

4

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES

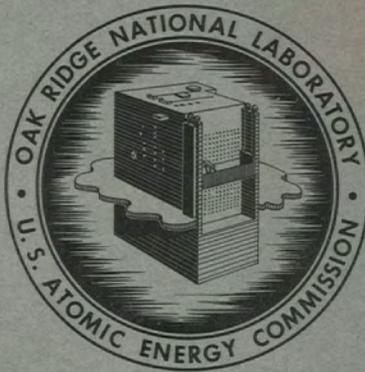
3 4456 0365935 1

ORNL-3458
UC-25 – Metals, Ceramics, and Materials
TID-4500 (22nd ed.)

SPECIFICATIONS AND PROCEDURES USED IN
MANUFACTURING U_3O_8 -ALUMINUM
DISPERSION FUEL ELEMENTS FOR CORE I
OF THE PUERTO RICO RESEARCH REACTOR

W. J. Kucera
C. F. Leitten, Jr.
R. J. Beaver

**CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION
LIBRARY LOAN COPY**
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this
document, send in name with document
and the library will arrange a loan.



OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

Printed in USA. Price: \$1.75 Available from the
Office of Technical Services
U. S. Department of Commerce
Washington 25, D. C.

— LEGAL NOTICE —

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

ORNL-3458

Contract No. W-7405-eng-26

Metals and Ceramics Division

SPECIFICATIONS AND PROCEDURES USED IN MANUFACTURING
U₃O₈-ALUMINUM DISPERSION FUEL ELEMENTS FOR CORE I
OF THE PUERTO RICO RESEARCH REACTOR

W. J. Kucera, C. F. Leitten, Jr., and R. J. Beaver

DATE ISSUED

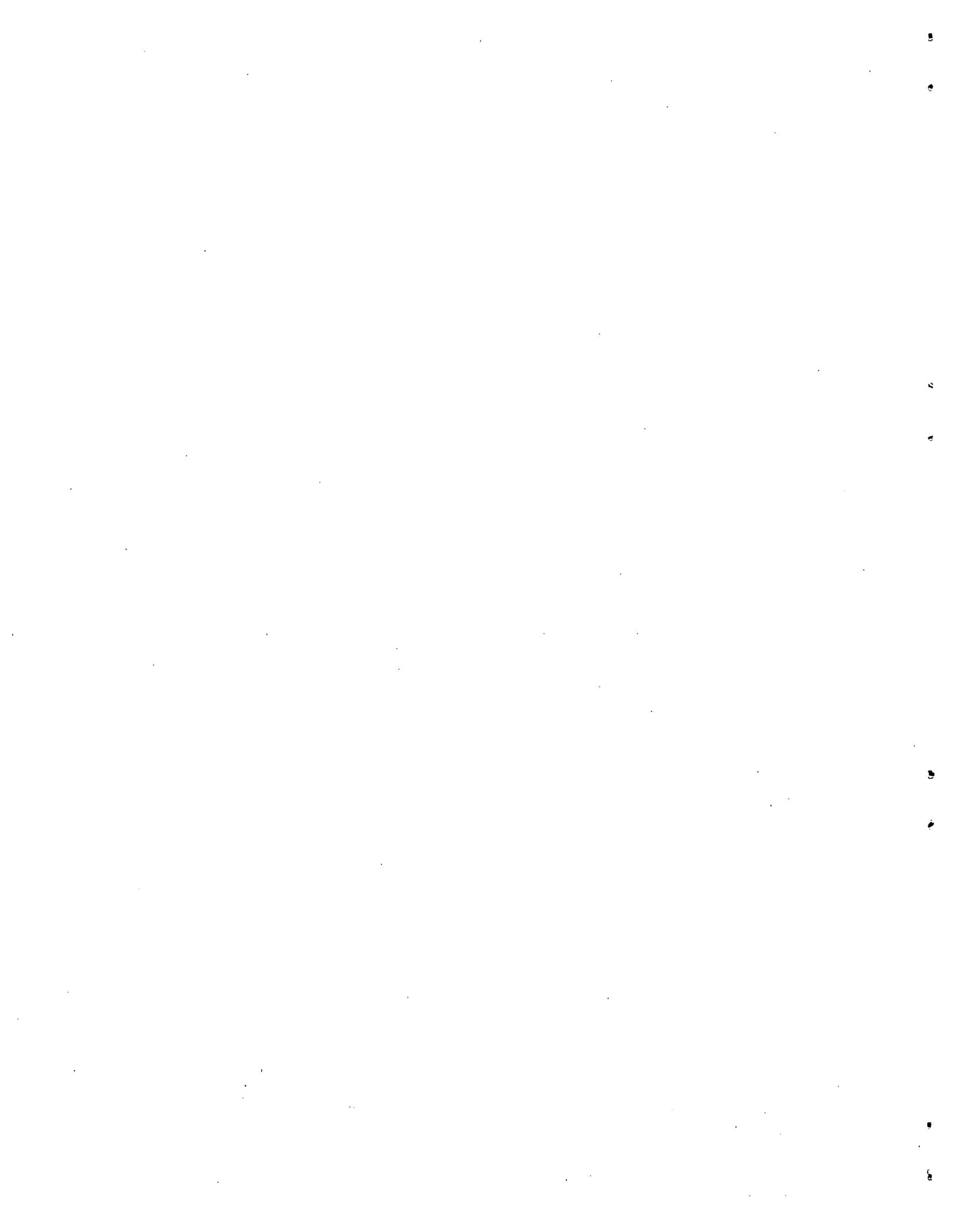
OCT 7 1963

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
U. S. ATOMIC ENERGY COMMISSION

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES



3 4456 0365935 1

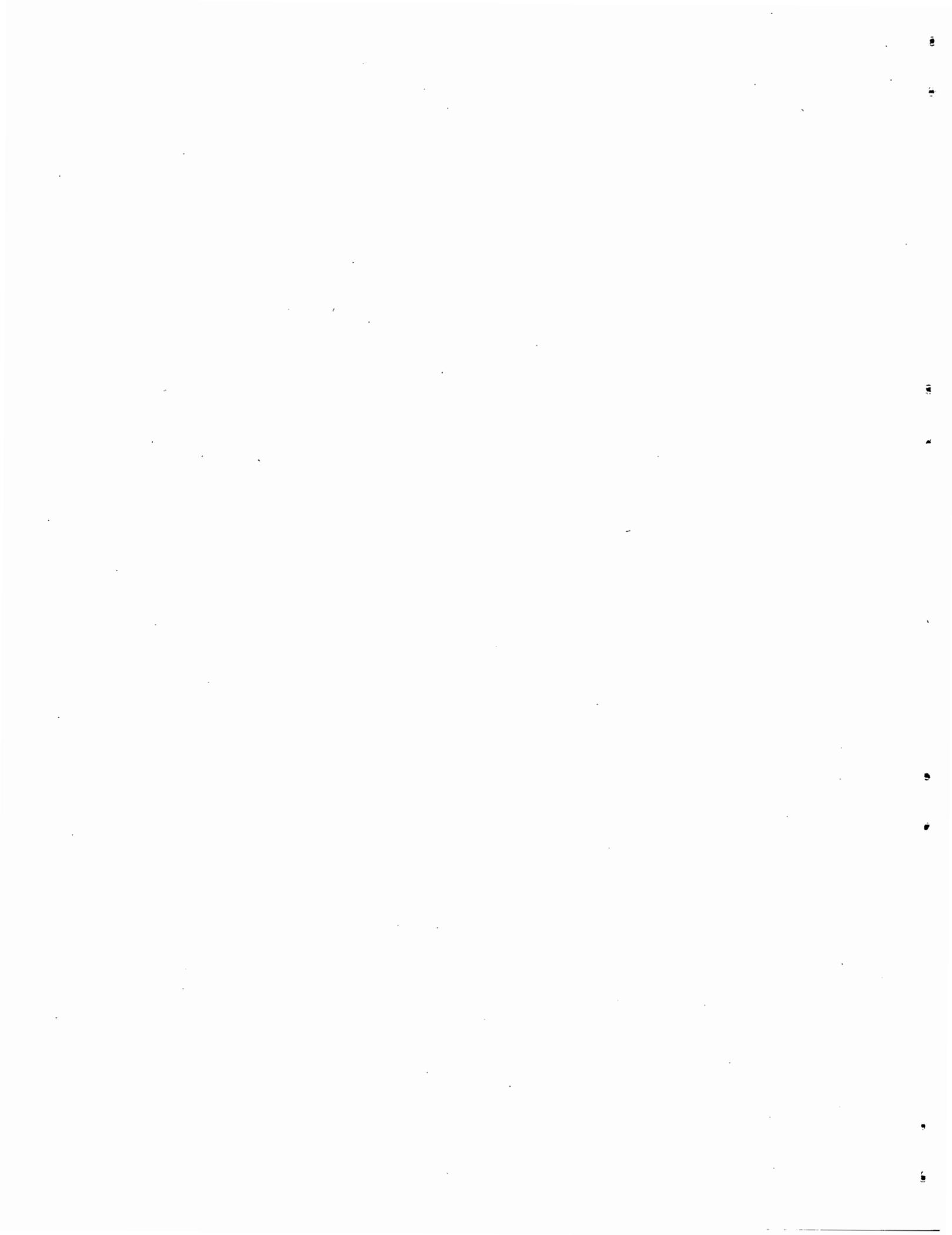


CONTENTS

	Page
ABSTRACT -----	1
I. INTRODUCTION -----	2
II. DETAILED DESCRIPTION OF FUEL ELEMENT -----	4
III. GENERAL REQUIREMENTS -----	11
IV. DESIGN AND MATERIAL SELECTION CRITERIA -----	13
A. Basic Requirements -----	13
B. Material Selection -----	14
1. Fissile Compound -----	14
2. Matrix Powder -----	15
3. Wrought Cladding and Structural Material -----	15
4. End Box Adapter Casting -----	17
5. Corrosion Protective Coating -----	17
V. STANDARD FUEL ELEMENT SPECIFICATIONS -----	17
A. Core Material Requirements -----	17
1. Fuel Loading -----	17
2. Composition of Fuel-Bearing Compact -----	17
B. Materials Specifications -----	18
1. U ₃ O ₈ Powder -----	18
2. Aluminum Powder -----	18
3. Fuel Plate Frames and Cladding -----	18
4. Fuel Element Side Plates -----	18
5. Handle and Pins -----	18
6. End Adapter -----	18
C. Dimensional Requirements -----	18
D. Finish Requirements -----	19
VI. MANUFACTURING PROCEDURES -----	19
A. Introduction -----	19
B. Records -----	19
C. Fuel Core Manufacture -----	21
1. Calculations -----	21
2. Weighing of Component Powders -----	21

	Page
3. Blending -----	24
4. Cold Pressing of the Core Ingredients -----	24
5. Sintering of Green Compacts -----	26
6. Inspection -----	26
7. Core Storage -----	26
D. Billet Assembly -----	27
1. Material Preparation -----	27
2. Welding of Billets -----	27
E. Composite Plate Fabrication -----	29
1. Hot Rolling -----	29
2. Fluoroscopic Examination -----	29
3. Annealing of Hot-Rolled Plates -----	31
4. Cold Rolling -----	31
5. Annealing of Cold-Finished Plates -----	31
6. Roller Leveling -----	31
7. Annealing of Roller-Levelled Plates -----	31
8. Fluoroscopic Examination and Marking -----	31
9. Final Shearing -----	33
10. Machining -----	33
11. Blister Anneal -----	35
12. Inspection -----	35
F. Plate Forming -----	35
G. Fuel Element Joining -----	35
1. Material Preparation -----	38
2. Assembly Procedures -----	39
H. Fuel Element Identification -----	43
I. Dimensional Inspection -----	46
J. Final Machining and Welding -----	46
1. Preliminary Machining of the End Adapter -----	46
2. Welding of End Adapter to Fuel Body -----	48
3. Final Machining -----	48
4. Attachment of Handle -----	48
K. Alodizing Treatment -----	48
L. Preparation for Shipment -----	49

	Page
VII. CONCLUSIONS -----	49
ACKNOWLEDGMENTS -----	50
APPENDIX A -----	51
APPENDIX B -----	55



SPECIFICATIONS AND PROCEDURES USED IN MANUFACTURING
U₃O₈-ALUMINUM DISPERSION FUEL ELEMENTS FOR CORE I
OF THE PUERTO RICO RESEARCH REACTOR

W. J. Kucera,¹ C. F. Leitten, Jr., and R. J. Beaver

ABSTRACT

The specifications and fabrication procedures developed at the Oak Ridge National Laboratory for incorporating heavy investments of nonweapon-grade enriched fuel into aluminum-base elements for use in research reactors are described. A thin plate-type element containing a dispersion of 20% enriched U₃O₈ was developed specifically for and successfully used in the 5-Mw pool-type research reactor at the Puerto Rico Nuclear Center.

The essential features of the component engineered for radioactive service at 60°C in relatively quiescent water are described. The underlying criteria that guided the design are presented. The technological factors, such as compatibility, corrosion resistance, and irradiation behavior, which led to the selection of U₃O₈ as the fissile compound and aluminum as the cladding and matrix material, are reviewed.

The fabrication procedures developed and adopted for manufacturing the component are presented in detail. The general scheme involves incorporation of 65 wt % U₃O₈ into aluminum compacts by powder metallurgy techniques, preparation of composite fuel plates by roll cladding, assembly of fuel plates into an integral unit by either the roll-swaging or pinning techniques, and corrosion protection of the element by an alodizing treatment to increase service life. Quality control measures that were adopted to ensure consistent production of components within dimensional tolerances on a pilot-plant basis are described.

The described procedures were demonstrated by the successful manufacture of 76 fuel elements within the established specifications. The powder-metallurgical approach to fabricating high uranium investment fuels consistently yielded fuel plates of high quality with accurate control of fuel loading and homogeneity. Mechanical joining of the fuel elements proved to be an economical method for assembling the pool-type fuel elements within dimensional specifications, thereby eliminating the need for brazing.

¹Presently with D. A. Stuart Oil Company, Chicago, Illinois.

I. INTRODUCTION

Under the Atoms-for-Peace Program of the U. S. Atomic Energy Commission, the Metals and Ceramics Division of the Oak Ridge National Laboratory (ORNL) embarked upon the development of aluminum-base fuel elements containing heavy fuel investments of nonweapon-grade enriched uranium. This work was culminated with the development of thin-plate, aluminum-base elements containing a dispersion of 20% enriched U_3O_8 and successful employment of this element in the operation of the 5-Mw pool-type research reactor at the Puerto Rico Nuclear Center (PRNC).

It is the purpose of this report to present the various aspects of materials technology advanced for incorporating heavy fuel investments into aluminum-base fuel components in an accurate and uniform manner for application in the PRNC reactor. The report describes the fuel element specifications and fabrication procedures developed and adopted for the first core loading of this reactor. The information is presented in sufficient detail to enable an industrial manufacturer to undertake the task of processing additional core loadings with only a minimum of development work. Although the procedures described in this report are specific for manufacturing only the standard fuel element employed in the PRNC reactor, the general processing scheme is also applicable to the manufacture of the control rod fuel elements and the partially loaded fuel elements.

The PRNC reactor, which was designed and engineered by AMF Atomics (a division of American Machine and Foundry), employs thin-plate-type aluminum-base fuel elements and is cooled and moderated with light water circulating through the elements at the relatively low velocity of 1.3 fps. The overall geometry of the individual plates and elements is approximately the same as normally specified for pool-type elements containing highly enriched uranium. As a result, the nonweapon-grade restriction in the enrichment of the U^{235} isotope (< 20%) dictated that each fuel plate contain a large quantity (approximately 53 g) of uranium.

Experimental studies at ORNL have shown that severe fabrication and material-control problems are encountered with the use of uranium-aluminum alloys containing such high uranium concentrations (approximately

48 wt %).^{2,3} These problems were circumvented by powder-metallurgical dispersions of a fissile-bearing compound in aluminum. The material compatibility problems associated with dispersions in aluminum of high uranium density compounds, such as UO₂ (ref 4) and UC (ref 5), can be minimized by the selection of U₃O₈ as the fissile dispersoid for this application. The superior corrosion resistance⁶ of U₃O₈-bearing aluminum dispersions in pool-type reactor water conditions as compared to a similar dispersion of UC₂ and the 48 wt % U-Al alloy also motivated the selection. Irradiation tests have demonstrated that no significant dimensional changes occur in U₃O₈-Al dispersions during exposures as high as 7.7×10^{20} fissions/cc at a fuel plate temperature of 90°C (ref 7). A dispersion of 65 wt % U₃O₈ in aluminum was therefore selected as the material for the fuel-bearing portion of the PRNC fuel plate.

In the past, the service lifetime of pool-type reactor fuel elements has been primarily limited by corrosion.⁸ Modifications were made in the manufacturing technology of conventional pool-type fuel elements, aimed at extending the life of the elements to the point where performance is limited by loss of nuclear reactivity rather than by corrosion. These modifications were the incorporation of an improved alodizing treatment for protection of the fuel plate surface and the selection of mechanical

²W. C. Thurber and R. J. Beaver, Development of Silicon-Modified 48 wt % U-Al Alloys for Aluminum Plate-Type Fuel Elements, ORNL-2602 (Mar. 9, 1959).

³W. C. Thurber and R. J. Beaver, Segregation in Uranium-Aluminum Alloys and Its Effect on the Fuel Loading of Aluminum-Base Fuel Elements, ORNL-2476 (Sept. 5, 1958).

⁴R. C. Waugh, The Reaction and Growth of Uranium Dioxide-Aluminum Fuel Plates and Compacts, ORNL-2701 (Mar. 9, 1959).

⁵W. C. Thurber and R. J. Beaver, Dispersion of Uranium Carbides in Aluminum Plate-Type Research Reactor Fuel Elements, ORNL-2618 (Nov. 5, 1959).

⁶W. J. Kucera, Met. Div. Ann. Progr. Rept. Sept. 1, 1959, ORNL-2839, pp 262-65.

