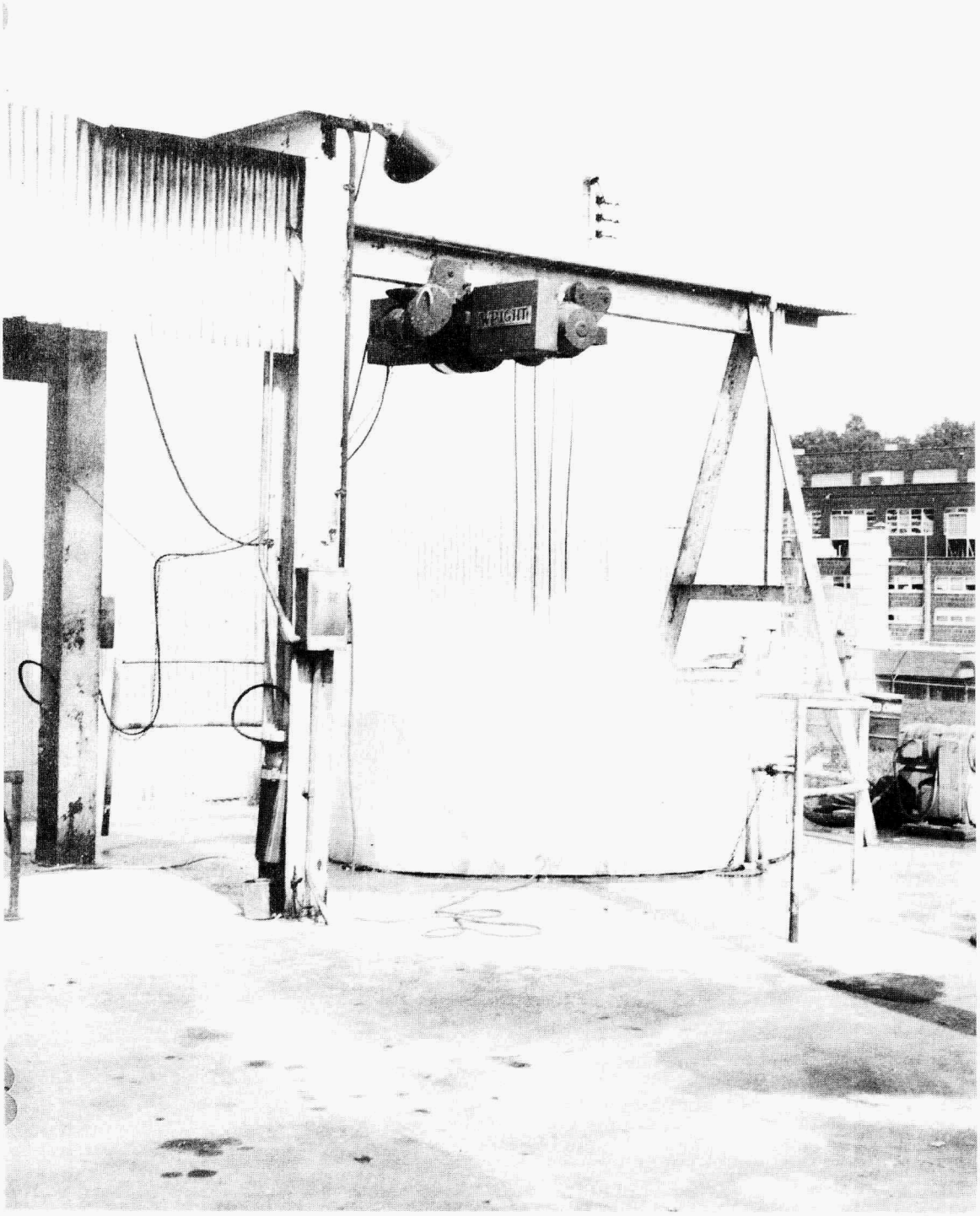


Fig. 28. Forming die at detonation.

Y-114908

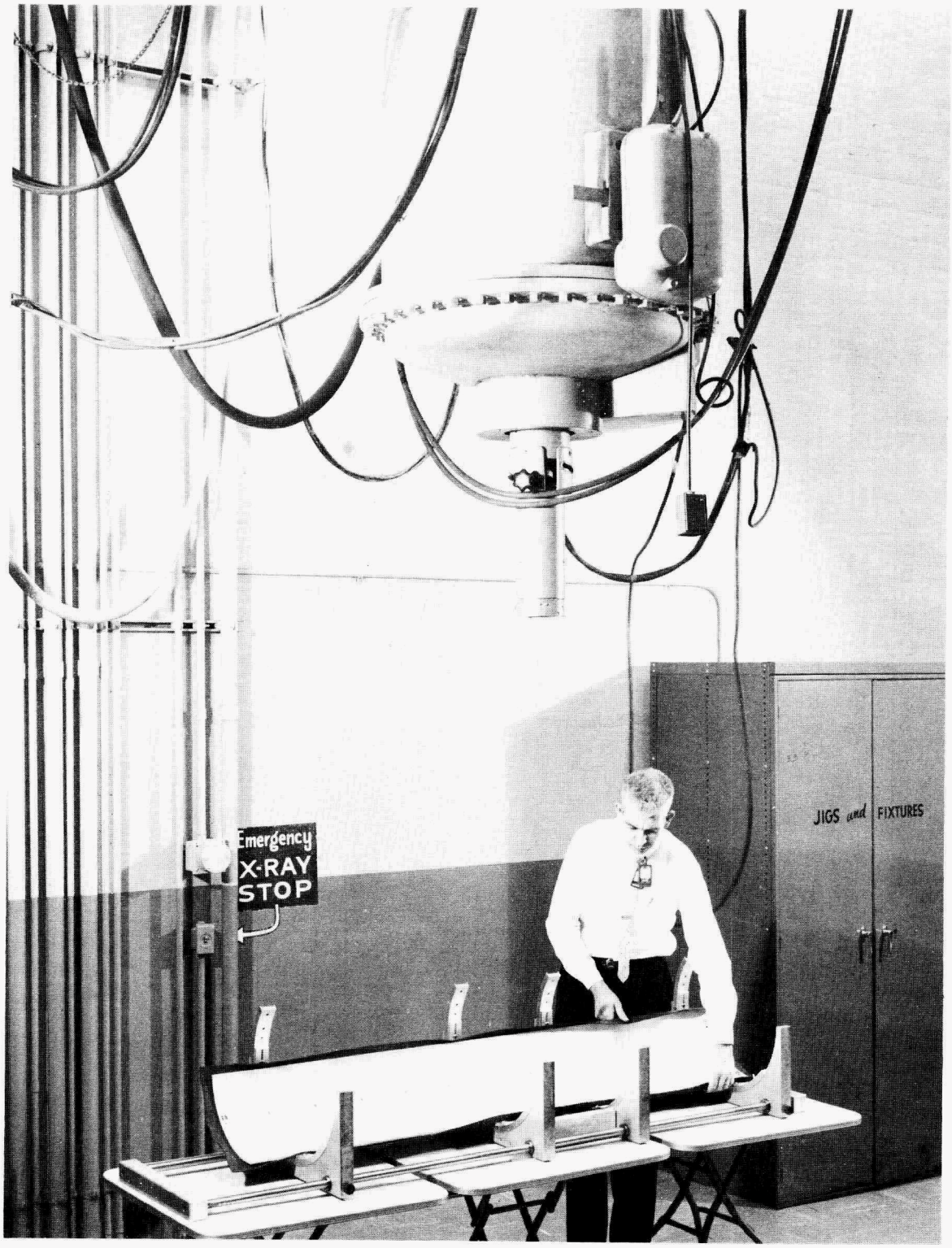


Fig. 29. Formed control plate being set up for radiography.

HFIR PLATE PROCESS INSPECTION FORM, Revision 1

Plate Number HC-65-0 Layout Inspector _____ Date _____

For Inner Cylinder or Outer Segment Radio Inspector [illegible] Date 5-28-65

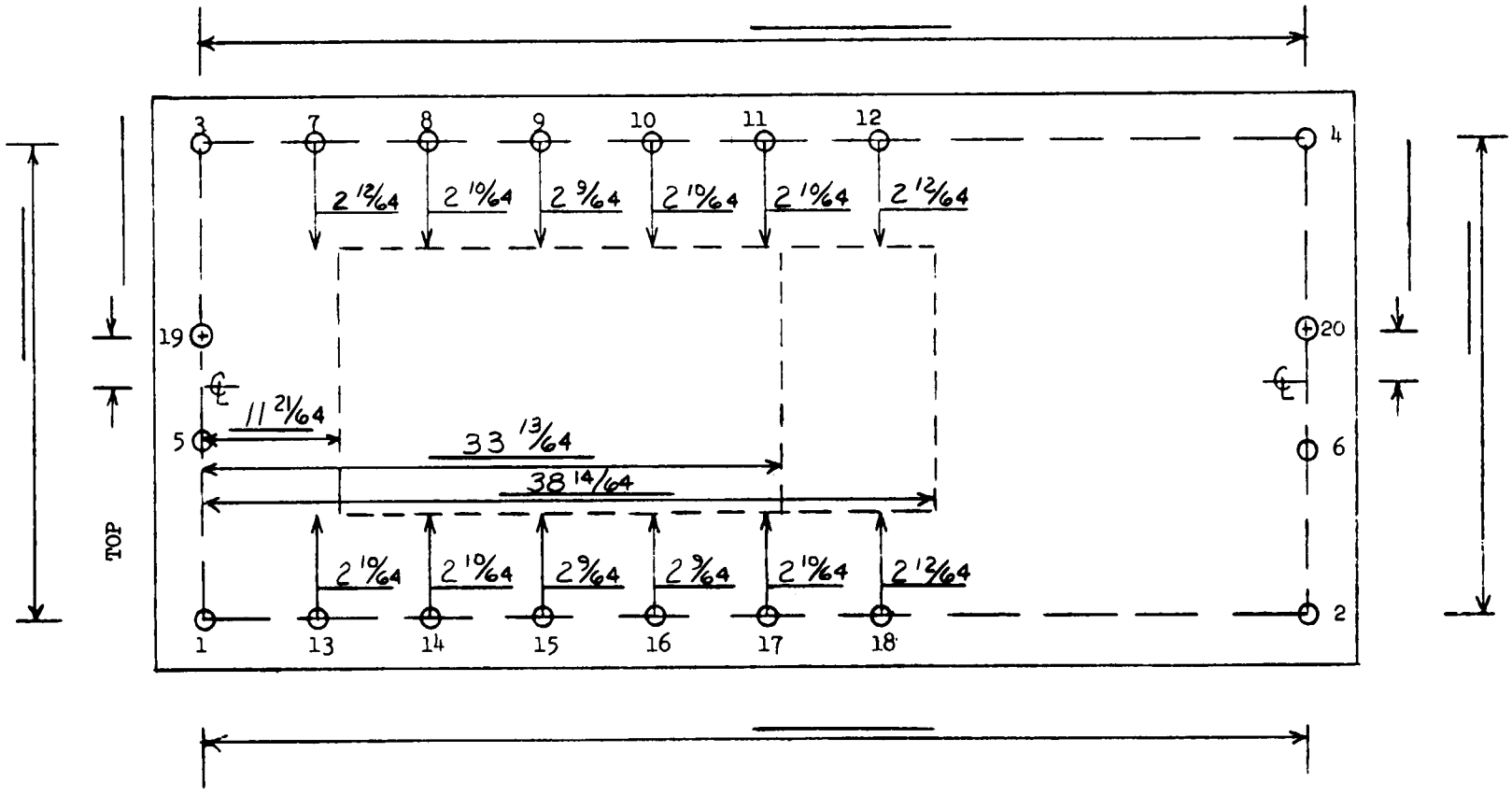


Fig. 30. HFIR plate process inspection form.

Straightening Outer Control Plates

In the later outer control plates manufactured, it became apparent that a more consistant method of attaching end fittings was required. In order to implement this new method, a straightening operation was introduced after explosive forming inspection. No attempt is made to modify the radius imparted by explosive forming; only twist is removed. The setup is illustrated in Figs. 31 and 32, Y-12 Photo 128127 and Y-12 Photo 128128. Extreme care must be taken to impart only enough reverse twist to correct the outer plate. Job specification HFIR No. 15, "Procedure for straightening HFIR outer control cylinder quandrants," in Appendix E outlines the straightening procedure. At straightening inspection, maximum edge variation shall not exceed 0.020 in. and outer plate ends in the plane of the edge shall be within 0.002 in.

Inspection and Layout of Centerlines

Inspection of the contour of the control plate is made as the control plate lies on the inspection mandrel in its free state as opposed to a posture which may have changed elastically if clamping were used. It is extremely important when setting the control plate in position that the contour imparted by the sizing operation not be disturbed.

The equipment for the contour inspection is also used during attachment of end fittings and although Fig. 33, Y-12 Photo 115650, shows an outer plate in a subsequent inspection, the photograph features the basic tooling and equipment used in this initial inspection. The mandrel consists of two discs with identical radii, which have the specified radius size for the inside of the outer plate. A similar type fixture is used for contour inspection of the inner plates. A master template which provides a reference surface for the inspection is installed on the chucked end of the mandrel.

Deviations from the specified radius are measured with a linear potentionmeter sensor probe connected to an X-Y recorder. The Y axis of the plot is the relative variation from the specified outside radius of the part and is accurate to within 0.005 in.; the X-axis of the plot is the relative distance along the length of the plate from the starting position. The potentiometer stylus can be seen resting on the outer contour. The potentiometer is zeroed with respect to the master templates. Five traces of the contour of each control plate are made with respect to the longitudinal axis. These traces are radially 1 5/8 in. apart. Axial position is referenced by means of a signal from the wheel potentiometer resting on the machine table.

The mandrel is centered on the machine with the control plate in its unrestrained condition and can be rotated by means of the indexing head located on the chucked end. Longitudinal alignment and elevation of the part above the mandrel are referenced to the master template.

Y-128127

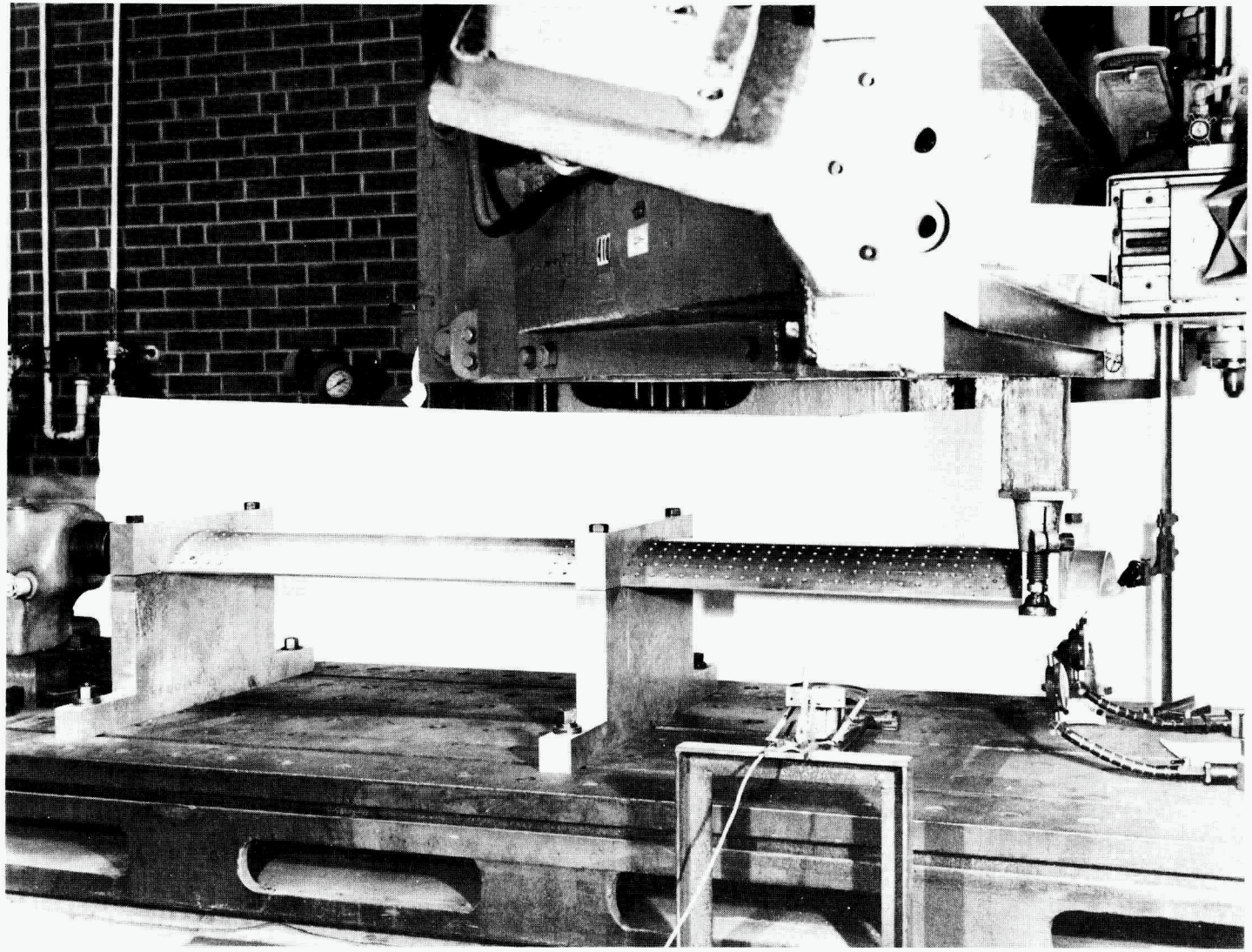


Fig. 31. Formed control plate fixtured to remove twist.

Y-128128

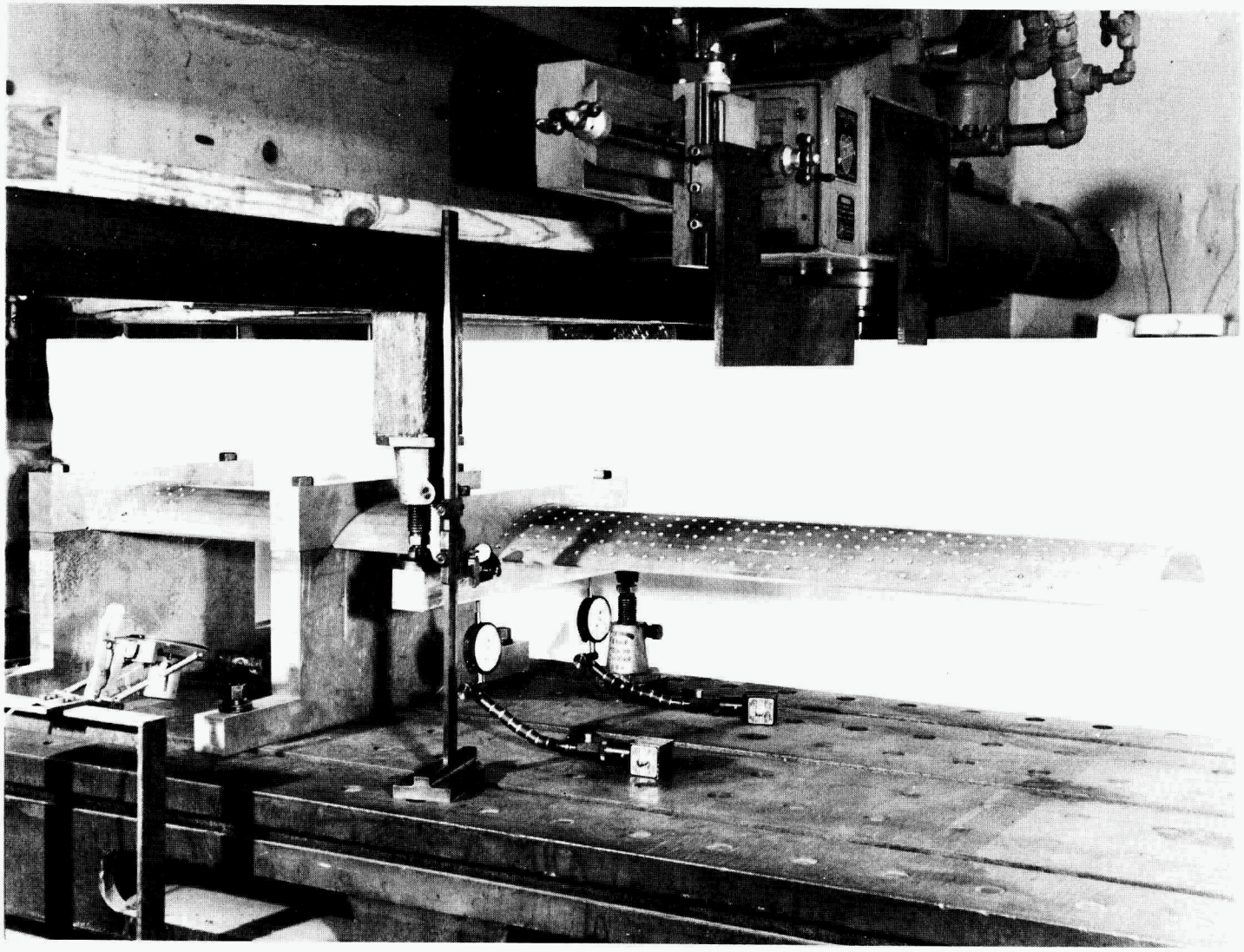


Fig. 32. Removing twist in a formed control plate.

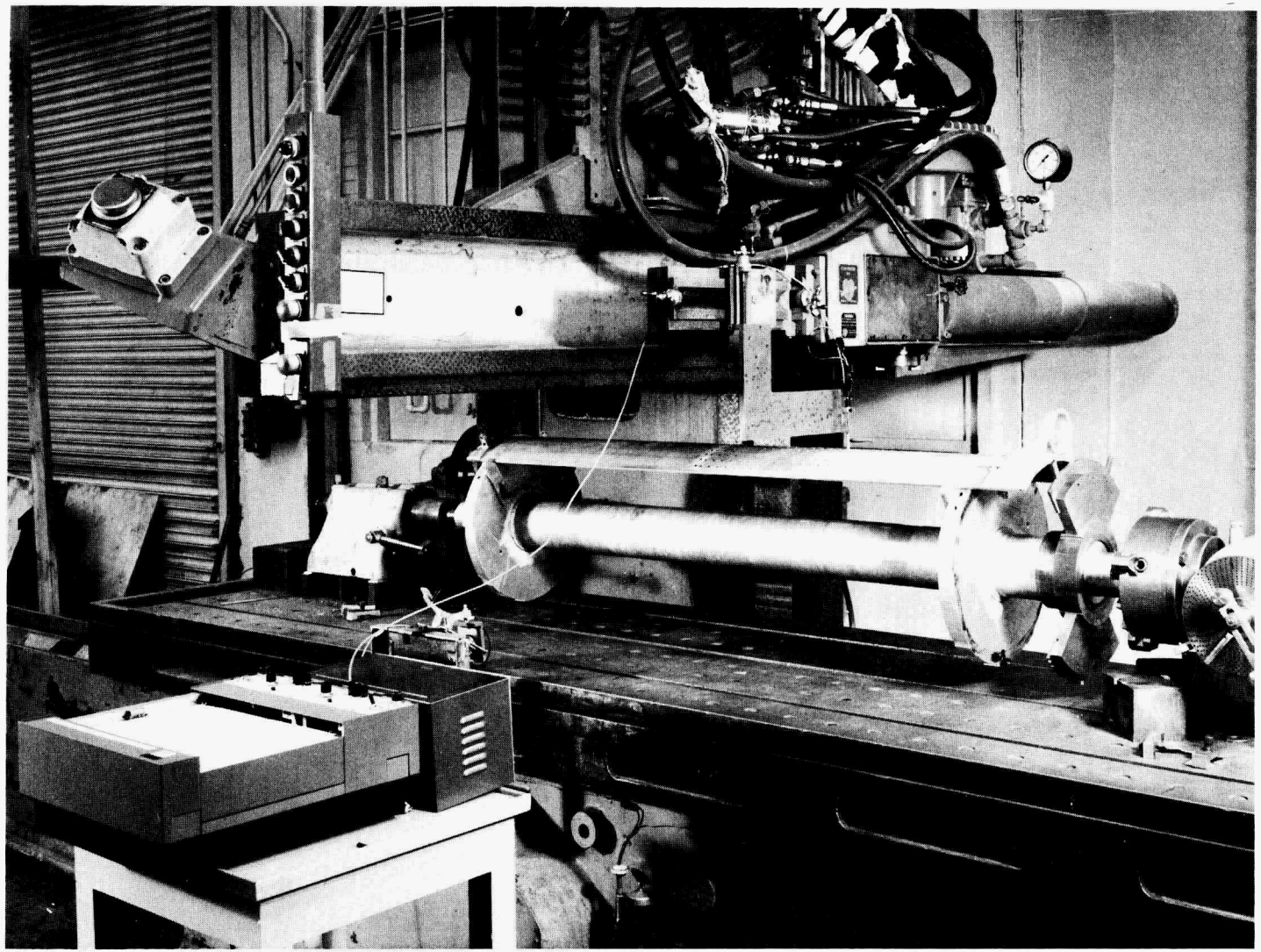


Fig. 33. Measuring the contour of a finished outer control plate.

The control plate generally requires positional adjustments prior to making the detailed scans, and a dial indicator is used in making these preliminary measurements. The adjustments are aimed at positioning the control plate about a "best fit" centerline as found by recorded deviations. The control plate is adjusted so that positive and negative deviations balance and are hopefully within the control plate contour tolerance. The nine scans taken down the length of the control plate represent a "fingerprint" of the control plate for attachment of end fittings.

It is not unusual to find that, as the control plates rest on the inspection discs in the free state, the corners of the control plates do not rest on the fixture. Shims are provided to fill in the gaps and help prevent elastic or plastic deformation.

Prior to making the detail scans, the "best fit" centerline designated ℄ - 2 is identified; its location is then marked on the plate and compared to the previous centerline measurement ℄ - 1. Layouts of centerlines are described briefly on Y-12 procedure Dwg E-M-55625. The procedure is as follows:

1. With the control plate resting on the inspection fixture and positioned with respect to the "best fit" centerline, a line is scribed through hole No. 9 parallel to the "best fit" centerline. This line should also be parallel to the edge of the core section and is a monitor defining the width of the aluminum left on the control plate edge in the latter stages of machining. Another line through hole No. 15, a short distance from the opposite edge of the core, serves the same purpose. Both lines are scribed the full length of the control plate.

2. The arc length A_p between these scribed lines is measured with a special template to a precision of ± 0.010 in. The width of the aluminum edging between hole No. 9 and the edge of the core, W_9, and the similar measurement from hole No. 15, W_{15}, are obtained from the radiographs of the explosively sized plate, and the core arc length, AC, is calculated.

$$AC = A_p - (W_9 + W_{15}) \quad .$$

3. Using hole No. 9 as a reference, the distance Dg to the core centerline is calculated and measured with a flexible tape to the centerline of the core.

$$Dg = \frac{A_p}{2} + W_g \quad .$$

A short line parallel to the lines already scribed alongside the core section is marked at each end of the control plate and is identified as ℄ - 2 and compared to ℄ - 1.

4. The operations described above are repeated using hole No. 15 as a reference, and the marks identifying ℄ - 2 at the control plate ends must coincide.

5. If ℄ - 2 deviates more than 0.050 in. from ℄ - 1, an analysis must be made to assure that the width of the aluminum edging alongside the "black" section of the finished outer control plate will be at least 0.125 in. For the inner control plate, the analysis must show that the edge will be ±1/16 in. of the 0.438 in. specified edge width.

6. Measure an arc length of 6.802 in. from ℄ - 2 on each side of ℄ - 2 and identify the location with a small punch mark.

Layout and Machining Outer Plates to Final Size

The final outer plate layout for machining is done with the outer plate clamped to the same mandrel used for this machining. The mandrel is shown in Fig. 34, Y-12 Photo 112947. It is made of steel and has replaceable aluminum shims bolted to it. With the two shims attached to the fixture, its outside radius is equal to the nominal inside radius of the outer plate. Two outer plates are clamped to the mandrel in opposing quadrants to better balance the mandrel and to make a more efficient machining operation. The mandrel is centered on the bed of a horizontal mill using a chuck at one end and a live center at the other. The setup is arranged so that precise angular measurements can be made using the chuck attached to a gear reducer and motor to provide rotation.

The final machined arc length of the plate is calculated from angular measurements taken with the outer plate mounted on the mandrel. The chuck drive system is used to rotate the mandrel during machining of the final outer plate length. The outer plate edges are machined by moving the mill bed under the milling cutter. The equipment is shown in Fig. 35, Y-12 Photo 112950, which illustrates the edge trimming operation.

The step-by-step procedures used for this final setup and machining are listed below:

1. The shim that fits between the plate and the mandrel should be prepared in advance of the actual machining. This shim should have a thickness such that the outer radius is the same as the nominal control plate inner radius (9.050 in. for the outer and 8.671 in. for the inner control plates). The areas along the edge of the shim which do not control the finished part within 1/4 in. should be undercut a minimum of 0.015 in. The shim should be thoroughly deburred and cleaned before use.

2. Transfer all hole and part identification numbers from the inner surface to the outer surface of the control plate, clean the control plate thoroughly, and carefully position the part on the shimmed mandrel.