⁷A. E. Richt, C. F. Leitten, Jr., and R. J. Beaver, "Radiation Performance and Induced Transformations in Aluminum-Base Fuels," pp 469-88 in Research Reactor Fuel Element Conference, September 17-19, 1962, Gatlinburg, Tennessee, TID-7642, Book 2 (1963).

⁸R. J. Beaver and J. E. Cunningham, "Recent Development in Aluminum-Base Fuel Elements for Research Reactors," pp 40-51 in Fuel Element Conference, Held at Gatlinburg, Tennessee, May 14-16, 1958, TID-7559 (Part 1) (1959).

techniques for joining the fuel elements in preference to the previously accepted brazing method.

Two methods for mechanically joining the fuel plates into the 18-plate array were investigated. One method used a roll-swaging technique in which the fuel plates were securely locked into the grooves of the side plates for forcing the guide lands immediately adjacent to each fuel plate into the edges of the plates. Approximately 30 elements were successfully assembled in this manner by the Atomic Power Equipment Department of the General Electric Company, San Jose, California, on a subcontract to ORNL. The other technique was based on joining the fuel plates to the side plates by a series of pins drawn through 1/16-in.-diam holes previously drilled through the edges of the side plates and the inactive sides of the fuel plates. The pins were spaced on 3-in. centers along the length of the side plates. The selection of two markedly different methods affords a good opportunity for comparison of performance of different types of mechanically joined fuel elements under reactor operating conditions. Since the roll-swaging methods used by the General Electric Company were proprietary, only the pinning technique employed by ORNL is described.

II. DETAILED DESCRIPTION OF FUEL ELEMENT

The active core of the PRNC pool-type reactor is composed of standard fuel elements, partially loaded fuel components, and control rod assemblies. As previously mentioned, the subject of this report is concerned only with the specifications and fabrication procedures developed for the manufacturing of the standard fuel element.

The basic segment of the standard fuel element (illustrated in Figs. 1 and 2) consists of 18 curved composite-type fuel plates joined to a pair of side plates by pinning or roll swaging to form an integral assembly with a nominal water-channel spacing of 0.117 ± 0.012 in. The curved plate is a composite of a 0.024-in.-thick core section containing 65 wt % U_3O_8 dispersed in a matrix of aluminum with 0.018-in.-thick cladding of wrought type 1100 aluminum on each side. A representative cross section of the composite plate is shown in Fig. 3. These composites were prepared by roll bonding to promote good heat transfer across the clad-core interface and to hermetically seal fuel and fission

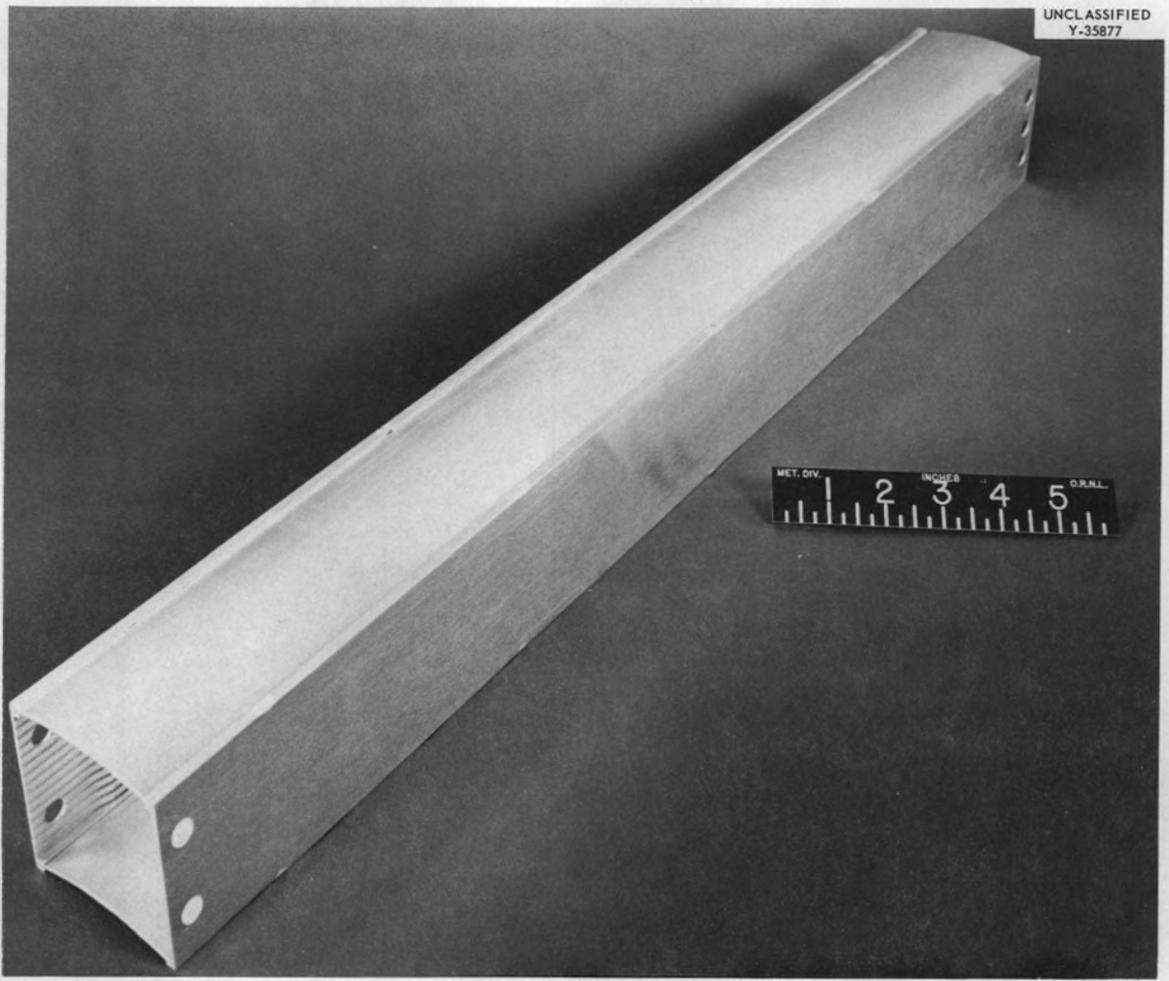


Fig. 1. Fuel Element Body Without End Box Adapters.

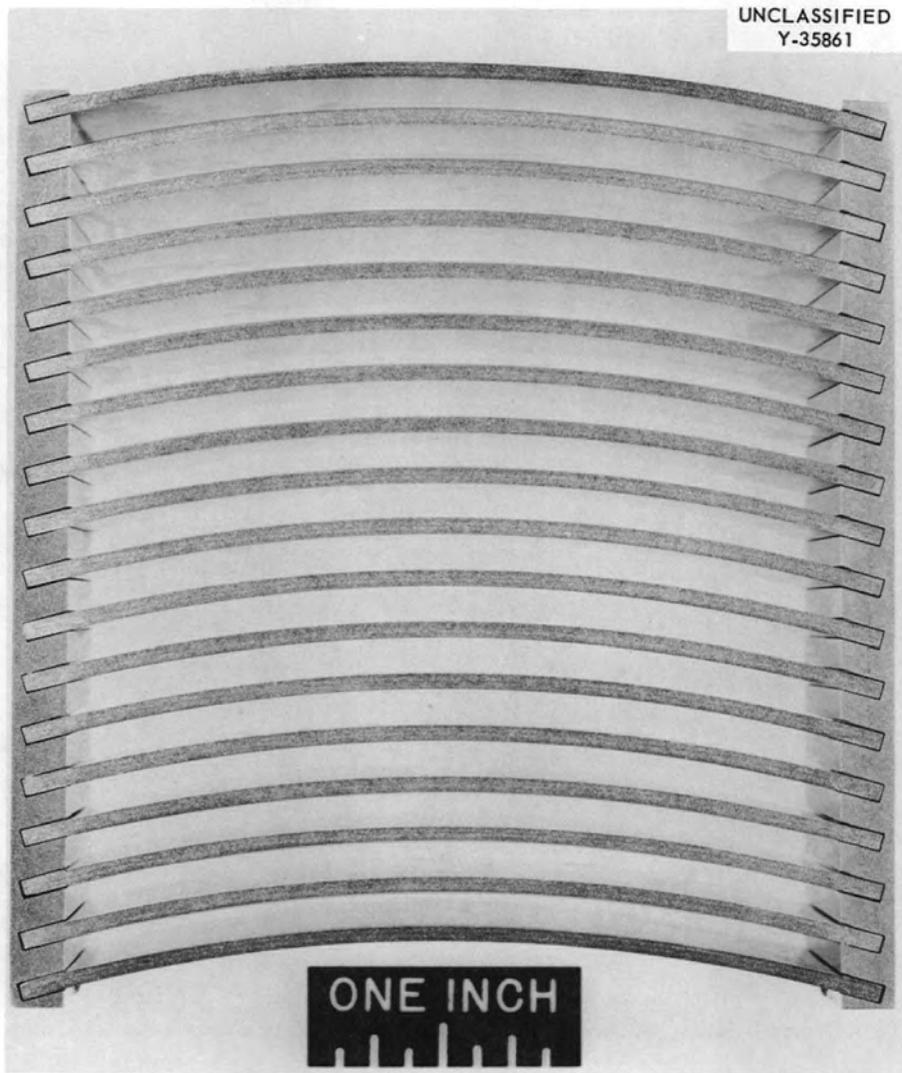


Fig. 2. Cross Section of Pool-Type Aluminum Base Pinned Fuel Element.

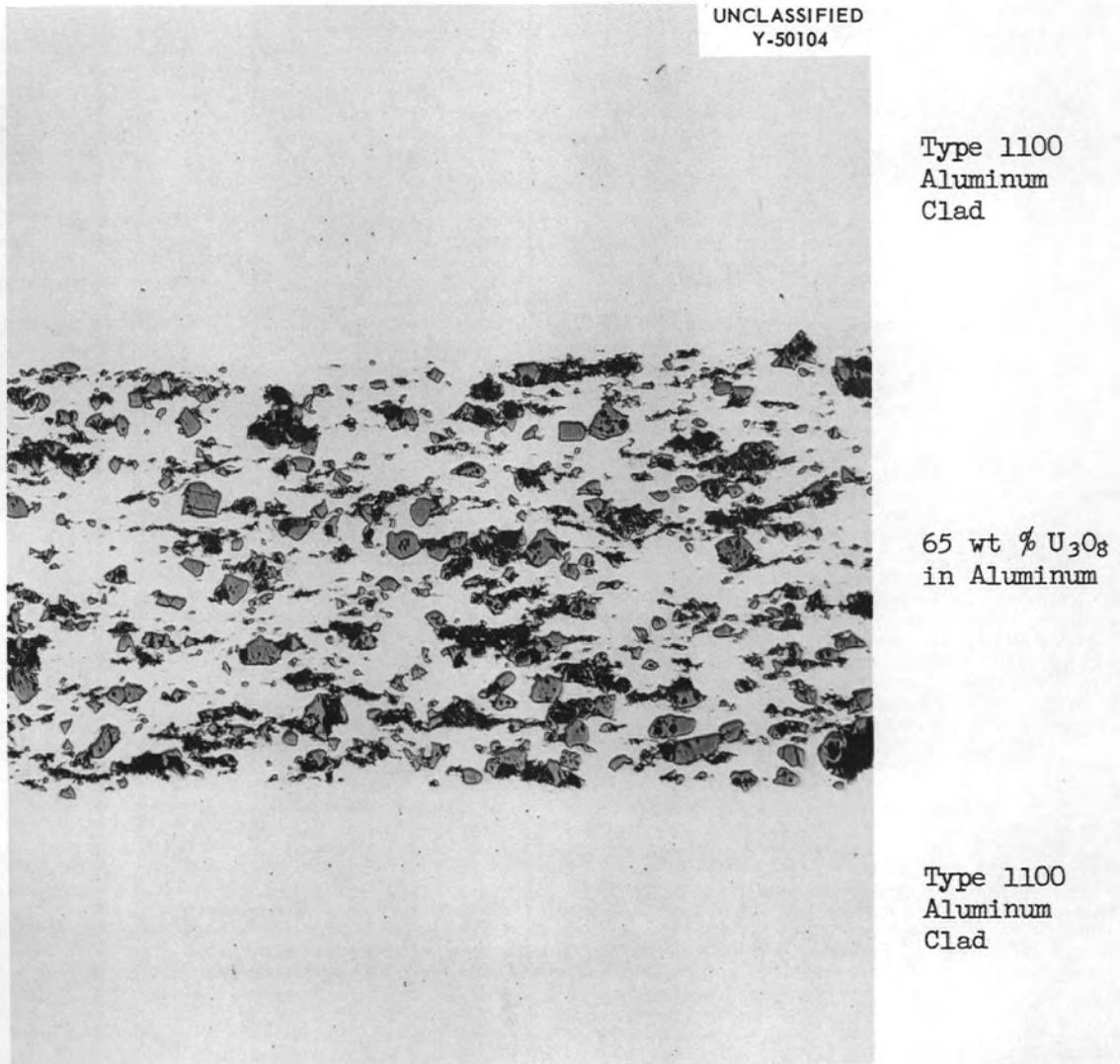


Fig. 3. Transverse Cross Section of Fuel Core Containing 65 wt % U_3O_8 in Aluminum. As-polished. 75X.

products from the water coolant. From the design and operational data presented in Table 1, it can be shown that each element contains approximately 1150 g of U_3O_8 . It should be noted in this table that the data given for makeup of the fuel-bearing section of each composite plate are for information only and will depend on the fuel enrichment, the uranium density of the compound, and the fabrication scheme.

Table 1. Pertinent Design Data for the Standard
PRNC Pool-Type Fuel Assembly

General Description			
Number of plates per assembly			18
Nominal fuel plate clad-core-clad thickness, mils			18-24-18
Nominal water gap spacing, mils			117
U^{235} content per assembly, g			192
Enrichment in U^{235} isotope, wt %			20 (max)
Nominal fuel core composition per plate			
	<u>g</u>	<u>wt %</u>	<u>vol %</u>
U_3O_8 (44-149 μ particle size)	64	64	37.0
Type 1100 aluminum (< 149 μ size)	36	36	64.2
Operating Data at 1-Mw Thermal Output			
Power density, kw/liter (av)			10
Average heat flux, Btu/hr-ft ²			6.9×10^3
Bulk water outlet temperature, °F			107
Average velocity in water-gap spacing, fps			1.3
Average thermal neutron flux, neutrons/cm ² -sec			5.2×10^{12}
Expected reactivity lifetime, Mwd			400-500
Estimated average burnup, % total U^{235} atoms in fuel-bearing section			12-14
Estimated average fission burnup, fissions/cc			1.3×10^{19}

A detailed drawing of the standard fuel element with dimensional requirements for this component is shown in Fig. 4. As illustrated in the detailed assembly drawing shown in Fig. 5, a cast-aluminum fitting was attached to the side plates at one end of the fuel-bearing segment

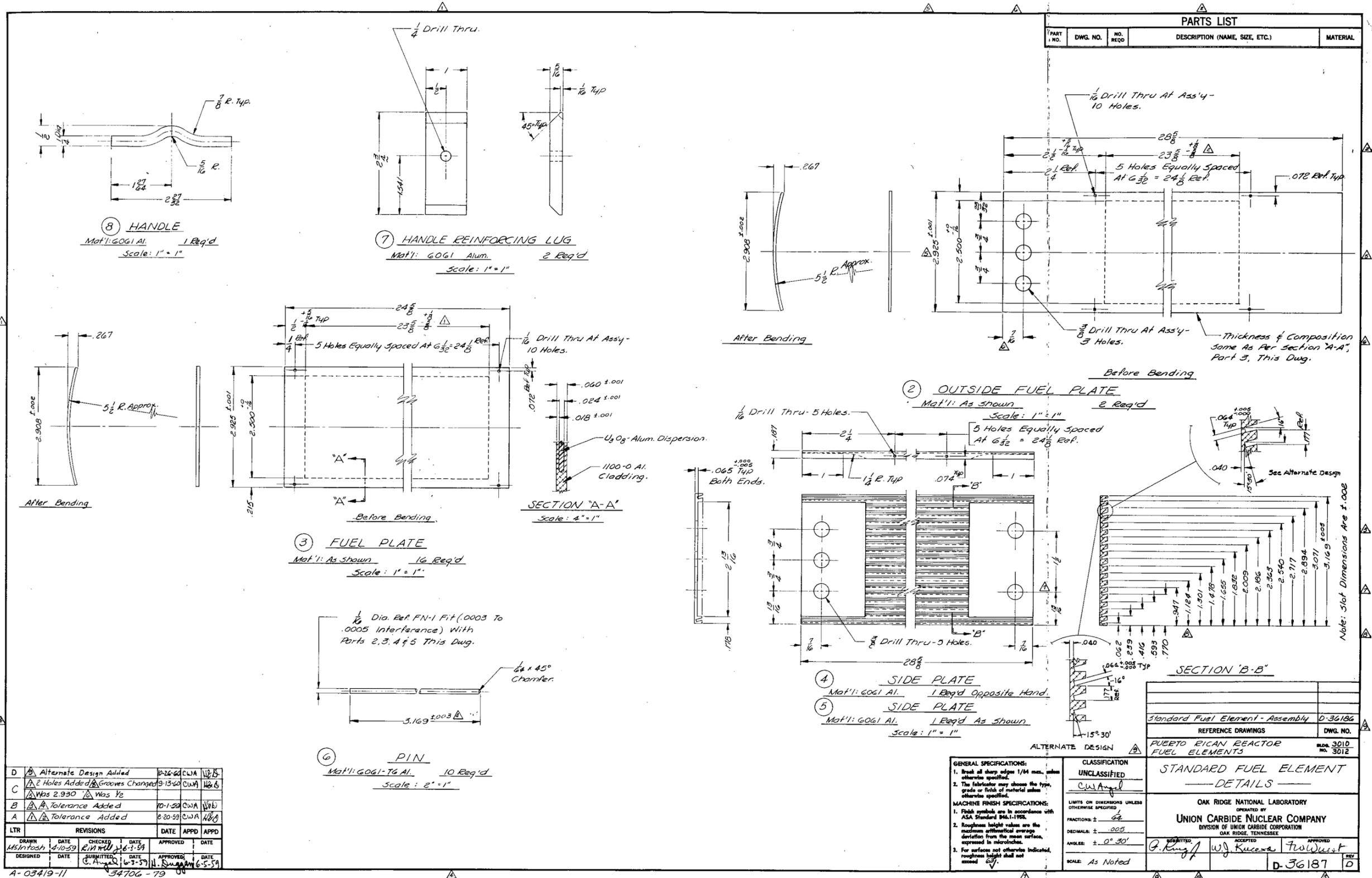


Fig. 4. Standard Fuel Element Details.

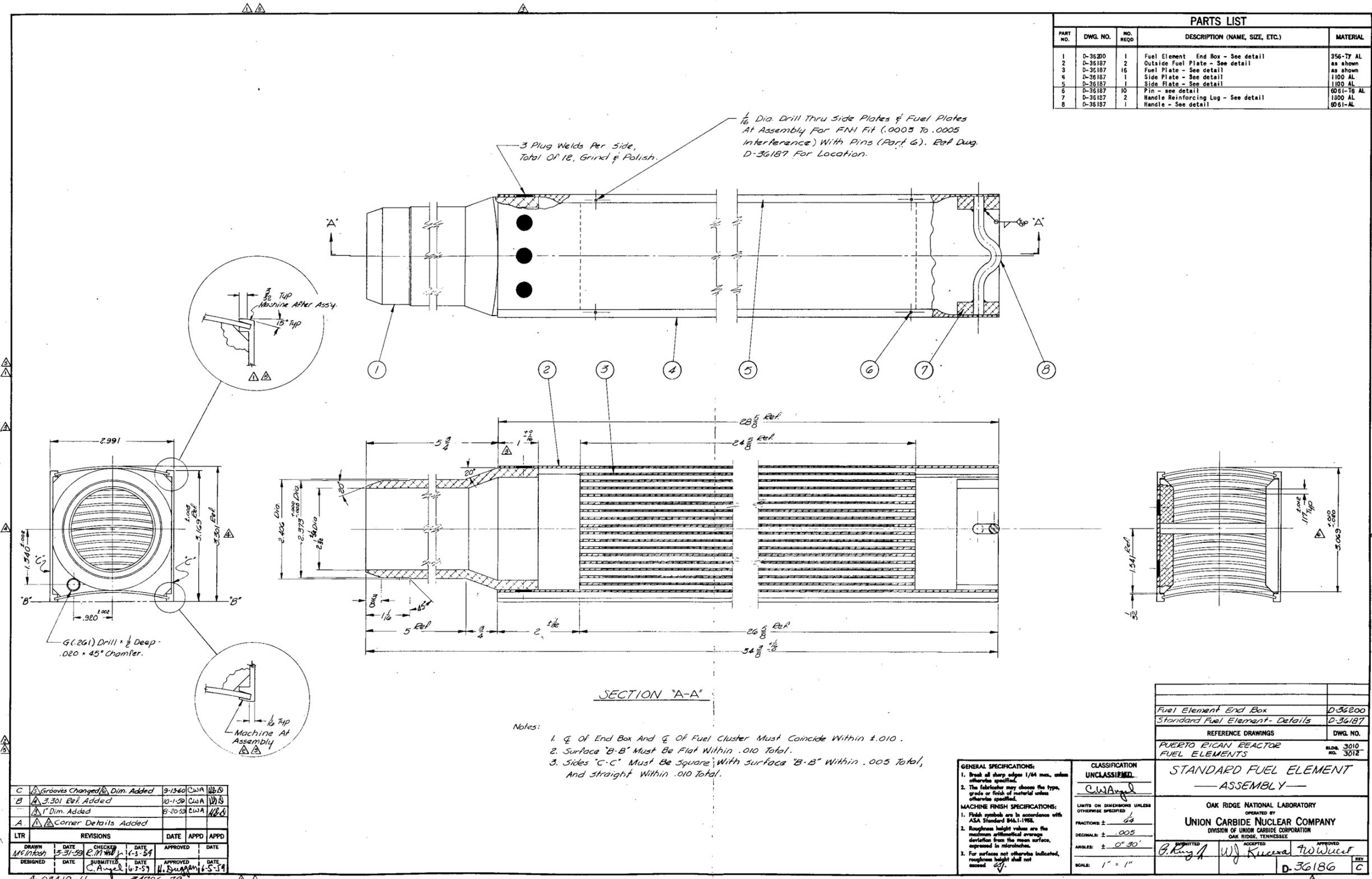


Fig. 5. Standard Fuel Element Assembly.

by tungsten inert-arc plug welding. The purpose of the end fitting is to adapt the unit to the supporting grid, which fixes the position of the element in the reactor core. (A detailed drawing of the fuel element end box is included in Appendix B along with the dimensional drawings for the control rod fuel element.) A handle is welded to the opposite end of the fuel element to facilitate handling of the element in the reactor. An overall view of the assembled fuel element is shown in Fig. 6.

III. GENERAL REQUIREMENTS

Satisfactory performance of the reactor and of the fuel components during their operating life required that special precautions be taken to ensure the following:

1. Accurate incorporation of the desired quantity of fuel into the component was mandatory. Loading greater excess reactivity than specified into the active core could lead potentially to a serious nuclear incident, while an error in the opposite direction could impair the reactivity lifetime of the core.
2. Uniform distribution of the fuel in the core of the composite plate had to be achieved. Inhomogeneity of this important ingredient could lead to undesirable hot spots.
3. A continuous metallurgical bond between clad and frame material and between clad and core-matrix material had to be obtained to (a) protect the fuel from corrosion by the coolant, (b) contain the highly poisonous by-products of fission, and (c) promote efficient heat removal. The nature of the resulting bond had to be free of potential blisters, which could rupture and release fission products to the coolant.
4. Uniformity in thickness of clad and core material had to be maintained to ensure proper corrosion protection and to achieve the required uniform concentration of fuel over the entire area of the active portion of the fuel plate.
5. The composition and processing of materials had to be controlled to minimize the presence of contaminants, which might (a) accelerate corrosion, (b) contribute to the parasitic absorption of neutrons,

UNCLASSIFIED
Y-52271

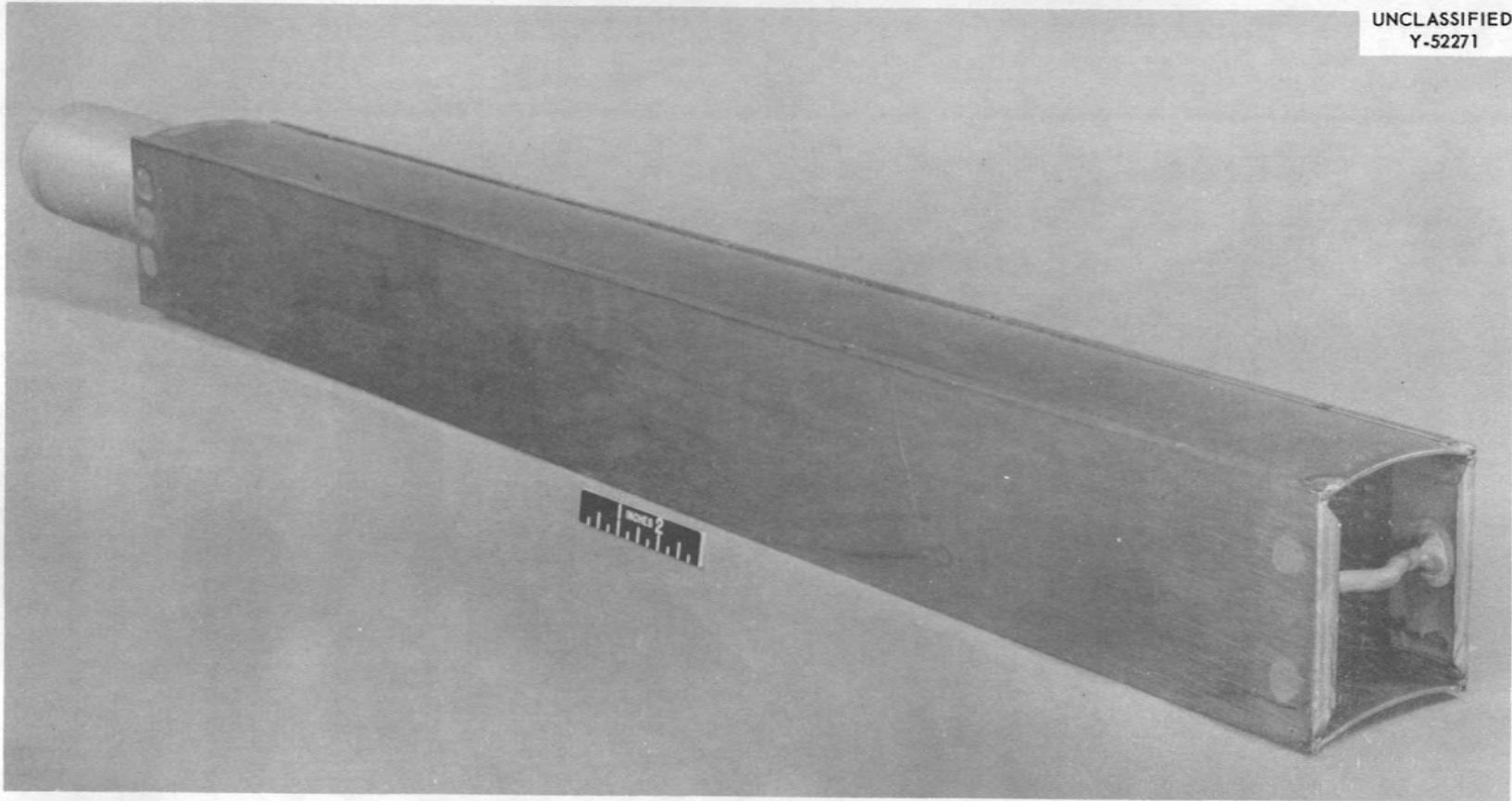


Fig. 6. Overall View of Pool-Type Pinned Fuel Element.

(c) reduce mechanical integrity, (d) promote diffusion or migration of fuel, (e) impair heat transfer, (f) promote gas release, leading to swelling or blistering, which could restrict coolant flow and ultimately result in cladding failure, and (g) increase the level of radioactivity in the pool water by contaminating the fuel element surfaces with traces of fissionable or fertile materials or other elements capable of undergoing transmutation and giving rise to high activity levels.

6. The various steps of framing, cladding, shearing, and machining had to be carried out and inspected in a manner to preclude the presence of fissionable material at the clad-frame interface, as well as to ensure that no portion of the fuel-bearing core was exposed to the coolant.

Experience in the manufacture of the first 76 fuel elements for the PRNC reactor has demonstrated the feasibility of fabricating components that consistently meet the product standards required.

Sufficient and proper supervisory and production control was provided (1) to ensure that all details of the fabrication procedure conformed at all times with the approved procedure, (2) to maintain rigid adherence to all specification requirements, (3) to protect personnel against human intake of alpha-emitting U_3O_8 by inhalation or ingestion, (4) to enforce safety measures to prevent a criticality incident, and (5) to safeguard and account for all fissionable material in accordance with the approved Atomic Energy Commission requirements.

Sufficient and proper records were maintained to supply complete metallurgical history, fuel accountability, inspection, quality control, and other pertinent data required in the fabrication of the fuel elements.

IV. DESIGN AND MATERIAL SELECTION CRITERIA

A. Basic Requirements

The design of and selection of material for the fuel element for service in the PRNC reactor was based on the following criteria:

1. The use of nonweapon-grade fissionable uranium in which the U^{235} isotopic concentration is limited to 20 at. %.
2. Cladding of the fuel-bearing material to afford corrosion protection and to retain fission products during service lifetime.

3. Dispersing of the fuel in a suitable diluent to maximize heat transfer and to prevent structural damage to the material of construction by overheating.

4. Utilization of inexpensive materials of construction and low-cost manufacturing methods to minimize processing costs.

5. Employment of a fuel-core-to-cladding metallurgical bond and thin plate-type construction to promote efficient heat removal.

B. Material Selection

In general, incorporation of the fuel in the form of a uranium-aluminum alloy containing greater than 35 wt % U is not considered practical because of the difficulties of obtaining plates having reproducible fuel concentrations with satisfactory homogeneity and fabricability. Therefore, the development of aluminum-base fuel elements requiring high uranium investments centered on the selection of a uranium-bearing compound that is chemically compatible when dispersed in aluminum and processed at elevated temperatures. The resultant dispersion should also have good radiation stability to prevent dimensional growth of the fuel plates and good corrosion resistance to minimize leakage of the highly radioactive fission products in the event of a clad failure.

1. Fissile Compound. Extensive studies at ORNL on the chemical compatibility, corrosion resistance, and irradiation stability of several high uranium density compounds dispersed in aluminum have shown that the refractory compound U_3O_8 meets these general requirements. Unlike UO_2 and UC dispersed in aluminum, U_3O_8 is compatible with aluminum in fuel element processing requiring temperatures as high as $600^\circ C$.^{9,10,11} Dispersions of U_3O_8 in aluminum exhibit better corrosion resistance in water at $180^\circ F$ than either a dispersion of UC_2 in aluminum or a

⁹R. C. Waugh, The Reaction and Growth of Uranium Dioxide-Aluminum Fuel Plates and Compacts, ORNL-2701 (Mar. 9, 1959).

¹⁰W. C. Thurber and R. J. Beaver, Dispersion of Uranium Carbides in Aluminum Plate-Type Research Reactor Fuel Elements, ORNL-2618 (Nov. 5, 1959).

¹¹Metals Handbook, 8th edition, Vol 1, pp 931-36, American Society for Metals, Novelty, Ohio, 1961.

48 wt % U-3 wt % Si-Al alloy.¹² In addition, the compound U_3O_8 can be produced in an economical manner and has a relatively high uranium content. Dispersions of U_3O_8 in aluminum are also relatively insensitive to radiation damage at pool-type reactor temperatures as manifested by the negligible volume changes noted after exposures as high as 7.7×10^{20} fissions/cc (ref 13). The chief disadvantages of low thermal conductivity and brittleness, which are characteristic of U_3O_8 , are largely overcome by its being dispersed in aluminum.

Although U_3O_8 can be prepared by a variety of methods to yield a product with various characteristics, a fairly dense and inert grade of oxide with an oxygen-to-uranium ratio near stoichiometric is desirable for use in the dispersion-type fuel elements. The product should be free of agglomerates, platelets, rods, and clinging surface fines, which give rise to fragmentation and stringering during processing. In addition, particles larger in size than 44μ are desirable to minimize fission-fragment damage to the matrix aluminum. The dead-burned U_3O_8 developed at the Y-12 Plant of the Union Carbide Nuclear Company (UCNC) meets these requirements. Procedures for manufacturing this type of U_3O_8 are listed in Appendix A. The typical appearance of powder received from Y-12 is illustrated in Fig. 7.

2. Matrix Powder. The dispersant in the fuel-bearing compacts was -100 mesh, type 1100 aluminum.

3. Wrought Cladding and Structural Material. Wrought type 1100 aluminum was selected as the cladding and type 6061 aluminum as the structural material for the PRNC components. These materials are relatively cheap, readily available in the desired form, and amenable to most mechanical working and welding operations.¹¹ They have good corrosion resistance in quiescent low-temperature water and adequate strength and ductility to withstand the thermal stresses and gradients encountered in

¹²W. J. Kucera, Met. Div. Ann. Progr. Rept. Sept. 1, 1959, ORNL-2839 pp 262-65.

¹³A. E. Richt, C. F. Leitten, Jr., and R. J. Beaver, "Radiation Performance and Induced Transformations in Aluminum-Base Fuels," pp 469-88 in Research Reactor Fuel Element Conference, September 17-19, 1962, Gatlinburg, Tennessee, TID-7642, Book 2 (1963).

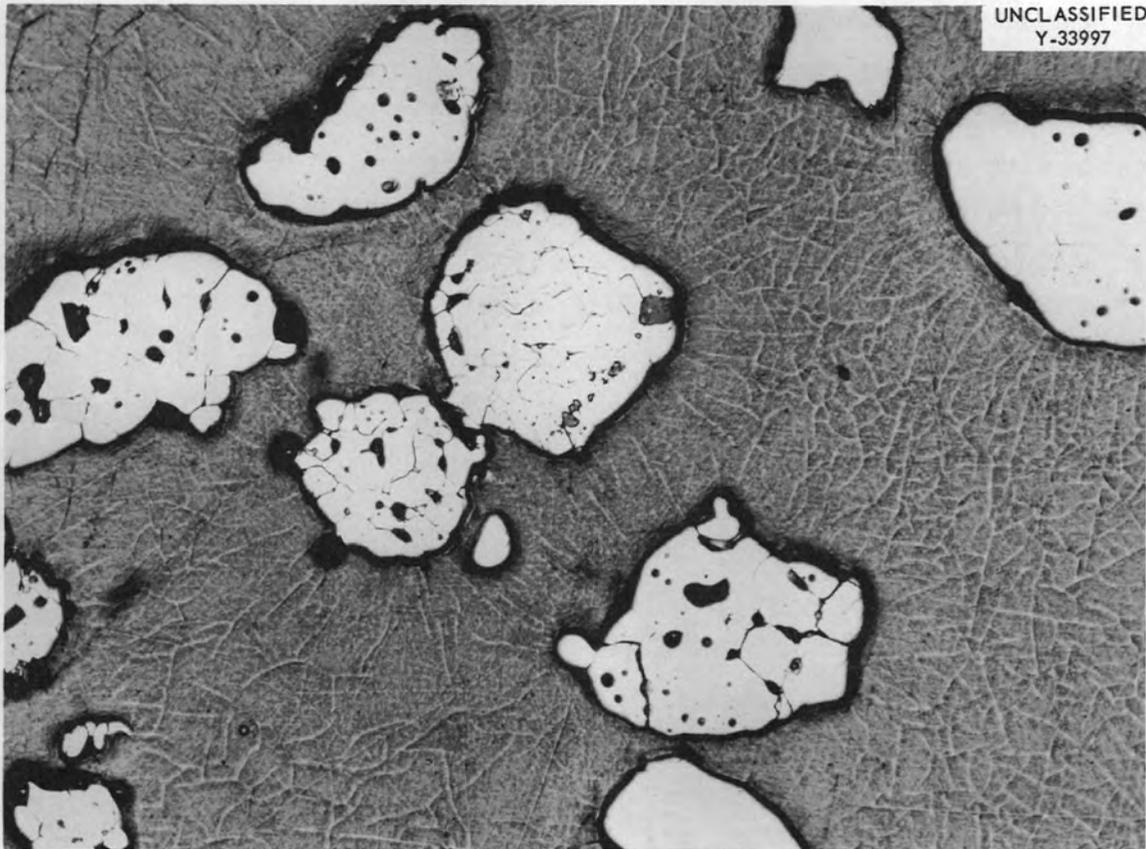


Fig. 7. Typical Appearance of Dead-Burned U_3O_8 Received from Y-12 and Used in PRNC Fuel Elements. 250X.

operation.¹⁴ The alloys have excellent heat-transfer properties and are not subject to serious structural damage under irradiation.¹⁵

4. End Box Adapter Casting. Type 356-T6 aluminum was the material selected for the end adapter. Castings prepared by either sand- or permanent mold-casting techniques were suitable.