Y-112947

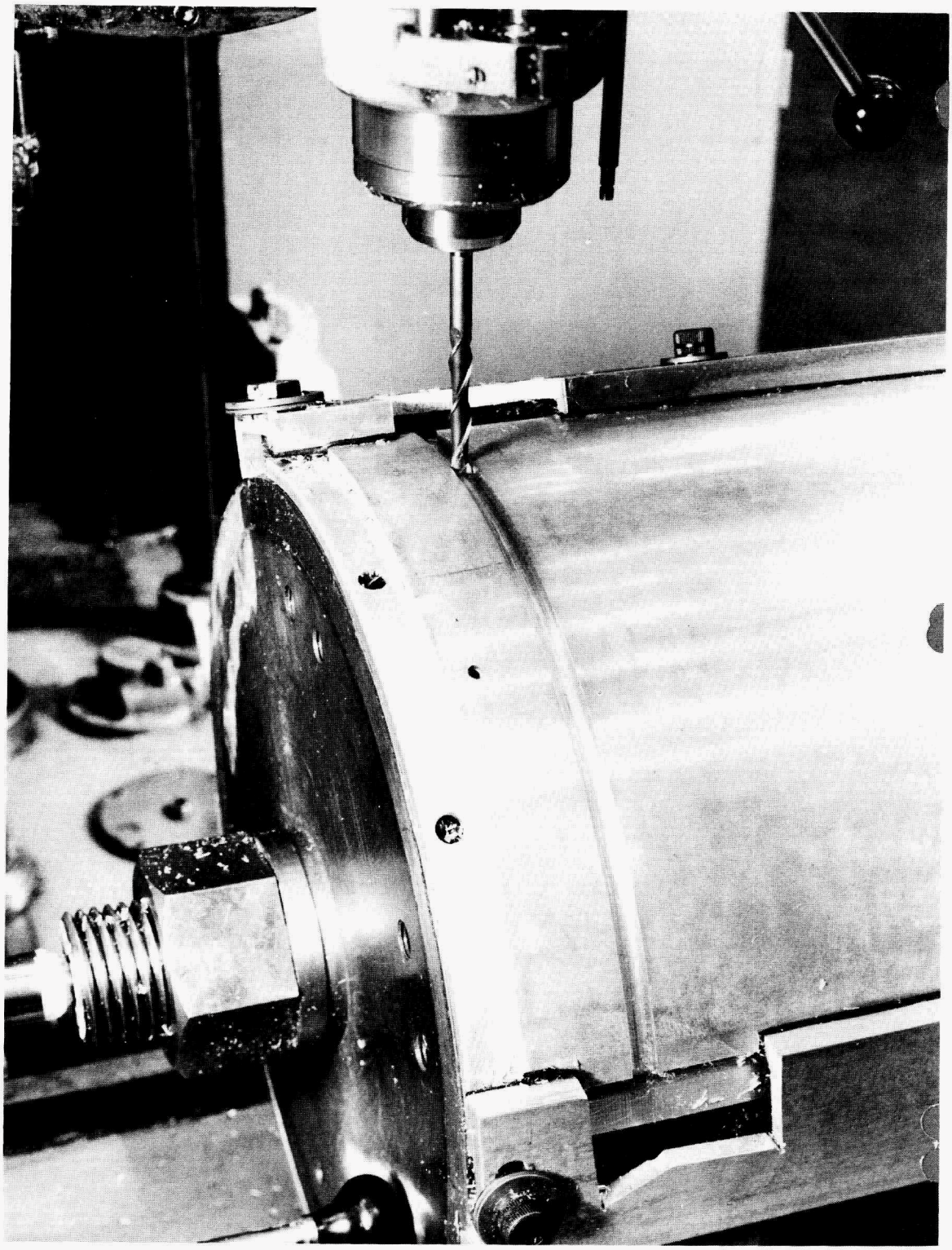


Fig. 34. Machining a control plate to length.

Y-112950

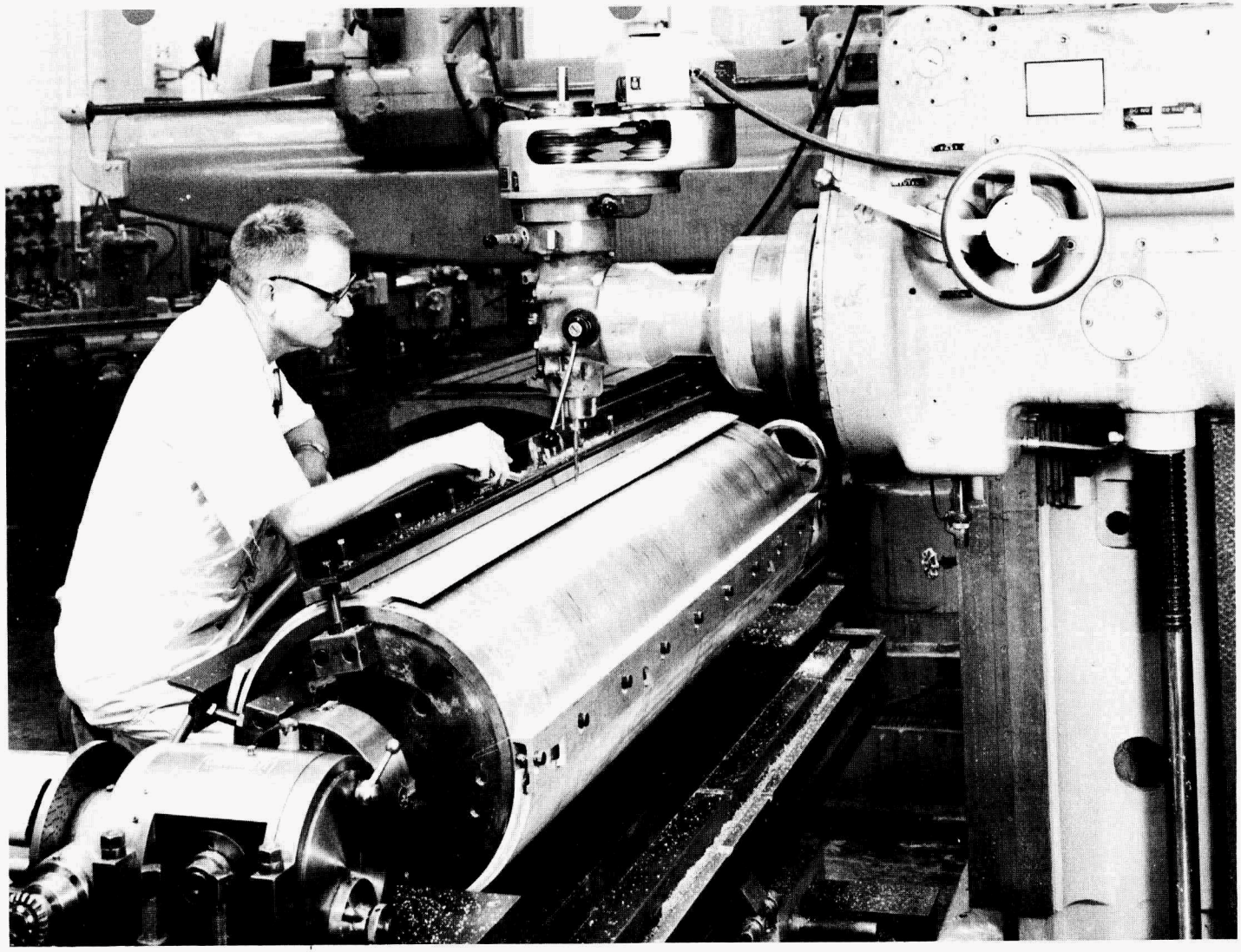


Fig. 35. Machining a control plate to width.

3. The part is placed on the mandrel in a free state, care being taken not to force it laterally. A small clamp is placed at each end at the center of the part to hold it firmly against the mandrel.

4. A wiggler centering device is installed in the mill head and the control plate rotated so that one set of holes (3, 7, 8, 9, 10, 11, 12, 4) through which a guide centerline was scribed is perpendicular to the mill head (see Y-12 Dwg. E-M-55625). Each hole is centered using the wiggler, then the plate is rotated to the opposite set of holes (1, 13, 14, 15, 16, 17, 18, 2) and the process repeated. Maximum runout may not exceed 0.025 in. without Operations Division approval. Generally, a runout not exceeding 0.030 to 0.040 in. may be allowed dependent upon core width.

5. The outer plate is clamped securely to the mandrel, and the check in Step 4 is repeated to assure that the outer plate did not shift during the clamping operation.

6. Using the indexing head, measure the angle of rotation between holes Nos. 9 and 15. The measurement is made to the scribe lines previously made adjacent to the holes. It is very important on all angular measurements and rotations in the procedure that the slack in the rotating and angle measuring system is eliminated. The angle is recorded as angle $\emptyset$ for reference.

7. Using the curved plate radiographs, the core angle of rotation is calculated and identified as angle α. This angle α is obtained by measuring the distance between the core edges and holes Nos. 9 and 15 and calculating the two angles which are identified as angle β_1 and angle β_2. The difference between angle $\emptyset$ and angle $\beta_1 + \beta_2$ is angle α.

8. One-half angle $\emptyset$ is angle θ, which identifies the core centerline. From holes Nos. 9 and 15, scribe lines rotate through angle θ. These two rotations establish the core ℄ - 3 and should meet at the coincident point at the plate center. ℄ - 3 should be within 0.050 in. of ℄ - 1; if the divergence is greater, Operations Division approval is required to proceed. If ℄ - 1 and ℄ - 3 are separated by more than 0.030 in. and do not cross at some point along the axis of the part, Operations Division approval is required to proceed to the next step.

9. From ℄ - 3, rotate 41°54'30" and mark this point at the 4 edge corners of the plate. These marks should coinside with marks previously established by inspection.

10. Machine each edge using the center point in Step 9 as the trim line. After machining, the chord should measure 12.424 in. If the chord dimension is greater than 12.430 in., remove equal stock from each edge to obtain a chord dimension of 12.430 to 12.424 in. The chord is measured and verified by inspection while the plate is still on the mandrel.

11. The end clamps are now removed and edge clamps are used to allow a clean surface for end machining.

12. With the part clamped to the mandrel, measure in from hole No. 19 the dimension established by inspection at flat plate radiography and make a small punch mark. This defines the top end of the plate. Machine the end square with ℄ - 3.

13. Establish the bottom plate end from the finished top end by measuring down the plate 66 3/16 in. Machine this end parallel with the opposite end and square with ℄ - 3.

14. The plate identification number which was removed during machining is scribed at the same end of the outer plate.

DRILLING 1/4-INCH DIAM HOLES IN OUTER CONTROL PLATES

As detailed in Dwg E-49823, 467 1/4-in. diam holes are drilled in each outer plate. Drilling such a large number of holes made it desirable to use a tape-controlled drilling machine. Prior to drilling these holes, the mandrel, with the two plates still clamped in place, is positioned on the drilling machine bed on centers. The setup is illustrated in Fig. 36, Y-12 Photo 112676. Angular rotation with respect to the part centerline is accomplished using a precision indexing head shown in the foreground. Axial spacing is established automatically by the tape-controlled carriage.

The operation proceeds by drilling an entire row of holes along the axis of the part, indexing, and then drilling the next row of holes. With this repetition, all rows of holes are completed as directed by the tape control. The drill passes through the outer plate but barely enters the shim backing plate. A completely drilled plate, the drill, and guide bushing are shown in Fig. 37, Y-12 Photo 112677. To minimize galling of the drill, White and Bagley chloride-free oil is used. Oil feed is a once-through operation in order to avoid possible chloride contamination should the oil pass through the central lubrication system.

During the drilling operation, the aluminum chips principally from the row of holes closest to the gray-black interface, are reserved for possible chemical analysis. Y-12 Dwg. E-M-55623 defines the holes from which these chips are collected.

Dimensional Inspection of Machined Outer Plate

Prior to radiusing the holes, each plate is radiographed primarily to (1) verify the width of the finished aluminum edging alongside the core and (2) compare the actual length of the black-gray interface from the numbered end of the plate with the specified dimensions. The width of the edging must not be less than 0.125 in. and the black-gray interface must be within $\pm 1/32$ of its specified distance of 30 5/8 in. from the numbered end of the plate, ORNL Dwg. E-49823.

The radiographic technique is essentially the same as described in radiographing after explosive sizing, where the stretched wire down the middle of the plate and overlapping film are utilized. A typical result for plate HC-65-0 is shown in Fig. 38, which shows that the minimum edging is 7/32 in. and the distance from the numbered end of the plate to the black-gray interface is 30 25/32 in.

Radiusing 1/4-in. Diam Holes

The control system hydraulics demands that the sharp edges on both sides of each 1/4-in. diam hole be radiused and that the radius surface be smooth and free of burrs and chatter marks. The radius is 1/32 in. and must blend to avoid sharp edges. This detail is described in ORNL Dwg. E-49823.

Y-112676

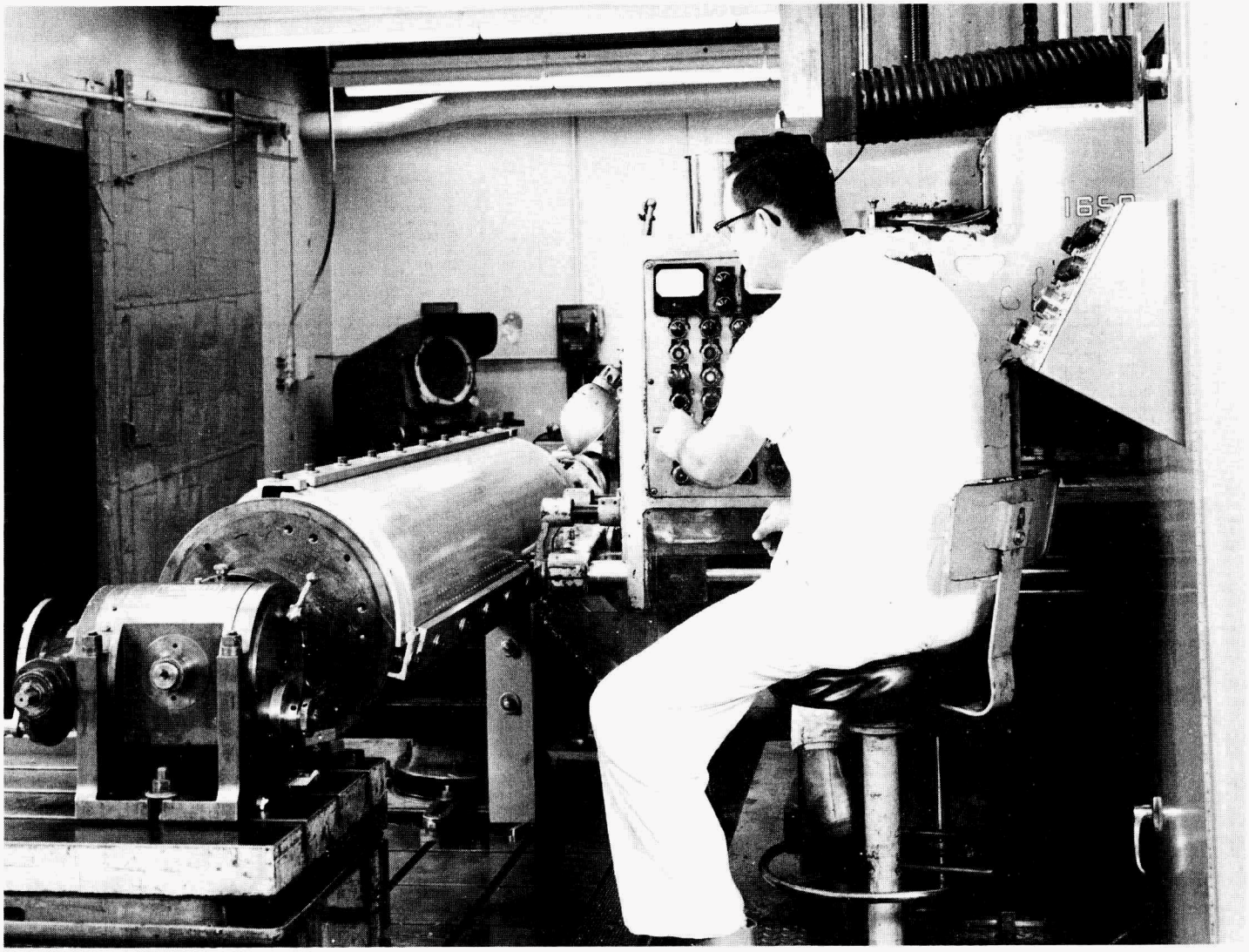


Fig. 36. Drilling holes in a control plate.

Y-112677

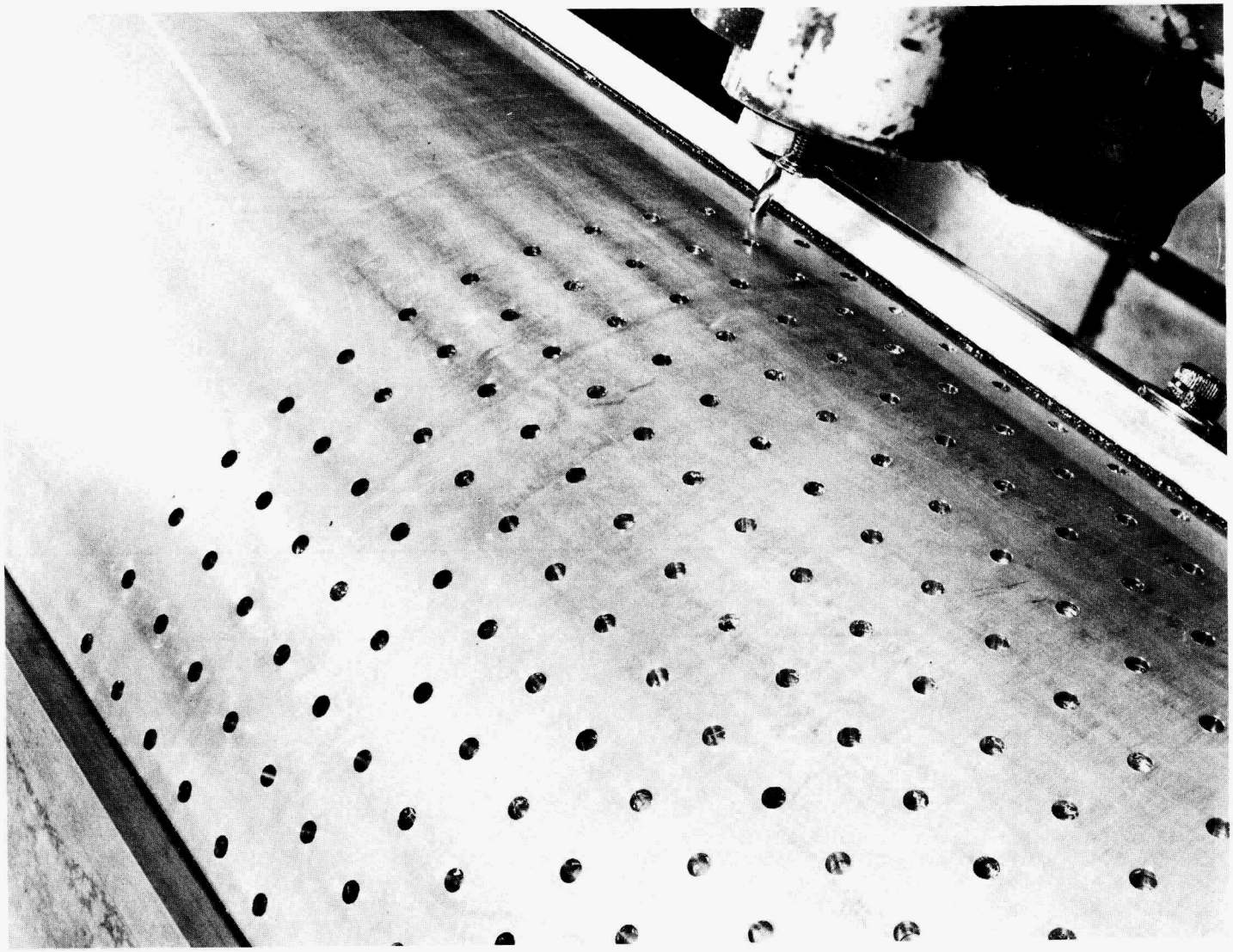


Fig. 37. Hole drilling in a control plate.

HFIR SEGMENT INSPECTION FORM

(For Inner or Outer Segment After Machining)

Part Number HC-65-0 Radio Inspection ~~7/84~~ Date 6-25-85

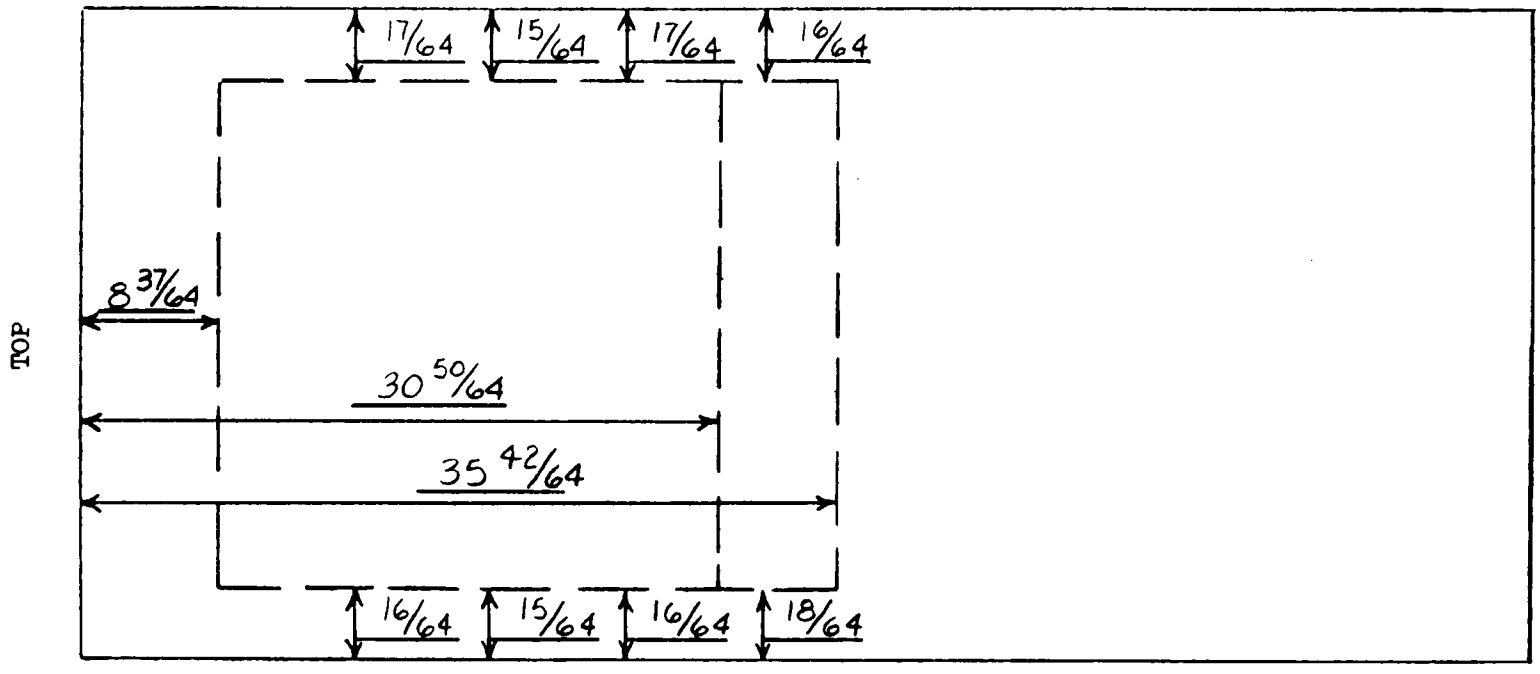


Fig. 38. HFIR segment inspection form.

Special tooling was designed and constructed to ensure acceptable radii.

The tooling is described in detail in Dwg. D-T-33263. A motor-driven tool is used to provide a speedy operation. A closeup of this equipment is shown in Fig. 39, Y-12 Photo 115695. The locking nut which restricts the travel depth of the cutter is evident and an alignment dowel can be seen in the foreground. Isopropyl alcohol was selected as a lubricant during cutting and the tubing lines and clamps used to meter this fluid are visible. The face of the tool support is contoured to match the profile of the part and, by means of close fitting dowels in adjacent holes, aligns the radiusing cutter with the hole being radiused. The cutter is equipped with a nylon bushing with pilots which align the cutter into the hole being radiused. A cam action is used to raise and lower the cutter. A positive-stop control limits the depth of travel of the cutter. The cutter depth is preset on a test plate and locked before radiusing is started on the control plate.

An overall view of the radiusing operation is illustrated in Fig. 40, Y-12 Photo 115698, showing the outside surface mounted on a micarta support fixture. When radiusing the holes from the inside surface, a cradle fixture of micarta is used.

To ensure that the radiused surface of each hole is smooth and free of burrs and chatter marks, the cutter is sharpened periodically. The radiused surface is finally finished by polishing with aluminum wool.

Y-115694

Fig. 39. Radiusing holes in a control plate.

Y-115698

Fig. 40. Radiusing hole in a control plates.

ATTACHMENT OF END FITTINGS TO OUTER CONTROL PLATES

Proper positioning and attachment of the end fittings to the control plates is a sensitive and critical operation. Its importance must not be underrated because the end fittings fit into the reactor assembly, and in this manner, the relative position of the outer control plates to the adjacent reactor components is established. The outer control plates are positioned between the Be reflector and the inner control cylinder with clearances of 0.136 in. and 0.129 in., respectively, which must be closely controlled.

Finished Plate Inspection

After completion of the edge and end trimming and the hole drilling and radiusing, it is necessary to inspect the control plate to assure that its contour has not dimensionally changed. The procedure is similar to that used after explosive sizing. Since the locations used during explosive sizing have been machined away, a master template is used to aid in positioning the control plate and identify measuring locations. The procedure is given below.

1. The control plate is set up on the inspection mandrel and aligned to a master template. The control plate is checked to make sure that its edges are parallel to and the ends square with the bed travel of the machine. If a compromise is required in the setup, it may be made by balancing the total indicator reading (TIR) between the two edges. The edge and end TIR are recorded.

2. The radial variations are inspected by taking measurements at 6° intervals starting at the longitudinal centerline. These measurements are taken 7/8 in. from the cored end of the control plate and 1 7/8 in. from the opposite end. The indicator is zero adjusted using the master template and variations greater than ±0.005 in. from the 9.300-in. radius require that the control plate be restraightened as previously mentioned and shown in Figs. 31 and 32.

3. In order to have setup points which can be used to set the control plate for installing the end fittings and for checking the part setup after the end fittings are installed but before final machining, three additional measurements are taken at each end of the control plate. The measurements are taken between the second and third rows of 1/4-in.-diam holes from each end, radially at the plate centerline, and between the first and second row of holes from the edge.

4. The same linear potentiometer sensor probe used in the contour measurements after explosive sizing is used for these measurements.

End-Fitting Preparation

Raw material for upper and lower end-fitting weldment fabrication is 3/4-in. 6061 T6 aluminum plate, ORNL Dwgs. E-49825 and E-49821. The plate is rolled into a cylinder 19 1/4-in. O.D., seam welded, and reheat-treated to the T6 condition. Cylinders are limited to 24-in. lengths for ease of handling. The steps in manufacturing the rough-machined lower flange are listed below.

1. Using a lathe, turn the O.D. to 19.100 ± 0.005 in. and counterbore one end to 18.440 ± 0.002 in., 3.750-in. deep. Bore through 17.937 ± 0.003 in. diam and cut off a 4 1/16-in. length at the counterbored end.

2. The ring provides sufficient material for four end fittings. Lay out bearing lug and coupling flange locations and drill a 3/32-diam hole through the cylinder at the center of each bearing lug. These are vent holes for welding.

3. Shrink fit cylinder to welding restraining fixture, Y-12 Dwg. E-T-66773. See Figs. 41 and 42, X-10 Photos 81644 and 81645.*

4. Using a welding fixture, Y-12 Dwg. E-T-66767, locate and weld all appendages except the bearing lugs.

5. Remove welding fixture and heat treat the welded cylinder with the welding restraining fixture in place. Heat to 775°F (413°C). Hold for two hours then cool at 50°F (10°C) per hour to 500°F (260°C), remove from furnace, and allow to cool to room temperature. This treatment is to obtain "0" temper.

6. Reassemble in welding fixture and weld the bearing lugs in place.

7. No additional heat treating will be allowed.

8. Remove from welding fixture and measure 43° on each side of each coupling flange center and saw cut four end fittings from ring.

9. Inspect part for machining cleanup.

10. Clamp end fitting securely to machining fixture, Y-12 Dwg. E-T-66756, and align on milling machine.

11. Face bottom of coupling flange to establish 2 29/32-in. dimension to the bottom of the bearing lugs.

*These figures show rings yielding three end fittings per ring. See ORNL Dwgs. E-49821-4 and E-49821-2 for flange weldments yielding four end fittings from each ring.

ORNL-PHOTO 81645

Fig. 41. Lugs welded to upper end fitting.