5. Corrosion Protective Coating. Alodine 1200, a product of the American Chemical Paint Company, Ambler, Pennsylvania, was selected as the protective coating for aluminum surfaces to minimize pitting and extend the life of the pool-type fuel element.

V. STANDARD FUEL ELEMENT SPECIFICATIONS

A. Core Material Requirements

1. Fuel Loading

U ²³⁵ content per plate, g	10.67 ± 1%
U ²³⁵ isotopic concentration, wt %	19.65 ± 0.35%

Allowable Tolerances¹⁶

Weighing	±0.05%
U _T /U ₃ O ₈	±0.25%
U ²³⁵ /U _T limit of error at 95% confidence level	0.05%
Handling loss	-0.19%

2. Composition of Fuel-Bearing Compact. Typical fuel and matrix requirements per plate are as follows:

64 g of U₃O₈ and 36 g of type 1100 aluminum powder.

The exact weight of matrix material per plate is subject to the considerations described in Section VI.

¹⁴R. B. Mears, "Aluminum and Aluminum Alloys," pp 42-43 in The Corrosion Handbook, ed. by H. H. Uhlig, John Wiley and Sons, Inc., New York, 1948.

¹⁵S. H. Bush, "Aluminum and Its Alloys," pp 498-99 in Reactor Handbook, 2nd ed., Vol 1, ed. by C. R. Tipton, Jr., Interscience Publishers, Inc., New York, 1960.

¹⁶Allowable tolerances were established by ORNL as a result of evaluation of the uncertainties involved in fabricating Core I.

B. Materials Specifications

In addition to any other requirements, all materials specified below were certified by the seller to contain less than 10 ppm B and 80 ppm Cd.

1. U₃O₈ Powder. The U₃O₈ powder used in the PRNC fuel plates was prepared at the Y-12 Plant at Oak Ridge, Tennessee. The procedure for manufacturing this material is outlined in Appendix A. The oxide particle sizes ranged from 44 to 149 μ (-100 +325 mesh) and were 99.9% pure. The minimum acceptable density was 7.4 g/cm³. Enrichment of the uranium in the U²³⁵ isotope was 19.65 \pm 0.035 wt %.

2. Aluminum Powder. The aluminum powder conformed to the Specifications for the Aluminum Company of America's Atomized Powder No. 101.

3. Fuel Plate Frames and Cladding. The fuel plate frame and cladding material was type 1100 aluminum, conforming to the requirements for alloy 990A prescribed in the Tentative Specifications for Aluminum Alloy Sheet and Plate (ASTM Designation: B 209 - 58 T).

4. Fuel Element Side Plates. The side plate material was type 6061 aluminum, conforming to the requirements for alloy GS 11A tempered to T6 condition prescribed in the Tentative Specifications for Aluminum Alloy Sheet and Plate (ASTM Designation: B 209 - 58 T).

5. Handle and Pins. The handle and pin material was type 6061 aluminum, conforming to the requirements for alloy GS 11A prescribed in the Tentative Specifications for Aluminum Alloy Bars, Rods, and Wire (ASTM Designation: B 211 - 58 T).

6. End Adapter. The end adapter for the fuel assembly was type 356 aluminum, conforming to the requirements for alloy GS 70A tempered to the T6 condition, prescribed in the Tentative Specifications for Aluminum-Base Alloy Sand Castings (ASTM Designation: B 26 - 58 T) or Tentative Specification for Aluminum-Base Alloy Permanent Mold Castings (ASTM Designation: B 108 - 58 T).

C. Dimensional Requirements

The component parts were manufactured and assembled in accordance with the dimensional specifications set forth in the drawings listed as follows:

Dwg 36200 Rev A	Fuel Element End Adapter
Dwg 36187 Rev D	Standard Fuel Element - Details
Dwg 36186 Rev C	Standard Fuel Element - Assembly
Dwg 36185 Rev C	Control Rod Fuel Element - Details
Dwg 36184 Rev C	Control Rod Fuel Element - Assembly

D. Finish Requirements

All machined surfaces in contact with the coolant had a finish of at least 125 RMS except where noted on the drawings. Rolled surfaces had a surface finish of at least 50 RMS.

VI. MANUFACTURING PROCEDURES

A. Introduction

The flow of material in processing standard fuel elements for the PRNC is illustrated in the simplified diagram shown in Fig. 8. The essential operations required in processing were: (1) weighing and blending of the component powders for each individual fuel compact, (2) pressing and coining into a compact of the required dimensions, (3) sintering, (4) encapsulating the core within a welded billet, (5) cladding by roll bonding, (6) descaling of the hot-rolled plate, (7) cold rolling to specified final thickness, (8) annealing, (9) roller leveling, (10) marking and shearing of the composites, (11) machining to finished length and width dimensions, (12) assembly and joining, (13) inspection of fuel element, (14) attachment of end adapters, (15) final machining, and (16) alodizing. After final inspection, the elements were degreased and packaged for shipment to the reactor. These general procedures and the more specific details, which will be described later, represent methods developed and adopted by ORNL for manufacturing aluminum-U₃O₈ fuel elements for service in the 5-Mw pool-type reactor at PRNC.

B. Records

During processing, positive identification of each fuel plate was maintained along with appropriate data in order to ensure: (1) proper process control, (2) quality control, (3) metallurgical history record,

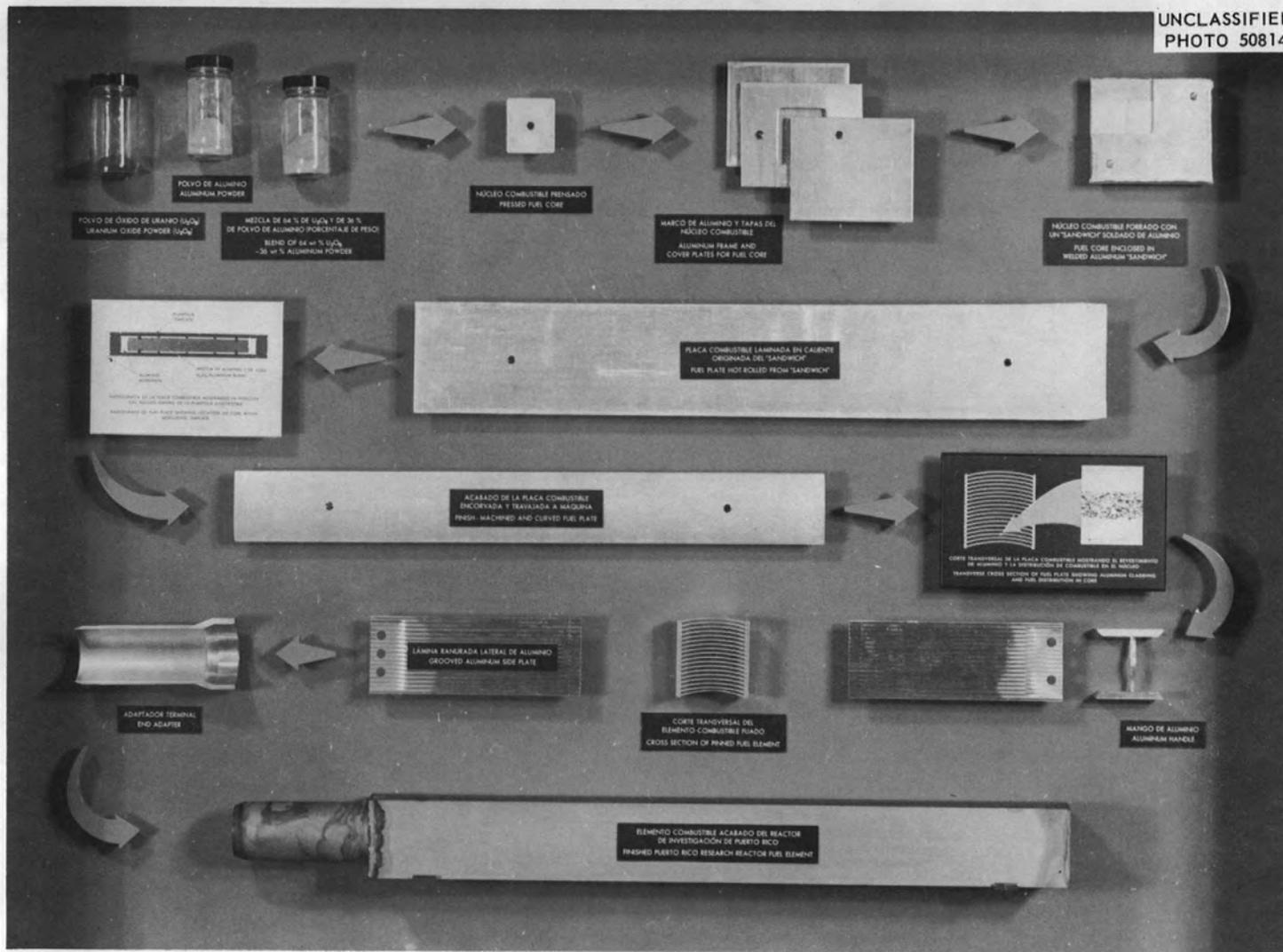


Fig. 8. Flow-Processing Diagram.

(4) removal of rejected material, and (5) fuel accountability. Records of the following items were maintained: (1) identification of each lot of U_3O_8 received from the U_3O_8 processing plant, (2) master log containing materials makeup data and the detailed processing schedule employed in the manufacturing of each plate, and (3) fuel element critical dimensions.

C. Fuel Core Manufacture

1. Calculations. The fuel and matrix powders were specified in terms of grams of U^{235} and aluminum. Since the fuel was used in the form of U_3O_8 , it was necessary to determine by calculation the quantities of these materials which were to be incorporated into each core. Each batch of as-received U_3O_8 was assayed for total uranium content as well as for isotopic concentration of U^{235} .

Sample calculations illustrating the method used to determine the quantity of U_3O_8 required in each fuel plate are listed below.

Data required:

wt % U^{235} in U	19.65
wt % U in U_3O_8	84.00
g U^{235} per plate	10.67

Determination of grams of U_3O_8 per plate:

$$\text{Grams of } U_3O_8 = \frac{10.67 \text{ (g } U^{235}\text{)}}{\frac{84.00}{100} \text{ (wt \% U in } U_3O_8\text{)} \times \frac{19.65}{100} \text{ (wt \% } U^{235}\text{ in U)}}$$

As might be expected, the final density or the densification factor $\left(\frac{\text{measured density}}{\text{theoretical density}}\right)$ of the as-fabricated core material has a significant effect on the charge of aluminum powder required to meet dimensional specifications in the finished composite plate. This factor was determined to be 0.95 for the specific equipment and processing methods employed at ORNL.

2. Weighing of Component Powders. The component powders for each individual compact were separately weighed and combined in a single blending jar. Except that it does not allow for possible losses during subsequent pressing and sintering operations, this method offered accurate accounting of the U^{235} in each fuel compact within the limits

of the accuracy of the balance. The aluminum powder was the first material loaded into the blending jar and was followed by the U_3O_8 . This sequence permits the aluminum powder to be handled in air in a conventional manner, thus eliminating the inconvenience of weighing it within a dry box as is required during handling of finely divided U_3O_8 . During processing, ten jars were handled as a unit operation. The weighing procedure for the individual components was as follows:

a. Weighing of the aluminum powder. The aluminum powder was weighed to an accuracy of at least 0.05% on a pan balance. A 4- x 4-in. sheet of glazed paper with glazed side up and of known weight was first placed on the pan. The aluminum powder was then added to the paper and accurately weighed. The material was then poured into a clean, wide-mouthed glass jar of 4-oz capacity. A camel's-hair brush was used to brush any remaining particles of aluminum into the jar, which was then capped.

b. Weighing of U_3O_8 powder. Uranium oxide was weighed in the sealed protective box shown in Fig. 9, connected to an exhaust system to maintain a slight negative pressure. The box was designed with sufficient capacity to hold ten jars or more. Gloves were attached to the two front ports and access to the interior was gained through the side port. The box was equipped with a pan balance of 100-g capacity on which the U_3O_8 could be weighed with an accuracy of $\pm 0.05\%$. The quantity of U_3O_8 required for one fuel compact was weighed directly on the scale pan of the balance using a scoopula for fine adjustment of fuel quantity. The specified weight of fuel was added to the jar containing the aluminum powder. The jar was then capped and placed on the right or exit side of the box.

These operations were repeated until the lot of ten jars had been processed. The jars were decontaminated by wiping the outside with tissue paper and were withdrawn through the side port. After removal from the dry box, the joint between the cap and the jar was sealed with masking tape. The U_3O_8 lot number was then marked on each jar and the jar placed in a transfer box for removal to the blending area. When the supply of U_3O_8 remaining in the dry box was insufficient to prepare ten compacts, it was set aside for later use in smaller lots.

UNCLASSIFIED
Y-13060

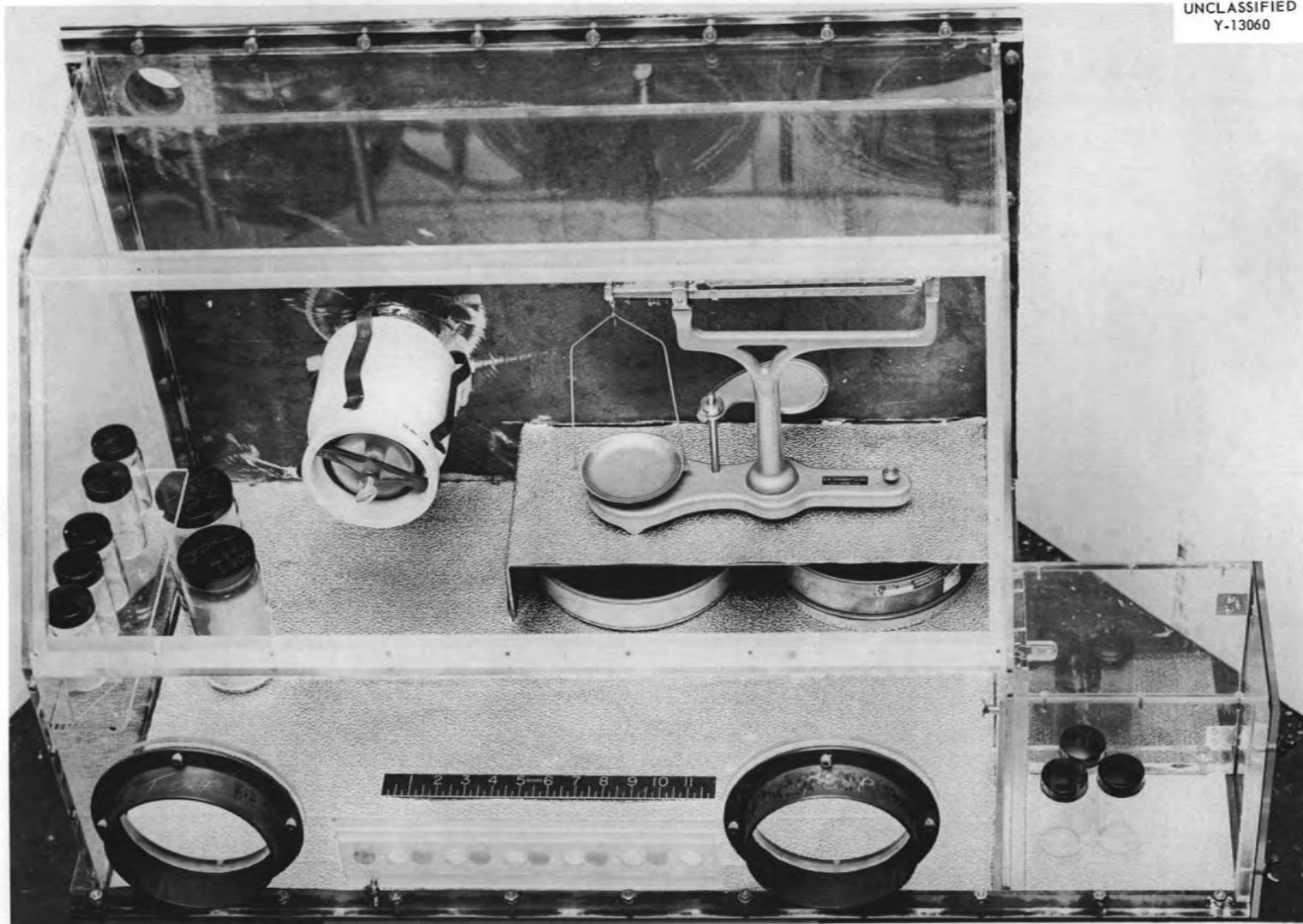


Fig. 9. Enclosure for Weighing U_3O_8 Powders.

3. Blending. In order to obtain a homogeneous mixture of fuel and matrix material, the powders were blended in a modified U. S. Stoneware Company Double Cone Blender, Model 733. The standard blender cones were replaced by a pair of two-quart steel cans mounted on the motor shaft at an angle of 30° with the vertical. Ten jars, each containing the specified quantities of U_3O_8 and aluminum, were loaded into each can with sufficient padding to prevent breakage of the jars during blending. The powders were blended by rotating the cans at their oblique angle for 3 hr.