ORNL-PHOTO 81644

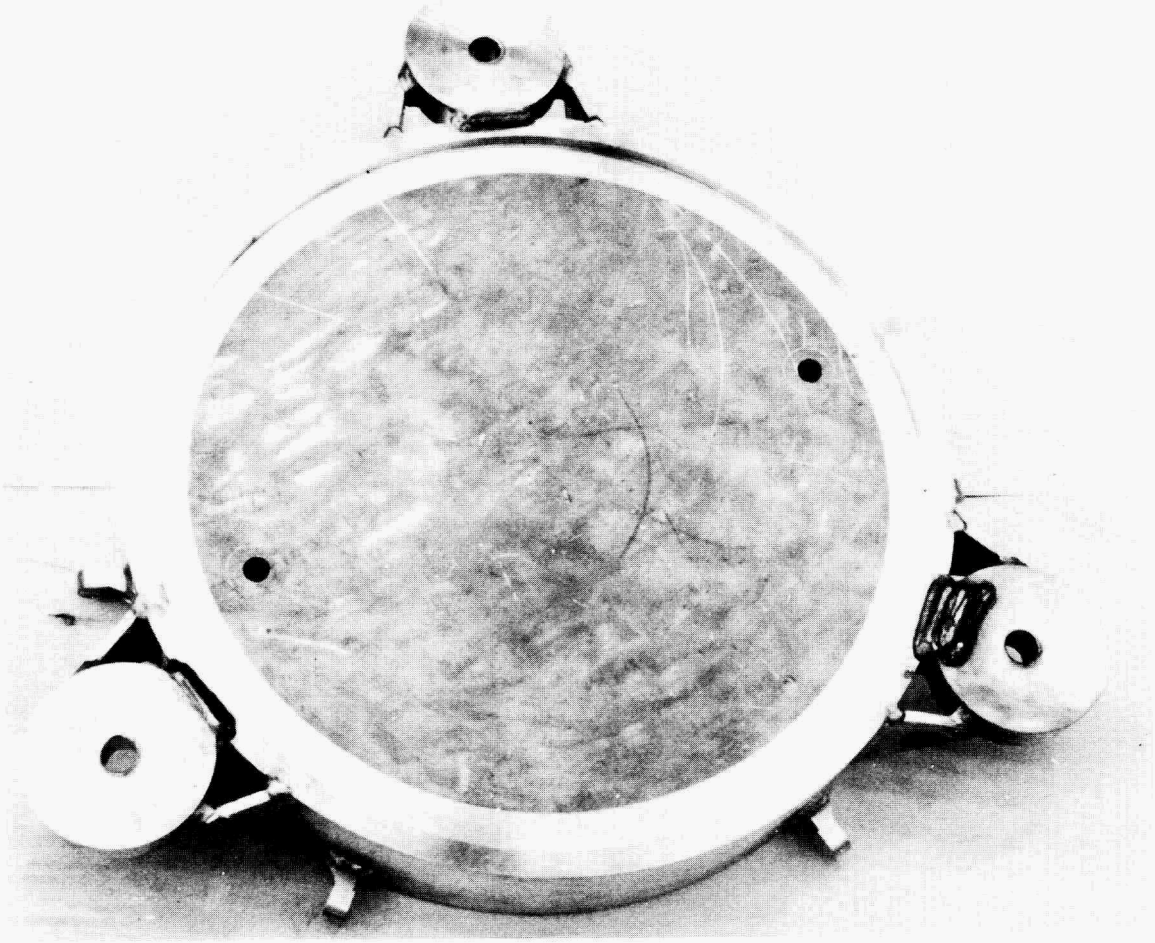


Fig. 42. Lugs and flanges welded to lower end fitting.

12. Bore coupling flange to 3.065-in. diam and counterbore 3 7/23-in. diam.

13. Reverse part for machining opposite side, finish coupling flange to 0.812 - 0.813-in. thick, then finish all surfaces of this side.

14. Locate and drill and tap for coupling lock screw. Install coupling lock screw.

15. Remove part from fixture and mount on Lucas tape milling fixture, Y-12 Dwg. E-T-66750. Locate fixture with part on mill.

16. Contour backside of side with flange and lugs; machine 9.300-in. radius and 9.050-in. radius. Machine coupling flange relief, holding 0.437-in. dimension from the face of the flange to the shoulder.

17. Inspect and record all dimensions.

Critical operations in the manufacture of the lower control plate flange, ORNL Dwg. E-49821, have been described. The upper flange, ORNL Dwg. E-49825, is treated similarly and needs no further explanation. The final finish of both flanges is completed after they are mounted to the control plate.

Setup of Outer Plate for End-Fitting Attachment

After explosive forming, the control plate is straightened such that coincident ends of the control plate are aligned within 0.002 in.; this accuracy is necessary in order to match the end fittings at opposite ends of the control plate. The top and bottom end fittings are illustrated in Fig. 43, Y-12 Photo 132118. The inside radius of the end fittings is machined to 9.300 in. which is the nominal outside radius of the control plate. An extremely important feature of both end fittings is the fact that bearings are subsequently attached to the lugs visible in the illustrations. These bearings serve to guide as well as separate the outer control plates as they move between the inner control cylinder and the beryllium reflector. The bottom end fitting has a flange which fits over the guide rod coupling in the reactor.

The mandrel discs, on which the control plate is mounted for end and edge machining, are machined to a radius approximately 0.075 in. less than the control plate inside radius. This permits the control plate to be adjusted at the corners to the same difference in variation from the nominal tolerance radius as was obtained from the control plate inspection after edge and end machining and hole drilling. The center of the control plate is set at each end to the same variation from nominal tolerance radius that was obtained from the end fitting contour inspection. The template reference pin is used to indicate the zero position. The edges are checked for TIR and the control plate adjusted to give the same TIR along the edges as was obtained at the control plate end fitting contour

Y-132118

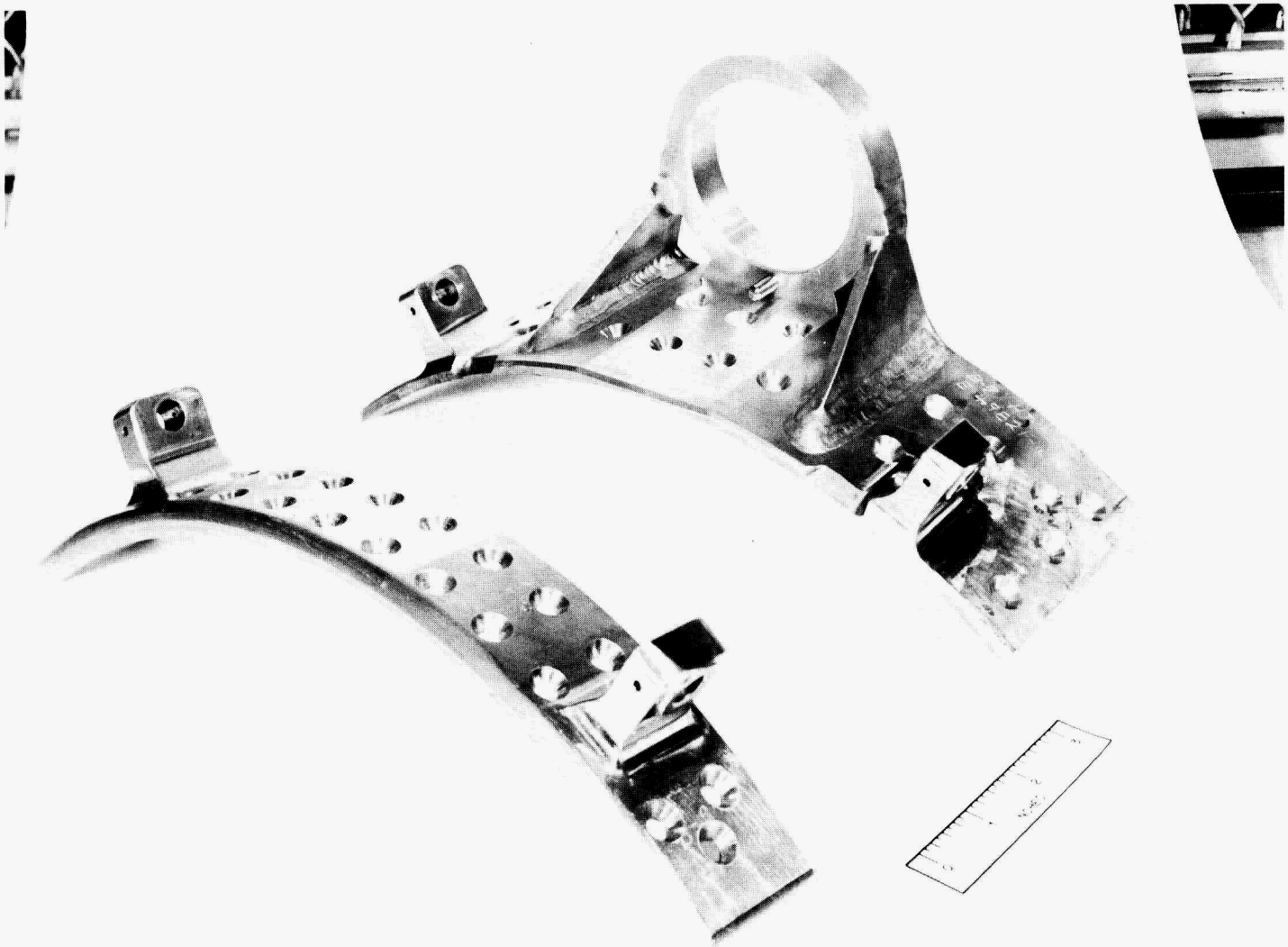


Fig. 43. Finished upper and lower outer end fittings.

inspection. It is important that, for this setup, the control plate not be deflected from its natural free state position. This is ascertained by positioning dial indicators at the center of the control plate and near each edge just inside the part-holding clamps. The clamps are then released and the dial indicator deflection should be less than 0.002 in. The clamps are then retightened and the indicators should return to their original zero readings. If necessary, pads are adjusted in order to obtain a minimum deflection on the dial indicators while maintaining the proper center and edge positions of the control plate with respect to the template setup position. The purpose of this setup is to have the control plate positioned exactly the same as it was positioned during the previous inspection except the part is 0.041 in. offset from the centerline. The final inspection of the part is made with respect to a template which also has a 0.041-in. offset.

With the aid of a master template, the end fittings are aligned and attached to the control plate with screws. Each screw is staked four places at 90° intervals (Fig. 44, Y-12 Photo 125620). After the end fittings are installed, the part alignment is checked on the mandrel before lug machining. Using the master template as a reference, the lugs are faced to size and bored. Machining to the master template allows the bearings shafts to match properly, making it unnecessary to use eccentric shafts which could not be readily replaced.

The work is done with the control plate resting on the inspection mandrel. Figure 45, Y-12 Photo 115488, illustrates an outer control plate which is in the last phase of completion. The equipment shown is the same equipment described previously when machining the edges and ends to final size. The mandrel is centered and can be rotated using the precision indexing head. The master template at the chucked end of the mandrel has reference surfaces to which the part is positioned, the lower flange aligned, and to which the bearing lugs on both upper and lower end fittings are faced and bored. It also provides a reference centerline to which the 5/8- and 3/4-in.-diam holes can be drilled. The engineering details of this master template are shown on Dwg. E-T-55964, a careful review of these details in relation to the requirement described in Dwgs. E-49821, E-49820, and E-49825 is mandatory to fully understand the function of the master template in establishing the positions of the end fittings and their various parts relative to the control plate surface. The finished control plate is mounted on the original inspection mandrel and aligned so that the posture of the control plate relative to the master template is identical or very close to its posture identified previously in the inspection after explosive sizing. Where necessary, shims are used to locate a contour with, as closely as possible, the same "fingerprint" variation's listed in the previous inspection. Edge and end run-out are checked to ensure that the control plate is positioned so that ends are square and that edges are parallel with the bed of the mill. The edge and end TIR are recorded.

In order to be certain that the posture of the control plate on the mandrel used during attachment of the end fittings is identical with that determined in the previous inspection, the radius variation from 9.300 in.

Y-125620

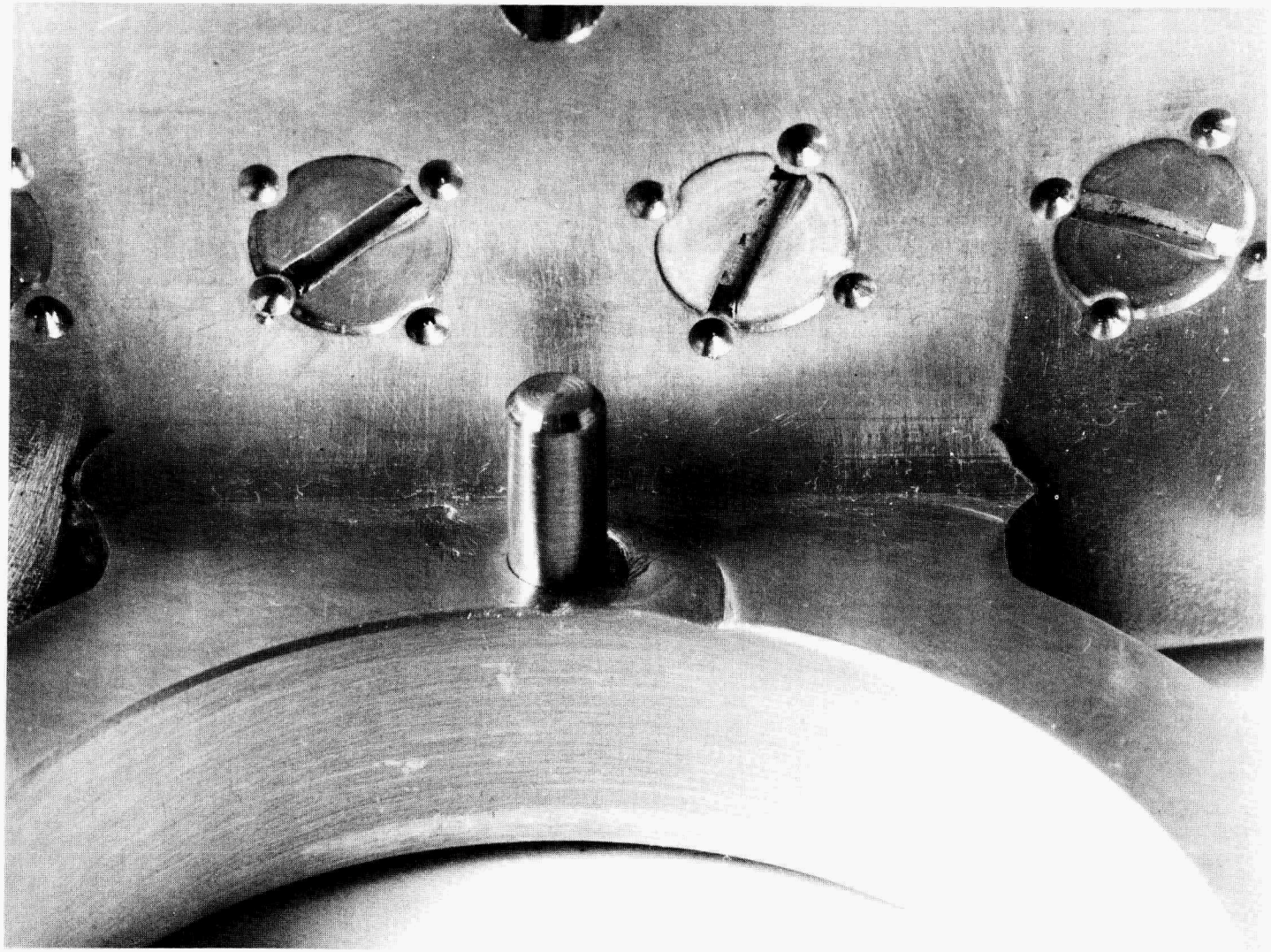


Fig. 44. Lug screws staked in place on end fitting.

Y-115488

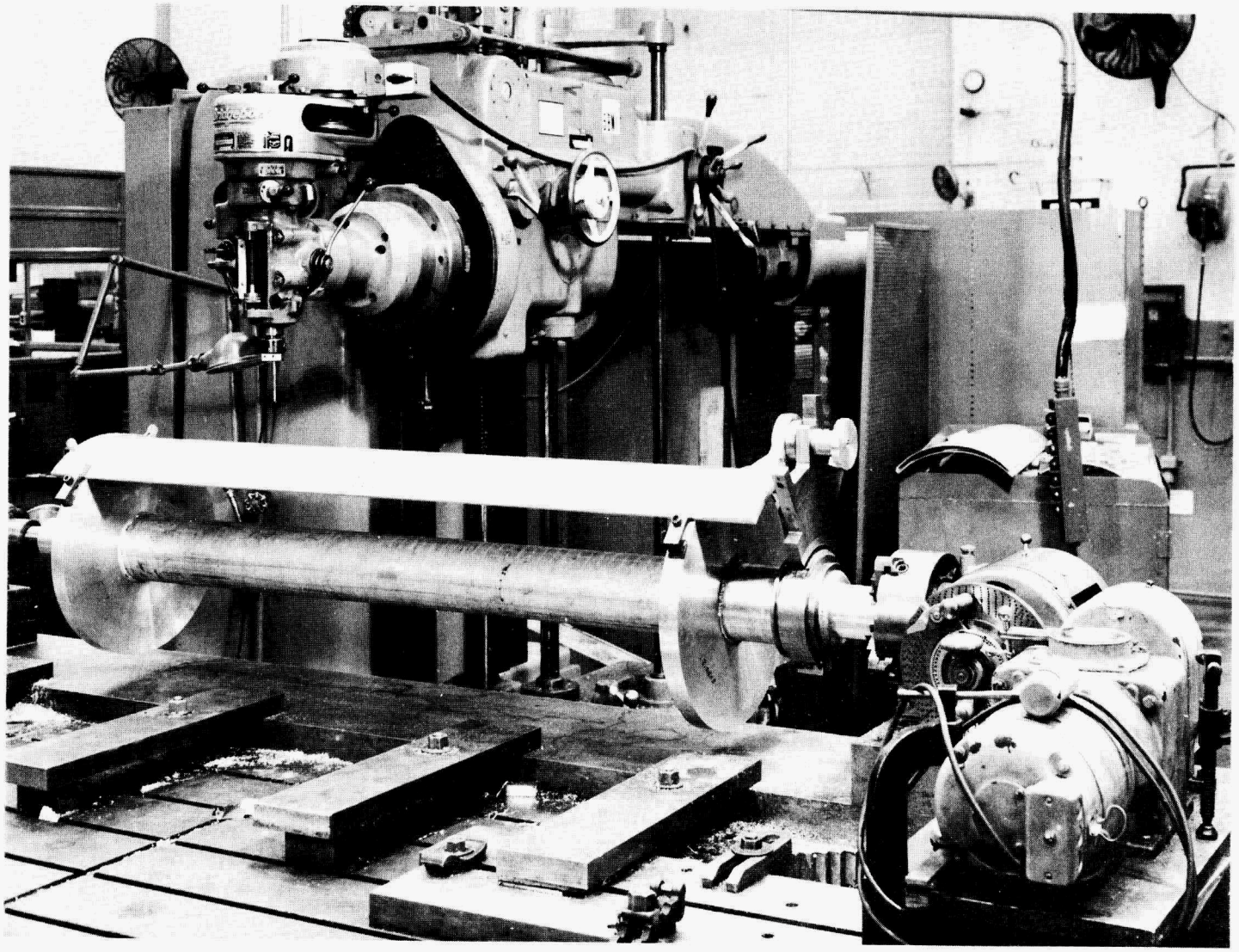


Fig. 45. Outer control plate assembly setup for final machining.

is identified near each end. The arbitrary locations selected are between the second and third transverse rows of holes in from each end at a point on the longitudinal centerline and at points located between the first and second longitudinal rows of holes in from each edge. A typical inspection result from plate HC-65-0 is shown in Fig. 46.

The bearing and washer are installed onto the shaft and the shaft pressed into the bored hole in the lug. Finally the lug and shaft are drilled, reamed, and locked together with a 1/8-in. diam pin which is secured by flaring.

The control plate is manufactured with maximum quality control. The fitup of the control plate in the reactor is critical and must be, as near as possible, identical from plate to plate. More important, the nuclear life of the control plate is longer than the life of the bearing; so the installation of end fittings and lug machining must be controlled such that these bearings can be remotely replaced when necessary.

Outer Plate Assembly Final Inspection

The finished control plate assembly is inspected for dimensions, cleanliness, abrasions, and scratches. It is checked very critically for anything which may be detrimental to reactor operation. The final acceptance is determined by the control plate fitup in the female clearance gauge ORNL Dwg. E-50098. This is a go-no-go device which establishes whether the control plate will have the proper fitup in the reactor. All dimensions and observations are recorded and retained as a permanent record of the quality of the control plate assembly.

Final Cleaning Outer Plate Assembly

The final cleaning of the finished and assembled control plate is accomplished using the following procedure:

1. Thoroughly scrub all surfaces with hot water using bristle or nylon brushes.

2. Scrub all surfaces including holes thoroughly with Alconox* detergent solution, one tablespoon per gallon of hot water (approximately 160°F). Care must be taken to thoroughly clean all holes using a nylon test-tube brush.

3. Scrub all surfaces with hot water and rinse thoroughly to remove all detergent.

4. Air dry the assembly. Caution: Do not use compressed air.

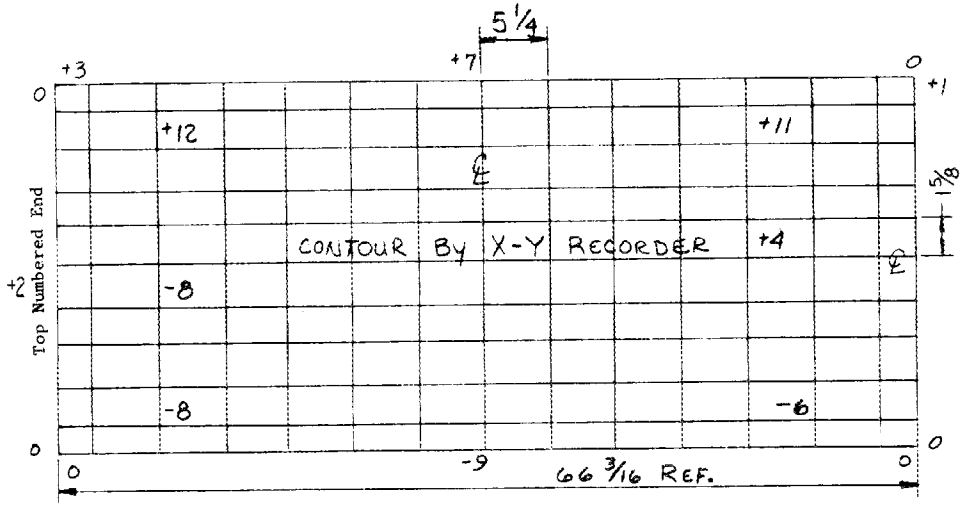
5. Seal parts in a clean plastic bag and place in shipping container.

*Alconox Master Cleaner is a product of Aloe Scientific Division of Brunswick, St. Louis, Missouri 63103.

SWEEP INSPECTION AND R-Ø DATA FOR REACTOR-GRADE OUTER SEGMENTS
(After Machining)

End Fitting Inspection Data*			
R-Ø Radius	Wall Thickness	Sweep Variation	Ø Degrees
		+14	40°
		+9	32°
		+5	24°
		0	18°
		-3	12°
		-6	6°
		-10	0°
		-11	6°
		-11	12°
		-10	18°
		-11	24°
		-12	32°
		-15	40°

Distance in from end 7/8



End Fitting Inspection Data*		
Ø Degrees	Sweep Variation	Wall Thickness	R-Ø Radius
40°	+20		
32°	+19		
24°	+17		
18°	+14		
12°	+10		
6°	+7		
0°	+3		
6°	+3		
12°	+3		
18°	+4		
24°	+2		
32°	-1		
40°	-5		

Distance in from end 1 7/8

*Make measurements 1/2, 1, and 1 1/2 in. in from each end.

Plate No.: HC-65-0

Inspector: Ethridge

Setup Radius: 9.300 R

Date: 7/16/65

Inspection No.: END FITTING

Use 9.050 in. Sweep Radius

Record Adjustments Made to Arrive at "Best Center Line" Below:

Vertical Movement of ℄: _____

Horizontal Movement of ℄: _____

Movement of South Part Support Fixture: _____

Movement of North Part Support Fixture: _____

Fig. 46. Sweep inspection and R-Ø data for reactor grade outer segments.

LAYOUT OF INNER CONTROL CYLINDER PLATES PRIOR TO MACHINING

The inner control cylinder is composed of four composite alclad plates similar to the outer control plates containing black and gray core regions of idential length but with overall dimensions that are slightly different. The processing of these control plates to the point where they are machined to the specified arc length is essentially the same as the methods used for the outer control plates except for some slight modifications. The reference holes in the layout pattern used are shifted slightly as shown in Fig. 47, representing the detail reported after radiographic inspection of the control plate dimensions during layout, and it should be noted that, except for dimensional differences, it is the same as the layout detail reported on the outer control plates. When trimming the control plates prior to explosively sizing, they are machined to an arc length of 16 in. instead of the machined arc length of 13 9/16 in. for the outer control plates. In this operation, an equal width of aluminum edge is left on each side of the core section.

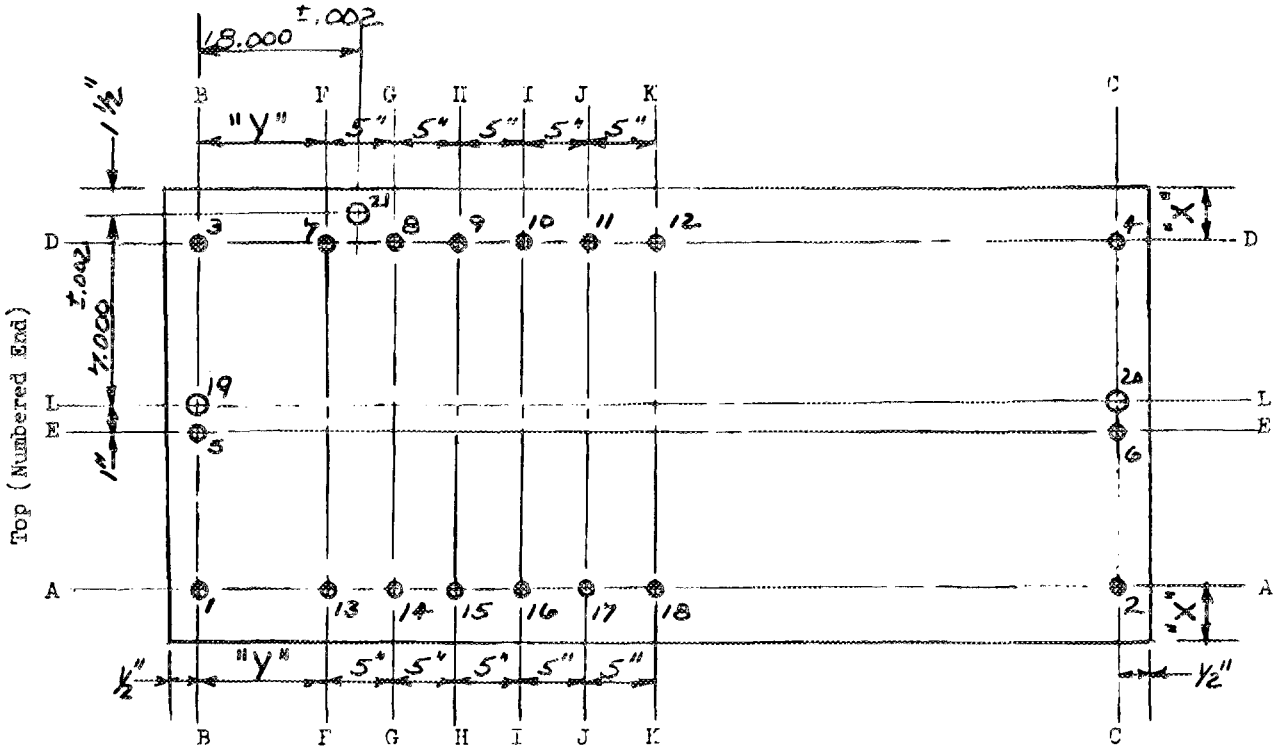
Dwg. E-M-56370 defines the slot and spacing of the hole when sizing the outer segment plate and Dwg. E-T-53690 shows the 0.375-in.-thick shim and other differences in the sizing operation.

As with the outer control plate, the inner control plates are radiographed and the dimensional detail reported. The centerline of the control plate (℄ - 2) after explosively sizing is also identified, but it is worth noting that for both the outer and inner plates, a tolerance of ±0.050 in. from the centerline of the core section (℄ - 1) is acceptable. Dwg. E-M-56371 details the procedure for identifying ℄ - 2 for the inner control plate.

Machining Inner Control Plates to Final Arc Length

The inner control plate is assembled on the same mandrel used for outer control plates; however, mandrel tooling is changed to be compatable with the requirements of the inner control plate outer radius of 8.928 in. The control plate is laid on the mandrel and firmly clamped without disturbing the natural contour imparted to the plate by the explosive sizing operation. As described previously for the outer control plate, two different techniques are used to determine the centerline of the formed plate, and two values (one designated ℄ - 2 and the other identified and ℄ - 3) are reported as deviations from the centerline of the core section (℄ - 1) as outlined in Y-12 Dwg. E-M-56371. Both must be within ±0.050 in. of ℄ - 1 and, if not, the effect of greater deviations on the width dimension of the aluminum edging of the plate must be evaluated.

Figure 48, Y-12 Photo 115491, shows a control plate mounted on a mandrel as set up on the bed of a horizontal planer. Only one control plate is placed on this mandrel and the heavy bars on the lower side are counterweights to balance the weight of the control plate. The clamps firmly hold the control plate to the mandrel so that complete contact is assured. The center clamp is tightened first and the edge clamped last. A force of 25- to 30-in.-lb is applied in torquing the hold-down bolts.



NOTES:

1. Calculate Dimension "X": Outer, "X" = $\frac{W - 17.5"}{2}$; Inner, "X" = $\frac{W - 15"}{2}$

   where "W" is the average width of the control plate.
2. Dimension "Y" = 12" for the Outer control plates.
3. Dimension "Y" = 17.5" for the Inner control plates.
4. Holes 1-18 are 1/16" in diameter and must go through the 1/4" plate. Holes 19-21 are drilled and reamed for a 0.250" dowel and must go through both the 1/4" plate and the backup plate.
5. Lines AA, DD, and LL are parallel to each other. Lines BB and CC are parallel to each other and perpendicular to lines AA, DD, and LL.
6. Locate and drill holes 1 and 2.
7. Locate and drill holes 13 through 18.
8. Locate and drill holes 3 and 4.
9. Locate and drill holes 7 through 12.
10. Locate and drill holes 5 and 6.
11. Locate and drill holes 19 and 20.
12. Locate and drill hole 21.
13. Scribe the hole number next to each hole
14. Measurements between holes 1 and 2, 3 and 4, 2 and 4, and 1 and 3 should be taken to the nearest 0.001" and recorded for each part on the inspection form before the plate is removed from the setup.

Fig. 47. Layout hole pattern for HFIR inner or outer control plates.