4. Cold Pressing of the Core Ingredients. The first step in shaping the blended powders into a compact suitable for assembling into a fuel plate billet was to cold press into a "green" compact. A Baldwin press of 150-ton capacity and with a Vickers hydraulic control system to permit variable movement of the ram was employed for compaction. The press has two rams, a fixed upper ram extending down from the top cross-piece and a movable lower ram. On the top of the movable lower ram was fastened a large platen, onto which was placed the dry box containing the die set. The die set, illustrated in Fig. 10, consisted of a die punch, a filler block, and a female die, which was spring mounted to the movable ram. The bottom of the die punch contacted the movable ram, while the top of the filler block, inserted into the die cavity after the powder, contacted the stationary ram.

Since pressing of the blended powders again involved handling finely divided U_3O_8 , hooding under slightly negative pressure was necessary to prevent human intake of airborne activity by ingestion or inhalation. Figure 10 illustrates the dry box containing the pressing dies. The top of the box, not shown, was built with a hole in the middle which was sealed with a rubber gasket to permit motion along the stationary ram without excessive leakage.

Ten jars containing the blended powders, a 1/4-in. camel's-hair brush, a scoopula, and a bottle of 10 wt % cp stearic acid-90 wt % carbon tetrachloride die lubricant were inserted into the pressing box. By use of the glove ports, strips of lubricant for each die charge were applied with the camel's-hair brush around the top of the die cavity and the lower sides of the filler block. Occasionally the die face was

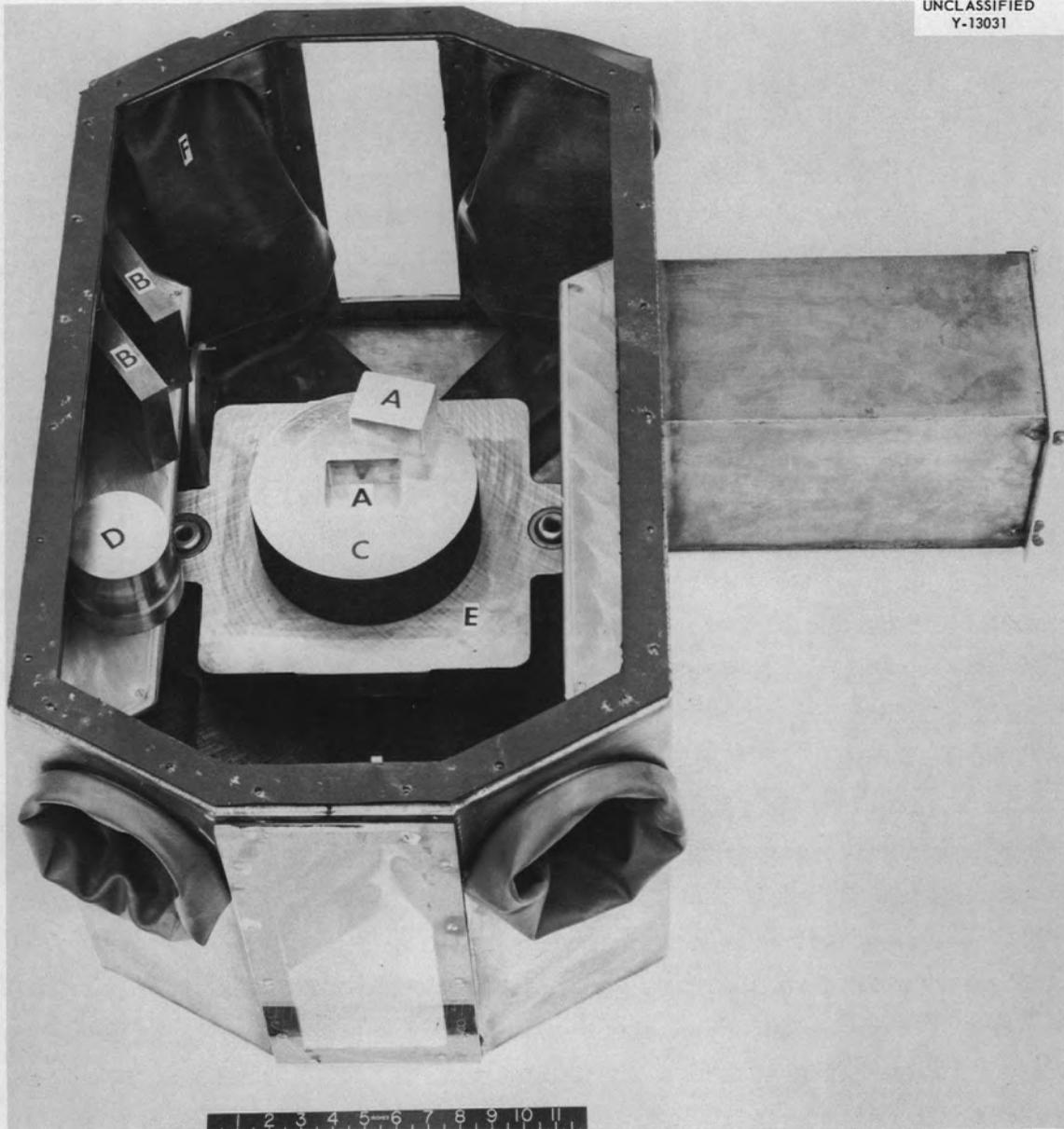
UNCLASSIFIED
Y-13031

Fig. 10. Enclosure for Pressing Compacts Containing Dispersions of U_3O_8 in Aluminum: (a) Die Punches, (b) Compact Ejection Blocks, (c) Die Body, (d) Filler Block, (e) Die Set, and (f) Dry Box.

lubricated when it became roughened to the extent that the pressed compact adhered to it. The powder was poured from a blending jar into the die cavity and the jar was brushed thoroughly to ensure complete transfer. Once the material for the compact had been loaded into the die, it was leveled with the scoopula. The filler block was inserted into the die and the lower ram was then raised until the stationary ram was contacted. The blended powders were then pressed at 33-tsi pressure (approximately 142-ton total force) for 15 sec to a thickness of approximately 0.317 in. The filler block was removed and the green compact ejected. After ten charges had been pressed, the compacts were loaded into a stainless steel transfer box which was then closed and removed from the dry box. The U_3O_8 lot number was recorded.

5. Sintering of Green Compacts. The compacts were sintered in air in a conventional resistance-wound furnace with a maximum operating temperature of $1000^{\circ}C$. Two layers of ten green-pressed compacts each were placed in a shallow aluminum pan lined with a heavy gage stainless steel screen. Also, a stainless steel screen separated the two layers. The compacts were then sintered for 1 hr at $400^{\circ}C$.

6. Inspection. To establish the U^{235} content, the compacts were weighed in batches of ten before and after sintering. Batches whose gross weights deviated from the nominal batch weight by more than 0.5% were placed aside for individual compact weighings. Individual compacts which deviated by more than 1.0% from the nominal weight were rejected. Weight changes during sintering were generally negligible, but the batches were weighed again to ascertain that the weight had not decreased because of damage, such as chipping of a corner, which could have occurred during handling in the sintering operation. The thickness of each compact was measured with a micrometer after the heat treatment. Compacts whose thickness at the corners varied by more than 0.005 in. were rejected. Obvious flaws such as cracks and chips were also cause for rejection.

7. Core Storage. Each acceptable lot of ten compacts was wrapped in paper, marked with a U_3O_8 lot number, and placed in a desiccator. If a storage time of more than 48 hr was required, a vacuum desiccator was used. Criticality control limited the number of compacts which could be stored in a single desiccator at any one time to a maximum of 80.

D. Billet Assembly

1. Material Preparation. As illustrated in Fig. 11, each fuel plate billet required two cover plates and one picture frame in addition to a fuel compact. Cover plates were fabricated from 1/4-in.-thick aluminum plate by cold rolling to a thickness of 0.224 ± 0.002 in. and shearing to $4 \frac{1}{4} \times 5 \pm 1/16$ in. Picture frames were fabricated from 5/16-in. aluminum plate by cold rolling to 0.302 ± 0.002 in. and shearing to $4 \frac{1}{4} \times 5 \pm 1/16$ in.

It was important that the aluminum plate be tested for blisters. After cold rolling to specified thickness, the material was tested by annealing in air for 3 hr at 600°C . Any portion that blistered was rejected. A core hole 1.963×2.270 in. with 1/8-in. corner radius was then punched from the center of the picture frame.

Immediately prior to billet assembly, both surfaces of the picture frame and the surfaces of the cover plates which contact the picture frame and core were thoroughly cleaned by scratch brushing with a power-driven stainless steel brush. Attention is called to the identical dimensions of the fuel core and the hole in the frame. The core width and length were designed to be identical to the frame in order to obtain an interference fit between core and frame. These were assembled by heating the frame to 500°C , slipping the cold fuel core into the expanded hole, and then allowing the frame to cool to room temperature. The 0.015-in. greater thickness of the fuel core provided excess fuel material that during subsequent roll cladding flowed into the voids that remained after shrink fitting.

2. Welding of Billets. The cover plates were welded to the picture-frame plate by the inert-gas tungsten-arc method. Since the object of the welding was to prevent possible shifting of the billet components during initial hot-rolling operations, only a tack weld was required. The four corners were left unwelded for a nominal distance of 1/2 in. to permit escape of entrapped air during the initial stage of hot rolling.

Billets that were not processed immediately were stored in a vacuum desiccator to prevent oxidation. Security, criticality, and accountability regulations dictated careful control during storage.

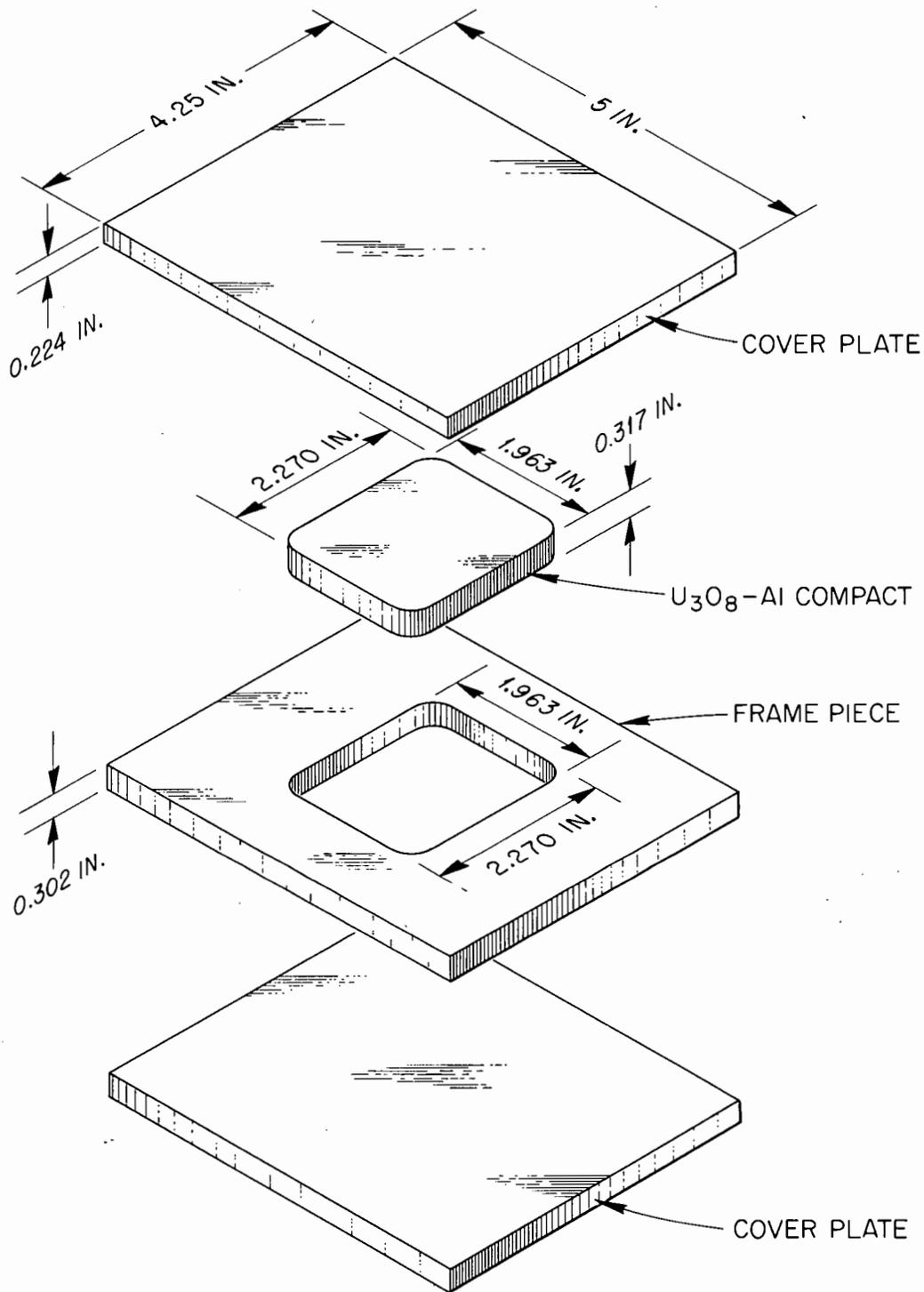
UNCLASSIFIED
ORNL-LR-DWG 6970R3

Fig. 11. Design of Billet Used in Roll Cladding PRNC Fuel Plates.

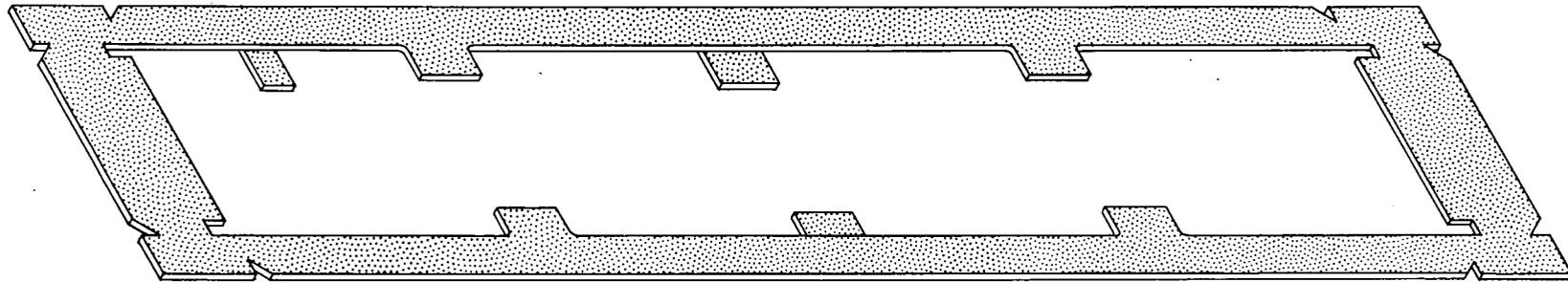
E. Composite Plate Fabrication

1. Hot Rolling. The assembled and welded billets were hot rolled in lots of ten to a thickness of 0.064 ± 0.002 in. on a two-high United Mill equipped with 12-in.-diam \times 14-in.-wide rolls. The billets were heated in a furnace to $600 \pm 10^\circ\text{C}$ for at least 60 min prior to the first pass and were reheated for at least 5 min between passes. The billets were rotated about their longitudinal and transverse axes between passes. They were hot rolled in two passes at 10% reduction followed by sufficient passes (approximately 8) at 30% reduction to obtain the required thickness. The actual thickness of the hot-rolled plate was measured with a micrometer near the end of the fabrication schedule, and the schedule was modified as required.

Special care was exercised during rolling to minimize cambering or "rainbowing" of the plates, which tended to decrease the amount of aluminum at the inactive edge and, if severe, could be cause for rejection. Cambering of the fuel plate could possibly be corrected, if not too severe, by passing the plate through the mill at a slight angle. Gross rainbowing occurring during hot rolling or during the initial stages of cold rolling usually could not be corrected. A level mill and proper feeding were maintained to circumvent this difficulty.

After cooling and prior to fluoroscopic examination, the hot-rolled plates were lettered and numbered consecutively starting with A-1 for the first plate processed. Letters and numbers 1/2 in. high were stamped on the inactive section at either end near the edge of the plate. The letter identified the U_3O_8 batch and the numbers identified the individual plates processed from that batch.

2. Fluoroscopic Examination. After visual inspection, acceptable plates were fluoroscoped using a 175-kvp machine to locate internal defects, determine straightness, and delineate the fuel-bearing core section of the composite plate. A template, illustrated in Fig. 12, was used to scribe lines for shearing. The template was constructed to locate scribe lines 1/2 in. beyond the sides of the fuel core and $2 \frac{3}{4}$ in. beyond the ends for either long or short plates. The template was centered over the core before the scribe lines were made. The fuel plate number was then restamped, with the same identification previously used,



30

SCALE 0 1 2 3 4 5 6 7 8 9 10 INCHES

Fig. 12. Rough Shearing Template for PRNC Fuel Plates.

at a location just inside the scribe line at the same end of the plate. A good impression was made to assure retention of identification throughout subsequent processing.

3. Annealing of Hot-Rolled Plates. Prior to cold rolling, the plates were annealed for 1 hr at 500°C to remove stresses induced in the last few passes of the hot-rolling process.

4. Cold Rolling. The annealed fuel plates were cold rolled to accurately obtain the required plate thickness, using the same two-high United Mill that was used for hot rolling. The hot-rolled plates were cold reduced in thickness approximately 2% per pass to a final thickness of 0.060 ± 0.001 in. Total cold reduction in thickness was approximately 6.7%. Total overall reduction (both hot and cold) was 92.0%.

The cold-rolled plates were degreased in trichloroethylene vapor preparatory to subsequent fabrication procedures.

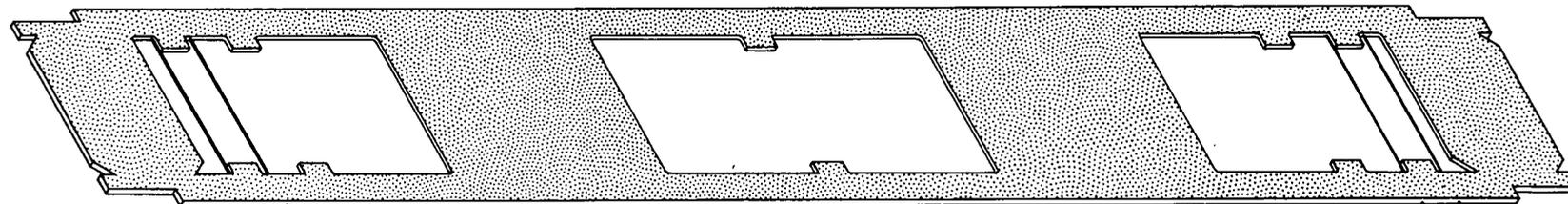
5. Annealing of Cold-Finished Plates. Annealing of the cold-worked plate for 1 hr at 500°C was found to be desirable for obtaining reproducible flat plates in the subsequent roller-leveling operation.

6. Roller Leveling. A Stanat Roller Leveler, Model DRL-211, was used to obtain a high degree of flatness in the fuel plates that were not sufficiently flat after cold rolling. This was accomplished in two passes. After the first pass, the plate was rotated about the longitudinal and transverse axes.

7. Annealing of Roller-Levelled Plates. Roller-levelled plates were again degreased in trichloroethylene vapor and annealed for 1 hr at 500°C.

8. Fluoroscopic Examination and Marking. The active fuel core within the fuel plate was located by comparing its fluoroscopic outline to that of a template positioned over the plate. As illustrated in Fig. 13, the template was designed to permit positioning of the fuel section symmetrically with respect to the subsequently sheared edges and ends of the plate and to ensure sufficient aluminum at the edges and ends to meet the dimensional specifications. The plates were marked to establish reference lines for shearing.

Prior to shearing, the fuel plate number was again inscribed, this time with a Burgess Vibrotool in letters and numbers about 1/4 in. high at the plate end inside the scribed line.



SCALE 0 1 2 3 4 5 6 7 8 9 10 INCHES

Fig. 13. Final Shearing Template for PRNC Fuel Plates.

9. Final Shearing. The scribed long side was sheared first. Using stops on the shear at a fixed reference, the other long side was sheared to yield a plate width of $3 \pm 1/64$ in. The ends of the plates were then sheared from the scribe lines to lengths of $24 \frac{3}{4} \pm 1/16$ in. and $28 \frac{3}{4} \pm 1/16$ in. for inner and outer plates, respectively.

10. Machining. The fuel plates were machined to final width, using the machining fixture illustrated in Fig. 14. The fixture consisted of a rectangular frame and a movable clamp plate to securely hold the stack of fuel plates. The top and bottom edges of the frame were ground parallel. Two parallel-ground 2-in.-thick blocks were employed to support the fixture above the milling machine table. In stacking and machining the fuel plates, the ends of the fixture were securely fastened to the table with step blocks and horseshoe clamps.

The fuel plates were usually machined in lots of 40 on a vertical milling machine. Prior to machining, aluminum backup plates of 1/8-in. thickness and of the same length and width as the sheared composites were placed on each side of the stack of plates. All plates were referenced for machining from two parallel blocks that were placed on the milling machine table and positioned between the two ground blocks supporting the fixture. After aligning each plate edge with references to the parallel blocks, the open edge of the stack was machined with a Carbaloy flycutter tool. A table speed of $2 \frac{1}{4}$ to $3 \frac{1}{8}$ in./min and an arbor velocity of 545 RPM to 815 RPM, depending on the quality of the cutting tool, were used for this operation. After rotating the fixture 180° and reclamping to the table, the fuel plates were machined to the required width, which was measured with a micrometer.

After removal from the fixture, the stack of fuel plates was machined to the required length on the same vertical milling machine using a 4-in.-long side-cutting mill. The lot of plates was clamped to the table over two supporting blocks. Equal amounts of aluminum were removed from each end of the stack. After completion of the machining operations, the plates were degreased in a vapor degreaser and the machined edges were lightly deburred by hand filing at a 45° angle. Special care was taken to minimize rounding of the edges.

UNCLASSIFIED
ORNL-LR-DWG. 76182

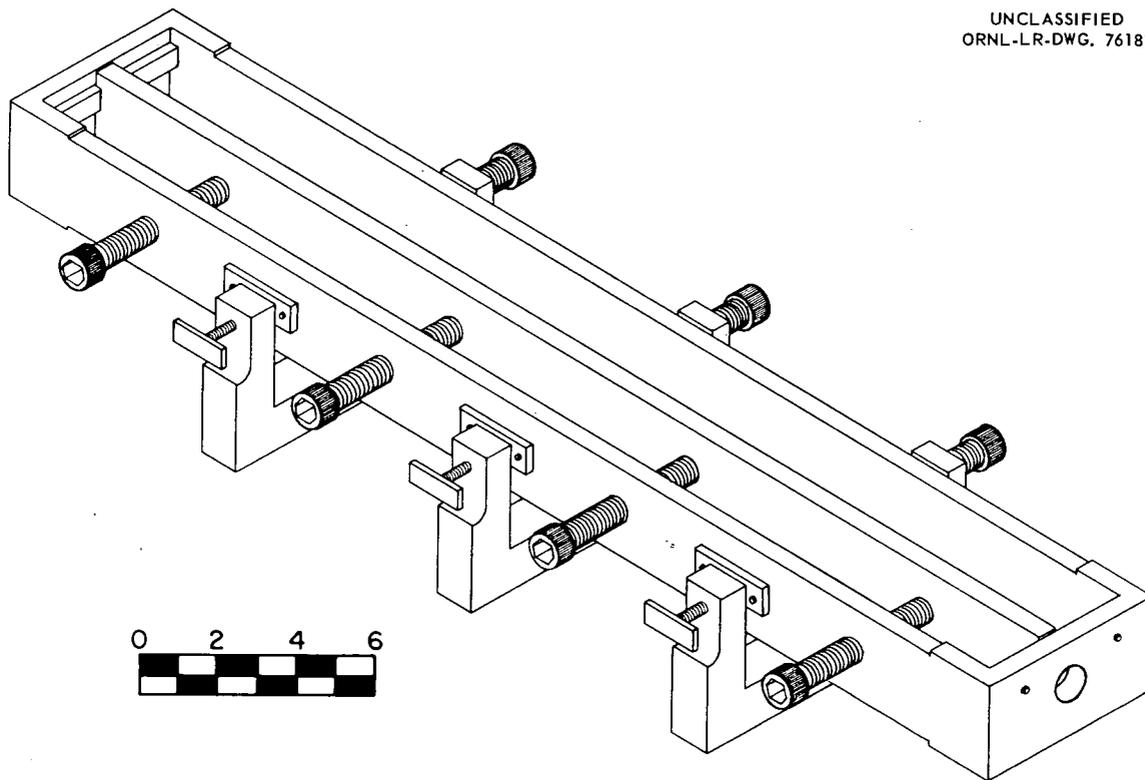


Fig. 14. Fuel Plate Machining Fixture.

11. Blister Anneal. Prior to forming, the machined and deburred fuel plates were blister annealed for 1 hr at 500°C. This treatment was basically designed to determine whether blisters would appear on the surfaces of the fuel plates when heated at 500°C and was the final test for bonding of the composite plate or defects in the cladding. Plates which had visible blisters were rejected.

12. Inspection. All fuel plates were fluoroscopically inspected to ensure that the specified dimensions had been met. Final inspection templates, shown in Figs. 15 and 16, were constructed on the go-no-go principle. Minimum core width of 2.437 in. and maximum width of 2.500 in., as well as minimum and maximum inactive edge widths, were inspected with this template. Width inspection slots were spaced 2.437 in. apart and 0.032 in. wide. The width between the outer edge of the slot and the edge of the template was 0.212 in. Length inspection slots were spaced to determine whether or not the core length lay within the 23-in. minimum and 23 3/4-in. maximum specified.

One plate representative of each production batch of ten plates was radiographed to examine for (1) homogeneity of the U_3O_8 and (2) existence of fuel particles in the presumably solid aluminum ends of the fuel plate. The radiographic procedures were designed to obtain maximum contrast between the U_3O_8 particle and the aluminum matrix. Segregation was most frequently observed as streaks of low- or high-density material. If a plate exhibited segregation or the appearance of U_3O_8 particles in the "inactive" plate ends, it was rejected and the plates remaining in the batch were radiographed to determine their acceptability.

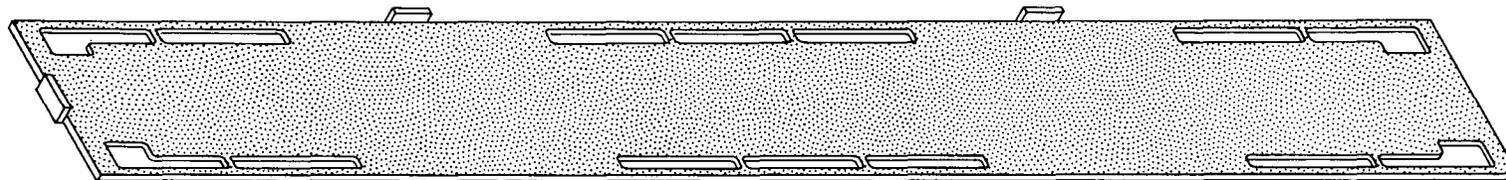
F. Plate Forming

The fuel plate was formed to a 5 1/2-in.-nominal radius by pressing at 20 tons (approximately 475 psi) at room temperature, using a metal-to-metal die. After forming, each plate was degreased in trichloroethylene vapor and thoroughly rinsed in turbulent water at 90°C.

G. Fuel Element Joining

Fuel plates were positively attached to the side plates by drawing a pin through an assemblage of plates. The general procedure was:

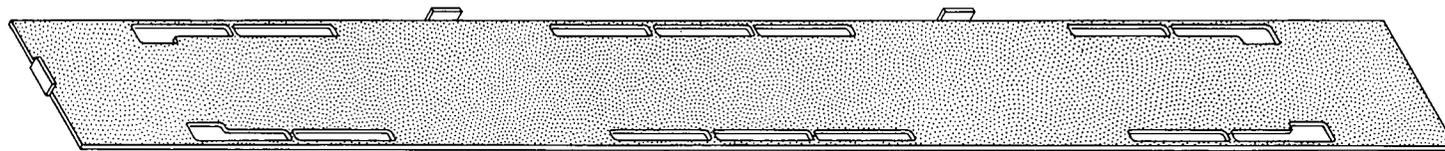
UNCLASSIFIED
ORNL-LR-DWG 29458



SCALE 0 1 2 3 4 5 6 7 8 9 10 INCHES

Fig. 15. Final Inspection Template of PRNC Inner Plate.

UNCLASSIFIED
ORNL-LR-DWG 29459



SCALE 0 1 2 3 4 5 6 7 8 9 10 INCHES

Fig. 16. Final Inspection Template for PRNC Outer Plate.

(1) drill 1/16-in.-diam holes through the edges of the side plates; (2) groove the side plates; (3) assemble the fuel plates into the grooves of the side plates; (4) using the holes in the side plates as guides, drill through the inactive sides of the fuel plates; (5) draw pins through the side plates and fuel plates; and (6) weld the pins to the edges of the side plates.

1. Material Preparation

a. Side plates. The side plates were machined from 0.187 ± 0.003 in. aluminum sheet stock and were sawed to $29 \times 3 \frac{1}{2} \pm \frac{1}{16}$ in. in size. Each plate was deburred with a file after sawing. A stack of twenty plates was then sandwiched between two pieces of 1/8-in.-thick aluminum sheet of approximate side-plate dimensions to prevent distortion of the side plates during milling. The assembly was table clamped lengthwise and was straddle milled on a horizontal milling machine. Two 8-in.-diam staggered-tooth steel cutters rotating at approximately 20 rpm with a 1/2 in./min feed were used to mill the stack of plates to final width in one pass. The assembly was then transferred to a vertical milling machine and was machined to the proper length with a side-cutting mill rotating at 150 rpm with a 1 in./min feed.

Prior to grooving, 1/16-in.-diam holes were drilled through the edges of the side plates at locations shown in Fig. 4. Each side plate was completely deburred with a file to ensure a good grip by the vacuum chuck employed during grooving. The chuck was 36×12 in. with vacuum holes on 1/2-in. centers. Holes not covered by the side plate were covered with two layers of heavy masking tape. The vacuum for the chuck was supplied by a large industrial vacuum cleaner. The 18 grooves per plate were cut in one pass on a horizontal milling machine. Special care was exercised in locating the saw blades on the machine arbor to ensure that the dimensions were correct. The cutters rotated at 60 rpm and the feed was about 1 5/8 in./min. A heavy sulfur-base cutting oil was used for lubrication.

Subsequent to machining and grooving, the plates were degreased and each plate was dimensionally inspected. The "backbone" of all of the grooves in the side plate was determined with a micrometer or with a thin roller attached to a dial indicator. The groove separations were

measured with a micrometer from plates inserted in the grooves or with a disk-type micrometer.

b. Retention pins. An important concept in the pinning technique was the design of the pin in two 4-in. sections, one 0.0615 in. in diameter and the other 0.053 in. in diameter. This allowed easy insertion of the 0.053-in.-diam portion through the 0.062-in.-diam holes in the side plate edges and inactive sides of the fuel plate. When pulled through, the wider portion of the pin galled in position, thus rigidly fixing itself and the fuel plates in place. The pins were welded to the side plates. If for some unanticipated reason the welds were to fail in service, it is extremely unlikely that the retention pins would fall out of the element.

The pins were prepared from 1/16-in.-diam type 6061 aluminum wire. The wire was sheared into 10-ft sections, filed to a point at one end, and then drawn through an 0.0615-in.-diam die. The drawn wire was sheared to 8-in. lengths and a 4-in. segment at one end was swaged to 0.053 in. The swaged pins were annealed for 1 hr at 600°C and then air cooled, straightened, and stored in 8-in.-long, 1-in.-diam tubes.

2. Assembly Procedures. Figure 17 demonstrates the fuel plate-side plate assembly jig relationships during assembly. As illustrated, fuel plates were consecutively inserted in the side plates from the lowermost position, with the numbered end of the fuel plate and the two-holed end of the side plates at the open jig face. Individual fuel plate positions within a fuel unit were recorded at assembly. Spring-loaded end clips were fastened to the open jig face after the last fuel plate had been inserted and the nonstationary jig side member was tightly bolted, as shown in Fig. 18. Plate spacings were spot checked with 0.105-in.- and 0.129-in.-diam go-no-go gages and element width was measured along the upper side plate edges. Any measurement not within the allowable channel spacing (0.105 to 0.129 in.) or fuel element width (2.986 to 2.996 in.) required a partial or complete reassembly.

Figure 19 illustrates the redrilling operation in which the assembled fuel plates were pierced for acceptance of the retention pins. A 1/16-in.-long shank, short-twist drill was guided through the side

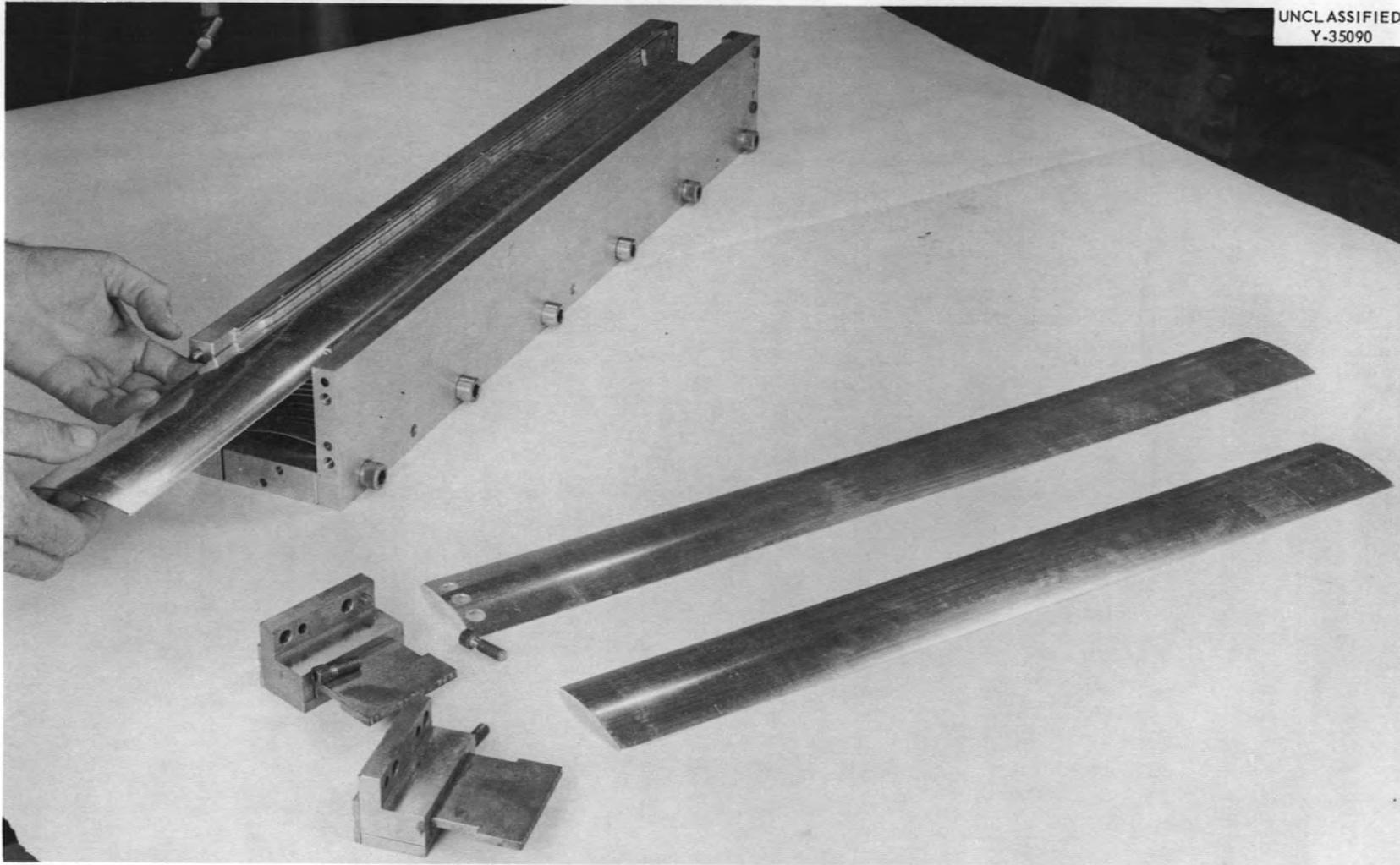


Fig. 17. Fixture for Assembling Pinned Fuel Element.