Y-115491

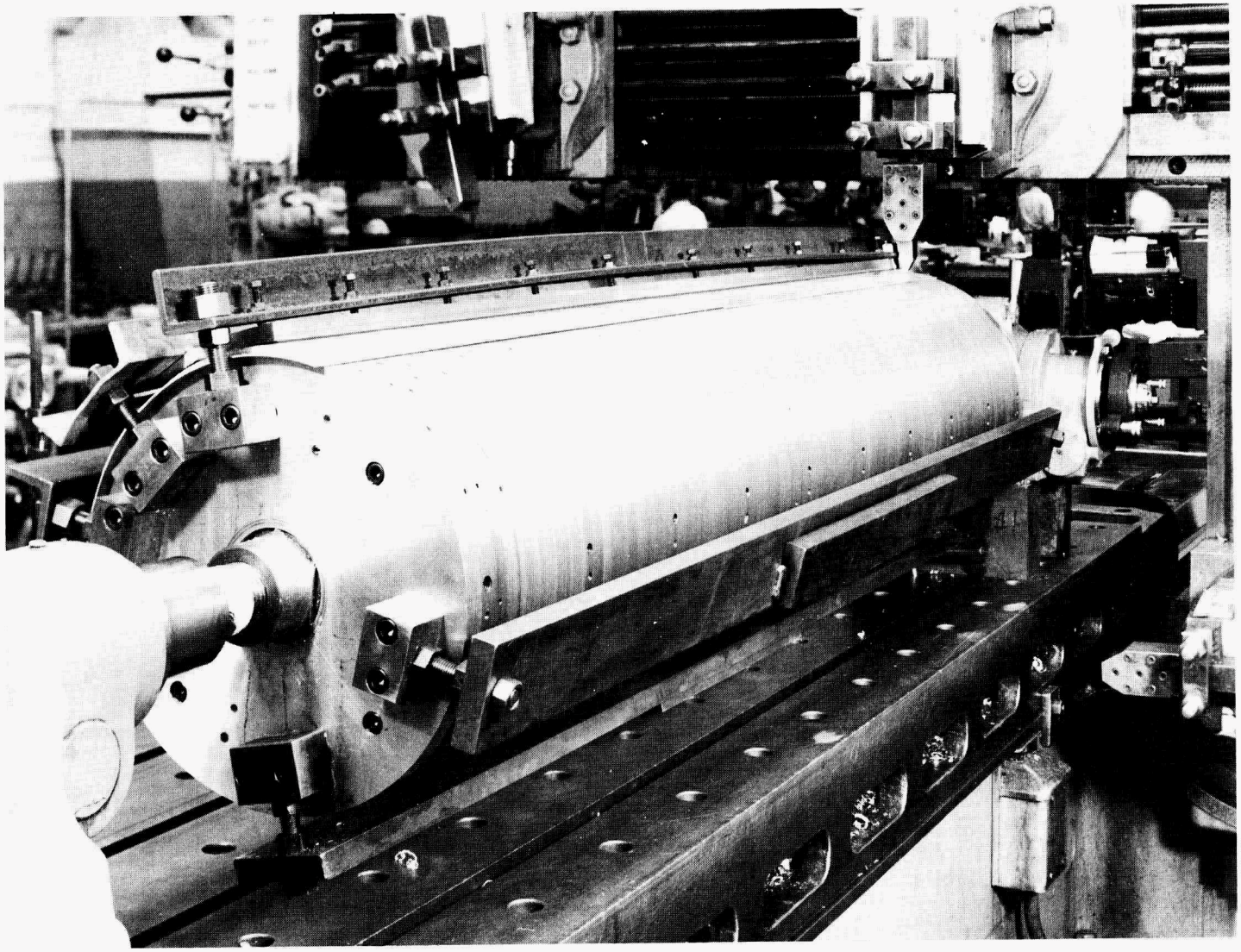


Fig. 48. Inner control plate setup for edge machining.

After identifying ℄ - 3, the arc length to which the control plate is machined is measured and the control plate is machined to the specified arc length (generally 14.04 in.) using the same techniques as those described previously for the outer control plates. Dwg. E-M-56370 details the procedures used.

The final machining operation consists of cutting a bevel along each edge of the control plate. The detail of this beveling operation is shown in Fig. 49, Y-12 Photo 137460, and when two control plates are butted together, the bevels form the joint design for welding.

The final two operations consists of scribing. One set of scribe marks is located at the end of each control plate for inspecting alignment of two control plates when they are butted together for welding. The other set along the edges serves as a monitor of the weld shrinkage. Figure 48, Y-12 Photo 115491, illustrates the setup used and shows the scribing of the circumferential alignment markings at the end of a control plate. The distance between this mark and the black-gray interface for each control plate is 36 1/2 in. to ensure that the black-gray interface for each control plate is at the same horizontal plane of the welded inner control cylinder. The detail for locating this scribe mark is listed in Dwgs. E-M-56370 and E-M-56371.

Figure 50, Y-12 Photo 115486, shows the setup for scribing the weld shrinkage monitors on the control plate. The vernier height gauge is used to locate the position of the scribe line 0.500 in. inside and parallel to the land of the beveled edge. The markings are not made along the edges of the region containing the europium oxide even though the depth of the scribe mark is less than 0.002 in.

Dimensional Inspection of Machined Inner Control Plate

The size of the inner control plates prior to welding is critical. The arc length of three of the control plates is 14.041 in., and the outside diameter of the welded control cylinder is 17.846 ± 0.010 in. The arc length of the fourth segment is determined from the evaluation of the shrinkage caused by welding and expansion due to planishing when welding the first two segments together to form a half-cylinder. The arc length values before and after the welding and planishing operations are obtained from gauge block-type measurements. Special gauge discs each with a radius of 8.673 in. were designed to measure the arc length of each segment after machining and each half-cylinder after welding two segments together. As illustrated in Fig 51, Y-12 Photo 116422, a disc is mounted and clamped to each end of the half-cylinder with 75 to 150 in.-lb of torque to assure zero clearance between the disc and the plate. The measuring equipment, a vernier height gauge with a dial indicator capable of measurements to within ±0.001 in. and a Cadillac height gauge, is shown in the foreground. A closeup of the gauge disc clamped to the half-cylinder is shown in Fig. 52, Y-12 Photo 116421. The lands of the three slots represent surfaces from which the arc length can be gauged. The arc length from the stop plate in the slot shown on the right to the land of

Y-137460

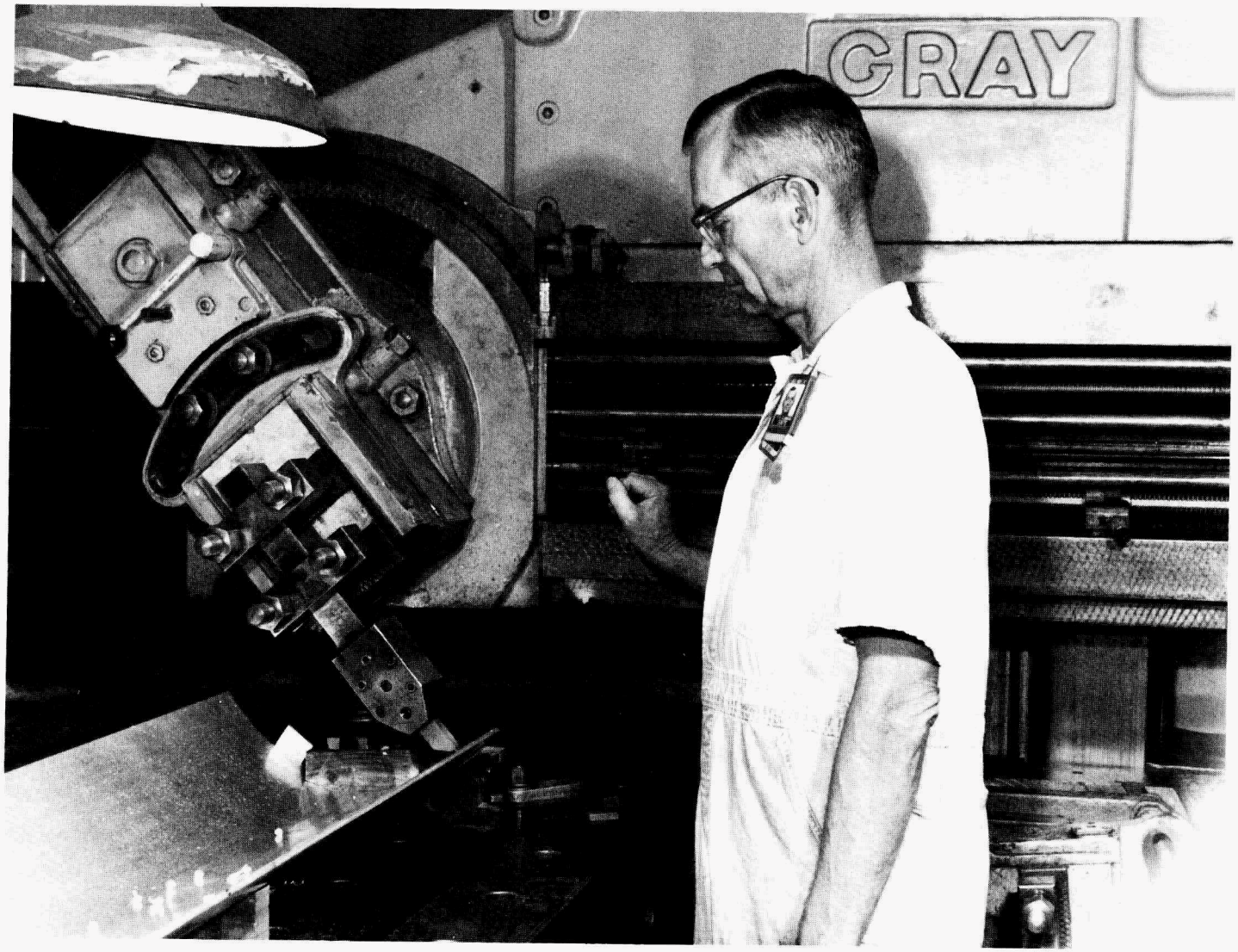


Fig. 49. Beveling for weld preparation on an inner control plate.

Y-115486

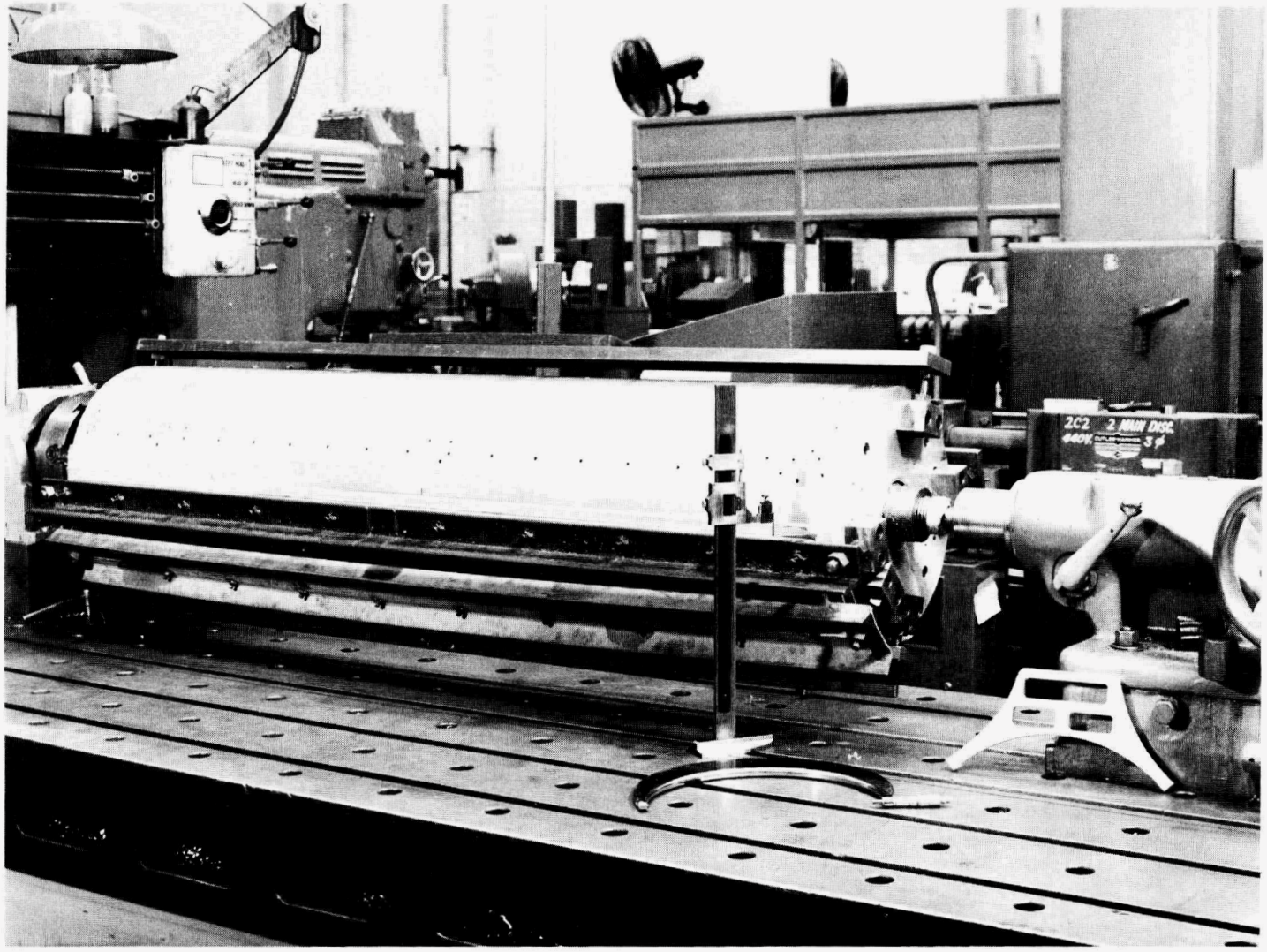


Fig. 50. Scribing weld shrinkage monitors on the inner control plate.

Y-116422

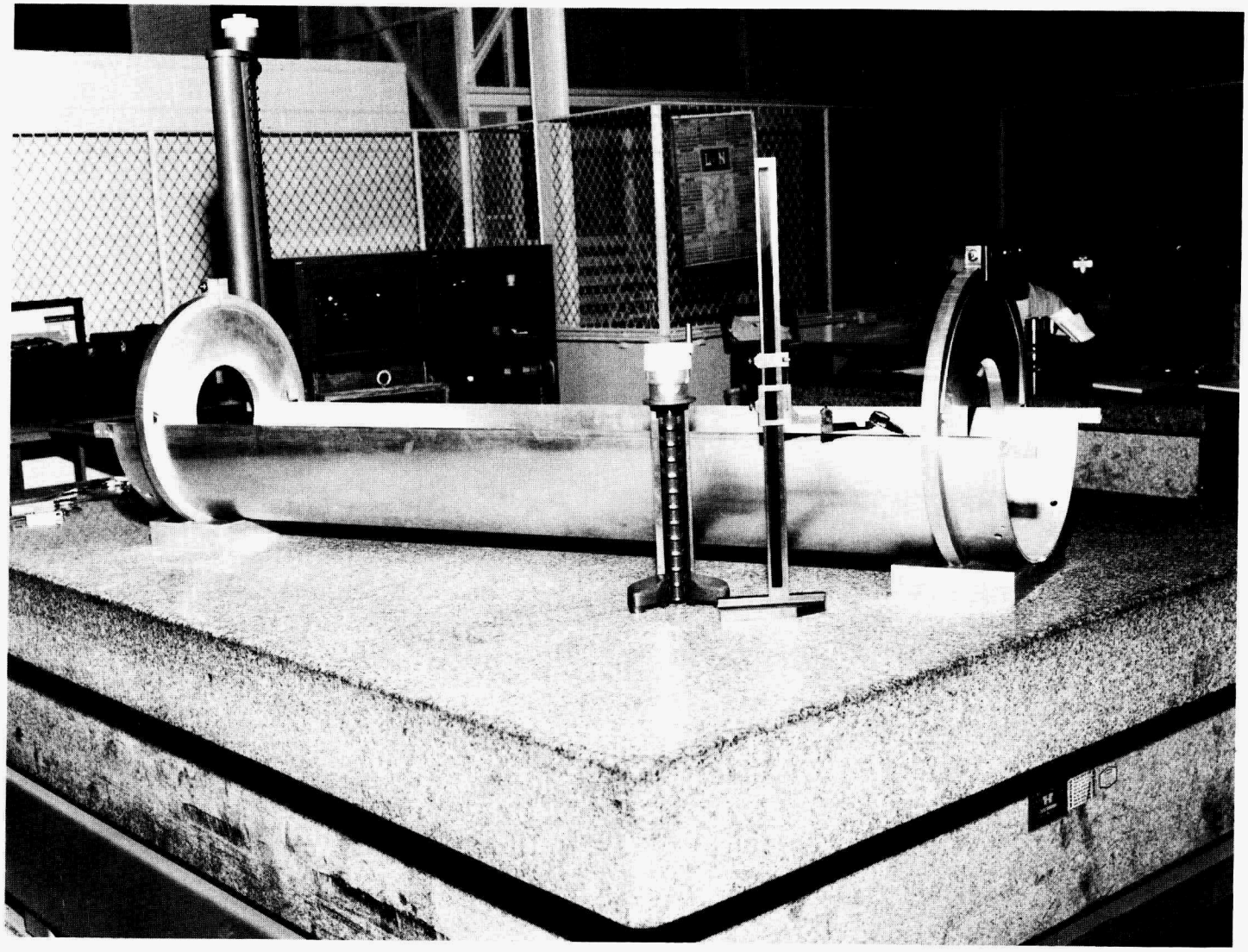


Fig. 51. Measuring the arc length of two inner control plates after welding.

Y-116421

Fig. 52. Inspection fixture for measuring arc lengths of inner control plates.

the slot at the bottom is 14.041 in., and to the land of the slot at the left the arc length is 28.057 in. A dial indicator between the weld land of the plate segment and the land of the slot, or, in the case shown in the illustration, a half-cylinder and the land of the slot, measures the difference between the arc length of the gauge and the control plate. The arc length of the control plate segment or of the half-cylinder is calculated from this value. In order to match the control plate part and the 1/4-in. shim plate to the gauge, the assembly is clamped with the weld land against the stop plate. A torque of 75 to 150 in.-lb is applied to assure zero clearance between the part and the gauge. The arc length is based on at least four gauge measurements, one at each end and one 22 in. from each end. If any individual value obtained is not within ± 0.006 in. of the average, additional measurements must be made.

WELDING OF INNER CONTROL CYLINDER

The process selected for welding the control plates together to form the inner control cylinder uses programmed, tungsten arc, inert gas, straight polarity welding in combination with automatic wire feed. The overall plan requires that two control plates first be welded together to form a half-cylinder. Based on inspection data obtained on the half-cylinder, the arc length of the fourth control plate segment is selected and the plate machined. The third and fourth control plate segments are welded together to form the second half-cylinder. The two half-cylinders are then welded together to form the inner control cylinder. Prior to making the fourth and last weld, the circumference of the incomplete cylinder is measured to determine whether the cylinder will be the correct size after welding and planishing the final joint. If correction is necessary, the weld prep groove can be remachined to obtain a smaller diameter, or the weld groove can be opened to provide a larger diameter.

An overall view of the equipment is shown in Fig. 53, Y-12 Photo 115672. Shown in the illustration is a Pandjiris external seamer with a Linde side-beam carriage and wire feeder and a Heliweld automatic head control panel, model HMC-F. The heliarc torch is a Linde HW-13 equipped with a No. 10 metal cup. A Miller SR-600 power supply is used. The figure shows two plate segments after welding and the fixture used to hold the plate in position while being welded. The fixture for this half-cylinder consists of two rails attached to a series of supports. Bands at these supports hold the fixture to the mandrel and prevent the plate from springing away from its fixed position during welding. Fig. 54, Y-12 Photo 115673, is a more detailed view of this fixture and clamping arrangement. The edges which form the weld groove are held in position by 50-psig air on the hold-down clamps of the Pandjiris welder. The surfaces of the control plates are covered with paper to within about 1 in. of the weld joint to protect them from surface damage.

Figure 56, Y-12 Photo 115759, shows the welder inspecting the setup prior to welding and is a good view of the arrangement in the area of the weld joint. The two control plates are clamped to form the weld groove by the copper chill clamps and is backed by a copper chill bar. All copper components are nickel-plated to prevent contamination of the control plates. The copper chill bar has an 8.650-in. radius. Figure 55, Y-12 Photo 115761, shows the cylinder clamped in place in preparation for the fourth weld. Note that the cylinder is clamped tightly to the mandrel for this weld as well as the third weld.

Pertinent details of the preparations for welding, the welding process, and the post-weld operations are listed below.

1. Run-off and starter tabs 2-in. long by 3/4-in. wide and with the same bevel and land as the control cylinder segment joint.

2. All handling of the segments during the setup must be done while wearing clean white gloves.

Y-115672

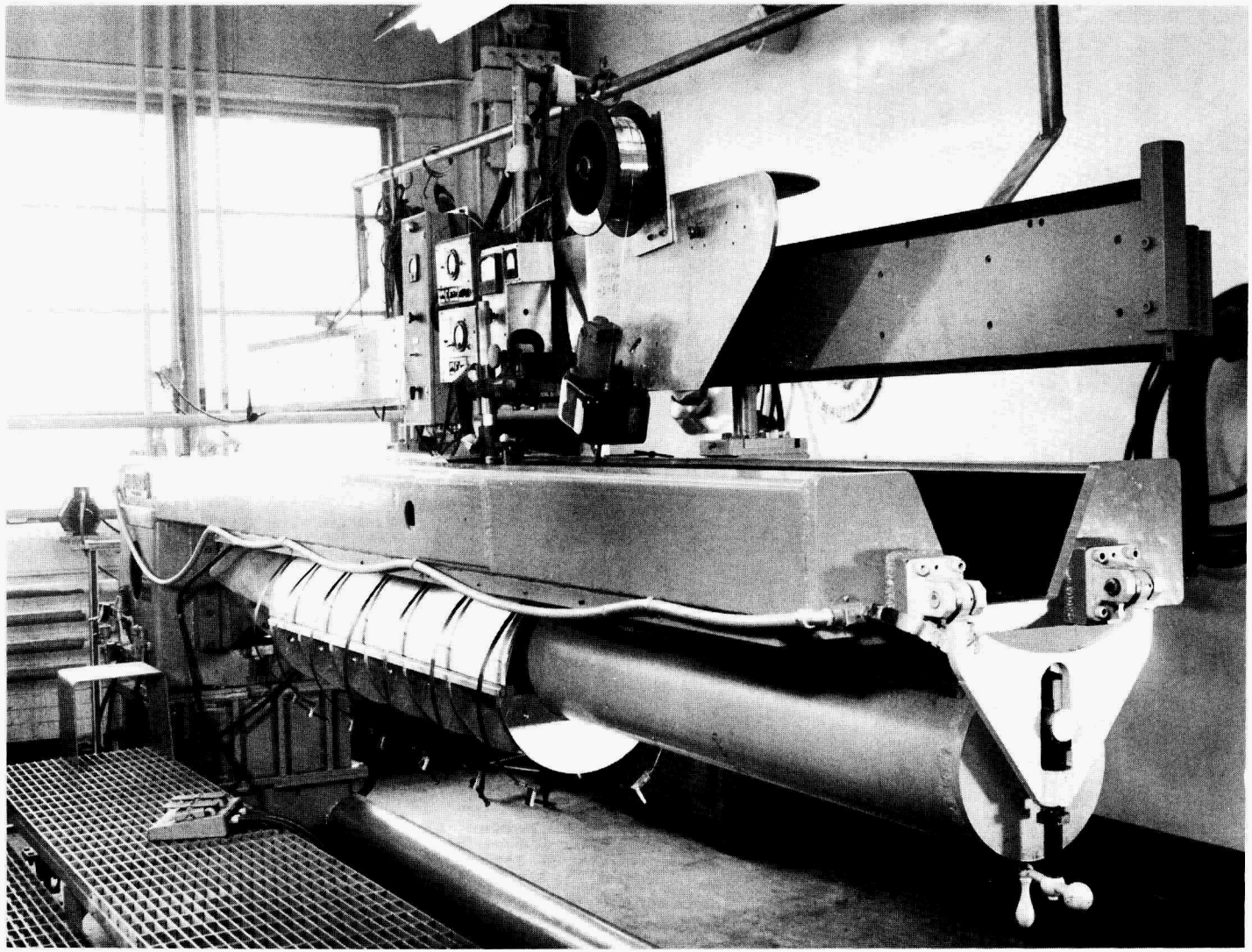


Fig. 53. Two inner control plates set up for seam welding.

Y-115673

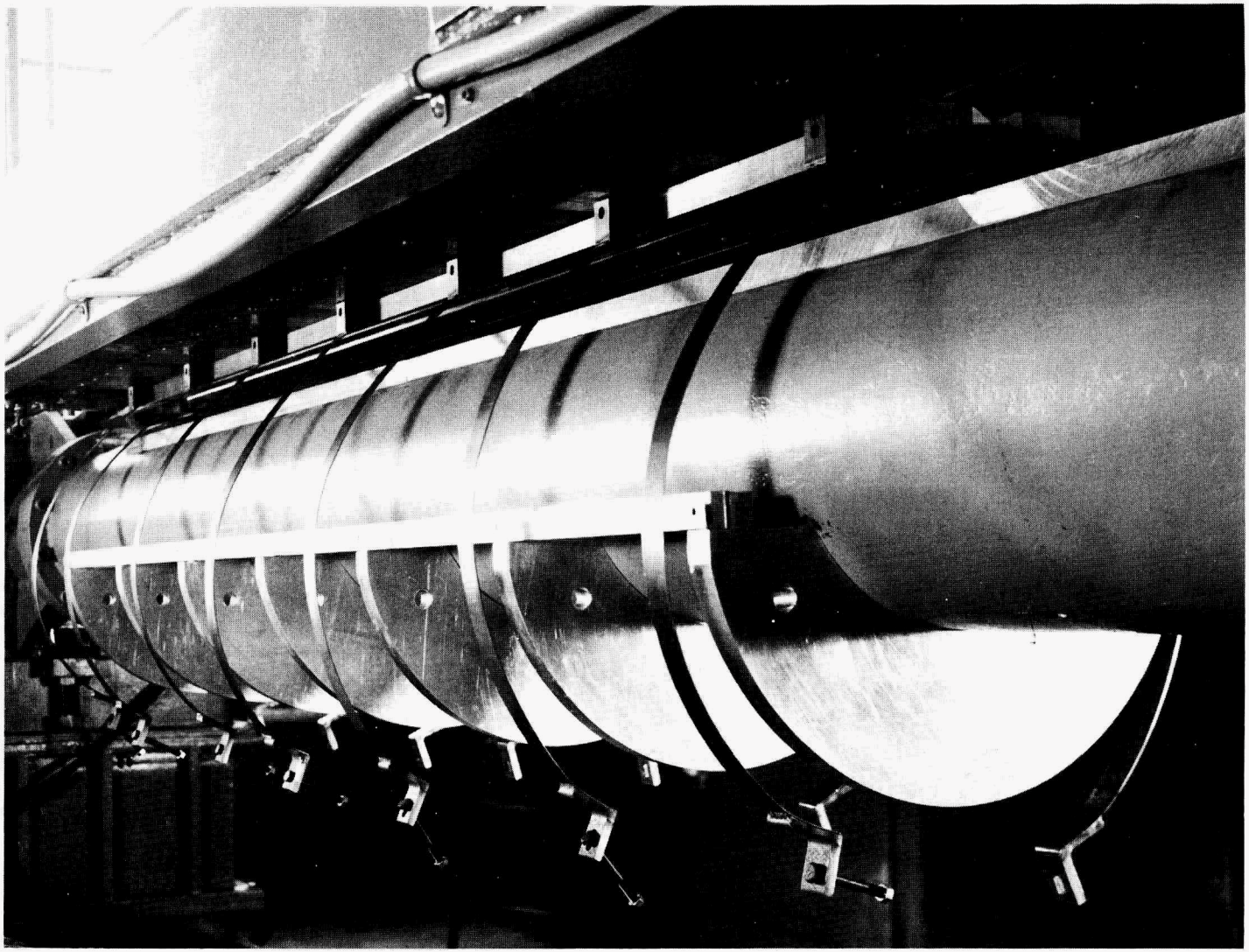


Fig. 54. Welding fixture for seam welding inner control plates.

Y-115761

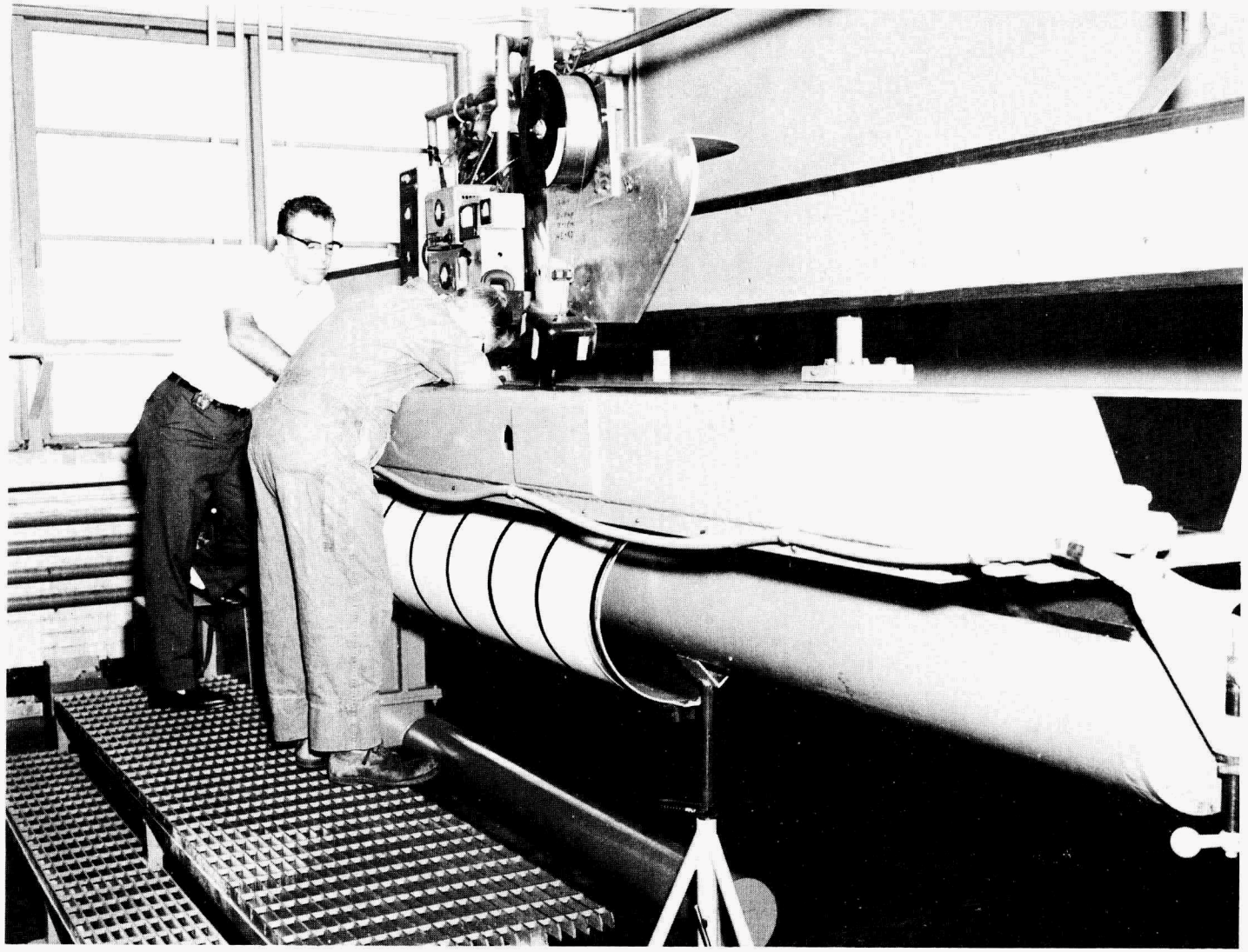


Fig. 55. Seam welding inner control plates.