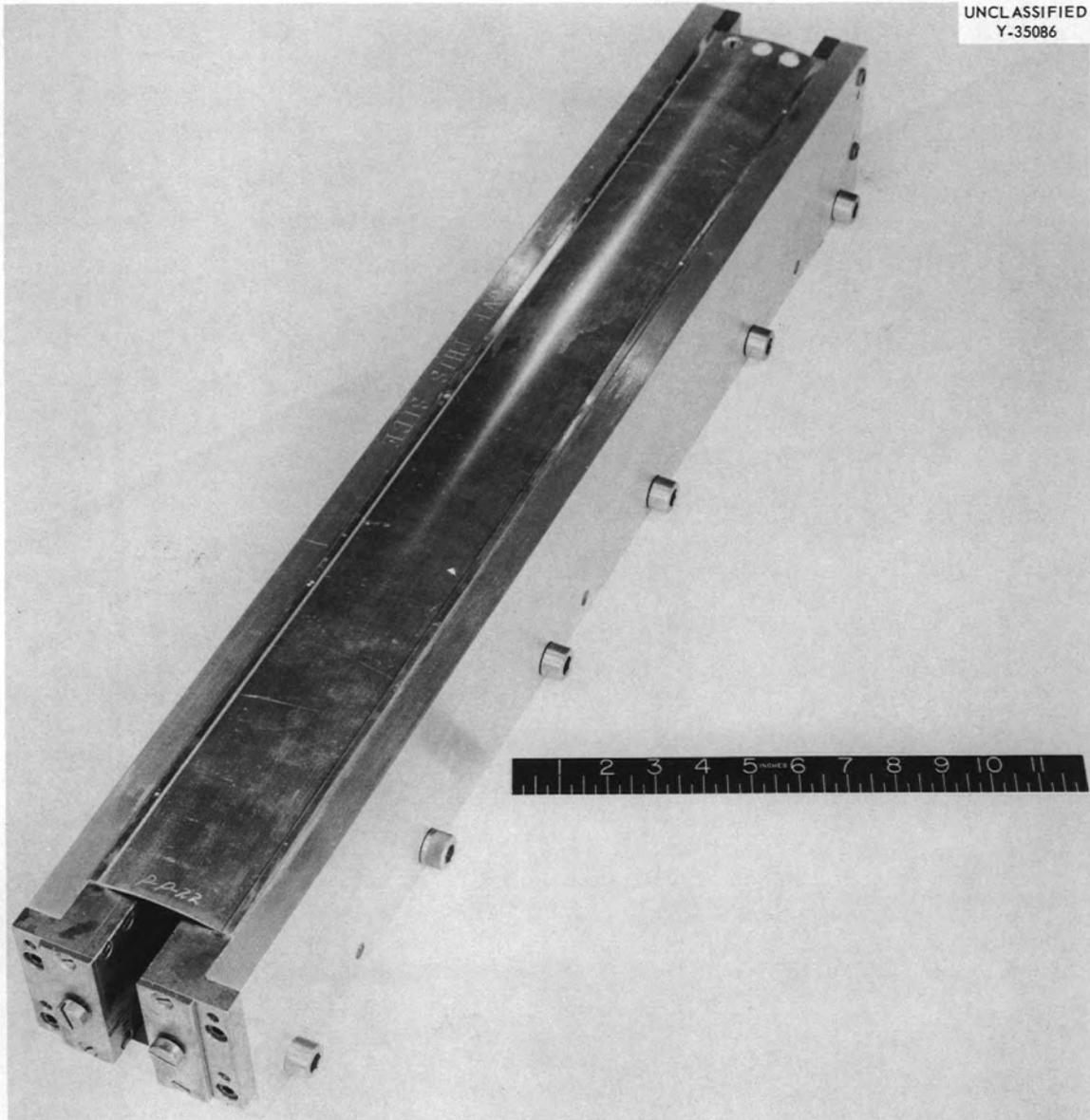


Fig. 18. Finished Assembled Fuel Element Prior to Drilling Operation.

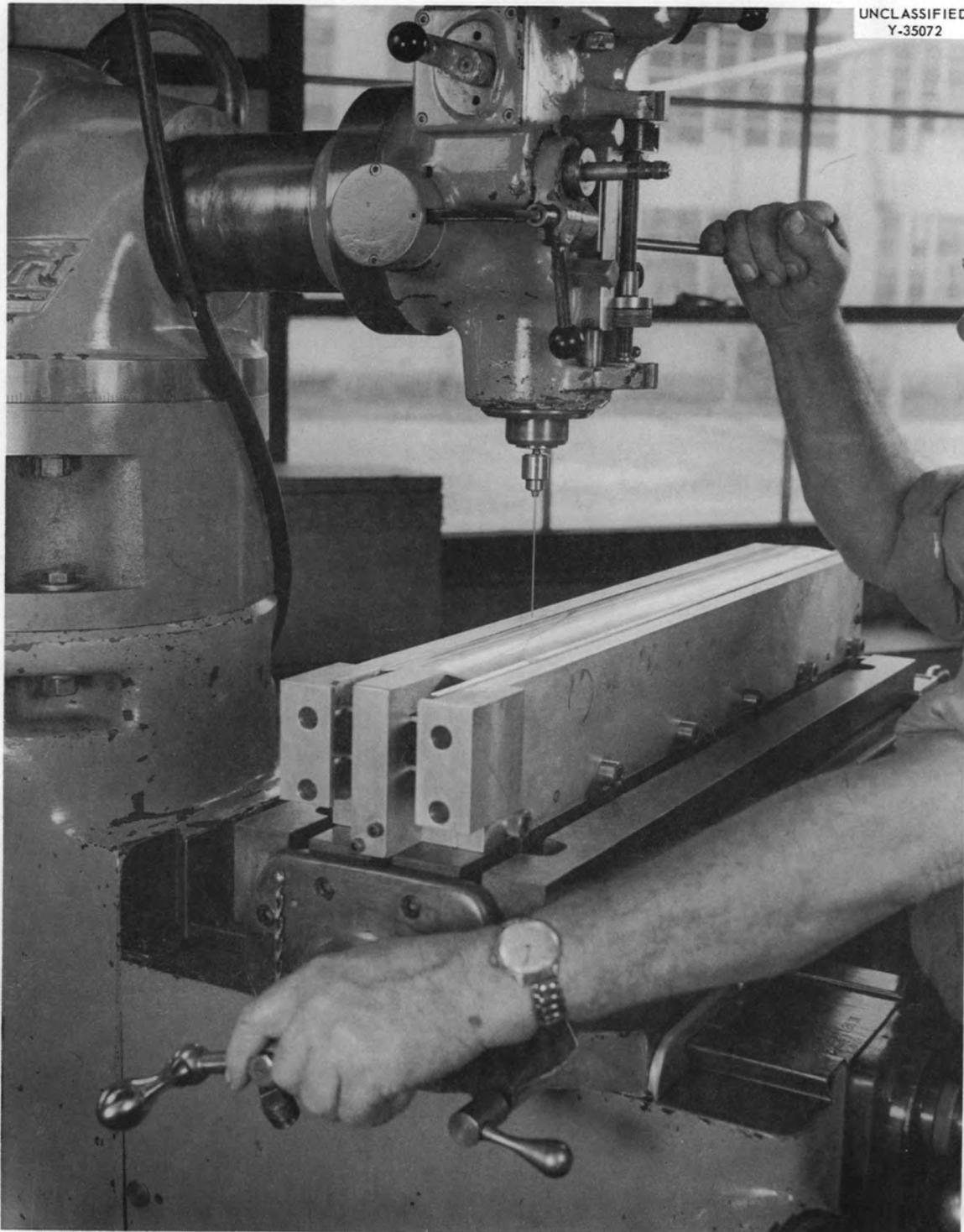


Fig. 19. Redrilling Operation Prior to Insertion of Pins.

plates by the holes previously drilled through the side plates. Alignment of the drilled holes was maintained by the insertion of a 1/16-in. drill rod.

a. Placement of the retention pins. The position of the assembly jig during the placement of the retention pins is illustrated in Fig. 20. By convention, the pins were inserted from left to right down one side of the assembly and the sequence was repeated for the remaining side. In placement of the pin, the drill rod was removed and the pin was inserted in the hole. When the pin emerges from the hole on the underside of the assembly, it was pulled into position by steady tension on the narrow pin section.

The hole was completely filled with heavy gage pin stock when less than 1/2 in. of the pin protruded above the upper side plate edge. At this point the pin was crimped approximately 1/16 in. above the side plate and flush with the assembly jig base plate.

b. Welding the pins. As illustrated in Fig. 21, the upper portion of the pin was welded while the element was firmly held in the assembly jig. The pin protruded 1/16 to 1/8 in. above the side plate edge and was fused to the side plate using a high-frequency Heliarc welding torch and type 4043 aluminum filler material. Excess weld metal was subsequently removed with a hand file.

The lower portion of the pin was prepared for welding by rotating the fuel element 180° and reinserting it in the jig. To prevent crushing of the outside fuel plate, the side plates rested on 1/4-in.-square by 30-in.-long removable rails placed at the base of the jig. The pins were trimmed to a level 1/16 in. above the side plate and were fused in the manner described above. Excess weld metal was removed by hand filing.

H. Fuel Element Identification

The fuel elements were identified by a serial number preceded by a block letter legend that indicated the fuel element type. Numerals and letters were approximately 2 in. high and were scribed into one side plate adjacent to the handle or upper fuel element extremity.

UNCLASSIFIED
Y-35074

Fig. 20. Technique for Inserting Pins Through Side Plates of Fuel Element.

UNCLASSIFIED
Y-35076



Fig. 21. Welding Pins to Side Plate Edges.

I. Dimensional Inspection

The critical dimensions of a fuel assembly to be inspected prior to attachment of end fittings were the interplate spacing, the width of the fuel element, and the vertical center height of the fuel plate stack. An elliptical probe with a 0.136-in. major axis and a 0.095-in. minor axis was employed in the measurement of interplate spacings. The probe was mounted onto the end of a 0.1-in.-diam \times 30-in.-long rod which passed through a hole in a 1 \times 3 \times 6 in. plastic block as shown in Fig. 22. The hole was the center of a radial scale, which indicated the spacing (thickness) as the angularly displaced probe touched the upper and lower surfaces of the adjacent fuel plates. The probe and scale assembly had been calibrated by rotating the probe between gage blocks and noting the angular displacement of the dial gage.

Plate spacings at the apex of each channel at locations of 3, 12, 16, and 25 $\frac{5}{8}$ in. from the lower end of an element were measured and recorded. The nominal plate spacing was 0.117 in. and a deviation of $\pm 10\%$ was permitted.

The element width was measured using a 2- to 3-in. micrometer. Measurements were made at the top, center, and bottom of the side plates at distances of 2 $\frac{1}{2}$, 7, 12, 16, 21, and 26 in. from one end. The vertical center height of the fuel element was measured at the same longitudinal locations using a 3- to 4-in. micrometer with a stationary ball anvil.

J. Final Machining and Welding

1. Preliminary Machining of the End Adapter. The as-cast and machined-end adapter dimensions are shown in Dwg D-36200, Rev A in Appendix B. The internal bore of the end adapter was first reamed to a 2.032 ± 0.032 -in.-diam cylindrical shape. The parallel sides of the end fittings were then straddle milled to 2.852 to 2.856 in. followed by machining of the convex and concave surfaces to the specified size with a 5 $\frac{1}{2}$ -in.-radius flycutter. The end adapter corners were finally trimmed to a 45° chamfer $\frac{1}{4}$ in. deep using an end mill and variable station checks.

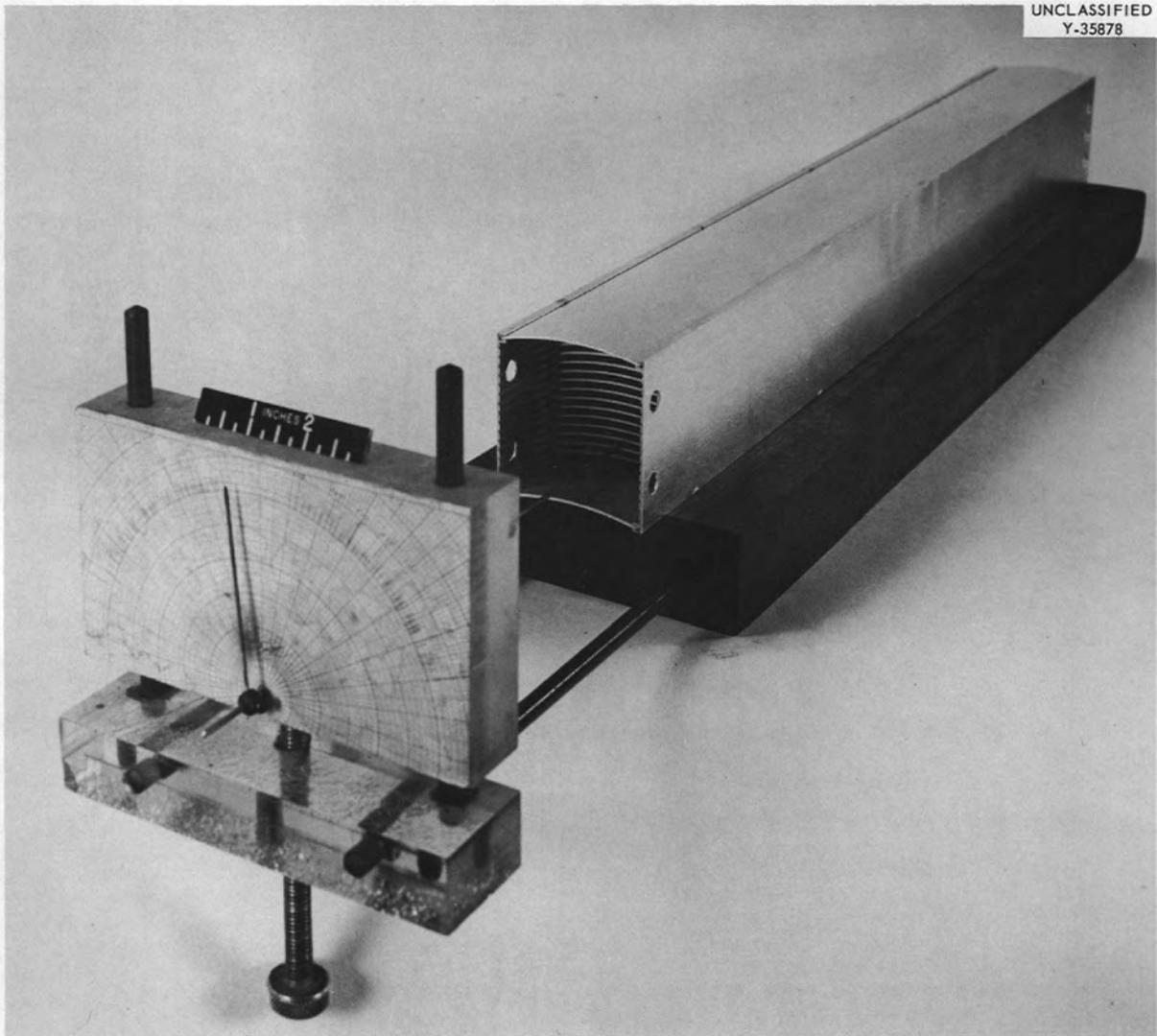


Fig. 22. Device for Measurement of Plate Spacings in Fuel Elements.

2. Welding of End Adapter to Fuel Body. The end adapter was plug welded to the fuel body using tungsten-inert-gas (TIG) welding and type 4043 aluminum filler metal. The end box and fuel assembly were aligned during welding by using the fuel element side plates and the inner cylindrical portion of the end box as references. The welding jig employed allowed free rotation of the fuel element about its longitudinal axis, permitting symmetrical welding and thus minimizing distortion. It was general practice to first plug weld the central holes of the convex side, then the concave side, and finally the side plates. The eight remaining welds were made consecutively as the element was rotated about its longitudinal axis.

3. Final Machining. Final machining on the fuel element was restricted to finishing the end adapter to size in a lathe. The end fitting was held by an expanding mandrel at the lathe drive, while the opposite end of the fuel element was held by a plug that floated in a ball-bearing center. This arrangement minimized element distortion.

The end adapter was machined to the specified dimensions and the concurrency of fuel body and end-box center lines was monitored with a dial gage while the whole assembly rotated about its longitudinal axis.

4. Attachment of Handle. A three-piece array consisting of two lugs and a handle was loosely assembled in the top of the fuel element. The reinforcing lugs were first plug welded by the TIG process at the areas exposed by the 3/8-in.-diam holes in the side plates. Subsequent fillet welds fused the side plate to the lugs. Finally, the handle was welded to the lugs. Type 4043 aluminum filler metal was used in all welding.

K. Alodizing Treatment

Aluminum that is not protected from quiescent water is susceptible to pitting, which can be sufficiently severe to impair the longevity of a pool-type fuel element. It was, therefore, important that the cladding surfaces be pretreated with a protective adherent coating. Such protection could be afforded by Alodine 1200. Procedures that were used at ORNL for placement of this coating on all surfaces of the finished fuel element are listed as follows:

1. Degrease fuel element in trichloroethylene vapor for 30 min.
2. Pickle at room temperature in aqueous HF-HNO₃ solution for 5 min (1 part 60% HF-10 parts concentrated HNO₃-100 parts H₂O by volume).
3. Rinse in an erect position in turbulent hot water (near boiling) for 3 to 5 min.
4. Clean in Ridilene Cleaning Bath at 180°F for 3 to 5 min.
5. Rinse in cold water, raising element up and down, for 5 min.
6. Rinse for 1 to 2 min in a weak solution of Alodine 1200 (50 g of Alodine and 50 gal of H₂O) heated to 140°F.
7. Insert for at least 3 min in Alodine 1200 solution containing 2.85 kg of Alodine 1200 and 53 gal of H₂O.
8. After removal from this alodizing bath, dry in air for at least 4 hr.
9. Bake at 131°F for at least 24 hr.