Y-115759

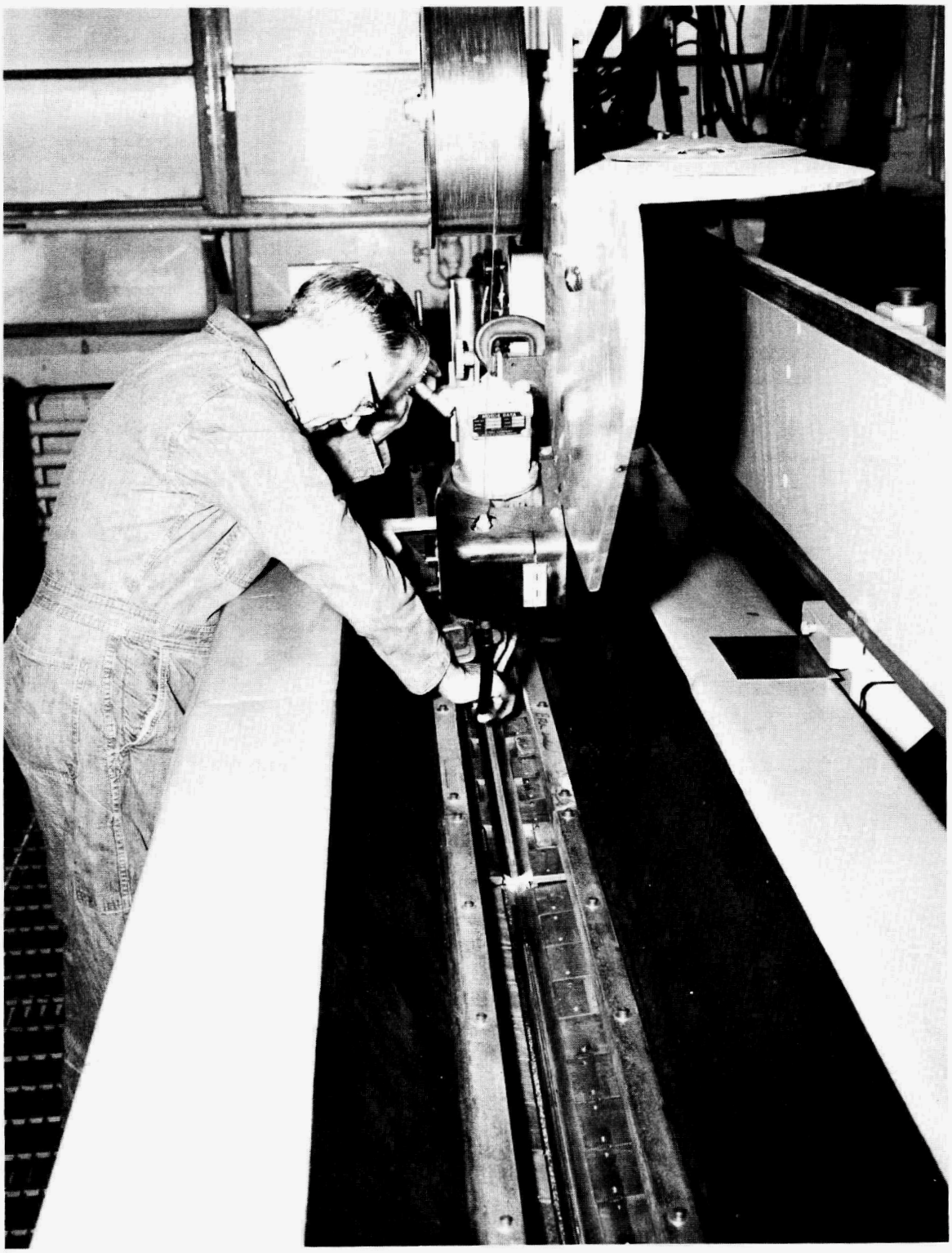


Fig. 56. Aligning inner control plates for seam welding.

3. The bevel, the land, and the areas adjacent to the bevel and land on both the inner and outer surfaces are wire brushed to remove the oxide coating. After brushing, they are cleaned with isopropyl alcohol.

4. The first segment is positioned in the Pandjiris so that the edge of the weld land is in the middle of the chill bar groove. The chill bar groove is 1/8-in. wide by 1/32-in deep full length (Y-12 Dwg. C-T-28283). A pressure of 15 psig is then applied to the top clamps to hold this segment in position as shown on Y-12 Dwg. E-T-55995.

5. The second segment is butted to the first segment and the weld-positioning scribe marks at the top ends of the segment are aligned. Pressure is then applied to the clamps over the second segment.

6. The gap is checked between the weld lands and, if excessive, the plates are readjusted to minimize the gap. Maximum gap width is 0.010 in. at the weld start. Beyond the weld start, 0.020 in. is permitted. If the joint does not match properly, it is scraped to fit.

7. The fixtures used to hold the parts during welding are adjusted to just lightly hold the parts. The clamp hold-down pressure is then increased to 50 psig and the gap between the weld bevel lands is checked. The distance between the hold-down clamp and the weld groove edge is approximately 3/8 in. and parallel with the groove.

8. The holding fixture bands are then tightened to lightly hold the segments without scratching (see Y-12 Dwg. E-T-55995).

9. The 2-in. by 3/4-in. weld start and run-off tabs are now welded to the segments. This will reduce the weld gap slightly.

10. The welding head is traversed the length of the weld groove to determine lateral adjustment required during the welding operation.

11. A final check is made to make sure all segments have their number at the same end and that the weld scribe marks are aligned.

12. An automatic gas tungsten arc, straight-polarity process is used.

13. Welding grade helium is used to shield the weld area. A backing gas is not used.

14. The torch is placed in a 5° forehand position.

15. The 5/32-in. electrode is 2% thoriated tungsten and is ground to a 60° included angle with a 1/32-in.-diam flat end. This electrode extends 5/8 in. below the end of the cup.

16. The feed wire is type 4043 aluminum 1/16 in. in diam.

17. The arc is struck on the run-off tab and then the equipment set for automatic welding. The electrode to work distance is controlled by the heliweld automatic head control to assure the voltage and amperage shown in Table 4.

18. After the first pass, the weld is wire brushed to remove oxide.

19. If the welding process goes out of control and the operation cannot be corrected, the welding is stopped. After proper repair or adjustment, the weld is continued.

20. A second weld pass is made by again running off the run-off tab onto the weld groove.

21. Any visible surface defects may be repaired using the W-603 TIG process which is hand welding using 3/32-in.-diam type 4043 filler wire.

22. Heavy asbestos paper is inserted between the mandrel and the control cylinder and between the hold-down clamp and the control cylinder before the control cylinder is removed from the Pandjiris.

Table 4. Welding parameters for welding HFIR inner control cylinders

Pass	Amperage (meter)	Voltage (meter)	Speed		Shield gas on torch (cfh)
			Carriage ipm	Wire ipm	
1	325±15	13±1	6	19	85
2*	310±15	15±1	6	36	85

*The automatically controlled wire feed is adjusted on this pass if deemed necessary.

INSPECTION OF INNER CONTROL CYLINDER WELDS

After each weld is completed, it is inspected visually and radiographed. The specification requires that the welded joint be sound except for scattered porosity. Acceptable porosity is defined by comparison of a standard film approved by the Operations Division.

The radiographic film is 16 in. by 4 in. Sixteen of these strips are overlapped and properly identified with lead numbers on the part prior to radiographing. The radiographs are used to identify the width of the aluminum separating the neutron absorber sections of the respective control plates and also to check the alignment of the gray-black interfaces. The width of the aluminum separation between plate cores is 3/4 $\pm$ 1/32 in., the gray-black interfaces must be aligned 1/4 in. of each other as shown on ORNL Dwg. E-49824.

Scraping and Planishing Inner Control Cylinder Welds

After each weld had been inspected and accepted, it is scraped and planished as shown in Fig. 57, Y-12 Photo 113338. The weld bead which protrudes above the plate surface must be scraped, planished, and rescraped to as nearly as possible match the plate surface to assure proper cylinder diameter prior to final explosive sizing. The cylinder is placed on the planishing fixture. All surfaces of the fixture which could scratch the cylinder are covered with asbestos paper to protect against scratches. The scraping tool and fixturing illustrated in Figs. 57 and 58, Y-12 Photo 113338 and Y-12 Photo 113339, are designed to first scrape the crown of the weld to a flat without scoring the aluminum cladding. The flats serve as uniform tracks during subsequent planishing, preventing the planishing rolls from slipping and damaging the clad surface. As illustrated in Figs. 57 and 58, the scraping tool is designed and used like a wood planer. The scraper rides on a track which is aligned over the center of the weld, and the scrape blade is adjusted to cut a thin shaving as it is moved across the crown of the weld. The planisher was manufactured by Airline Welding and Engineering Company. The rolls are 5 1/2 in. in diameter and 2 7/8 in. wide, with a crown of 5/16 in. To provide satisfactory tracking and alignment, the mid-section of the upper roll was ground to a flat 7/8 in. wide at a constant pressure of 15 psig. The degree of circumferential spread decrease as the number of planishing passes increase. For example, after two passes, the average increase in circumferential growth is 0.009 in. The growth after two additional passes is reduced to 0.005 in. During the planishing operation, a pi-tape is used to monitor diameter changes; special locations are provided at each end of the cylinder for the pi-tape, to assure an accurate measurement.

After the weld surfaces are planished, the scraping operation is repeated. The weld area is finally smoothed using first coarse then fine grit alumina paper. During these operations, the weld area is monitored with a template at frequent intervals to determine when the final plate contour is obtained.

Y-113338

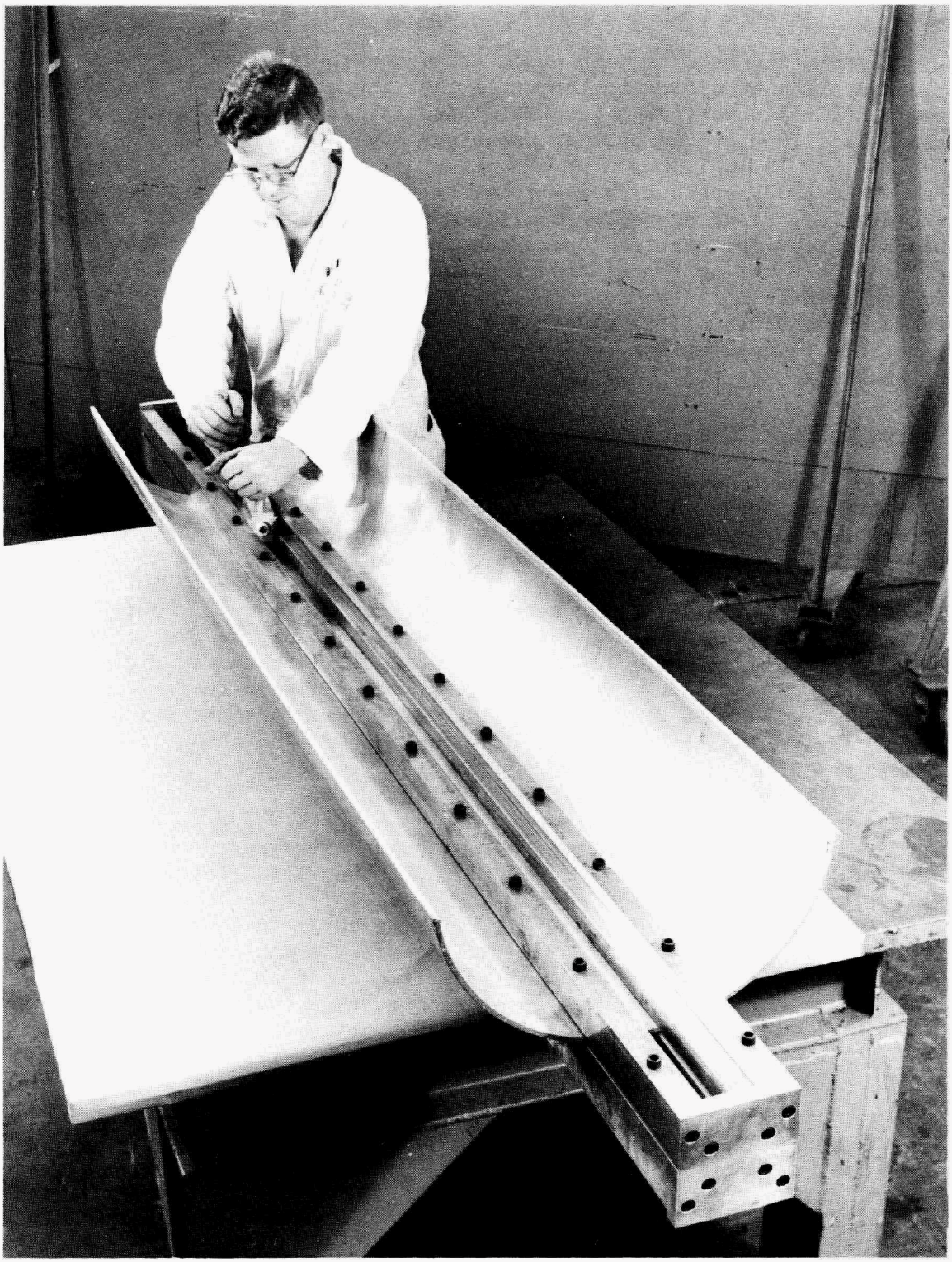


Fig. 57. Scraping the inner control plate weld seam.

Y-113339

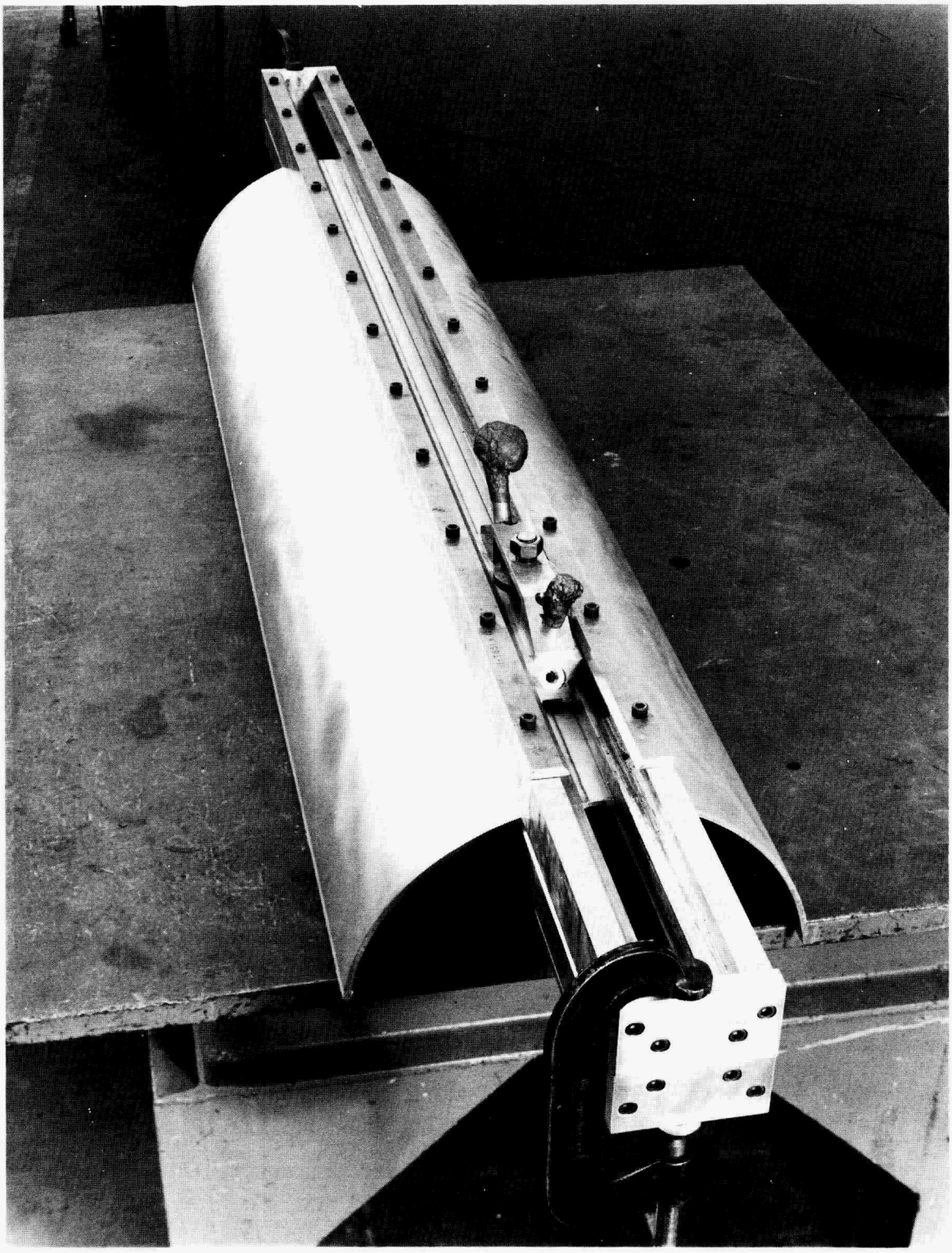


Fig. 58. Fixture and tool for scraping seam welds.

Facing Ends of Inner Control Cylinder

The individual control plates are aligned by the gray-black interfaces for welding. This method of alignment causes the welded cylinder ends to be uneven. This unevenness, if not removed, is enough to damage the rubber boot used to cover the cylinder during final explosive sizing.

The cylinder is mounted on an expandable mandrel shown on Dwg. E-T-53501. Mandrel and cylinder are mounted on a lathe and centered. Both ends of the cylinder are then faced, removing metal until the alignment hole and slot used during the previous forming are just removed. Care is exercised to assure that the markings at each end identifying ℄ - 3 are not removed. The individual control plate identification numbers are transferred 3/8 in. inside the finished length dimension at the top of the cylinder located near the centerline scribe marks.

After the facing operation, the average cylinder diameter is obtained from 12 individual pi-tape measurements to assure that the cylinder is the proper diameter for final explosive sizing.

Explosive Sizing of Inner Control Cylinder

The sizing of the welded cylinder to its final shape and size is done explosively. As was previously stated, the europium oxide-aluminum core is very brittle and to prevent it from cracking during forming, the forming is done with the cylinder in compression. The desired as-welded outside diameter of the cylinder is 17.846 in. and the nominal finished O.D. is 17.842 in. The sizing die is split longitudinally and has an inside diameter of 17.832 in. Engineering details of the die are shown on Dwgs. Y-12 E-T-46481 through E-T-46494. Figure 59, Y-12 Photo 116053, illustrates the two die halves (with the control cylinder in position) being squeezed together. The outside surfaces of the die are tapered and designed so that forces generated from tightening the tie bolts act to close the two die halves. When the die halves are closed, the control cylinder is compressed from a nominal 17.846 (17.856 maximum) in. to 17.832 in. diam. A rubber boot is inserted into the die sealing the control plate and bottom plate. The boot is flanged at the top and is sealed to the top of the die. The bottom of the die rests on a mounting plate sealing the bottom of the die. A rubber "O" ring is used to seal the die halves. In this manner, the interface between the die and the cylinder is sealed from the external environment. Ports in the die provide means for evacuating this interface. The explosive consists of a 96-in. length of 50-grains/ft prima cord centered in the die and is detonated with a No. 6 electric blasting cap. Prior to detonating the charge, the rubber boot is filled with water (Fig. 60, Y-12 Photo 116058).

When not in use, the die component surfaces are coated with rust-preventative and covered with a tarpaulin. The procedures used for preparing the die for the explosive sizing operation are as follows:

1. The die bottom seal is removed and replaced with a slider plate.

Y-116053

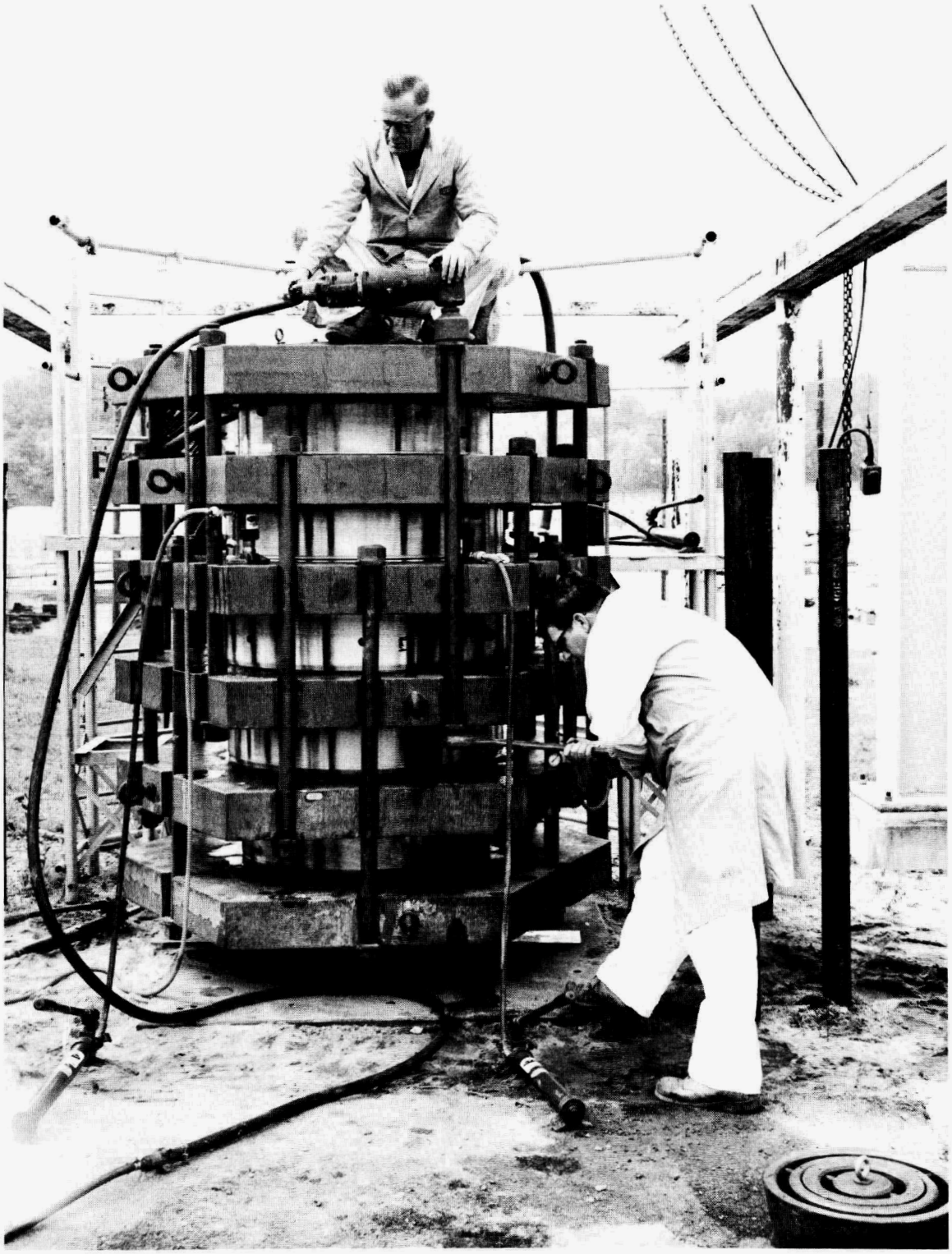


Fig. 59. Explosive sizing fixture for inner control cylinders.

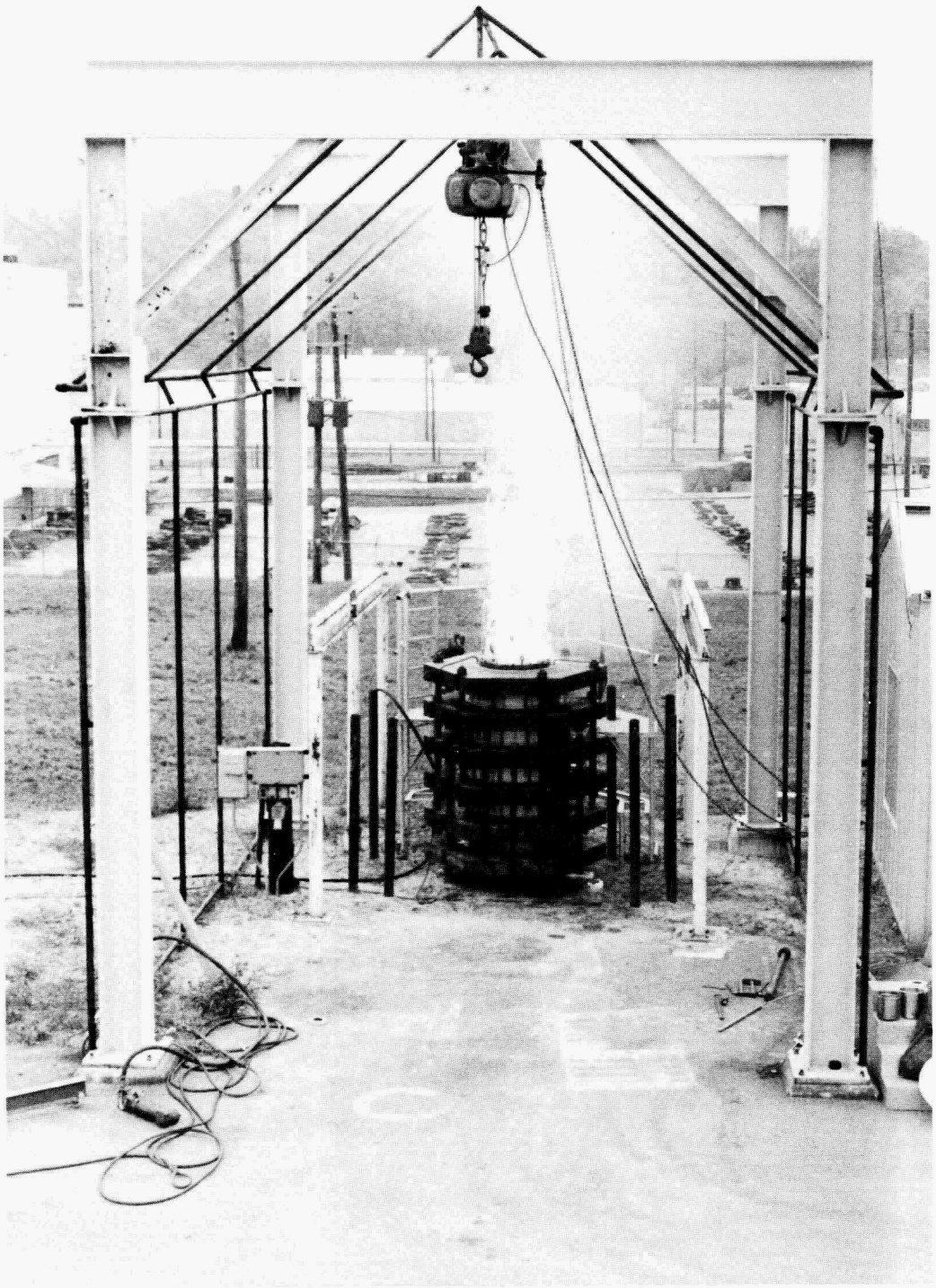


Fig. 60. Inner control sizing die at detonation.

2. The top flange and rubber boot are removed.

3. The die is partially disassembled by removing the three top rings and resting the three bottom rings on the base plate.

4. The inside surfaces of the die are cleaned using fine grit paper, if needed, to remove any rust and a solvent is used to remove the rust-preventative. The surfaces are forced-air dried and wiped with a clean cloth.

5. The die halves are separated by removing the tie bolts which hold the halves together and using the jack screws in the opposing halves of the die body to jack the halves apart. The halves slide on the slider plate at the base of the die. The separation between each half is about 1 in.

6. To prevent scoring of the control cylinder by the edges of the die during insertion into the split die, thin (0.010-in.) aluminum sheets about 2 in. wide by 15 in. long are bent and placed over the joint openings.

Immediately after the control cylinder is cleaned with isopropyl alcohol and wiped with a clean cloth, the lifting fixture illustrated in Fig. 61, Y-12 Photo 116054, is inserted. The lifting fixture has two pneumatic tubes which are expanded to grip the inside diameter of the cylinder; details of the lifting fixture are shown in Dwgs. E-T-47296 and E-T-47494. The control cylinder is fixtured with the numbered end up.

The control cylinder is inserted into the die using an overhead hoist. The cylinder is carefully lowered into the split die making certain that no scoring occurs by preventing the cylinder from swinging against the die. Although the out-of-roundness is slight, the cylinder is oriented so that the major axis is about 90° from the split region in the die. Care is also exercised to ascertain that no weld seam is close to the split region between the die halves.

After removing the aluminum protective strips, the die is closed using the procedure listed below.

1. The jack screws are retracted below the surface of the split halves.

2. The longitudinal "O" ring seals along the split half are inspected to make certain that they are seated in their grooves and that they protrude slightly above the surface at both the top and bottom of the die faces.

3. The cylinder is inspected to make certain that is rests in the 1/4-in. wide land at the bottom of the die and is not cocked.

Y-116054

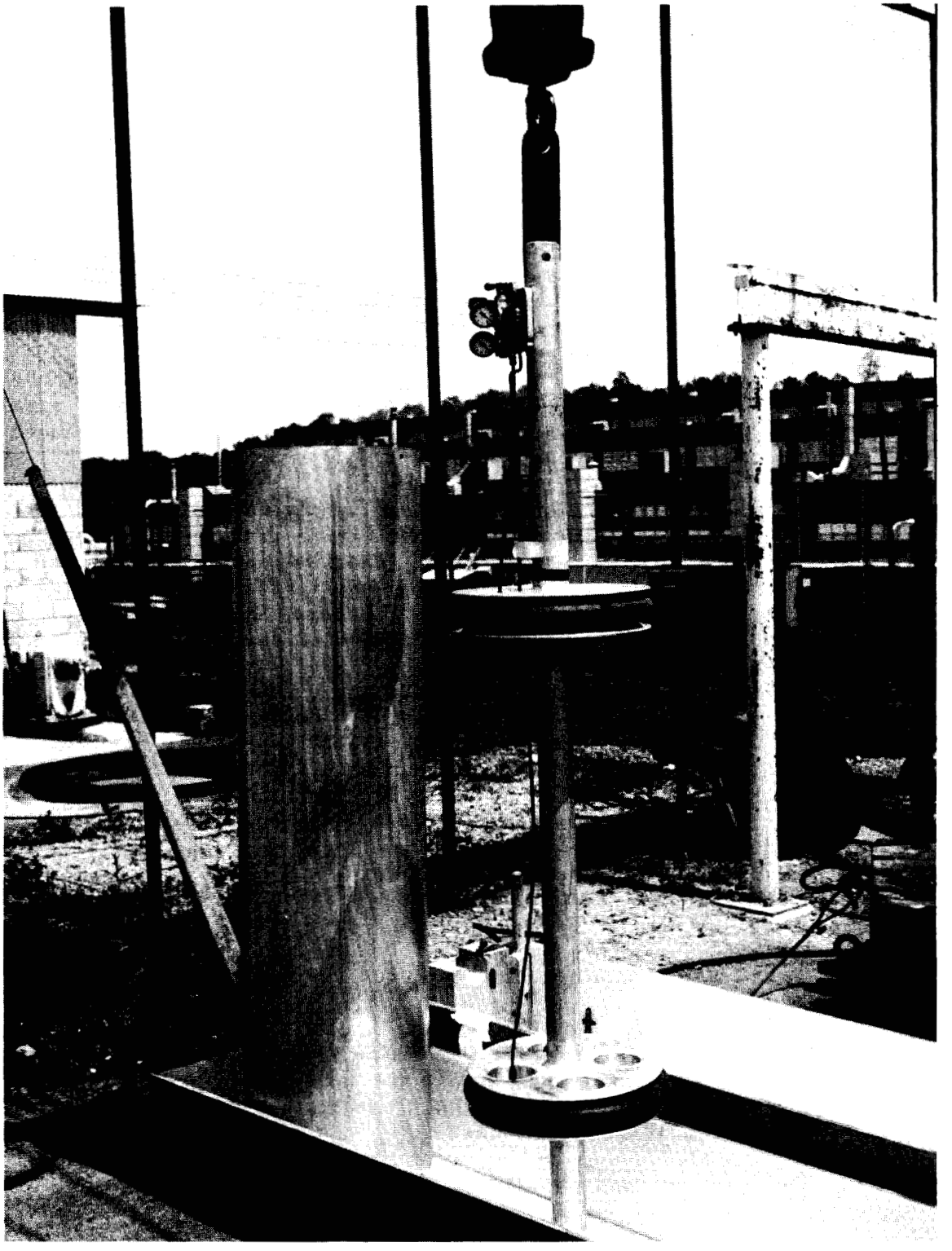


Fig. 61. Inner control cylinder with lifting fixture.

4. The die halves are slowly drawn together using the tie bolts along the sides. Dowels in the halves maintain alignment during separation and closing. A small gap between the mating surfaces of the halves exists after the tie bolts are snugged because the outside diameter of the cylinder is larger than the 17.832-in. inside diam of the die.

5. The outside tapered surfaces of the die are lightly lubricated with oil and the clamp rings installed individually. Prior to installation, the inner surface of each ring is cleaned and oiled. Alignment of the rings is maintained throughout by positioning the tie bolts and tightening the nuts by hand as the rings are installed. When all of the rings and tie bolts are installed, they are tightened uniformally. Gradually the diameter of the cylinder compresses and the die halves are closed with the assistance of a pneumatic impact wrench and four 10-ton hydraulic jacks. The die halves are closed metal to metal.

6. The die is jacked up a few inches and the slider plate is replaced with a 5-in.-thick steel plate for the explosive sizing.

7. Lead protectors are taped over the vacuum inlets at the top of the die to prevent the rubber boot from sealing the die cavity prematurely.

8. The rubber boot is cleaned and carefully lowered into the die. The top flange is installed to seal and hold the rubber boot.

9. The die cavity is evacuated with a mechanical pump. The assembly is considered acceptable if there is no indication of leakage on the gauge.

Two separate charges of 50-grains/ft prima cord are used to size the cylinder. Each charge is 96 in. long. The live charge is centered in a fixture designed so that it coincides with the longitudinal centerline of the cylinder. This fixture, illustrated in Fig. 62, Y-12 Photo 116056, is lowered to the bottom of the die where it fits into a tapered sleeve. The sequence of operations which is climaxed with the detonation of the prima cord and sizing of the cylinder are listed below.

1. The sleeve for centering the fixture to which the line charges are attached is lowered into the die cavity.

2. A 96 in. length of 50-grains/ft prima cord is attached to the charge fixture. This fixture is lowered into the die cavity and fitted into the previously positioned sleeve.

3. The explosive cord is pulled out around a wooden bar at the mouth of the die and coincident with the longitudinal centerline.

4. The die cavity is filled with water to within 2 in. of the top.

Y-116056

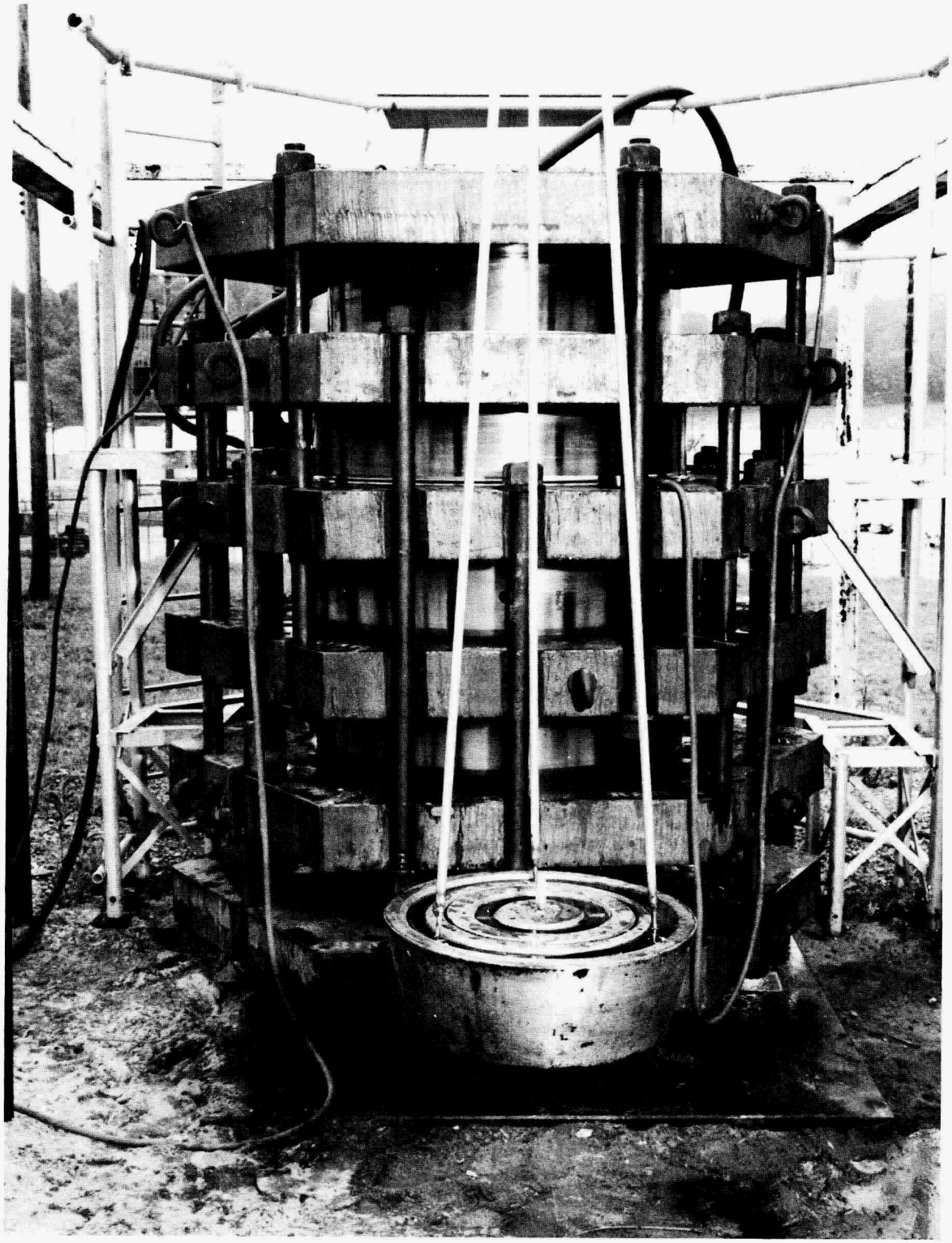


Fig. 62. Inner control cylinder sizing fixture with bottom plate.

5. The charge is armed with a number of electric blasting caps, and then detonated.

6. After pumping the water from the die cavity, the leak rate is examined to confirm that no leak results from the explosion. The rubber boot is also inspected for visible damage.

7. If no damage has occurred, the fixture is recharged and a second charge is set off, repeating procedure steps 2 through 6.

After the second charge, the water is again removed and another inspection for possible damage is made. The boot is removed and after dismantling the rings, the die halves are parted. The aluminum protective sheets are placed over the parted region to protect the surface of the cylinder during removal from the die. The same handling fixture used for the insertion is used during the withdrawal. After removal from the die, the cylinder is inspected, at the site, to determine whether it meets drawing requirements or whether a third sizing is required. If a third sizing operation is required, it is done at once; if not, the die and other components are wiped dry, inspected, sprayed with a rust inhibitor, and covered with a tarpaulin.

Radiographic Inspection of Explosively Sized Cylinders

The explosively sized cylinder is radiographed prior to subsequent machining operations to determine whether or not cracks developed in the welds or at the core-frame interface of the plates as a consequence of the sizing operation. The procedures are identical to those described previously.

Dimensional Inspection and Machining of Explosively Sized Cylinders

Prior to proceeding with the machining operations, the cylinder is inspected dimensionally. At this time, the cylinder contour must meet the dimensional specifications or be returned for resizing because subsequent machining operations would make it impossible to resize explosively. If the cylinder is acceptable dimensionally, the two ends are machined.

The inspection and end machining are accomplished in one setup. The control cylinder is mounted on an expandable mandrel so positioned that the mandrel shoes will be clear of all subsequent machining operations. The control cylinder and mandrel are mounted on a lathe on centers, and the mandrel shoes are adjusted to align the control cylinder on its best centerline. At this time, the mandrel shoes at the top end of the cylinder are adjusted to round out the cylinder as accurately as possible, since this end of the cylinder will ultimately be held round by the end fitting. The shoes at the opposite end are adjusted only tight enough to contact the cylinder without distorting it. A dial indicator is mounted on the lathe compound and set at zero for 8.921 in. from the control cylinder center; now by rotating the cylinder and traversing the lathe compound longitudinally with respect to the cylinder, the 8.921 $\pm$ 0.030 in.

radial requirement for the cylinder can be inspected. If the cylinder is rejected, it is sent back for reforming; if it is accepted, the opposite end mandrel shoes are tightened to true up that end of the cylinder for machining. The reference starting points for machining the cylinder to length are the scribe lines which locate the gray-black interface of the core. From this reference, the end nearest the core is finished and bored to receive the end fitting; then, using the finished end as a reference the opposite end is finished to yield a cylinder length of 68 3/8 in. and a 1/8 in. radius is machined on the edges on this end.

Drilling and Radiusing of Holes

In order to relieve hydraulic pressure during reactor operation, 2,180 holes 1/4 in. in diameter are drilled in the explosively sized cylinder. In addition, four 5/8-in.-diam holes are drilled for installation alignment. The only areas of the cylinder left unmachined are the europium-aluminum core area and the areas adjacent to the welds.

The control cylinder is not removed from the mandrel used in the previous machining operation. The cylinder and mandrel are removed from the lathe and mounted on a Giddings and Lewis tape-control milling machine with a live center at one end and an indexing head at the other. The indexing head locates the cylinder radially, and the tape control locates it longitudinally. Zero reference for setting up the cylinder is the scribe lines identifying the gray-black interfaces which were also used for welding and end-machining alignment. The critical row of holes radially is located 1 in. from the gray-black interface over the tantalum, or gray, section. The longitudinal location of this critical row of holes is located and the cylinder is moved longitudinally until the 1/4-in. drill is located over the first row of holes on the numbered, or top end, of the cylinder. Using the dividing head, the cylinder is rotated and zeroed at a scribe line at the center of one of the longitudinal welds then indexed 6°11' to the location of the first hole. The machine is now switched to automatic and the first longitudinal row of holes is drilled. Each subsequent row of holes is 6°11' radially from the previously drilled holes. The machine is reset radially to mark each segment. White and Bagley cutting oil No. 1 is used as a lubricant in the hole drilling operation to minimize galling (alcohol could be used). A fresh and separate supply system is provided for this oil and it is certified to be free of chlorides and chlorine.

The four 5/8-in.-diam holes are located 90° apart and machine indexing is referenced from the gray-black interface scribe lines and the weld center scribe lines.

All 1/4-in.-diam holes are radiused using the procedures previously described for the outer control plates.

Attachment of End Fittings and Final Machining

The end of the inner cylinder which is closest to the "black" section has heretofore been identified as the top since during manufacture this end has contained the plate identities and all position references. In the reactor, this end is the bottom and contains a stainless steel drive bracket which adapts the cylinder to the reactor. A view of this end fiting attached to a cylinder is shown in Fig. 64, Y-12 Photo 115294. The center support of the bracket has a sleeve which couples the inner cylinder through a shaft to the control drive rod mechanism. The location and orientation of this end fitting relative to the reactor grid and cylinder is critical since the guide bearings for the cylinder must ride along the weld seams and not over the cored area of the cylinder. Identifying marks on the end fitting and cylinder are matched at assembly to assure proper orientation. Details of the drive rod bracket are included in Dwg. E-42376 and the details of the assembled parts are given in Dwg. E-49822.

The drive rod bracket is assembled to the cylinder by shrink fitting the cylinder onto the bracket. The cored end of the cylinder is heated to 120°F with an acetylene torch while being protected with an asbestos blanket. The asbestos blanket is removed and the cylinder is slipped over the bracket with care being taken to make sure that the alignment scribes are lined up.

After the end fitting has been installed, the assembly is set up on a Giddings and Lewis horizontal boring mill. A top cap is put on the open end of the control cylinder and a long bolt is positioned to locate the top cap and extends through the center hole on the bracket, as shown in Fig. 64, Y-12 Photo 116325, providing a means to pull the bracket square and to bottom the bracket on the cylinder. The composite cylinder is set up on its best vertical centerline and the cylinder and bracket are drilled, counterbored, tapped, and fastened together with 1/4-20 NC flathead screws. The layout pattern for the screws is shown on its assembly drawing, Dwg. E-49822.

The bracket and the screws which attach it to the control cylinder are stainless steel. Rather than staking a hard screw to soft aluminum, the screw ends are tack welded to the bracket, and the welds are blended smooth.

Prior to and after the end bracket is attached, the cylinder contour is inspected to make sure that the cylinder shape has not changed. In a previous inspection, this contour was mapped and this map is used as an inspection guide.

Final Inspection

The final inspection of the inner control cylinder is made with the component in an unrestrained vertical position so that all natural radial distortions can be detected. The cylinder shown, in Fig. 65, Y-12 Photo 116327, is set up on the inspection device with the top end resting on a

Y-115294

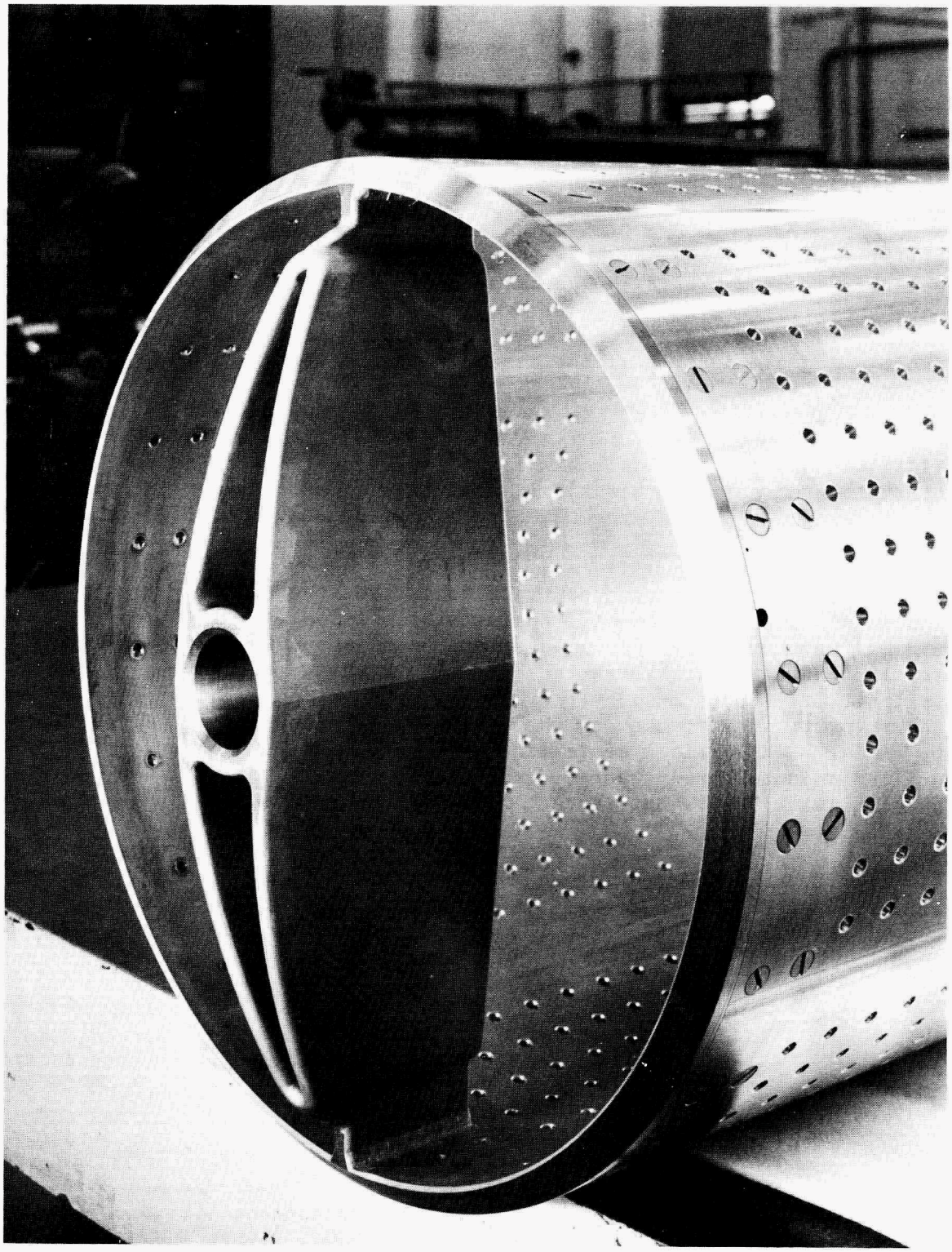


Fig. 63. Inner control cylinder with end fitting.

Y-116325

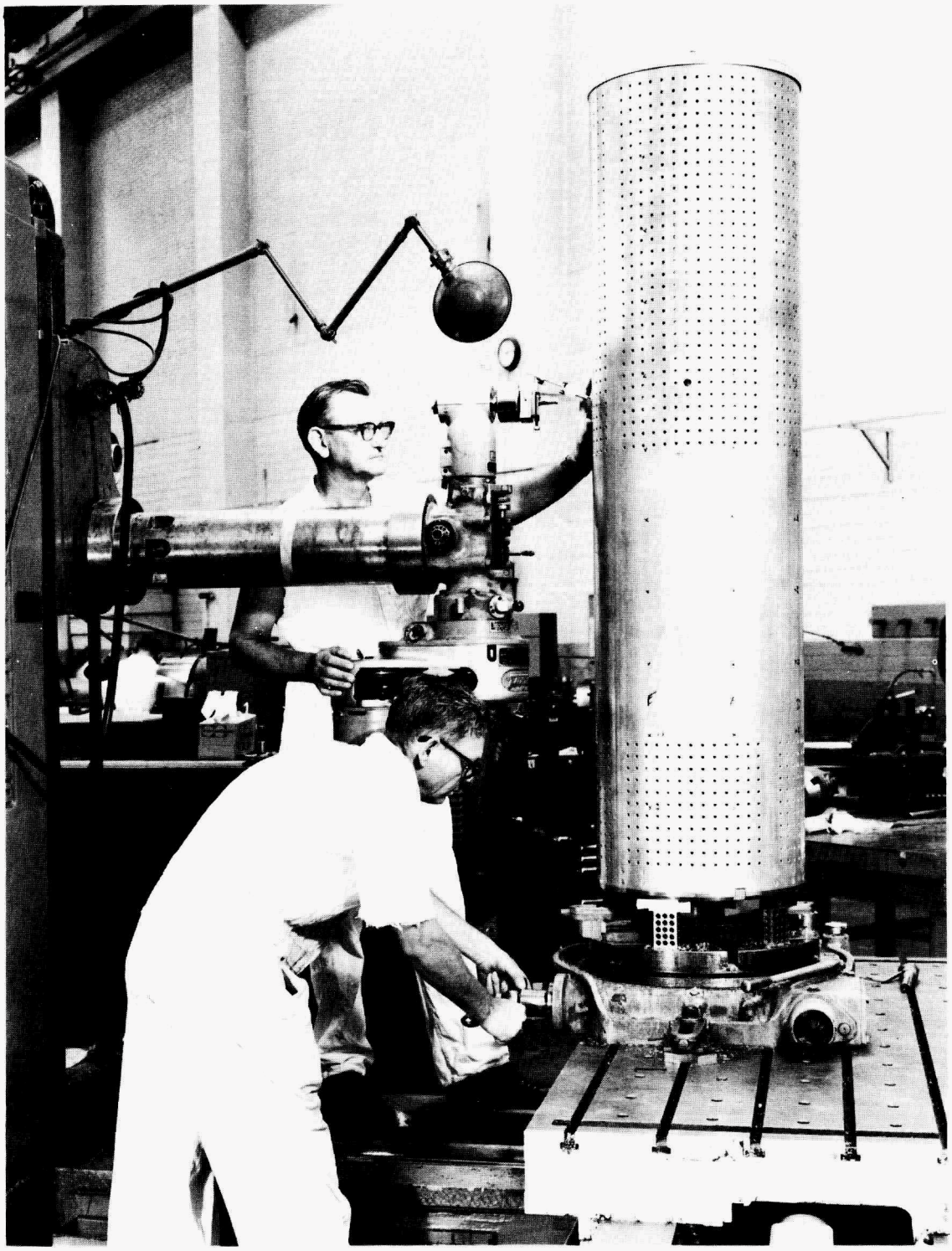


Fig. 64. Setup for drilling and tapping to mount lower ending fitting on inner control cylinder.

Y-116327

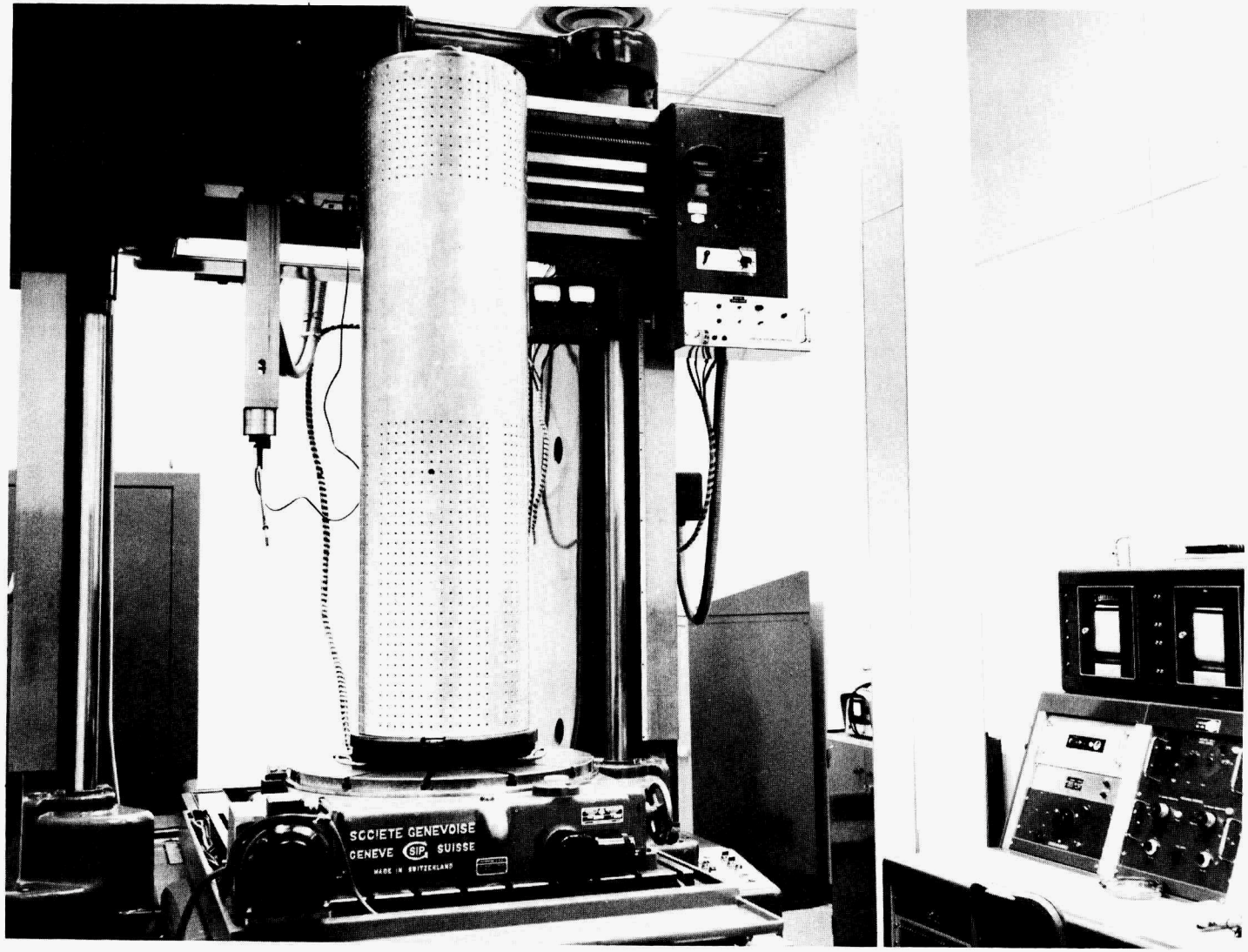


Fig. 65. Control cylinder on inspection device.

leveling table attached to the rotary table of the inspection machine. The radial deviations from the nominal 8.921-in. radius are measured with an electrojet sensor probe interconnected with an integrator. The radial measurements are made at 12 locations along the length of the component. The first location is 1 in. below the interface between the end fitting and the cylinder. The remaining 11 measurements are spaced at 6-in. intervals from the first location.

At each location, the cylinder is rotated and a continuous trace of the radial deviations is recorded. Prior to making any measurements, the cylinder is leveled so that the TIR between No. 1 radial inspection location and the No. 12 inspection location is minimum. For comparison with the best centerline located previously, the initial recording of each inspection "band" is made at the same radial location along the length of the cylinder.

The integrator presents the average diameter at each inspection location and represents 180 data points. The average diameter of the entire cylinder is based on the average of the 12 values recorded.

Prior to shipment, the surfaces of the cylinder are cleaned with isopropyl alcohol to remove all traces of oil and dykum remover used to eliminate reference markings. The cylinder is then cleaned with detergent as described for the inner control plate. The completed control cylinder is shown with one of its outer control plate counterparts in Fig. 66, Photo 80958.