L. Preparation for Shipment

The alodized elements were stored in individual plastic bags to prevent surface damage. A quantity of active silica gel was added to each bag, which was then hermetically sealed.

VII. CONCLUSIONS

Following the basic procedures described in this report, 76 fuel elements were successfully manufactured within the established specifications. The results obtained in manufacturing these elements demonstrate that:

1. The fissile compound U₃O₈ is compatible with aluminum in the processes required for manufacturing research reactor fuel components.
2. Powder-metallurgical procedures are amenable to manufacturing research reactor fuel elements containing high uranium investments.
3. Research reactor fuel elements can be economically assembled by mechanical joining within the required dimensional specifications, thereby eliminating the need for brazing.

4. Employing powder-metallurgical techniques where high uranium investments are required yields fuel plates with excellent control of fuel loading and homogeneity.

5. The procedures used in fabricating dispersion-type fuel materials consistently yield high-quality fuel plates.

ACKNOWLEDGMENTS

The authors wish to acknowledge the guidance of T. E. Cole and J. E. Cunningham during this program and the assistance of H. J. Wallace, W. W. Proaps, J. N. Hix, T. W. Coffey, and Clyde Hamby in developing and manufacturing the components. Special thanks are due also to the ORNL Graphic Arts Group for the illustrations, the Metallographic Section of the Metals and Ceramics Division for the photomicrographs and photographs, Sigfred Peterson for a technical review of the manuscript, and the Reports Office of the Metals and Ceramics Division for the fine stenographic work and other help furnished on the report.

APPENDIX A



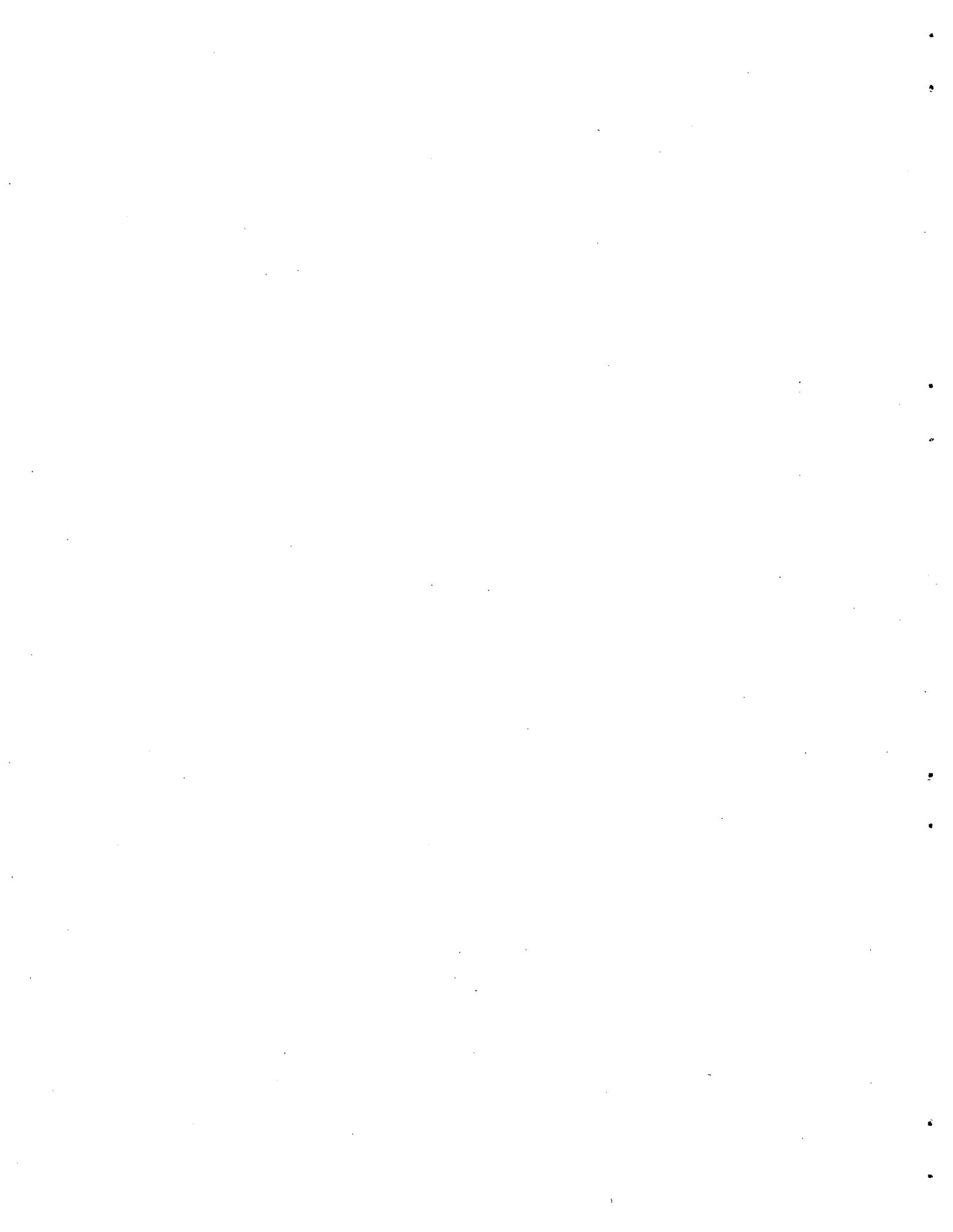
Y-12 Procedure for Manufacturing "Dead-Burned" U_3O_8

1. Burn 12 kg of 20% enriched metal to U_3O_8 .
2. Dissolve U_3O_8 in batches limited to 400 g U^{235} per batch (2360 g U_3O_8 per batch) using 1 cc of cp HNO_3 per gram of oxide.
3. Filter solution through sintered glass funnel.
4. Dilute solution with demineralized water to 40 liters in a 30-gal drum.
5. Adjust the pH of solution to 2.0.
6. In a 4-liter beaker mix 1140 cc of concentrated NH_4OH and 852 cc of 30% H_2O_2 .
7. Add this mixture to the 40 liters of solution in the 30-gal drum while agitating.
8. If the pH differs from 2, readjust with NH_4OH or H_2O_2 .
9. When the pH is 2, add 1 liter of H_2O_2 while agitating.
10. Allow the batch to age for 30 min.
11. Filter and hold filtrate in tared critically safe bottles.
12. Wash the cake with demineralized H_2O , holding the wash in critically safe bottles.
13. Calcine to U_3O_8 in platinum boats at $800^\circ C$.
14. Mill and screen U_3O_8 to -80 mesh. (Care must be taken in milling in order to produce as little material as possible of extremely fine mesh, as in the final product all -325 mesh material will be rejected.)
15. Fire in pit furnace for 4 hr at $1350^\circ C$, then raise the temperature to $1400^\circ C$ for 2 hr. All firing is to be done in air.
16. Cool, mill, and screen to -100 +325 mesh.
17. Package in 1/2-gal plastic bottles for shipping.

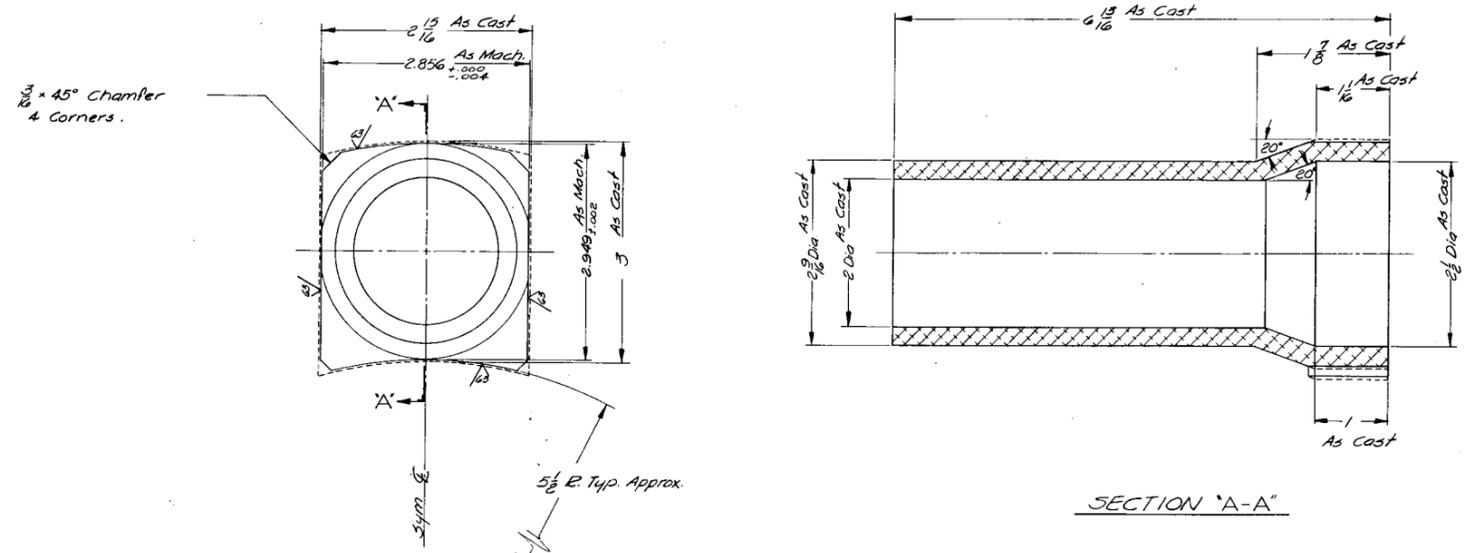


APPENDIX B

Control Fuel Element and Fuel Element End Box Drawings



PARTS LIST				
PART NO.	DWG. NO.	NO. REQD.	DESCRIPTION (NAME, SIZE, ETC.)	MATERIAL



$\frac{3}{16} \times 45^\circ$ Chamfer
4 Corners.

Material: 356-T7 Aluminum.

Note:
Sandblast interior surfaces before installation
with fuel cluster.

Special Fuel Element	D-7206
Fuel Element	D-7208
REFERENCE DRAWINGS	DWG. NO.
PUERTO RICAN REACTOR FUEL ELEMENTS	REV. 3010 REV. 3012

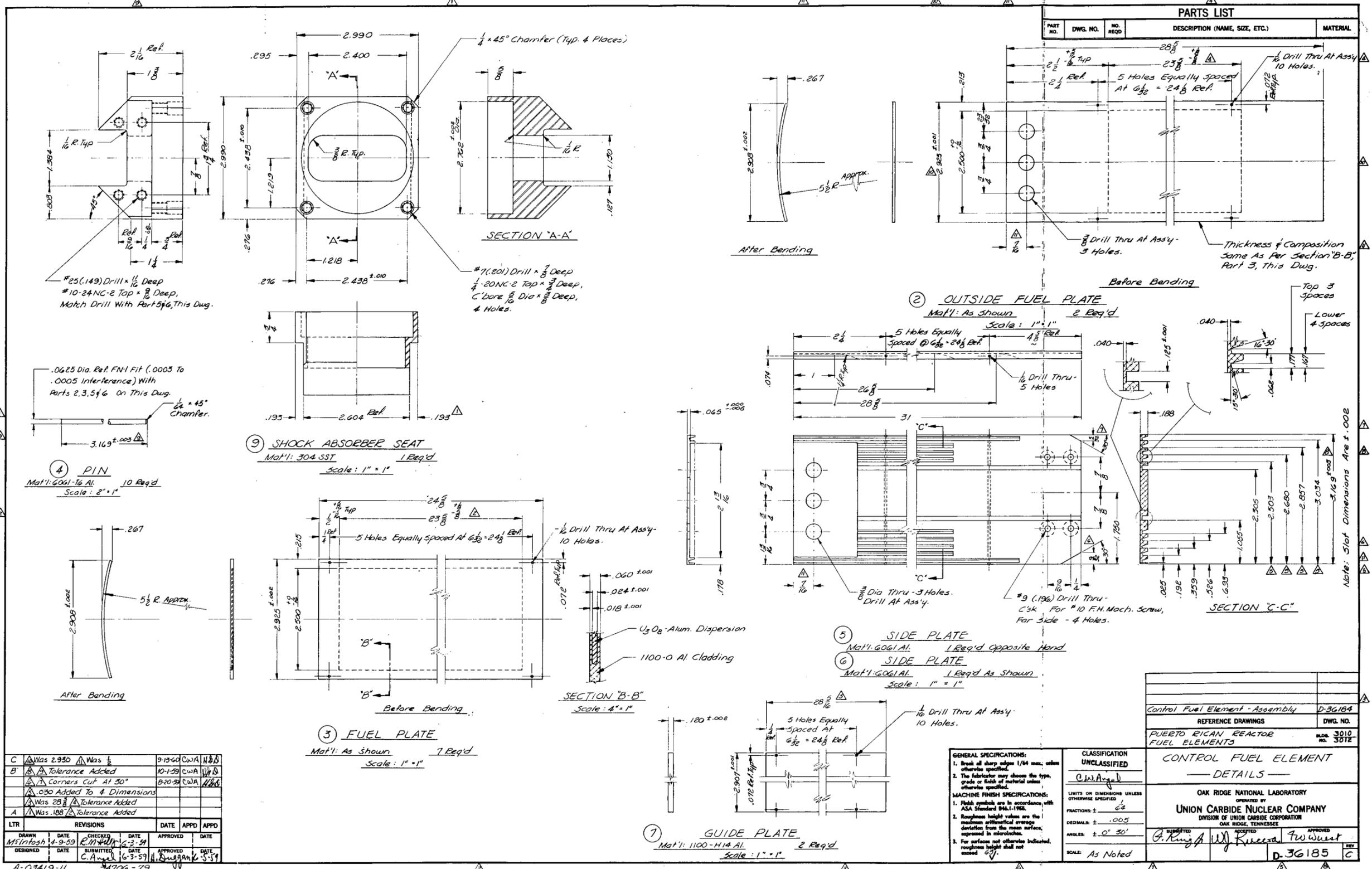
GENERAL SPECIFICATIONS:
1. Break all sharp edges 1/64 max., unless otherwise specified.
2. The fabricator may choose the type, grade or finish of material unless otherwise specified.
MACHINE FINISH SPECIFICATIONS:
1. Finish symbols are in accordance with ASA Standard B46.1-1958.
2. Roughness height values are the maximum arithmetical average deviation from the mean surface, expressed in microinches.
3. For surface not otherwise indicated, roughness height shall not exceed 63.

CLASSIFICATION
UNCLASSIFIED
C.W. Angel
LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRACTIONS: $\pm \frac{1}{16}$
DECIMALS: $\pm .005$
ANGLES: $\pm 0^\circ 30'$
SCALE: 1" = 1"

FUEL ELEMENT END BOX
OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE NUCLEAR COMPANY
DIVISION OF UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE
SUBMITTED: P. King
ACCEPTED: W.D. Kucera
APPROVED: F.W. Wood
D-36200 A

A	Was Bulk Shielding Reactor	9-13-54	CWA	126
LTR	REVISIONS	DATE	APPD	APPD
DRAWN	DATE	CHECKED	DATE	APPROVED
DESIGNED	DATE	SUBMITTED	DATE	APPROVED

A-03419-11 34706-79



ORNL-3458
 UC-25 - Metals, Ceramics, and Materials
 TID-4500 (22nd ed.)

INTERNAL DISTRIBUTION

- | | |
|-------------------------------------|----------------------------------|
| 1. Reactor Division Library | 51. M. M. Martin |
| 2. ORNL Patent Office | 52. R. W. McClung |
| 3-5. Central Research Library | 53. J. R. McWherter |
| 6-7. ORNL - Y-12 Technical Library | 54. J. F. Murdock |
| Document Reference Section | 55. G. W. Parker |
| 8-27. Laboratory Records Department | 56. S. Peterson |
| 28. Laboratory Records, ORNL R.C. | 57. S. A. Rabin |
| 29. G. M. Adamson | 58. S. A. Reed |
| 30. R. J. Beaver | 59. A. E. Richt |
| 31. J. A. Burka | 60. H. E. Seagren |
| 32. J. E. Cunningham | 61. G. M. Slaughter |
| 33. J. H. Frye, Jr. | 62. J. A. Swartout |
| 34. D. A. Gardiner | 63. W. C. Thurber |
| 35. B. L. Greenstreet | 64. A. M. Weinberg |
| 36. R. L. Heestand | 65. W. J. Werner |
| 37. D. M. Hewette | 66. R. G. Wymer |
| 38-42. M. R. Hill | 67. A. A. Burr (consultant) |
| 43. C. E. Larson | 68. J. R. Johnson (consultant) |
| 44-48. C. F. Leitten | 69. C. S. Smith (consultant) |
| 49. A. L. Lotts | 70. R. Smoluchowski (consultant) |
| 50. H. G. MacPherson | |

EXTERNAL DISTRIBUTION

- 71. C. E. Adams, Jr., MIT
- 72-73. David F. Cope, ORO
- 74. D. E. Baker, GE, Hanford
- 75. Ersel Evans, GE, Hanford
- 76. J. L. Gregg, Cornell University
- 77. W. J. Kucera, D. A. Stuart Oil Company, Chicago
- 78. J. M. Ponce de Leon, Madrid, Spain
- 79. Robert A. Noland, Argonne National Laboratory
- 80. J. Simmons, AEC, Washington
- 81. E. E. Stansbury, University of Tennessee
- 82. Donald K. Stevens, AEC, Washington
- 83. Research and Development Division, AEC, ORO
- 84-668. Given distribution as shown in TID-4500 (22nd ed.) under Metals, Ceramics, and Materials category (75 copies - OTS)