ORNL-PHOTO 80958

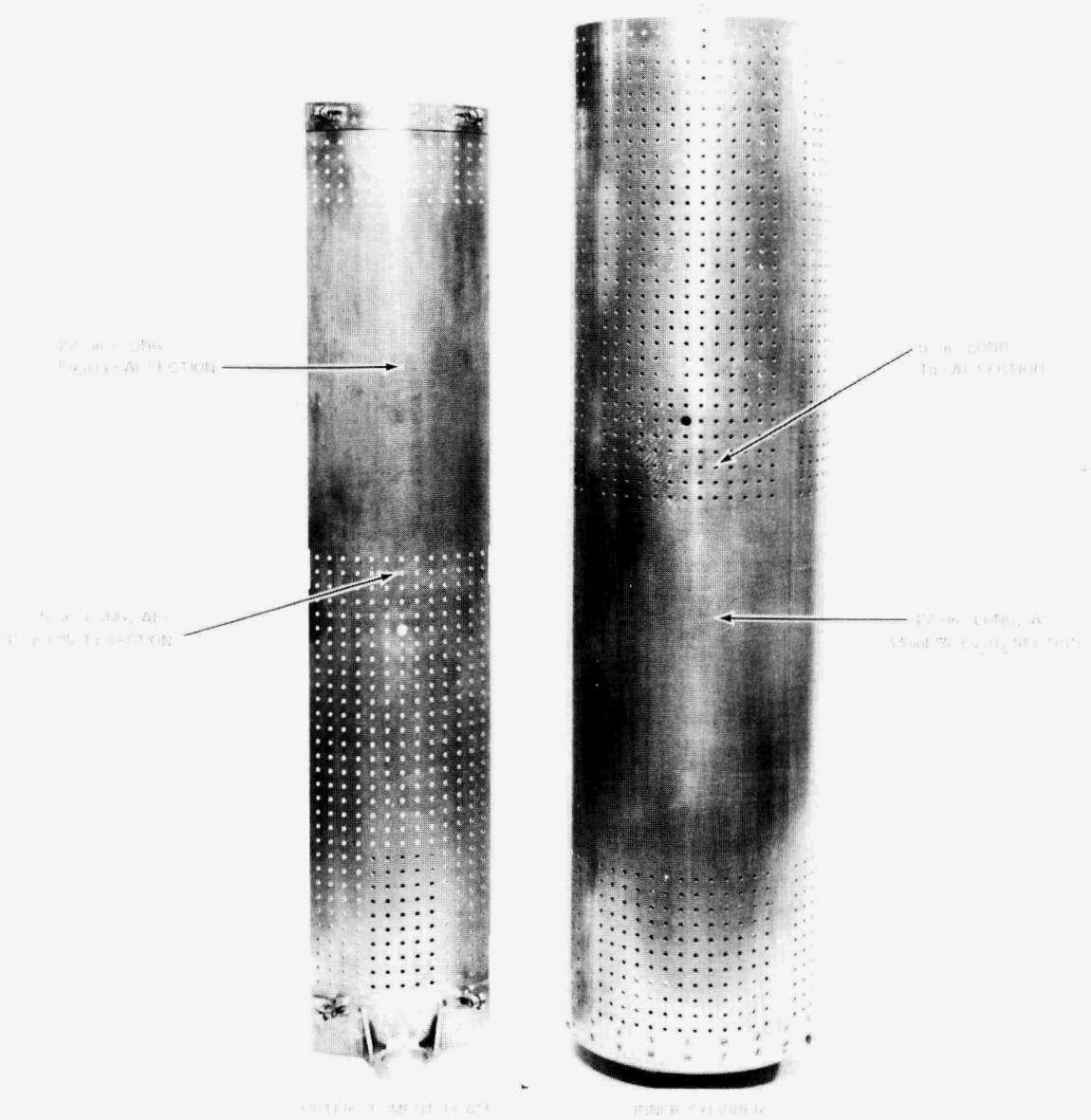


Fig. 66. Finished inner control cylinder and outer control plate.

RESULTS

Comparison of Radius in Preformed Plates Prior to and After Removing "Backup" Plates

An interesting phenomenon was observed in the preforming results for both inner and outer control plates. For best forming results, it was deemed advisable to explosively size a plate whose outside radius was larger than the inside radius of the die. The inside radius of the die for the outer plate was 9.300 in. The desired outside radius of the preform was 9 5/8 in. It was observed that the radius of the preform decreased when the backup plate was removed by approximately 1/2 in. The desired 9 5/8-in. outside radius for the outer control plate was achieved by preforming the plate (with "backup" plate attached) to an inside radius of 9 7/8 ± 1/8 in. As shown below, when the backup plate was removed, the inside radius decreased generally to 9 3/8 in.

Similarly, the inside radius of the die for explosive sizing the inner control plate was 8.975 in. With the backup plate attached, these inner control plates were preformed to 9 5/8 ± 1/8. When the backup plates were removed, the radius decreased to approximately 9 1/8 in.

Table 5. Inside radius variations in preformed outer control plates

Plate No.	Preformed inside radius with backup plate attached (in.)	Preformed inside radius with backup plate detached (in.)	Estimated outside radius of preform (in.)
HC-47	9 7/8 ± 1/8	9 1/8 to 9 1/4	9 3/8 to 9 1/2
HC-48	9 7/8 ± 1/8	9 1/16 to 9 3/16	9 3/8 to 9 7/16
HC-50	9 7/8 ± 1/8	9 1/8	9 3/8
HC-51	9 7/8 ± 1/8	9 3/8 to 9 7/16	9 5/8 to 9 11/16
HC-62		9 3/8	9 5/8
HC-63		9 3/8 to 9 7/16	9 5/8 to 9 11/16
HC-64		9 3/8 to 9 7/16	9 5/8 to 9 11/16
HC-65		9 3/8 to 9 1/2	9 5/8 to 9 3/4

Comparison of Layout Centerlines

Three layout centerlines were used while processing the inner and outer control plates. Centerline 1 (℄ - 1) is the longitudinal centerline of the black section. Centerline 2 (℄ - 2) is the longitudinal centerline of the control plate as explosively sized to its specified radius. Centerline 3 (℄ - 3) is a verification of ℄ - 2 using a different technique. Obviously, it was desired that ℄ - 1 coincide with ℄ - 2 and ℄ - 3. Deviations exist because of the nature of the forming procedure.

Large deviations could cause rejections of the control plate, particularly the outer control plate, because the minimum aluminum edge width specification along the black section can ultimately be violated as a consequence of a poorly formed plate.

The comparative results are tabulated in Table 6. In general, the maximum variation was less than 1/16 in. which is excellent. Even in the worst case, the specification for the aluminum edging along side the black section was not violated.

Table 6. HFIR inner segment parts comparison of layout centerlines

Part No.	Distance between ℄ - 1 and ℄ - 2		Distance between ℄ - 1 and ℄ - 3	
	Top	Bottom	Top	Bottom
HC-52	0.020	0.075	0.020	0.015
HC-53	0.035	0.060	0	0.040
HC-54	0.046	0.080	0.060	0.080
HC-56	0.046	0.115	0.056	0.105
HC-57	0	0.010	0	0.026
HC-59	0.075	0.030	0.075	0
HC-60	0.015	0.030	0.012	0.018
HC-61	0.045	0.025	0	0.025

Variations in Core and Edging Dimensions in Formed Control Plates

The variations in the critical dimensions of the core section of the inner and outer control plates are listed in Tables 7 and 8 and are self-explanatory. The first row of holes in the gray section is nominally 1 in. from the gray-black interface. An overflow of the Eu_2O_3 into the tantalum beyond the defined interface between the gray-black interface occurs as a result of the plate fabrication practice. It was specified that this overflow be limited to 0.250 in., and it can be seen from the data that this limit was not exceeded. Several plates did exceed the desired black section maximum length; however this was judged to be insignificant and was accepted.

The width of the aluminum edging of the outer control plates was not permitted to be less than 0.125 in., and it can be seen from the data that this critical specification dimension was met in all cases.

The arc length of the core section in the inner control plate ranged from 13.031 in. to 13.214 in. and for the outer control plates this dimension varied from 13.141 in. to 13.237 in.

Table 7. Critical core dimensions in formed HFIR inner control plates

Plate No.	Average length of black section	Maximum length of black section	Average length of gray section	Average core arc length
HC-52	21.910	22.615*	4.860	13.097
HC-53	22.035	22.485*	4.790	13.153
HC-54	22.170	22.245	4.770	13.109
HC-56	21.875	22.410*	4.795	13.111
HC-57	22.145	22.725*	4.990	13.092
HC-59	21.935	22.350*	4.990	13.214
HC-60	21.940	22.160	4.925	13.062
HC-61	22.045	23.380*	4.985	13.031

*Out of specification, but acceptable.

Table 8. Critical core dimensions in formed HFIR outer control plates

Plate No.	Average length of black section	Maximum length of black section	Average length of gray section	Average core arc length	Minimum width of aluminum edging
HC-47	21.845	22.080	4.825	13.226	0.208
HC-48	21.875	22.050	4.960	13.234	0.192
HC-50	21.970	22.265	4.840	13.141	0.224
HC-51	21.860	22.335	4.805	13.203	0.192
HC-62	22.060	22.420	4.940	13.213	0.239
HC-63	21.940	22.125	4.875	13.187	0.239
HC-64	21.970	22.155	4.910	13.197	0.224
HC-65	22.185	22.515*	4.980	13.237	0.224

*Out of specification, but acceptable.

Variations in Contour of Explosively Sized Outer Control Plates

Because of the need for dimensional control of the water passage between the control plate components and their surroundings, it is necessary to control the local deviations in the specified radius of the outer control plate to ±0.025 in. of the specified 9.300 in. radius. A summary of the results is included in Table 9 and is based on scanning data typified in Fig. 67, ORNL Dwg. 65-11803, for plate HC-65. Examination of these eight traces of the plate contour shows that no values were observed that exceeded ±0.015 in. of the specified 9.300 in. radius. There was concern that the machining operation might cause changes in the uniformity achieved by the sizing operation. Extensive measurements were made after (1) explosive forming, (2) the hole drilling operation, and (3) attachment of end fitting. The results are summarized in Table 9 and reveal that the machining operations were accomplished with no significant changes in the precision achieved at explosive sizing. It can also be seen that the contour of all plates conformed to the desired specification that local regions be within ±0.025 in. of the specified 9.300 in. radius.

Table 9. A summary of the range of local variations from the specified 9.300 in. radius of the outer control plate

Plate No.	Variations after sizing		Variations after hole drilling		Variations after fittings	
	+	−	+	−	+	−
HC-47	0.012	0.018	0.018	0.019	0.015	0.014
HC-48	0.018	0.017	0.018	0.019	0.019	0.017
HC-50	0.016	0.014	0.014	0.014	0.012	0.015
HC-51	0.013	0.014	0.019	0.018	0.014	0.017
HC-62	0.015	0.012	0.015	0.014	0.015	0.017
HC-64	0.014	0.012	0.018	0.008	0.011	0.010
HC-68	0.022	0.015	0.019	0.021	0.013	0.023

ORNL-DWG 65-11803

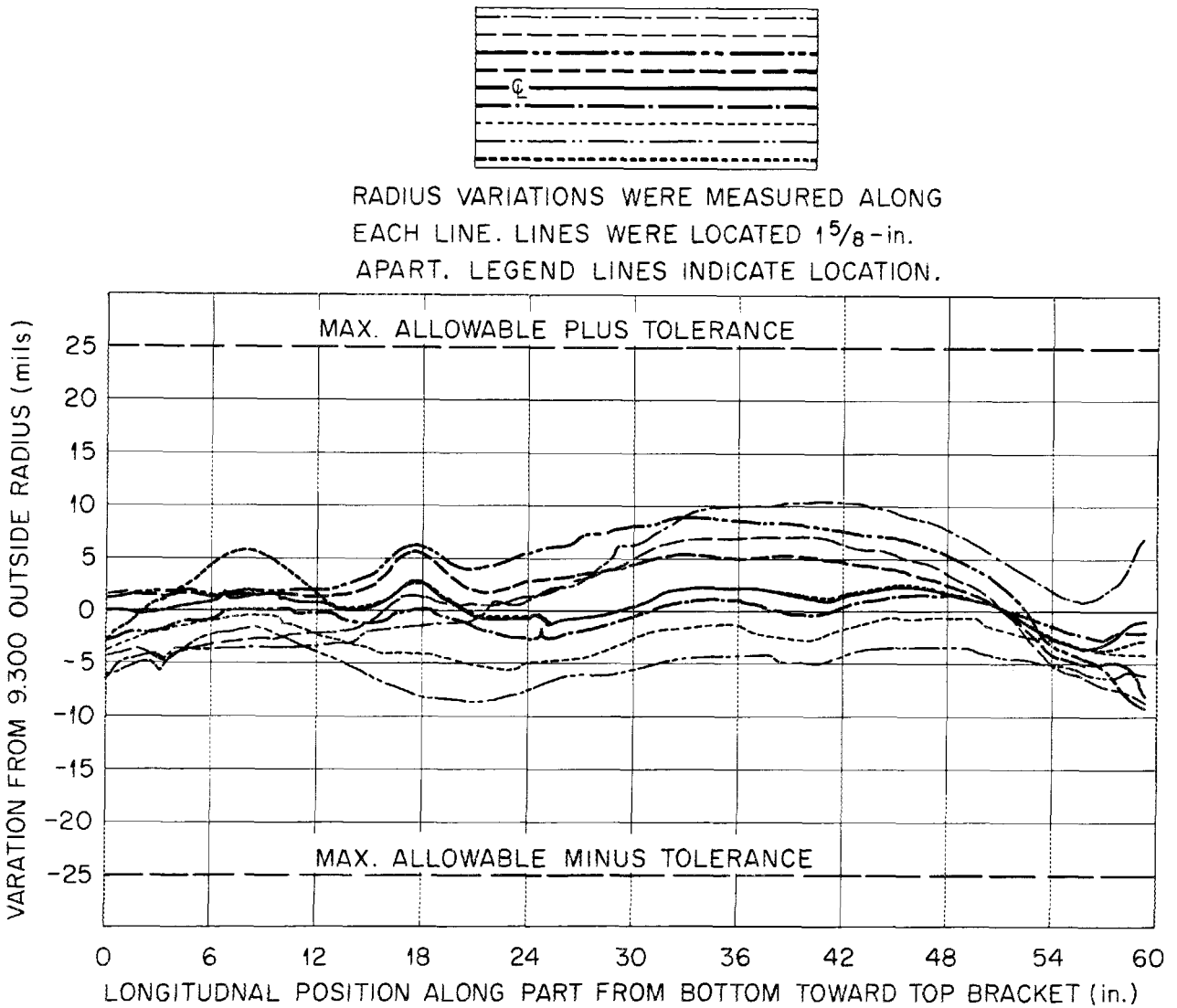


Fig. 67. Outside radius variation vs. axial position - HFIR outer control plate, Part HC-65.

Arc Length of Inner Control Plates

To weld the inner control plates together and control the outside diameter to 17.846 ± 0.010 in., it is necessary to machine them to a precise arc length. In the original plan, a weld shrinkage per joint of 0.025 in. was established and, on that basis, the arc length of three segments was chosen to be 14.041 in. One plate was reserved, pending shrinkage results after welding the first two segments together. When it appeared that the total shrinkage including planishing was about 0.040 in., the fourth segment was machined to an arc length of 14.118 in. This plan was also followed for the second inner cylinder except that the fourth segment was machined to 14.111 in. instead of 14.118 in. Inspection results of the machined arc lengths are listed in Table 10. Except for one plate, the machined arc length was within ±0.006 in. of the desired value.

Table 10. Variations from target arc length, inner cylinder segment parts after machining

Plate No.	Target arc length (in.)	Arc variation from target arc length in thousandths of an inch
HC-52	14.118	+4
HC-53	14.041	-1
HC-54	14.041	-5
HC-56	14.041	-0
HC-57	14.041	+2
HC-59	14.111	-14
HC-60	14.041	-6
HC-61	14.041	-6

Welding and Planishing of Inner Control Cylinder

Welding four plates together to form a cylinder whose diameter of 17.846 must be controlled to ±0.010 in. requires a knowledge of weld shrinkage and expansion which occurs while planishing welds. Tables 11 and 12 illustrate the results obtained in welding together the first two inner control cylinders. A comparison of the two methods selected to monitor weld shrinkage are comparable within ±0.005 in. The results show that the weld shrinkage can only be controlled within ±0.010 in. of the 0.060 in. average value which is not sufficient control to rely on; fortunately, planishing welds offers a technique which lends control to the operation since it results in plastic deformation of the weld region and, thus, an increase in the welded arc length. For example, Table 12 (inner control cylinder No. 2) shows that after welding plates HC-54 and HC-56 together, the shrinkage was 0.054 in. After four planishing passes on

this weld, 0.016 in. was regained, resulting in an overall shrinkage of 0.048 in. of the arc length of the two plates prior to welding. This table also reveals that, after welding the two half cylinders together to form the cylinder, no planishing of the third and fourth welds was required because the diameter was within specification. Table 12 shows that, in making the No. 2 cylinder, the third and fourth welds were planished in order to increase the diameter to meet the 17.846 ± 0.010 in. specification. It was felt that planishing each weld is a more desirable practice because (1) the cast structure of each weld is worked and (2) the local diametric control is improved. It can be seen that, utilizing planishing, 0.005 in. to 0.016 in. per joint was restored (one and four planishing passes, respectively). It was anticipated that more than 0.016 in. could be regained if necessary.

Table 11. Inner control cylinder 1, weld shrinkage data summary

Weld	Parts welded	Average weld shrinkage based on arc length before and after welding	Average weld shrinkage based on scribe lines located 1 in. apart before and after welding	Number of planishing passes	Growth from planishing	Total joint shrinkage
1	HC-54 and HC-56	0.054	0.054	4	0.016	0.038
2	HC-52 and HC-53	0.060	0.059	4	0.0125	0.048
3	HC-52 and HC-54	----	0.068	0	----	
4	HC-53 and HC-56	----	0.070	0	----	

Total of measured arc lengths of four segments before welding	56.239
Average growth from planishing weld 1	0.016
Average growth from planishing weld 2	0.013
Equivalent circumference of cylinder before welding	56.268
Equivalent circumference of cylinder after welding (17.851 pi-tape diam x 3.1416)	- 56.081
	0.187
Average shrinkage per joint	0.047 in.

Table 12. Inner control cylinder 2, weld shrinkage data summary

Weld	Parts welded	Average weld shrinkage based on arc length before and after welding	Average weld shrinkage based on scribe lines located 1 in. apart before and after welding	Number of planishing passes	Growth from planishing	Total joint shrinkage
1	HC-61 and HC-60	0.045	0.053	2	0.006	0.039
2	HC-59 and HC-57	0.054	0.060	2	0.008	0.046
3	HC-61 and HC-57	----	0.058	1	0.0045	0.054
4	HC-60 and HC-59	----	0.060	1	0.0045	0.056

Total of measured arc lengths of four segments before welding	56.210
Average growth from planishing weld 1	0.014
Average growth from planishing weld 2	0.009
Equivalent circumference of cylinder before welding	56.233
Equivalent circumference of cylinder after welding (17.849 pi-tape diam x 3.1416)	- 56.074
	0.159
Average shrinkage per joint	0.040 in.

Diametric Variations in Welding Inner Control Cylinder

The care exercised in welding inner control plates together produced cylinders with precise diametric dimensions, well within the desired average diameter of 17.846 ± 0.010 in. Table 13 lists the 12 diametric measurements at 6-in. intervals made along the longitudinal axis of each of these components. These measurements were made with a pi tape. The variations in cylinder No. 1 were somewhat greater than for cylinder No. 2. It is believed the improvement in cylinder No. 2 was due to the planishing operation.

Table 13. Diametric variations in welding inner control cylinders

Axial position*	Cylinder No. 1	Cylinder No. 2
1	17.850	17.852
7	17.848	17.845
13	17.849	17.846
19	17.855	17.850
25	17.856	17.850
31	17.855	17.852
37	17.860	17.855
43	17.848	17.843
49	17.846	17.845
55	17.849	17.848
61	17.847	17.847
67	17.849	17.850
Average	17.851	17.849

*Measured from end of cylinder at point where it will be cut to fit end of bracket.

Diametric Variations in Inner Control Cylinders After Explosive Sizing

The improvement in the diametric variations in the inner cylinder as a result of explosive sizing is apparent when the results of Tables 11 and 12 are compared with those of Table 13. The evidence shows that the diametric variations can be controlled to within ±0.003 in. of the average diameter. It is also clear that the as-sized outside diameter of the control cylinder is larger than the 17.832-in. inside diameter of the die. As might be expected, the larger the diameter of the welded part, the larger the diameter of the explosively sized component. The difference, however, is not significant.

The variations in roundness along the longitudinal axis are small and, in the case of the second cylinder, essentially negligable.

Final Inspection Results of Diameter and Roundness of the Inner Control Cylinder

The diametric variations of the completed No. 1 and No. 2 inner control cylinders (end fitting attached) are listed in Table 14. The diametric variations are similar to those reported from the pi-tape measurements, although the actual values are 0.001 to 0.002 in. less. Variations in roundness at 6-in. intervals along the longitudinal axis were held within ±0.025 in. for the No. 1 cylinder. These variations for cylinder No. 2 were held to within ±0.010 in. Both of these cylinders, and especially the second, were well within the specification that roundness variations be held to within ±0.030 in. of the nominal 17.842 in.

Table 14. Final inspection results, inner control cylinders

Location of inspection band*	Deviation from setup radius of 8.921 in. in mils				Integrated average diameter	
	cylinder 1		cylinder 2		cylinder 1 (in.)	cylinder 2 (in.)
	max.	min.	max.	min.		
1	+7	-6	+5	-4	17.840	17.842
7	+7	-10	+3	-7	17.838	17.836
13	+14	-13	+4	-6	17.838	17.837
19	+19	-15	+3	-6	17.842	17.839
25	+23	-17	+3	-5	17.842	17.839
31	+25	-22	+4	-5	17.840	17.839
37	+24	-21	+3	-6	17.840	17.838
43	+20	-21	+2	-6	17.837	17.837
49	+19	-19	0	-6	17.837	17.838
55	+18	-17	+2	-6	17.837	17.838
61	+13	-14	+2	-6	17.836	17.838
67	+11	-9	+4	-5	17.838	17.840
				Average	17.839	17.838

*Located with respect to edge at end bracket.

CONCLUSIONS

1. When backup plates are glued to the control plates, the plates can be preformed without cracks occurring in the core material or cladding. The preformed radius can be controlled to within ±1/8 in. of the intended radius.

2. The centerline of the finished explosively sized plate can be controlled to within ±1/16 in. of the centerline of the core section in the plate.

3. Outer control plates can be produced well within critical dimensions specified, i.e., minimum of 0.125-in. aluminum edge along the core section and variations in the plate contour of less than 0.025 in. from the specified 9.300 in. radius.

4. Inner control plates can be formed, explosively sized, and welded together to form a welded inner control cylinder whose diametric variations can be controlled to within ±0.010 in. of the specified 17.846 in. diameter.

5. Inner control cylinders can be explosively sized under compression to produce a product in which the diametric variations are within ±0.005 in. of the average diameter and whose average diameter is within ±0.035 in. of the specified 17.842 in. diameter. Roundness variations can be controlled to within ±0.025 in. of the specified 17.842 in. diameter.

REFERENCES

1. The High Flux Isotope Reactor, A Functional Description, ORNL 3572 (Rev. 2) UC-Reactor Technology, Vol. 1A, May 1968.

2. R. J. Beaver and M. M. Martin, The Status of Europium Compounds for Reactivity Control in Nuclear Reactors, ORNL-4368, February 1969.

APPENDIX A

SUMMARY OF ACTIVITIES TO BE PERFORMED BY METALS AND CERAMICS DIVISION, FABRICATION AND QUALITY ASSURANCE PLAN MET-Mat FQ-30, FOR THE FABRICATION OF HFIR INNER AND OUTER CONTROL COMPONENTS

		Metals and Ceramics Division Document
1.	Characterization of as-received europium oxide power	MET-MatP-D-49
2.	Arc-melt buttons of Eu_2O_3	MET-MatP-D-50
	Press powder	MET-MatP-SOP-41
	Press powder	MET-MatP-SOP-48
3.	Crush, screen, and weigh Eu_2O_3 powder and issue blend sheets for compact	MET-MatP-D-51
	Arc melt	MET-MatP-SOP-69
4.	Characterization of as-received aluminum powder	MET-MatP-D-52
5.	Anneal, screen, and weigh aluminum powder and issue blend sheets for compacts	MET-MatP-D-53
6.	Characterization of as-received tantalum powder	MET-MatP-D-54
7.	Screen and weigh tantalum powder and issue blend sheets for compact	MET-MatP-D-54
8.	Prepare and inspect compacts	MET-MatP-D-55
	Weigh and blend powder	MET-MatP-SOP-21
	Consolidate blended powder	MET-MatP-SOP-49
	Anneal compacts	MET-MatP-SOP-21
9.	Prepare aluminum cover plates	MET-MatP-D-56
10.	Prepare aluminum frames	MET-MatP-D-57
11.	Prepare aluminum evacuation stems	MET-MatP-D-62
12.	Assign compacts to billet position	MET-MatP-D-58
13.	Oakite etch frame and cover plates	MET-MatP-SOP-31
14.	Assemble billet	MET-MatP-D-58
15.	Weld billet	MET-MatP-D-58
16.	Degas billet	MET-MatP-D-58
17.	Roll billet	MET-MatP-D-59
18.	Anneal control plate and check for blisters	MET-MatP-D-59
19.	Inspection, visual, ultrasonic, X-ray and dimensional (Inspection Engineering Job Plan GB 5-26-76)	MET-MatP-D-59
20.	Ship control plates to Y-12	MET-MatP-D-59

APPENDIX B

SUMMARY OF ACTIVITIES TO BE PERFORMED BY THE Y-12 FABRICATION DIVISION FOR THE FABRICATION OF HFIR OUTER CONTROL PLATES

		Y-12 Procedure No.
1.	Receive plates from ORNL	
	Stage 1 inspection	AA6-C-7989-55
2.	Anneal backup plates	
	First machining setup No. 3	AA6-T-7989-55
3.	Prepare plates	
	First cleaning	AA6-Y-001
	First anneal and flatten	AA6-Y-003
	Second cleaning	AA6-Y-001
	Glue backup to core (procedure)	AA6-G-001
	Glue backup to core (sign off)	AA6-GF-7989-55
4.	Drill hole pattern for layout	
	Second machining setup No. 6	AA6-T-7989-55
	Stage 2 inspection	AA6-C-7989-55
5.	Flat plate X-ray	
	First radio (Section 4)	AA6-Q-001
6.	Lay out centerline and scribe for preforming	
	Machining setup No. 9	AA6-T-7989-55
	Stage 3 inspection	AA6-C-7989-55
	Third machining setup No. 10 (preform)	AA6-T-7989-55
7.	Stripping for backup plates	
	Remove glue (procedure)	AA6-G-001
	Remove glue (sign off)	AA6-GF-7989-55
	Third clean	AA6-Y-001
	Second anneal	AA6-Y-002
	Fourth clean	AA6-Y-001
8.	Drill positioning hole and slot	
	Fourth machining setup No. 15	AA6-T-7989-55
	Stage 4 inspection	AA6-C-7989-55

APPENDIX B
(Continued)

		Y-12 Procedure No.
9.	Explosive sizing	AA6-Y-7989-55
10.	Semicurve X-ray	
	Second radio Section 5	AA6-Q-001
11.	Inspection and layout of centerlines based on linear measurements	
	Machining setup No. 19	AA6-T-7989-55
	Stage 5 inspection	AA6-C-7989-55
	Courtesy radio, Section 6	AA6-Q-001
12.	Layout of segments for machining of arc length and overall length	
	Fifth machining setup No. 20	AA6-T-7989-55
	Drill 1/4 holes setup No. 21	AA6-T-7989-55
	Third radio (Section 5)	AA6-Q-001
	Sixth machining setup No. 23 (radius holes)	AA6-T-7989-55
	Stage 6 inspection	AA6-C-7989-55
13.	Install end fittings	
	Seventh machining setup No. 25	AA6-T-7989-55
	Stage 7 inspection	AA6-C-7989-55
	Eighth machining setup No. 27	AA6-T-7989-55
14.	Pack and ship to ORNL	AA6-T-7989-55

APPENDIX C

SUMMARY OF ACTIVITIES TO BE PERFORMED BY THE Y-12 FABRICATION DIVISION FOR THE FABRICATION OF HFIR INNER CONTROL CYLINDERS

	Y-12 Procedure No.
1. Receive plates from ORNL	
Stage 1 inspection	AA6-C-7091-21
2. Anneal backup plates	
First machining setup No. 3	AA6-T-7091-21
3. Prepare plates	
First cleaning	AA6-Y-001
First anneal and flatten	AA6-Y-003
Second cleaning	AA6-Y-001
Glue backup to core (procedure)	AA6-G-001
Glue backup to core (sign off)	AA6-GF-7989-55
4. Drill hole pattern for layout	
Second machining setup No. 6	AA6-T-7091-21
Stage 2 inspection	AA6-C-7091-21
5. Flat plate X-ray	
First radio (Section 4)	AA6-Q-001
6. Lay out centerline and scribe for preforming	
Machining setup No. 9	AA6-T-7091-21
Stage 3 inspection	AA6-C-7091-21
Third machining setup No. 10 (preform)	AA6-T-7091-21
7. Stripping for backup plates	
Remove glue (procedure)	AA6-G-001
Remove glue (sign off)	AA6-GF-7989-55
Third clead	AA6-Y-001
Second anneal	AA6-Y-002
Fourth clean	AA6-Y-001

APPENDIX C
(Continued)

		Y-12 Procedure No.
8.	Trim plate to arc length for explosive sizing	
	Fourth machining setup No. 15	AA6-T-7091-21
	Drill positioning hole and slot - setup No. 16	AA6-T-7091 21
	Stage 4 inspection	AA6-C-7091-21
9.	Explosive sizing	
	First forming	AA6-Y-7091 21
10.	Semicurve X-ray	
	Second radio, Section 5	AA6-Q-001
11.	Inspection and layout of centerlines based on linear measurements	
	Machining setup No. 20	AA6-T-7091-21
	Stage 5 inspection	AA6-C-7091-21
	Courtesy radio, Section 6	AA6-Q-001
12.	Layout of segments for machining of arc length	
	Fifth machining setup No. 21	AA6-T-7091-21
	Machining setup No. 21	AA6-T-7091-21
	Stage 6 inspection	AA6-C-7091-21
13.	Welding half cylinder and cylinder	
	Sixth machining setup No. 23	AA6-T-7091-21
	Sixth machining setup No. 24	AA6-T-7091-21
	Radio welds and edge clad	AA6-Q-001
14.	Inspect cylinder and face off ends	AA6-T-7091-21C
15.	Explosive size cylinder	
	Second forming	AA6-Y-9135-31
	Radio welds and edge clad	AA6-Q-001
16.	Inspect cylinder; machine to length and C-bore	
	Machining setup No. 27	AA6-T-7091-21

APPENDIX C
(Continued)

	Y-12 Procedure No.
17. Drill and radius 1/4 and 5/8 holes	
Machining setup No. 28 (drill)	AA6-T-7091-21
Machining setup No. 29 (radius)	AA6-T-7091-21
Inspection	AA6-C-7091-21
Radio Section 7	AA6-Q-001
18. Install end fitting	
Machining setup No. 30	AA6-T-7091-21
Inspect runout	AA6-C-7091-21
Tack weld screw, setup No. 31	AA6-T-7091-21
19. Cleaning and final inspection of cylinder	
Clean, setup No. 32	AA6-T-7091-21
Machining setup No. 33	AA6-C-7091-21
Inspection	AA6-C-7091-21
20. Pack and ship setup No. 35	AA6-T-7091-21

APPENDIX D

MEASUREMENT OF HFIR CONTROL PLATE CORES

Measurement Procedure

1. Draw base line tangent to edge of cores.

2. Draw reference line at convenient point across tantalum section and at right angles to base line.

3. Measure distance from reference line to adjacent end of Eu_2O_3 at 14 locations spaced about equally across the core. All measurements are to be recorded on Sheet D.1 for inner control plates and D.2 for outer control plates.

4. Obtain the average distance from the above 14 measurements and draw a line across the Ta/Eu_2O_3 interface at this distance from the reference line.

5. Measure

   1a. Minimum distance of Eu_2O_3 into tantalum from the line drawn in Step 4 above.

   1b. Maximum distance of Eu_2O_3 into tantalum from the line drawn in Step 4 above.

6. Draw a line at 90° to the base line and tangent to the extreme protrusion of the Eu_2O_3 into the aluminum - Measure 1c. (Distance from reference Ta/Eu_2O_3 interface to opposite extreme end of Eu_2O_3.)

7. Draw a line at 90° to the base line and tangent to the extreme protrusion of the tantalum into the aluminum - Measure 2a. (Overall length of both cores.)

8. Draw a line parallel to the base line and tangent to the opposite edge of the cores at the farthest point - Measure 2b. (Maximum core width.)

9. Draw a line at 90° to the base line and tangent to the farther protrusion of the tantalum into the Eu_2O_3. The distance between this line and the Step 7 line is 3c. (Maximum length of tantalum.)

10. Measure the distance from the Step 7 line and the Step 9 line to the adjacent ends of the tantalum at 14 equally spaced locations across the core width. Add the 28 measurements and divide the total obtained by 14. Subtract the value obtained here from the value in Step 9 above to get the value of 3a. (Average length of tantalum.)

11. Measure the width of the tantalum section at five equally spaced locations along the length. The average of these is 3b.

APPENDIX D
(Continued)

12. Unless irregular edges exist on the cores, the largest number obtained under Step 11 may be used as the maximum width of the tantalum section - 3d. If irregular edges do exist, measure the maximum.

13. Measure from the Step 6 line to the farthermost protrusion of the Eu_2O_3 into the aluminum at 14 equally spaced locations across the width of the core. Obtain the average of these and subtract this value from the value in Step 7 above to determine the average length of the Eu_2O_3 section - 4a.

14. Measure the width of the Eu_2O_3 section at ten equally spaced locations along the length. Average these values to obtain 4b. (The average width of the Eu_2O_3 section.)

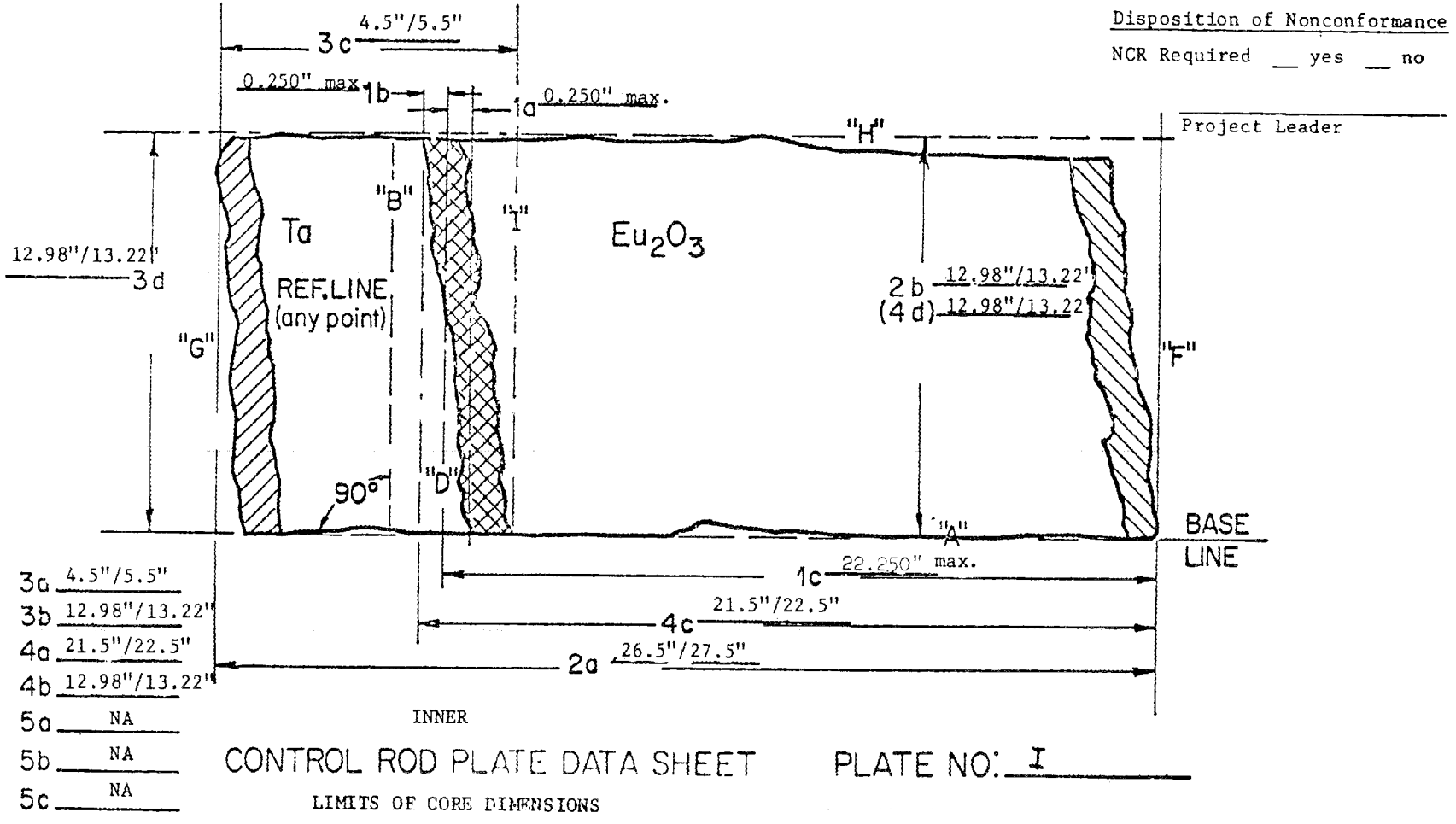
15. Add the value of Step 5, 1b, to the value of Step 7 to obtain the overall length of the Eu_2O_3 section - 4c.

16. The largest dimension obtained under Step 14 above may be taken as the maximum width of the Eu_2O_3 - 4d unless some point extends beyond this measurement; if so, measure it.

17. Measure the mixing length of the tantalum with the aluminum at 14 equally spaced locations across the core. The average of these is 5a.

18. Measure the mixing length of the tantalum with the Eu_2O_3 at 14 equally spaced locations across the core. The average of these is 5b.

19. Measure the mixing length of the Eu_2O_3 with the aluminum at 14 equally spaced locations across the core. The average of these is 5c.



Disposition of Nonconformance

NCR Required __ yes __ no

3a 4.5"/5.5"
3b 12.98"/13.22"
4a 21.5"/22.5"
4b 12.98"/13.22"
5a NA
5b NA
5c NA

CONTROL ROD PLATE DATA SHEET PLATE NO: I

LIMITS OF CORE DIMENSIONS

NOTE: Any out-of-tolerance dimensions will be circled on this form.

QA&I SKETCH NO. 12424-4A

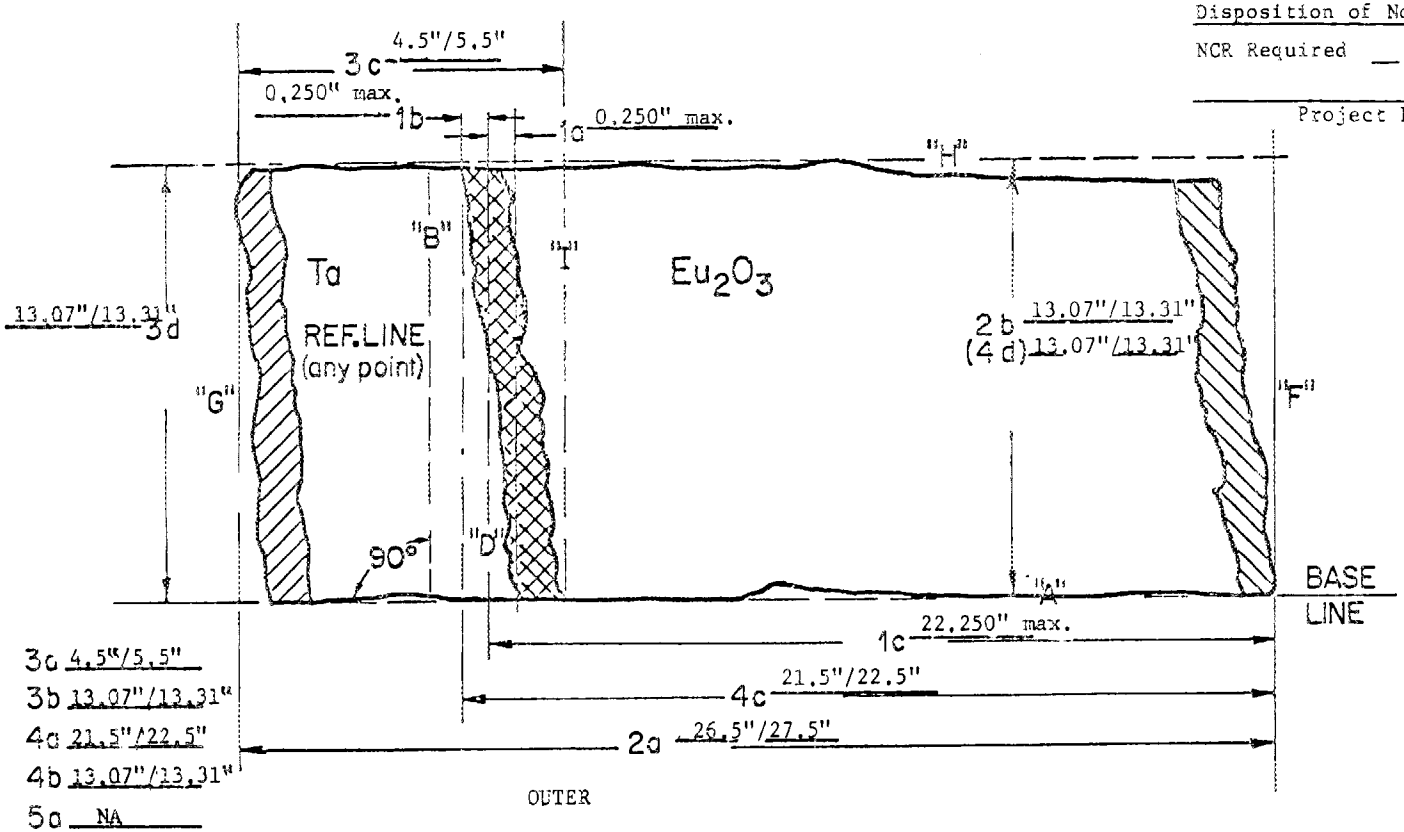
See Attachment B for instructions

Fig. D.1. QA&I Sketch No. 12424-4A.

Disposition of Nonconformance

NCR Required __ yes __ no

Project Leader



3a 4.5"/5.5"
3b 13.07"/13.31"
4a 21.5"/22.5"
4b 13.07"/13.31"
5a NA
5b NA
5c NA

CONTROL ROD PLATE DATA SHEET PLATE NO: 0-

LIMITS OF CORE DIMENSIONS

NOTE: Any out-of-tolerance dimensions will be circled on this form.

QA&I SKETCH NO. 12424-4B

See Attachment B for instructions

Fig. D.2. QA&I Sketch No. 12424-4B.

APPENDIX E

MANUFACTURING DRAWINGS, PROCEDURES, AND TOOLING DRAWINGS FOR MANUFACTURING HFIR CONTROL COMPONENTS

Document Control Tabulation

EJN No.	Specification or Dwg. No.	Rev.	Date	Status	Title
Spec.	QA-O-JS-50		5/20/80	CFC	Requirements for stainless steel materials
	QA-O-JS-52		12/15/81	CFC	Requirements for aluminum materials
	D-42092	A	6/26/64	CFC	HFIR procurement notes SPN-1
	JS-15		2/03/69	CFC	Procedure for straightening HFIR outer control cylinder quadrants
	QA-O-JS-24		1/30/81	CFC	Dimensional inspection procedure
	QA-O-JS-28		3/14/80	CFC	Requirements for the fabrication of components by outside suppliers
	QA-O-JS-31		12/16/81	CFC	Cleaning and cleanliness requirements
	JS-37		4/15/76	CFC	Welding procedure for inner control cylinder
	WPS-302		4/76	CFC	Gas tungsten-arc welding of chromium-nickel steel
	WPS-1003		10/69	CFC	Gas tungsten-arc welding of aluminum alloys 6XXX
	UNC W-302		5/05/75	CFC	Gas tungsten-arc welding of chromium-nickel steel
	UNC W-607		8/29/75	CFC	Gas tungsten-arc welding of 60XX aluminum plate
Job Plan	GB-5-26-76	3	5/01/84	CFC	QA&I - inspection of HFIR control plates

Document Control Tabulation

EJN No.	Specification or Dwg. No.	Rev.	Date	Status	Title
Y-12 Spec.	AA6-C-7091-21	D	10/04/78	CFC	HFIR inner control rod inspection procedure
	AA6-C-7989-55	E	11/02/78	CFC	HFIR outer control rod inspection procedure
	AA6-Q-001	D	4/29/77	CFC	HFIR inner and outer control rod assembly procedure
	AA6-GF-7989-55	B	3/17/77	CFC	HFIR inner and outer control rod assembly procedure
	AA6-Q-001	E	2/20/79	CFC	HFIR inner and outer control rod radiography
	AA6-T-7091-21	E	11/21/78	CFC	HFIR inner control rod machining procedure
	AA6-T-7989-55	F	10/04/78	CRC	HFIR outer control rod machining procedure
	AA6-Y-001	A	2/03/77	CFC	HFIR inner and outer control rod cleaning procedure
	AA6-Y-002	B	12/22/77	CFC	HFIR inner and outer control rod stress relieve procedure
	AA6-Y-003	B	12/22/77	CFC	HFIR inner and outer control plate flatten procedure
	AA6-Y-004	A	9/27/78	CFC	HFIR inner control rod cylinder explosive sizing procedure
	AA6-Y-7989-55	A	5/27/77	CFC	HFIR outer control rod explosive sizing procedure
	AA6-Y-7091-21	A	10/03/77	CFC	HFIR inner control rod explosive sizing procedure

Document Control Tabulation

EJN No.	Specification or Dwg. No.	Rev.	Date	Status	Title
M&C Spec.	MET-MatFQ-30	2	3/15/83	CFC	Fabrication of HFIR control rod plates
	MET-MatP-D-49	0	4/27/76	CFC	Characterization of as-received europium oxide powder
	MET-MatP-D-50	0	4/27/76	CFC	Fabrication of arc-melted buttons of europium oxide powder
	MET-MatP-D-51	0	4/27/76	CFC	Prepare and characterize Eu_2O_3 powder
	MET-MatP-D-52	0	4/28/76	CFC	Characterization of as-received aluminum powder
	MET-MatP-D-53	0	4/28/76	CFC	Prepare and characterize aluminum powder
	MET-MatP-D-54	0	4/29/76	CFC	Characterization of as-received tantalum powder
	MET-MatP-D-55	0	4/29/76	CFC	Prepare and inspect control rod compacts
	MET-MatP-D-56	0	5/10/76	CFC	Prepare aluminum covers
	MET-MatP-D-57	0	5/13/76	CFC	Prepare aluminum frames
	MET-MatP-D-58	0	5/17/76	CFC	Prepare and assemble evacuated billets
	MET-MatP-D-59	0	6/16/76	CFC	Fabrication control plates
	MET-MatP-D-62	0	5/17/76	CFC	Prepare aluminum evacuation stems

Document Control Tabulation

EJN No.	Specification or Dwg. No.	Rev.	Date	Status	Title
OP-11460-2	E-42376	M	3/05/76	CFC	Inner control rod drive bracket
	E-49443		5/11/76	CFC	Inner and control rod billets
OP-11460-1	D-49444		5/05/76	CFC	Inner and outer control rod details
	D-49711	D	9/24/75	CFC	Outer control rod Type L bearing mount detail
	D-49712	H	12/02/76	CFC	Outer control rod Type L bearing sub-assembly
	E-49820	S	1/18/78	CFC	Outer control rod assembly
OP-11460-1	E-49821	R	2/11/76	CFC	Outer control rod lower flange detail
	E-49822	H	3/24/76	CFC	Inner control rod assembly
	E-49823	K	8/25/77	CFC	Outer control rod quadrant detail
	E-49824	H	8/25/77	CFC	Inner control rod details
OP-11460-1	E-49825	M	2/11/76	CFC	Outer control rod upper flange detail
	E-50098	D	12/17/68	CFC	Outer control rod female clearance gauge
	D-501		1/23/68	CFC	Drill jig for bearing shaft mounting lugs
M-11460	ØH-100-D		6/8/77	CFC	Outer control rod Type "R" bearing

Document Control Tabulation

ORNL Ref. Dwg. No.	Y-12 tooling Dwg. No.	Rev.	Date	Status	Title
	B-T-24112	A	6/23/63	AFC	Lifting device, inner rod
	B-T-24728		3/27/63	AFC	Pneumatic lifting fixture, inner rod
	B-T-24763		5/23/63	AFC	Pneumatic lifting fixture, inner rod
	B-T-25265	A	9/13/63	AFC	Sizing die wrench, inner rod
	B-T-26829		3/13/67	AFC	Outer rod, pin expanding tool
E-42293	C-T-27644		3/14/63	AFC	Explosive forming, charge centering post, inner rod
E-42293	C-T-28283	B	9/28/67	AFC	Fixture welding, inner rod
	C-T-28447		7/8/63	AFC	Explosive forming gasket, inner rod
	D-T-32492	B	3/27/63	AFC	Pneumatic lifting fixture, valve assembly, inner rod
E-42293	D-T-33029		4/17/63	AFC	Explosive forming die platform, outer rod
E-49820	C-T-33078		12/27/67	AFC	Drill jig
	D-T-33263		6/4/63	AFC	Deburring tool
E-42293	D-T-33276	A	7/12/63	AFC	Welding fixture clamp, inner rod
	D-T-33886	B	4/16/69	AFC	Pneumatic lifting fixture
	D-T-33926		7/24/63	AFC	Explosive sizing die, wooden charge positioner
	D-T-33944		8/19/63	AFC	Gauge adaptor, outer rod

Document Control Tabulation

ORNL Ref. Dwg. No.	Y-12 tooling Dwg. No.	Rev.	Date	Status	Title
	D-M-34945		9/01/64	AFC	HFIR reactor grade, X-ray grid
	D-T-35777		5/01/65	AFC	Functional gauge stand, inner rod
E-49900	D-T-36093		7/15/64	AFC	Shipping container for inner rod
	D-T-41378		5/02/67	AFC	Molding forming press brake die mold
	D-T-41379		5/02/67	AFC	Mold shipping container
	E-T-45841		2/07/63	AFC	Annealing fixture, outer rod
E-42293	E-T-46069		3/02/63	AFC	Shipping container, outer rod
E-42293	E-T-46070		3/04663	AFC	Lifting device, outer rod
E-42293	E-T-46184	B	6/17/65	AFC	Explosive forming body, outer rod
E-42293	E-T-46185		3/02/63	AFC	Lifting device, carrier, outer rod
E-42294	E-T-46481	B	10/17/63	AFC	Explosive forming, sizing die assembly, inner rod
E-42294	E-T-46482	A	9/09/63	AFC	Explosive forming, sizing die assembly, inner rod
E-42294	E-T-46483	D	9/30/63	AFC	Explosive forming, sizing die detail, inner rod
E-42294	E-T-46484	A	9/09/63	AFC	Explosive forming, sizing die detail, inner rod
E-42294	E-T-46485	A	9/09/63	AFC	Explosive forming, sizing die detail, inner rod
E-42294	E-T-46486	A	9/09/63	AFC	Explosive forming, sizing die detail, inner rod

Document Control Tabulation

ORNL Ref. Dwg. No.	Y-12 tooling Dwg. No.	Rev.	Date	Status	Title
E-42294	E-T-46487	A	9/09/63	AFC	Explosive forming, sizing die assembly detail, inner rod
E-42294	E-T-46488	A	9/09/63	AFC	Explosive forming, sizing die assembly detail, inner rod
E-42294	E-T-46489		3/20/63	AFC	Explosive forming, sizing die assembly detail, inner rod
E-42294	E-T-46490	A	4/09/63	AFC	Explosive forming, sizing die assembly detail, inner rod
E-42294	E-T-46491	A	4/09/63	AFC	Explosive forming, sizing die assembly detail, inner rod
E-42294	E-T-46492		3/20/63	AFC	Explosive forming, sizing die assembly detail, inner rod
E-42294	E-T-46493		3/20/63	AFC	Explosive forming, sizing die assembly detail, inner rod
E-42294	E-T-46494		9/09/63	AFC	Explosive forming, sizing die assembly detail, inner rod
	E-T-46495	A	9/09/65	AFC	Explosive forming, gauge and mandrel, inner rod
E-42294	E-T-46693	C	9/16/63	AFC	Pneumatic lifting fixture, center ring, inner rod
E-42294	E-T-46813	A	9/09/63	AFC	Explosive forming, gauge and mandrel, inner rod
E-42294	E-T-46814	A	9/09/63	AFC	Explosive forming, gauge and mandrel, inner rod
E-42294	E-T-46815	A	9/09/63	AFC	Explosive forming, gauge and mandrel, inner rod

Document Control Tabulation

ORNL Ref. Dwg. No.	Y-12 tooling Dwg. No.	Rev.	Date	Status	Title
E-42294	E-T-46816	A	9/09/63	AFC	Explosive forming, gauge and mandrel, inner rod
E-42294	E-T-46817		6/26/63	AFC	Explosive forming, gauge and mandrel details, inner rod
E-42294	E-T-46818		9/20/63	AFC	Explosive forming, gauge and mandrel, inner rod
E-42294	E-T-46819		6/26/63	AFC	Explosive forming, gauge and mandrel details, inner rod
E-42294	E-T-46820		6/26/63	AFC	Explosive forming, gauge and mandrel details, inner rod
E-42294	E-T-46821		6/26/63	AFC	Explosive forming, gauge and mandrel details, inner rod
E-42294	E-T-46822		6/26/63	AFC	Explosive forming, gauge and mandrel details, inner rod
E-42293	E-T-46853	A	6/17/64	AFC	Explosive forming, body detail, outer rod
E-42293	E-T-46859		4/25/63	AFC	Flat plate shipping container
E-42294	E-T-46861		4/19/63	AFC	Lifting fixture, inner rod
E-42294	E-T-47046		4/19/63	AFC	Anneal fixture, inner rod
E-42294	E-T-47055		5/21/63	AFC	Pneumatic lifting fixture, shipping box, inner rod
E-42294	E-T-47124		6/26/63	AFC	Explosive forming, gauge and mandrel details, inner rod

Document Control Tabulation

ORNL Ref. Dwg. No.	Y-12 tooling Dwg. No.	Rev.	Date	Status	Title
E-42294	E-T-47125		6/26/63	AFC	Explosive forming, gauge and mandrel details, inner rod
E-42294	E-T-47126		6/26/63	AFC	Explosive forming, gauge and mandrel details, inner rod
E-42294	E-T-47127		6/26/63	AFC	Explosive forming, gauge and mandrel details, inner rod
E-42294	E-T-47128		6/26/63	AFC	Explosive forming, gauge and mandrel details, inner rod
E-42294	E-T-47295		5/21/63	AFC	Pneumatic lifting fixture, shipping box, inner rod
E-42294	E-T-47296		5/21/63	AFC	Pneumatic lifting fixture, details, inner rod
E-42294	E-T-47327		5/21/63	AFC	Pneumatic lifting fixture, details, inner rod
E-42294	E-T-47494		5/21/63	AFC	Pneumatic lifting fixture, details, inner rod
	E-T-48222		5/14/63	AFC	Rubber mold, inner rod
	E-T-48231		5/17/63	AFC	Spreader bar lifting fixture, inner rod
	E-T-48783		7/08/63	AFC	Explosive forming, paddle, inner rod
	E-T-50370		9/17/63	AFC	Pneumatic lifting fixture, details, inner rod
E-49901	E-T-52715		3/16/64	AFC	Machining mandrel, detail, outer control rod
E-49901	E-T-52716		3/16/64	AFC	Machining mandrel, detail, outer control rod
E-49901	E-T-52717		3/16/64	AFC	Machining mandrel, assembly, outer control rod

Document Control Tabulation

ORNL Ref. Dwg. No.	Y-12 tooling Dwg. No.	Rev.	Date	Status	Title
E-49901	E-T-52727		3/19/64	AFC	Machining mandrel, detail, outer control rod
E-49901	E-T-52731		3/16/64	AFC	Machining mandrel, detail, outer control rod
E-49902	E-T-53501	A	5/05/64	REF	Riveting mandrel, assembly, inner and outer control rod
E-49902	E-T-53502		4/15/64	REF	Riveting mandrel, assembly, inner and outer control rod
E-49902	E-T-53503	A	5/05/64	REF	Riveting mandrel, details, inner and outer control rod
E-49902	E-T-53504		4/27/64	REF	Riveting mandrel, details, inner and outer control rod
E-49902	E-T-53505	A	5/06/64	REF	Riveting mandrel, details, inner and outer control rod
E-49902	E-T-53506		4/29/64	REF	Riveting mandrel, details, inner and outer control rod
E-49824	E-M-53688	B	12/16/65	REF	Inner rod, dummy cylinder No. 2
E-49823	E-M-53689		9/01/64	REF	Inner rod, dummy cylinder No. 2
	E-T-53690		6/15/64	AFC	Inner control rod, explosive forming, body liner
E-42293	E-M-53694	A	9/22/64	REF	Outer rod, mech. research, outer control rod
	E-T-54167		6/16/65		Curved rod fixture (radiography)

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ORNL Ref. Dwg. No.	Y-12 tooling Dwg. No.	Rev.	Date	Status	Title
	E-M-54520		9/01/64	REF	Inner rod, dummy cylinder No. 2
E-49823	E-M-55623	F	8/22/77	AFC	HFIR outer control rod segment, layout of holes
E-49823	E-M-55625	D	8/19/77	AFC	HFIR outer control rod segment, procedure for layout and machining
	E-T-55922		2/16/65	AFC	Small I.D. sweep gauge, sheff. head detail
	E-T-55923		2/16/75	AFC	Small I.D. sweep gauge, sheff. head detail
	E-T-55930		2/16/75	AFC	Small I.D. sweep gauge, sheff. head assembly
	E-T-55938		2/05/65	AFC	Seam welder mandrel assembly, inner rod
E-49825	E-T-55964	A	12/25/65	AFC	Aligning fixture for machining
	E-T-55977		1/22/65	AFC	Flaring pressure assembly
	E-T-55978		1/22/65	AFC	Flaring pressure details
	E-T-55979		1/22/65	AFC	Flaring pressure details
	E-T-55990	A	3/13/65	AFC	Gauge functional 17.346 dia. clamp assembly inner rod
	E-T-55991		3/09/65	AFC	Gauge functional 17.846 diam clamp assembly, inner rod
	E-T-55992		3/05/65	AFC	Set up gauge assembly, outer rod

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ORNL Ref. Dwg. No.	Y-12 tooling Dwg. No.	Rev.	Date	Status	Title
E-49824	E-T-55995	A	3/26/65	AFC	Seam welder support assembly, inner rod
E-49824	E-T-55996		3/22/65	AFC	Seam welder support detail, inner rod
	E-T-55997		3/22/65	AFC	Fixture machining mandrel accessories detail
	E-T-55998		3/29/65	AFC	Hole chamfering tool assembly
E-49824	E-T-56370	A	9/09/77	AFC	HFIR inner control rod, layout of holes
E-49824	E-T-56371	D	9/09/77	AFC	HFIR inner control rod segment, procedure for layout and machining
E-49824	E-M-56393	B	9/09/77	AFC	HFIR inner control rod assembly
	E-T-65500		10/03/67	AFC	Mold storage container inner rod
E-49825	E-T-66750		12/21/67	AFC	Machining fixture, outer rod flange
E-49825	E-T-66756		12/21/67	AFC	Inspection fixture, outer rod flange
E-49821	E-T-66767		2/14/68	AFC	Machining and welding fixture, outer rod flange
E-49821	E-T-66773		2/14/68	AFC	Header for lower flange, outer rod
E-49825	E-T-66774		2/14/68	AFC	Header for upper flange, outer rod

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